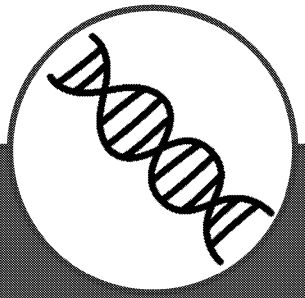
Note – this is a draft copy of the textbook and not the final version.



F170 Fundamentals of Human Biology

Topic 1: Human cells and tissues

1.1. Understanding and observi

1.1.1. Cells

Life is abundant on Earth; we find it in al[illegible] location across the globe, i
locations such as at the bottom [illegible] deep ocean by hydrothermal vents, wh
are high and oxygen co[illegible]. Yet even in these habitats, life persists, an
the cell.

What is a cell?

The **cell** is the fundamental unit of life. All living organisms are composed of c
units carry out essential biological processes required to enable life, such as A
production, growth, and reproduction.

Many organisms consist only of a single cell. Known as unicellular organisms, u
and some algae. Other organisms, including humans, are multicellular – made
together in coordinated systems to enable the survival of the organism.

Structure and function of eukaryotic cell components

Eukaryotic cells contain many specialised structures, each with a distinct form adapted to its function. These subcellular structures, known as **organelles**, work together to support the survival of th[illegible]ganism.

Most eukaryotic cells contain a core s[illegible]mponents:

- cell membrane
- cytoplasm
- nuc[illegible]

The quantity of these and other organelles present within the cell is affected b

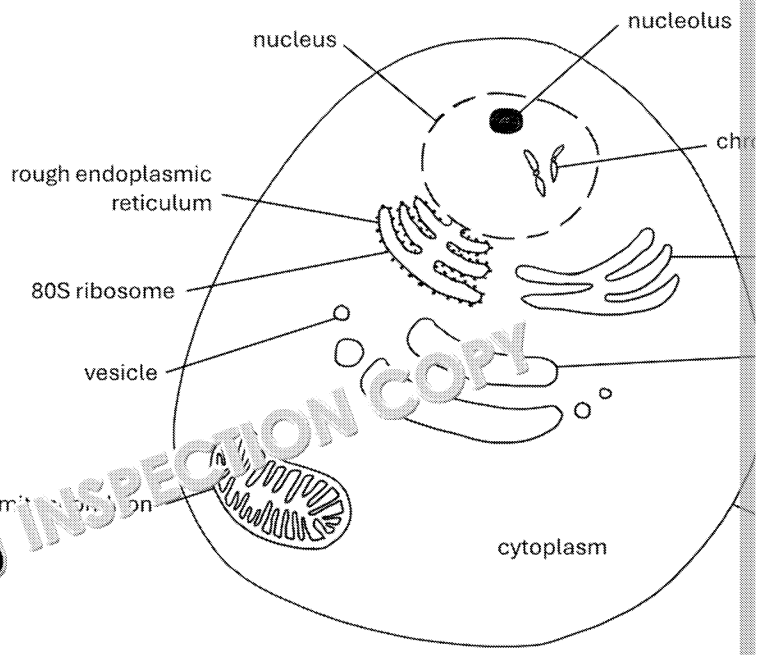


Figure F1.1. *A diagram of a generalised animal cell and its org*

Cell surface membrane

The cell surface membrane, also known as the plasma membrane, encloses the cell, f
the intracellular environment and the external surroundings. It is composed of a pho
with proteins, cholesterol, and carbohydrates. It is selectively permeable; the
membrane-embedded components regulate the entry and exit of substances
and assist their transport through the membrane. Glycoproteins and glycolipids
enable cell-to-cell communication and responses to environmental signals. The
cell surface membrane can change shape, and this enables processes including
endocytosis, **exocytosis**, and cell signalling.

Cytoplasm

The cytoplasm is a fluid-like substance made primarily of water with dissolved salts a
It is the site of most metabolic reactions, and intracellular communications are trans
the cytoplasm. Membrane-bound organelles are suspended within the cytoplasm, an
interlinked through it.

Nucleus

Most eukaryotic cells have a nucleus. The nucleus contains the genetic material of th
cellular activities using enzymes and other factors. It is surrounded by the nuclear m
membrane perforated by nuclear pores. This separates and protects the DNA from th
in the cytoplasm. The pores allow the selective exchange of molecules, including mR
nucleotides and proteins in.

Nucleolus

The nucleolus is a dense, spherical region within the nucleus, which produces riboso
is synthesised and combined with proteins to create ribosomal subunits.

Mitochondria

Mitochondria (singular: mitochondrion) are the site of aerobic respiration, responsib
triphosphate (ATP) – the energy currency of the cell. Through a series of enzyme-co
mitochondria release energy stored in the bonds of molecules, such as
carbohydrates, to make ATP. ATP is then used for energy-dependent cellular
processes, including active transport, protein synthesis, and muscle contraction.

The enzymes and cofactors required for these reactions are either present
within the interior fluid, known as the **matrix**, or are bound to the inner
mitochondrial membrane. The inner membrane is highly folded into **cristae**
(singular: crista), greatly increasing surface area and the rate of ATP production.

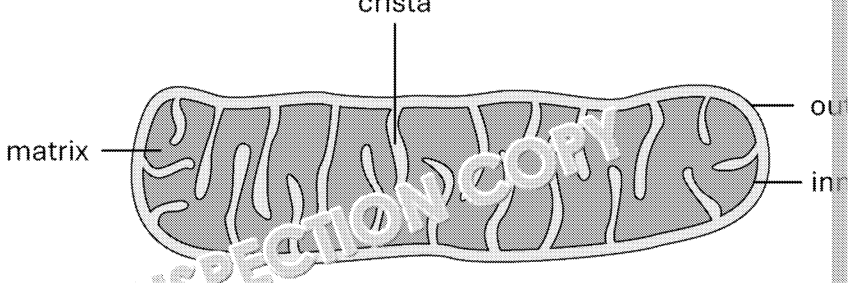


Figure F1.2. A 2D diagram of the internal structure of a mitochondrion.

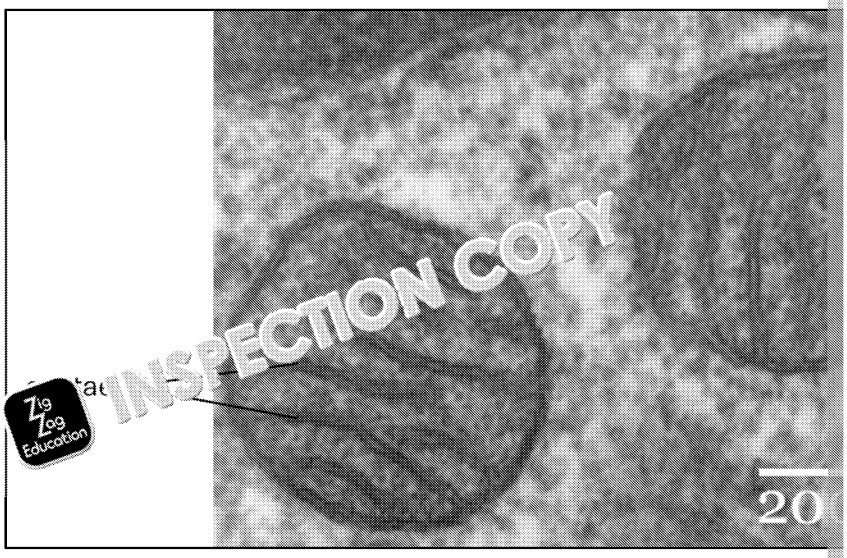


Figure F1.3. *A transmission electron photomicrograph of mitochondria, showing the c*

Mitochondria have their own mitochondrial DNA (mtDNA), which contains 37 g
and rRNA. They also have specific ribosomes (called mitoribosomes), so they c
proteins, replicate independently, and regulate aspects of their internal enviro
theory (see page 20) which suggests that mitochondria were once free-living p
maternally inherited and is implicated in some inherited metabolic diseases (se

Ribosomes

Ribosomes are composed of proteins and ribosomal RNA (rRNA) and are not m
organelles. Each ribosome contains a small subu it that binds the mRNA strand
the mRNA triplet code with the corresp ding amino acid and joins them toget

Ribosomes are manufa the nucleolus then transported to the cytopla
cytoplasm and s proteins for internal use, or bound to the membran
reticulu to produce proteins for secretion or insertion into membranes

Smooth and rough endoplasmic reticulum (SER/RER)

The endoplasmic reticulum (ER) is a network of single-membraned structures
envelope. It exists in two forms:

- rough ER (RER) – studded with ribosomes that synthesise proteins destin
  secretion by exocytosis or membrane insertion
- smooth ER (SER) – lacks ribosomes; it manufactures carbohydrates and li

The RER packages newly synthesised proteins into transport vesicles which move to the Golgi apparatus.

The quantity of each form of ER varies depending on the role of the cell. For ins ce, cells which **secrete** proteins su s ntibodies, hormones or digestive e.g. plasma cells, pan ic ve extensive RER, but cells inv lipid metabolism (e.g. liver cells) hav minent SER.

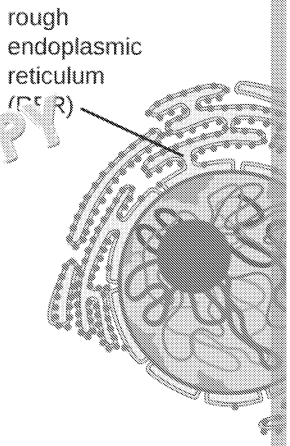


Figure F1.4. *A diagram sho*
endoplasmic retic

Golgi body/apparatus

The Golgi body, or Golgi apparatus, is another single-membrane-bound organelle, structurally similar to the SER. It consists of a stack of flattened, membrane-bound sacs called **cisternae** (singular: cisterna), where proteins, carbohydrates and lipids are modified, sorted, and packaged for delivery.

Modifications to molecules arriving at the Golgi apparatus include:

- **glycosylation**, where carbohydrate groups are attached to proteins (to form glycoproteins) or lipids (making glycolipids)
- the addition of functional groups (such as PO_4^{2-} ions onto carbohydrates)
- the activation of enzymes by combining them with cofactors

Once modified, molecules are enclosed within vesicles that bud off from the Golgi apparatus.

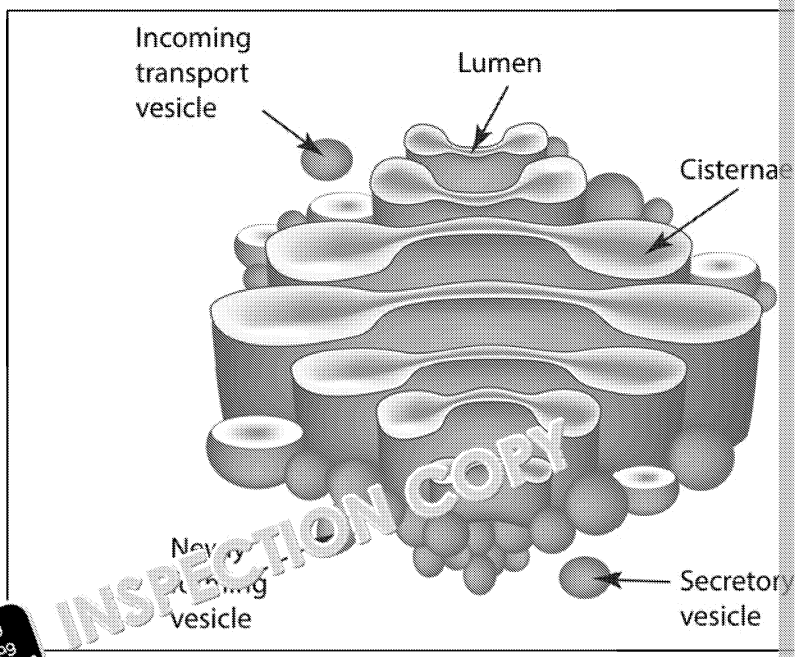


Figure F1.5. *A diagram showing the structure of Golgi apparatus.*

Vesicles and lysosomes

Vesicles and lysosomes are single-membrane-bound structures, formed by pinching off from the endoplasmic reticulum or Golgi apparatus. This traps the contents inside the vesicle membrane.

Transport vesicles move substances between organelles, for instance from the ER to the Golgi apparatus.

Secretory vesicles transport contents to the cell surface membrane for secretion out of the cell by exocytosis, e.g. antibodies, hormones, digestive enzymes and skin oils. The secretory vesicle fuses with the surface membrane and unwraps, releasing its contents outside the cell.

Lysosomes, derived from the Golgi apparatus, remain in the cell and carry **hydrolytic enzymes** to break down cellular debris, such as worn-out organelles, and **pathogens** and their **toxins** through phagocytosis. They are involved in **apoptosis** (programmed cell death) under specific conditions, leading to the destruction of the cell.

hydrolytic enzymes – substances by adding water and include proteases

pathogen – a bacterium which can cause disease

toxin – a poison released harm to the infected individual

apoptosis – programmed the total destruction of coordinated process.

Cilia and flagella

Cilia

Cilia (singular: cilium) are hair-like **projections** of the cell surface, composed of **microtubules** enclosed by the plasma membrane. Cilia can be motile, beating rhythmically from side to side to move substances across a surface, or non-motile (stationary) and function as sensory organelles or signalling hubs.

In humans, cells with motile cilia are found on the inside of the trachea and along the **oviduct**. In the trachea, the cilia move mucus to the back of the throat, keeping the lungs clear of pathogens and debris. In the oviduct, cilia move the egg cell towards the uterus. This ensures that if the egg cell is fertilised, the embryo reaches the uterus, or if it remains unfertilised, it passes out of the body.

Non-motile cilia are found within the nose, inner ear, and retina of the eye, and have sensory functions. They are also located within the kidney, where they help to

Cilia contain microtubules that provide structure. Nine pairs of fused microtubules are positioned around the outer part of the cilia in a wheel-like arrangement. In motile cilia, there are a further two unfused microtubules in the centre: the 9+2 arrangement. As the parallel pairs of microtubules move over each other, driven by motor proteins and using ATP, the motile cilia move.

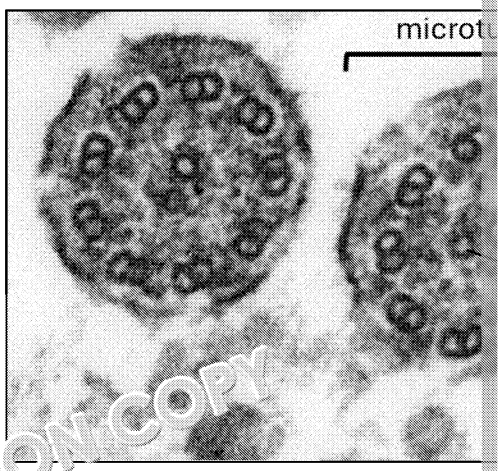


Figure F1.6. *A transmission elec*
the 9+2 arrangement of microt

Flagella

Flagella (singular: flagellum) are longer tail-like projections, anchored to the ce sperm cells are the only cells with a flagellum. Powered by ATP, they generate the cell forward. As with motile cilia, they also have the 9+2 microtubule arra

Microvilli

Microvilli are short, finger-like cell surface membrane extensions containing actin filaments. Intestinal epithelial cells have microvilli that vastly increase the surface area, which greatly increases absorption of nutrients and water from the gut.

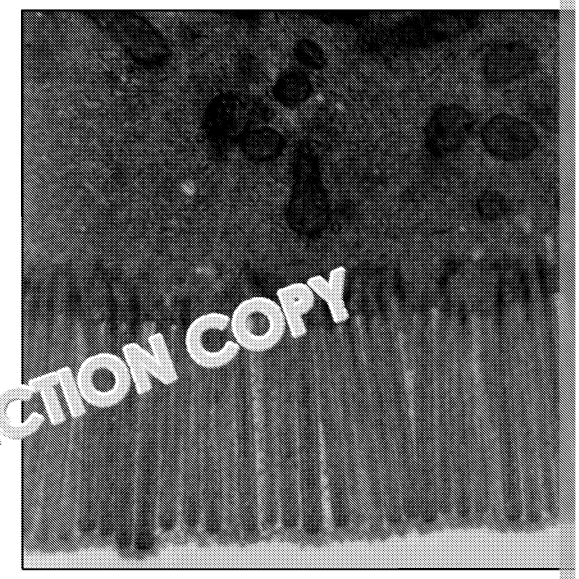
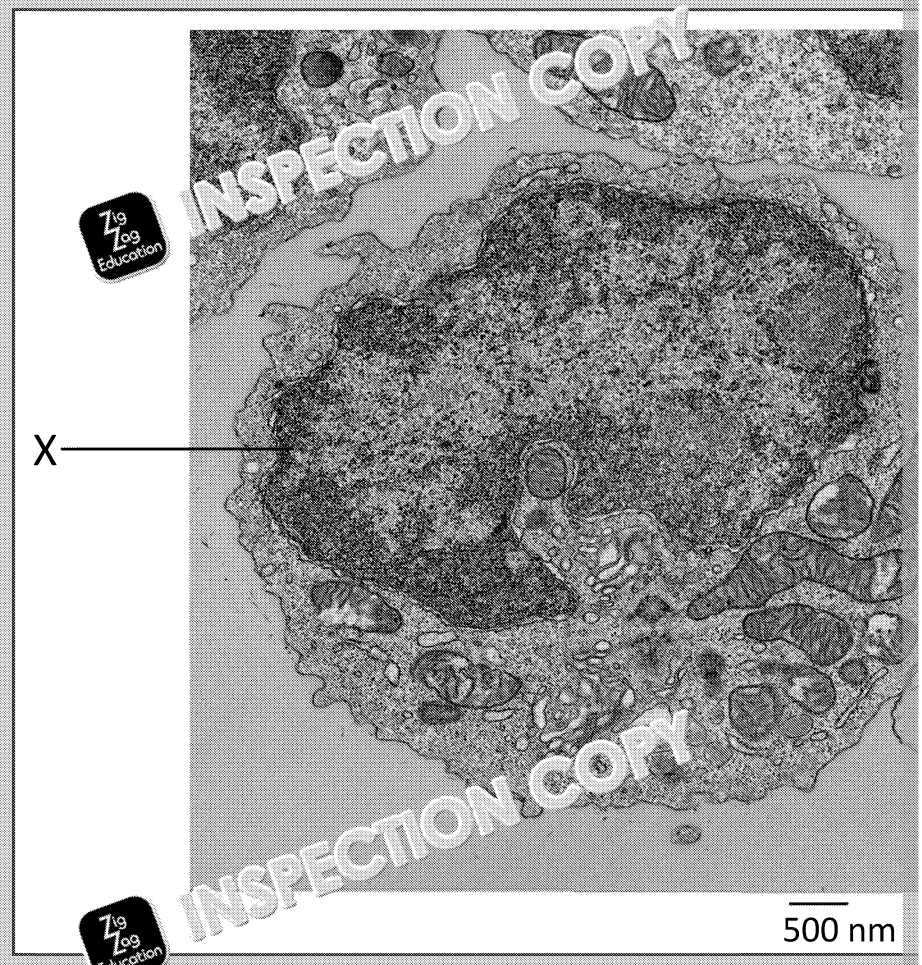


Figure F1.7. *A transmission electron micrograph s*

Apply your knowledge

1. Describe the function of the nucleolus and state its location within the cell.
2. Identify parts X and Y on the electron micrograph of a B lymphocyte, and explain you
for your choices.



3. Explain the structural and functional differences between the rough endoplasmic reticulu
endoplasmic reticulum (SER).
4. Compare and contrast the functions of cilia, flagella and microvilli, and state an example o

Adult stem cells

What are stem cells?

Stem cells are undifferentiated cells that have not adopted any specific function, su
generating movement, and therefore can develop into a range of specialised cell typ
ability to divide indefinitely via mitosis, stem cells play a vital ro in growth, tissue d
throughout an organism's life.

Stem cells are classified based on their ... differentiate:

- Totipotent – can form all ... so capable of forming a whole organism. M
16 embryoni... ell.
- Pluripote... form almost all specialised cells from all tissue types but cann
Found as e... yonic stem cells.
- Multipotent – can form specialised cells within a specific tissue type only; for in
in adult bone marrow can differentiate into all specialised blood cells but canno
tissues such as muscle or nerve. Found in adult stem cells.

Adult stem cells

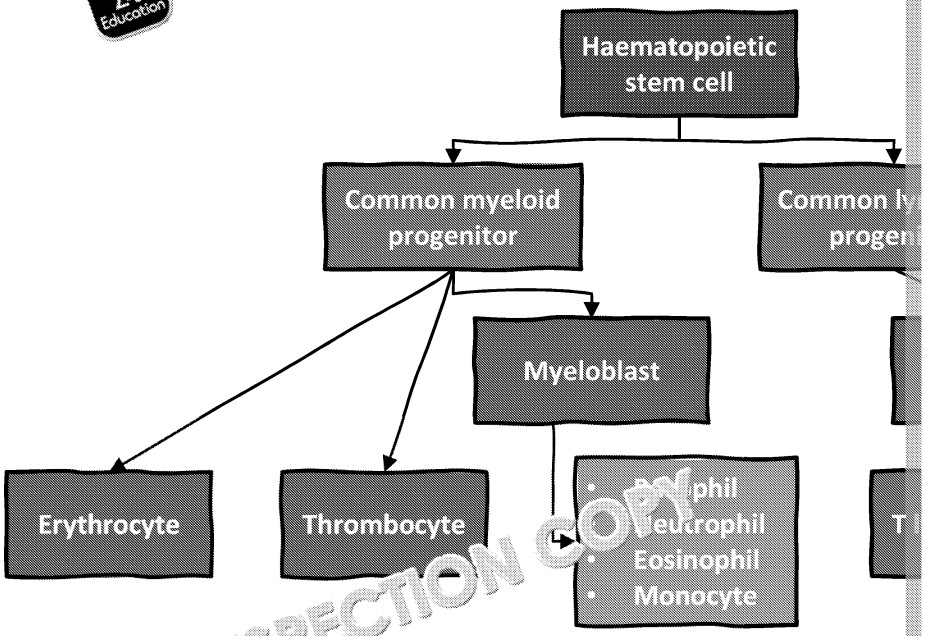
Adult stem cells are multipotent and are found within all tissue types, such as
repair tissue by replacing damaged cells, and enable adaptation during growth

Haematopoietic stem cells

Haematopoietic stem cells are found within adult bone marrow and can differ

- erythrocytes (red blood cells)
- leucocytes (white blood cells)
- thrombocytes (platelets)

This process is contin[illegible]ghout life. Mature erythrocytes lack a nucleus
lifespan [illegible]ys, while some leucocytes may function for only a few



*Fi[illegible] Haematopoietic stem cell differentiation pathway showing how e
and all leucocytes are produced from a common stem c*

Other tissue-specific stem cells

Skin stem cells are found in the basal layer of the epidermis. They are respons
cells, but do not produce hair follicle cells, which are made from different ste
rate, as skin is replenished approximately every 28 days.

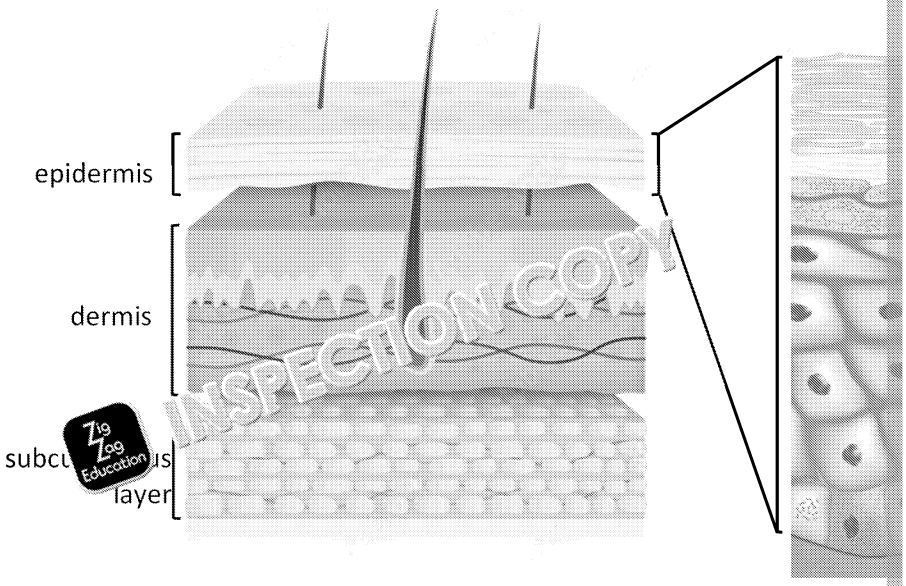


Figure F1.9. *Skin stem cells are located at the bottom of the epidermis i*

Specific muscle stem cells known as satellite cells are present within muscle fibres. T
or mechanical stress (such as strength training) and are responsible for the formatio

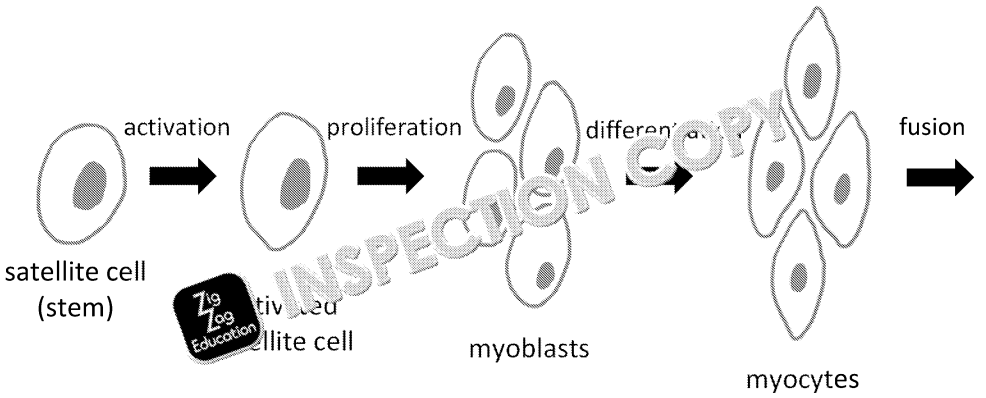


Figure F1.10. *Muscle satellite cells mature into myofibres when activated*

Stem cell differentiation

Stem cells can remain inactive for extended periods – a state known as quiescence. T
proliferate slowly, such as bone and brain, and also applies to haematopoietic stem c
cells. Quiescence helps protect the genome by limiting exposure to mutation-induci

In contrast, some stem cells divide frequently to replenish tissues with high turnover rates, such as the skin and gut lining. After division by **mitosis** (see section 1.1.5), stem cells may remain undifferentiated and continue through **interphase**, enter quiescence phase G_0, or differentiate into specialised cells.

mitosis
generates
daughter
interpha
the cell c
functions
by replica

Differentiation involves activating genes t
e proteins essential for specific functions (e.g. haemo
in erythrocytes), while silencing other genes not required f
t cell type. Silenced genes are tightly wound around
forming a com
ru re that prevents transcription. This restricts mRNA synthes
of unnecessary
ns.

Whether a stem cell remains undifferentiated or becomes specialised is influenced b
surrounding microenvironment. These include hormones and growth factors from n
those which trigger tissue maturation during puberty, or create specific leucocytes d
triggers such as mechanical stimuli (e.g. repeated muscle stretching) or nutrient ava
or inhibit differentiation.

It is essential that the body tightly regulates the proliferation of stem cells and their differentiated cells. Delayed differentiation can lead to impaired tissue repair and ageing. Excessive proliferation can lead to tumour development, with potential progression to cancer and **metastasis** causing secondary tumours.

Uses for stem cells

The **umbilical cord** provides a rich source of m
otent stem cells that can be harvested without invasive medic
roc res. Both umbilical and adult multipoten
stem cells can be artificiall
o mmed into pluripotent stem cells *in vitro*, which
makes them m
ef
medicine and research. Once in this state, they can be expanded to p
large quantities, induced into dormancy for storage until need

Pluripotent stem cells support lab-based research into complex diseases (e.g. Huntin
cultured tissues for testing drug efficacy. If harvested from a patient's own tissues, p
used to make patient-specific tissues that can be transplanted back into the patient's
because the tissue will not be rejected as foreign (non-self).

However, using stem cells to treat disease or damage is still, for the large part, possible. This is complex medicine which involves detailed understanding of h in specialisation, and how molecules interact to enable cell signalling. Therefo cells for medicinal purposes is still in its infancy. Current experimental uses in leukaemia, minimising nerve damage caused by multiple sclerosis, repairing d growing skin tissue for regrafting onto burn victims.

Recall questions

1. Outline th[illegible]ces between multipotent, pluripo[illegible] st[illegible] cell
2. [illegible]cribe the role that stem cells have in tissue repair
3. Outline the factors that influence the differentiation o
4. Discuss whether using embryonic stem cells should b[illegible] for or against.

Structure and function of highly specialised cells

Highly specialised cells have structural adaptations that enable efficient funct approximately 30 trillion cells, and each cell works together with other cells t cohesive, living system.

Sperm cells

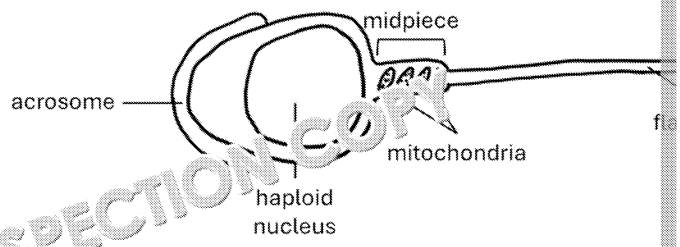


Figure F1.11. *A diagram of a sperm cell showing specialised fe*

The sperm cell is the male **gamete**, responsible for delivering genetic materia to the female egg cell (ovum) during fertilisation, starting the formation of a new human life. As a gamete, it is **haploid**, meaning it carries half the usual number of chromosomes found in a typical body cell. Its structural specialisations are tightly linked to its function:

- a long flagellum which acts as a whip-like tail, propelling it through the fluid environment of the reproductive tract
- many mitochondria, concentrated in the midpiece to supply ATP, poweri
- the acrosome, a cap-like structure at the tip of the head, contains digesti ovum's outer layers, facilitating entry during fertilisation

Ova

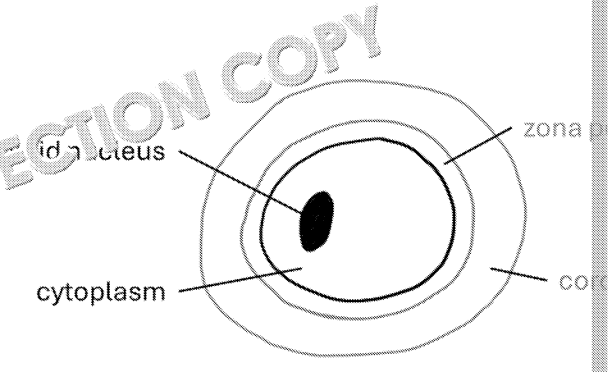
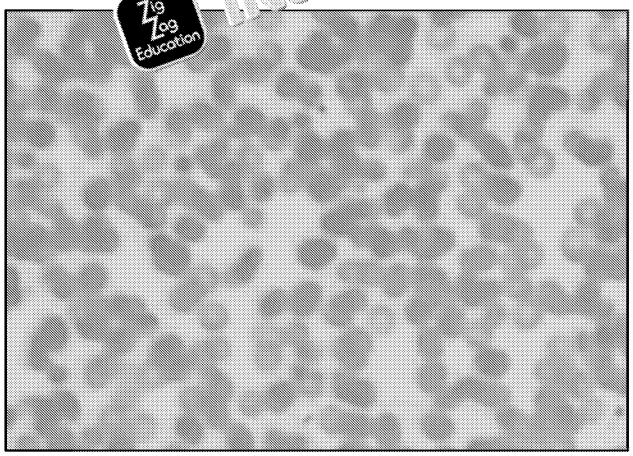


Figure F1.12. *A diagram of an ovum, showing specialised fea*

The egg cell, or ovum (plural: ova), is the female gamete, also haploid, and carries genetic material to be fused with that of the sperm cell. Its adaptations support early-stage embryonic development and cellular protection:

- A nutrient-rich cytoplasm contains lipids to sustain the developing **embryo** prior to implantation.
- The zona pellucida, a jelly-like layer surrounding the cell membrane, offers struc protection from mechanical damage, and is involved in f isation.
- An outer coating of follicle cells called the coron a radiata, derived from the ovar and provides additional protection dur ne lation.

Erythrocytes



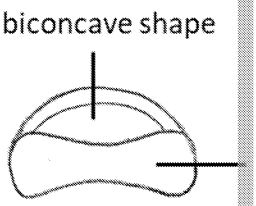


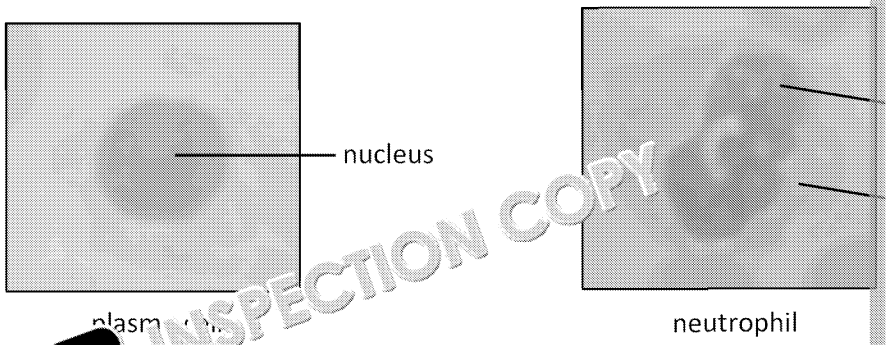
Figure F1.13. *A light photomicrograph showing human red blood cells at ×100 magnificati showing a transverse section through a red blood l to reveal its biconcave s*

Erythrocytes, red blood cells, transport oxyg ug out the body. Mature erythro key adaptations:

- no nucleus or other org axim ising space for haemoglobin
- haemoglo n i taining **conjugated protein**, which reversibly binds oxy
- a biconcave disc shape, which increases the surface-area-to-volume ratio, improving the rate of oxygen diffusion into and out of the cell

Their lack of organelles also limits energy usage and prevents them from completing relatively short lifespan (approximately 120 days).

Leucocytes



Figu *Light photomicrographs of a plasma cell (B lymphocyte) and a neutrophil at × showing the differences in their specialised features as viewed when stained using me*

Leucocytes, or white blood cells, are immune cells with diverse specialisations that p from pathogens.

Neutrophils

Neutrophils are the most common type of leucocyte in circulation. They have a
enables them to squeeze between cells to reach sites of infection. Granulated
packed with digestive enzymes used to destroy pathogens via phagocytosis.

Lymphocytes

Lymphocytes are produced either in the **B**one marrow (**B** lymphocytes) or the
divided into subtypes with a specialised immune function:

T lymphocytes	T helper cells	Produce interleukins, a cell-signalling molecule, which a antibody production. Activate the other T cell types. Stimulate **macrophages** to destroy the pathogen by
	T killer cells	Produce a chemical called perforin, which makes ho membrane, causing the cell to rupture and die.
	T memory cells	Provide immunological memory: upon reinfection, T killer cells which swiftly destroy the pathogen.
	T regulator cells	Oversee the immune system: • Prevents over-reaction and destruction of self-c • Suppresses processes that are initiated to destro
B lymphocytes	Plasma cells	Rapidly manufacture large quantities of antibodies an infection. • Have a large nucleus and lots of rough endoplas
	B effector cells	Divide to create clones of plasma cells.
	B memory cells	Provide immunological memory for antibody produ they provide a rapid and amplified antibody response

Table F1.1 Functions of the subtypes of B lymphocytes and T ly

Eosinophils

Eosinophils target parasitic infections by producing toxic granules which can kill these organisms. When viewed using a light microscope, these granules can be seen in the cytoplasm, surrounding a **bilobed** nucleus. If over-stimulated, they can cause allergic reactions and inflammation, which can lead to tissue damage.

Monocytes

Monocytes are precursors for tissue-specific macrophages. They circulate in th
where they differentiate into localised immune cells, such as Kupffer cells in th
nervous system. These macrophages are specialised to clear damaged cells an
their respective tissues.

Sensory, relay and motor neurons

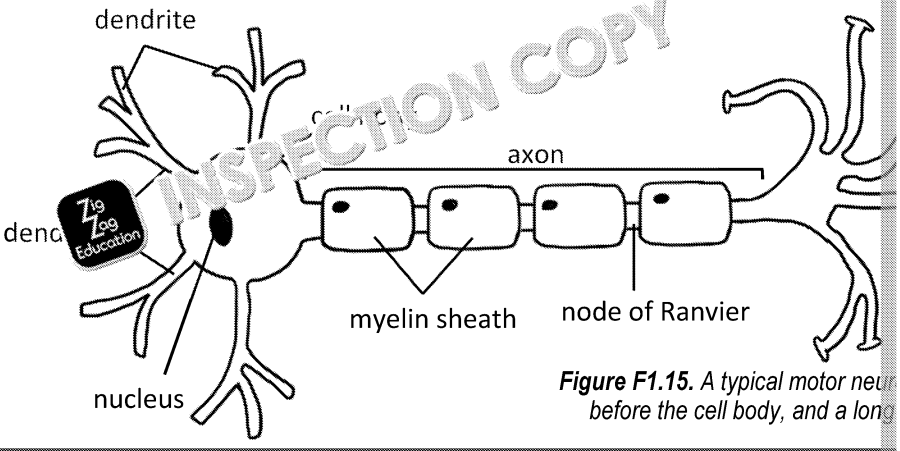


Figure F1.15. *A typical motor neu
before the cell body, and a long*

Neurons are highly specialised cells responsible for conducting electrical impulses th
These signals allow the brain to receive information from receptors and send comma
rapid responses to internal and external environmental changes. Due to their comple
neurons do not undergo mitosis, which is why nerve damage is often permanent.

Neurons have the following specialised features:

- Dendrons and dendrites – extend towards the cell body, branch into dendrit
neurons or receptors. Multiple dendrites per ne[illegible] allow multiple pathways to
- Axon – a long, thin extension that conducts electrical impulses away from the ce
neurons or effectors.
- Axon terminals – located at the end of the axon, these branch out to form synap
communi[illegible]with multiple target cells.
- Myelin she[illegible] present on many but not all neurons, it is a fatty insulating laye
It insulates the axon and prevents current leakage, supporting faster impulse co
- Nodes of Ranvier – gaps between each myelin segment, which allow impulses to
in a process called saltatory conduction, greatly increasing conduction speed by

There are three types of neuron:

- Sensory neurons – transmit signals from sensory receptors to a relay neuron in t
The cell body is located centrally and the dendron and axon are of roughly equal
- Relay neurons – found in the central nervous system, they connect sensory neur
enabling signal processing and integration. They typically have a central cell bod
incoming signals, and a short axon transmitting impulses onwards.
- Motor neurons – carry signals from the CNS to effectors, such as muscles or gla
includes short dendrons connecting to other neurons, a cell body positioned nea
long axon that extends to the effector.

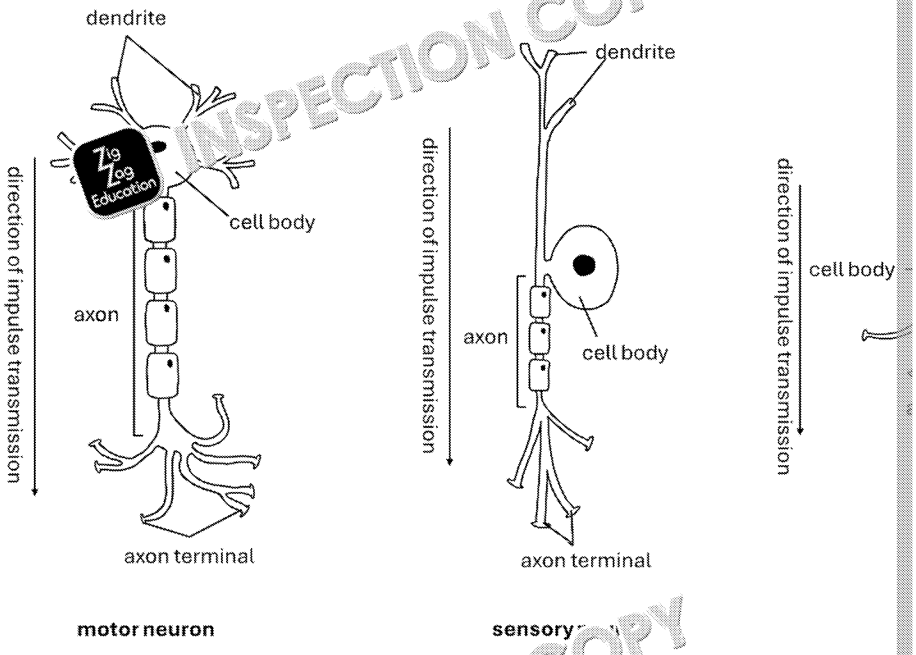


Figure F1.16. *Diagram showing the structure of [illegible]ensory and relay neurons and the direction*

Hepatocytes

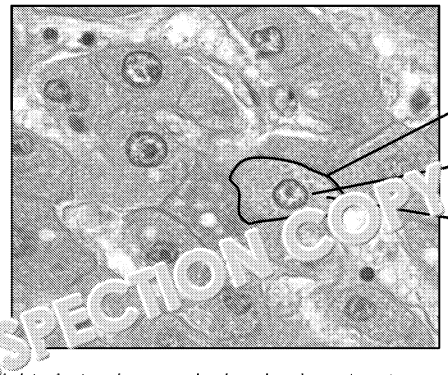


Figure F1.17. Light photomicrograph showing hepatocytes, each with a distinct nucle

Hepatocytes are specialised epithelial cells that make up approximately 80 % o liver's mass. These cells are essential in metabolic processing, including the **catabolism** of toxic substances such as alcohol and drugs into non-toxic substa

Key structural features include:

- granular cytoplasm, indicative of high metabolic activity
- many mitochondria, supplying the ATP required for the energy-intensive biochemical reactions
- central nucleus, enabling regulation of complex metabolic functions
- extensive rough and smooth endoplasmic reticulum, producing enzymes protein synthesis
- many lysosomes, supporting waste disposal and cellular recycling

Renal tubule epithelial cells

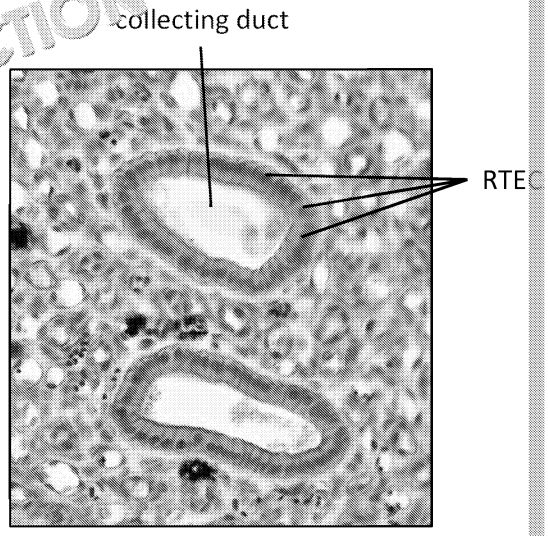


Figure F1.18. *Light photomicrograph showing a cross section through the kidney collecting duct can be identified with large, darkly staining nuclei in the cells surrounding th*

Renal tubule epithelial cells lin ey nephrons, Bowman's capsule and c the filtration of blood metabolic waste and regulation of water an epithelial morphology (size, shape and structure) varies depen contain itochondria that produce ATP used for active transport and fi granular cytoplasm to support high levels of protein synthesis and metabolic a

Photoreceptor cells

The retina at the back of the eye detects visible light and transmits electrical impuls
nerve. Photoreceptor cells – rods and cones – respond to light differently: rods are s
whereas cones are sensitive to specific wavelengths of light. This means that rods e
optimised for low-light conditions and are found in greatest concentrations around t
while cones enable colour vision in bright light and are densely clustered in the fove

Cone photoreceptor cells

There are three types of cones in the hu[illegible]ving us trichromatic vision. They
(medium) or blue (short) wavele[illegible]s of light. Cone cells have a complex structure w
to a neuron in the optic ne[illegible]e:

- Outer seg[illegible] cal shape with many membrane layers containing light-se
photopsin[illegible]arrangement forms a vast surface area.
- Inner segment – contains many mitochondria, the cell nucleus and endoplasmi
production and protein synthesis.
- Lower segment – links with a neuron in the optic nerve via a synapse.

Rod photoreceptor cells

Rod cells have a similar layout to cone cells but differ structurally with a rod-shaped
slightly longer and thinner than cone cells.

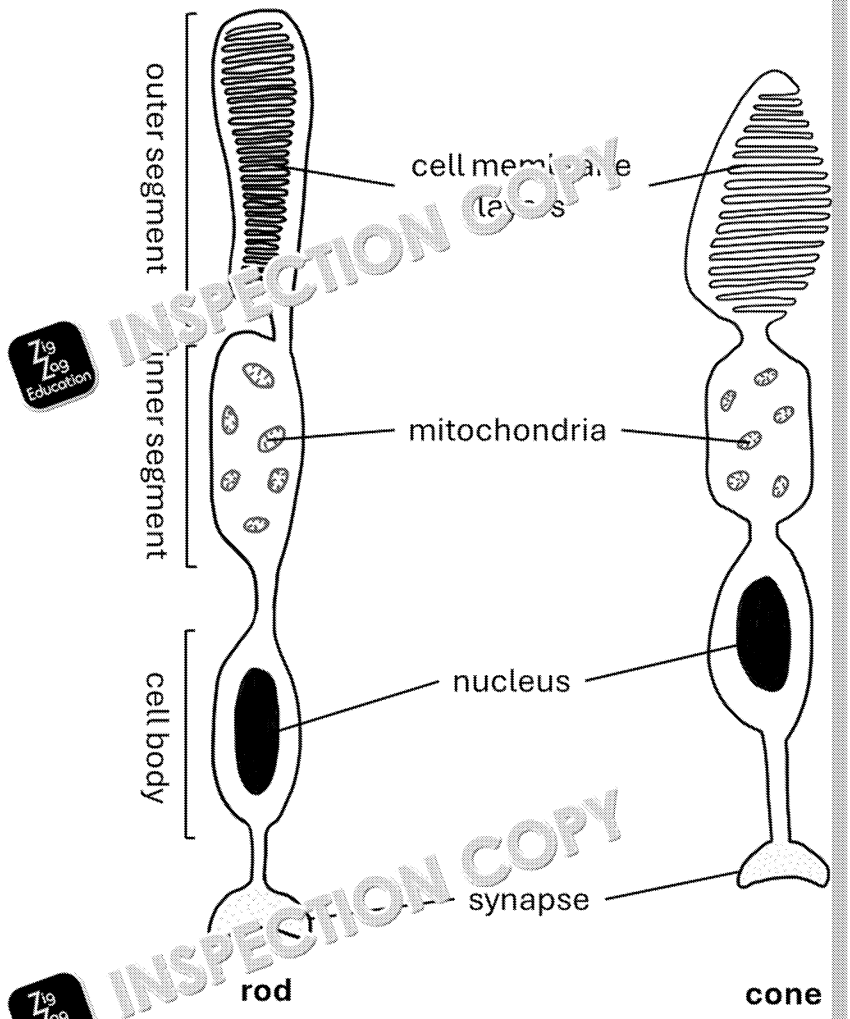


Figure F1.[illegible] Structure and layout of rod and cone photoreceptor cells, showing structural sim

Tracheal and oviduct ciliated epithelial cells

Tracheal columnar epithelium contains two main cell types: goblet cells, which release mucus that traps pathogens and dirt particles, and ciliated cells that have motile cilia which beat rhythmically to move this mucus up the trachea to the throat for expulsion or digestion. This provides some protection to the lungs against infection and contamination.

Oviduct epithelium also features cilia[illegible] that transport the ovum from the ovary to the uterus. They facilitate the movement of sperm cells toward the egg cell for potential fertilisation, and they ensure the zygote moves appropriately through the system, either for implantation or expulsion if fertilisation does not occur.

Figure F1.

Alveoli squamous epithelial cells

Squamous epithelial tissue lining the alveoli (singular: alveolus) of the lungs consists of extremely thin, flat cells, arranged in a single layer. This minimal thickness facilitates rapid gaseous exchange between the air in the alveoli and blood in the surrounding capillaries. Their flattened shape and close proximity to the capillary walls minimise diffusion distance, allowing efficient transfer of oxygen into the blood and carbon dioxide out of

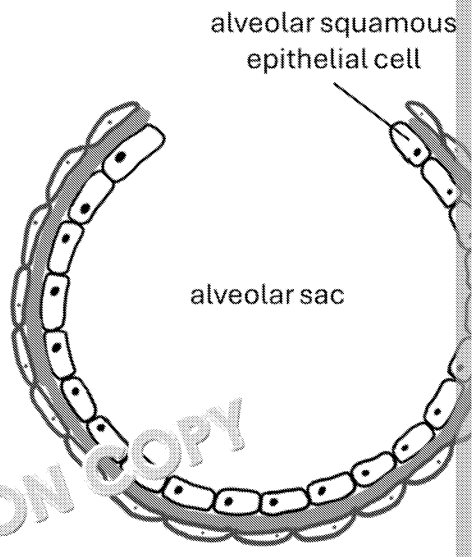


Figure F1.21. *Squamous epithelial cell[illegible] their flattened shape and close proxim[illegible]*

Muscle cells

There are three distinct types of muscle cells, each specialised for different forms of movement:

- Skeletal/striated – provides voluntary, conscious movement of limbs.
- Smooth – provides involuntary movement, such as through the digestive tract, the pupils in the eyes, and the erector pili muscles which raise or lower the hairs on our body.
- Cardiac – provides involuntary, regular, and rhythmic contraction of the heart.

All muscle cell types contain actin and myosin proteins which slide over each other and shorten cell length to contract the muscle and cause movement. They all contain large quantities of mitochondria, to provide sufficient ATP to facilitate this movement.

Figure F1.22. *Structural overview of cardiac, skeletal, and smooth muscles.*

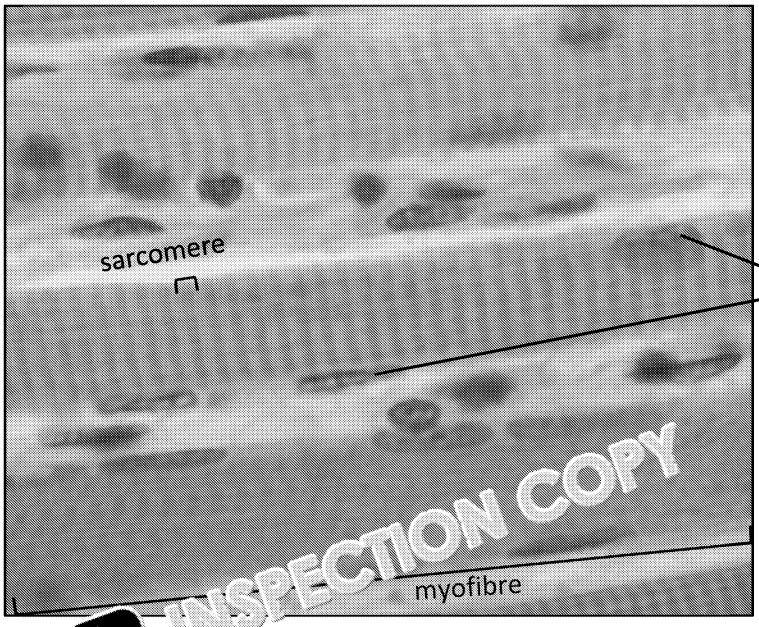
Skeletal muscle cells

Skeletal muscle fibres are formed by the fusion of immature muscle cells (myoblasts), which mature to create large, **multinucleated** cylindrical fibres with several nuclei and shared cytoplasm (see 'Other tissue-specific stem cells', page 8).

multin
nuclei p
sarco
section
actin a
enable

Nuclei are positioned just inside the cell surface membrane, preventing the obstruction of contractile fibres. The nucleus is a specialist to allow rapid synthesis of muscle proteins for efficient muscle maintenance.

Muscle fibres contain actin and myosin proteins that are regularly arranged in **sarco** the striated appearance. Each muscle fibre is individually innervated and can contrac enables the strength of contraction to be controlled and varied.



mult
per m

Figure F1.23. The striated appearance of skeletal muscle, as seen using a light m

Cardiac muscle cells

Cardiac muscle is found in the heart and is striated like skeletal muscle because of the presence of sarcomeres. Cells remain separate, so are **uninucleate**, but the Y-shaped cells are interconnected via **intercalated discs** – specialised junctions enabling rapid signal transmission between cells. Their coordinated response to a single stimulus ensures synchronous contractions, which is vital for effective blood circulation.

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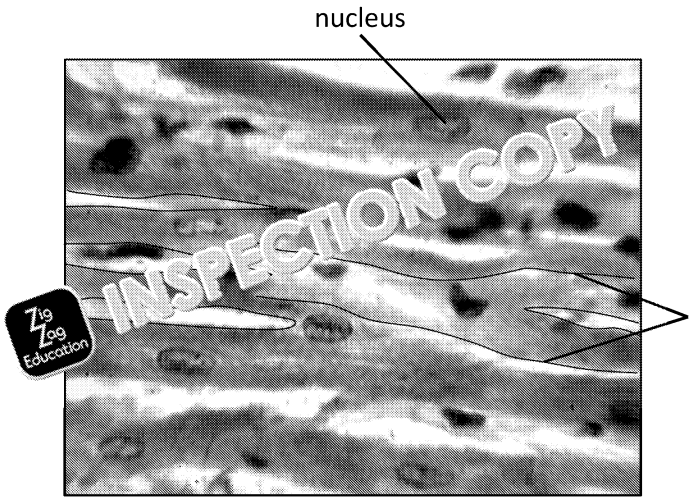

lines highl
the Y-shap

***Figure F1.24.** A light micrograph of cardiac muscle, showing the Y-shaped cells and the da*

Smooth muscle cells

Smooth muscle fibres control involuntary movement and regulatory functions as blood pressure and **sphincter** control. Cells are spindle-shaped, with a wide section and narrow, tapered ends and centrally located nuclei. They lack sarco so appear non-striated (not striped) under the microscope. Instead, the contra proteins – actin and myosin – are dispersed throughout the cytoplasm. This a contractile intensity to vary and long-duration contrac to be maintained u minimal energy, such as when controlling sphincters.

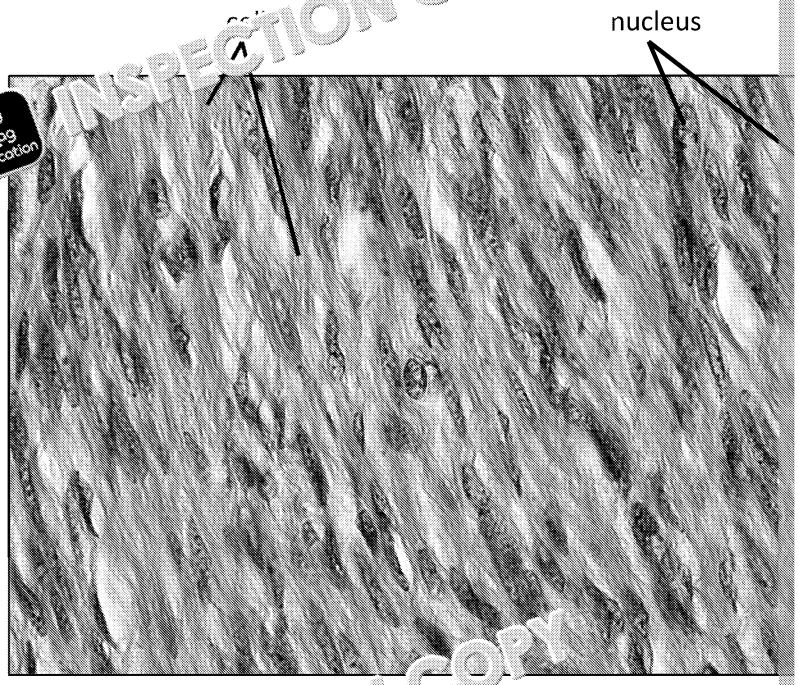

Figure F1.25. *A light micrograph of smooth muscle, at ×400 magn*

Gastric pit epithelia

Gastric pits are invaginations in the stomach lining formed by columnar epithe underlying gastric glands that secrete hydrochloric acid, enzymes and mucosa maintenance of the stomach environment.

The epithelia increase the surface area for secretion and absorption. They hav reticulum and vesicles that support the synthesis and export of enzymes and m stomach lining forms a protective barrier against self-digestion by enzymes an

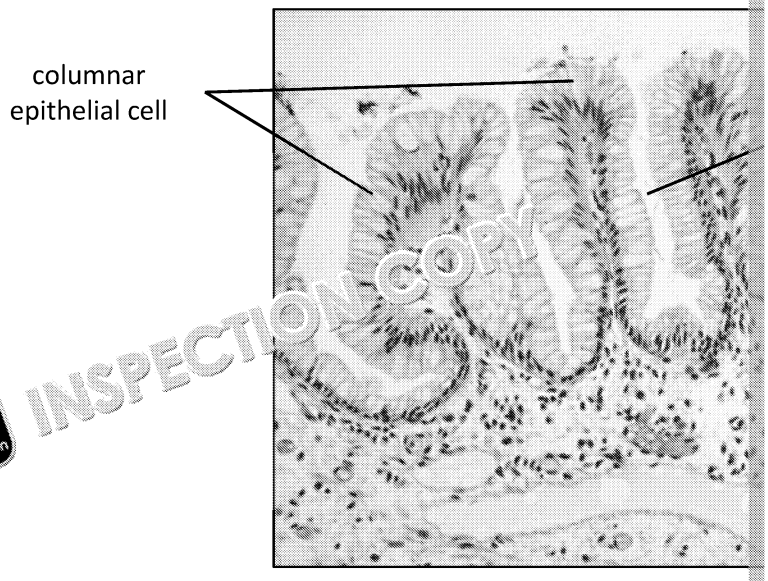

Figure F1.26. *A low power light micrograph showing columnar epithelial cells lining*

Recall questions

1. Describe the adaptations of erythrocytes and explain how t
their ability to transport oxygen.
2. Explain why sperm and ova are haploid but all other speci
3. Compare the adaptations of the tracheal ciliated epithelia
epithelial cells and describe how these adaptations suppo

Comparing eukaryotic and p[illegible]ic cells

Prokaryotic cells lack a nuc[illegible] DNA is located in a central region called the nucleoid
lengths called [illegible]ds [illegible] contain only a few genes that can be replicated indep

There are no membrane-bound organelles in prokaryotic organisms, so although pa
specialised functions, these occur in unsegmented regions. Protein synthesis is carri
are smaller and less dense (70S) than eukaryotic cells (80S).

Most prokaryotes have a cell wall containing peptidoglycan and may have short hair
pili that extend out from the cell surface. These are used to attach the cell to surface
DNA between prokaryotes, for motility, or to generate biofilm. Some prokaryotes us
move through their environment.

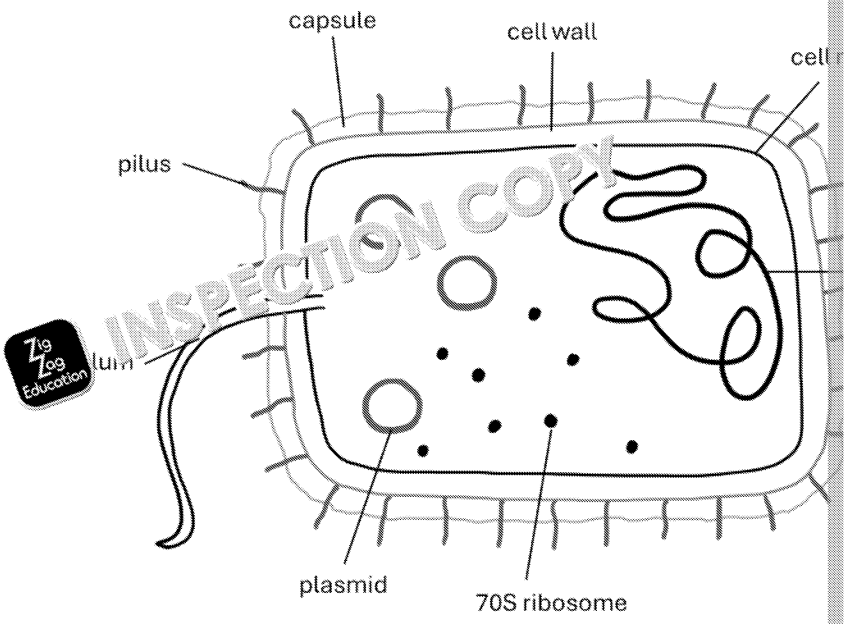

Figure F1.27. *Diagram of a generalised prokaryotic bacterial cell. See page 2 for diagram of a*

Differences in ribosomes

Prokaryotes and eukaryotes have different ribosomes: 70S or 80S. This value describ
of the ribosome following ultracentrifugation, which reflects d[illegible]rences in their size
differences in protein content.

	Prok[illegible]ic ribosome	Eukaryo
Size	70S	80S
Lo[illegible]	Free in cytoplasm	Free in cytoplasm endoplasmic retic
Protein content	Less protein content	More protein cont

Table F1.2. Summary of prokaryotic and eukaryotic ribosome feature

Mitochondria and chloroplasts have 70S ribosomes.

Endosymbiotic theory

Endosymbiotic theory proposes that about 1.5 billion years ago mitochondria
At some point shortly after this, these bacteria were engulfed by another ancestral cell but were not digested and a **symbiotic** relationship developed, benefiting both organisms. Over time, the engulfed bacteria transferred much of their DNA to the host cell and lost their ability to reproduce independently, evolving into mitochondria.

The recognition that mitochondria ha[illegible] own DNA (mtDNA) and produce are of a similar size and density to prokaryotic ribosomes, provides evidence t features suggest the [illegible] independent organisms.

Further your knowledge

A similar explanation has been proposed for chloroplasts in plant cells, which contain the to have originated from cyanobacteria through the same symbiotic process.

Apply your knowledge

1. Describe the main structural differences between eukaryotic cells and prokaryo
2. Describe and explain the evidence to support endosymbiotic theory. Suggest w

Practice questions: Cells

1 The diagram shows a cone photoreceptor, a highly specialised cell w

a. Label the three missing organelles (A, B and C on the diagram) on the photoreceptor cell. (3)

A

The top organelle is heavily folded. Explain why this is important in a cone photoreceptor. (2)

The cone photoreceptor is one of millions within the nervous system relaying information from the eye to the brain.

B

c. Describe the pathway through which electrical signals pass, starting with the trigger of photons and ending with the central nervous system. (3)

C

1.1.2. Observing cells and organelles

Cells are usually too small to observe with the naked eye and require a microscope t

The light microscope

There are several key parts to a light microscope:

Objective lenses
usually a rotating set of three lenses with magnifications of ×4 ×10 and ×

Stage
the platform where the glass slide holding the specimen is placed and secured with clips.

Light/mirror
illuminates the specimen from below, allowing light to pass through the specimen and lenses to reach the eye.

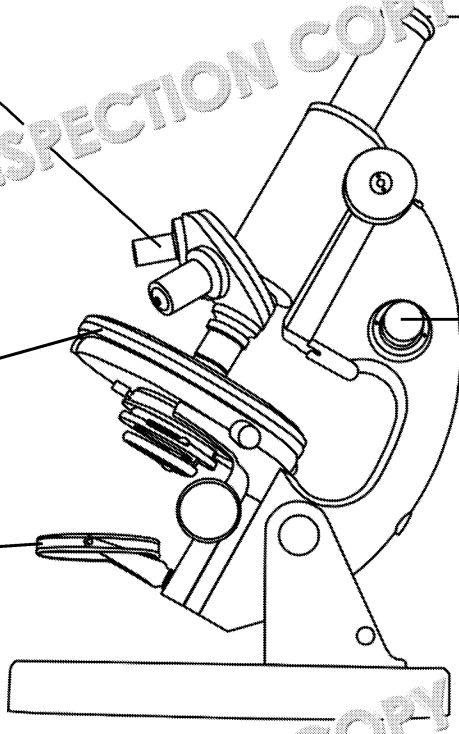

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Figure [illegible] key parts of a light microscope.

Using a light microscope

When using a light microscope, it is important to avoid contact between the lens and slide to prevent damage to the specimen or lens, and to adjust the brightness so it is safe to view.

To observe a specimen using a light microscope:

1. Place slide on stage and secure with clips.
2. Set objective lens to lowest magnification.
3. Raise stage to its highest point close to the lens.
4. Turn on light source or direct light onto the mirror and check brightness through the eyepiece.
5. Use the coarse wheel, followed by the fine focus wheel, to bring the specimen into focus.
6. Adjust objective lens to medium then high magnification and refocus using the focus wheels at each magnification.

Advantages and limitations of the light microscope

The light microscope is a familiar piece of equipment when studying biology at school. There are many advantages to using a light microscope, but they do have limitations, which are described below.

Advantages	Disadvantages
• Inexpensive and easy to use. • Quick specimen preparation. • Enables viewing in natural colour with the option to use stains to improve contrast. • Portable and suitable for classroom use. • Can observe living specimens in real time.	• Limited **resolution** (~200 nm). • Small organelles are not visible. • Only thin specimens can be viewed due to shallow depth of view. • Specimens must be transparent to view effectively. • Provides only 2D visual information.

Table F1.3. Advantages and disadvantages of the light microscope

Apply your knowledge

1. List four success factors that, if achieved, will ensure that a clear, sharp image is viewed using the light microscope.
2. When viewing an image on a smartphone, zooming in will initially show more detail, with the image becoming pixilated. Use the terms 'magnification' and 'resolution' to explain this.

Preparing temporary slides

Many specimens can be viewed using a light microscope, although slide preparation depends on the sample. Some samples are dry, some are wet or in suspension, and some require staining.

Slides prepared in school or college are temporary slides: they are made and used quickly, then cleaned up afterwards. In contrast, permanent slides are professionally prepared and may be stored for many years.

Preparing dry slides

Dry biological samples include thin plant leaves, human hair, and animal fur. If the sample is thin and relatively flat, such as a hair, then it can be viewed directly. However, normally the sample is placed on a glass slide and secured with a coverslip to gently flatten and stabilise it so that it is clear and steady, and protects the sample and the microscope lenses.

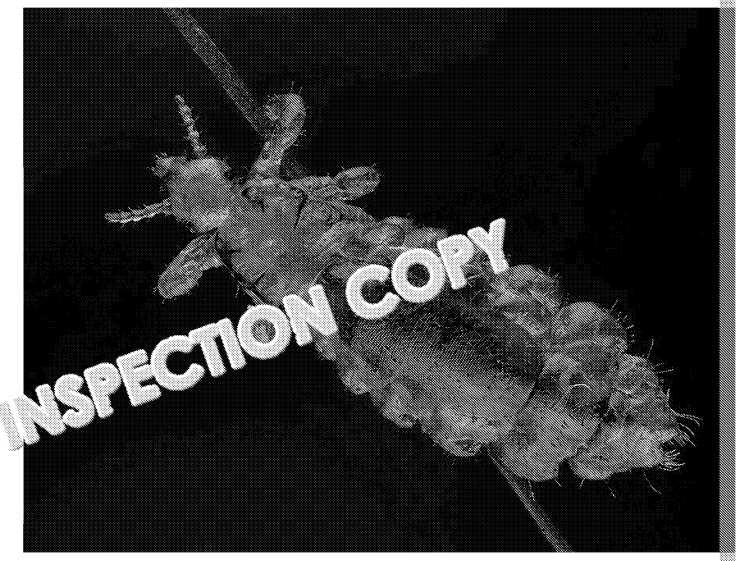


Figure F1.29. *A human head louse (Pediculus humanus capitis) attached to a human hair at ×3.5 mag*

Preparing wet slides

Wet samples, or those that require hydration to stop them from drying out quickly i need preparing directly on the slide using this standard procedure:

1. Place specimen flat and open on the glass slide.
2. Add 1–2 drops of water using a pipette to hydrate the sample.
3. Use tweezers to carefully flatten the sample into the water puddle.
4. Hold a coverslip at a 45° angle with one edge touching the slide.
5. Lower the coverslip onto the specimen to prevent air bubbles between the glas

Staining specimens

For some samples, stains can be adde[illegible] above either instead of, or as well a the contrast between organell[illegible] improves differentiation between different ce bacterial cells and [illegible] a blood sample. Common human tissue samples co school include[illegible] and blood smears.

Stain	Use
Methylene blue	Stains animal cell nuclei blue and enhances cell shape (see
H&E (haematoxylin and eosin)	Haematoxylin stains nuclei blue; eosin stains cytoplasm pink
Crystal violet	Used in Gram staining to identify bacterial cells (see *Figure*
Safranin	Highlights cell walls pink; used as a Gram counterstain (see

Table F1.4. Uses of different stains.

Using a stage microtome

A stage microtome cuts extremely thin sections from a s[illegible] using a very sharp The microtome is mounted on the microscope st[illegible] so [illegible] sections can be observe This is ideal for building up a 3D reconst[illegible] of a specimen, such as a tissue biops understanding of the sample.

A microtome c[illegible] particularly useful when preparing delicate or complex tissue sam sectioning using observation to ensure that cuts are made in relevant locations w structures. For instance, when preparing a sample of intestinal tissue for histological an fragile, highly structured, and difficult to section without it becoming distorted or dama microtome can reveal the fine structure of villi, by orientating the microtome to cut th last to preserve its structure. This is critical for allowing accurate diagnosis of condition

Figure F1.30. *A microtome preparing extremely thin sections o*

Recall questions

1. Describe how a coverslip should be placed on a slid technique is important.
2. Explain why a microtome may be useful when prepa lung cancer biopsy, and how careful use of the micr detail of delicate features.

The electron mic

Electron sc use a beam of electrons, rather than visible light, to gen biologica mens. They have much higher resolution and magnification tha the shorter wavelength of electrons – up to ×500,000 magnification and 0.2 n ultrastructure detail to be visible.

Types of electron microscope

There are two types of electron microscope: transmission and scanning:

- A transmission electron microscope (TEM) passes electron beams throug stained with heavy metals. It produces a 2D image.
- A scanning electron microscope (SEM) bounces electrons off the surface usually been coated with gold. This allows the surface detail of larger spe creates a 3D image.

Sample preparation

When samples are viewed in an electron m cr sc p , they are placed in a vac imaging beam from being scatte r lecules in air. Specimens must be d withstand the vacuum a el tron beam. For TEM samples, heavy metal contrast and high tures, but preparing samples is a complex and techn fragile b al structures. The sample must be dehydrated then embedded microton stained for contrast.

How images are formed

To create an image with a TEM, electrons pass through the specimen or interact wit
Electrons that pass through the specimen interact with the detector below, creating
negative: brighter areas correspond to transparent regions, while darker regions ind
more densely stained. These images are black and white, showing the presence or a
colour in electron micrographs is added digitally to aid interpretation.

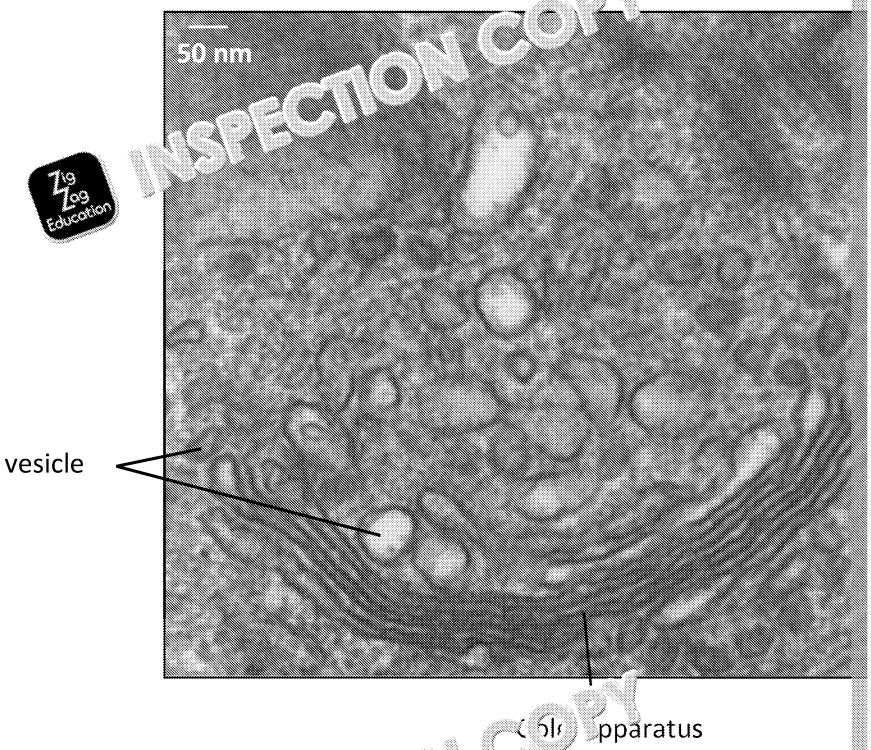


Figure F1.31. *Human leucocyte showi os of Golgi apparatus, taken with a transmiss*

With a SEM, electrons inte with the particles on the surface of the sample: some
dislodge electr om ons in the sample, known as secondary electrons. These
translated into led 3D surface image. SEMs are especially good at obtaining v
larger specimens.

Figure F1 *ning electron micrograph of a tardigrade Milnesium tar*

Recall questions

1. Describe the main differences between the transmission a
electron microscopes.
2. Explain why biological samples must be stained with heav
vacuum when observing using an electron microscope.

Calculating magnification

Microscopes allow us to observe cells and subcellular structures at a much lar
appear. Cell features are typically so small that they fall well below the resolu
Therefore, magnification is essential for detailed study.

Key terms in magnification

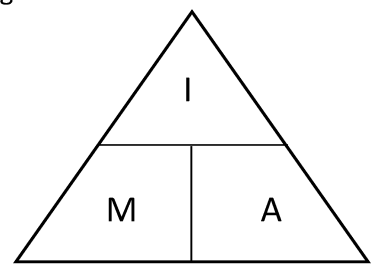
There are three measurements when interpreti[illegible] microscope images:

- image size – the apparent size of the [illegible]e when viewed or measured
- actual size – the real size of the [illegible]ucture
- magnification – the [illegible] or times an image has been enlarged compar

These va[illegible]e linked by the equation:

$$magnification = \frac{image\ size}{actual\ size}$$

You may prefer to use the equation triangle:



Common missteps and how to avoid them

While the formula is straightforward, applying it m[illegible] tricky. Avoid making
common pitfalls:

a) Being confused by terminology
Questions may use [illegible] phrasing for the terms 'image size' and 'actu
'real si[illegible]' or [illegible]meter'. It can be tricky to correctly identify them.
Car[illegible]ead the question to identify which values you are dealing with.

b) Misr[illegible]ching the units.
Actual size is often given in micrometres (10^{-6}, **µm**) or nanometres (10^{-9}, n
magnification) is usually measured in millimetres (10^{-3}, **mm**). Mixing these
to incorrect calculations.
Use powers of ten to convert between the units:
1 mm = 1000 µm
1 µm = 1000 nm

Tip!

There are 1000 nm in 1 µm, and 1000 µm in 1 mm.
To calculate the number of µm in 1 mm, multiply mm by 1000.
3 mm × 1000 = 3000 µm.
To calculate the number of µm in a v[illegible] in nm, divide nm by 1000
450 nm ÷ 1000 = 0.45 µm

Struggli[illegible] a cm section of a ruler.
In e[illegible]here are 10 mm. In every mm there are 1000 µm.
[illegible]every µm there are 1000 nm.
So, if there are 775 µm, then there will be <1 mm (0.775 mm) because to
there must be 1000 µm, and this is only 775 µm.

Tips for success

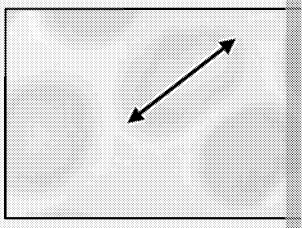
When calculating magnification, it is worth following these steps:

1. State the values you know from the question and label them clearly.
2. Convert units so they match before inserting into the formula.
3. Rearrange the equation if solving a different variable.
4. Show all your workings, including units at each step.
5. Double-check your answer by reversing the calculation.

Worked example 1: calculating magnification

An erythrocyte measures 7 µm but appears to be 2800 µm when viewed in a light
Calculate the magnification of the microscope.

1. State the values that you know:
   M = ? I = 2800 µm A = 7 µm
2. State the equation: M = I ÷ A
3. Substitute in the numbers with their units:
   M = 2800 µm ÷ 7 µm
4. Solve the equation:
   M = ×400
5. Check your work:
   A × M = I
   7 µm × 400 = 2800 µm

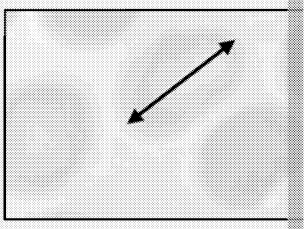


The first worked example is straightforward because it involves no unit conversions
are in micrometres. Here is an example where unit conversions are involved.

Worked example 2: calculating magnification

An erythrocyte measures 7 µm but appears to be 17.5 mm when measured in the
below taken using a light microscope. Calculate the magnification of the image, w
microscope and the printing magnifications.

1. State the values that you know and convert them to the same units:
   M = ? I = 17.5 mm × 1000 = 17 500 µm A = 7 µm
2. State the equation: M = I ÷ A
3. Substitute in the numbers with their units:
   M = 17 500 µm ÷ 7 µm
4. Solve the equation:
   M = ×2500
5. Check your work:
   A × M = I
   7 µm × 2500 = 17 500 µm ÷ 1000 = 17.5 mm
   The erythrocytes in this printed image are 2500 times larger than their actual



The second worked example is more complex because the units of image and actual size a
converted. It does not matter which way you do this, as long as you perform the calculatio

Your turn

1. A macroph[illegible] 17.4 mm down a light microscope with a magnification o
   Calculate the actual size of the cell, in micrometres.
2. An amoeba measures 2.4 µm and is being viewed at medium power with a magni
   Calculate the apparent size of the amoeba in micrometres.
3. A specimen of Ebola virus appeared to be 143.56 mm under an electron microsc
   Calculate the actual size of this virus in micrometres.

Measuring cell size

The true magnification of each microscope lens varies and therefore each mic
separately. Once calibrated, the accurate measurement of specimen size can b

To calibrate a microscope, two pieces of equipment are required:

- **eyepiece graticule**
  A transparent disc with a no-units scale that i[illegible] to the eyepiece lens, used for measuring a s[illegible].
- **stage micrometer**
  A microscope slide [illegible] very accurate known scale, used to calibrate th[illegible].

The eyep[illegible] graticule has an arbitrary scale (e.g. 100 divisions), but its units d
It must be calibrated against a stage micrometer at the magnification you plan
are used, the calibration must be done separately for each lens.

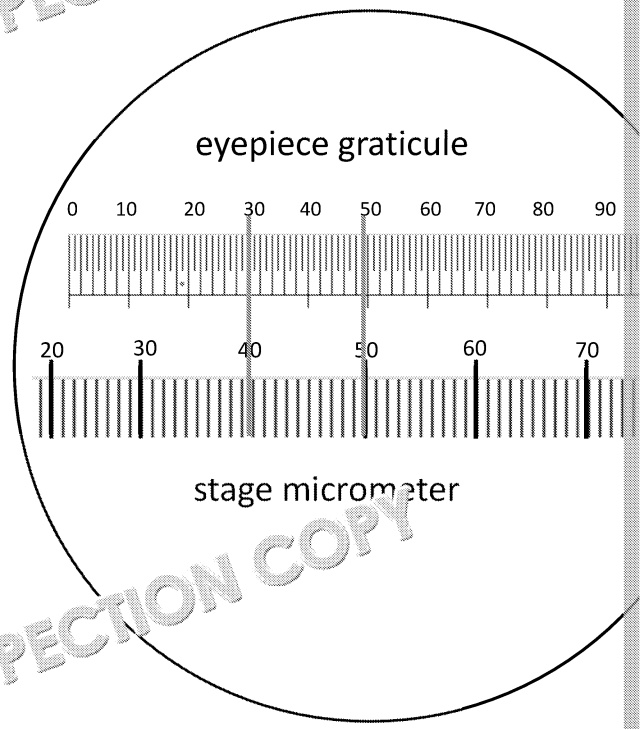
The stage micrometer is an exact length, usually 1 mm long, with ten larger d
further divided into 0.01 mm / 10 µm divisions.

When used together, accurate measurements of microscopic structures can b

Calibration

To calibrate the eyepiece graticule using the stage micrometer:

1. Align the scales:
   Put the stage micrometer on the microscope stage, and the eyepiece grat
   Focus the micrometer scale at the desired magni[illegible]n and align the sca
2. Compare scales:
   Count how many eyepiece divi[illegible] within an exact number of micron
   In the image, 50 – 30 = 2[illegible] eyepiece divisions ≡ 10 micrometer divisions.

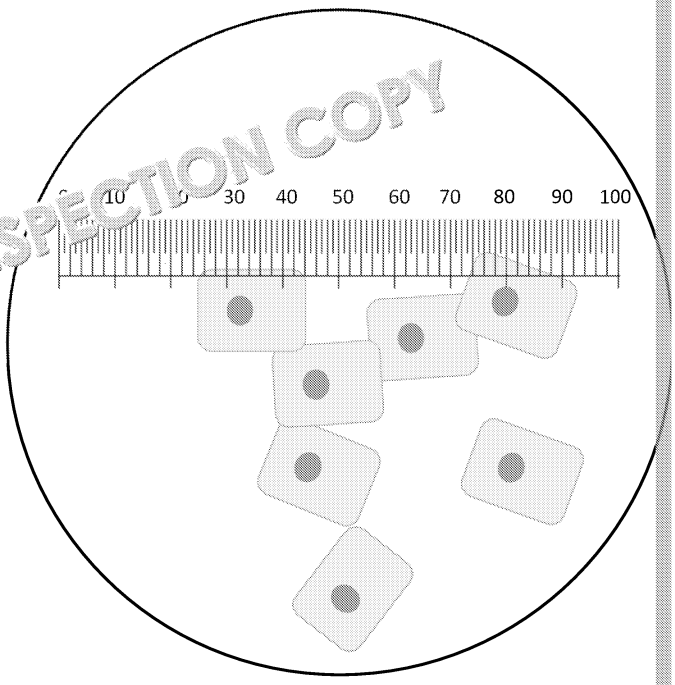


3. Calculate the relative size of each eyepiece division:
   100 micrometer units = 1 mm, so
   10 micrometer units = 0.1 mm
   0.1 mm ÷ 20 eyepiece divisions = 0.005 mm, so
   each eyepiece division is equal to 0.005 mm, or **5 µm**

Measuring specimen size

Having calibrated the eyepiece graticule, we now know the exact size of each divisio
magnification. Next, we can measure a specimen against this known scale.

4. Remove the stage micrometer and place the specimen slide on the stage.

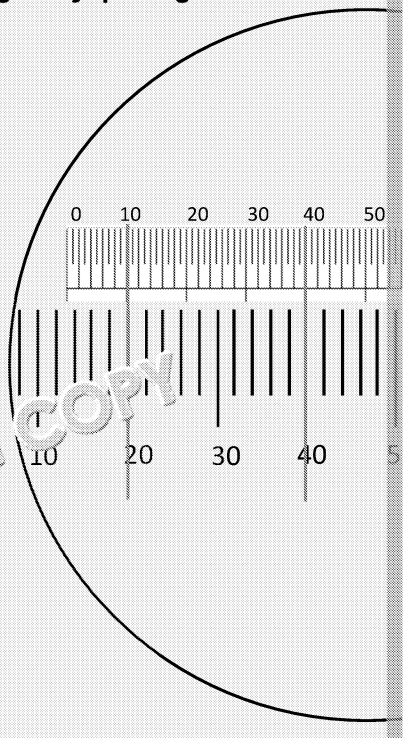


5. Focus at the same magnification used during calibration and align the specimen
graticule scale.
6. Count the number of eyepiece divisions the specimen is equal to.
In this example, the top-left cell spans from 25 t = divisions.
7. Calculate actual size:
Each division = 5 µm × 19 divisi
The cell is 95 µm wide

Worked example: calculating actual size using an eyepiece graticule

1. Compare the scales.
40 – 10 = 30 eyepiece graticule divisions ≡
40 – 20 = 20 stage micrometer divisions

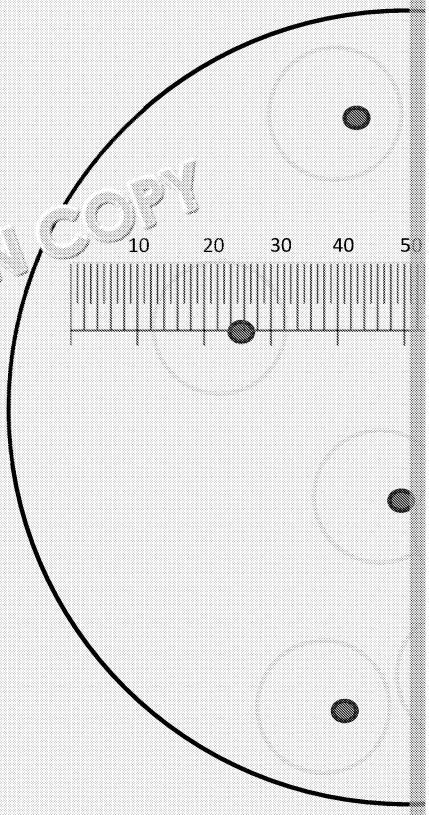
2. Calculate the relative size of each eyepiece division.
100 micrometer units = 1 mm
20 micrometer units = 0.2 mm
0.2 mm ÷ 30 eyepiece divisions
= 0.0067 mm, so each eyepiece division is equal to 0.0067 mm, or **6.7 µm**



Place specimen on stage.

3. Count the number of eyepiece divisions the specimen is equal to:
   32 – 12 = 20 divisions

4. Calculate the actual size:
   6.7 µm × 20 divisions = 134 µm



Your turn

1. Using the scale in the previous worked example, calculate the size of a ren
   which is three divisions wide.

Differential centrifugation

Differential centrifugation is a laboratory technique used to separate cellular components by density and size by rapidly spinning the sample at varying speeds in a centrifuge. Since organelles have different physical properties, sequential centrifugation at increasing speeds allows them to be progressively separated, from large, dense organelles, to small, light ones.

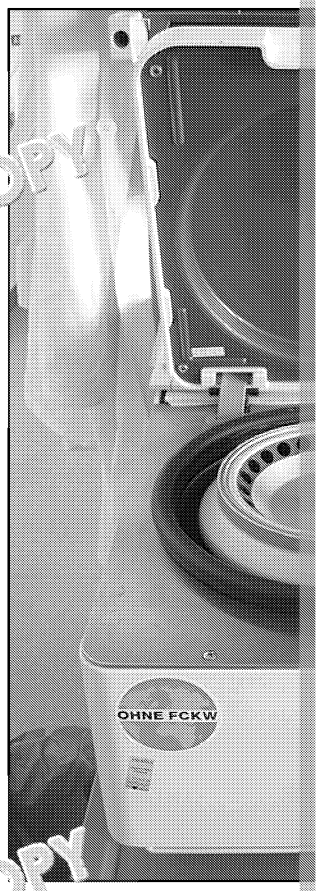


Figure F1.33. Ta

To centrifuge a cell sample for f... analysis:

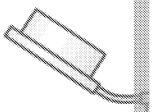
1. Homogenisation: th... of cell sample is broken d... release the cellular contents for separa...
   Homogenisation requires blending the tissue using a motorised homogeniser or a pestle and mortar to create a uniform suspension. Conditions must be carefully controlled. A cold, **isotonic buffered solution** is used to prevent enzyme activity and damage by osmosis or pH changes.
2. First centrifugation (low speed): the suspension is spun at low speed, causing large and dense organelles such as nuclei to settle as a pellet at the bottom of the vial.
3. Removal of supernatant: the supernatant (liquid layer above the pellet) is carefully removed and transferred into a new vial for further centrifugation.
4. Sequential spinning at higher sp... process is repeated at increasing ... ating progressively smaller organelles with e...

Organelle isc...

Pellets containing different organelles or cell components are removed after different centrifuge speeds.

Centrifuge speed	Cell components removed in pellet
Low	Nuclei
Medium	Mitochondria, lysosomes, peroxisomes
High	Microsomes, small vesicles
Ultra	Ribosomes, soluble proteins

Table F1.5. Cell components removed at different centrifuge speeds.



Pellet —

Figure F1.34. Duri... particles settle to th... rest remains sus...

This technique allows scientists to study specific organ... in isolation – for example, analysing mitochond... fu... or identifying enzyme activity within ... ne.

Recall questio...

1. State the purpose of the cold, isotonic buffered solution u... homogenisation.
2. Explain why different organelles can be separated using d... of centrifugation.

Counting cells in a sample

Accurate cell counting is essential in biological investigations, diagnostics, and
Two common tools used for estimating cell numbers in a suspension are the h
Coulter counter.

The haemocytometer

A haemocytometer is a specialised microscope slide which can hold a known v
counting of cells. Once the number of cells in the defined volume is calculated
the original sample can be calculated. Ideal for estimating red or white blood
microbial populations.

The haemocytometer has a finely etched grid, within a recessed chamber 0.1
surface. The coverslip rests above the chamber, creating a precisely known vo

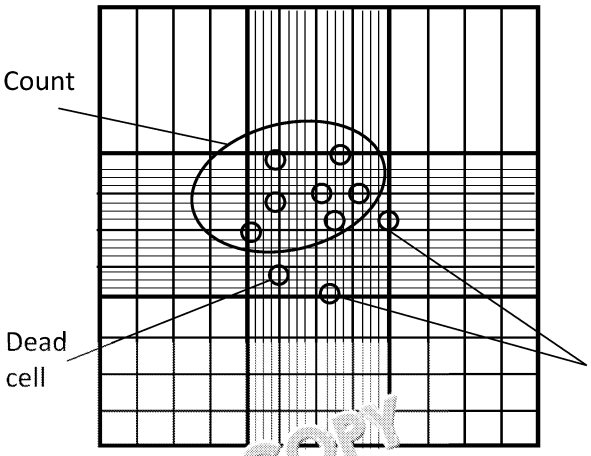


Figure F1.3 A haemocytometer can be used to count cells

To use the haemocytometer:

1. Dilute sample or cell suspension to a workable concentration.
2. Add known volume of diluted sample into the chamber.
3. Count the number of cells under a microscope using the etched grid.
4. Calculate the concentration using the known volume, cell count and dilut

The north-west rule (or 'top and left rule') can be used to determine whether
the boundary line in the count. Cells touching the top (north) or left (west) bo
touching the right (east) or bottom (south) boundary lines are excluded. This
counting cells and avoids double counting or artificially inflating or deflating t

Haemocytometry offers an effective method for determining cell population s

Advantages	Dis
• Known chamber volume allows a reliable estimate without calibration. • Inexpensive and portable. • Allows direct observation of other cell features. • Used for fieldwork and classroom settings.	• Requires precise te which needs trainin • Time-consuming an to inaccuracies and • Accuracy declines at concentrations. • Requires staining fo

Table F1.6. Advantages and disadvantages of haemocyto

The Coulter counter

A Coulter counter is an electronic device used to count cells and estimate their size, b
electrical resistance. A cell suspension is prepared in an electrolyte solution and is d
between two electrodes. Each time a cell passes through, it displaces electrolyte, cr
resistance. The amplitude of the signal indicates cell volume.

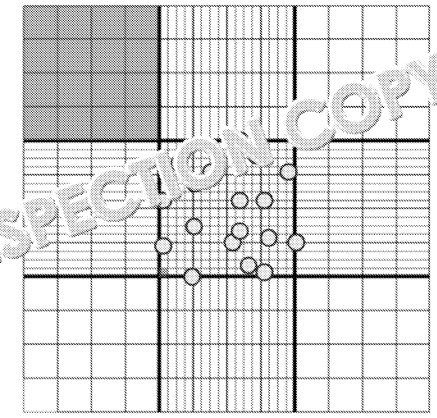
The Coulter counter can be used for very rapid cell counting and can differentiate be
based on their size and electrolyte displacement. This is useful when undertaking a c
part of a diagnosis, or monitoring cell size and growth in cultures.

Advanta	Disadvanta
• Rapid co of large volumes. • Accurate and detailed: measures cell count and volume. • Versatile: can analyse diverse cells and particles. • Removes human error and fatigue.	• Sample must be suspended in e promote cell clumping. • Tube diameter must match sa sizes can cause counting error through together and be coun • Requires regular cleaning, mai

Table F1.7. Advantages and disadvantages of the Coulter counter

Your turn

1. Use the haemocytometer to count the number of valid cells within the central sq

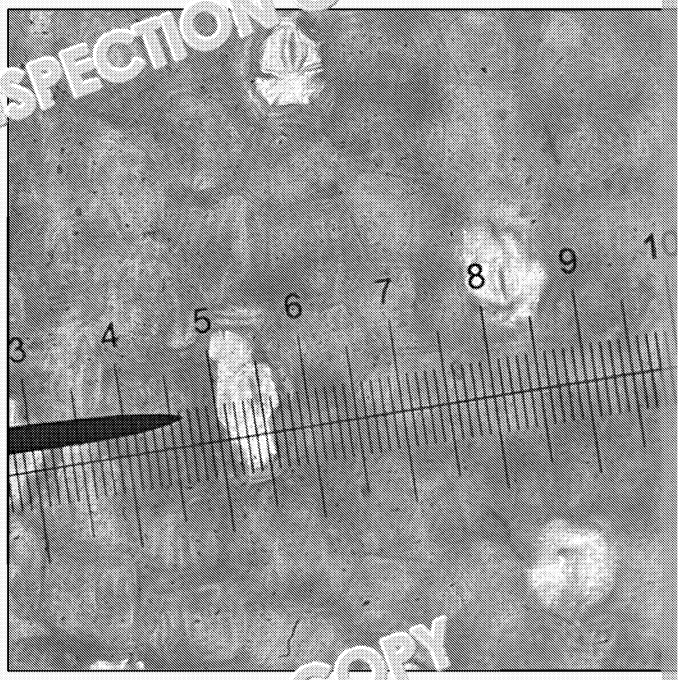


2. Compare and contrast the haemocytometer to the Coulter counter, in particular c
   - speed
   - accuracy
   - user training
   - sample preparation
   - cost

Practice questions: Observing cells and organelles

1 Calculate, in µm, the width of the guard cells (green, indicated by po
Tradescantia leaf, where:

- 100 micrometer divisions = 1 mm
- 10 micrometer divisions = [illegible] piece divisions



1.1.3. Link between organelle structure and function

Cells contain a variety of specialised organelles, each adapted for their specific functi
the quantity and structure of organelles can vary depending on the functional dema
do not work in isolation: their coordinated interaction is essential for maintaining ce

Just as departments in a factory – production, packaging, and logistics – must opera
organelles like mitochondria, lysosomes, and vesicles. Di[illegible]or in this balance ma
That could prove detrimental, or even fatal, for the [illegible].

Coordination between organelles

Coordination between the nucleus and mitochondria

The nucleus an[illegible]chondria share a tightly integrated relationship, rooted in evolu
Endosymbiotic theory, page 20). While mitochondria are able to synthesise some of t
their own mtDNA and mitoribosomes, the nucleus encodes more than 1000 mitocho
synthesised in the cytoplasm and imported into the mitochondria. In return, mitocho
energy-dependent cell processes, including transcription, translation, DNA replicatio

Some mitochondria are physically connected to the nuclear envelope, supporting **bilateral** communication. For instance, in response to cellular stress, mitochondria can signal to the nucleus to adjust gene expression, leading to reduced gene transcription or altered protein synthesis based on metabolic demand.

Organelle coordination in protein synthesis

Transcribing a gene in the nucleus into a protein in the cytoplasm is a complex, multi
several organelles.

1. Transcription in the nucleus.
   The coding strand of the gene is transcribed by [illegible]d – into messenger RNA (mR
   nucleus through nuclear pores int[illegible]cytoplasm.
2. Translation at the ribosom[illegible]
   mRNA attach[illegible]to [illegible]es, and its sequence of codons is used to place amino
   sequence[illegible]n a polypeptide chain.
   Ribosomes [illegible]made in the nucleolus but operate either free-floating in the cyt
   the rough endoplasmic reticulum membrane.
3. Protein processing in the Golgi apparatus.
   The polypeptide chain is modified and folded into its final shape by the Golgi ap
4. Transport and final destination.
   Proteins are packaged into vesicles or lysosomes, which deliver them to their s
   locations or secrete them via exocytosis.

For efficient protein synthesis, organelles must be coordinated. For instance, excess
amino acids leads to waste, as mRNA degrades quickly within the cytoplasm (typicall
few days). Conversely, overproduction of proteins can trigger inflammation or immu
misfolded or unregulated.

Your turn

1. Create a re[illegible]n b[illegible]ganelles and their functions, highlighting how some o
   intricately [illegible]to others.
2. Outline the organelles involved in protein synthesis and describe how they influe
   each other to maintain cell function.

1.1.4. The cell surface membrane

All cells are encased by the cell surface membrane that separates the interna
surroundings. It is not a passive boundary, but rather a dynamic and highly se
central role in controlling substance exchange, maintaining homeostasis, and

Structure of the cell surface membrane

The fluid mosaic model

The cell surface membrane, and inde membranes within living organi
(especially eukaryotic ones) i ade from phospholipids. The **amphip**
nature of phospholi s that they form as a **bilayer**, **hydrophobic** tails
pointing ds rom the water-based cytoplasm, and **hydrophilic** hea
forming mbrane's inner and outer surface. Embedded within the
phospholipid bilayer are many other components, including channel and carr
proteins, cholesterol, glycoproteins and glycolipids.

This arrangement is known as the fluid mosaic model and describes how cell membranes are assembled and function. This formation provides a flexible barrier which can be adapted to suit the specific cell and its function. For example, in nerve cells, the membrane's structure is crucial for the transmission of electrical signals, while in intestinal cells, it aids nutrient absorption.

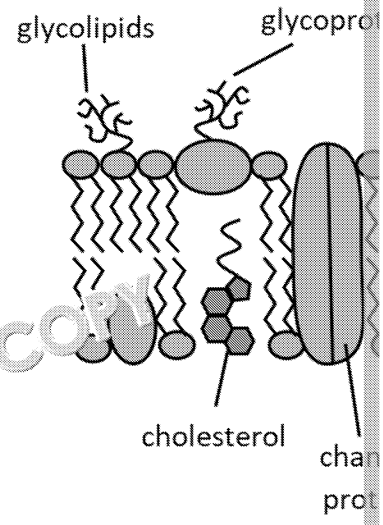


Figure F1.36. *The fluid mosaic m*
showing the phospholipid bila

The amphipathic nature of the membrane means that many substances are naturally prevented from moving through the membrane, either because they are t e to pass through the tightly pa ked membrane, or beca e charged and cannot p ro the hydrophobic middle. This ena e cell to control the entry and exit of substances.

Components within the membrane

Many elements can be embedded within the cell membrane and provide a ra

- enabling cell-to-cell recognition and communication – identifying the cel self or foreign, and the binding of hormones
- adhesion between cells to form tissues – by forming a **glycocalyx**, gap or tight junctions, and **desmosomes**
- providing channels to facilitate the movement of substances by, for example, diffusion, osmosis and active transport

To enable these functions, the cell surface membrane c ains various compo

- intrinsic proteins (see *Table F1.8*):
  - channel proteins (do not cha ape, and carrier proteins (do cha larger molecules tha wo herwise be unable to pass through the
  - aquaporin form of channel protein, that transport wate
- ext rc (see *Table F1.8*):
  - nt on the outer surface as receptor sites for hormones and oth
  - present on the inner surface, involved in cell signalling
- cholesterol (see next)
- glycoproteins (proteins with carbohydrates attached) and glycolipids (pho attached) allow cell-to-cell communication, cell recognition and adhesion

Intrinsic (integral)	Extrinsic (per
• Span the bilayer. • Amphipathic: hydrophobic and hydrophilic zones. • Connect both sides of the membrane.	• Within one side of the bi • Loosely bound to the hy phospholipid. • Do not enter the hydrop

Table F1.8. A summary of the key feat of intrinsic and extrinsic membran

	Glycoproteins	Glyco
Structure	carbohydrate	Phospholipid + carbo
Location	External (extracellular) side of the membrane, including form	
Main functions	Cell signalling, recognition and adhesion, immune response,	
Examples	Antibody and hormone receptors	Blood group antigens

Table F1.9. A comparison of structure and function of glycoproteins and gly

The role of cholesterol in the membrane

Cholesterol is a steroid component of the cell surface membrane. The cell can adjus cholesterol are present: the more cholesterol present, the greater the fluidity of the that the membrane can remain flexible at a greater range of temperatures or be ada functions. For instance, some cells significantly change shape as part of their functio when they are moving through narrow capillaries, and leucocytes when they move o into tissue spaces. Cholesterol in the cell surface membrane maintains fluidity to en change shape.

In addition to maintaining membrane fluidity, cholesterol plays a crucial role in the u epithelial cells. This is worth noting wh ns ing the advantage and disadvanta vessel endothelial membranes. Cholesterol is beneficial in these cell surface membra

- It controls membrane fluidity, providing elasticity in response to blood flow a but also i ns to body-wide blood pressure changes.
- It provides signalling functions important when controlling vasodilation and

However, too much cholesterol in the blood vessel endothelial membranes can increase uptake and retention of **LDL** in the cell surface membranes, which can increase the formation of plaques and increase the risk of heart attack or stroke. These plaques can narrow or block arteries, leading to conditions such as atherosclerosis, which significantly increases the risk of cardiovascular diseases.

LDL (low 'bad' chol found in s cellular fu stroke an excess in

Your turn

1. Draw and annotate a labelled diagram of the flui mosaic model to show the va components within the cell surface mem and summarise their functions.
2. Describe the role of cholester in the cell surface membrane, and outline its risks
3. Describe the import channel and carrier proteins in the cell surface memb why these ial, referring to the structure and properties of the fluid mos

Movement through the membrane

Some molecules can freely pass through the phospholipid bilayer; others can
required in higher concentrations inside the cell than they are present outside
requirements demands specialist transport through the cell surface membran

Bulk transport

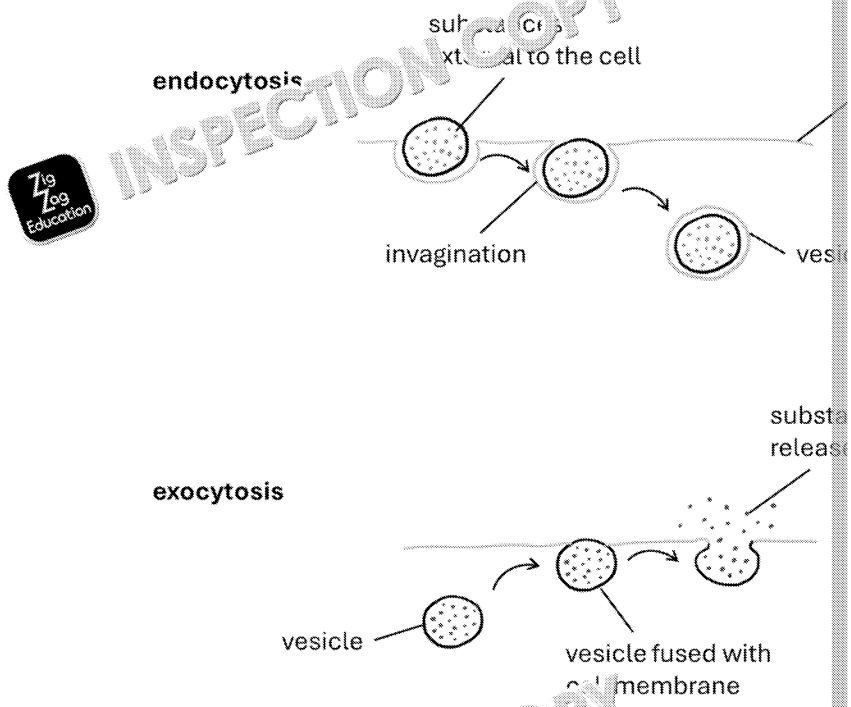


Figure F1.37. *Diagrams t sho e processes of endocytosis a*

One method of transportin s ost ces through the cell surface membrane is
when many molecu ec o be transported at once, or the substances to b
through ra proteins. Endocytosis allows cells to intake essential nutri
while ex s enables the secretion of vital substances like hormones and
when a part of a membrane (such as from the cell membrane or the Golgi app
a vesicle and is crucial for maintaining cell homeostasis and facilitating variou

Endocytosis involves the **invagination** of the cell surface membrane around a
substance external to the cell, thus engulfing it and bringing it into the cell.
Phagocytosis (used to engulf and destroy invading pathogens) and pinocytosi
to transport liquids into the cell) are examples of this process.

Exocytosis involves part of an organelle's membrane budding off to form vesi
apparatus or the rough endoplasmic reticulum. This transports carbohydrates
of the cell, such as in digestion or with antibodies.

Simple diffusion

Diffusion is the net movement of pa ci om an area of higher concentrati
concentration, due to the ra om ovement of particles. Particles move in a
of movement is do h c centration gradient. This movement continues u
process si oes not require energy and is therefore considered pass

Figure F1.38 shows oxygen diffusing through a cell surface membrane. For ins
move across the cell surface membranes of the alveolar epithelial cells, the ca
erythrocytes to bind to haemoglobin. This is possible because oxygen molecul
dioxide, are small and uncharged so are not restricted by the hydrophobic co

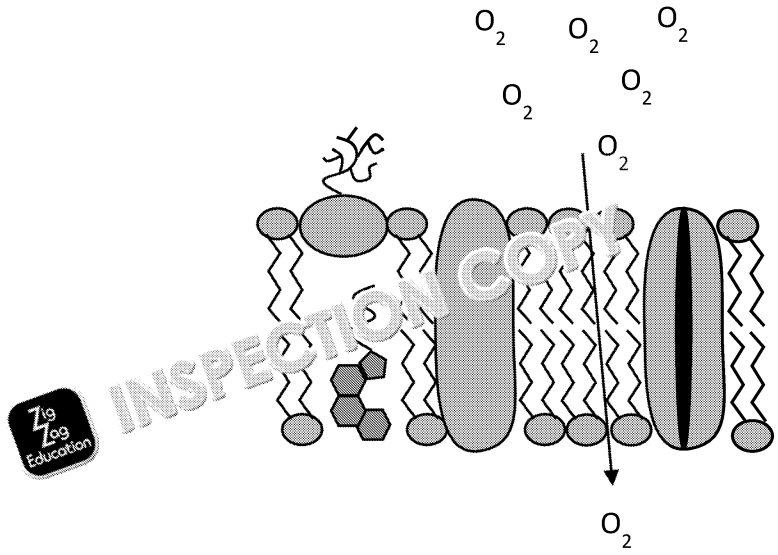


Figure F1.38. *A simplified diagram showing how oxygen molecules can move across the cell su*

Facilitated diffusion

Facilitated diffusion is a refinement of simple diffusion: as with diffusion, particles m concentration gradient, but they move through a protein channel embedded within because of their size and/or charge.

Channel proteins facilitate the movement of small, charged ions, such as sodium or p hydrophobic core of the bilayer.

Carrier proteins transport larger molecules like glucose acro membrane. The p part of facilitating diffusion, which enables only the specific molecule to move throu smaller particles getting through as well

Channel and carrier protei show selective permeability: only certain substances surface memb

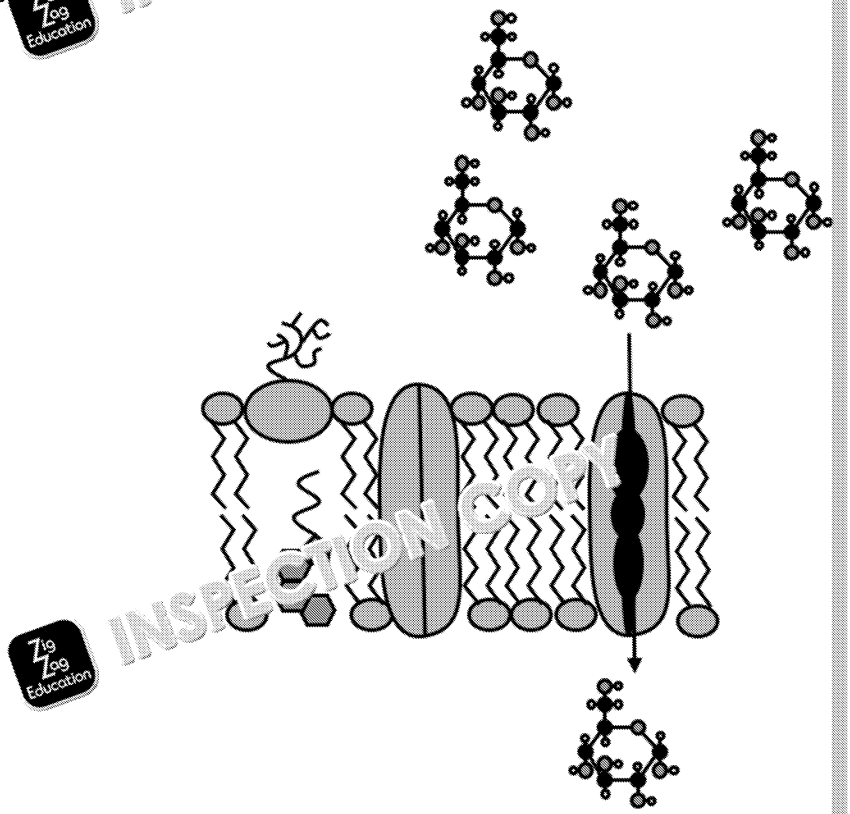


Figure F1.39. *A simplified diagram showing glucose being moved through the cell membran in the process of facilitated diffusion.*

Osmosis

Osmosis is a specialised form of diffusion – it is the net movement of water m
water potential to an area of lower water potential, therefore down the wate
selectively permeable membrane.

The bilayer is partially hydrophobic because the fatty acid tails of the phospho
water from moving through the membrane. Instead, i al membrane prote
entire membrane and facilitate the movement of wa through the membra

Osmosis is important for regulation water balance in animal cells in a process

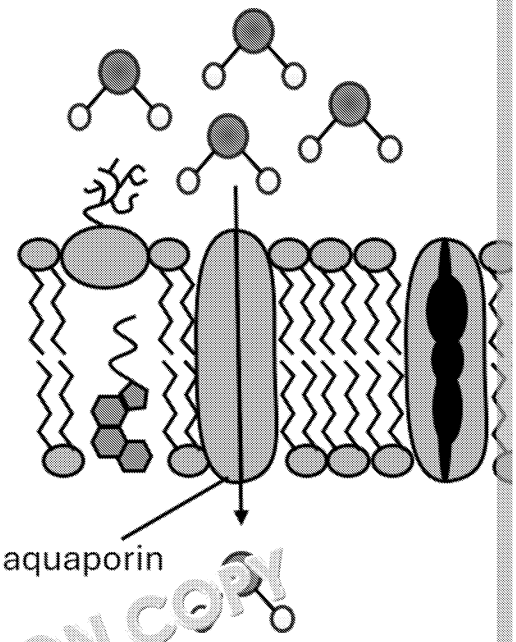


Figure F1.40. *A simplified diagram to show how water moves through the cell surface mem
aquaporin, which enables the polar water molecule to pass through the hydrophobic cent*

Active

Active tr t is the net movement of particles against their concentration g
occurs using intrinsic transport proteins and allows cells to maintain concentra
molecules across the cell membrane.

For instance, cells in the stomach lining use ATP to actively transport H^+ ions i
to create an acidic environment for digestion and defence against pathogens.

Recall questions

1. Describe how endocytosis and exocytosis enable bu
2. Explain the difference between diffusion, facilitated

Cell-to-cell communication

Cell-to-cell recognition

Cell-to-cell recognition occurs using extrinsic proteins, glycoproteins, and glycolipids
the cell. This includes identifying cells as self, and damaged and foreign cells that ne

This recognition is essential, and problems arise if it breaks dow Autoimmune dise
immune system mistakenly attacks its own cells. Exam s lupus, rheumato
and ulcerative colitis. Cancer cells evade detect to which is why they can prolif

In addition to autoimmune dis cell-to-cell recognition is an important factor w
organ transplant, inclu d. The tissue or organ being transplanted will not ha
markers on th rface, and this will trigger the body to reject it as foreign or no
response which es tissue death and decay and can prove fatal, not only because
transplanted was necessary for the patient, but because the rejection process can c
surrounding tissue damage.

When a transplant is being planned, one of the factors considered is how genetically
patient's tissues and blood are. The closer they are, the more likely the transplant w
why close family relatives are often good tissue matches. However, patients who ha
transplant will then take immunosuppressants for the rest of their life to prevent or
how close a tissue match they were. This is because the immune system will continu
organ as foreign and try to reject it. This is controlled by immunosuppressants, whic
response and reduce the chance of organ rejection. However, this increases the pat
infections.

Role of extrinsic proteins as receptors

Extrinsic proteins face outwards from the cell memb ane and facilitate cell-to-cell co
these functions is as a receptor to hormone chemical messengers from one part o
response in a different part of the body (see *Table F1.10*).

Hormone	Function
Insu	Targets liver cells to increase uptake of glucose from th it into glycogen for storage
Adrenaline	Targets vital organs to prepare the body for fight or flig
Testosterone	Development and maintenance of male characteristics
Oestrogen	Development of female characteristics and regulation o

Table F1.10. A summary of a few key hormones and their key functio

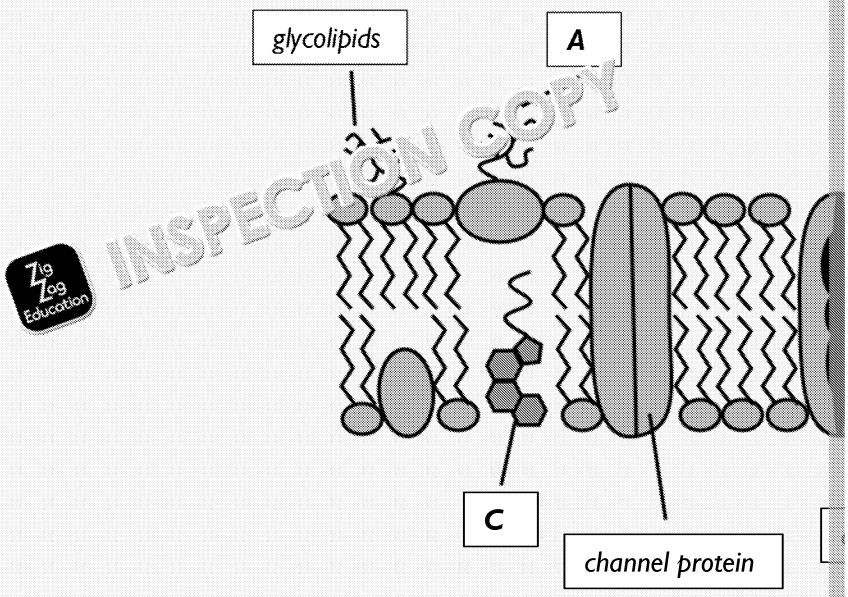
When a hormone binds to a receptor, the receptor changes shape and triggers an o
the cell which alters tissue function. A specific example can be seen with antidiuretic
binds to the receptor on the surface of renal tubule epithelial cells, a chain reaction
molecules and results in the positioning of aquaporins in the cell surface membrane
permeability of the membrane and water osmoses ou tubule cells back into t
reduces the volume of water excreted and con trate urine in response to low wa
which triggered ADH secretion from the pituitary gland.

Apply your knowledge

1. Describe the role that cell-to-cell recognition has in the success or rejection of organ t
2. Describe how extrinsic proteins are involved in hormone signalling.

Practice questions: The cell surface membrane

1 Below is a diagram of the cell membrane. Identify A, B and C from t



1.1.5. Mitosis and meiosis

Mitosis and meiosis are forms of nuclear division used by eukaryotic cells, including h
increases the number of cells within the organism's body, or replaces cells that have
infected or worn out. Meiosis is used to create gametes required for reproduction.

For nuclear division to occur, the cell must prepare itself for the process. This include
structures and frameworks to enable division and duplic[illegible]ce. components and D
enough organelles for division.

Not all cells can undergo nuclear division. Some cells are so complex and specialised
replicate. This section will explore the cell components required to enable division, s
fibres, and chromosomes, as well as the processes of mitosis and meiosis.

Chromosomes and DNA

Structure of chromosomes

Chromosomes are extremely long lengths of DNA, tightly coiled around histone proteins to form a complex called **chromatin**. Each chromosome contains a region called the **centromere**, which is essential when moving chromosomes during nuclear division.

chromosome – a s
tightly coiled DNA m
proteins, which hel
within the nucleus.

chromatin – DNA a

centromere – the s
chromosome that jo
together and attach
division.

chromatid – one of
chromosome, joine

homologous chro
chromosomes in a
mother; the other fr

During normal cell function (interphase) there is:

- one **chromatid** per chromosome
- one pair of each chromosome, one inherited from each parent, forming 23 homologous pairs

Homologous chromosomes are the same length as each other, have the same centromere position, and carry genes for the same traits at the same position on their chromosome.

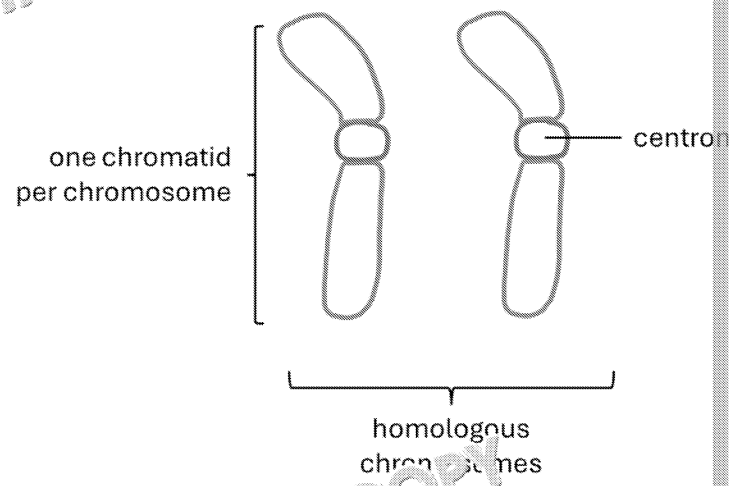


Figure F1.41. *A diagram showing one chromatid per chromosome and one pair of homol*

In most human **somatic** cells there are 23 pairs of chromosomes, a total of 46 chromosomes. The first 22 pairs are called autosomes that contain genes for general body functions. The 23rd pair consists of the sex chromosomes, which determine biological sex: XX for females; XY for males. These cells are described as **diploid**, meaning they contain two sets of chromosomes, and their DNA content is denoted as 2n.

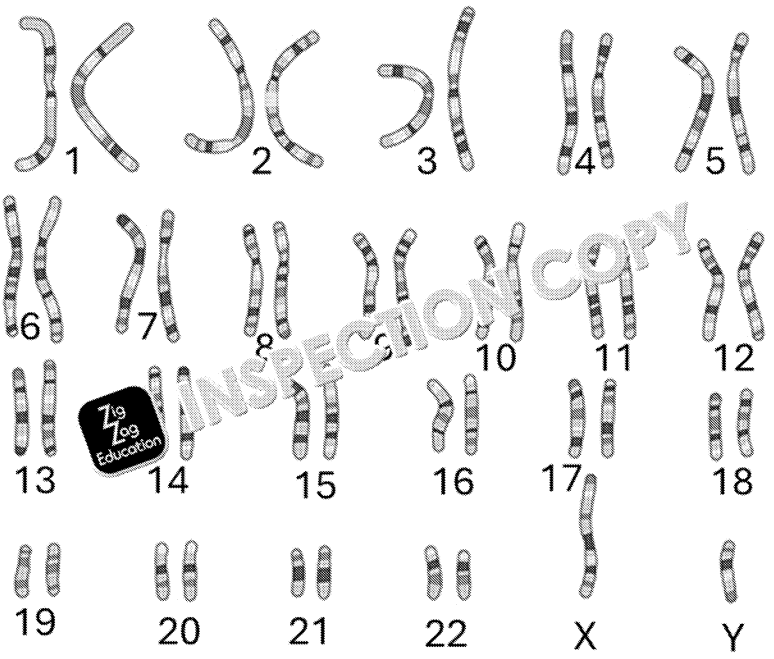


Figure F
of chrom
including
This type

Molecular structure of DNA

DNA is a polymer containing many millions of repeated monomers: the nucleo
substructure, comprising of a phosphate group and a pentose sugar containin
backbone, and one of four nitrogenous bases which contribute to the code.

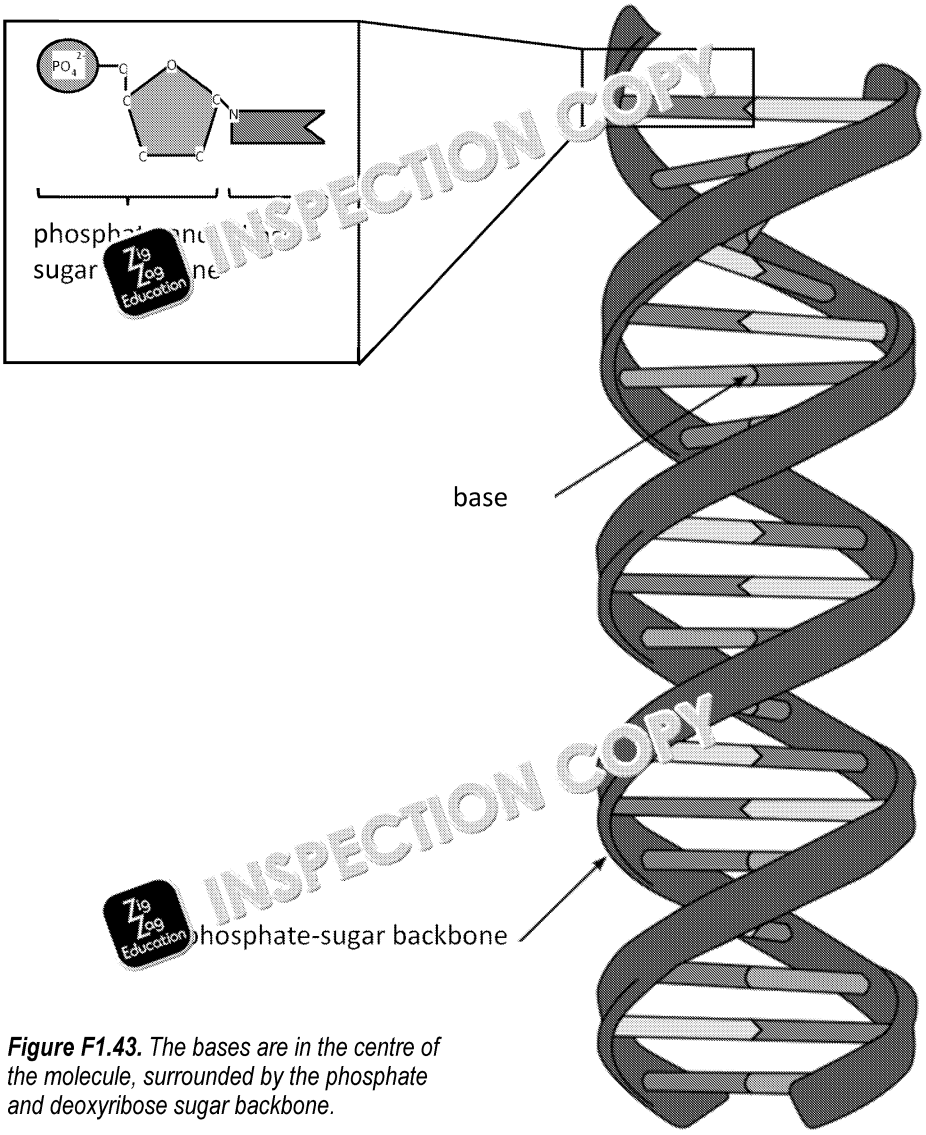


Figure F1.43. *The bases are in the centre of the molecule, surrounded by the phosphate and deoxyribose sugar backbone.*

Four nitrogenous bases include guanine (G), cytosine (C), adenine (A), and thymine (T
purines and comprise a hexagonal unit joined to a pentagonal unit. Cytosine and thy
contain only the hexagonal unit.

Tip!

Remember that pyrimidines have a long name and a short structure, whereas purines have a short name and a l[illegible]ructure!

Across the double helix, the bases guanine and cytosine pair with each other, and ad
together. These bases pair with each other because three hydrogen bonds form betw
and two hydrogen bonds form between adenine and thymine. In both cases, a purine
maintaining a consistent width along the double helix. As a result, if the quantity of ea
sample of double-stranded DNA, the number of guanine units will equal the numbe
number of adenine units will equal the number of thymine units.

Tip!

Remember the base pairing rules by remembering GoCAT! Ignore the 'o', then split the s
into two down the middle: G and C pair, and A and T pair.
GoCAT is also really useful in other ways too:

3		2		= hydrogen bonds
G	C	A	T	
Large	Small	Large	Small	= size of base

Note how the size and the number of hydrogen bonds decreases as you read across the

Importance of base pairing

Base pairing is important because it creates a double-stranded DNA. One strand contai
strand. The other strand contains the opposite of the code – the template strand. Th

- The code – the nitrogenous bases (G, C, A and T) – is stored in the central strand, offering maximum protection from charged particles and ionising radiation.
- There is implicit error checking because the two bases must match for a stable partnership and therefore less chance for error – mutation.
- When a gene is transcribed, the template strand is read so that the mRNA is the same as the coding strand.
- When DNA is being replicated, both strands are copied. The two new double helices contain one original strand and one copied strand, known as semi-conservative replication.

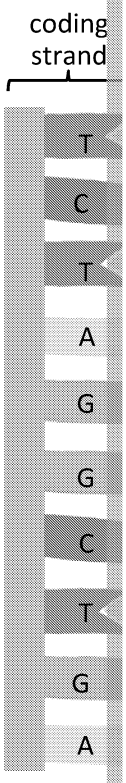


Figure F1.44. Th
into mRNA, whi
three bases – b
into each c

The molecular structure of a gene

A gene is a short length of DNA which codes for a particular protein. The order of bases within the gene is critical because [illegible] bases are read in order and transcribed onto the mRNA strand, which is then read by the ribosome and translated into equivalent amino acids. These are bonded together to form the polypeptide chain precursor of the protein.

Each amino acid is coded for by three bases: a **triplet**, and the triplets are non-overlapping. One triplet codes for one amino acid, but one amino acid may be coded for by several triplets, or **codons**: the DNA code is **degenerative**. This means that some changes to DNA bases can remain **silent**, resulting in no change to the amino acid that has been encoded.

Each gene has a 'start' codon and a 'stop' codon, which define the length of th
ATG, which codes for the amino acid methionine and indicates where the ribo
The stop codon is either TAA, TAG or TGA. No amino acid can be matched to t
polypeptide is released from the ribosome.

Each gene codes for a particular protein, but there are different versions of all genes, and these are known as **alleles**. Alleles carry minor differences between them which affect protein structure because the polypeptide chain varies slightly between them. Understanding the role of alleles helps explain how genetic variations (our **genotype**) influence certain traits (our **phenotype**). For example, some characteristics are solely controlled by the alleles that we inherit from our biological parents; other characteristics are controlled by complex interplay between our alleles and the environmental influences external to us. Our combination of alleles is unique unless we have an identical sibling. Therefore, the order of the bases in our DNA is both a direct consequence of the DNA that our parents have, and a direct cause of our characteristics or phenotype.

triplet – set o
one amino ac
codon – the t
or instruction
degenerative
encoded by t
that some mu
polypeptide c
silent – a mu
amino acid, o
alleles – var
genotype – t
cell or organis
its phenotype
phenotype –
individual as

The Human Genome Project

The Human Genome Project began in 1990 and concluded in 2003. Its aim was
genome, base by base, to produce a comprehensive catalogue of human DNA,
encoding 20,000 to 25,000 genes, and produced a catalogue that is freely avail
around the world.

It enhanced the development of technology and software used to read and an
advancements in genomics such as understanding genetics, evolution, and dis
genes involved in inherited genetic diseases and cancers. Furthermore, it enab
genome sequencing, including those of emerging diseases like COVID-19, and is facilitatin
personalised medicine and targeted drugs.

The project also brought to light significant ethical, legal, and social issues rela
include concerns about privacy, consent, and the potential misuse of genetic in
issues is crucial for ensuring that advancements in genomics are used respons

It was a hugely successful international research programme that greatly acce
of genetics. For instance, it has led to breakthroughs in diagnosing rare genetic
of targeted cancer therapies, and the creation of personalised treatment plans
genetic make-up.

Your turn

1. Using the rules and mnemonic to help you, state:
   a. the name of the four DNA bases
   b. the base pairing rules
   c. the number of hydrogen bonds formed between base pairs
   d. whether each base is a purine or a pyrimidine
2. Draw a two-chromatid chromosome, then label the sister chromatids, the c
3. Write a short news article summarising the importance and significance of

The cell cycle

The only way to create a new cell is to duplicate an existing cell. To achieve this, the
through a period of cell growth, before replicating DNA and dividing. One complete
cell is formed and ends once it has completed mitosis, although not all cells can or
whole cell cycle.

The cell cycle is split into two main phases:

1. interphase
2. M phase (nuclear division)

These phases are further divided into distinct subphases. M phase is much shorter
some human cells can undergo mitosis within one hour but require a further 23 hou
to be ready to duplicate again. The duration of these phases is crucial because it aff
proliferate. For example, in rapidly dividing tissues like skin or the digestive tract, a
quick replacement of cells, essential for maintaining tissue health.

Interphase

Interphase is a highly active phase of the cell cycle. It is the part of the cell cycle wh
normal biochemical functions. It is divided into several stages, processes and checkp
error-free copy of the cell is made during M phase and that a functioning cell exists

For example:

- Some cells, once created from a stem cell, never proceed through interphase a
instead **differentiate** then enter a period of **senescence**. Neurons and erythrocy
are examples. Neurons because they have an extremely complex structure;
erythrocytes because they lack a nucleus, which stops them from dividing.
- Other cells may go through the cell cycle multiple times to replenish tissue that
needs regular replacement. Skin, intestinal tract epithelia and hair follicles all
require constant replacement. Stem cells such as haematopoietic (create blood
cells) and basal (create skin cells) are also examples.

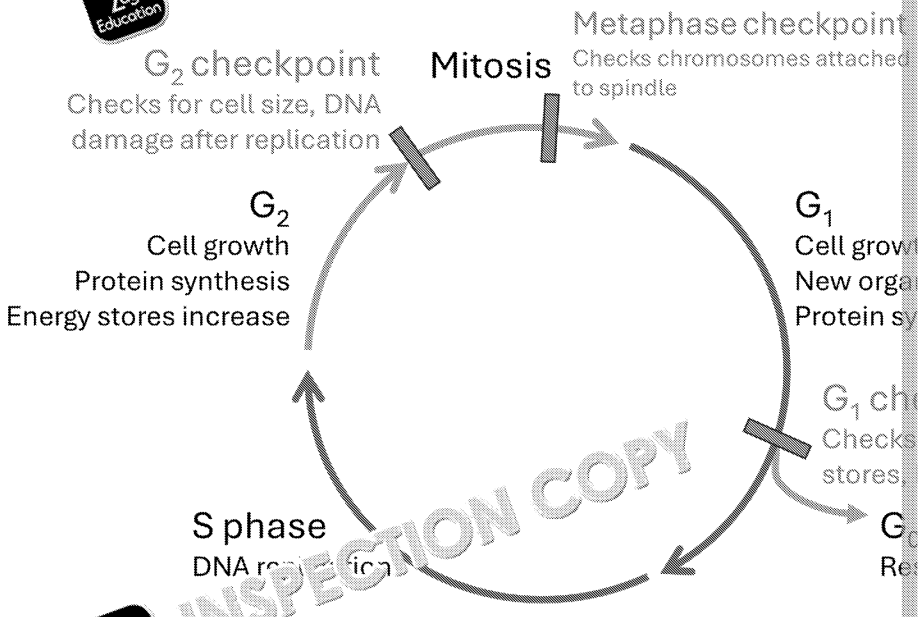


Figure F1.45. The cell cycle comprises several stages and three distinct check

There are three gap phases and one synthesis phase within interphase. Each phase
a particular purpose but exit from gap phases 1 and 2 requires successful completio
checks. If the checkpoint is not passed successfully, the cell can either be fixed, or if
possible, placed into senescence and flagged for **apoptosis** (programmed cell death

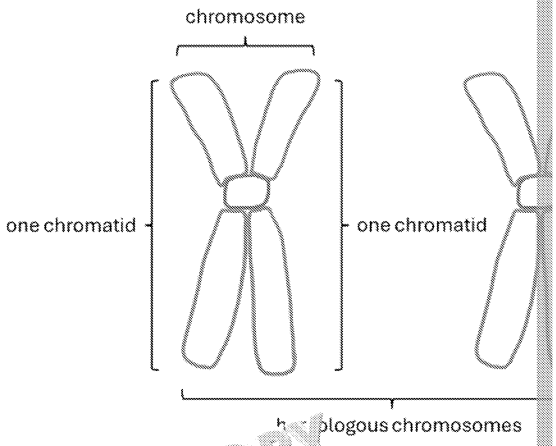
Phase	Processes comple
Gap phase 1 – G_1	Cell grows and new organelles are made. Protein synthesis occurs. Checkpoint genes control exit.
Gap phase 0 – G_0	Resting phase of variable duration (days, weeks phase, and some cell[illegible] leave this phase on In this stage [illegible] undergo apoptosis, diffe N[illegible] mature erythrocytes are examples [illegible] entered. Cells enter this phase after entering G_1 or S pha
Synthe[illegible]se – S phase	DNA replication: DNA in the nucleus is duplicate has two sister chromatids per chromosome.  *Aft[illegible] replication in S phase of interph* *ch[illegible]osomes consist of two chromatids*
[illegible] now committed to continuing with m	
Gap phase 2 – G	Further cell growth and production of proteins Energy stores increase. DNA error checking.

Table F1.10. A summary of the phases of interphase and the processes o

Mitosis

Once a cell has successfully completed interphase and passed the checkpoints,
This means that:

- DNA has been replicated, so each chromosome now contains two chrom
- DNA has been checked for errors to ensure accuracy.
- Sufficient cell structures have been built to enable cell division to occur s
- Sufficient energy stores are available to facilitate the process of cell divis
- The cell is large enough for division to result in viable daughter cells.

Mitosis is the form of nuclear division which c[illegible]eat[illegible]genetically identical, som
It is a complex process, and errors [illegible] mutations or malfunction.

To undertake cell di[illegible] with accuracy and precision, mitosis has five key sta

1. Pro[illegible]
2. Met[illegible]
3. Anaphase
4. Telophase
5. Cytokinesis

Remem[illegible]
with the

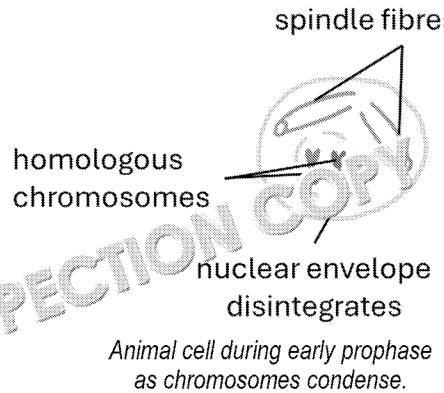
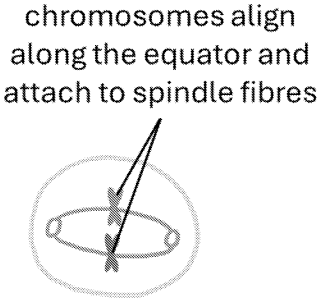
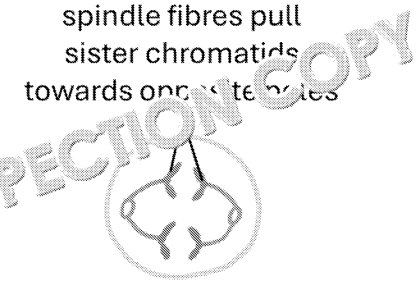
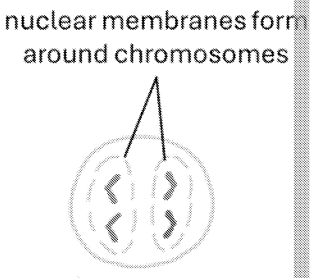
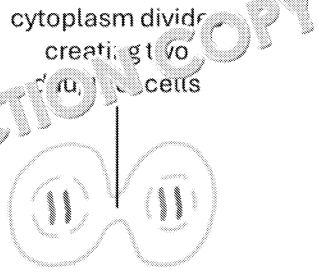
Stage of mitosis	Microscope image/diagra
Prophase Chromatin condenses and forms chromosomes consisting of two sister chromatids joined at the centromere. Spindle fibres assemble. Nuclear membrane disintegrates.	 *Animal cell during early prophase as chromosomes condense.*
Metaphase Chromosomes align along the equator of the cell and attach to spindle fibres by the centromere.	 *Chromosomes align on the equator during metaphase.*
Anaphase Spindle fibres pull each sister chromatid in opposite directions towards the poles of the cell. Chromatids are now called chromosomes.	 *Chromatids are pulled to the poles by the spindle fibres during anaphase.*
Telophase Separated chromosomes reach the poles. New nuclear membranes form around each pole. Nuclear division is complete.	
Cytokinesis The cytoplasm is divided by pinching the cell into two genetically identical daughter cells, each with its own nucleus. Also known as cleavage. Cell division is complete.	 *Cells are cleaved into two during cytokinesis.*

Table F1.11. Stages of mitosis.

Prophase, metaphase, anaphase, and telophase are stages of nuclear division where duplicated DNA is separated to each pole and the nuclei are formed. Following this, cell division occurs during cytokinesis, where the other cell contents are divided into two new daughter cells and a cell membrane forms between them.

Chec
you k
chrom

Meiosis

The process of meiosis is essential for cr ng ic diversity in offspring. Meiosis is a form of cell divisio a s gametes – sperm or ova – which a **haploid**: they contain o e set of chromosomes (n), rather than pairs chromoso as most somatic cells, which are diploid (2n).

During fe ation, two haploid gametes fuse to form a diploid zygote, restor the full set of chromosome pairs.

Meiosis shares many similarities with mitosis in the mechanisms of nuclear di differences that enable the formation of haploid gametes. These include:

- Two successive divisions – meiosis I and meiosis II – that produce four ge daughter cells.
- Genetic variation in gametes, generated by crossing over at chiasmata du independent assortment of homologous chromosomes during metaphas

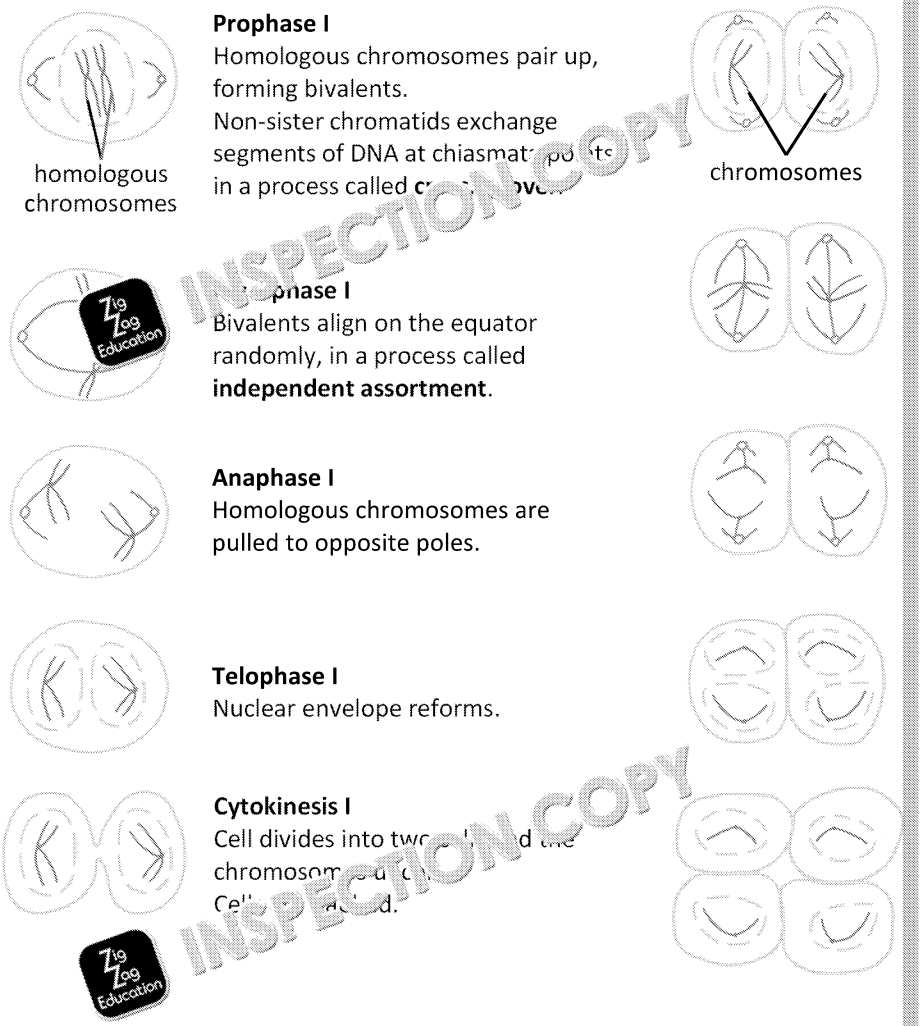


Figure F1.46. *There are two phases of meiosis, which includes crossing over and leading to genetic variation in the four daughter cells.*

Creating genetic variation

Genetic variation occurs through two processes:

1. Crossing over.
   This process occurs only once during prophase I. At this stage of meiosis, homologous chromosomes pair up to form **bivalents** and non-sister chromatids exchange segments of DNA at points called **chiasmata**. This process, known as crossing over, shuffles alleles from both parents, contributing to genetic variation.

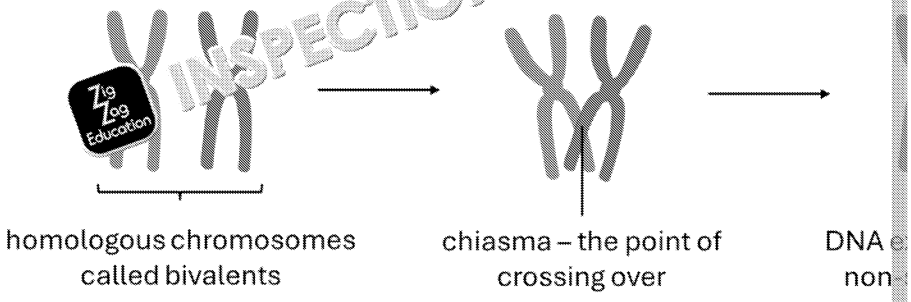


Figure F1.47. *The process of crossing over involves the exchange of genetic material be homologous chromosomes, one paternal and the other maternal in origi*

2. Independent assortment.
   This process occurs during metaphase I. Homologous chromosome pairs align i equator of the cell. The orientation of each pair towards the poles is random an assortment.

   When the homologous chromosomes are separated during anaphase I, the ran maternal and paternal chromosomes being sorted into gametes in different co genetic variation.

   In metaphase II, sister chromatids align independently. Although they are g they may differ due to crossing over during prophase I, so their random separati genetic variation.

Genetic variation produces almost endless variety. In humans with 23 pairs of chrom of variations is 2^{23}, equivalent to 8,388,608 potential combinations of maternal and p gamete! This is why siblings do not look identical to each other, nor their parents.

Comparing mitosis and meiosis

Mitosis and meiosis are both processes involved in cell division. There are a great ma processes, but many significant differences too. The key features are compared in *Ta*

	Meiosis	
Homologous chromosomes	Homologous chromosomes form bivalents	Homologou
Chromosomes in daughter cells	Daughter cells are haploid	Daughter c
Daughter cell genetics	Daughter cells are genetically different	Daughter c
Crossing over	Crossing over occurs	No crossing
Cell division and number of daughter c	Cell divides twice, resulting in four daughter cells	Cell divides daughter c

Table F1.12. A comparison between mitosis and meiosis.

Monohybrid crosses

When gametes fuse during fertilisation, the chromosomes present in the male gamete pair with the chromosomes in the female gamete. Each gene is present as a pair: one allele from the male, one from the female. Most genes have several alleles throughout the population, but every individual has only up to two of these available alleles.

Alleles may be **dominant** or **recessive** in their expression. Dominant alleles are always expressed in the phenotype, even if a recessive allele is also present. To express a recessive allele, two copies must be present. Dominant alleles are written with a capital letter (e.g. A) and appear before recessive alleles which are written with a lower-case letter (e.g. a). A genotype with two identical alleles is either **homozygous** dominant (e.g. AA) or homozygous recessive (e.g. aa). A genotype with two different alleles is **heterozygous** (e.g. Aa).

If the parents' genotypes are known, then it is possible to predict the likelihood of offspring that they have. We can use a Punnett square with one gene to predict outcomes of their children. If we consider the inheritance of tongue rolling, with RR (homozygous dominant: can roll tongue) and rr (homozygous recessive: cannot) chances of offspring being able to roll their tongue can be calculated using a Punnett square, write the alleles from one parent across the top and the alleles from the other. Then, complete the squares by combining the alleles from the top and the side to find potential offspring:

♀ / ♂	R	R
r	Rr	Rr
r	Rr	Rr

Every genotype in all offspring possibilities is Rr (heterozygous); therefore, 100% (expressed as a decimal (1.0), or a phrase (four of four)) will be able to roll their tongue as heterozygous for the characteristic.

If one of these children had their own children with someone else who is also heterozygous for tongue rolling, what are the chances of their children being able to roll their tongue? Again, a Punnett square can be used:

♀ / ♂	R	r
R	Rr	Rr
r	Rr	Rr

With this combination of genotypes, the chance of a child being able to roll their tongue is only three of the four genotype outcomes contain the dominant allele as either homozygous (Rr). The fourth possible outcome is homozygous recessive (rr) which is not able to tongue roll.

These are called **monohybrid crosses**: meaning they deal with one gene only.

Dihybrid crosses

Dihybrid crosses examine the inheritance patterns of two different genes simultaneously. These genes may be on the same chromosome or on different chromosomes and may influence each other's inheritance. By using a Punnett square, we can predict the expected ratios of various traits, although actual ratios may well vary due to factors such as natural skew in fertilisation and genetic link appear on the same chromosome but are not separated by crossing over during meios together, and this will affect the actual ratio of inherit[illegible]

Dihybrid crosses require consideration of two genes. Let's consider the potential out eye colour, together.

- Mother: bl[illegible] ha[illegible] blue eyes (ee)
- Father: br[illegible]ir (HH), brown eyes (EE)

What genetic combinations exist for their gametes?

- Mother: h, h, e, e → he, he, he, he
- Father: H, H, E, E → HE, HE, HE, HE

As all the allele combinations are the same, we can simplify this to he and HE.

Now we know the allele combinations, we can combine this in a Punnett square and potential outcomes:

♂ \ ♀	he	he
HE	HhEe	HhEe
HE	HhEe	HhEe

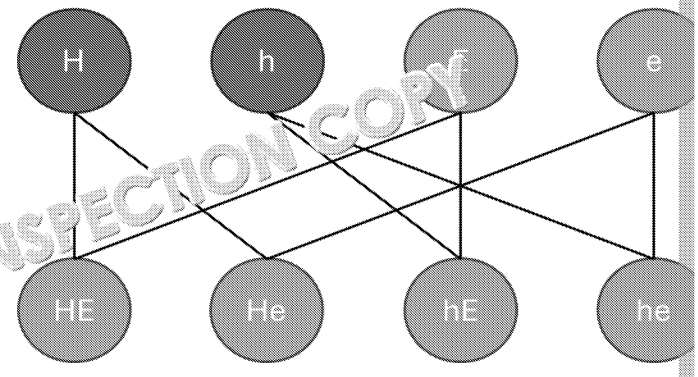
The same general rule applies: [illegible]minant allele letter is written first, but the pairs together. The out[illegible] their children will have HhEe genotypes and therefo brown eyes ph[illegible]es.

How about one homozygous parent and one heterozygous parent?

- Mother: brown hair (Hh), brown eyes (Ee)
- Father: blonde hair (hh), blue eyes (ee)

Which combinations exist for their gametes?

- The father is straightforward as there are only recessive alleles, therefore h and the only option.
- The mother is more complex because the heterozygous alleles can be inherited



Therefore, the mother's genotypes include HE, He, hE and he.

Putting these into a Punnett square results in the following outcomes:

♀ / ♂	HE	He	hE	
he	HhEe	Hhee	hhEe	

Analysing the outcomes shows that:

- brown hair, brown eyes (HhEe) = 1 of 4 = 25 %
- brown hair, blue eyes (Hhee) = 1 of 4 = 25 %
- blonde hair, brown eyes (hhEe) = 1 of 4 = 25 %
- blonde hair, blue eyes (hhee) = 1 of 4 = 25 %

There is an equal chance of this couple having a child with brown or blonde h

---

Let's consider an even more complex example – heterozygous parents:

- Mother: brown hair (Hh), brown eyes (Ee)
- Father: brown hair (Hh), brown eyes (Ee)

What are the allele combinations this time? For both parents, the allele comb

- HE
- He
- hE
- he

In a Punnett square:

♀ / ♂	HE	He	hE	
HE	HHEE	HHEe	HhEE	
He	HHEe	HHee	HhEe	
hE	HhEE	HhEe	hhEE	
he	HhEe	Hhee	hhEe	

The chances of having a baby with the following phenotypes are:

- brown hair, brown eyes (HHEE, HhEE, HHEe, HhEe) = 9 of 16 = 56.25 %
- brown hair, blue eyes (HHee, Hhee) = 3 of 16 = 18.75 %
- blonde hair, brown eyes (hhEE, hhEe) = 3 of 16 = 18.75 %
- blonde hair, blue eyes (hhee) = 1 of 16 = 6.25 %

Tip!

Getting a dihybrid cross corre

1. Organise the P... so allele combinations follow a logical pattern.
2. U... to help identify one phenotype from another. Remembe... in the same phenotype.
3. Th... number of alleles should equal 16, so add them up to check (9 + 3 +

Mitochondrial inheritance

The inheritance features and patterns that we have considered so far refer exclusive
provides almost all of the genomic content, but as discussed in section 1.1.1 (page 3)
DNA of their own, known as mitochondrial DNA (mtDNA). mtDNA encodes 37 genes
maternal line via the egg cell. This is because the egg cell is about 10 million times la
sperm and must provide sufficient nutrients and ATP for the zygote to divide many t
through which to get nutrients for growth and energy instead. Sperm cells do conta
these are only required to provide ATP for motility and are not passed onto the egg

Your mitochondrial DNA was inherited exclusively and entirely from your biological m
that sufficient ATP can be provided for the energy-intensive processes involved in ra
and the complex sequences involved in the early stages of embryonic development, it
are genetic mutations within the mtDNA, they will all be passed on to the offspring.
and therefore every mitochondrion in the body has identical mtDNA. Mitochondria a
components and are present in every living cell in the body. Therefore, harmful, det
mtDNA cause significant issues throughout the affected person's whole body but is u
with high ATP requirements, such as muscle tissues, the brain and the eyes.

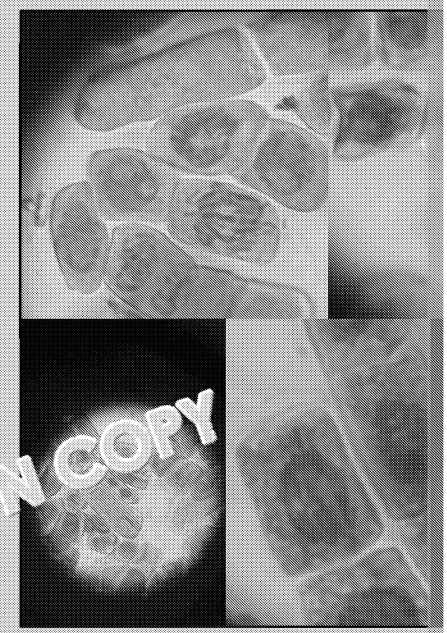
Research into mtDNA, inheritance and treatments for conditions caused by mtDNA m
for many years. One of the key treatment pathways requires diagnosing the mother
If a woman has a mitochondrial DNA condition, her unfertilised eggs can be harveste
removed from the egg cells. Mitochondria from a donor egg cell without mtDNA co
used to replace the mitochondria in the affected woman's eggs. This is known as mit
therapy. *In vitro* fertilisation is then used to create a fertilised embryo which is then t
woman's uterus for her to continue with the pregnancy as normal.

The consequence of this procedure is that the baby technically has three, not two, 'b
mother, the father and the female mtDNA donor. However, the 'third parent' has on
the approximately 25,000 genes in the whole genome – approximately 0.15 %.

Mitochondrial replacement therapy is a groundbreaking technique which offers a so
mitochondrial diseases, but is still undergoing regulatory scrutiny and ethical deba

Apply your knowledge

1. The father has wet earwax (Ee) and can taste bitter substances (TT). The mother has wet earwax (EE) and cannot taste bitter substances (tt). Predict the likely genotype and phenotype outcomes for their children using a dihybrid cross.
2. Describe the differences between mitosis and meiosis, including detailing the processes that lead to genetic variation.
3. Identify the stages of mitosis in the images, right, and describe the processes occurring at each sta



Practice questions: Mitosis and meiosis

1 Outline the role of checkpoints in the interphase phase of the cell cycle. (4)

1.2.1. Tissues

Multicellular organisms are composed of various highly specialised cells. These complete specific functions, creating a working and efficient organism. Human adult female, there are about 28 trillion cells, grouped into more than 200 diff types, which form part of approximately 60 different tissues, making up 11 ma how these cells work together, we need to look at tissues.

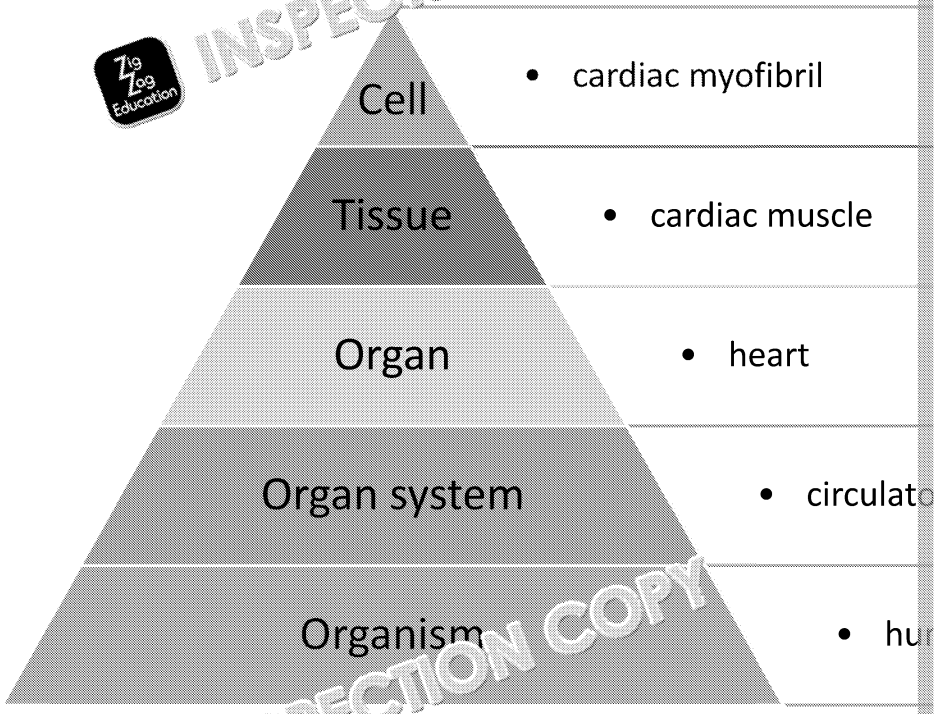


Figure 1.46 ... organisms are constructed in a hierarchy, starting with cells as

So, what is a tissue? A tissue is a collection of similar cells working together fo

Your turn

1. Starting with renal tubule epithelial cell, create an organisation hierarchy, s

1.2.2. Tissue structure and function

There are four primary categories of tissues:

- Epithelial tissues – these include skin and digestive tract lining, forming li
- Connective tissues – these include bone, cartilage and blood, supporting a together.
- Muscle tissues – these include skeletal, smooth and cardiac muscle, provi movement.
- Nervous tissue – these include neurons, which transmit electrical signals th

Each category is further divided into subcategories of increasingly specialised t ciliated and cuboidal epithelium.

Epithelial tissue

Epithelial tissue forms linings and support (basement) membranes over other tissue
epithelial tissue, and epithelium is found covering the inner and outer surfaces of al
digestive system and brain.

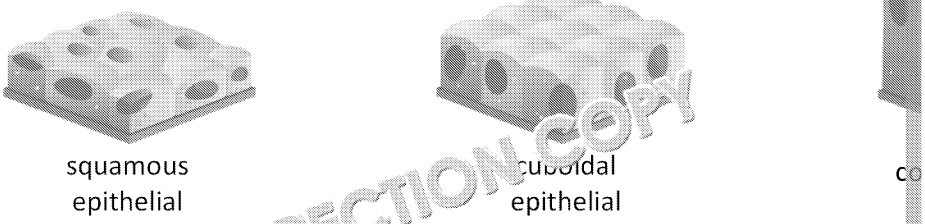
Types of epithelial tissue

There are several subcategories of epithelial tissue, inc squamous, ciliated and
suggest, these groups have pronounced differe s hape of the cells, and this is

Squamous epithelial tissue is m f very flat and thin square-shaped cells. We hav
in the alveoli of the lur ding a very thin layer through which diffusion of oxy
quickly occur (tio 1.1.1, page 16).

Ciliated epithelia are present in the trachea and the oviduct, as already discussed (s
The cilia provide a functional role in wafting contents of the tract in the correct dire

Cuboidal epithelial tissue is made of cube-shaped cells and is found in the kidney ne
page 14). These cells control and adjust the water and mineral ion content of the bl
products for excretion.



ure Comparison of squamous, cuboidal and columnar ciliated epithel

The basement membrane

Epithelial tissue can be categorised by the number of layers it contains:

- Simple epithelium, such as found in the alveoli, is one layer thick. This is essenti
  of gases between the blood and lung cavities.
- Stratified epithelium is made of several layers of epithelial cells, mounted upon
  The skin and the digestive tract are examples.
- Pseudostratified epithelium looks like it is made of several layers of cells, but ev
  attached to the basement membrane. The epithelium in the trachea is an exam

The basement membrane, present in stratified and pseudostratified epithelium, is m
macromolecules, arranged in an extracellular matrix of glycoproteins including colla
structure that provides structural support for the epithelial c o attach to. It also
permeable barrier separating the epithelial cells fro nnective tissue to which
basement membrane. This restricts and reg the interchange of substances suc
products between the two tissue la rs. F y, it forms a signalling layer which con
differentiation of stem cells sing growth factors which are required for the re
layer. Epithelial e c perience a great deal of wear and tear because of its lo
Therefore, it n be regenerated constantly.

Apply your knowledge

1. Compare and contrast the three types of epithelial tissue described and give example
   and roles within the body.

Muscle tissue

As discussed in detail in section 1.1.1 from page 17, there are three types of m
smooth and cardiac. These tissues have different functions:

- Skeletal/striated muscle provides consciously controlled movement throu
  interaction between the skeleton and the muscles. These cells are indivi
  innervated, allowing adjustment of the force generated. They are aligne
  muscle groups for maximum and coordinated for d appear striated
  because of this arrangement.
- Smooth muscle provides uncons controlled movement, such as th
  muscles are innervated gro s and shaped as spindles, which allows t
  little energy ex u his is essential when keeping sphincter junctio
  fun f t gestive system.
- Car uscle can innervate itself – is myogenic – which enables it to co
  prompted. The cells are joined to other cardiac muscle cells via intercalat
  coordinate this contraction to provide a functional heartbeat.

Recall questions

1. Name the three types of muscle tissue and describe
   structures and functions.

Connective tissue

Blood, bone and cartilage are all forms of connective tissue. Connective tissue
different sections of the body, provide support, and offer protection. For exa
and oxygen around the body, bones provide structure and support, and cartil
joints. Therefore, using these criteria, they are gro as connective tissue.

Bone tissue

Bones provide structu enable movement (in conjunction with the
delicate or s the brain, heart, and lungs.

Bones ar ade of specialised cells called osteocytes. These are embedded w
regenerated by specialised stem cells which renew and repair the bone tissue
an inner chamber where bone marrow is stored. Bone marrow is a spongy tis
marrow, which produces blood cells, and yellow marrow, which stores fat and
differentiate into bone and cartilage. In the femur (thigh bones), the red marr
stem cells which generate all types of blood cells (see Adult stem cells, page 8)

Cartilage tissue

Cartilage is smooth, strong, and flexible. There are three forms of cartilage wh
physical properties.

- Hyaline cartilage is found on the ends of bones at joints. It reduces frictio
  enabling high-impact actions like jumping and landi heavily to occur w
  forms the C-shaped supports in the trach ee g the airway open for
- Elastic cartilage provides flexible t the ear pinna (external ear) a
- Fibrous cartilage is found t tebral discs and provides structural s
  resisting compre

Recall questions

1. State the role of red bone marrow and name the st
   femur contains.

Nervous tissue

Nervous tissue is made of neurons: sensory, relay and motor (see page 13). All neuro
structures, and it is important to remember that one neuron is just one cell, and not

Sensory neurons have a centrally located cell body with relatively equal length axon a
efficient and fast communication between the sensory receptor at one end and the r

Relay neurons have a central cell body through which dendrons and axons interact. T
connections to be made between nerve cells, allowing the message to be relayed to mul
motor neurons for a coordinated multipart response where necessary.

Motor neurons have very short dendrons and very long, myelinated axons. Myelination enables **saltatory conduction** (see page 139) to occur, significantly increasing the speed of transmission by up to 100 times. This is essential to enable effective, rapid muscular responses.

saltatory
of nervous
axons, whi
node of Ra

Recall questions

1. List the three types of neurons and state their functions.

Blood tissue

Blood is a special form of connective tissue due to its liquid state and its role in trans
and waste products throughout the body, unlike other connective tissues that provid
unusual as it is one of only two types of tissue which is liquid, the other being lymph.

Composed of various cells, cell fragments and molecules suspended in plasma, blood includes leucocytes, erythrocytes and thrombocytes. Plasma is composed of water (about 90 %), proteins (like antibodies and clotting factors), nutrients (like glucose and amino acids), waste products (such as urea), and ions. The liquid matrix supports the various cells suspended within it and makes up about 55 % of blood volume.

Figure F1.50. *Blood is comprised principally of plasma and erythrocytes (red blood cells), with a very small percentage of leucocytes (white blood cells) and thrombocytes (platelets).*

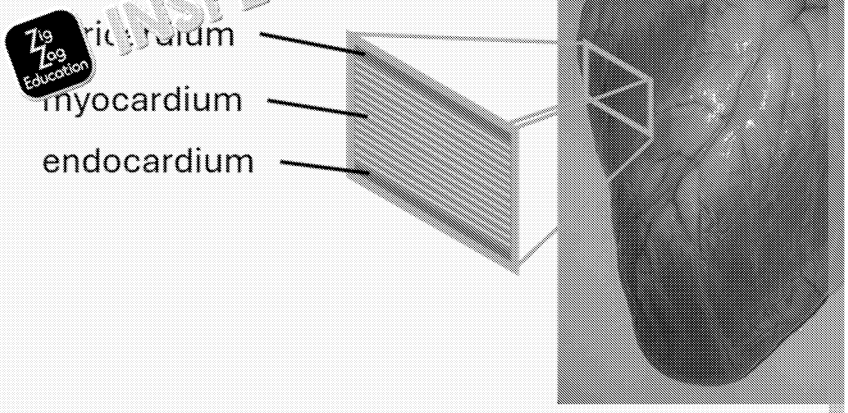
Apply your knowledge

1. Explain why blood is considered a type of connective tissue and describe the main fun
cellular components.

Practice questions: Tissue structure and function

1 The heart is an organ of the human body.

A cross section through the heart reveals three layers of tissue: the e
(mid), and pericardium (outer).



a. State the meaning of the term 'tissue'. (1)

b. Identify the specific type of tissue fou e myocardial layer

c. Describe two adaptati ocytes and explain why these functions. (4)

1.2.3. Use of tissues in research and development

Understanding how tissues function and interact with other tissues is crucial for disc
and developing effective treatment approaches. This knowledge helps researchers i
intervention and create therapies that can address the underlying issues at the tissu

Traditionally, this knowledge has been gained through animal labor tory models and di
advancements in ethical standards, there has been a shift t s using *in vitro* human t
Organoids are miniature, simplified versions of orga s ro ed *in vitro* that mimic som
and functions of real organs. They provid or ccurate model for studying human bi

In vitro huma tis tures

In vitro human cultures are grown in the laboratory rather than in a living organism such as a mouse or rabbit. This approach is ethically less controversial. While it has many benefits, there are limitations to the modelling it offers such as the inability to replicate complex interactions within a whole organism (see *Table F1.13*).

in vi
carri
in vi
carri

Benefits	Iss
• Ethically less controversial than using whole animal models. • Cheaper. • Uses human tissues, so no differences between model and patients. • Can be highly controlled and changed, leading to very precise research. • Can be used for testing drug toxicity and efficacy, without causing death to the or sm.	• Does not involve all t organism, so lacks de • Cells have a limited li differently when ***in vi*** • Tissue samples must b environment as no im gainst infection.

Table F1.13 Co pa g the benefits and problems of *in vitro* human tissue

To create an *in* hu tissue culture, cells must be grown in sterile conditions t which can com e the integrity of the culture and lead to inaccurate results. Th
- using a flow hood
- sterilising equipment and reagents
- wearing gloves, a lab coat and face mask

Obtain cells	• Dissect from patient or donor.
Isolate cells	• Isolate cells from their tissue matrix using enzymes or a mat them to migrate out.
Grow culture	• Use a growth culture of nutrient-r e ium and pH buffer • Incubate at 37 °C and high hu
Monitor	• Ch e and spread, shape and health, and contamina

***Figu* 1.** *A flow chart showing the process of obtaining and growing an* in vitro *hum*

Recall questions

1. List some benefits and limitations of using *in vitro* human t instead of animal models for research.

Stem cell cultures

Stem cell cultures are extremely useful in developing models for diseases and
instance, stem cell cultures have been used to develop organoids that mimic t
researchers with a live model to study neurological diseases such as Alzheime
derived from stem cells have been used to test the toxicity of new drugs, offe
toxicity and the unpleasant side effects caused. Stem cell cultures are also use
occurring during the development of the embryo.

Stem cells can be harvested from various sources:

- From the patient or donor, such as from bone marrow or skin.
- From embryos, which are a rich source of pluripotent stem cells.
- By reprogramming adult cells back to a pluripotent state, known as induc

As with human tissue cultures, using stem cells can mitigate several ethical co
models, including the welfare of animals and the applicability of animal data t
either from patient or donor, or using iPSCs, can also avoid the ethical issues re

However, stem cells must be cultured with great care to prevent them from ra
specialised cells, or from becoming overcrowded or infected and dying.

Benefits	
• Human cells, so research is directly applicable. If using patient cells, then results are directly relevant to the patient too. • Environment can be highly controlled allowing for very specific research to be conducted. • Induced pluripotent and adult stem cells do not have ethical issues that embryonic stem cells do.	• Still only provid lacks the detail organism such Cells may spon Some cells are (e.g. neurons) • Embryonic ste issues over righ

Table F1.14. Comparing the benefits and problems of human ste

The process of culturing stem cells is very similar to that of culturing human ti
culture medium is changed frequently to prevent differentiation, and this is ch
to ensure pluripotency is maintained.

Your turn

1. Create an information leaflet to explain to the public:
   a. from where stem cells may be harvested
   b. how they are used in research and development
   c. some of the limitations that are posed

Organoids in research

Organoids are miniature 3D models of human organs, grown from stem cells or tissu
used to more accurately mimic conditions within the body, allowing researchers to st
environment and develop more effective treatments. Brain organoids have been use
Alzheimer's and Parkinson's, while liver organoids have been used to test for drug to

An organoid has several characteristic features:

- 3D structure like the real organ
- a collection of different specialised [illegible] tissues, making it an 'organ'
- self-organising cells
- carries out [illegible] organ
- develope[illegible] stem cells
- can survive, renew and expand over a long period of time
- is genetically identical to the donor

Organoids offer exciting potential for research and development because of the accu
provide, including matching patient genetics, and fewer ethical issues involved in the
are limitations, including the influence that the basement membrane may have on th
cell behaviour and differentiation. Some tissue models are challenging to grow in thi
such as how nutrient diffusion works through the organoid (see *Table F1.15*).

Benefits	Limit
• Are developed using patient cells, so are useful for developing personalised medicine. • Contain complex range of stem and specialised cells, so can self-organise into complex structures to provide a 3D model. • Can mimic real tissue structure [illegible].	• Expensive to grow and specialised techniques [illegible] model. • The models can be in[illegible] membrane matrix on • Not suitable for all tiss

Table F1.1 Comparing the benefits and problems of organoids in research and

Apply your knowledge

1. Define an organoid and describe how they are created and why they are valuable for s diseases and developing treatments.

Practice questions: Use of tissues in research and developmen

1 State one possible source of stem cells. (1)

Topic 2: Human physiology, organs and systems

2.1. Human physiology

2.1.1. The concept of human physiology

Understanding human physiology is a key requirement of professionals workin general well-being or sports settings. These professionals use their detailed u body function to assess the disease or malfunction that their patient is experi and recovery plans that will manage and improve their situation.

For some patients, care may focus solely on managing symptoms to ensure th particularly in the context of life-limiting conditions. This approach is known as relieve suffering and support comfort, rather than cure the illness.

For others, treatment may involve lifestyle modifications to prevent further ha example, in the case of sports injuries, this might include adjusting training rou or braces during healing, and applying therapeutic or medicinal interventions t

In more complex or chronic conditions – such as diabetes or pulmonary diseas education, guidance, and motivational support to help patients adopt and sust that improve health outcomes and quality of life.

Recall questions

1. List the types of care options that may be considered ... such as type 2 diabetes.
2. Define the term 'palliative care' and describe how th forms of treatment.

2.1.2. Organ structure and function

What is an organ?

When a collection of different tissues is grouped together and shares a commo For instance, the heart is an organ because it contains several different tissues purpose: cardiac muscle, nervous tissue, connective tissues and epithelial tissu enable it to function.

Heart

The heart pumps blood around the body. An average adult has a **cardiac output** of between 5 and ... litres per minute. Blood enters the heart from veins, which, with the exception of the pulmonary vein, carry **deoxygenated** blood to the heart. Blood is then pumped to the lungs via the pulmonary artery so that carbon dioxide can be exchanged for oxygen, before it returns to the heart to be pumped again to the body via the aorta and other arteries. As a result of this, the human heart is called a double pump.

cardiac ... by the le... calculate...

stroke v... by the le...

deoxyg... oxygen t... dioxide f...

Gross heart anatomy

The heart has four chambers, divided vertically into the left and right side. The cham
the atria (singular: atrium), and those at the bottom are called the ventricles. Blood
into the ventricles, then pumped out of the ventricles to the lungs or the body.

The right ventricle moves blood to the lungs for **gaseous exchange**. Blood must be at low pressure to prevent rupture of the bloo
vessels around the alveoli, so the right ventricle wall
thin (3–5 mm) as little force is required.

gaseous ex
oxygen into
dioxide out o

The left ventricle pumps oxyg
against gravity,
(10–15 mm) th
right, so more force is generated, and blood is pumped at high

The left and right sides of the heart are separated by a wall known as the central **septum**. The septum separates the deoxygenated and oxygenated blood.

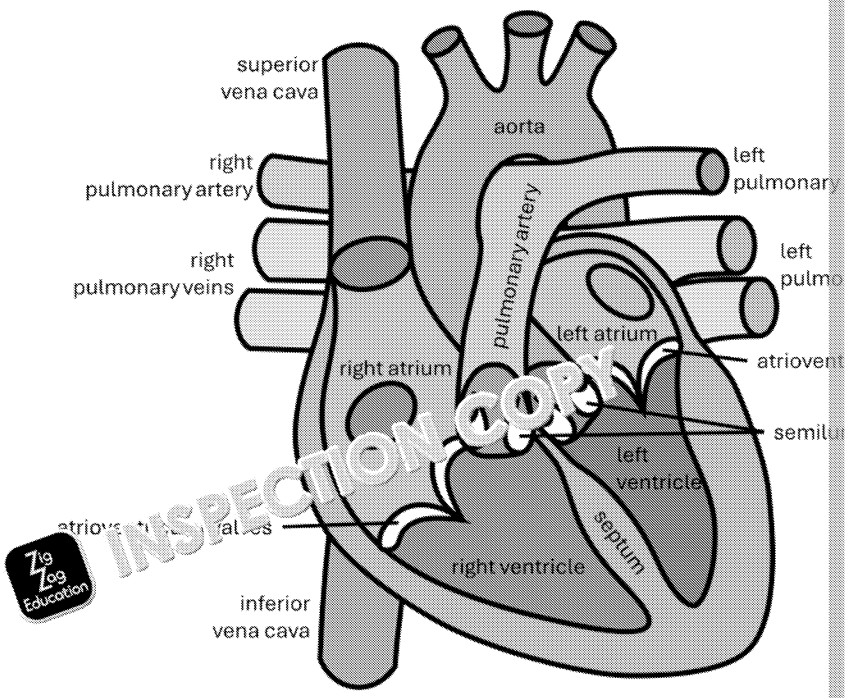


Figure F2.1. *The internal anatomy of the heart, showing the blood vessels, chambers, va*

Tip!

Remember the locations of the heart chambers by thinking about the shape of the capi
names. The Atria are at the top, just as the A joins at the top. The Ventricles are V-shap
at the bottom of the heart, just as the V is joined at the bottom of the letter.

Blood enters and leaves the heart via veins and arteries. Veins tr
transport blood away from the heart. The major blood v
- Vena cava – the inferior and superior vena cava r
- Pulmonary artery – the only artery
pressure from the heart to
- Pulmonary vein – th
after gase
- Aorta – th

Tip!

Remember that Arteries transport blood Away (A, A) from the heart, whereas veins transport blood 'tovvards' the heart (the double v = 'w').

There are two groups of valves within the heart, which prevent backflow of b
positioned between the atria and the ventricles, although may also be referre
(left) and the tricuspid valve (right) . The valves between the ventricles and th
valves because of their shape, but may also be called the pulmonary (right) an

The valves are attached to the inner walls of the heart by tendons called **chor
tendineae**. These are attached to muscles which contra nd relax in time wi
heartbeat to ensure the valves close and open i n ony. As the valves clos
make a slapping sound which we hear as h tbeat. The first 'lub' sound is
atrioventricular valves closing f d by the second 'dub' sound which indic

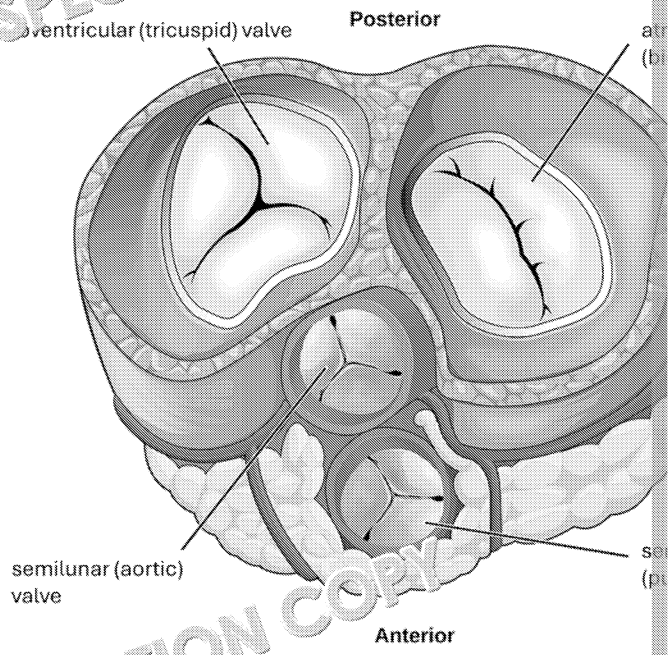


Fig 2 Cross section through the top of the heart, showing the

Tip!

When viewing images and drawings of the heart, remember that you are lookin
the body of someone facing you. Therefore, the left side of the heart in the dia
side of the page, and vice versa.

Heart function

Blood moves through the heart, lungs and body in a continuous flow so gases
is circulated:

1. Deoxygenated blood is returned to the heart from the body via the vena
2. It enters the right atrium.
3. It moves into the right ventricle via the atrioventricular valve.
4. It is pumped from the ventricle via the semilunar valve and passes throu
   the lungs.
5. Gaseous exchange occurs at the lungs
6. Oxygenated blood is returned t art via the pulmonary vein.
7. Blood enters the left at m.
8. It is moved int ntricle via the atrioventricular valve.
9. It is ed the ventricle via the semilunar valve and passes throu

Heart histology

The heart tissue is composed of three distinct layers:

- Endocardium – a thin inner layer made of endothelial tissue.
- Myocardium – a thick middle layer made of cardiac muscle cells.
- Pericardium – a thin outer layer made of epithelial and connective tissue

The endocardium provides a smooth surface which reduces friction as blood moves t
This prevents clots from forming. It also controls electrical conduction which is esse
contraction of the heart.

The myocardium is composed almost entirely of cardiac muscle cells and therefore is responsible for the contractile force produced by the heart. The myocardium is thickest in the left ventricle, ensuring that blood is pumped at high pressure to the body. The muscle cells must contract in a coordinated manner and this is regulated by the **Purkinje fibres** and the **bundle of His** (see cardiac cycle, next).

The pericardium protects the heart and produces a fluid which reduces friction between it and surrounding tissues. It also contains the coronary blood vessels which supply blood to the heart tissue itself. If these become blocked, the availability heart muscles is restricted. The heart requires a constant supply of oxygen to maint rates required to produce enough ATP for its continuous function. Restricted blood f infarction (heart attack), or other coronary heart diseases (CHDs) including angina a (reduced oxygen to parts of the heart muscle).

The cardiac cycle

The cardiac cycle is a sequence of events throughout one heartbeat. At rest, it lasts a averaging 70 beats per minute. There are three stages to the cardiac cycle:

- Diastole – relaxation of the heart muscles.
- Atrial systole – contraction of the atrial muscles.
- Ventricular systole – contraction of the ventricular muscles.

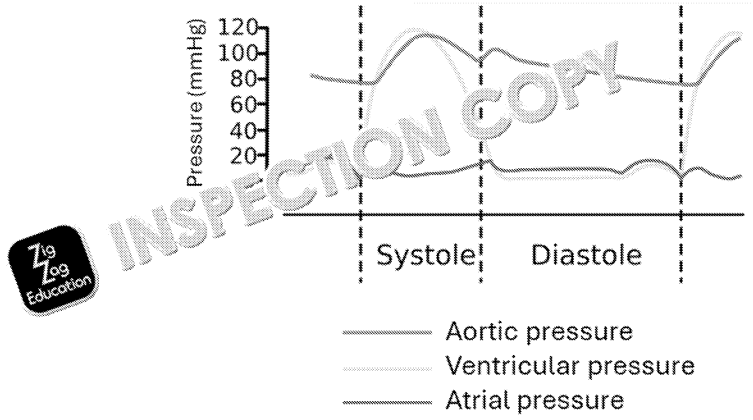


Figure F2.3. *Heart pressure graph showing changes in pressure in the atria, ventricl*

Diastole is the longest phase of the heartbeat and involves the relaxation of the card heart so occurs in all chambers simultaneously. It occurs after the heart has contract the start of diastole and refills with blood. We can therefore conclude that as blood e

- Blood flows from the veins (vena cava and pulmonary) into the atria.
- The atrioventricular valves are open so blood flows passively from the atria into
- Atrial and ventricular blood volume is low and increases.
- Atrial and ventricular blood pressure is low and incr
- The semilunar valves between the ventricles an th teries (pulmonary and a blood leaving.

Atrial systole follows and i s rial muscle contraction. Blood moves from the a therefore, we nc e that:

- Atrial bloo me decreases.
- Atrial blood pressure is low but increases as the heart muscles contract then de
- Ventricular blood volume and pressure is low and increases as blood moves fro
- The atrioventricular valves are open so that blood can flow from the atria into t
- The semilunar valves between the ventricles and the arteries (pulmonary and a blood leaving.

Ventricular systole follows next and involves ventricle muscle contraction. Blo
via the arteries to the lungs or the body. We can conclude that:

- The atrioventricular valves close to prevent backflow.
- Ventricular blood pressure increases rapidly as the heart muscles contrac
  pumped from the heart.
- Ventricular blood volume reduces as blood leaves the heart.
- The semilunar valves are forced open by ventricu[illegible]ood pressure, and

The cardiac cycle requires careful coordi[illegible]or, and this is controlled through

- Cardiac muscle fibres – ar[illegible] (see Cardiac muscle cells, page 17),
  approximately 60 b[illegible]minute without any stimulation. This allows
  with[illegible]ny [illegible]al resources.
- Sin[illegible]ode (SAN) – acts as a pacemaker, stimulating contraction at a
- Rela[illegible]mponents within the heart – include the atrioventricular node (A
  fibres, which relay the electrical stimulation, initiated by the SAN, throug

The SAN is located in the top right of the heart, above the right atrium and pr
cause the atria to contract (atrial systole). This forces the atrioventricular valv
the atria into the ventricles.

The impulses are blocked from travelling further by a band of non-conducting
the ventricles. This ensures that atrial systole occurs before ventricular systol
contractions, during which the ventricles fill with blood.

The atrioventricular node (AVN), located at the top of the septum between th
and relays electrical signals through the bundle of His, which runs down the v
ventricles. As the electrical signal passes through the wall[illegible] of the ventricles by
contract (ventricular systole) from the bottom of t[illegible]ar[illegible] up. This ensures t
heart, via the semilunar valves and throu[illegible]th [illegible]teries.

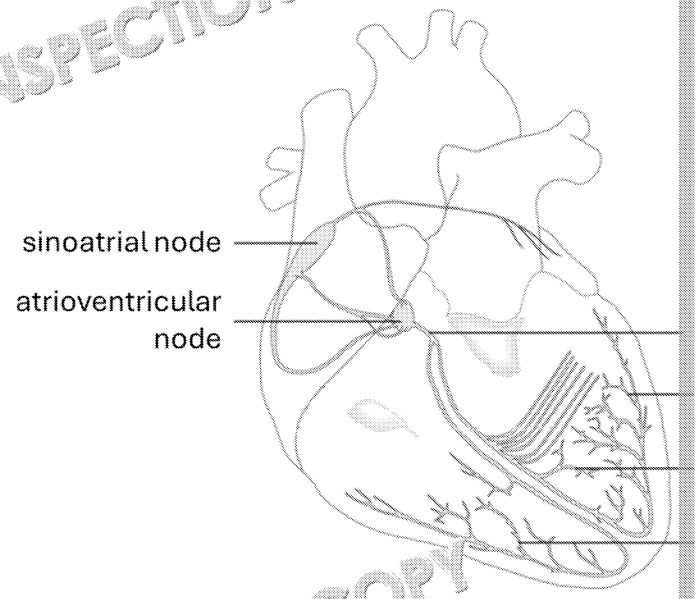


Figure F2.4. *The locations [illegible] S[illegible]N, AVN, bundle of His and Purkinje fi*

Your turn

1. Stat[illegible]unction of the heart and its adaptations to enable this to occur.
2. Calculate your cardiac output: assume your stroke volume is 5.37 dm^3 and
3. Create a flow chart of the sequence of blood flow through the heart, listing
   in order, and the oxygenation state of the blood.
4. Produce a table showing the stage of heart contraction or relaxation, chan
   heart valves, and the electrical activity of the nodes or fibres.

Blood vessels

Blood is a tissue that is pumped around the body by the heart and moves through th
Blood vessels run throughout the body and there are three main types:

- Arteries – carry blood away from the heart.
- Veins – return blood back to the heart.
- Capillaries – facilitate exchange of substances between blood and tissues.

In addition to these major vessels, there are also:

- Arterioles – smaller than arteries, they transport blood from arteries to capillari
- Venules – smaller than veins, they transport blood from capillaries to veins.

Therefore, as blood is transported around the body, it moves from the heart into an arterioles then arteries, before merging into venules then into veins, before return

All organs have an artery delivering oxygenated blood and nutrients to it, and a vein re and waste products. For instance, the kidney is served by the renal artery and vein, wh artery and vein. Arteries, veins and capillaries each have specific structures to facilitate

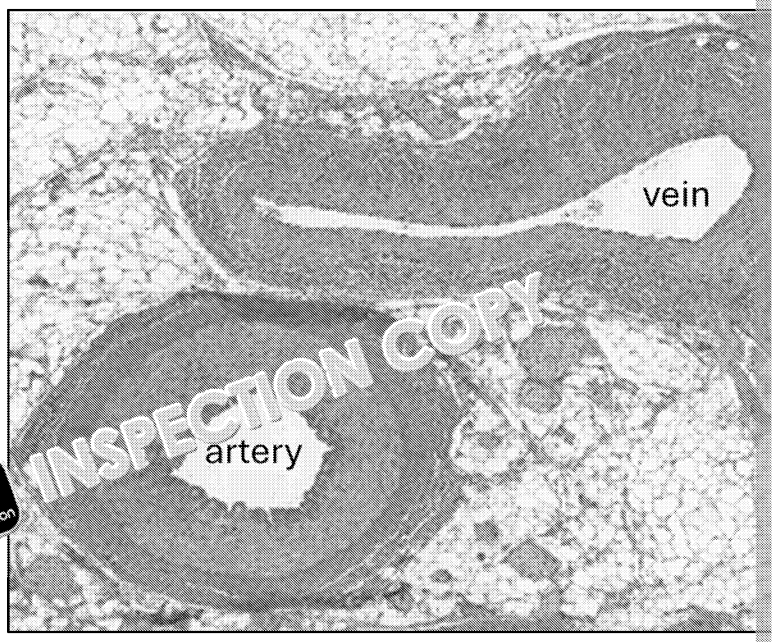


Figure F2.5. *Light micrograph of a vein and an artery, showing the visibly different lumen sizes and dia*

Arteries

Arteries are blood vessels that transport blood from the heart to the organs of the b oxygen-rich, having bound oxygen at the lungs. Only the pulmonary artery transport the heart to the lungs.

Arteries must transport blood quickly to the organ, to provide sufficient levels of oxygen tissues for their cell functions. For instance, mitochondria require a supply of oxygen and to create ATP via aerobic respiration, while other cell processes require other nutrients s

Arteries have a wall comprising three distinct layers, surrounding the **lumen** through the blood flows:

- Endothelium – the inner layer, also known as the tunica interna, provides a smo surface for friction passage of blood through the artery.
- Smooth muscle and elastic fibres – these form a thick middle layer, called the tu media, and can contract and relax to pump blood through the lumen. This is fel the pulse at different points in the body.
- Connective tissue – the thin outer layer, the tunica externa, protects the tunica artery into the surrounding tissue layer.

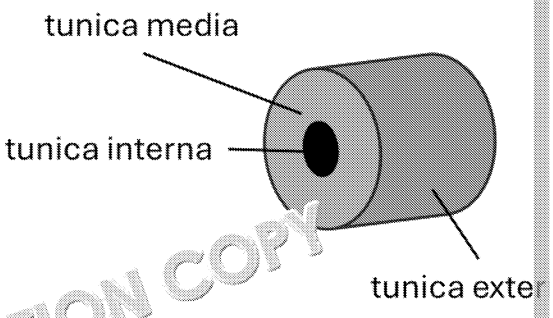


Figure F2.6. *The structure of an artery, showing the three distinct tissue layers*

Distinct[ie]s have a narrow lumen and a thick tunica media. These featu[re]s high pres[sure] and for that pressure to be maintained along the length of the a[rtery] coordinated with the heartbeat by the brain.

Veins

Veins return blood from the organs of the body to the heart. Blood is usually r[eturned] with fewer nutrients and more waste products, although the pulmonary vein [is] oxygenated blood from the lungs to the heart for further circulation.

Veins transport blood at a lower pressure and slower speed than arteries. This[is] with fewer nutrients and more waste products, which need to be processed a[gain]

Veins have a similar structure to arteries. The innermost layer is a smooth end[othelium] low-friction passage of blood. The next layer, the tunica media, comprises mu[scle] diameter of the lumen can be adjusted. The outermost layer, the tunica extern[a] the tunica media and anchors the vein in the surrounding tissue.

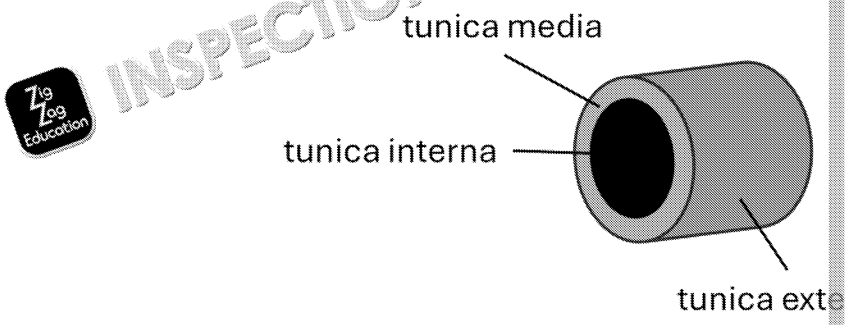


Figure F2.7. *The structure of a vein, showing the three distinct tissue layers*

However, there are some key differences between arteries and veins:

- Veins transport blood at lower pressure than arteries, because the venou[s] tunica media is much thinner.
- Some veins are very long and transport blood against gravity, such as thos[e] from the feet and ankles back to the heart. These veins have valves within [the] blood and ensure that blood returns to the heart. This is aided by the con[tract] the veins.

Furt[her] your knowledge

Varicose veins are painful, swollen veins, usually within the legs. It most often affects pe[ople] of time with little movement, such as soldiers and police officers on sentry duty. Varicose [veins] of blood in pocket valves in the veins because of lack of movement. This causes the vei[n] their effectiveness.

Capillaries

Capillaries facilitate the exchange of nutrients and waste products between the bloo
the cells and tissue fluids of the organs. As blood moves through the capillaries, it de
nutrients and gains waste products.

The capillaries are uniquely structured to facilitate the rapid exchange of nutrients a
between the blood and the tissues. Unlike veins and arteries, the capillary wall is on
made of squamous endothelial cells that are extreme[illegible] flat and
thin. This creates a very short diffusion dista[illegible] ensuring rapid
exchange and transport.

Furthermore, the capill[illegible]en is narrow, and in some cases, it
is narrower th[illegible]rythrocyte. This slows the movement of red
blood cells thro[illegible]he capillary, and they pass in single file,
which increases the time for oxygen to diffuse and presses the
walls of the erythrocytes against the capillary wall, reducing the
diffusion distance even further.

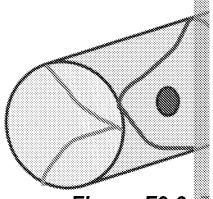


Figure F2.8. *T*
showing the ve

Further your knowledge

Sickle cell anaemia is a genetic condition which causes the distortion of erythrocytes due to a mu
gene. It is a painful condition because the red blood cells do not move smoothly through narrow
sickle shape. This is particularly pronounced when heart rate increases at times of stress or incr

Apply your knowledge

1. Name the three tissue layers of arteries and veins and [illegible]e their role in the blood
2. Describe how capillaries are specifically adapted f[illegible]unction.
3. Describe the similarities and differen[illegible]e[illegible] arteries and veins.

Muscle

The term 'muscle' can refer to different biological structures: a muscle cell (myocyte),
muscle cells), or a muscle organ (composed of multiple tissues). When we consider a
skeletal muscle is a complex structure made of many tissues working together. Skele
consists of muscle tissue (collection of many myocytes working together), connective
epithelial tissue (that encases different subsections of the muscle fibres, for instance),
(required to innervate the muscle fibres). Muscles are connected to bones by tendons
non-contractile connective tissues.

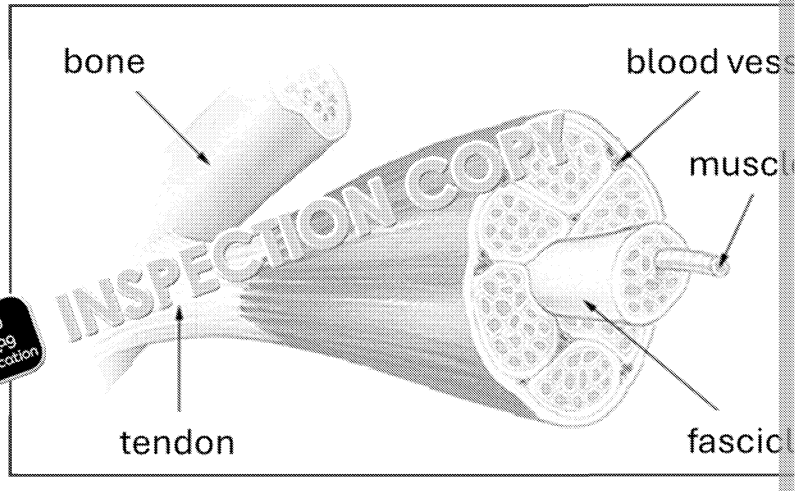


Figure F2.9. *The structure of skeletal muscle, showing overall structure and attac*

Muscles have a detailed macrostructure. A muscle organ is divided into fascic
capillaries and motor neurons, surrounded by an outer layer of epithelial tissu
arranged muscle fibres that maximise the force produced during muscle cont
myocytes, made of myofibrils that contain many contractile filaments made o
Each muscle fibre is surrounded by a sarcolemma, equivalent to the cell mem
(like cytoplasm) and the nucleus. Beneath that is the sarcoplasmic reticulum,
muscle fibre to the individual myofibrils to generate c ction.

An artery supplies blood to the musc a vein returns the blood to the he
dispersed throughout the mu es. This ensures a rich supply of oxyge
production of ATP re muscle contraction.

Your t

1. Create a flow chart showing how myocytes are grouped into larger segme
2. Explain why muscles require a rich blood and nerve supply.

Bone

Bone is both an organ and a tissue, which supports and protects the body, an
tissue, page 55 for more detail).

Bones are metabolically active; therefore, they have a good blood supply. The
several specialised cells, including:

- fibrocytes – produce collagen fibres which give bone tensile strength (str
- osteoblasts – secrete a fluid called osteoid wh ens to form the ca
- osteocytes – maintain bone tissue

These specialised cells are tain within a calcified matrix containing colla
hard, while the fib strength. This combination resists bones from s

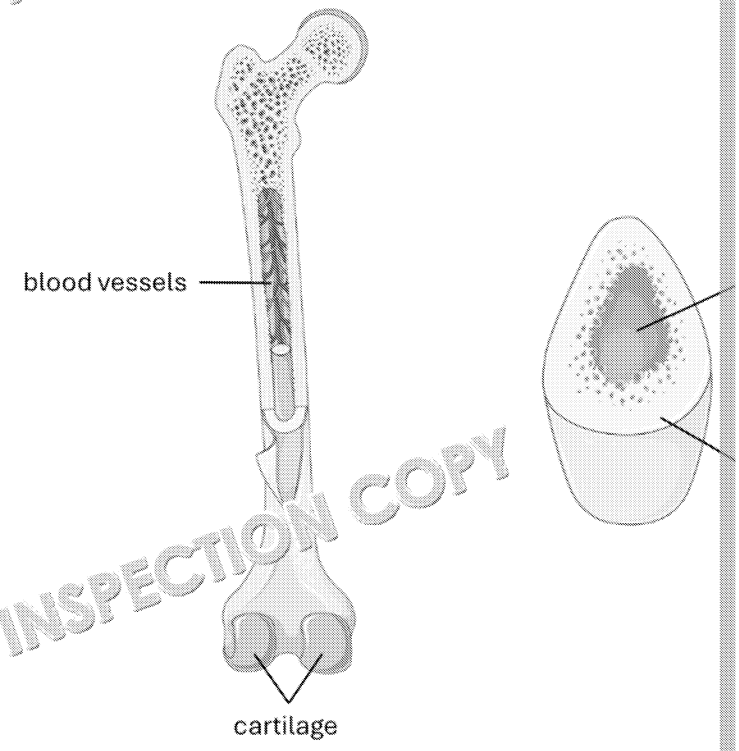


Figure F2.10. *The structure of bone, showing the presence of a rich blood su*

If bones fracture, they can repair the damage. Bone repair requires a rich supply of g
synthesis, oxygen for aerobic respiration, and calcium ions for matrix reconstruction
which involves many different specialised cells:

1. Upon fracture, blood vessels rupture and cause a blood clot to form. This invites
and, with osteocytes, produce signals to trigger repair.
2. Next, fibroblasts migrate to the site and lay down cartilage and fibrous tissue that b
two sections of the fractured bone.
3. Then, osteocytes recruit osteoblasts to move to the sit nd secrete osteoid wh
calcified matrix.
4. Finally, excess bone is reabsorb d, n llagen fibres are added to restore bon

Osteocytes dete am uit other cells into the site to repair the damage, and
They also regu e mineralisation process and maintain mineral balance.

Recall questions

1. Describe three roles that bones have within our body and
supports these functions.
2. Describe the role of red bone marrow.
3. Explain why bones require a good blood supply and list the

Liver

The liver is the largest internal organ and is located within the upper abdomen, unde
muscle. It is positioned on the right side of the body opposite the stomach and exten
above the stomach. It weighs approximately 5 % of a person's body mass – between 1
average adult.

The liver has many different vital functions, i ng toxifying blood, metabolisin
producing bile to aid digestion of fat, st glycogen and a range of other vitamins
synthesising blood proteins m ng factors. This explains its considerable size an

The liver recei po a the hepatic artery from the heart (approximately 25 % of
hepatic portal v m the small intestines (approximately 75 % of blood volume).
the liver with sufficient nutrients, energy and oxygen for the wide array of processes
supply the substances, or metabolites, to be processed, such as drugs and toxins wh
(breaking down), and glucose which may need anabolising (building up) into glycoge

The liver is formed from specialised cells called hepatocytes. These create channels called sinuses through which blood from the hepatic portal vein and the hepatic artery can mix. The proximity of the hepatocytes to this blood supply enables rapid and efficient processing of metabolites. It also enables effective absorption of substances from the blood supply for stor th e liver, or secreti ubstances from the liver into the bloodstream for circulation.

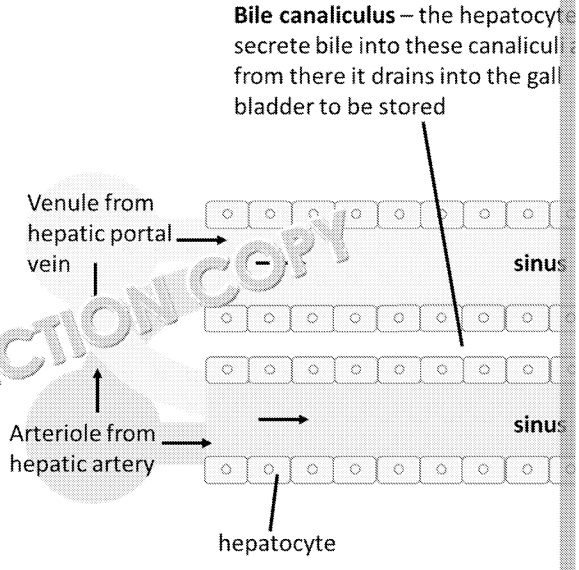


Figure F2.11. *The structure of the liver involves dra*

Narrow channels called canaliculi (singular: canaliculus) are located on the oth
secrete bile into the canaliculi. Bile drains into the gallbladder where it is store
into the duodenum: the first part of the small intestine.

Recall questions

1. List the essential functions of the liver and explain w
blood supply.
2. Describe the location of hepatocytes and how their
about their function.

Lungs

The lungs carry out gaseous exchange. Oxygen in the alveoli diffuses into the bl
diffuses into the alveoli. The lungs provide an important interface between the

Gaseous exchange occurs deep within the lungs. Air is inhaled through the mo
trachea. The trachea has a wide lumen, and the walls are reinforced with C-sh
support the trachea and keep it open and unobstructed, and the gap in the ri
positioned alongside the trachea. The trachea branches into the left and right
lobes of the lungs. The bronchi divide into many smaller bronchioles, which co
alveoli sac at the end.

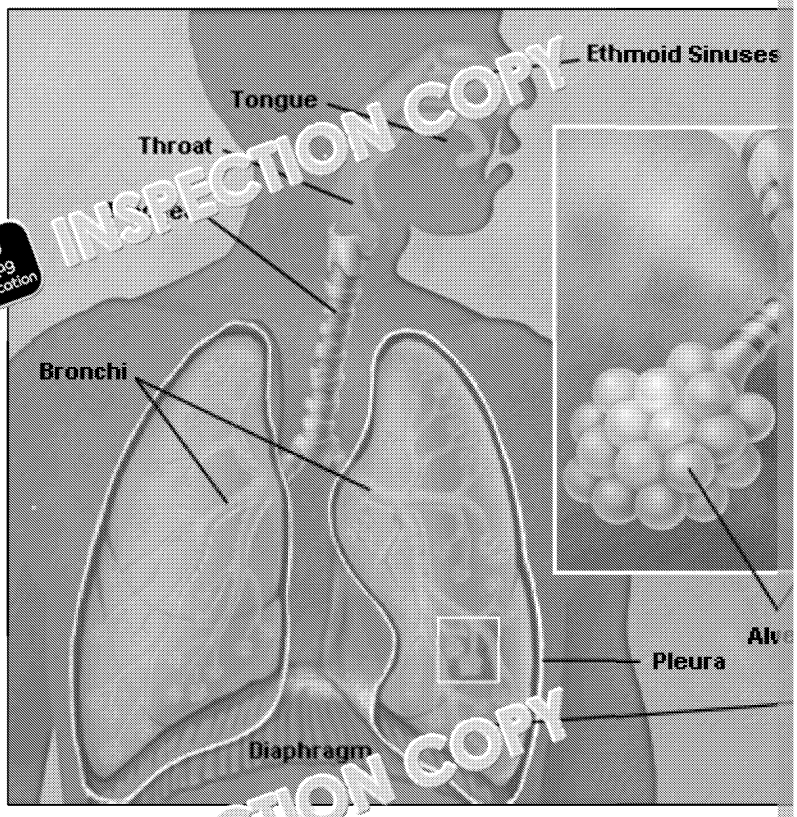


Figure F2.12. *The anatomy of the lungs.*

Gaseous exchange must occur rapidly and efficiently. To achieve this, three fac
1. A large surface area over which exchange can occur.
2. A short distance to move through.
3. A pathway that does not unnecessarily restrict the movement of substanc

A large surface area is achieved by having more than 700 million alveoli in each lung a dense capillary network. Alveoli enable half a tennis court's worth of surface area t your chest! The surface area of each alveolus is maximised by its small, rounded bub this shaping is lost and the alveoli become smoother. This reduces the surface area a the symptoms.

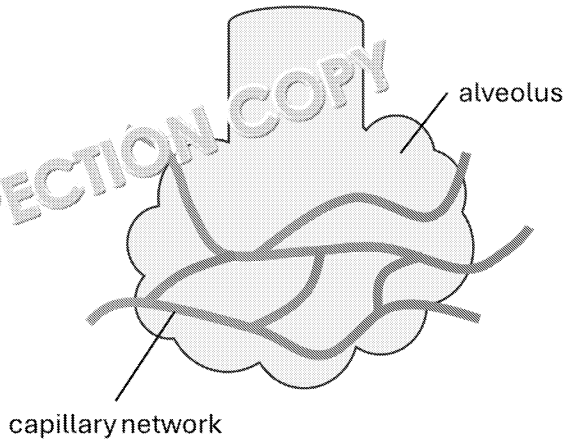


Figure F2.13. *The alveolus has a rich capillary supply and a high surface*

The diffusion pathway is short in part because both the alveoli and the blood capilla thick. In addition, the squamous epithelial cells in the alveoli, and the squamous end capillaries are both extremely thin specialised cells (see section 1.1.1, page 16).

The movement of substances is unrestricted partly because the inner surface of the a gases to dissolve in the liquid, known as surfactant, and diffuse more rapidly. In addi extremely permeable to oxygen and carbon dioxide, so gases move through the

When gaseous exchange is impaired, or wh movement of air into and out of th (in conditions such as asthma and br symptoms including fatigue and short quickly apparent.

Recall questions

1. List the pathway through which inhaled air flows during in
2. Describe the structural features of alveoli that allow for effici

Stomach

The stomach is positioned in the upper left section of the abdomen, opposite the liver and below the diaphragm.

Food enters the stomach through the cardiac sphincter between the end of the oesophagus and the stomach. The sphincter seals the stomach at the top and prevents reflux, a process whereby stomach contents move into the oesophagus and creates an unpleasant burning sensation called heartburn.

The corpus, or body, of the stomach enables physical, enzymatic and chemical digestion. Physical digestion occurs as the stomach muscles contract and relax to churn the food over. Hydrochloric acid aids digestion by activating pepsinogen into the enzyme pepsin and lowering the pH to create optimum conditions for stomach enzymes to function.

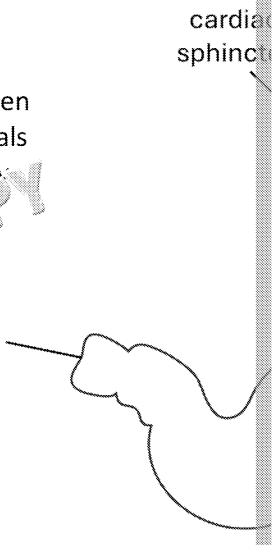


Figure F2.14. *The stomach is divided in*

The low pH also destroys pathogens that enter with the food and **denatures** e
made in the mouth, which must be remade in the small intestine.

The stomach wall contains gastric pits which are made of several specialised c
These cells manufacture gastric secretions including hydrochloric acid, enzym
mucus (see section 1.1.1, page 18). Mucus is crucial for providing a protective
and the digestive contents (see Stomach conditions, pag 892).

The pyloric sphincter separates the stomac fr m duodenum. It is closed
regulate the movement of conte into t small intestine.

The stomach can ab sh e in substances and not others because of the mu
small ar th gh the stomach wall, and the quantity increases if the sto
solute co ation and high water potential). Alcohol can be absorbed throu
can diffuse through the mucus barrier. This is especially problematic if the sto
consumed, as this enables rapid absorption, causing the drinker to become qu
and electrolytes can also be absorbed through the stomach wall, including as

The stomach has a rich blood supply via the gastric arteries and the portal vei
oxygen and metabolic substrates required for ATP production, which is neede
required by the stomach.

Apply your knowledge

1. Describe how the gastric wall and the secretions it produces contribute to dige
2. Describe how the stomach protects itself from being digested and explain why

Intestines

The intestines digest and abs ts and process waste ready for egesti
Stomach contents, n **yme**, enters the small intestines. The small
intestine pl stion and absorb the products. Chyme then moves th
into the testines where water is reabsorbed and faeces are produced.

The small intestine

The small intestine is a long, narrow tube averaging 6–7 metres in adults. It o
lying beneath the stomach and liver, and includes the duodenum and the ileu

By the time partially digested food reaches the small intestine, it has been me
into chyme – a semi-liquid mixture of food particles and digestive secretions.
sphincter into the duodenum, where digestion resumes under very different c

The stomach's highly acidic environment (pH 1.5–3.5) contrasts sharply with t
environment (pH 6–8). This change is achieved through the secretion of bile a
duodenum, which neutralise stomach acid. As a result, stomach enzymes
denature, while intestinal enzymes, including prot s such as trypsin,
carbohydrases including amylase and malt se, an ases, become active. The
catalyse the breakdown of protei ar drates and lipids into their
respective monomers: ami icid glucose and other **monosaccharides**, and
fatty acids and gl s.

In the ile ese monomers are absorbed through the intestinal wall into a
The mucosal surface of the small intestine is folded into villi, which greatly inc
for absorption. Each villus is lined with epithelial cells which have dense array
microscopic, finger-like projections of the epithelial cell surface membrane th
absorbing surface by up to 600 times and form the brush border.

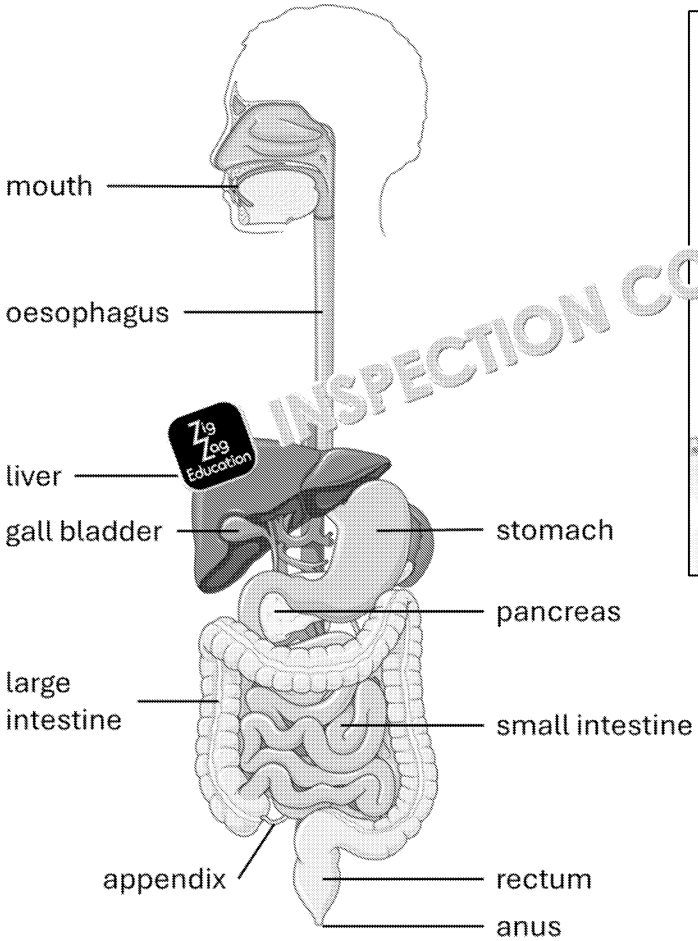


Figure F2.15. *The organs of the digestive system.*

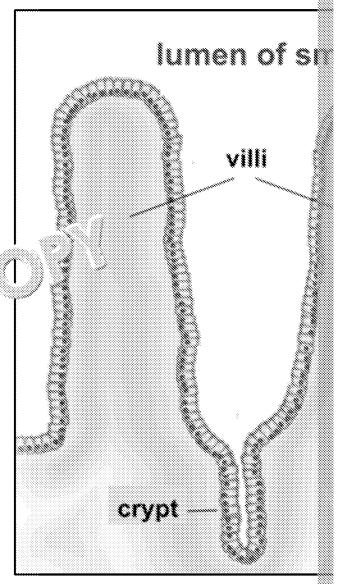


Figure F2.16. *The lumen of t with surface area greatly e*

Microvilli have brush border en ncluding several carbohydrases that catalyse the breakdow **charides** into monosaccharides:

- Lactase – es lactose into glucose and galactose.
- Sucrase – yses sucrose into glucose and fructose.
- Maltase – catalyses maltose into glucose.

These enzymes are embedded in the cell surface membrane, allowing immediate up by the same cell. A deficiency in lactase, for example, leads to lactose intolerance, d digest lactose effectively.

In addition, membrane-bound transporters facilitate the movement of nutrients fro epithelial cells and on into the bloodstream. Once absorbed, nutrients travel to the vein, for processing, detoxification and distribution.

The large intestine

The large intestine borders the small intestine and w ile wider, it is also shorter long. It consists of five main segments: th appendix, colon, rectum and an stages of digestion, water absorp , ar aeces formation.

Chyme from th l i estine enters the caecum: a pouch-like region at the beginning of th intestine. Here, excess water and salts are absorbed, starting the process of solidifying the chyme. Adjacent to the caecum is the appendix; a narrow finger-like projection. This plays a role in maintaining **gut flora** balance and supporting immune function, particularly after gastrointestinal infections.

The partially dehydrated chyme then moves into the colon, the longest sectio
It continues to absorb water and electrolytes, gradually transforming chyme i

The caecum and colon host a dense **microbiome**, a complex ecosystem of mi
- ferment undigested carbohydrates
- synthesise some vitamins, including vitamin K, which supports bone heal
- outcompete pathogenic microbes, providing a cri[illegible] layer of immune d

However, broad-spectrum oral antibi[illegible] inadvertently reduce the biom
fermentation and vitamin s[illegible] and results in diarrhoea due to incomple

Once fa[illegible] att[illegible] reaches the rectum, it is temporarily stored. The rectal wa
detect p[illegible] build-up from faeces, triggering the urge to defecate. During d
the anus, which is regulated by two sphincters:
- internal anal sphincter – involuntarily controlled
- external anal sphincter – voluntarily controlled, allowing conscious regul

The movement of chyme and faeces throughout the large intestine is driven by **peristalsis**: the coordinated, rhythmic contractions of smooth muscle. The consistency of faeces depends upon water balance – dehydration can lead to hard, dry faeces that are more difficult to pass.

Apply your knowledge

1. Describe the role of the microbiome in digestion and overall health.
2. Describe the differences between the small and la[illegible] testines and the ada
different functions.
3. Explain how the presence of vill[illegible] crovilli enhance digestion.

Kidney

The kidneys are vital organs that filter blood, to remove waste products of metabolism such as urea, and regulate water and electrolyte balance. Human have two kidneys, located in the lower back. Blood enters each kidney via the renal artery and exits through the renal vein.

The kidney macrostructure comprises:
- The outer capsule, which encases the kidney.
- The cortex, the outer area that interlocks with the medulla.
- The medulla, on the inner side of the cortex, contains renal pyramids, which converge onto central calyces (singular: calyx).
- The calyces drain into t[illegible] ureter, which t[illegible] urine to t[illegible] for storage.

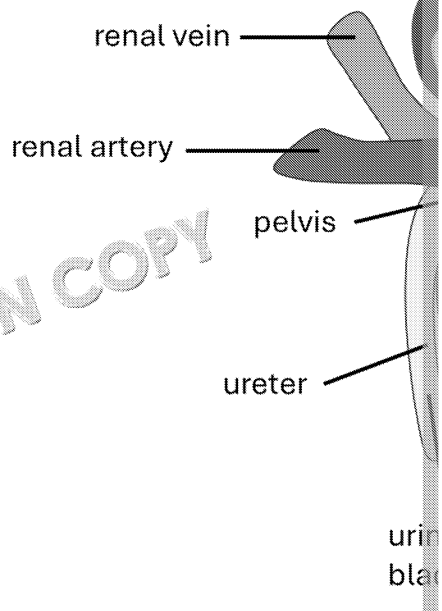


Figure F2.17. *The kidney ha*

Filtration and reabsorption

Blood filtration occurs in the **nephrons** of the kidney: specialised structures which span the medulla and cortex. For filtration to occur, blood enters under high pressure, aided by differences in the lumen diameter of the inbound (afferent) and outgoing (efferent) arterioles. This pressure, combined with selective permeability of the **glomerular cells**, generates **ultrafiltration**. All small molecules, except proteins and blood cells, are pushed into the kidney tubules to form filtrate.

As the filtrate passes through a series of tubules, it interacts closely with surrounding capillaries so that:

- Glucose, some electrolytes and water are reabsorbed into the bloodstream.
- Urea, excess salts, and surplus water are retained in the tubules and excreted as urine.

The tubules converge into collecting ducts, which drain into the bladder. Final adjustments are controlled by the hormone ADH (antidiuretic hormone):

1. When blood water concentration is low, ADH secretion increases.
2. ADH stimulates the insertion of aquaporins (water channels; see section 1.1.4, page) into the collecting ducts.
3. Water diffuses into surrounding tissues and re-enters the bloodstream.
4. This produces concentrated urine, a common response in hot conditions or dehydration.

Normal function can be maintained with just one kidney, enabling transplant from a donor.

Recall questions

1. Outline the structural adaptations of the kidney that enable it to filter blood efficiently and regulate water balance.
2. Describe what happens to the different filtrates as they pass through the nephron.
3. Describe how the hormone ADH influences urine concentration and explain why this is important when dehydrated.

Pancreas

The pancreas is a long, tapering organ located behind the stomach. It has both exocrine and endocrine functions.

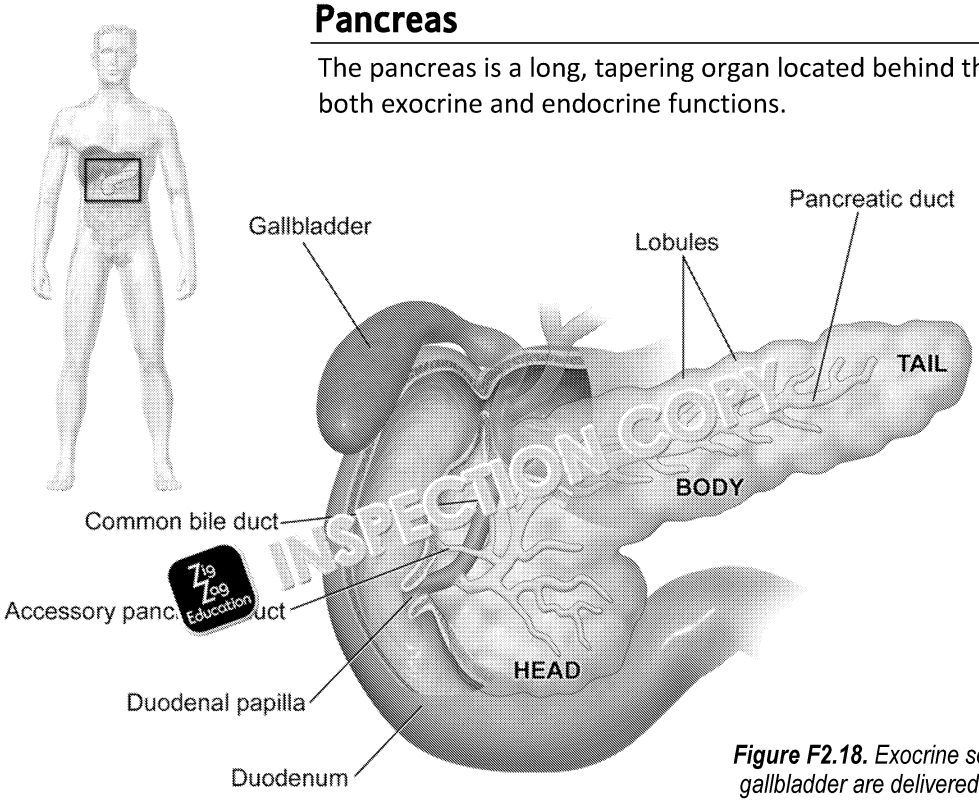


Figure F2.18. *Exocrine secretions from the pancreas and gallbladder are delivered directly to the duodenum.*

Exocrine function

The pancreas aids digestion by secreting enzymes into the duodenum. These e

- pancreatic amylase – catalyses starch to maltose
- proteases (e.g. trypsin) – catalyse proteins into amino acids
- pancreatic lipase – catalyses lipids into fatty acids and glycerol

These enzymes are produced by specialised cells calle[illegible]i, arranged in clust
Secretions flow out through the pancreatic du[illegible]t, w[illegible]n merges with the duod

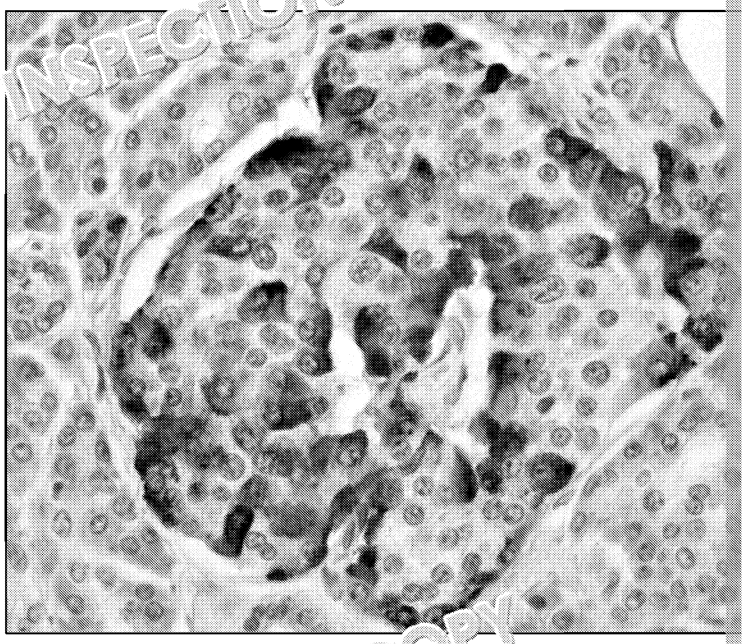


Figure F2.19. *Light micrograph of pancreatic cells. Brown-stained cells in i[illegible]ngerhans, surrounded by blue acini cells*

Endocrine functi[illegible]

The end[illegible]pa[illegible]reas regulates blood glucose concentration by producing h
cells calle[illegible]s of Langerhans, embedded throughout the exocrine tissue. In

- Insulin, released by β (beta) cells when blood glucose levels are high, pro
  cells in the liver and muscles and its conversion to glycogen for storage, l
- Glucagon, secreted by α (alpha) cells when blood glucose levels are low,
  the liver, increasing blood glucose concentration.

Recall questions

1. State which cells release insulin and glucagon and d
   these hormones.
2. Describe the functional differences between the aci
   the islets of Langerhans.
3. Describe how the pancreas c[illegible]tributes to exocrine f
   digestive system

Practice qu[illegible] Organ structure and function

1 [illegible]w ADH levels in the kidneys adjust when blood water con

2.1.3. Disease and organ failure

Diseases may be classified as either communicable or non-communicable, depending on their causes and transmission routes. Communicable diseases are caused by pathogens, such as bacteria, viruses and protists. These illnesses can be spread from one person to another, and examples include influenza (viral), typhoid (bacterial) and malaria (protist).

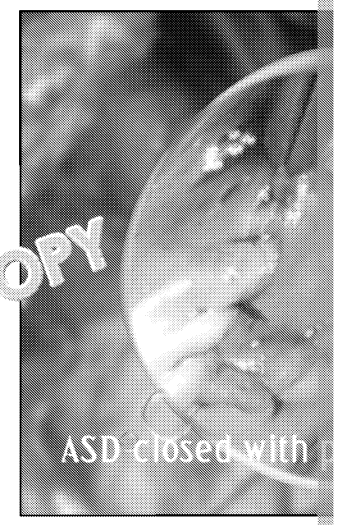


Figure F2.20. *Septal defe*

Most non-communicable diseases (NCDs) are not transmissible and typically are due to a combination of genetic and environmental factors. They fall into two broad categories:

- Genetic disorders – conditions inherited from parents through genes, including type 1 diabetes, some cancers and asthma.
- Lifestyle-related diseases – conditions influenced by habits and behaviours. Risk fa consumption, poor diet, lack of exercise. Diseases include type 2 diabetes, some c

Organ failure occurs when an organ loses its ability to perform its normal function e This may result from:

- chronic disease progression (e.g. liver failure from cirrhosis)
- genetic defects (e.g. kidney failure)
- lifestyle factors (e.g. heart failure due to long-term hypertension or poor diet)

This section explores a range of non-communicable diseases, both inherited and life mechanisms that contribute to organ failure.

Heart defects

The heart is a vital organ that contracts rhythmically to circulate blood throughout t unidirectional flow and prevents backflow during contraction.

The right side of the heart receives deoxygenated blood from the body and pumps i exchange. The left side receives oxygenated blood from the lungs and circulates it to

Septal structure

The right and left sides of the heart are separated by an impervious muscular wall ca comprises two sections:

- the atrial section (upper portion)
- the ventral or ventricular septum (lower portion)

After birth, small openings in these septa normally close. However, if these remain o septal defects develop – **congenital abnormalities** classified by location and sympto

Ventral septal defect (VSD)

A ventral, or ventricular, septal defect (VSD) is an opening in the ventricular septum two common forms:

- muscular VSD – located lower in the septum wall
- perimembranous VSD – located near the heart valves where the septum is thi

The left ventricle generates higher pressure than the right ventricle, so that blood can However, if a VSD is present, blood may be shunted from the left to the right ventricle increasing pulmonary (lung) circulation and pressure. This leads to excess blood volume (pulmonary hypertension) in the lungs. This can cause heart failure, especially if the ho

Small VSDs are often asymptomatic and may heal themselves but larger defects req

Atrial septal defect (ASD)

An atrial septal defect (ASD) is an opening in the atrial septum, with three ma
- secundum ASD – occurs in the centre of the septum and is most commo
- primum ASD – occurs in the lower region near the valves
- sinus venosus ASD – occurs in the upper region near the major veins

ASDs cause left-to-right shunting of blood, down the p re gradient, which and can lead to the following symptoms:
- pulmonary hypertension
- stroke
- arrhythmias (ir art rhythms, including atrial fibrillation)

Small AS be asymptomatic and close on their own, but larger holes usu

Valve malfunction

The atrioventricular and semilunar valves maintain one-way blood flow and produce the familiar 'lub-dub' sound when closing. They can become damaged and malfunction, and this can be detected via **auscultation** using a **stethoscope**.

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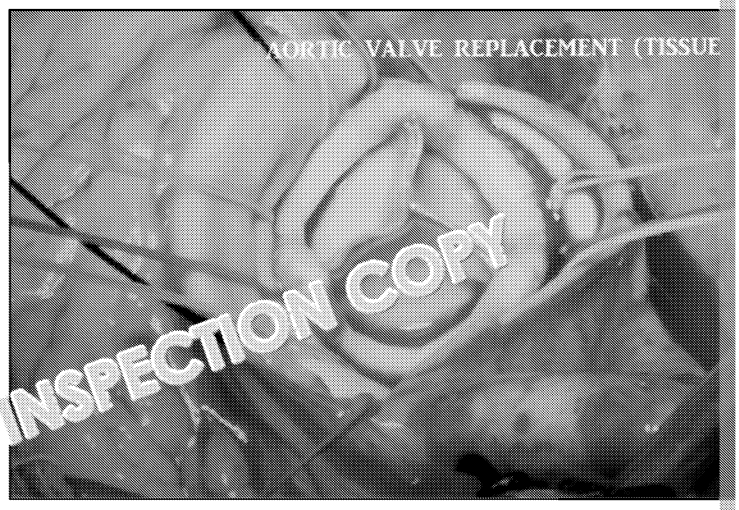

Figure F2.21. *Faulty valves can be replaced surgica*

There are three types of valve malfunction:
- stenosis – a narrowing of the valve which restricts blood flow and makes
- regurgitation or incompetence – the valve does not close properly, and b
- prolapse – the valve leaflets bulge backwards, which can lead to regurgit

These malfunctions may cause an array of clinical symptoms, including:
- shortness of breath, especially during exercise or when lying flat
- fatigue, dizziness or fainting
- chest pain or 'pressure'
- heart arrythmia or pal tio
- oedema (sw ankles, feet or abdomen

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Recall questions

1. State what ventricular septal defects (VSD) and atria are and list the symptoms in each.
2. Describe how these heart malfunctions affect blood
   a. Stenosis b. Regurgitation c. Pro

Atherosclerosis

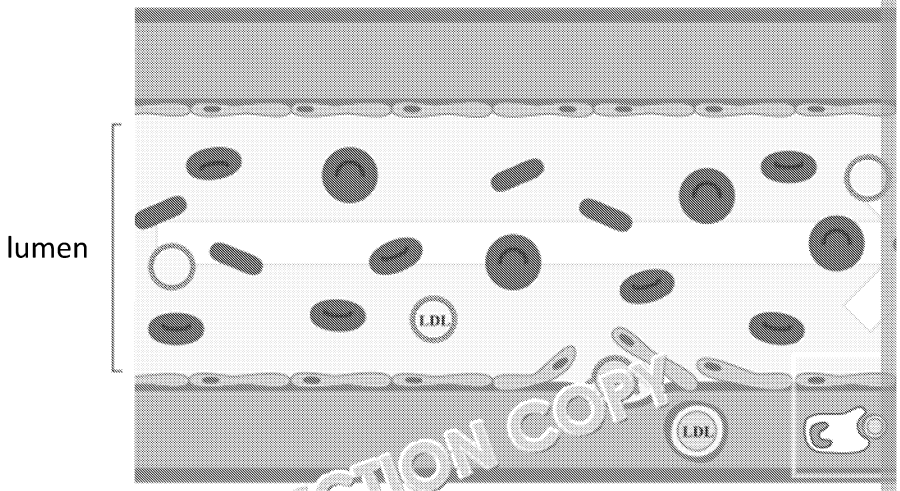
Atherosclerosis is a progressive disease in which fatty plaques (atheroma) accumula
These plaques are made of cholesterol, lipids and cell debris, and gradually narrow t
harden over time. The result is restricted blood flow, which can lead to serious com
attack and stroke.

Plaque development

Plaque formation usually begins with damage to the arte wall, caused by natural
(such as smoking or high blood pressure). Once damaged, the site traps cell debris a
there are elevated levels of LDL (low density lipoprotein) cholesterol, triglycerides a

These trapped ial tract other molecules, forming the plaque that grows and
artery further a pairing blood flow to dependent organs.

STEP 1: Damage to the arterial wall



STEP 2: Lipid-laden macrophages accumulate in early plaques

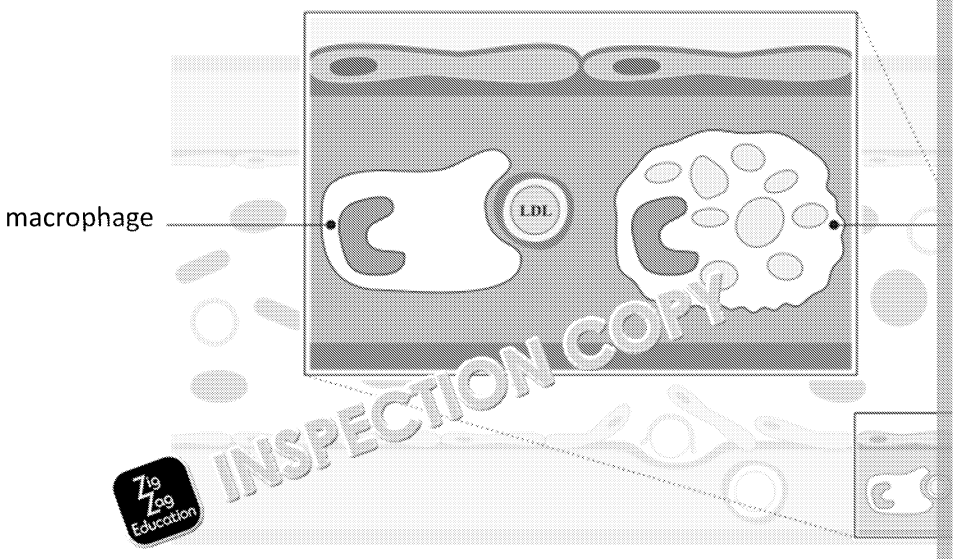


Figure F2.22A. *Steps 1 and 2 of the formation of an atherosclerotic plaque, and its rupture to*

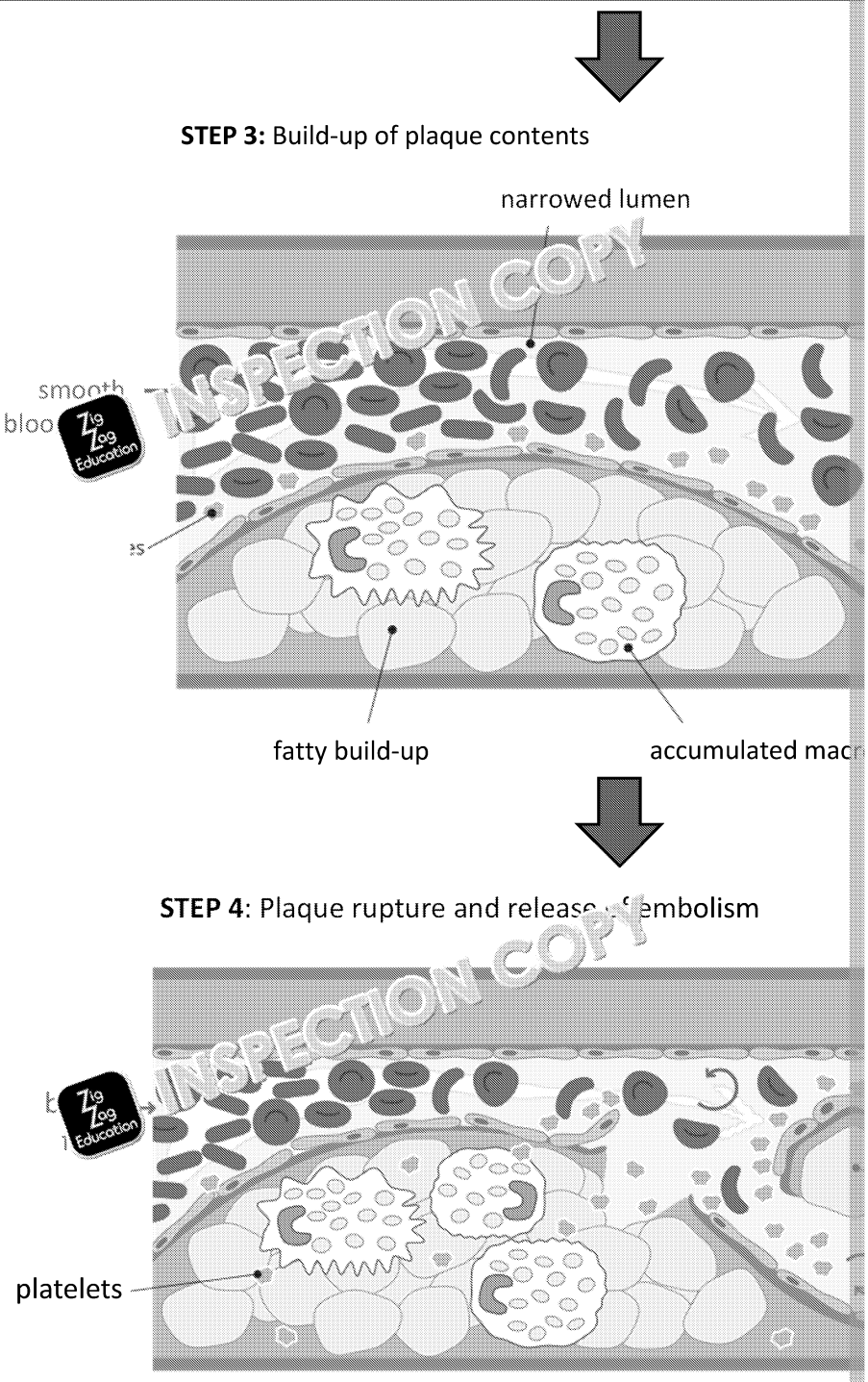


Figure F2.22B. *Steps 3 and 4 of the formation of an atherosclerotic plaque, and its rup*

Embolism

If a plaque ruptures, its contents may enter the bloodstream as an **embolus** – a circulating mass that can lodge in smalle[illegible]ries, causing blockages in vital organs. This can have catast[illegible]ects if the embolus becomes lodged in the heart, lungs o[illegible] (see *Table F2.1*).

Organ affe[illegible]	Embolism type	Resulti[illegible]
[illegible]ea[illegible]	Cardiac embolism	May trigger heart attac[illegible]
Lungs	Pulmonary embolism	Often a result of a deep[illegible] Causes breathing difficu[illegible]
Brain	Cerebral embolism	Can cause stroke

Table F2.1. A summary of the conditions caused by embolisms lodging in t[illegible]

Causes and risk factors

Lifestyle choices increase the risk of developing atherosclerosis, including a poor diet and sugars, lack of exercise, and smoking.

These may lead to conditions such as diabetes, obesity, high blood pressure, and high which increase the risk of developing atherosclerosis further.

Family history is important too as some genetic factors also increase the risk.

Symptoms

Atherosclerosis may be asymptomatic for years, and when symptoms do arise, they vary site of the atheroma but may include:

- shortness of breath
- fatigue, dizziness and confusion
- chest pain and angina
- pain in limbs during exercise

Your turn

1. Create a flow chart or cartoon to show the development of a plaque and its rupture of an embolism. Add as much detail as possible.
2. Describe the causes and risk factors for atherosclerosis and the symptoms that may

Aneurysms

An aneurysm refers to the abnormal dilation or bulging of an artery wall, caused by the weakening of its structural layers. This can result from **chronic** pressure or **degenerative** changes.

A **thrombus** may form within an existing aneurysm and increase its risk of rupture. Because arteries transport blood under high pressure, a ruptured aneurysm can lead to catastrophic internal bleeding and may prove fatal if not treated promptly.

chronic condition

degener of tissue ageing, di

thrombu blood ve

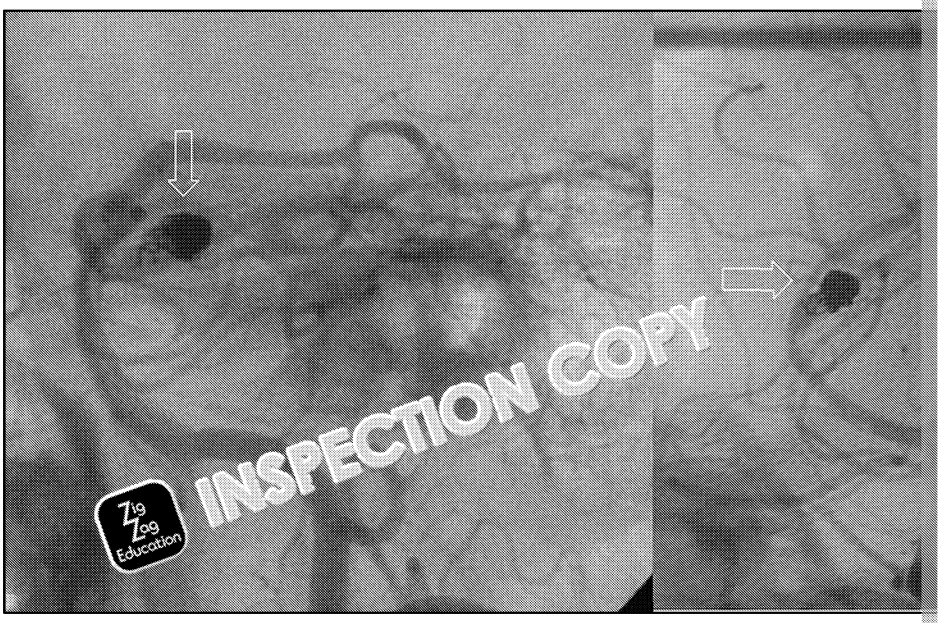


Figure F2.23. *Saccular aneurysm visible in a patient under X-ray, due to the injection of a*

Classification

Aneurysms can also be classified by how much wall is involved:

- True aneurysm – involves dilation through all three arterial wall layers (tu externa; see section 2.1.2, page 65).
- False aneurysm (pseudoaneurysm) – involves blood leaking through the i tunica media; not all wall layers are involved.

Dissection or rupture of the aneurysm

An aneurysm may break. The exte[nt] to which this happens affects the severity involved will determine the interventions required and the damage caused.

Dissecti[ng] an aneurysm describes a tear developing in the inner endothelial This allo[ws] blood to split the vessel wall layers, which may progress through th widen the lumen.

A rupture is a full thickness tear of the arterial wall: all three layers give way, c the surrounding tissues. If the affected artery is substantial, the body can go i A ruptured cerebral aneurysm causes a stroke, while a ruptured aortic aneury

Aortic aneurysms

The aorta, the main artery leaving the heart, can develop aneurysms in two k

- Abdominal aortic aneurysm (AAA, or triple A) – located in the lower aorta until rupture.
- Thoracic aortic aneurysm (TAA) – located near the heart; may cause ches

There are several risk factors for aortic aneurysms, inc[luding] atherosclerosis, genetic disorders (e.g. Marfan syndrome), and age. If an aortic aneurysm rupt and essential to prevent death from [internal] bleeding.

Pulmonary aneurysm

A pulmo[nary] aneurysm forms in the artery transporting deoxygenated blood rare con[dition] but can be life-threatening.

It is caused by high blood pressure in the lungs (pulmonary hypertension), infe trauma, congenital heart defects and connective tissue disorders.

Rupture leads to bleeding on the lungs, severely impairing breathing and gase

Apply your knowledge

1. Define the term aneurysm, list the different types of aneurysm, and describe th
2. Explain why a ruptured aneurysm is considered a medical emergency and des from a rupture.
3. Identify three or more risk factors for developing an aortic aneurysm and explai the condition.

Muscle deterioration

Muscle deterioration, or muscle **atrophy**, refers to the loss of muscle mass, strength and function. It primarily affects skeletal muscles and can occur due to various biological and lifestyle factors.

Causes

Muscle atrophy is a progressive disease which may develop slowly or rapidly depend

- Ageing – after the age of 40, muscle mass and strength decline naturally due to changes in metabolism. This process is known as sarcopenia.
- Lack of use (disuse) – a sedentary lifestyle or prolonged immobility from bed rest surgery limits muscle stimulation.
- Malnutrition – inadequate protein intake or poor nutrient absorption impairs m
- Neurological disorders – conditions like multiple sclerosis and spinal muscular at neurons, interrupting muscle innervation.
- Genetic conditions – disorders such as muscular dystrophy weaken muscle fibre inherited structural defects.
- Endocrine disorders – hormonal imbalances, including hyperthyroidism and Cus protein metabolism and muscle maintenance.
- Autoimmune and inflammatory disorders – chronic illnesses such as AIDS can le inflammation and muscle wasting.

Symptoms

As muscle fibres progressively deteriorate, patients experience muscle weakness and and tone. This leads to difficulty in daily activities such as walking and climbing stairs, and impaired balance and strength, increasing the risk of falls.

Recall questions

1. List four common causes of muscle atrophy and explain ho muscle mass and strength.
2. Describe the main symptoms of muscle atrophy and explai in daily life.

Osteoporosis

Osteoporosis is a progressive condition in which bone mineral density decreases, lea fragile bones. It often affects post-menopausal women, although it is not exclusive t remain undetected until a fracture occurs, sometimes from minor incidents such as s

Causes and risk factors

Bones are living tissues which undergo constant remodelling. This balance is maintaine osteoblasts, and breakdown by osteoclasts (see section 2.1.2, page 68). In osteoporosis bone formation, reducing bone density, causing porous, brittle bones which are more commonly affect weight-bearing bones, such as the spine, hips and wrists, which abso

While osteoporosis is associated with older women, there a several other risk factors, in addition to age and sex, including:

- low sex hormone levels – reduced oestrogen (in women) or testosterone (in men)
- sedentary lifestyle and lack of weight-bearing exercise
- smoking and excessive alcohol consumption
- long-term steroid use – steroids (e.g. prednisolone) are used to treat a wide range of conditions, including asthma and eczema
- poor nutrition, including lack of calcium and vitamin D, low body mass index (BMI) or eating disorders
- family history of osteoporosis

Further you

Vitamin D enables absorption and is body using UV ra Vitamin D is also fo Calcium is presen dairy products an kale and broccoli

Diagnosis

Osteoporosis is diagnosed and monitored using DEXA (Dual-Energy X-ray Abso
imaging technique uses two low-dose X-ray beams at different energy levels t
It measures how much radiation is absorbed by bone compared to soft tissue a

DEXA provides two bone density scores:

- T-score – compares bone density against a healthy young adult
- Z-score – compares bone density against others of the same age, sex and

T-score range	Diagnosis
Above -1	Normal
-1 to -2.5	Osteopenia (early bone loss)
Below -2.5	Osteoporosis

Table F2.2. The T-score range compares bone density of the patient to that

DEXA scans are routinely offered to women over the age of 65 and men over t
menopausal women with known risk factors, and individuals who are on long
or with a history of fractures, may also be offered scans at a younger age.

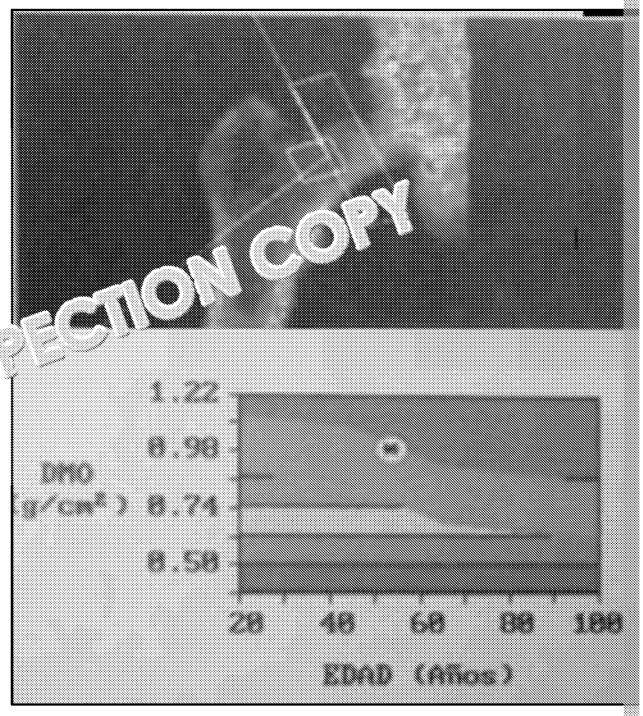


Figure F2.24. *Bone density image and reference graph from a female femur. Areas in*

Recall questions

1. List some common risk factors associated with the d
of osteoporosis
2. Describe how the DEXA scan is used to diagnose an
Differentiate what the T-score and Z-score represent.

Liver cirrhosis

Liver cirrhosis is a chronic condition where long term damage leads to the gradual replacement of healthy tissue with scar tissue (**fibrosis**). This disrupts normal digestive and metabolic processes, such as bile production (for lipid digestion) and blood detoxification (see section 2.1.2, page 69). As fibrosis advances, liver function becomes increasingly impaired, potentially resulting in liver failure.

Causes

The most common cause of cirrhosis is chronic alcohol misuse. However, other factors can also contribute to progressive liver damage, including:

- non-alcoholic fatty liver disease (NAFLD) – associated with obesity; fat accumulation can eventually cause inflammation and fibrosis
- chronic viral infections – hepatitis B or C
- autoimmune liver conditions – e.g. autoimmune hepatitis
- genetic disorders – e.g. Wilson's disease (causes copper accumulation), haemochromatosis (causes iron overload)
- toxic substances and medications – long-term exposure increases detoxification demands and chronic inflammation

These conditions cause hepatocytes to become inflamed and damaged over time. Repeated damage leads to scarring.

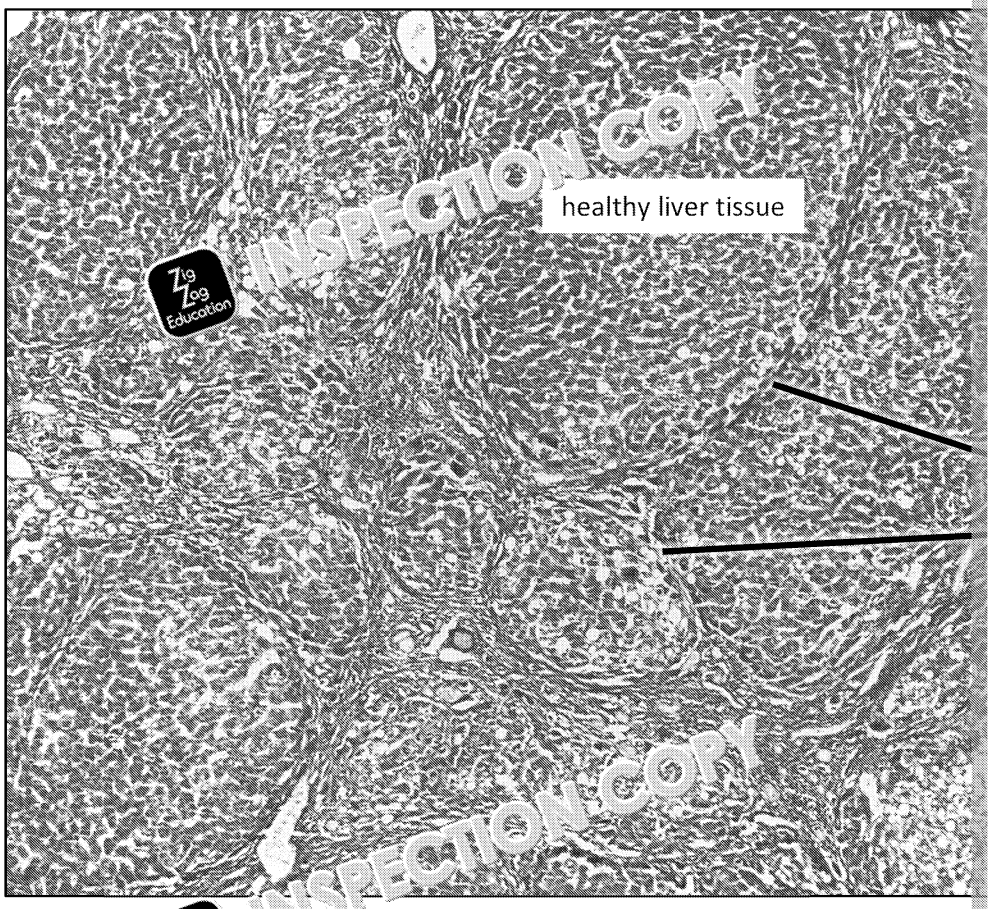


Figure F2.25. *Fibrosis clearly visible in this light micrograph of cirrhotic liver tissue. The fibroids appear as deep blue bands running through the purple healthy tissue, causing scarring and distortion.*

Symptoms

In early stages, cirrhosis may be asymptomatic. As damage progresses, sympto
and toxin accumulation within the bloodstream, including:

- fatigue, weakness and loss of appetite
- jaundice – yellowing of skin and eyes, due to impaired processing of biliru
  when erythrocytes break down)
- itchy skin – often linked to bile salt accumulation
- abdominal swelling and liver enlargement
- vascular changes – spider-like blood vessels under the skin, red palms, ea
- cognitive symptoms – confusion, poor concentration
- internal bleeding – vomiting blood, black faeces

Recall questions

1. List the primary causes of liver cirrhosis and how they
   of fibrosis.
2. Describe the symptoms associated with liver cirrhosi
   occurs in affected individuals.

Lung conditions

The lungs are a vulnerable target for disease and infection. They form an esse
external and internal environments, are moist to enhance diffusion, and have
which contribute to the possibility of developing issues.

Asthma

Asthma is a chronic respiratory condition, characterised by **acute** episodes of
and swelling, muscular contraction (bronchospasm), and excess mucus produc
lead to the narrowing of the bronchi and bronchioles. This restricts airflow and
characteristic wheezing, coughing, chest tightness and shortness of breath, ex

Causes

Asthma is a genetically influenced condition, with symptoms often triggered b
include airborne allergens, irritants, dust or infections. Exercise, especially in c
emotional responses such as stress, laughter and crying which change breath
Some medications are also triggers, including non-steroidal anti-inflammatory
beta blockers (for hypertension).

Chronic obstructive pulmonary disease (COPD)

Chronic obstructive pulmonary disease (COPD) is a progressive lung condition
narrowing of the airways and damage to the alveolar surface. COPD includes
bronchitis and emphysema.

Chronic bronchitis

Chronic bronchitis is defined by persistent inflammation of the bronchi and br
least three months per year for two consecutive years. Inflammation stimulate
mucus, narrowing the airways and restricting air flow. Epithelial cilia are also d
and retaining pathogens and debris in the airways, increasing the risk of infecti
the alveoli reduces the efficiency of gaseous exchange and can lead to hypoxia

Symptoms of chronic bronchitis include a persistent productive cough (smoker
coupled with wheezing, shortness of breath, fatigue and frequent chest infecti
may have bluish lips and nails (cyanosis) from poor oxygenation, ankle swelling
circulation, and crackling sounds when breathing indicating mucus or fluid in t

Emphysema

Emphysema involves progressive damage to the alveoli (air sacs responsible for gase
which reduces oxygen uptake, causing breathlessness and leading to long-term resp

When the alveoli become damaged, the walls break down, and they lose their struct
merge into larger, less efficient air spaces, which reduces the surface area available f
exchange. This also traps air, making it difficult to exhale e tly. Over time, this
inflation (hyperinflation), laboured breathing, and in re the risk of lung infectio
air and reduced clearance.

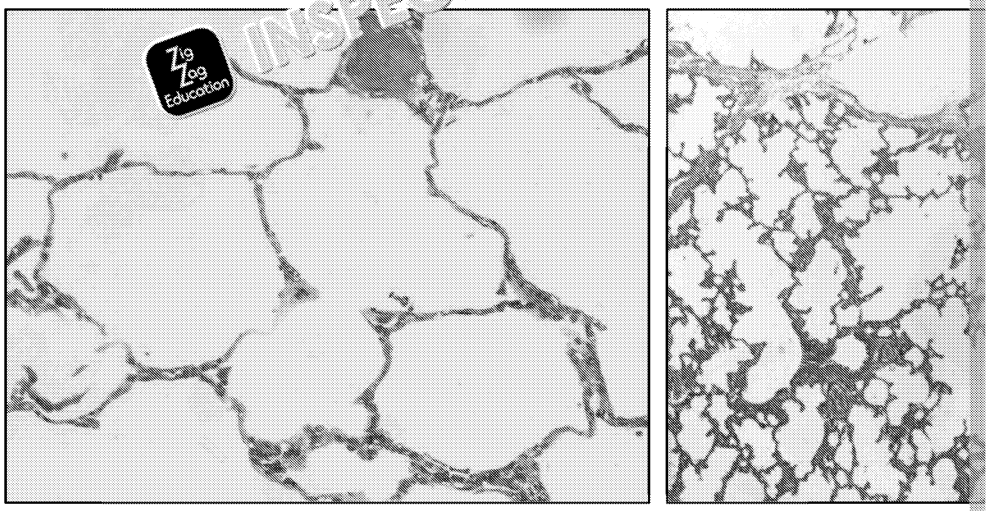


Figure F2.26. *Light micrograph on left shows normal lung alveoli, showing high su
compared to emphysematous tissue on right, which has dated alveoli and substa*

Causes and risk factors

The leading cause of COPD is s cluding passive smoking. Smoke contains v
damage lung tiss lea reversible structural changes. Other contributing fa

- age – the on usually develops in individuals over the age of 40
- occupation exposure – to air pollution or chemical fumes

Lung cancer

Cancer is a disease caused by uncontrolled cell division. Lung cancer is one of the m
worldwide and the leading cause of cancer-related death because it progresses quic
tends to be diagnosed at an advanced stage, making treatment complex.

There are three types of lung cancer:

- Non-small-cell lung cancer (NSCLC) – most common subtype; includes adenocarcinoma, squamous cell carcinoma and large-cell carcinoma.
- Small cell lung cancer (SCLC) – more aggressive, meaning it rogresses quickly and is more likely to **metastasise** (migrat
- Secondary lung cancer – occurs when can us ells metastasise to the lungs from another organ in the y the bloodstream.

Unlike COPD a hn s re impairment is due to narrowed airways or damage
disrupts functi ugh abnormal cell growth.

Causes and risk factors

The primary cause of lung cancer is smoking, which accounts for around 70 % o
Lung cancer also has several other risk factors, including:

- air pollution – in particular, PM2.5 particles (airborne particulates < 2.5 µ
  the lungs; this includes soot, sulfates and nitrates released in vehicle exha
- occupational hazards – such as exposure to asbestos, diesel fumes or indu
- radiation exposure – X-rays and CT scans
- family history of lung cancer and inherited mutations

These risk factors increase the likelihood but do not guarantee that the disease
damage accumulates over time.

Symptoms

Early stages of lung cancer are often asymptomatic, which delays diagnosis. W
be similar to other lung conditions, and include a persistent cough, often with
fatigue and chest pain. Sudden, unexplained weight loss, hoarseness and recur
observed. These stem from impaired gaseous exchange leading to reduced aer
flow to the tumour, and local tissue invasion by the tumour, with associated in

Recall questions

1. List the main causes and symptoms of asthma and de
   condition is diagnosed.
2. Describe the differences between chronic bronchitis
3. Describe the major risk factors for developing lung c

Stomach conditions

Stomach ulcers

Stomach ulcers are painful sores on the stomach lining. They are caused by the a
gastric lining due to the absence of the protective mucus layer. The mucus laye
from degradation by acid, and its absence causes damage by burning from the

Causes

There are two main causes of stomach ulcers:

- *Helicobacter pylori* (*H. pylori*) infection – a bacterium which disrupts the m
  acid to interact with the stomach lining.
- Long-term use of non-steroidal anti-inflammatory drugs (NSAIDs) – includ
  make the lining more vulnerable to acid.

However, there are other risk factors which increase the likelihood that these d
including smoking, excessive alcohol consumption and stress.

Symptoms

Not all stomach ulcers are painful. Typical symptoms include a burning or g
abdomen; indigestion, heartburn and acid reflux; and nausea, bloating and fee
vomiting blood, blood in the faeces, and a sudden, sharp abdominal pain may
sudden perforation or bleed.

Stomach cancer

Stomach cancer occurs when abnormal cells in the stomach lining divide uncontrolla
tumour. This can impair digestive processes, reduce nutrient absorption, and occup
These cancers are relatively uncommon in the UK but are medically serious, often d
due to non-specific early symptoms which are similar to ulcers and gallstones.

Risk factors and symptoms

There are several factors which increase the risk of developing stomach cancer. The
increases risk due to abnormal exposure of stomach epithelial cells to corrosive gast
infections therefore increase the risk because the protective mucus lining is damage
by increasing the likelihood of genetic mutation occurring in the underlying cells of t

Smoking and excessive alcohol consumption increase the risk because of carcinogen
cause tissue damage and mutation. Interestingly, a diet high in salt, or smoked or pic
in fruit and vegetables also increases the risk. Other risk factors include older age (o
history, pernicious anaemia, and blood group A. These risk factors may lead to malig
increase inflammation, cause **oxidative stress**, or cause damage to DNA.

Stomach cancers are often diagnosed at a late stage because early symptoms are va
for indigestion, ulcers or gallstones. Persistent heartburn, indigestion, bloating, abd
appetite and feeling full quickly are symptoms common to stomach ulcers and canc
symptoms include unexplained weight loss, common to many cancers due to redire
tumour and systemic nutrient deficiency; difficulty swallowing (dysphagia) due to ob
blood or black faeces, which indicates internal bleeding.

Recall questions

1. List the primary causes and symptoms of stomach ulcers a
their diagnosis.
2. Compare the risk factors for stomach ulcers and stomach c

Bowel conditions

Inflammatory bowel disease (IBD)

Inflammatory bowel disease (IBD) is a group of chronic disorders which affect the ga
characterised by persistent inflammation. The two main forms are ulcerative colitis a
share typical symptoms including abdominal pain, diarrhoea and fatigue, but differ s
location and the depth of tissue involvement.

Condition	Area affected	Inf
Ulcerative colitis	Colon and rectum only	Inner lin
Crohn's disease	Anywhere between mouth and anus, but most commonly in the intestin	Full thick

Table F2.3. Location and depth of inflammation for ulcerative colitis and Croh

Unlike irritable bowel syndrom which involves no inflammation, IBD involves
which damages GI tissue

Symptoms

Symptoms are caused by inappropriate immune-mediated inflammation, which disrupts digestion, nutrient absorption, water balance and faecal processing. They often follow a relapsing-remitting pattern, with acute episodes triggered by diet, stress or infection.

During an acute episode, symptoms may include:

- diarrhoea, often with blood or mucus – symptomatic of inflammation
- abdominal pain and cramping
- urgency to defaecate
- fatigue, loss of appetite, and weight loss
- fever – a result of inflammation

Causes and risk factors

IBD is an autoimmune disease involving the immune system wrongly attacking several where the exact cause is unknown; however, there is evidence to sugg infection, coupled with genetic predisposition, can lead to chronic immune activation. Other factors may also act as a trigger for the disease, including smoking, infections, use of **NSAIDs**, and changes to the gut microbiome, including from substantive dietary changes or the use of oral antibiotics. Age is also a factor: patients are most often diagnosed with IBD between the ages of 15–30 and 50–70.

Foods that often trigger an acute episode vary but are linked specifically to the irritate the gut wall. This includes high-fibre foods like grains and raw vegetab foods, coffee, alcoholic drinks, and artificial sweeteners. Therefore, avoiding t acute episode, is well advised.

Stress is also a trigger, due to hormonal effects on gut function, and because stress often include reduced diet quality (for instance, increased consumption caffeinated or alcoholic drinks) and less exercise.

Cancer of the colon

Colon cancer is caused by the uncontrolled cell division of abnormal epithelial cells in the lining of the large intestine, forming a **malignant** tumour. When the rectum is also affected, the term colorectal cancer is used instead. These cancers usually start as polyps – small, **benign** growths on the inner mucosal lining – which can become cancerous if not detected and removed early.

Symptoms and causes

Colon and colorectal cancer symptoms may be absent until the tumour is large depending on its location, size and degree of spread. Symptoms typically inclu

- blood in the faeces
- changes in bowel habits – persistent diarrhoea or constipation
- abdominal pain, bloating or cramping
- fatigue and unexplained weight loss
- feeling of incomplete bowel movement

Risk factors include both genetic and lifestyle factors. A family history or pre-e disease (IBD) increases the risk of developing colon or colorectal cancer. Lifest include smoking, alcohol consumption, obesity, and type 2 diabetes, low levels or processed meats and low in fibre, which because these factors may inflict a and mucosal health, which contribute to chronic inflammation and can lead to with age.

Recall questions

1. List the lifestyle factors that increase the risk of deve bowel disease and colon cancer.
2. Describe the main differences between ulcerative co

Kidney failure

Kidney failure is a condition where one or both kidneys are unable to effectively filte
regulate fluid and electrolyte balance, or maintain homeostatic control. The failure
the ultrafiltration membrane, nephron tubules, or impaired water and ion reabsorp

Causes and symptoms

There are many causes of kidney failure, including:

- infections – inflammation and damage to nephr ins uce filtration efficiency
- hypertension – increased pressure d ag trafiltration membranes, allowing the filtrate
- polycystic kidney dise cys s (fluid-filled sacs) displace tissue and compress
- genetic co ns, g. diabetes insipidus (inability to produce ADH) – causes c which can nephron damage

Symptoms of kidney failure are often systemic due to the kidney's role in homeosta

- hypertension – from fluid retention and increased blood volume
- proteinuria or haematuria – presence of protein or blood in the urine because o
- anaemia and fatigue – reduced erythropoietin secretion (a hormone produced b stimulates bone marrow to manufacture erythrocytes, see page 123) leads to l production (anaemia), resulting in reduced oxygen transport and reduced aero
- bone pain and joint stiffness – linked to impaired calcium/phosphate ion regula
- fracture risk – chronic kidney disease alters bone metabolism, causing weakene

Recall questions

1. Outline the main causes and symptoms of kidney failure.

Pancreatic conditions

Diabetes mellitus

Diabetes mellitus is a chron c ti n where the body fails to effectively regulate b due to impaire lin e uction or insulin function. There are two types – type 1 a and causes dif

Type	Defect	Cause	
Type 1	Pancreatic β cells unable to produce insulin	Autoimmune destruction	Family hi triggers
Type 2	Insufficient insulin produced or target cells become resistant to insulin	Metabolic dysregulation	Obesity, p sugar int

Table F2.4. The defects, causes and risk factors for types 1 and 2 diabetes

Type 1 diabetes

Type 1 diabetes typically develops during childhood or adolescence, although it can ar autoimmune destruction of pancreatic β cells, leading to complete insulin deficiency, a

Symptoms include the sudden onset of excessive thi , fre ent urination and unexplained weight loss. **Hyperglycaemia** m to confusion and behavioural changes. **Hypoglycaemi** ca e slurred speech, drowsiness and disorientation. Both ext ead to coma or death if left untreated.

To manage the io , patients require lifelong insulin therapy via injections to r concentration. dition, they must frequently monitor their blood glucose levels t hyperglycaemic episodes.

Ongoing research into stem-cell-based therapies is exploring the possibility of growi Successful transplant would restore insulin production and not be vulnerable to reje patient's own cells.

Type 2 diabetes

Type 2 diabetes is usually diagnosed in adulthood, but incidences are rising in y
dietary habits and increased obesity. It occurs when either the pancreas canno
target cells become resistant to insulin, so reducing glucose uptake by cells.

The primary cause of type 2 diabetes is obesity, due to overconsumption of re
have been processed to remove fibre, vitamins and minerals, leaving behind r
sugars. Examples include white bread, pizza dough, dairy cereals, bagels, waf
fruit juices and fizzy drinks.

Symptoms include the gradual onset of persistent thirst, fatigue, blurred visio

Due to its nature, lifestyle treatment involves lifestyle modification: weight loss
low-calorie, and regular physical activity. In some cases, and often initially w
effect, medications are required to either stimulate insulin production or reduc
In advanced or unresponsive cases, insulin injections may be required. Studies
diabetes can be reversed if significant lifestyle changes are sustained, especiall

Pancreatic cancer

Pancreatic cancer typically presents at a late stage, resulting in a poor prognos

The pancreas contains two functional types of cells: endocrine cells that secret
into the bloodstream; and exocrine cells that secrete digestive enzymes into t

Most pancreatic cancers occur in the exocrine cells and are classified as adeno
neuroendocrine tumours (NETs) can also occur from hormone-producing cells.

Symptoms

Pancreatic cancer often remains asymptomatic until advanced stages. Sympto
gastrointestinal conditions such as indigestion, gallstones or IBD, making early
appear, they may include:

- dull and persistent upper abdominal pain
- jaundice due to bile duct blockage caused by abnormal growth in the pa
- steatorrhoea – fatty, pale faeces caused by poor fat digestion due to obstru
- loss of appetite or unexplained weight loss
- new-onset or worsening diabetes
- nausea, vomiting and fatigue

Causes and risk factors

As with many cancers, there are several prevalent risk factors, notably smokin
Cigarettes contain many carcinogens which damage DNA, and obesity or poor
and promotes inflammation, causing damage to tissues and DNA.

Ongoing conditions like pancreatitis and diabetes also increase the risk of pancreat
involves persistent inflammation which causes repeated tissue damage and may al
puts stress on the body's metabolism and creates inflammation that can lead to tis

Age is also a factor, due to the accumulation of cell and DNA damage through
Most cases of pancreatic cancer are diagnosed in patients over the age of 65 y

Apply your knowledge

1. Describe the main differences between type 1 and type 2 diabetes mellitus with
   treatment approaches.
2. Describe the types of lifestyle modifications that can be effective in managing t
3. Explain why pancreatic cancer is often diagnosed at an advanced stage.

Practice questions: Disease and organ failure

1 A 53-year-old male presents with the following history, background and sy

Medical history	Background	Sy
Recent *H. pylori* infection, but all cleared Mother died of breast cancer Father had long-term stomach ulcers	Smoker Drinks 4-7 pints per week Has increas[illegible]ercise in last 2 m[illegible]about 20 mins [illegible] day of light workouts and ~8000 steps per day Consumes 2-3 portions of fruit/veg per day, recently improved Sleeps well	Bl Re Fe Mi Fa Ge On

Using this patient history:

a. State one lifestyle changes that the patient could make immediately (1)

b. Outline one possible diagnosis for the patient and explain your reason

2.1.4. Transplanted and artificial organs

The human body consists of highly specialised organs and systems that intera
When organ function becomes impaired, either through disease, damage or c
significantly reduce quality of life. In many cases, corrective surgery or organ t
replace lost function. This section explores key interventions across major org
advantages and limitations.

Transplants and corrective surgery

Heart

Surgical interventions [illegible] needed when electrical conduction fails, valves
cardiac m[illegible] is [illegible]. Each of these issues can be addressed using corre

Main problem	Caused by	
Uncoordinated contraction	Damage to sinoatrial node (SAN) or atrioventricular node (AVN)	Pac
Antidirectional blood flow	Septal defects	Sur
	Faulty valves	Val (me
Coronary artery blockage	Atherosclerosis in coronary artery	Cor

Table F2.5. Surgical interventions for heart issues.

For end-stage heart failure, a heart transplant may be required, replacing the
using a heart from a recently deceased donor.

Lungs

Surgical solutions address recurrent collapse, [illegible] obstruction, or localised

Main problem	Caused by	
Recu[illegible]nt [illegible]thorax	Lung collapse caused by air leakage into the pleural (lung) cavity	Pleuro chest
Pe[illegible]t airway obstructions	Structural weakness or collapse	Stent reinfo
Localised disease	Various causes including infection, tumour, trauma	Lobec remov

Table F2.6. Surgical interventions for lung issues.

In chronic, widespread conditions such as cystic fibrosis and COPD, lung trans
may be considered.

Liver

Corrective surgery targets ducts, blood vessels and tumours.

Main problem	Caused [illegible]	
Bile duct damage	Gallstone[illegible]	Repair tear
Portal hypertension	[illegible] veins causing increased blood pressure	Shunts fitte
T[illegible]	Malignant growth	Liver resec

Table F2.7. Surgical interventions for liver issues.

Liver transplants are offered for end-stage liver disease or large malignant tu
partial transplants.

Stomach

Corrective surgery may be offered for structural or functional complications.

Main problem	Caused by	Surg
Ulcers	Damage to the mucosal layer	Gastrectomy: the stomach
Cancer	Malignant growth	
Reflux	Weak cardiac sphinct	Fundoplicati using the fun
Gastric outlet obstruction	Restricti t. pyloric duct	Pyloroplasty pyloric canal

Table F2.8. Surgical interventions for stomach issues.

Stomach trans re are and usually performed as part of a multivisceral transplantation, involving the intestines, liver and pancreas.

mu org wit

Intestines

Surgical corrections are common in Crohn's disease, diverticulitis, or intestinal failur

- bowel resection and anastomosis – removal of the diseased segments and reco
- stoma creation – diverts waste into an external bag when anastomosis isn't pos
- stricturoplasty – widens strictures (narrowed sections of bowel) to improve mo

Multivisceral transplants may be offered for conditions like short bowel syndrome o

Kidney

Corrective surgery on kidneys can be used to address obstructions, tumours and cal

Main problem	Caused by	Surgical co
Obstruction	Narrowing of collecting ducts or ureter	sty: reconstructio
Tumour	Malignant growth	Nephrectomy: partial or to
Kidney stones	Crysta tion o salts ons	Lithotripsy: ultrasound to f natural passing Surgical removal

Table F2.9. Surgical interventions for kidney issues.

Kidney transplantation is the most common solid organ transplant and can be perfo donor tissue, as function can be maintained with only one kidney.

Bone and spine

Orthopaedic surgery addresses fractures, joint degeneration, spinal deformities and

Main problem	Caused by	Surgica
Fractures	Trauma, osteoporosis	Internal fixation w and rods
Joint damage	Cartilage erosion, injury	Joint replacemen
Deformity	Abnormal growth, congenital defect, e.g. scoliosis, spondyliti	Spinal rods, osteo and reshaping), re
Spinal instability	Prolapsed disc, vertebr l e	Spinal fusion to st

Table F2.10. Surgical interventions for bone and spine issues.

Bone grafts (not whole bon s) may be harvested from the patient's femu especially in the o usion and reconstructive surgeries.

Apply your knowledge

1. Outline the main surgical interventions available for treating diseases of the heart, lung intestines, kidneys, and spine.
2. Describe when a transplant might be preferred over corrective surgery.
3. Explain how bone grafts contribute to the healing process in reconstructive and spinal s

Organ rejection

Organ rejection occurs when the recipient's immune system recognises the tr
initiates an immune response to eliminate it. This response is triggered by diff
antigens of the host and transplanted tissues. These markers are genetically u
uses these molecular identifiers to distinguish between self and foreign cells.

Transplanted tissues carry foreign antigens, even if donor and recipient are th
T lymphocytes which destroy the cells, triggers antibody production, and ultim
and tissue damage. To prevent rejection, patients are given immunosuppressa
activity and maintain the function of the transplanted organ.

In graft versus host disease (GvHD), donor immune cells are transplanted with t
The donor immune cells recognise the recipient's cells as foreign and attack th
in bone marrow transplants, because this tissue contains haematopoietic stem c
lymphocytes. However, it can also affect skin, liver and gastrointestinal tract gra
complications including sepsis and multi-organ failure if not managed effectively

Recall questions

1. Compare and contrast organ rejection with graft ve
2. Explain how organ rejection and GvHD involve the i

Artificial organs

Artificial organs are man-made and replicate the function of biological tissues,
metals or biologically derived materials such as animal tissue, or may be lab g
organs are increasingly used in surgery, including joint replacements and prost
cell-derived organs show potential, they are still largely used within research a

Deciding between donor and artificial organs involves multiple considerations,
ethical concerns, longevity of use, and resource availability and availability.

	Benefits	
Donor organs	• Full biological functionality • Integration with body systems	• Limited availabilit • Organ rejection o without lifelong i • Average lifespan
Artificial organs	• Longer average lifespan: ~15 years • No need for immunosuppression	• Reduced or speci • Limited to certain and replacement • High developmen

Table F2.11. Surgical interventions for bone and spine is

Decisions around organ replacement involve many considerations:

- Ethical issues – including consent, allocation priority and fairness.
- Moral dilemmas – such as animal-derived vs man-made materials, and a
- Medical risks – for example, surgical complications, organ failure, immun
- Financial costs – including long-term care, cost of research and developm

Artificial organs may reduce waiting lists and avoid immune rejection but may o
as whole organ replacement is essentially functioning, complex systems s

Recall questions

1. Describe the key differences between donor organs
2. Outline the factors considered when deciding betwe
of a donor organ and the use of an artificial organ.

Practice questions: Use of tissues in research and develo

1 Explain the limitations of creating a heart organoid that could be use

2.2.1. Organ systems

We have examined how specialised tissues work together as an organ for a specific p
the review further by identifying that a collection of different organs working togeth
For example, the circulatory system has many different tissu d organs working t
blood vessels and the heart are organs within this sy .

The eleven different organ systems pr w n the human body are:

1. **U**rinary or excretory syst
2. **D**igestive sy m
3. **R**espirato m
4. **I**mmune sy
5. **N**ervous system
6. **C**irculatory system
7. **M**usculoskeletal system
8. **E**ndocrine system
9. **R**eproductive system
10. **Integumentary system** (hair, skin and nails)
11. **Ly**mph system

T
Remember the eleven h
with the mnemonic U D

Recall questions

1. Describe how an organ differs from an organ system.

2.2.2. System structure and function

There are eleven different organ systems within t e u an body. This chapter will e
systems and consider their component s, tu s and adaptations.

Blood circulatory s m

The circulatory s m is a critical support system that moves blood throughout the b
biological proce s essential for survival. It includes the following organs:

- heart
- blood
- blood vessels

Blood carries many substances either dissolved or suspended in plasma, including:

- oxygen – delivered to all cells for aerobic respiration
- nutrients – including glucose, amino acids, vitamins and minerals, necessary for c
- waste products – including carbon dioxide and urea for excretion
- immune system components – antibodies and lymphocytes that provide defen
- hormones – regulating homeostatic mechanisms and coordinating responses

Blood also plays an important role in thermal regulation, i.e. di ibuting heat evenly
maintaining a stable internal temperature.

The circulatory system works closely with e er body systems to supply essential subst
removing metabolic waste for p ing and disposal, and transmitting chemical mes

Chemical com tic through the circulatory system complements the nervous s
signals to enab effective communication and coordination across the body.

Recall questions

1. List the organs in the blood circulatory system.
2. Explain why the blood circulatory system interacts with all o

Lymphatic system

The lymphatic system acts as a secondary drainage system and immune network, complementing the circulatory system by returning excess tissue fluid to the bloodstream and defending against infection.

Tissue fluid that does not re-enter capillaries drains into lymphatic capillaries – blind-ended tubes that form a network throughout body tissue. This fluid, now called lymph, flows through a series of larger vessels by compression caused by skeletal muscle contraction. As with veins, lymph vessels have valves that ensure unidirectional flow and prevent backflow. Lymph is eventually returned to the bloodstream via veins located under the clavicle (collar bone).

Lymph is similar to blood plasma, except it has higher levels of fatty acids and lower concentrations of nutrients and oxygen. It is enriched with lymphocytes, which collect at the lymph nodes and detect pathogens. At the lymph nodes, bacteria are phagocytosed by macrophages, and B lymphocytes produce antibodies that are passed into the bloodstream. During an infection, the lymph nodes often become swollen because of increased immune cell activity. This is why doctors palpate (examine by touch) lymph node sites, such as in the armpits, groin or neck.

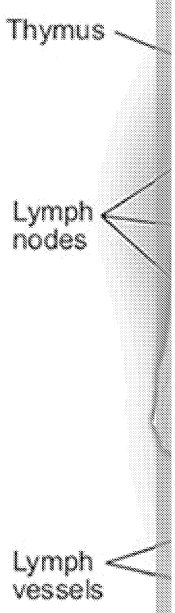


Figure F2.27. *The network of vess*

Comparing the lymphatic and circulatory systems

The lymphatic and circulatory systems have notable structural and functional

	Lymphatic system	
Type of system	Open-ended: lymph drains from the tissues	Closed
Vessels	Lymph capillaries, vessels and ducts	Arteries
Movement caused by	Muscle contraction	Heart
Organs involved	Lymph nodes, spleen, thymus, tonsils	Heart,
Transports	Lymph: tissue fluid with lymphocytes and fatty acids	Blood:
Waste removal	Removes cell debris, bacteria and toxins	Remove lungs a
Immune role	Filters pathogens via the lymph nodes	Transp and ar

Table F2.12 Comparison of the lymphatic and circulatory s

In conclusion, the circulatory system delivers nutrients and removes waste to homeostasis in tissues, the lymph drains excess tissue fluid, monitors the im back to the bloodstream. Together, they maintain fluid balance and operate a

Recall questions

1. Outline the key differences between the blood circula
2. Explain why the lymphatic system is not a circulator

Musculoskeletal system

The musculoskeletal system includes bones, skeletal muscles, and the connective tiss
and tendons, that support, stabilise and coordinate movement. Ligaments are tough
bone, providing joint stability. Tendons are fibrous cords that attach muscle to bone,
muscles contract.

The musculoskeletal system has three key roles:

1. Movement and coordination: achieved by muscle contraction acting on the skel
2. Posture and balance control: using proprioceptors in the joints that detect change in
3. Protection of internal organs: the skull protects the brain; the ribcage protec
pelvis protects the reproductive organs and the lower GI tract.

Other roles of bones

Bone tissue provides a major calcium reservoir. This is essential for the structural int
the activation of muscles at the neuromuscular junction.

Long bones, such as the femur, have a spongy inner matrix called bone marrow whic
production of some stem cells and the storage of fat (see Bone tissue, page 58).

Other roles of muscles

Muscles are important for blood glucose homeostasis: they provide a substantial sto
They provide useful reservoirs of amino acids, which can be mobilised during fasting
and immune support. They are also significant in thermoregulation: shivering genera
contraction, which is essential when body temperature has dropped due to exposure

Recall questions

1. Outline the role of bones and muscles within the musculos
2. Explain why both muscles and bones are required to enabl

The homeostatic system refers to a collection of linked biological processes that wor
internal environment despite external fluctuations: homeostasis. This is essential fo
required for cell function, enzyme activity and overall survival.

Key processes involved in homeostasis include:

- thermoregulation – regulates body temperature
- blood glucose regulation – maintains blood glucose concentration
- osmoregulation – controls water balance and solute concentration

Role of the hypothalamus

Homeostatic processes are coordinated by the hypothalamus, a specialised region in
regulatory hub, constantly monitoring the composition of blood flowing through its t
changes away from normal levels.

The hypothalamus detects changes in a wide range of conditions, including:

- blood water potential (osmolarity)
- core body temperature
- salt (electrolyte) concentration
- blood pressure
- blood oxygen and carbon dioxide levels

Responses are communicated via neuronal pathways for rapid changes, and hormon
longer-lasting effects.

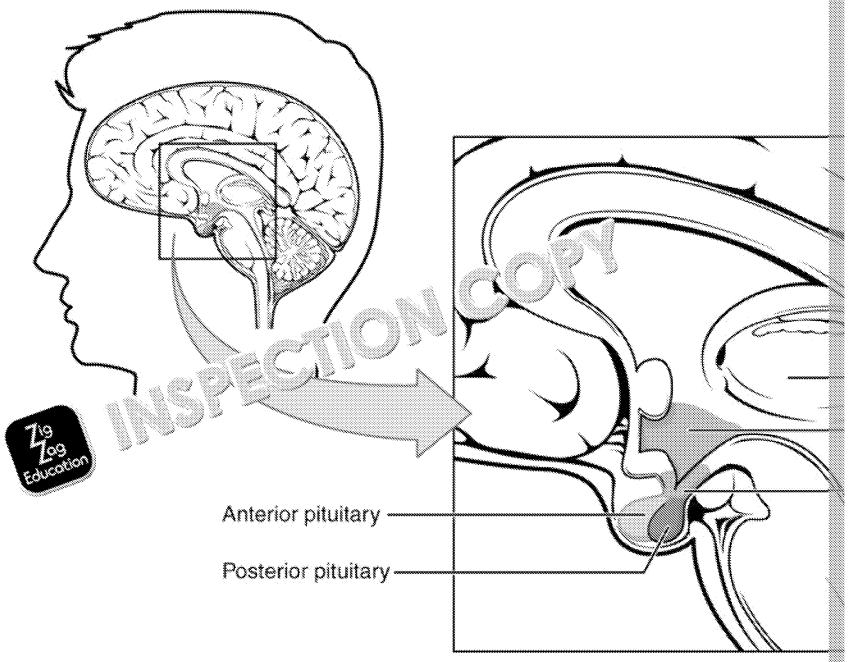


Figure F2.28. *The hypothalamus is nestled alongside the pituitary*

Recall questions

1. Outline the location and roles of the hypothalamus.
2. Briefly describe how the hypothalamus causes chan
response to changes in internal conditions.

Gastrointestinal system

The gastrointestinal (GI) system, also known as the digestive tract, is a continu
through our body. It facilitates ingestion, mechanical and chemical digestion,
elimination and water reabsorption. These processes are vital for ATP producti

The GI system includes the following major regions, in order that food passes th

1. Buccal cavity (mouth).
   Site of ingestion and initial mechanical digestion through mastication (ch
   Salivary enzymes (e.g. amylase) begin carbohydrate breakdown.
2. Oesophagus.
   Muscular tube that moves food to the stomach via peristalsis.
3. Stomach.
   Secretes gastric juices that contain hydrochloric acid and pepsin for prote
4. Small intestine.
   Includes the duodenum and ileum.
   Primary site for chemical digestion and nutrient absorption.
   Receives enzymes from the pancreas and bile from the gallbladder to aid
5. Large intestine.
   - Colon. Reabsorbs water and electrolyt
     Compacts undigested material to faeces.
     Supports gut microbiome involved in vitamin synthesis a
   - Rectum and anus. Store and expels waste during defecation.

The GI system includes other organs which are not part of the digestive tract, inclu
digestion: the gallbladder (which stores bile ready for secretion), and the pancrea

Recall questions

1. List the organs and organ systems linked directly to
2. Outline the role of the digestive organs in digestion.

Excretory system

The excretory system removes metabolic waste products from the body to maintain
and prevent the accumulation of harmful substances. There are two organ systems i
kidneys and the skin.

Renal excretion

The kidneys are the primary excretory organs. They fil[illegible] and to remove metaboli
substances in excess, including:

- Urea – nitrogenous waste produ[illegible] from amino acid deamination (deco
  Urea is formed in the liv[illegible] the ornithine cycle.
- Excess salts [illegible] ic[illegible] including sodium, potassium and calcium.
- Water – r[illegible]g blood volume and pressure.
- Toxins and [illegible]gs – metabolised by the liver.

Urea combines with water to form urine, which passes through ureters for storage i
eventual elimination via the urethra.

Cutaneous excretion

The skin also contributes to excretion via the production of sweat from glands in the
water, salts, especially sodium and chloride ions, urea and uric acid, present in lowe

Sweating is therefore involved in excretion but also forms an important part of ther
The evaporation of sweat removes heat thus cooling the surface of the skin and ena
internal body temperature.

Apply your knowledge

1. Describe the similarities and diff[illegible]ween renal and cutaneous excretion.
2. Explain why cutaneous [illegible] is important.

Respiratory system

The respiratory system, also known as the gaseous exchange system, carries out ins
expiration (exhalation) of air, enabling uptake of oxygen from the atmosphere, and
from the bloodstream. It consists of a series of specialised structures that support a
and optimise gaseous exchange.

The system comprises:

- Trachea.
  A single, hollow tube, reinforced with C-shaped cartilage rings that keep the air
  It moves air from the mouth and nasal cavity toward the lungs.
- Bronchi.
  The trachea divides into left and right primary bronchi ([illegible]lar: bronchus), eac
  These branch again into secondary and tertiary [illegible]eeding air deep into t
- Bronchioles.
  Many fine, progressively narr[illegible]nches of the bronchi that lead to the alv
  They control airflow t[illegible] and improve the efficiency of gaseous excha
  area avail[illegible]ation.
- Alveoli.
  Tiny air sacs surrounded by capillaries, where gaseous exchange occurs.
  Oxygen diffuses into the blood; carbon dioxide diffuses out.
- Lungs.
  Composed of bronchioles, alveoli and connective tissue.

- Ribcage.
  Skeletal framework that protects the lungs and provides a structure for b
- Intercostal muscles.
  Located between the ribs.
  The external intercostal muscles contract to lift ribs up and out during in
  The internal intercostal muscles contract to draw ribs down and in during
- Diaphragm.
  A large, dome-shaped skeletal muscle be[illegible] lungs.
  Contracts and flattens during inh[illegible] – increases chest volume and de
  Relaxes and returns to d[illegible] during exhalation – reduces chest vo

Your t[illegible]

1. List the parts of the respiratory system that air does not pass through and parts are essential to the functioning of the system.

Practice questions: System structure and function

1 Identify two organ systems involved in the involuntary response of s

2.2.3. Measuring system activity

Comparing a patient's organ system function against established reference ra concerns and guide further medical investigation and trea ments. To support t diagnostic technologies have been developed to a[illegible]an monitor organ sy

This chapter explores several comm[illegible] medical devices and techniques conditions they investigate, h[illegible] collected and interpreted, and the be technology in clinical [illegible]

Sphyg[illegible]anometer

A sphygmomanometer is a clinical device used to measure arterial blood pressure, usually at the brachial artery in the upper arm. It is used to diagnose and monitor **hypertension**, **hypotension**, and other conditions where blood pressure regulation is disrupted, such as sepsis, heart failure or renal disease.

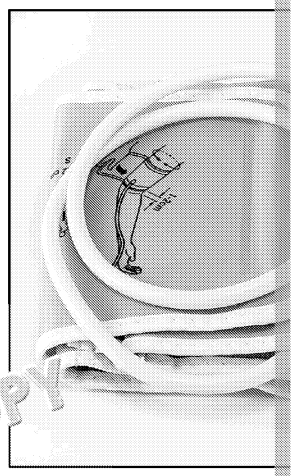


Figure F2.29.

> **hypertension** – high blood pressure.
> **hypotension** – low blood pressure.

Sphygmomanometers may be manual or digital, and typically consist of the following pieces of equipment, which may be separate c[illegible]ned:

- Inflatable cuff – fitted [illegible] and the upper arm to temporarily res[illegible] flow.
- Pre[illegible] measures the pressure inside the cuff.
- Bul[illegible]alve (manual models) – used to manually inflate and deflate th
- Pump (digital models) – electronic device which automatically inflates an
- Stethoscope (manual use) – positioned over the brachial arterial to hear sounds), which indicate systolic and diastolic pressure.

There are several types of sphygmomanometer, including mercury, aneroid a

Method of use

To use a manual sphygmomanometer:

1. Fit the cuff securely around the patient's upper arm.
2. Position the stethoscope over the brachial pulse and listen for the Korotkoff so
3. Inflate the cuff until no Korotkoff sounds are heard – the artery is fully **occlude**
4. Slowly release the pressure until the first Korotkoff sound is heard – this is systolic pressure.
5. Continue releasing the pressure until the sound disappear – this is diastolic pr

Korotkoff sounds are caused by turbulent blood flow through the brachial artery, as reduces, altering the degree of partial occlusion. The sounds occur in five distinct p

- Phase I, the tapping sound, indicates systolic pressure when blood begins t compress
- Phase V, when all sounds disappear, indicates diastolic pressure when blood flo

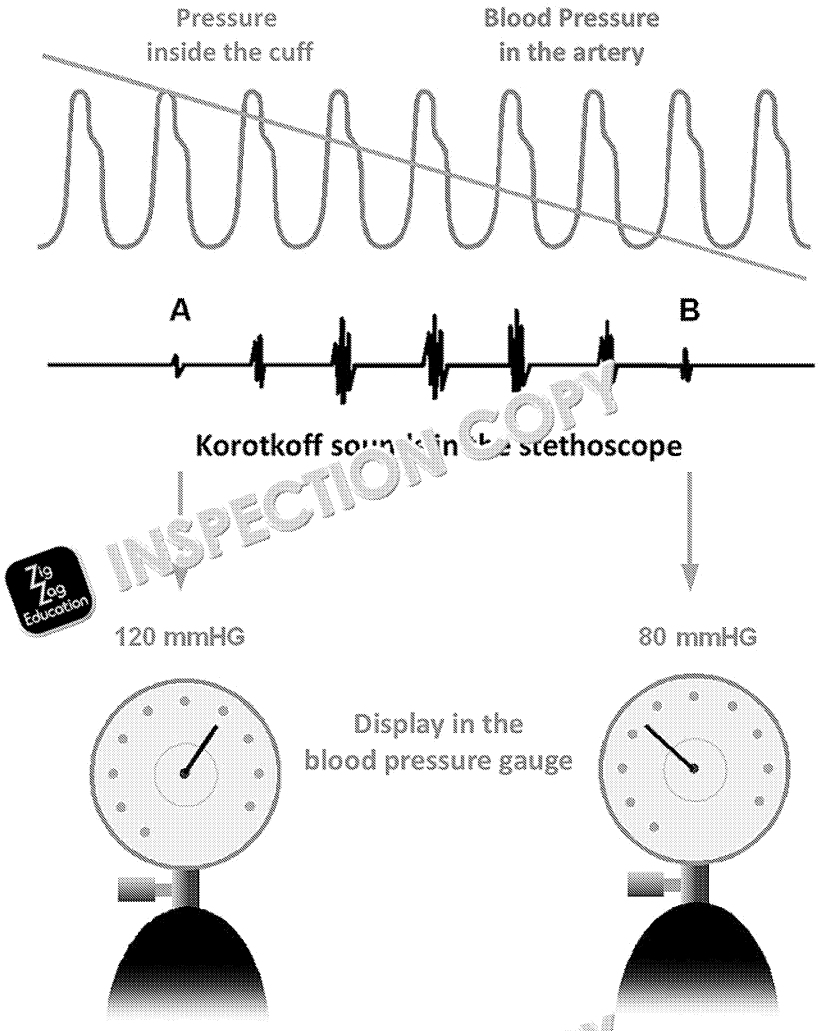


Figure F2.30. *Korotkoff sounds relate to the pressure in the cuff and blood pressure*

Blood pressure is recorded as:

$$\frac{\text{systolic pressure}}{\text{diastolic pressure}}$$

Average blood pressure for a healthy adult is < 120/80 mmHg. Hypertension is cons pressures over 130/80 mmHg, and hypotension is diagnosed with pressures < 90/60 vary depending on baseline measurements.

Benefits and limitations of the sphygmomanometer

Manual and digital sphygmomanometers accurately measure arterial blood p
results. It provides important information to clinicians on the general health o
inform diagnoses and treatment or management plans.

Type	Description	Advantages	
Mercury	Column of merc[illegible] pressure	• [illegible]curate • Portable • Reliable • Can be used on most patients	• C ca di • M ob • R
Aneroid	Mechanical dial with metal spring	• Portable • Safe as mercury-free • Can be used on most patients	• R • Le m in • M ob • R
Digital (oscillometer)	Uses sensors and algorithms	• Safe as mercury-free • Portable • Good reliability • Can be used on most patients	• M ob • R
Automated spot-check device	Uses sensors and [illegible]	• Safe as [illegible]ury-free • [illegible]ght • Compact • Portable • Easy to use • No observer bias	• M of
Wrist device	Uses sensors and algorithms	• As with spot-check device, but increased patient comfort	• As • R re to • Le ar
Finger device	Uses sensors and algorithms	• As wrist device	• As m • M w

Table F2.13. Advantages and limitations of various types of sphyg

Blood pressure varies naturally throughout th[illegible] day, and may rise temporarily
emotional stress (including stress [illegible] medically examined), or environme
loud noises and temperat[illegible] extremes. These variations must be considered
drawing clinical c[illegible]ns.

Apply your knowledge

1. Compare and contrast the aneroid and digital sphygmomanometers and state
2. Describe how phase I and phase V Korotkoff sounds relate to blood and cuff p

Radial pulse readings

Pulse points are locations where an artery lies close to the skin and it is possible to f
and relaxation of muscles in arterial walls due to pressure changes in the cardiac cyc
wrist) is most commonly assessed in routine practice.

Clinical importance

Monitoring pulse rate gives an indication of cardiac fun[illegible] shows physiological
exertion, stress, cardiac interventions like pace[illegible] whether arrhythmias are

The pulse can be characterised b[illegible]

- rate – beats per mi[illegible]
- rhythm – [illegible] regular
- strength – [illegible], weak, bounding
- equality – compare left and right pulses

How to take a reading

To take the radial pulse:

1. Ensure the patient is seated and relaxed.
2. Position the index and middle fingers lightly over the radial artery, located on t
   wrist, just below the thumb side of wrist crease.
3. Count the number of pulses felt over 60 seconds (or 30 seconds × 2 if rhythm is

Never use the thumb – it has its own pulse and will interfere with measurements.

The normal pulse range for adults is 60–100 bpm. This is higher in children and decre
Bradycardia describes heart rates < 60 bpm, whereas tachycardia is seen in pulses >

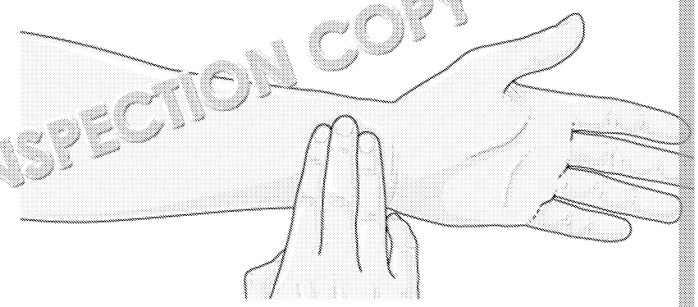


Figure F2.31. *Taking a radial pulse.*

Benefits and limitations of taking the radial pulse

Taking a pulse provides a good indication of cardiac health. As with all techniques, t
limitations to the procedure.

Benefits	Limitati
• Non-invasive, quick. • Useful for assessing general heart health. • Minimal equipment required (stopwatch). • Easily repeated to monitor trends.	• May be difficult to locate in • Pulse ra[illegible]e can be elevated b • [illegible] p[illegible]lse is weaker than • Does not reveal arrhythmias

Tabl[illegible] A[illegible]ages and limitations of taking the radial pulse

Your t[illegible]

1. Describe th[illegible]ur characteristics of a pulse, and the way a pulse would be record
   conscious patient, an infant, and a collapsed patient.
2. Outline the limitations of taking a radial pulse reading.
3. Record your or your peer's pulse rate, noting the key characteristics.

Electrocardiogram (ECG) readings

An electrocardiogram (ECG) is a diagnostic tool that measures electrical activity of the heart over time. It is used to detect cardiac abnormalities, including:

- arrhythmias – irregular heart rhythms
- **myocardial infarction** (heart attack) – heart muscle damage from ischaemia (restricted blood flow to heart muscle)
- fibrillation – rapid, irregular, and uncoordinated contraction of muscle fibres
- other cardiac conditions, including conduction defects, electrolyte imbalances, and chamber enlargement

During the heartbeat, changes in electrical impulses are detected by the ECG on the skin.

Taking an ECG

To take an ECG:

1. Prepare the patient:
    a. Lie them flat on the bed, arms by their side and legs uncrossed.
    b. Remove jewellery and ensure skin is clean and dry.
    c. Expose the chest and limbs.
    d. Clean the skin where electrodes will be placed (shave chest hair for better contact).
2. Place the four limb and six chest electrodes.

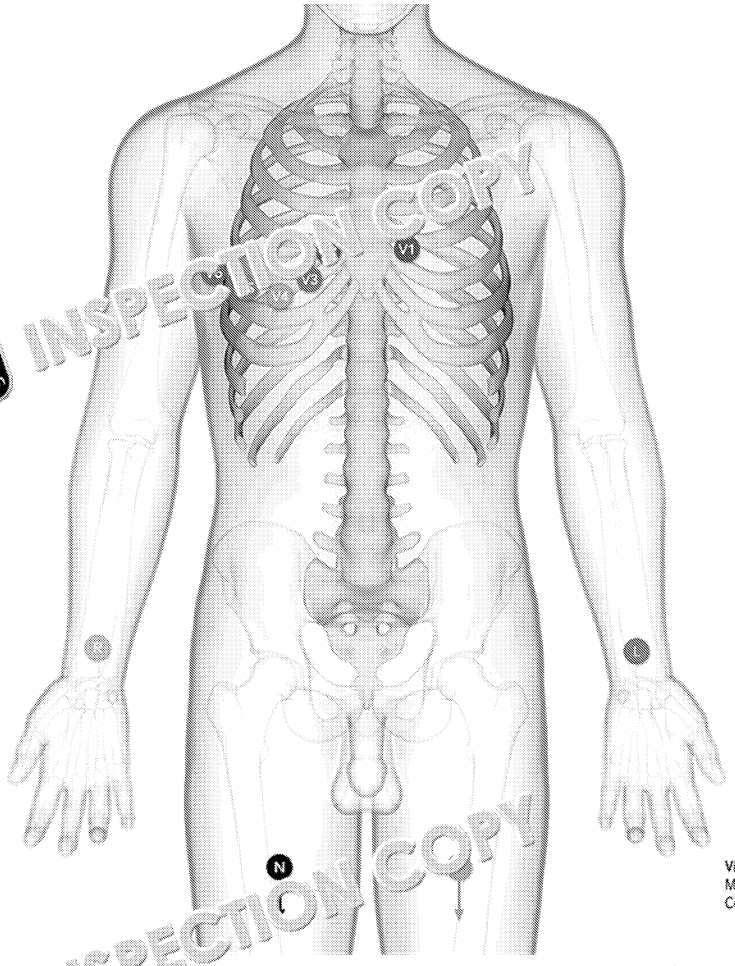


Figure 2.32. *The 10 electrodes should be placed on specific parts of the body.*

3. Record the trace:
    a. Connect leads to ECG machine and ensure good contact.
    b. Instruct the patient to lie still and breathe normally.
    c. Start recording – check trace for clarity, and adjust calibration if required.
    d. Print or save trace.

Interpreting the trace

Typical ECG readings present as follow:

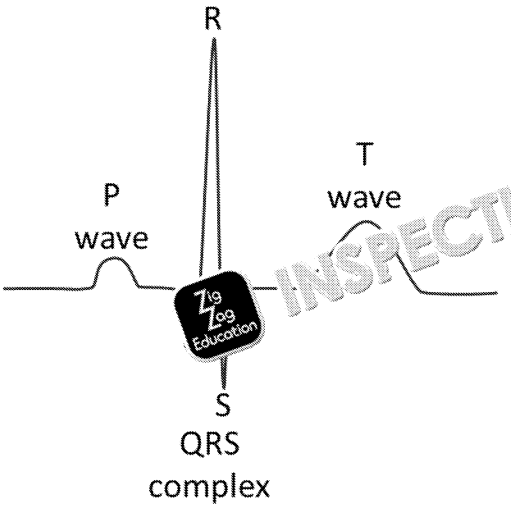


Figure F2.33. *Typical ECG trace.*

The trace is made up of the fo
- P wave – atrial depolarisa
- PR interval – conduction
- QRS complex – ventricula
- ST segment – ventricular
- T wave – ventricular repo

Changes in the shape of the trace indicate cardiac abnormalities. For instance, a widened QRS complex, absent P waves or erratic rhythms may suggest **fibrillation**, **tachycardia** or **bradycardia**, **ischemia** or **infarction**. The ST segment should be flat, and depression may indicate ischemia, while elevation may indicate infarction (damage across the full thickness of the heart wall).

Benefits and limitations of an ECG

As with all medical procedures, ther are benefits and limitations.

Benefits	Limitat
• Rapid, non-invasive and inexpensive. • Provides view of electrical activity in real time. • Assists in diagnosis and monitoring.	• Requires specialist equip • Requires training in inter • May not detect all struct • Can be affected by stress, poor contact.

Table F2.15. Benefits and limitations of an ECG.

Your turn

1. Draw and label the typical, healthy ECG trace and what each part indicates.
2. Describe the uses of an ECG and outline the procedure involved in taking an ECG.
3. Explain how prolonged ischemia could progress to in or.

Ultrasound scans

Ultrasound is a non-invasive imaging technique that uses high-frequency sound wav images of inter dy structures. It is most often used to monitor foetal develop also be used to:
- detect fluid-filled cysts or solid masses in breast tissue
- assess structures in the neck, such as the thyroid or lymph nodes
- visualise abdominal organs, including the liver, gallbladder and GI tract

How ultrasound works

The machine emits sound waves from a hand-held **transducer**, which are directed into the body. These waves reflect off tissues based on their density and **acoustic properties**. Soft tissues, bone and fluids all reflect sound waves differently. The pattern of reflected waves is translated into a diagnostic image on the screen.

Ultrasound does not use ionising radiation, so it is safer than X-rays or CT scans, especially when used during pregnancy or for paediatric care.

How to perform an ultrasound scan

To take a basic ultrasound scan:

1. Prepare the patient:
   a. Position the patient to best view the part of the body to be scanned.
   b. Apply a water-based gel to the target area to enhance sound transmission through the skin.
2. Conduct the scan:
   a. Place the transducer against the skin, using firm, steady pressure.
   b. Move the transducer methodically to capture various views.
   c. Use the machine to take screenshots or videos. The device can also record.
3. Clean up:
   a. Remove gel from patient's skin and transducer.
   b. Print or save images.

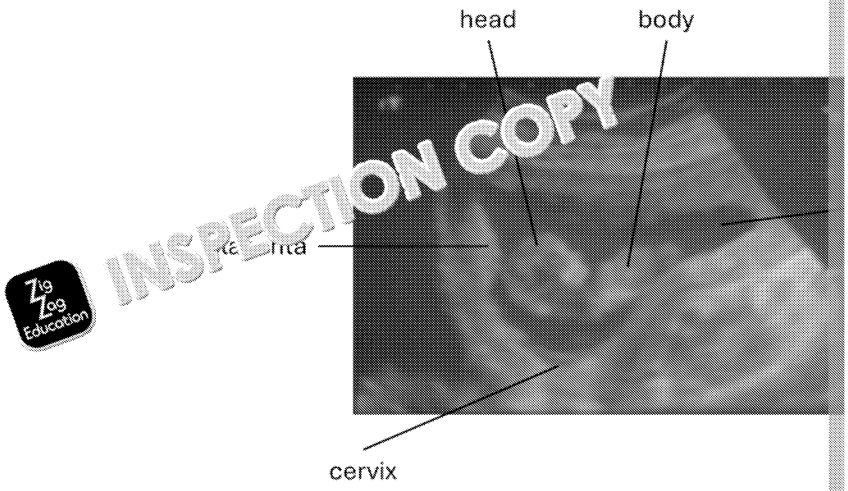


Figure F2.34. *An ultrasound of a 20-week foetus, clearly showing he*

Benefits and limitations of ultrasound

Ultrasound offers a non-intrusive, inexpensive and quick imaging method.

Benefits	Lim
• Safe – no radiation – suitable for foetal and paediatric imaging. • Real-time images. • Inexpensive, quick and portable. • Useful in initial diagnostic assessment.	• Image clarity can vary. • Quality depends on accu • Training required to operate • May require other imagi more detail.

Table F2.16. Benefits and limitations of ultrasound

Recall questions

1. Describe how ultrasound works and the benefits this patients such as pregnant women.
2. Explain why a gel is applied to the skin before scan

Colonoscopy

Colonoscopy is a diagnostic procedure used to examine the inner lining of the large i
inserting a long, flexible instrument called a colonoscope, with a camera and light at
the rectum and through the colon.

It is a useful medical procedure, used to investigate the cause of symptoms such as
changes in bowel habit and unexplained weight loss; screen for and monitor conditio
polyps and inflammatory bowel diseases (IBDs); and remove polyps and take biopsie

Taking a colonoscopy

Colonoscopy is in[illegible]ive [illegible]use discomfort and requires careful preparation in a
visibility of the [illegible]wall.

For a successful colonoscopy:

1. Prepare the patient.
    a. A low-fibre diet must be followed for 2–3 days before the procedure.
    b. A strong laxative is taken the day before to clear the colon of faecal matte
    c. On the day, the patient fasts and may only consume clear fluids.
2. Perform the colonoscopy.
    a. The patient lies on their left side with knees tucked up into a curled positio
    b. A sedative or gas and air is administered to sedate the patient.
    c. The colonoscope is inserted via the anus.
    d. Carbon dioxide gas is used to inflate the colon to improve visibility.
    e. Examination of the colon and the collection of biopsies and removal of pol

The procedure usually leaves the patient feeling bloated and [illegible]omfortable, due to
can cause bleeding, especially after biopsy or polyp r[illegible]va[illegible]nd these can, on rare
require surgical repair.

Benefits and limitations of colonoscopy

This invasive a[illegible]sta[illegible]lar procedure has several benefits and limitations.

Benefits	Limitat
• Detailed examination of colon wall. • Enables biopsy and polyp removal. • Crucial for cancer screening and monitoring.	• Requires specialist facilitie • Invasive, uncomfortable a • Requires substantial patie procedure recovery.

Table F2.17. Benefits and limitations of colonoscopy.

Apply your knowledge

1. Describe the preparations the patient must do in advance of a colonoscopy to ensure
   explain why these are important.
2. Describe some of the risks and issues with a colonoscopy and why these might arise.

Urinalysis

Urinalysis refers to the analysis of urine's chemical composition, physical appe
contents. Because urine reflects many systemic changes – especially those aff
processes – urinalysis serves as a valuable tool for assessing general health an

Tests within urinalysis

Urine can be analysed:

- visually – to check colour, clarity and odour for immediate indicators
- chemically – to detect substances such as glucose, proteins and ketones u
- microscopically – to view cells, crystals, casts and microorganisms und

Visual a

Visual inspection of urine can reveal signs of disease:

- colour – pale yellow to amber is normal; red or brown indicates blood or
- clarity – clear is normal; cloudy suggests infection or high protein conten
- odour – sweet smell signals diabetes; foul odour indicates urinary tract in (UTI); other unusual smells may offer diagnostic indicators

Chemical analysis

A chemical dipstick test uses reagent strips that change colour when exposed t
substances, like litmus paper changes colour to indicate pH. Based on visual in
of the urine sample, plus the patient history, clinicians select dipsticks to test f

Test	Normal	Indicative
pH	Typically, pH 6.0, but within range of pH 4.5–8.0	Acidic: pH < 4.5 • infecti n • boiic imbalance
Protein	Negati e ng/dL)	Persistent elevation: > 30 mg/dL • chronic kidney disease • diabetes • hypertension-related damage
Glucose	Negative/trace (≤ 15 mg/dL)	> 15 mg/dL: • diabetes mellitus
Ketones	Negative	> 20 mg/dL: may indicate: • diabetic ketoacidosis • alcohol-related ketoacidosis • prolonged vomiting/illness • starvation or mal trition
Blood	0–3 cells per **high power field (HPF)**	> 3–4 cell y indicate: tion kidney stones • trauma (including sexual activity) • medications (e.g. aspirin, antibiotics, blood thinners) • chronic conditions (polycystic kidney disease, sickle cell disease, haemophilia, bladder/kidney cancer, enlarged prostate)

Test	Normal	Indicative	Notes
Leucocyte esterase and nitrites	Both absent: no likely infection	Both present: • likely bacterial urinary tract infection (UTI) Leucocytes present, nitrites absent: • inflammation without bacteria Leucocytes absent, nitrites present: • early infection or immune suppression	Leucocyte esterase – enzyme released by inflammat Nitrites – s especially (see page into nitrite
Bilirubin and urobilinogen	Bilirubin: negative Urobilinogen: 0.1–1.8 mg/dL	Bilirubin present: • liver disease • obstructive jaundice (e.g. gall es) • impaired bile flow (bili or eaks into bloodstream) Urobili absent: • w obstruction antibiotic use • liver failure Urobilinogen high: • liver disease (e.g. hepatitis) • haemolytic anaemia	Bilirubin is erythrocy processed excreted i Urobilinog when inte convert bi urobilinog reabsorbe bloodstrea in urine.

Table F2.18. Details of various dipstick tests.

Microscopic examination

Microscopic analysis after differential centrifugation reveals particles not visible to the nak
Key findings include:

- cells:
  - erythrocytes (> 4 cells/HPF) – requires further investigation
  - leucocytes – indicates infection or inflammation
  - epithelial cells – normal: 0–5 cells/HPF; if > 5 cells/HPF:
    - squamous – from outer urethra or genital area; usually due to sample contam
    - transitional – from bladder, ureters or renal pelvis; indicates bladder irritation
    - renal tubular – from kidney tubules; signals kidney damage or disease
- microorganisms – bacteria, yeast and parasites; requires further investigation to confi suggest appropriate treatment
- structures – requires further investigation:
  - casts – protein structures from kidney tubules
  - crystals – can indicate kidney stones

Benefits and limitations of urinalysis

Urinalysis is a useful diagnostic tool that can aid diagnosis or suggest further areas for inves

Benefits	Limitations
• Non-invasive and easy to perform. • Rapid results in minutes for quick screening. • Cost-effective: ideal for routine screening. • Useful for chronic conditions monitoring. • Enables home testing with dipsticks.	• Accuracy depends on timing and sample • May produce false positives/negatives d contamination (e.g. from menstruation) • Dipstick methods are qualitative not qu • Limited specificity: suggest further testi • Cannot diagnose all conditions; better for s

Table F2.19. Benefits and limitations of urinalysis.

Despite its limitations, urinalysis is an essential diagnostic tool because it is quick, accessible and supports clinical inter ion or

Apply your knowledge

1. Summarise the different types of tests conducted through urinalysis and includ tests are able to reveal about the patie
2. If a patient presents with signs of an in inflammation, which tests would confirm

Blood glucose levels

Measuring blood glucose levels is essential for diagnosing and managing cond
diabetes, gestational diabetes (which occurs during pregnancy), and identifyin
developing prediabetes. A variety of tests can assess current levels, fluctuatio
control of blood glucose.

Test	How it work	
Finger prick	Small sample of b[illegible] taken from fingertip and analysed on a hand-held [illegible] glucometer).	Monitor in diabe
Fast[illegible]cose	Venous or capillary sample after 8+ hours without food.	Diagnos or moni using gl
Oral glucose tolerance test (OGTT)	Fasting sample followed by glucose drink; blood tested at intervals over 2 hours.	Diagnos type 2 d
HbA1c test	Laboratory test of glycated haemoglobin (haemoglobin-bound glucose in erythrocytes) from venous blood. Provides average blood glucose over past 2–3 months, because of average lifespan of red blood cells (8–12 weeks).	Assessin and mo assessin (e.g. ret cardiova
Continuous glucose monitoring (CGM)	Wearable sensor tracks gluc[illegible]vels in real time via interstitial (tissue) fluid.	Continuo hypogly Especial insulin-d to hypo

Table F2.20. Details of various blood glucose tests

Oral glucose tolerance test (OGTT)

The oral glucose tolerance test (OGTT) is used to assess how efficiently the bo
It is commonly used to detect gestational diabetes, type 2 diabetes and predia

Method

1. Preparation.
   Patient fasts for 8–12 hours before the test – only water is allowed.
   Patient should avoid smoking and certain medications which may affect b
2. Baseline measurement.
   A venous blood sample is taken to measure fasting blood glucose levels.
3. Glucose challenge.
   Patient drinks a solution containing 75 g gluco[illegible] for pregnancy scre
4. Monitoring.
   Blood samples are taken at 30 m[illegible]tervals over 2 hours.

Interpreting re[illegible]

Elevated [illegible]e levels may indicate:

- insu[illegible]sistance, where cells like hepatocytes, myocytes and adipocytes
  insulin secreted by the pancreas
- glucose intolerance, the effect of insulin-resistant cells, indicated by high
  glucose levels

Elevated glucose levels are classed as prediabetic – not high enough to be classified a
normal levels. It is possible to have insulin-resistant cells but not be glucose intolera
overcompensates by producing more insulin. However, glucose intolerance is almost
degree of insulin resistance.

It can also be used to diagnose gestational diabetes between 24 and 28 weeks of pre
influences care decisions, including delivery method such as i ction or Caesarean

Time point	Normal range	Prediabetic range
Fasting	< 6.1 mmol/L	6.1–6.9 mmol/L
2 hour	< 7.8 mmol/L	7.8–11.0 mmol/L

Table F2. anges of glucose levels in normal, prediabetic and diabetic patients when fas

Benefits and limitations of testing blood glucose levels

The different approaches to blood glucose monitoring and assessment offer varying
convenience and accuracy.

Test	Benefits	
Finger prick glucometer	• Quick, easy to use and inexpensive. • Portable and widely available. • Useful for spot checks and insulin dosing.	• Requires fre • Only provide no data tren • Accuracy de strip quality
Lab-based tests (OGTT, HbA1c)	• Provides long-term glucose control data. • Useful for diagnosis a treatment planning. • N s t or in measurement.	• Not suitable • Requires ven and lab proc • Doesn't refle
Continuous glucose monitoring (CGM)	Real-time glucose tracking (> 288 readings per day). • Trends and fluctuations detected – enables proactive management. • Can alert for hypo/hyperglycaemia. • Reduces need for finger prick tests.	• Expensive. • May require • Slight lag be interstitial re slightly delay • May cause sk • Not suitable

Table F2.22. Benefits and limitations of testing blood glucose level

Recall questions

1. Outline the procedure for an oral glucose tolerance test a of when this might be necessary.
2. Compare the finger prick a o uous monitoring test and their use in m g abetes.

Thermometer

Core body temperature is one of the four vital signs – alongside pulse, breath
can be assessed using a thermometer to evaluate a patient's physiological sta

Accurate temperature monitoring is crucial for the early detection of illness, as
may indicate infection, inflammation or systemic disease. It also helps track tre
assessing the effectiveness of antibiotics, or ensuri[illegible]t recovery after surge
by infection.

Types of thermomet

There are [illegible] thermometer, used for different purposes and with

- Dig[illegible]ed orally, rectally or axillary (under the arm); high accuracy.
- Infra[illegible] used temporally (forehead) or tympanically (ear canal); provide with moderate to high accuracy depending on device positioning.
- Mercury – used orally, rectally or axillary; high accuracy but rarely used be of mercury.
- Gallium – used orally, rectally or axillary; high accuracy; alternative to me
- Strip – used temporally; low accuracy as measures skin temperature only colour with temperature.

Rectal digital or gallium thermometers offer the highest clinical accuracy, esp
The infrared thermometer used temporally, or the tympanic thermometer of
measurements.

Methods of taking temperature

There are many sites from which the body temper[illegible] can be assessed.

Site	Recom[illegible]d technique	Accurac
Or[illegible]	Wai[illegible] minutes after eating/drinking. [illegible]ace probe under tongue and keep mouth closed.	High (± 0.1
Rectal	Use a lubricant and gently insert probe into rectum.	Very hig
Axillary	Ensure armpit skin is dry, and thermometer is in full contact. Hold arm in snugly against the body.	Moderate t
Tympanic	Pull ear up and back to straighten the canal. Insert thermometer carefully, aiming towards the eardrum.	High if corre positione
Temporal	Sweep thermometer across the forehead and down the neck (if required b[illegible]pe)	Moderat
Infrared	Hold 1–2 inches from [illegible]kin forehead or wrist. Ad[illegible]° to readings for oral equivalent.	Variable

Table F2.23. Details of the sites from which body temperature ca

The normal range varies depending on site, and the threshold for determining a fev
accordingly and considered in context with other clinical signs.

Site	Reference range (°C)	Fever thresh
Oral	36.4–37.5	≥ 37.6
Rectal	36.6–38.0	≥ 38.0
Axillary	34.9–3[illegible]	≥ 37.4
Tympanic	[illegible]–38.0	≥ 38.0
Temporal	35.8–37.6	≥ 37.7

Table 1. Normal temperature ranges at various sites for taking body tem

Benefits and limitations

The choice of thermometer and measurement site depends on how important accu
and the setting that it is being measured in. For example, infrared thermometers su
speed and convenience, while rectal digital devices offer superior accuracy for critic
thermometers are inexpensive, widely available and easy to use.

Apply your knowledge

1. Outline the advantages and disadvantages of digital, infrared and gallium thermomete
each thermometer might be used.
2. Compare and contrast rectal and oral methods of taking body temperature and state s
would be most appropriate.

Spirometry

Spirometry is a diagnostic test [illegible] to assess lung function by measuring the volume
be inhaled and exhaled. It plays a vital role in diagnosing and monitoring respiratory
chronic obstructive pulmonary disease (COPD) and pulmonary fibrosis, as well as in
progression, treatment effectiveness, and readiness for surgery or return to work.

Taking measurements

A spirometer records several key respiratory parameters:

- Tidal volume (TV)
  - Volume of air inhaled or exhaled during normal breathing.
- Forced vital capacity (FVC)
  - Total volume of air exhaled forcefully after full inhalation.
- Forced expiratory volume in 1 second (FEV_1)
  - Volume of air exhaled in the first second of forced breath.
- Peak expiratory flow rate (PEFR)
  - Maximum speed of exhalation.

Using these values, additional calculations can be made:

- FEV_1/FVC ratio
  - < 0.7 suggests airflow obstruction, possibly obstructive lung disease.
- Pulmonary ventilation rate (PVR)
  - PVR (L/min) = breathing rate (breaths/min) × tidal volume (L)

To perform spirometry:

1. The patient sits upright and wears a nose clip.
2. They take a deep breath and exhale forcefully into a mouthpiece.
3. The test is repeated two to three times to ensure accuracy.
4. In some cases, a bronchodilator is administered, and spirometry is repeated to assess reversibility of airway obstruction.

Figure F2.35. *Taking mea*

Assessing reversibility

Reversibility testing helps distinguish between different respiratory conditions by measuring lung function before and after administering a bronchodilator (medicine that dilates the bronchioles). If there is a significant improvement in airflow, and especially in the FEV_1 reading, it suggests that a reversible condition such as asthma is most likely. If there is no significant improvement, it may indicate a chronic non-reversible condition such as COPD,

Interpreting results

Spirometry results reveal two key patterns:

- Obstructive pattern (e.g. asthma or COPD)
  - Reduced FEV_1
  - Normal or reduced FVC
  - Reduced FEV$_1$/FVC ratio (< 0.7)
- Restrictive pattern (e.g. fibrosis or neuromuscular disease):
  - Reduced FEV_1 and FVC
  - Normal or increased FEV_1/FVC ratio

Benefits and limitations

When interpreted alongside symptoms and patient history, spirometry provide and monitoring respiratory health. However, it has some benefits and limitatio

Benefits	
• Quick, non-invasive and repeatable. • Identifies and monitors respiratory conditions. • Tracks disease progression and treatment response. • Supports pre-operative and workplace assessments.	• Not suitable for all • Requires patient co technique. • Unsuitable during a • May not detect int asthma between a

Table F2.25. Benefits and limitations of spirometry

Applying knowledge

1. Calculate the pulmonary ventilation rate for a 10-year-old child with a suspected a rate is 37 breaths per minute and tidal volume is 0.175 L.
2. Describe how an obstructive pattern differs from a restricted pattern, and what con
3. Describe the differences between the forced exhalation volume in 1 second (FEV- and what the relationship between these two values can indicate.

Pulmonary ventilation rate changes

Pulmonary ventilation rate (PVR) represents the volume of air exchanged between t environment per minute. It provides a useful baseline for assessing lung function an responses to exercises, illness or training.

It can be calculated using:

PVR (L/min) = breathing rate (bre min) × tidal volume

For a healthy adult at rest, normal values are:

- Tidal volume (TV): ~0.5 L (volum breath).
- Breathing rate (BR): ~12 minute.

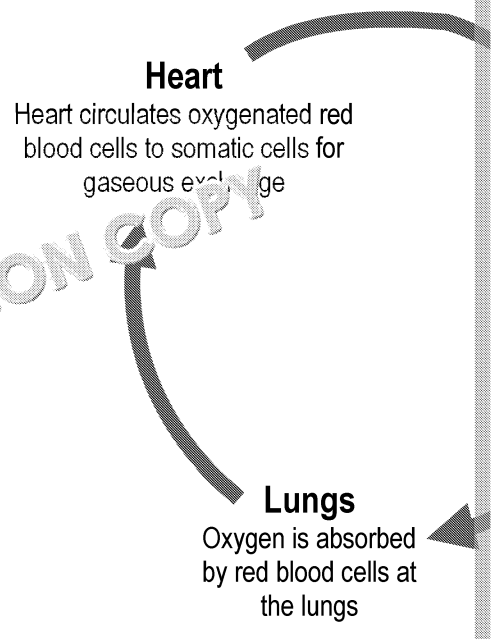
Therefore, the average adult is:

PVR = BR × TV
= 12 × 0.5
= ~6.0 L/min

Well-trained athletes typically exhibit a higher tidal volume and lower resting breath enhanced respiratory efficiency due to cardiovascular adaptation.

Changes in pulmonary ventilation rate

PVR varies according to physiological demands or medical conditions. Understanding this requires linking pulmonary ventilation (movement of air in the lungs) to cellular respiration, especially in muscle cells (myocytes), which require oxygen to generate ATP.



During exercise

During exercise, cell ener ments increase sharp in demand for oxygen. To fulf breathing rate, tidal volume, and heart rate all increase.

If oxygen demand exceeds supply, an oxygen debt forms. The body shifts from aerobic to anaerobic respiration, producing lactic acid, which leads to muscle fatigue.

After exercise, elevated ventilation and heart rate continue temporarily to repay the delivered to muscles to oxidise lactic acid and remove carbon dioxide.

In cardiovascular disease

In cases of heart disease or congenital defects, the heart's redu d pumping efficien tissues. To compensate, PVR increases – both breathing nd tidal volume rise – t oxygen uptake even if systemic circulation is limit d.

Apply yo w.edge

1. Explain w breathing rate, tidal volume and heart rate all increase on exercise, and w remain elevated for a few minutes after exercise has ceased.
2. Use the equation to calculate your pulmonary ventilation rate, assuming a lung volum would expect this value to change if you completed one minute of high-intensity activi

Peak flow readings

Peak flow readings assess how quickly air is forcefully exhaled from the lungs (PEFR) – using a hand-held peak flow meter. This test is especially useful in as detect asthma attacks early, track lung function changes and guide treatment

Using a peak flow meter

A patient's highest recorded reading during a symptom-free period becomes t serves as a reference point for future measurements. Regular daily readings c asthma attack and help to identify triggers, such as pollen or exercise.

Lower readings indicate narrowed airways and may indicate an asthma or COPD attack. In such cases, bronchodilators may be prescribed. Further monitoring can assess treatment response or signal the need for hospital care, such as nebuliser therapy.

Figu

To use a peak flow meter:

1. Reset meter to zero.
2. Stand or sit upright.
3. Take a deep breath in.
4. Seal lips around the mouthpiece.
5. Blow out as hard and fast as possible.
6. Repeat three times and record highest value.

Interpreting results

Results are interpreted as a percentage of the normal reading:

- Green zone (80–100 %) – normal lung function.
- Yellow zone (50–80 %) – possible airway narrowing; caution advised.
- Red zone (< 50 %) – possible asthma attack; urgent medical attention nee

For instance, if your normal reading is 400 L/min then:

- Green: 320–400 L/min
- Yellow: 200–319 L/min
- R

Measurements should be taken morning and evening, before medication, usi values in a peak flow diary supports pattern recognition and identification of t effective treatment adjustments are.

Benefits and limitations

The peak flow meter is a simple device that can be used at home to monitor c COPD. As with all procedures, there are benefits and limitations.

Benefits	L
• Simple, inexpensive and portable. • Enables personalised tracking of lung function. • Supports early intervention and treatment planning. • Encourages self-management through daily monitoring and independence.	• Accuracy depends o technique. • Only measures airflo minor airways can a • May miss subtle cha • Less reliable if not u isolation.

Table F2 Benefits and limitations of the peak flow m

Though not a substitute for lung function testing, peak flow meters offer v consistently and interpreted alongside clinical signs.

Apply your knowledge

1. Describe how to use a peak flow meter and when this might be useful.
2. A patient's normal reading is 360 L/min. Calculate their green, amber and re

Fractional exhaled nitric oxide (FeNO) test

The fractional exhaled nitric oxide (FeNO) test is a fast, non-invasive procedure used t
inflammation, which is particularly helpful in diagnosing and managing allergic asthm
when spirometry results are inconclusive, allowing clinicians to differentiate asthma f

Nitric oxide (NO) is produced by epithelial cells lining the airway. Elevated levels of N
inflammation caused by eosinophils – a type of leucocyte that is involved in immune
parasites and infection. This form of inflammation is linked to allergic asthma that ty
inhaled corticosteroids.

The FeNO test

To complete a FeNO test:

1. The patient inhales deeply through the mouth.
2. The patient then exhales slowly and steadily into the mouthpiece of a hand-held
3. The test is repeated for accuracy.

To avoid false readings, patients should avoid smoking, exercise, hot drinks and nitra
spinach) at least 1–3 hours before testing.

The monitor measures FeNO concentration in parts per billion (ppb).

Interpreting results

Result ranges are interpreted as follows:

	FeNO level (ppb)		Interpret
	Adults	Children	
Low	< 25	< 20	Airway inflammation unlikely
Intermediate	25–50	20–35	Consider clinical history and o
High	> 50	> 35	Significant inflammation; alle

Table F2.27. Interpretations of FeNO levels in adults and children

Apply your knowledge

1. Describe how to complete a FeNO test and the conditions required to avoid false read
2. A child presents at a doctor's surgery with intermittent shortness of breath, particularly
   exercise such as running, and asthma in the family history on both sides. A FeNO tes
   State your asthma diagnosis with reasons.

Practice questions: Measuring system activity

1 State the test to use in these clinical scenarios.
   a. 8-year-old with intermittent shortness of breath
   b. Pregnant woman with suspected gestational diabetes

Topic 3: Endocrinology, neurobiolog and reproduction

3.1. Key concepts of endocrin

3.1.1. The endocrine system and homeostasis

To survive and function effectively, the human body relies on constant commu between its tissues and organs. Internal conditions – such as temperature, blo content – must be carefully regulated in response to both internal activity and environmental changes. This regulation is known as homeostasis.

One of the key systems involved in coordinating these responses is the endocr messengers called hormones, which are released by specialised glands into the travel to target tissues and trigger changes that help maintain internal balance

In this chapter, we will explore how the endocrine system functions, how hor how the system works both independently and in partnership with the nervou communication network – to support homeostasis and regulate the body's res

The endocrine system

The endocrine system coordinates responses using hormones: chemical messe bloodstream by specialised glands. These hormones allow distant tissues to re or external environment and help maintain homeostasis.

The endocrine system consists of:

- endocrine glands – specialised organs that act as coordination centres by effectors by responding to signals from other organs, and releasing hormo
- hormones – chemical messengers secreted by endocrine glands and trans to target tissues
- target cells – cells with specific receptors that detect and respond to part physiological changes

Endocrine signals may act across the whole body – systemically (e.g. thyroxine (e.g. ADH).

Speed and duration of hormonal responses

The endocrine system communicates more slowly than the nervous system be the bloodstream, then must interact with cell surface membrane receptors to This results in responses taking from minutes to hours to initiate and resolve.

Hormonal responses can vary greatly in duration. Some are short-lived, lasting as insulin reducing blood glucose or ADH adjusting water balance. Others are l like hormonal changes during puberty, which involve changes to gene expressi specialisation. These long-term responses typically reshape tissues and influen to years.

Hormones of the endocrine system

Many hormones are involved in the endocrine system, each triggering different acti

Hormone	Functions	Released from
Adrenaline	Initiates fight or flight response	Adrenal glands (above kidneys)
Thyroxine (T_4)	Regulates metabolic rate	Thyroid gland (stimulated by TSH from pituitary gland)
Somatostatin	Inhibits growth hormone and other hormones	Hypothalamus, pancreas, GI tract
Erythropoietin	Stimulates red blood cell production	Kidneys (renal cortex interstitial cells)
Calcitonin	Lowers blood calcium levels	Thyroid gland (C cells)
Insulin	Lowers blood glucose	Pancreatic β cells (islets of Langerhans)
Anti-diuretic hormone (ADH)	Regulates water reabsorption	Hypothalamus, then stored and released from posterior pituitary gland

Table F3.1. Details of hormones involved in the endocrine system

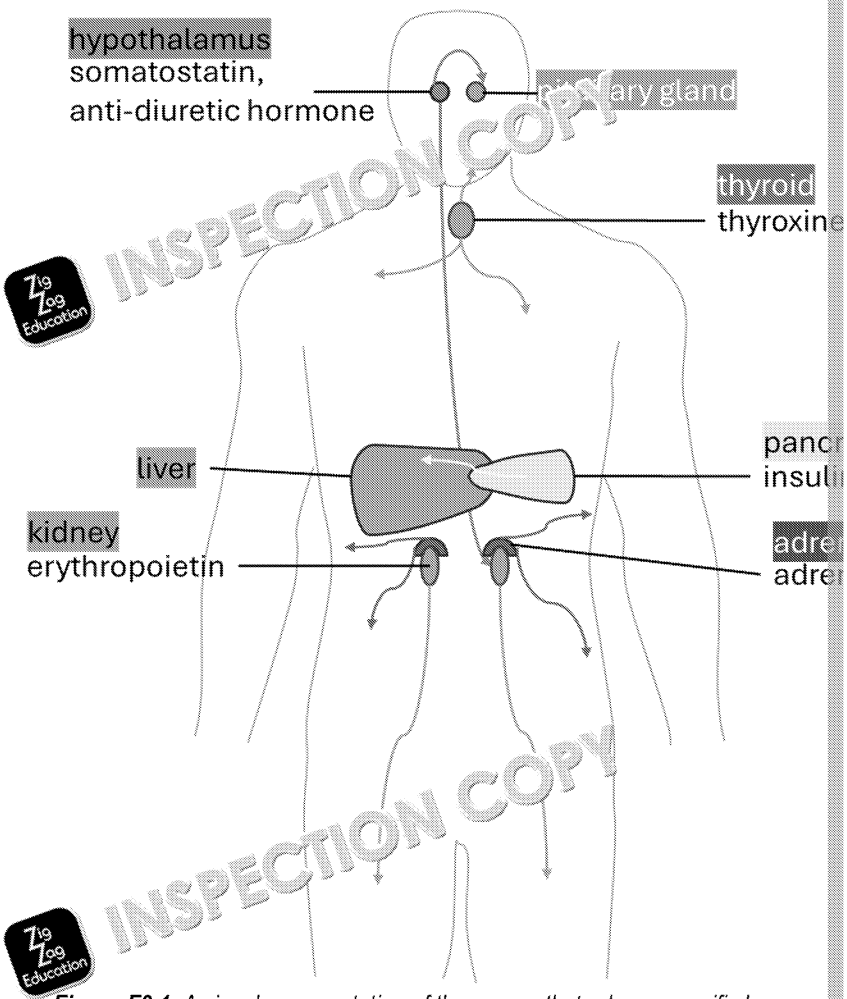


Figure F3.1. *A visual representation of the organs that release specific hormones approximate areas where these hormones have their effect.*

Adrenaline

Adrenaline, also called epinephrine, is a hormone secreted by the adrenal gla
the kidneys. It is released in response to stress, excitement or danger, such as
or the elation after public speaking. It triggers the body's rapid-response mec
or flight' response.

Adrenaline plays a central role in preparing the body
simultaneously:

- eyes: pupil dilation – enhances
- lungs: increased ventil
aerobic respira
- hea
- inte
- pain suppression – temporarily dampens pain perception to prevent dist
emergency responses
- enhanced blood flow to muscles and brain – supports fast motor reactio
- greater energy availability – stimulates the breakdown of glycogen into g
cells can generate ATP quickly

Adrenaline also has important medical applications. It is used in emergency tr
severe allergic reactions, such as anaphylaxis. Devices like EpiPens deliver adr
by rapidly reversing airway constriction and supporting cardiovascular functio

Thyroxine

Thyroxine, also known as T_4, is a hormone produced by the thyroid gland, loca
It is a systemic hormone, meaning it affects nearly all
metabolic rate (BMR) – the rate at which cells
influences the pace of all cellular pro

Thyroxine has several
- incr
- reg
- adjusts protein synthesis – promotes both the synthesis and breakdown o
requirements
- affects cardiovascular and digestive systems – elevated levels increase he
of food through the gut

Thyroxine secretion is tightly regulated by a multistage negative feedback loo
and pituitary gland (see *Figure F3.2* on the following page).

Hypothyroidism is a condition where thyroxine levels are suppressed. This cau
symptoms of fatigue, weight gain, cold intolerance and bradycardia (slow hea
typically treated with synthetic thyroxine (e.g. levothyroxine) to restore norm

Hyperthyroidism (including Grave's disease) in
an elevated heart rate, anxiety, weigh
medications that suppress TSH
used to destroy over
lifelong

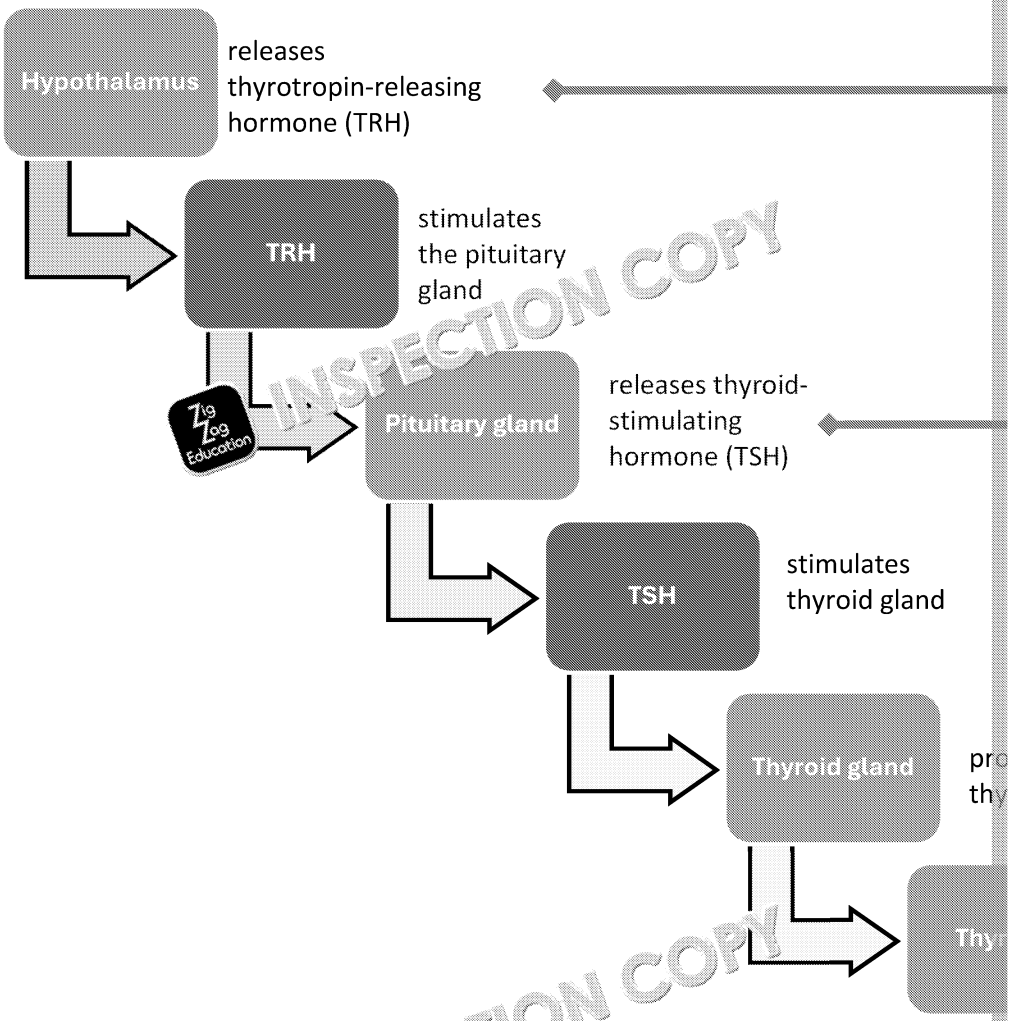


Fig. [illegible] multistage negative feedback loop for thyroxine secretion.

Somatostatin

Somatostatin is a hormone that plays a critical inhibitory role in various physiological multiple tissues, including the hypothalamus, pancreas and gastrointestinal (GI) tract suppressing the release of other hormones or slowing digestive activity.

Its site-specific functions include:

- hypothalamus – inhibits release of growth hormone (GH) and TSH from anterior regulate growth and metabolism
- pancreas (delta (δ) cells) – suppresses insulin and glucagon secretion, contributi glucose levels
- GI tract – slows digestion by reducing hydrochloric acid secretion, inhibiting pan delaying stomach emptying, and slowing intestinal peristalsis. This controls the

Somatostatin is involved in several negative feedback loops, where its release preven responses that could disrupt homeostasis. This regulating mechanism maintains and digestive systems.

Synthetic som in is used therapeutically to treat hormone-secreting tumours a syndrome, a ra dition caused by tumours of the nervous and hormone system diarrhoea. It is also used to control gastrointestinal bleeding, particularly resulting f oesophageal **varices**.

Erythropoietin

Erythropoietin (EPO) is a hormone primarily produced by the kidneys in respo
to **hypoxia**. Its main function is to stimulate erythropoiesis – the production o
erythrocytes in the bone marrow, thus increasing the oxygen-carrying capacity
the blood.

As erythrocyte numbers rise, more haemoglobin bec[illegible] available to transpo
oxygen, helping to correct hypoxic conditions. [illegible] notes both the prolife
and differentiation of red blood cell p[illegible]rs, making it vital when oxygen
requirements are high.

EPO sec[illegible]is [illegible]ated via a negative feedback loop:

1. In h[illegible] conditions, such as anaemia, high altitude, chronic lung disease
   are triggered by hypoxic conditions activate the EPO gene.
2. This causes increased synthesis and secretion of EPO, increasing erythrop
3. As oxygen levels improve, hypoxic conditions decline, reducing EPO gene
   of EPO, slowing erythrocyte production.

This feedback mechanism ensures that red blood cell numbers remain within a
blood from thickening.

Synthetic EPO (e.g. epoetin alfa) is used to treat anaemia in patients with chro
undergoing chemotherapy.

However, EPO has also been used illegally by athletes to enhance performance
counts improve endurance. Such misuse can lead to dangerous side effects inc
blood clots.

Calcitonin

Calcitonin is a hormone [illegible]d by C cells of the thyroid gland. Its main funct
(Ca^{2+}) level[illegible]the [illegible]ve become elevated, helping to maintain calcium ion hom

Calcitoni[illegible]eves this through several mechanisms, including:

- inhibiting osteoclast activity – osteoclasts break down bone tissue, releasi
  bloodstream; suppressing their activity limits bone reabsorption and prev
- increasing renal calcium ion excretion – promotes the loss of calcium ions
  reabsorption from the filtrate in the kidneys

Calcitonin secretion is inhibited by somatostatin, and together they modulate
these functions, calcitonin has limited physiological impact in humans, becaus
calcitonin (e.g. post-thyroidectomy) usually remain asymptomatic.

However, synthetic calcitonin (e.g. salmon calcitonin) can be used therapeutic
of bone, manage hypercalcinaemia, alleviate symptoms caused by bone metas
relief from osteoporotic fracture pain.

Calcitonin is also used as a diagn[illegible]m[illegible]er, since elevated levels may indicat
hyperplasia, a condition [illegible]n excessive growth of calcitonin-secreting cell

Insulin

Insulin is a hormone produced by β cells within the islets of Langerhans in the pancre
glucose homeostasis by stimulating cells – particularly in the liver, muscles and adipo
from the bloodstream. Excess glucose is converted to glycogen for storage or used i

Insulin has several inter-related functions:

- facilitates cellular glucose uptake, especially in liver, fat and muscle tissues
- promotes glycogenesis, the conversion of glucose to glycogen for storage
- inhibits gluconeogenesis and glycogenolysis, the production of new glucose and stored glycogen
- enhances lipogenesis, fat storage through the synthesis of triglycerides
- supports protein synthesis – increases amino acid uptake and anabolic activity

Insulin secretion is primarily triggered by elevated blood glucose levels, for instance
impaired in type 1 diabetes mellitus, due to immune destruction of β cells, and type
insulin resistance (see page 91).

Synthetic insulin (e.g. insulin lispro) is manufactured using genetically engineered bac
insulin. It is critical in managing type 1 diabetes and is sometimes required in advanc
Formulations include rapid-, short-, and long-acting forms, each tailored to reflect dif

ADH (anti-diuretic hormone)

Anti-diuretic hormone (ADH), also known as vasopressin, is a hormone vital for main
pressure and concentration of solutes in the plasma. It is produced by the hypothala
posterior pituitary gland, from where it is released in response to low water levels o

ADH targets cells in the collecting ducts of the kidney (see pages 74–75), causing aq
inserted into the cell membranes. These channels increase the collecting ducts' perm
reabsorption into the bloodstream and decreasing water loss in urine.

When ADH levels are high (as during dehydration), the kidneys produce small v
concentrated u

Changing water balance affects the concentration of solutes in the plasma, blood vo
affects ADH secretion. An increase in osmolarity (reduction in water potential causin
concentration) or a reduction in blood volume or pressure all lead to increased ADH
opposite effect as it inhibits ADH secretion, leading to increased volumes of dilute u

Insufficient or excessive ADH secretion is clinically significant. Diabetes insipidus is c
secretion by the hypothalamus or pituitary gland (called central DI) or kidney insens
nephrogenic DI). It is characterised by excessive urination and dehydration. Convers
inappropriate ADH secretion (SIADH) is caused by excess ADH. Water retention incr
hyponatraemia (dilution of sodium ions in the blood) and lower haemoglobin conce
cell swelling, particularly in brain tissue.

Synthetic ADH (e.g. desmopressin) is used to treat central diabetes insipidus, noctur
beyond childhood), and certain bleeding disorders because of ADH's role in enhanci

Apply your knowledge

1. State three physiological effects that adrenaline causes during the 'fight or flight' resp
2. Outline the main functions of insulin and describe the result if the body cannot produc
3. Describe how the endocrine system is involved in maintaining homeostasis.
4. Compare and contrast the action of hormones with electrical signals in the nervous sy

Homeostasis

Homeostasis is the maintenance of optimum internal conditions, essential for
and biological systems. It includes the regulation of water balance, blood gluc
temperature, among many others.

Deviations from these ideal conditions impair cell function

- Enzyme activity reduces or enzymes denature, slowing metabolic reac
- Substrate concentrations are no longer optimal, limiting reaction efficien
- Gene expression and protein synthesis are reduced, affecting cell perfor
- Active transport and intracellular signalling no longer function effectively
- Cell si... ma... r..., causing damage to cell structure.

Maintaining homeostasis

To restore balance when internal conditions fluctuate:

1. The endocrine and nervous systems detect changes using specialised rec
2. These changes trigger hormonal release or nervous impulses, coordinate
   brain or pancreas.
3. The signals are relayed to effectors, such as muscles or glands, which res

Negative feedback mechanisms

Homeostasis operates through negative feedback loops, where a rise in one h
and promotes the opposite response. The two responses counterbalance each
back to the optimum.

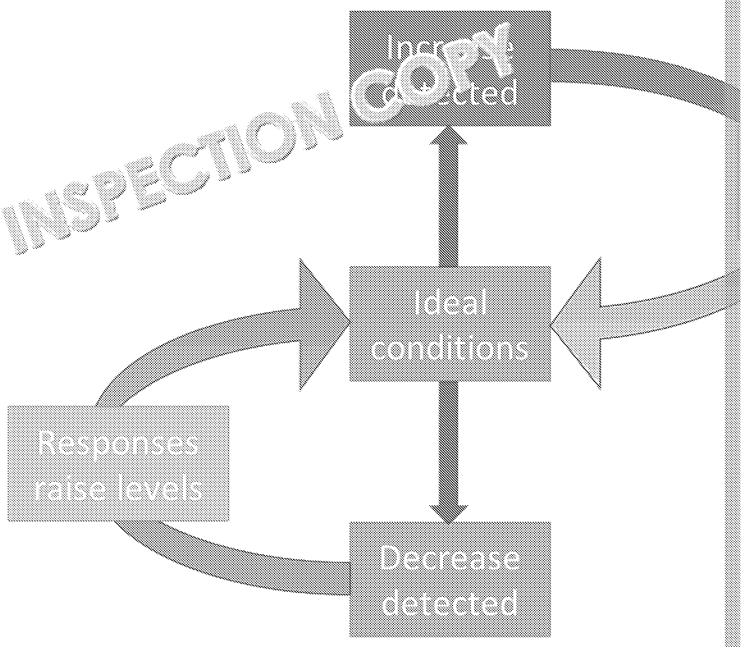


Figure F3.3. *An overview of how negative feedback mechanisms help to ma*

Recall questions

1. List th... ee ... ponents essential for the mainten
2. ...lin... how negative feedback mechanisms work, w
3. Explain why homeostasis is so important for good c

Thermoregulation

Thermoregulation is the process of maintaining a stable internal body temperature, t
healthy adults. This is critical for enzyme function, as lower temperatures slow enzy
temperatures risk enzyme denaturation, disrupting metabolic processes.

Detection and coordination

Changes to core temperature are detected by the thermore[illegible]ory centre in the hy
continuously monitors blood temperature. The hypo[illegible]m then interacts with th
gain centre, triggering appropriate physiolo[illegible]sponses via nervous and hormon

Responses to increased co[illegible]erature

To promote heat l[illegible]s, [illegible]r responses are coordinated, including:

- vasodilati[illegible]rterioles in skin surface – increases blood flow nearer skin surfa
  radiate aw[illegible]kin appears pink and flushed
- sweating – enhances heat loss through evaporation of water from the skin
- relaxation of erector pili muscles – body hair lies flat, reducing insulation and a
  more easily
- reduced metabolic rate – lowers aerobic respiration, generating less internal he

Responses to decreased core temperature

To conserve and generate heat, the following responses are triggered:

- vasoconstriction of arterioles in skin surface – restricts blood flow near the skin
  skin appears pale
- shivering – involuntary, rapid muscle contractions generate heat via increased
- contraction of erector pili muscles – body hair stands upright, trapping a layer of
- increased metabolic rate – increases respiration to generate more internal heat

Negative feedback

Regulating core body temperature relies on negative feedback mechanisms to preve
maintain stable internal conditions. This process works as follows:

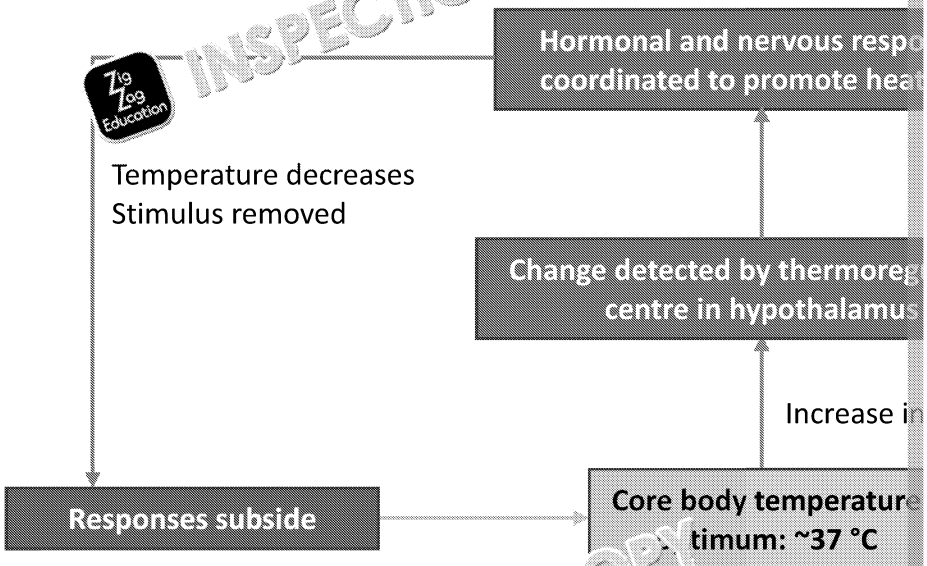


Figure F3.4. Negative feedback mechanism for regulating core body temp

The same feedback loop applies in the opposite direction:

- A decrease in core te[illegible] triggers responses that increase core temperatu
- Once the [illegible]ra[illegible]ises and returns to normal, these responses are suppres

Apply your knowledge

1. Compare the physiological responses to increases and decreases in core temperatur
2. Explain why maintaining a constant core body temperature is essential for health.

Osmoregulation

Osmoregulation is the control of the balance of water and dissolved electroly
potassium and chloride, within body fluids. This regulation ensures a stable in
function and homeostasis.

Effects of plasma tonicity

Hypotonic blood plasma causes water to move into cells by osmosis, causing swelling and potential **lysis**. Conversely, **hypertonic** blood plasma causes water to move out of cells by osmosis, leading to **crenation** and shrinkage.

Detection and coordination

The osmoregulatory centre of the hypothalamus contains osmoreceptors that monitor plasma water potential and solute concentrations. Deviations from the optimum trigger corrective responses, primarily involving the hormone ADH (anti-diuretic hormone).

Response to hypertonic conditions

Hypertonic conditions are caused by water loss or electrolyte gain and can be corrected by retaining water. In these conditions, ADH, stored in the posterior pituitary gland, is secreted into the bloodstream and binds to receptors on cells in the kidneys' collecting ducts.

ADH activates an intracellular signalling cascade that inserts aquaporin channe
As filtrate passes through the collecting ducts, water molecules are reabsorbe
They move into the interstitial fluid and then into the bloodstream, conserving

The kidneys produce small volumes of concentrated urine because less water
pathways stimulate thirst, promoting behavioural modification leading to fluid

Response to hypotonic conditions

In hypotonic conditions, there is excess water and insufficient electrolytes, wh
The osmoregulatory centre detects this change and causes the pituitary gland
Fewer aquaporins are inserted into the cell membrane of the kidney tubules a
Larger volumes of dilute urine are produced to eliminate excess water.

Additional control

Changes in blood **plasma osmolarity** also affect blood volume, which alters blood pressure. These shifts are detected by baroreceptors in the aorta and carotid arteries (in the neck), influencing ADH release. Low pressure or volume leads to an increase in ADH, while high pressure or volume suppresses ADH release.

pla
con
blo
ele
glu
pot
pla
con

Negative feedback

Responses to changes in osmolarity rely upon negative feedback mechanisms

- stimulus (increase in plasma osmolarity) is detected by osmoreceptors in gland to increase release of ADH → ADH acts on kidneys to increase wate plasma osmolarity → ADH secretion is reduced

Recall questions

1. Define what is meant by a negative feedback pathw
2. Outline the roles of ADH and aquaporins in maintai
3. Outline the negative feedback pathway that is trigg
4. Describe how changes in water balance are detecte

Glucose regulation

Glucose is the primary molecule used in aerobic respiration. It enters the bloodstrea
capillaries and is transported to cells throughout the body. However, excessive gluco
osmotic balance:

- High blood glucose concentration causes water to move out of cells by osmosis
  risking cell shrinkage.
- Low blood glucose concentration causes water to m[illegible] into cells by osmosis, ri

Maintaining optimal blood glucose lev[illegible]tial to protect cell integrity and ens
available for respiration.

Detection an[illegible]rdination

Normal blood g[illegible]ose concentration lies between 4–6 mmol/dm^3 (or 90 mg / 100 cm
7.8 mmol/dm^3 in the two hours after eating. Deviations from this range are detecte
of Langerhans in the pancreas.

These cells secrete hormones into the bloodstream, targeting liver (hepatocytes), m
tissue (adipocytes). The hormones bind to specific receptors and initiate responses t

Response to increased glucose levels

Increased glucose levels stimulate β cells to secrete insulin, which binds to receptors
and adipocytes and:

1. Promotes GLUT4 transporter insertion into membranes, increasing glucose upta
2. Stimulates glycogenesis (conversion of glucose to glycogen for storage).
3. Inhibits gluconeogenesis and glycogenolysis in the liver.
4. Enhances lipogenesis (production of lipids) and prot[illegible]nthesis.

Together, these actions reduce blood gl[illegible]e c[illegible]ncentration, returning levels to norm

Response to dec[illegible]ea[illegible]se levels

Low glucose le[illegible]ggers α cells to secrete glucagon, which restores levels via:

- reduced gl[illegible]se uptake by cells
- increased glycogenolysis – breakdown of stored glycogen into glucose
- increased gluconeogenesis – synthesis of glucose from amino acids and glycero
- increased lipolysis – breakdown of lipids into fatty acids and glycerol for aerobic

These processes release glucose into the bloodstream, correcting the deficit.

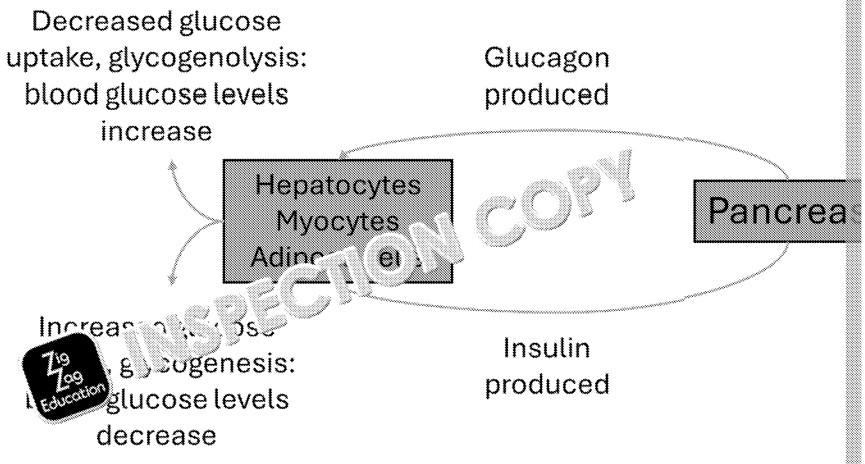


Figure F3.5. *A schematic overview of blood glucose regulation.*

Negative feedback loops

Blood glucose regulation relies on a negative feedback loop:

- rising glucose → insulin release → absorption and storage → glucose fall
- falling glucose → glucagon release → mobilisation and synthesis → gluco

Your turn

1. Outline the processes involved in [illegible]sing and increasing blood glucose
2. Create a detailed flow [illegible]t on the components and stages involved in the glucose level[illegible]ating a large meal. Include the target blood glucose c this [illegible]trolled through a negative feedback loop.

Practice questions: The endocrine system and homeosta

1 Complete the table to match the hormone to the regulatory pathwa

Hormone	Regulatory pat
A.	Osmoregulation
Insulin	B.
C.	Metabolic regula
Calcitonin	D.

3.1.2. Monitoring homeostasis

Failure in homeostatic systems can lead to serious health consequences. This chapte
disrupted regulation and how health professionals can assess and manage these im

Malfunctioning thermoregulation

Maintaining a stable core body temperature is vital f e fi t metabolism and enz
Thermoregulation is coordinated by the hyp mus and involves both the nervou

When internal temperatur e a significantly from the optimum (~37 °C), the bo
either hypothe lo e perature) or hyperthermia (high temperature), both of
clinical conseq

Symptoms of poor thermoregulation

Hypothermia

Hypothermia occurs when core body temperature drops below 35 °C and the body
it can generate. It is a medical emergency, potentially affecting organ function, cons

Common causes of hypothermia include:

- prolonged exposure to cold conditions without adequate protection (e.g. mountain
- cold indoor environments, particularly for elderly or vulnerable individuals
- medical conditions that impair thermoregulation, such as hypothyroidism, mal
- substance use, including alcohol or sedatives which suppress thermal responses

Symptoms worsen as severity increases:

Severity	Core temperature	Symp
Mild	32–35	Shivering, pale skin, con speech, fatigue
Mod	28–32	Delirium, slowed reflexe bluish skin, unconsciou
Severe	< 28	No shivering, coma, abn respiratory failure

Table F3.2. Symptoms at different severities of hypothermia.

Infants may have cold, red skin, be floppy and unusually quiet and refuse to feed.

Treatment includes moving the patient to a warm, dry location, removing wet cloth
blankets, and warming with warm non-alcoholic drinks or warmed intravenous (IV) f

Hyperthermia

Hyperthermia occurs when core body temperature rises above 40 °C, overwhelm
mechanisms. Unlike fever, which is a regulated response, hyperthermia is uncont

Hyperthermia has several contributing factors, including:

- prolonged exposure to heat, including during heatwaves and high humid
- strenuous activity in hot conditions or inappropri[illegible]othing
- disorders affecting thermoregulation, suc[illegible]rthyroidism, stroke or
- medications and drug reactions, [illegible]g from diuretics or when used d

Symptoms of hyperth[illegible]a worsen as core temperature increases:

[illegible]	Core temperature (°C)	Sy
Heat stress	~37.5–38.5	Thirst, headache, dizziness
Heat exhaustion	~38.5–40	Heavy sweating, nausea, ra
Heat stroke	> 40	Dry skin, delirium, seizures

Table F3.3. Symptoms at different stages of hyperther

Treatment includes relocating to a cool environment and removing excess clo
intravenous saline with electrolytes, and active cooling using ice packs applie
(axillae), cool water immersion or fans.

Comparing hypothermia and hyperthermia

The symptoms of hypothermia and hyperthermia reflect opposing thermoreg
body's attempt to restore core temperature.

In hypothermia, the body strives to conser[illegible]e h[illegible]eat, t[illegible]ough vasoconstriction,
and symptoms like confusion and d[illegible]w[illegible]s which indicate metabolic slowin
mechanism, producing war[illegible]th [illegible]gh involuntary muscle contraction.

Convers[illegible]hy[illegible]rmia, the body works to dissipate excess heat. Respor
and incr[illegible]reathing and heart rate. Delirium and seizures may occur whe
vasodilation drive heat loss but lead to electrolyte depletion, so treatment of
therapy, typically administered via IV fluids.

Monitoring core temperature

The accurate measurement of core temperature is essential for diagnosis and

Method	Accuracy	U
Rectal thermometer	Very high	Emergency and clinical ass
Oral/Tympanic	Moderate – High	Convenient and non-invasi
Oesophageal probe	Very high	Surgical and critical care; in

Table F3.4. Accuracy and uses of diff[illegible]ethods of monitoring c

Other methods are also available (see [illegible]13), and selection depends on th
precision and the patient cond[illegible].

Recall questions

1. List the primary causes and symptoms of hypother
2. Describe the physiological responses that the body
temperature during extreme cold and heat.
3. Compare the use cases and accuracy of the rectal t
oesophageal probe.

Malfunctioning osmoregulation

Water balance is critical to cell health, blood pressure, and overall fluid homeostasis. the movement of water and electrolytes, ensuring plasma osmolarity remains within

When osmoregulation fails, the body's ability to maintain water and electrolyte bala can lead to cell dysfunction, fluid imbalance and serious clinical consequences, depe being retained or lost excessively.

Symptoms of poor osmoregulation

Excessive water retention

A key condition involving excessive water retention is the syndrome of inappropriate SIADH results in persistent ADH secretion, causing excessive water reabsorption in th

Common symptoms include:

- hyponatraemia (low plasma sodium ion concentration)
- headache, nausea and lethargy
- muscle cramps, confusion and **ataxia**
- cerebral **oedema** in severe cases

Neurons reduce excitability in low plasma sodium ion concentrations, causing neurological symptoms. Excess water retention also dilutes plasma solutes, so it becomes hypotonic and water enters cells via osmosis.

ataxia – a that resul coordinat unsteady slurred sp

oedema accumul causing s feet, ank

antagon blocks o actions o

Treatment includes restricting fluid intake, then salt tablets or hypertonic saline for moderate cases, and ADH antagonists in resistant or severe cases.

Excessive water loss

Conditions wh excessive water is lost include diabetes insipidus, excessive alcoho post-operative loss. Symptoms include:

- excessive urination
- excessive thirst
- dehydration, with dry mucous membranes, such as eyes, mouth and throat
- hypotension and tachycardia (elevated heart rate) due to reduced blood volum
- hypernatraemia (increased plasma sodium ions)
- fatigue, dizziness and confusion

Reduced water retention increases plasma osmolarity, drawing water out of cells by function, especially in the brain.

Treatment includes drinking plenty of water daily. In more se cases, synthetic AD to improve water retention, and a low sodium diet m b ful to reduce electroly plasma osmolarity.

Monitoring blood osmotic potential

Blood osmotic potential can be monitored using several methods, including:

Method	Description	Advan
Direct lab measurement	Uses freezing point to assess solute concentration.	Highly accu
Calculated osmolarity	Estimates levels of [illegible]ons, glucose and urea [illegible] [illegible]d is collected, allowed to clot and the clot removed before testing.	Rapid Accessible
Blood pressure	Provides an indication of blood volume. Can infer potential osmotic imbalance, particularly in cases of dehydration or fluid overload.	Rapid Non-invasiv
Urine analysis	Measure volume and solute concentration. Can distinguish between types of water imbalance (e.g. SIADH vs diabetes insipidus).	Fast Practical May indicate

Table F3.5. Methods of monitoring blood osmotic poten

Recall questions

1. List the m[illegible]ptoms of excessive water retentio
[illegible]fore[illegible]lation.
2. [illegible]scribe the treatment options for conditions like d
3. Describe the methods used to monitor blood osmo
the advantages and disadvantages of each.
4. Explain how the body responds to excessive water

Malfunctioning glucose regulation

Glucose is the body's primary energy source, essential for aerobic respiration
powers cell processes. Its concentration in the bloodstream must be carefully
while avoiding osmotic imbalance and vascular damage.

Poor regulation of blood glucose is characteristic of type 1 and type 2 diabete
results from autoimmune destruction of β cells in the p[illegible]reatic islets of Lang
preventing glucose uptake by cells (see page 9[illegible]).

Type 2 diabetes involves redu[illegible]sensitivity or β cell exhaustion, leadi
despite the presenc[illegible] (see page 92).

In both c[illegible]oorly managed diabetes can result in hypoglycaemia (low bloo
(high blood glucose), each with distinct symptoms and risks.

Symptoms of hypoglycaemia and hyperglycaemia

Hypoglycaemia

Hypoglycaemia is defined when blood glucose levels drop below 4.0 mmol/L. Sympt
energy and osmotic changes affecting cell balance.

Early symptoms include shaking or tremors, sweating, **palpitations**, hunger, anxiety or irritability and tingling lips.

Later symptoms include confusion and poor co[illegible]nt[illegible], blurred vision, slurred speech, drowsiness, seizures a[illegible] [illegible]onsciousness.

Treatment for mild cases i[illegible]s fast-acting carbohydrates such as glucose tablets o
severe cases, i[illegible]no[illegible]glucose and rehydration with emergency care may be req

Hyperglycaemia

Hyperglycaemia occurs when blood glucose levels exceed 7.0 mmol/L at fasting, or 1

Symptoms often develop slowly and may include increased thirst, frequent urinatio
blurred vision. If sustained, unintentional weight loss, recurrent infections and slow

In severe cases, rapid breathing, fruity-smelling breath, confusion and drowsiness a

High blood glucose creates a hypertonic environment, causing water to leave cells b
excess glucose increases abnormal metabolic activity. Mild increases in blood glucos
with hydration, exercise and dietary adjustments. Persistent increases require insuli
emergency cases require hospitalisation for the administration of IV fluids to correc
insulin therapy to reduce blood glucose levels.

Lifestyle changes

Long-term complications of untreated hyperglycaemia include neuropathy (nerve da
loss), nephropathy (kidney damage) and cardiovascular disease. However, lifestyle a
most severe symptoms and have a range daily adjustments. These include:

- Consuming foods with a low glycaemic index to promote gradual release of gluc
  These foods contain few, complex carbohydrates.
- Regular, moderate exercise, timed to avoid after-eating (postprandial) spikes he
  and good cardiovascular function.
- Minimising alcohol consumption to avoid glucose fluctuations.
- Avoiding smoking, which exacerbates cardiovascular risk and inflammatory dam

Monitoring glucose levels

Blood glucose levels can be monitored using several methods (see page 111), includi
continuous glucose monitors (CGMs) and HbA1c blood tests for long-term control.

Recall questions

1. Describe the causes of type 1 and type 2 diabetes.
2. Describe the symptoms of hypoglycaemia and explain the immediate treatment steps for a mild episode.
3. Explain how hyperglycaemia leads to dehydration and out long-term complications if it is not managed properly.

Practice questions: Monitoring homeostasis

1 An otherwise healthy young man becomes stranded in the African outback find them. They are found at about 2am in the open savannah. Temperatur night to 42 °C during the day.

Name one regulatory malfunction he may be suffering from.

3.2.1. The nervous system

The nervous system produces rapid, short-lived responses by transmitting ele
It plays a fundamental role in enabling fast reactions to sudden internal or ext
Interactions between the nervous and endocrine syst[illegible]llow a wide range o
and sustained over varying durations.

Organisation of the nervous system

The nervous syst[illegible]ded into two major components:

- The [illegible]l nervous system – consists of the brain and spinal cord and co
- The [illegible]pheral nervous system – comprises all the neural structures and co

The peripheral nervous system is further subdivided into:

- The somatic nervous system – responsible for all voluntary actions under
  (e.g. movement, sensory perception).
- The autonomic nervous system – regulates involuntary processes such as
  and respiratory function.

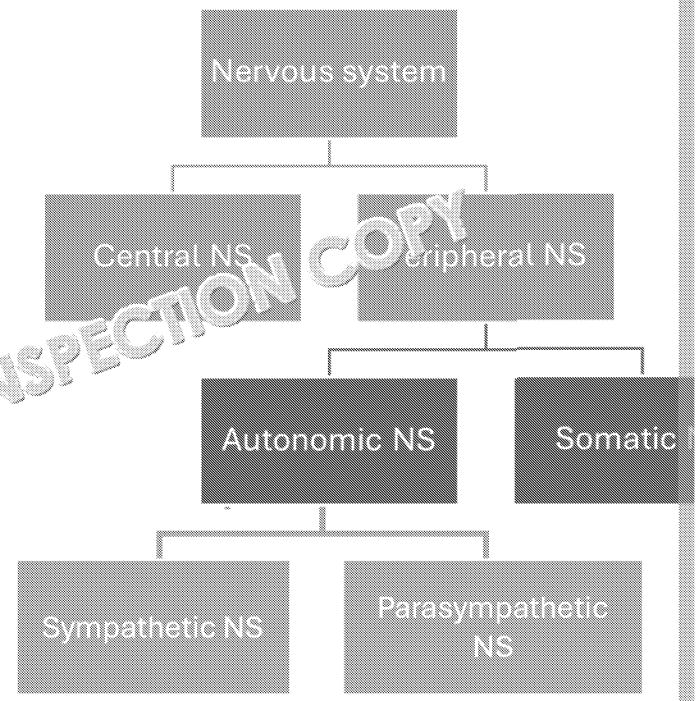


Figure F3.6. *The overall organisation of the nervous system and its s*

The somatic nervous system

The somatic nervous system enables conscious perception and control. Senso
light, sound, pressure, pain) detect stimuli and signals are transmitted via sens
A response is coordinated and relayed thro[illegible] neurons to effectors (sk

The autonomic nervous system

The autonomic [illegible] system (ANS) controls involuntary responses, such as
digestio[illegible]es through internal sensors that detect changes in body sta
Signals a[illegible] to control centres, usually in the brain, spinal cord or pancreas
Effectors, including smooth or cardiac muscles, or glands, carry out the adjust

Many autonomic responses involve interaction between nervous and endocri
between the two systems or integrate the response across both, depending o

Sympathetic and parasympathetic divisions

The ANS is divided into two antagonistic systems:

- The sympathetic nervous system – activates 'fight or flight' response, such as in releasing adrenaline.
- The parasympathetic nervous system – promotes 'rest and digest' functions, in encouraging digestion, and sleep.

Together, they coordinate a response followed by a return to balance through oppos

Pathway through the nervous system

All nervous responses follow a predictable pathway:

1. A stimulus is detected by a receptor.
2. The signal travels via a sensory neuron to a control centre (usually the brain or s
3. Within the CNS, the signal is processed by relay neurons.
4. The response is transmitted via a motor neuron to an effector (muscle or gland) the action.

Your turn

1. State by which part of the nervous system the responses of yawning and sneezin
2. Suggest why most body functions and processes are controlled autonomically.
3. Create a flow chart of the signalling pathway through the nervous system.

Nerve function

Structure and function of neurons

Neurons are highly specialised cells with specific structural adaptations that enable communication across the nervous system. There are three main types of neuron – s relay – each tailored to its specific function (see pages 12–13).

One key feature of motor neurons, and some sensory neurons, is the myelin sheath – insulating layer formed by Schwann cells along the axon. Interrupting this sheath at r gaps known as nodes of Ranvier, each approximately 20 nm wide. These nodes are e conduction, a process that enables the electrical impulse to 'jump' between nodes. T transmission speed – up to 100 times faster than conduction along unmyelinated ax disrupted in conditions such as multiple sclerosis and motor neuron disease.

Features of nerve impulse transmission

The transmission of a nerve impulse along an axon relies on a wave of **depolarisation** followed by **repolarisation**, which occurs in a rapid, sequential manner along the axon membrane.

Resting potential

When a neuron is at rest, the membrane is polarised, with a resting potential of approximately -70 mV. This electrical gradient is maintained by differences in ion distribution across the membrane, particularly involving sodium ions (Na^+) and potassium (K^+).

Action potential and depolarisation

A stimulus, such as activation of a sensory receptor, triggers a depolarisation event. enter the neuron, making the inside of the axon less negative than the outside. As d membrane potential increases to about +40 mV, generating an action potential that

Repolarisation

Once the peak voltage is reached, K^+ ions move out of the neuron, restoring th
– a process known as repolarisation. The potential falls back towards -70 mV.

Hyperpolarisation

During repolarisation, the membrane potential briefly drops below the restin
hyperpolarisation. The neuron then stabilises back to the resting potential, rea

Reading a nerve impulse from a potential difference graph

A typical nerve impulse can be visualised on a membrane potential graph, sho
potential, depolarisation, repolarisation and hyperpolarisation. These changes
resulting in the changes during transmission of the nervous impulse along th

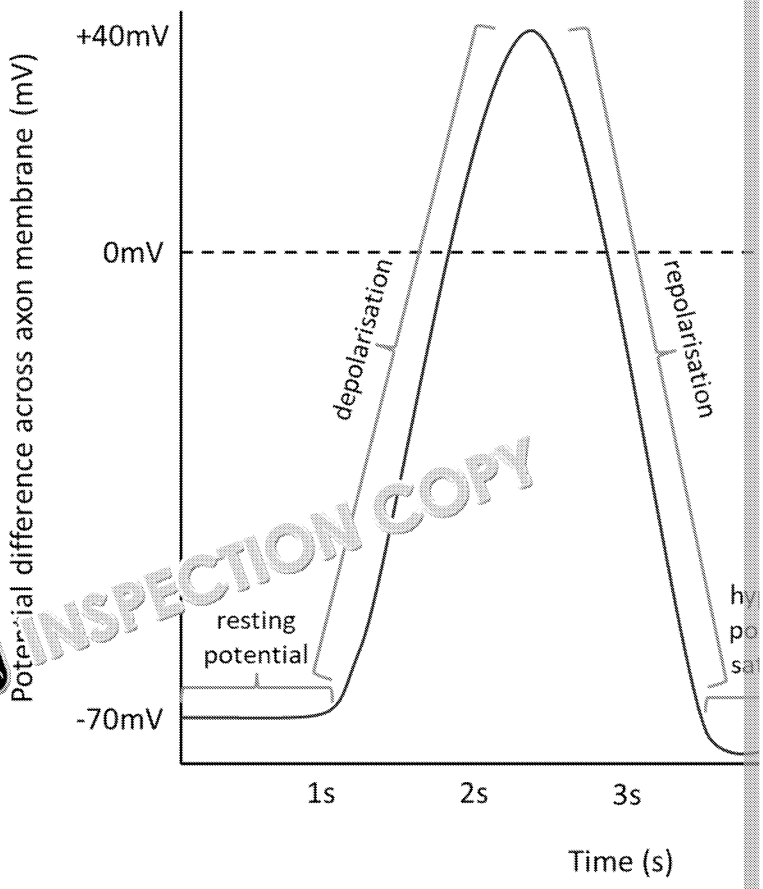


Figure F3.7. *A potential difference graph showing depolarisation, repolarisation and hyper*

Saltatory conduction

Saltatory conduction is the rapid transmission of electrical impulses along a m
unmyelinated neurons, where depolarisation and repolarisation must occur co
myelinated neurons allow ion exchange only at the nodes of Ranvier.

At a depolarised node, positive charge builds inside the axon, while the
adjacent resting node remains negatively charged (at resting potential).
This establishes a local current causing the impulse to 'jump' from node to
node. The myelin sheath acts as an **insulator**, preventing ion movement
across the intervening axon segments and vastly increases conduction speed.

This is essential for the rapid transmission of long-distance motor and sensory
and coordinated movement.

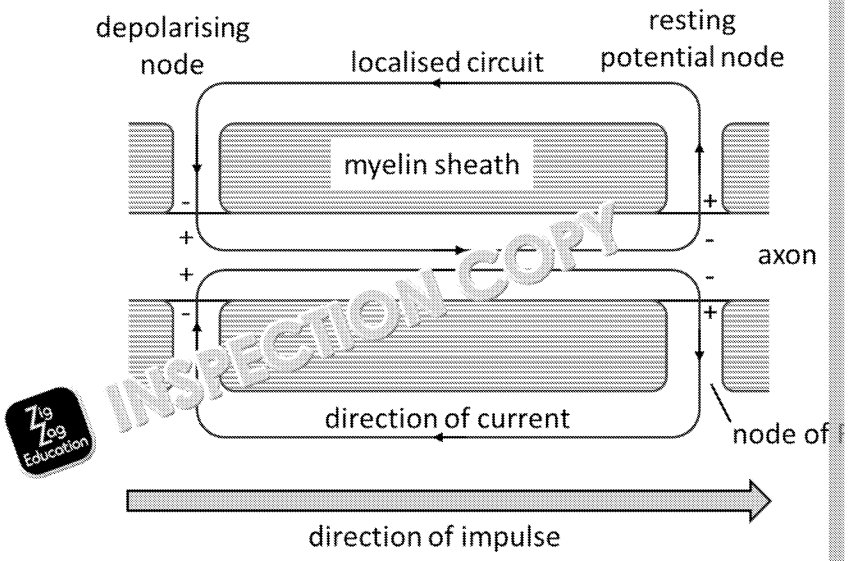


Figure F3.8. *The myelin sheath insulates the neuron membrane, and each sheath is s next, leaving a gap called the node of Ranvier. This allows currents to create localised electrical impulse to jump along the axon, vastly increasing its speed*

Recall questions

1. State the neuron resting potential and describe how the i the neuron changes during depolarisation, repolarisation a
2. Explain the roles of the myelin sheath and the nodes of Ra

The reflex arc

The reflex arc uses a shortened neural pathway to produce an extremely rapid, auto vital in situations where conscious processing would take too long, potentially leadi delayed protective reaction such as withdrawing from a hot surface or a sharp object.

The basic principle of neuronal transmission still applies:

stimulus → receptor → sensory neuron → relay neuron → motor ne

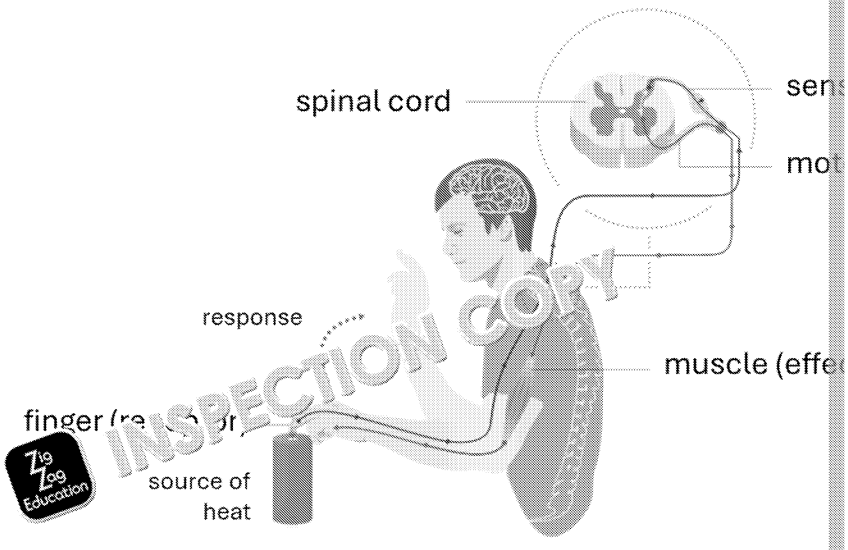


Figure F3.9. *The reflex arc.*

However, reflex actions bypass conscious thought. Unlike typical voluntary re
the brain, reflexes are hard-wired anatomically. The stimulus is detected by re
sensory neurons to the spinal cord, where relay neurons connect directly to m
immediate response from the effector (usually a muscle).

At the same time, a secondary signal is sent to the brain for processing, but thi
place. This is why your body moves to protect you bef ou are consciously
speed of reaction over awareness of response.

Recall questions

1. Explain why the reflex arc leads to rapid, involuntary this is an important survival response.
2. Describe how the brain is updated as part of the re why it is not included in the initial response.

Multiple sclerosis

Multiple sclerosis (MS) is a chronic, potentially life-limiting neurological condi
nervous system (CNS), specifically the brain and spinal cord, and the optic ner
system mistakenly attacks the myelin sheath, the protective insulating layer p
This leads to demyelination, inflammation and ultimately, to irreversible nerve

Causes and risk factors

Although the exact cause is unknown, MS is believed to result from a combina
and lifestyle factors, including:

- Autoimmune dysfunction
  T cells and B cells target and d a elin and neurons.
- Genetic predisposi
  It is not direc d, but ~200 gene variants may increase susceptib
- Env n triggers
  Low n D levels due to reduced sun exposure, Epstein–Barr virus inf
  obesity are associated with increased risk.

Symptoms

MS symptoms vary depending on which regions of the CNS are damaged by th
However, symptoms may be grouped into functional categories:

Category	Common symptom
Sensory	Numbness, tingling, burning, electric-shock sensatio
Motor	Muscle weakness, spasms, tremors, difficulty walki
Visual	Blurred or double vision, optic uritis (inflammatio
Cognitive	Memory issues, poo ce ration, slowed thinkin
Autonomic	Bladder o o ysfunction, sexual problems, fati
E ion	sion, anxiety, mood swings, pseudobulbar af emotional outbursts unrelated to genuine feelings, c emotional expression neural pathways)

Table F3.6. Common MS symptoms.

Course and classification

MS is a condition involving the immune system. Symptoms may improve (remission) immune activity and worsen (relapse) when inflammation escalates. The most comm relapsing-remitting MS (RRMS) and follows this pattern of worsening symptoms follo

Impact on saltatory transmission

Damage to the myelin sheath disrupts saltatory conductio MS, demyelination wi forcing impulses to travel via slower non-saltator co nd along parts of the axo fewer impulses 'jump' effectively betwe o , nd the speed of transmission red leads directly to motor, sensory a cog ve symptoms, depending on which nerve

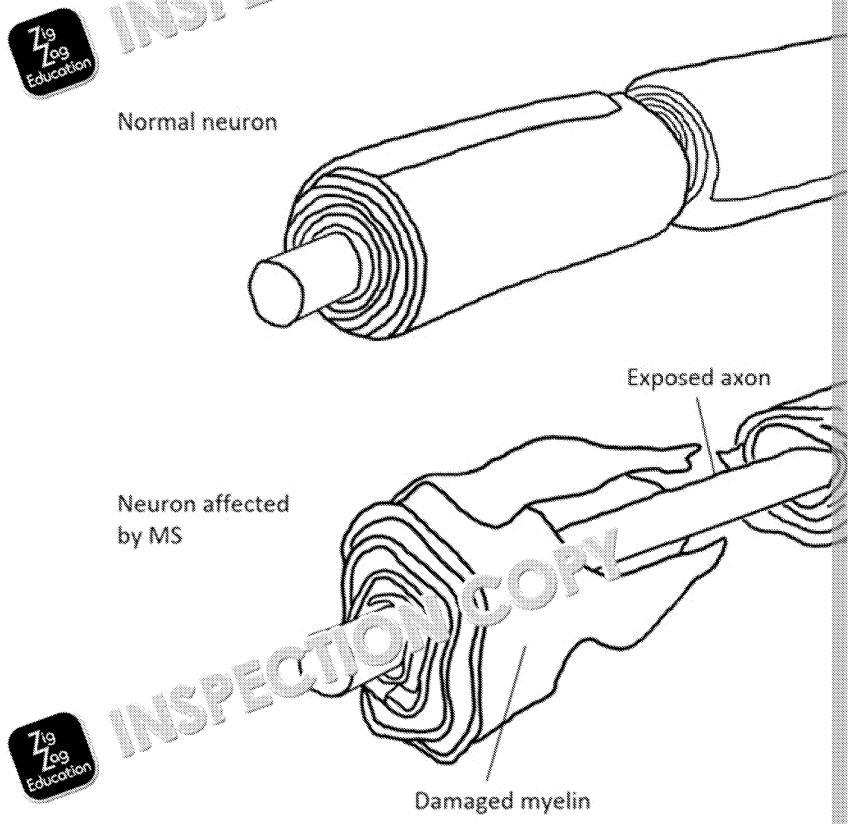


Figure F3.10. *Multiple sclerosis is caused by damage to the myelin sheath which impair*

Recall questions

1. Describe the symptoms of multiple sclerosis depending o nerve damage and the different forms this illness may take
2. Explain why damage to the myelin sheath causes these sy

Practice questions: The nervous system

1 The transmission of signals from the e e to th brain occurs extremely qui neuron axons. The distance is ap ox mately 5.5 cm and the time taken is a

a. Calculate th s ed of transmission in metres per second (m/s). Give y /2]

Use the equation *speed = distance ÷ time*

b. Describe how a myelinated axon is structured [3].

3.2.2. The brain and spinal cord

The brain and spinal cord are the primary structures of the central nervous sy
coordinating responses and maintaining communication across the body. Toge
centre for sensory processing, motor function, homeostatic regulation and re

The brain contains distinct functional regions, each specialised for tasks such a
interpretation, motor coordination, and memory fo ic . The spinal cord is
brain and the peripheral nervous system a d ne for spinal reflex arcs.

This chapter explores the st tur d function of the CNS, adding additiona

Struct n unction of the brain

The brai tains an estimated 86 billion neurons, each forming connections
creating a densely interconnected network. This makes anatomical interpreta
magnification.

Regions of the brain

The brain is divided into the left and right hemispheres, which are connected b
corpus callosum. Key functional areas include:

- Cerebrum (cerebral hemispheres):
  The largest region; divided into lobes (frontal, parietal, temporal and occ
  Controls conscious thought, sensory perception, memory, emotions and v
- Cerebellum:
  Located beneath the cerebrum.
  Coordinates balance, posture and fine motor control.
- Medulla oblongata and brain stem:
  Includes midbrain, pons and medulla; connects brain to spinal cord.
  Regulates vital functions, including breathing and heart rate, core body te

Key regulatory cent :

- Hyp m
  Mo nternal conditions such as blood pressure, core temperature a
  integrates signals from the nervous and endocrine systems.
- Pituitary gland:
  Often referred to as the 'master gland', which responds to signals from th
  hormones that regulate growth, metabolism, reproduction and stress re

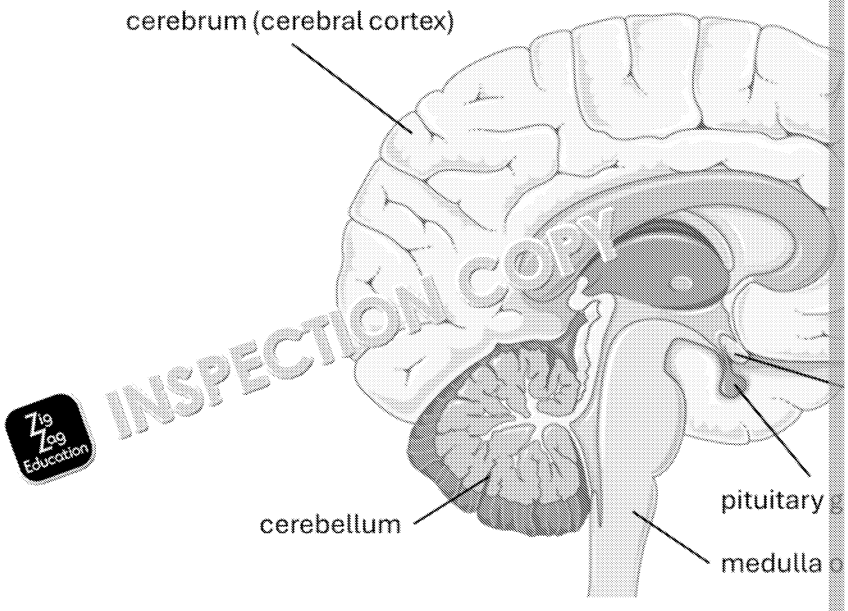


Figure F3.11. *The areas of the brain.*

Protection and internal structures

The brain is encased within three protective membranes that also surround the spin
collectively as the meninges. These layers prevent mechanical damage and infection
meningitis, which is why this is a medically critical condition.

The brain contains four interconnected cavities called ventricles that produce and ci
(CSF). This fluid cushions the brain against trauma, delivers n nts and removes w
pressure and maintains chemical stability throughou th C

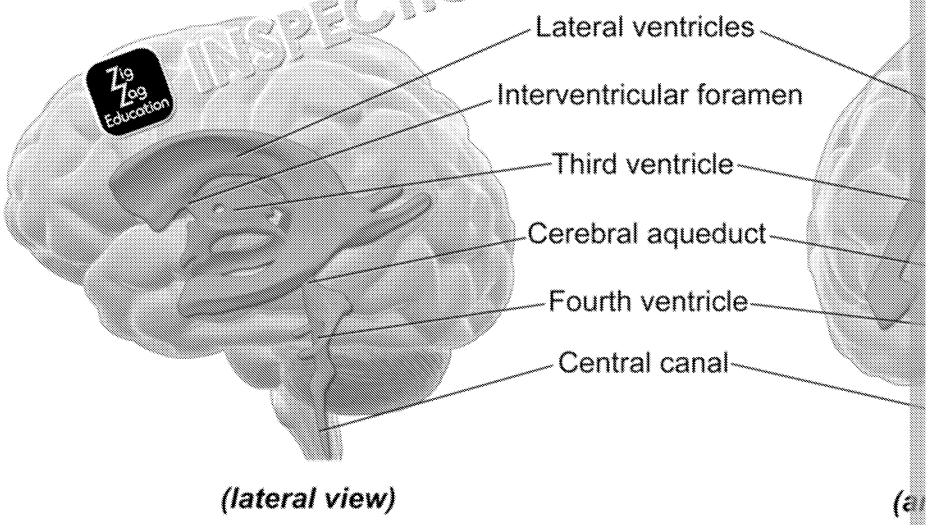


Figure F3.12. *The brain has four interconnected ventricles t at are filled with cerebr*

Interpreting brain scans

MRI or CT scans produce cross-sectio i ges hat reveal internal brain structures

In vertical sectio (VS) e are taken front-to-back, as if facing the patient. Earl
cavity and fro es, while deeper cuts reveal the cerebellum and brainstem nea

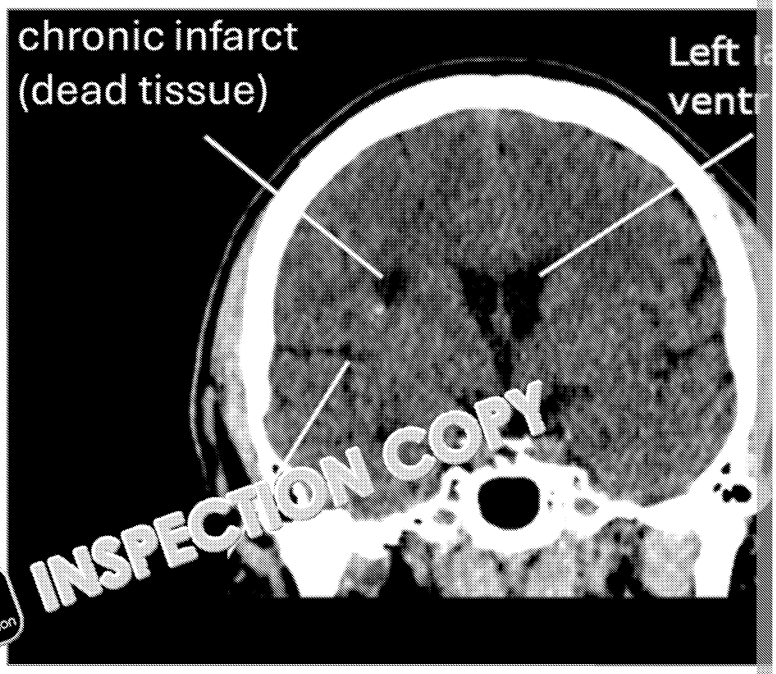


Figure F3.13. *CT scan of brain showing a chronic infarct, as seen in a vertic*

In transverse sections (TS), images are taken from top-to-bottom, from crown
cerebral cortex, followed by structures like the hypothalamus and pituitary, o
Deeper levels reveal the cerebellum then the medulla.

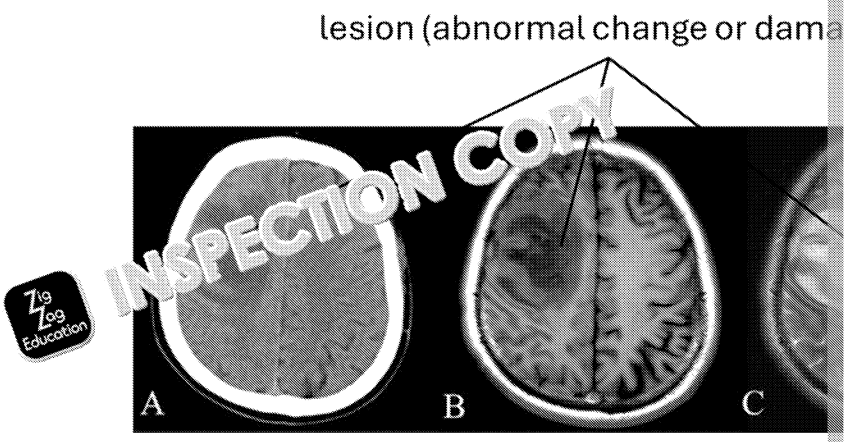


Figure F3.14. *CT (image A) and MRI scans (images B and C) showing a lesion in the b*

Understanding how anatomical regions appear in imaging supports clinical dia
of the structure of the brain.

Recall questions

1. State the regions of the brain and their overall funct
2. Outline the protective internal structures of the brai
prevent damage.
3. Describe the difference between images taken of ve
of the brain.

Structure and function of the spinal cord

The spinal cord is a cylindrical column of nervous tissue containing approximat
It exten t medulla oblongata at the base of the brain, down to the lu
column. cal part of the CNS, it is the main route for sensory input, moto
between the brain and the rest of the body.

Organisation

In adults, the spinal cord is protected by 31 vertebrae, grouped into five regio

Region	Number of vertebrae	L
Cervical (C)	8	
Thoracic (T)	12	Up
Lumbar (L)	5	M
Sacral (S)	5	Lo
Coccygeal		Cocc

Table F3.7. Details of the five regions of vertebrae

Internal anatom

A transv ct on of the spinal cord reveals distinct features. The outer laye
contains myelinated axons grouped into ascending sensory, and descending m

The central section is known as grey matter. This region contains neuron cell b
dorsal (posterior, rear) horns for sensory processing, ventral (anterior, front) h
(side) horns for autonomic neurons in the thoracic and lumbar regions.

Running through the grey matter is the central canal, which circulates cerebrospina
nourishes the spinal cord.

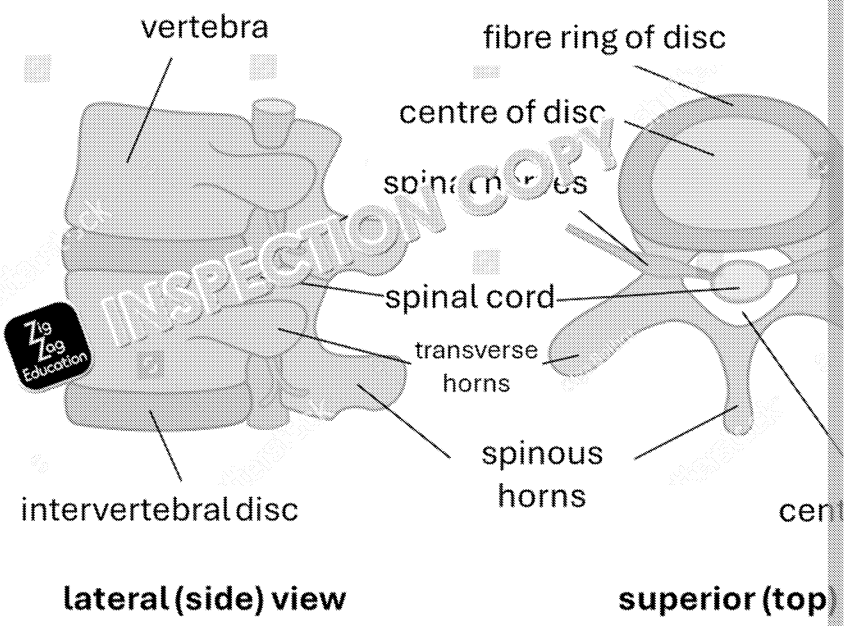


Figure F3.15. *Spinal cord anatomy showing the vertebrae, nerves and interverte*

Protective structures

The spinal cord is protected by the vertebral column. This is a flexible, articulated bo
the spinal cord and protects it.

It is also protected by the meninges, which continue down the spinal column from th

Interpreting spinal cord imagi

MRI and CT scans offer di c ss-sectional views of the spinal cord.

In vertical sect e spinal cord is viewed from front-to-back. This shows organs (
lungs) plus spinal structures. It will show spinal cord anatomy, including white and g
canal, and vertebrae.

In transverse sections, the spinal cord is viewed from top-to-bottom, so images will s
slices of the body, alongside bones, muscles and other soft tissues.

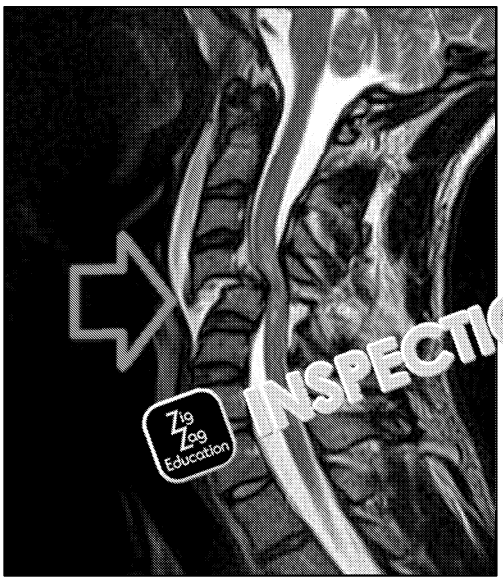


Figure F3.16. *A cervical spine vertical MRI section showing a C4 fracture and spinal cord compression.*

Figure F3.17. *A tra through the spinal cord*

Sampling cerebrospinal fluid

Lumbar puncture is the primary method for obtaining cerebrospinal fluid (CSF) between the L3–L5 vertebrae, below the end of the spinal cord, to avoid dam

CSF testing can reveal neurological conditions that are not evident in blood o barrier. Therefore, it can support diagnosis of:

- Infections
  - Meningitis (inflammation of the m
  - Encephalitis (inflammati rain)
  - Tuberculosis and fungal CNS infections
- Autoimmune disorders
  - ple sclerosis
  - ain–Barré syndrome (where the immune system attacks periph
- Bleeding
- Neurodegenerative and other conditions
  - CNS cancers
  - Alzheimer's disease

Recall questions

1. State the organisation and internal anatomy of the s structures that protect it.
2. List some of the diseases that lumbar puncture can describe how this procedure is completed.

Practice questions: The brain and spinal cord

1 he sections of the spinal column in the diagram. (4)

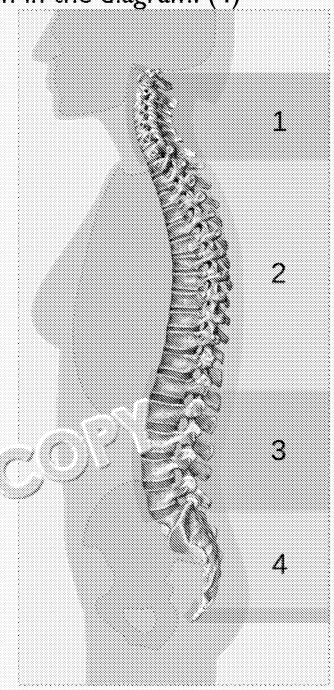


Image credit: William Crochot

3.3.1. The reproductive system

Reproduction is the biological process by which genetic material is passed from one g
In humans, this occurs via sexual reproduction, where genetic information from two
produce genetically diverse offspring. This diversity plays a crucial role in evolution a

Successful reproduction involves several interconnected steps:

- The production of gametes – sperm in males and ova in females – via meiosis, a
that halves the chromosome number.
- The union of gametes during sexual intercourse, leading to fertilisation.
- The specialised structures of the male and female reproductive systems, which s
transport and fertilisation.
- In females, the ability to nurture the developing embryo and facilitate childbirth

This chapter explores the anatomical features and physiological functions that under
laying the foundation for understanding fertility, pregnancy and developmental biolo

Female reproductive system

The female reproductive system matures during puberty. It typically remains reproduc
teens to around age 50–55, between puberty and menopause – a period of roughly 3

This system includes several highly adapted organs, each with specialised roles:

- ovaries – produce and release ova (egg cells); secrete reproductive hormones
- oviducts (fallopian tubes) – link ovaries to uterus; site of fertilisation
- uterus – muscular organ where foetal development occurs
- cervix – connects the uterus to the vagina, regulates access between internal an
- vagina – muscular canal for sexual intercourse and childbirth
- vulva – the external genital structures providing protection and sensory function

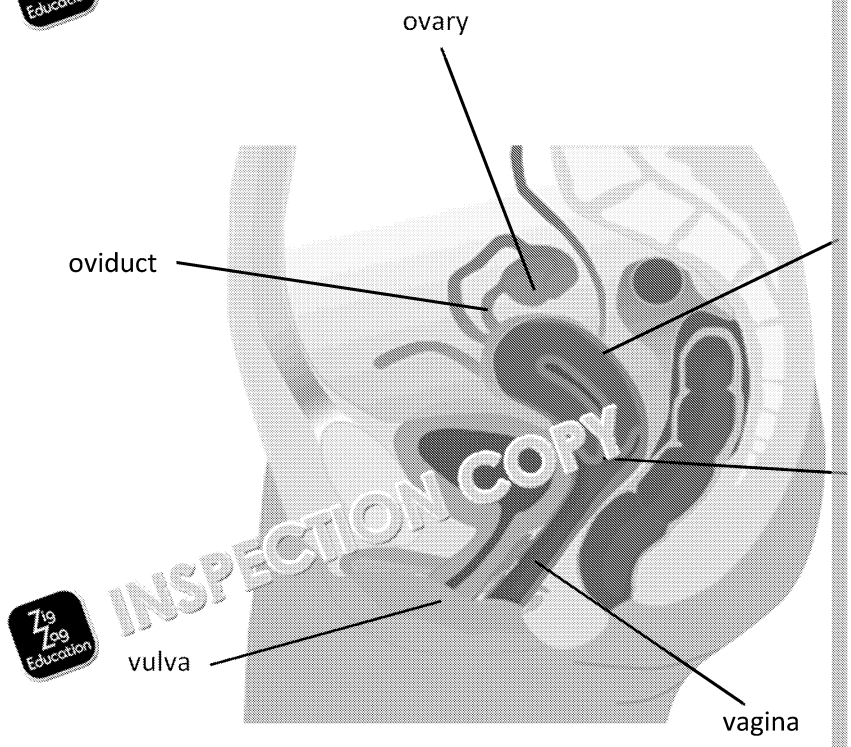


Figure F3.18. *The female reproductive system.*

Ovaries

At birth, the ovaries contain approximately 1 million immature ova. From pub
typically matures per cycle and is released into the oviduct during ovulation.

The ovaries are also endocrine glands, secreting oestrogen and progesterone
menstrual cycle, support pregnancy and influence secondary sexual character

Oviducts (fallopian tubes)

Each oviduct is lined with ciliated c i ne ells that assist in moving the ovu
usually occurs here, allowi e z gote to divide and develop into a blastocy
for implantation

Uterus

The uterus is a muscular, pear-shaped organ capable of significant expansion d
it develops a thickened lining to support potential implantation. If fertilisation
hormonal changes trigger the shedding of this lining as menstrual blood flow

Cervix

The cervix acts as a sphincter-like gateway between the uterus and vagina, re
internal organs. During pregnancy, it remains tightly closed to maintain and p
the developing foetus. During labour, the cervix dilates to enable birth. It also
which change throughout the menstrual cycle to either hinder or enable sper

Vagina

The vagina is a highly elastic muscular canal that accommodates the penis du
sperm to be deposited near the cervical opening. It i o he birth canal, stre
childbirth. The vaginal environment is acidi , r ain ed by beneficial microbe

Vulva

The vulva c om e external genitalia, including the protective skin fo
contribu exual sensation, and plays a role in guiding the penis during in

Recall questions

1. Describe how the parts of the female reproductive s
enable the development of an embryo.
2. Explain how the vagina protects the other parts of t
from pathogens.
3. Explain how the cervix maintains pregnancy and ho

Male reproductive system

The male reproductive system is responsible for the pr tion, storage and d
It also functions as part of the endocrine syste , fo cing testosterone, the

The system matures during pu remains active throughout adult life.
as spermatogenesis o om puberty until death, although both sperm
decline wi ge.

Fertility a depends on successful sperm delivery to the female reproductive
by ageing, illness or hormonal factors.

The male reproductive system comprises several key organs and glands, including:

- testes – produce sperm and secrete testosterone
- epididymis – sperm maturation and storage
- vas deferens – transports sperm to the ejaculatory ducts
- seminal vesicles – secrete fructose-rich fluid to nourish and add volume to seme
- prostate gland – adds enzymes and alkaline fluid to semen
- urethra – carries semen and urine out of the body
- penis – delivers semen into female reproductive tra[illegible]uring intercourse

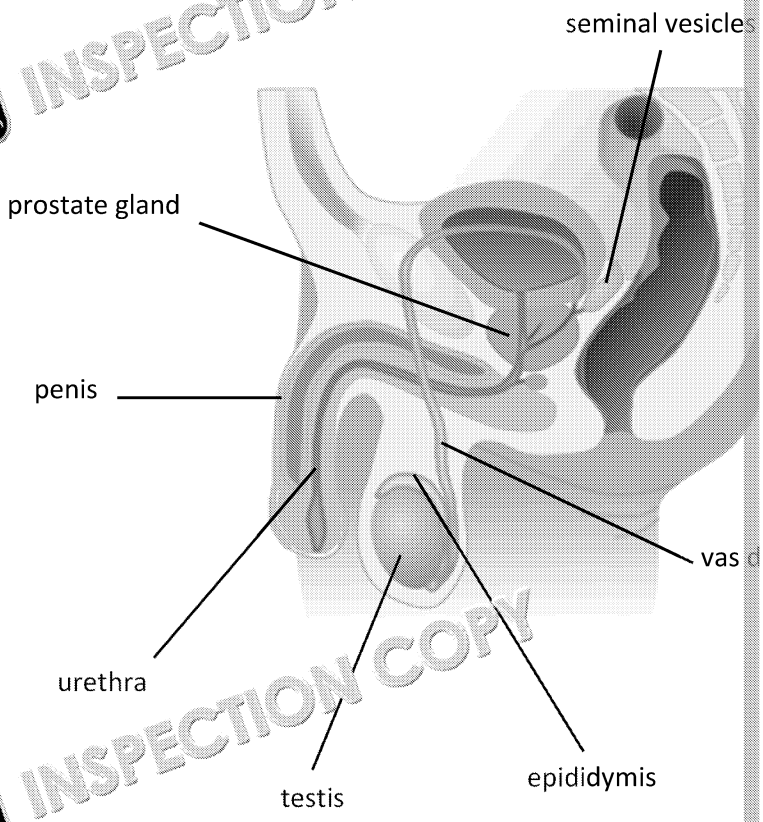


Figure F3.19. *The male reproductive system.*

Semen is the fluid ejaculated during sexual intercourse, and it consists of two main c

- Sperm – makes up 5–10 % of the total semen volume.
- Accessory fluids – comprises the remaining 90–95 % of semen and includes sec vesicles and prostate gland. This:
  - provides nutrients (e.g. fructose) for aerobic respiration for sperm motility
  - creates an alkaline environment to neutralise vaginal acidity
  - adds enzymes and mucus to aid sperm transport and survival

Testes

The testes (singular: testis) contain tightly coiled seminiferous t[illegible]ules where sperma Surrounding these are interstitial (Leydig) cells, which s[illegible]re[illegible]testosterone. This hor male characteristics and maintains sperm prod[illegible]o

The optimum temperature fo[illegible]oduction is 2–3 °C lower than the body's ave 37 °C. This is bec[illegible]e i[illegible]s[illegible]temperatures can impair sperm count, motility and D testes are loca[illegible]side the body in the scrotum to maintain a cooler environment

Epididymis

Immature sperm, called spermatids, travel from the seminiferous tubules into the ep coiled tube located behind each testis. Sperm mature and are stored here until ejacu

Vas deferens

The vas deferens is a thick-walled duct made of smooth muscle that moves sperm towards the urethra using peristaltic contractions (similar to contractions through ejaculation.

Seminal vesicles

The seminal vesicles are glands that secrete a fructose-rich fluid that enables A movement and contributes significantly to semen volume. These secretions m the prostate.

Prostate gland

The prostate gland adds enzymes and alkaline fluid to semen, which enhances acidic environment of the vagina and optimising conditions for sperm survival.

Urethra

The urethra is a shared passageway for urine and sperm, but not simultaneously mechanisms prevent urine flow by closing off the bladder neck, ensuring only s

Penis

The penis is an external organ composed of erectile tissue. During arousal, it b erection, and enables penetration of the vagina to deposit sperm near the cervix centre of the penis and ejects semen at high speed during ejaculation.

Recall questions

1. Describe the contents of semen and the process and in order to create it.
2. Describe the functions of the hormone testosterone.
3. Explain why the testes hang outside the body.

Intersex individuals

Intersex individuals are born with biological sex characteristics, such as chromo hormone levels or external genitalia, that do not fit the typical definitions of m be visible at birth, emerge during puberty, or remain undetected without medi

Intersex variation reflects the natural diversity of human development and ma following categories:

- chromosomal variation, where individuals have unusual chromosomal pat
- ovary or testes (gonads) differences
- genital anatomical alterations
- hormonal pattern differences

Chromosomal variations

These involve atypical combinations or structures of sex chromosomes, includi

- XXY – Klinefelter syndrome
  Individuals typically have small testes and undescended testicles. They r reduced fertility and experience hormone imbalances.
- XO – Turner syndrome
  Affects females, who have a single X chromosome. Common features incl ovaries, and distinct physical features such as a webbed neck, low-set ear usually impaired.
- Mosaicism – some cells XY, some XX, or other combinations
  This arises through errors in mitosis after fertilisation and can result in a w hormonal outcomes.

Gonad differences

Gonad differences may include a combination of ovarian and testicular tissue (ovotestes), undescended or absent testes, or underdeveloped or non-functional gonads. Gonad structure influences hormone production and reproductive potential.

Genital anatomical differences

These may present as ambiguous genitalia, such as an enlarged clitoris, or micropenis involve the atypical placement of the urethra, such as in the condition hypospadias, is located on the underside of the penis, rather than at the tip.

Some individuals may have internal reproductive structures that differ from their ext For instance, in androgen insensitivity syndrome, individuals with XY chromosomes external genitalia internally possess undescended testes, and lack a uterus or ov Müllerian duct syndrome, individuals with male external genitalia may retain female as a uterus and oviducts.

Hormonal pattern differences

These involve disruptions in hormone production or receptor function. Androgen in when the body does not respond to male hormones (androgens), leading to feminise Congenital adrenal hyperplasia develops when there is excess androgen production and may cause external genitalia to have masculine features.

Sex, gender and developmental complexity

Sex refers to biological traits, such as chromosomes, hormones and anatomy that ar whereas gender refers to identity and social roles that the individual adopts, which their biological sex. Intersex individuals may identify as male, female, non-binary or non-intersex people do.

Human reproductive development is a complex, multistage process. All embryos beg develop both male and female anatomy. The presence of testosterone promotes ma absence leads to the formation of female structures. Therefore, disruptions in hormo sensitivity or gene expression can lead to mixed or atypical development pathways,

Recall questions

1. List the main types of intersex variations, and describe how individual's chromosomes, gonads, and external genitalia.
2. Describe how androgen insensitivity syndrome influences sex characteristics in individuals with XY chromosomes.
3. Describe the difference between biological sex and gende relate to the experiences of intersex individuals.

Practice questions: The reproductive system

1 Add the missing labels to the male reproductive organ diagram. (3)

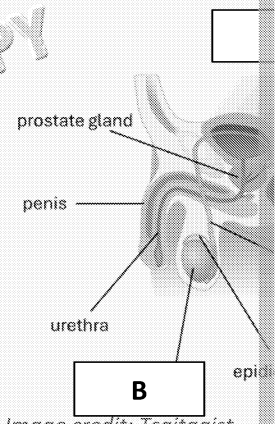


Image credit: Tsaitgaist.

3.3.2. Hormonal control of gametogenesis

Gametogenesis is the biological process by which gametes – ova and sperm – a
its core mechanism involves chromosomal reduction, gametogenesis is also a
events, influenced by signals from multiple endocrine glands.

In females, this regulation is orchestrated by four key hormones – follicle-stim
hormone (LH), oestrogen and progesterone. These hormones follow a cyclical
concentrations, guiding the maturation of ova, ovulation, and the preparation
potential embryonic development.

In males, testosterone plays a dominant role in maintaining spermatogenesis
contribute to the development and maintenance of secondary sexual charact
and LH.

This chapter explores the interplay between hormones and gamete productio
mechanisms, physiological changes, and the hormonal basis of reproductive h

Role of hormones in female reproduction

During foetal development, approximately 1 million immature ova (primary o
prophase I, remaining dormant until puberty. From the onset of the menstrua
a regular hormonal cycle causes the maturation of ova, ovulation, and prepar
implantation and embryonic development.

Hormonal control during puberty

The onset of puberty is driven by increased secretion of gonadotropin-releasi
hypothalamus, which stimulates the pituitary gland to release FSH and LH. The
oestrogen and progesterone.

Oestrogen promotes the development of secondary sexual characteristics inc

- develo breasts
- wid of hips
- prod ion of pubic and axillary (armpit) hair
- initiation of menstrual cycle

Progesterone supports the maturation of the uterus.

Hormonal regulation of the menstrual cycle

The menstrual cycle is governed by the interplay of four key hormones:

Hormone	Source	
Follicle-stimulating hormone (FSH)	Pituitary gland	Stimulates follicle d production
Luteinising hormone (LH)	Pituitary gland	Triggers ovulation a luteum
Oestrogen	g follicles in ovary	Thickens uterine lin stimulates LH surge
Progesterone	**Corpus luteum**	Maintains uterine l

Table F3.8. Source and functions of the four key menstrual h

This hormonal feedback creates a cyclical process, typically resulting in the release of one ovum per cycle, and the development of a thickened uterine lining that is suitable for implantation.

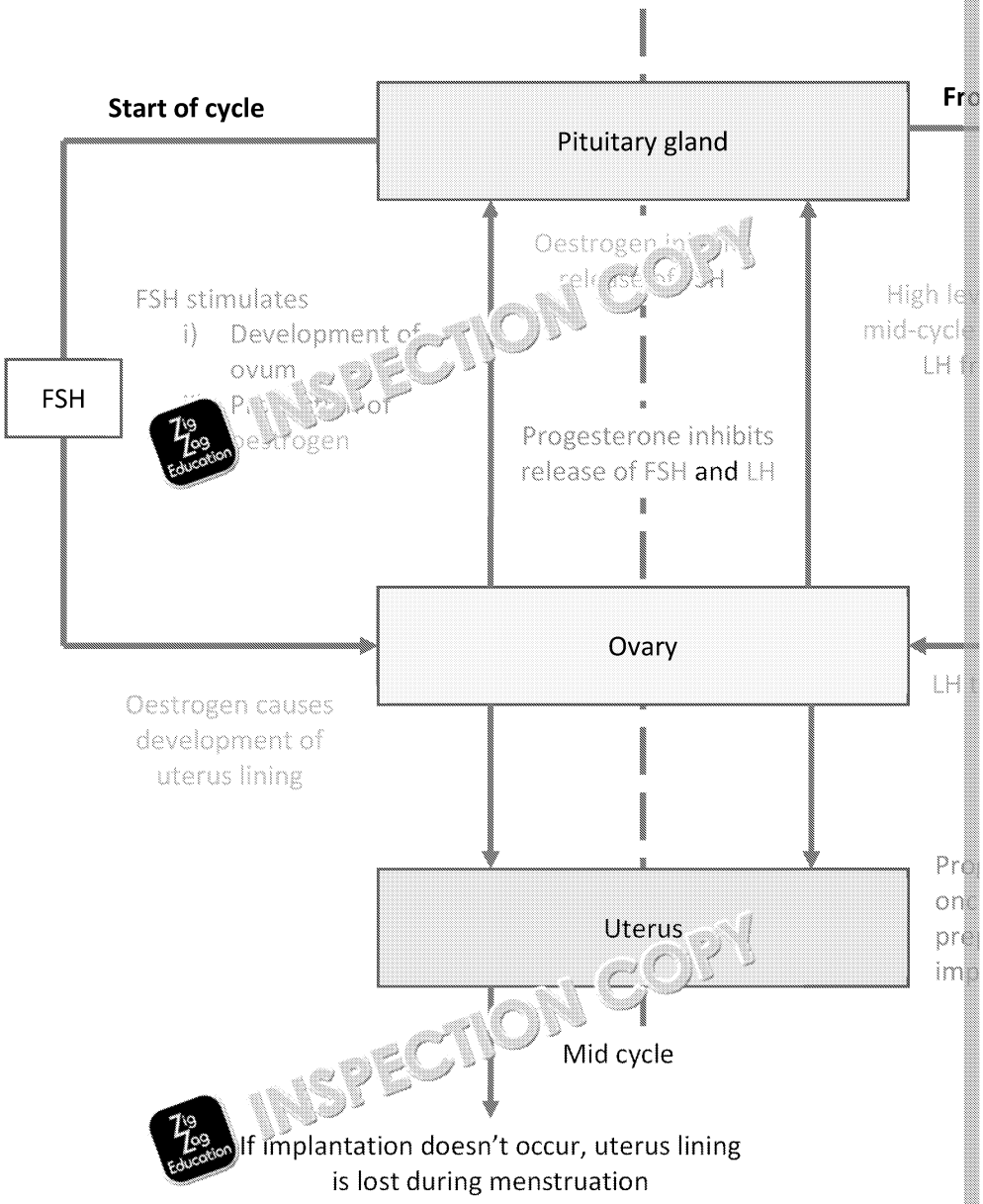


Figure F3.20. *Hormonal regulation of the menstrual cycle.*

Follicle-stimulating hormone (FSH)
FSH is released from the start of the menstrual cycle by the pituitary gland. It stimulates **follicle** maturation and the secretion of oestrogen.

Oestrogen
Release of oestrogen from the maturing follicle is stimulated by FSH. Oestrogen pro development of the uterine lining, but as oestrogen levels increase, it inhibits FSH.

Luteinising hormone (LH)
High levels of oestrogen at mid-cycle cause a surge of luteinising hormone (LH) from This induces ovulation and corpus luteum f n.

Progesterone
Progesterone i lly s ted by the ovaries and then by the corpus luteum – the when the ovu ased. Progesterone inhibits the release of both FSH and LH wh ovulation and m ains the uterine lining for implantation.

If fertilisation does not occur, progesterone levels decline, leading to menstruation.

However, if implantation does occur, progesterone levels remain high to support pr further ovulation.

Role of hormones at fertilisation

During fertilisation, progesterone is released by cells that surround the ovum. This attracts them to the ovum. Progesterone also enhances motility by attaching to channels in the sperm, crucial for successful penetration.

Once a sperm has attached to the ovum, enzymes in the sperm acrosome digest the ovum wall (see Ova, page 10). Granules in the ovum release enzymes to prevent multiple sperm entry (polyspermy). Fertilisation triggers mitotic division, which forms a ball of cells that implants into the uterine lining a few days after fertilisation.

Hormonal regulation during pregnancy

Throughout pregnancy, levels of progesterone remain high. This maintains the uterine lining and LH prevents ovulation, preventing further ovulation.

Other hormones are essential for successful pregnancy. Human chorionic gonadotrophin from the developing placenta. This maintains the corpus luteum during early pregnancy, ensuring progesterone production; both hormones are essential for maintaining the uterine lining. hCG is used in pregnancy tests as it is present from very early pregnancy in detectable quantities.

Oestrogen stimulates uterine expansion and prepares the body for labour and **lactation**. Human placental lactogen (hPL) supports mammary gland development, critical for lactation after birth, and adjusts maternal metabolism to support foetal development.

Lastly, once the placenta is formed, placental growth hormone replaces maternal GH to support foetal development.

Hormonal control during birth

Towards the end of pregnancy, progesterone levels decline, which removes inhibition on the uterus.

Another hormone involved is oxytocin, released from the posterior pituitary gland. This creates a positive feedback cycle, causing contractions to intensify as labour progresses.

In addition, the hormone relaxin is produced by the placenta and the corpus luteum. It softens ligaments in the pelvis, facilitating birth.

Evolutionary reasoning for periodic ovulation

In mammals, ovulation occurs at regular intervals, and in humans this typically occurs every 28 days. This periodicity reflects evolutionary compromises, balancing the need for fertility with the substantial metabolic and physiological costs of reproduction.

Female reproduction requires the coordinated action of multiple hormones, signalling uterine tissue development to support follicle maturation, ovum release and uterine preparation. Limiting opportunities ensures that these processes are only activated when conditions are favourable.

Furthermore, embryonic survival depends not only on ovum availability but also on the uterine internal environment. Cyclical separation between ovulation and the development of the uterus for implantation can occur under optimal conditions, improving reproductive efficiency.

In species with long **gestation** periods and postnatal care, like humans, continuous ovulation would increase the risk of simultaneous pregnancies. This is unsustainable because of the physical demands of carrying a foetus and the high level of care required after birth for the baby.

Periodic ovulation also influences behavioural patterns. In humans and several other
changes around ovulation slightly alter mood, scent and physical appearance, which
and increase mating success.

Humans have evolved to produce fewer offspring with a higher probability of survival
offspring with limited survival odds and parental investment (as seen in species like
strategy is supported by controlling the number of ova released, restricting the period
availability, and regulating hormones to align maternal behaviours, lactation and social
these features maximise the success of each reproductive event while conserving bio

Recall questions

1. List the four key reproductive hormones and state where they are produced and their main roles.
2. Describe how the four key hormones interact to regulate the menstrual cycle and ovulation in females.
3. Describe how hormones support pregnancy and how they change during gestation at each stage.
4. Describe the evolutionary advantages that periodic ovulation

Role of hormones in male reproduction

The process of spermatogenesis starts at the onset of puberty and continues throughout life. It is controlled by the interaction of hormones from the hypothalamus, pituitary gland and testes.

Hormonal control during puberty

Puberty begins when the hypothalamus increases secretion of gonadotropin-releasing hormone (GnRH), which stimulates the anterior pituitary gland to release follicle-stimulating hormone (FSH) and luteinising hormone (LH).

FSH and LH act on the testes, which begin secreting testosterone, initiating the development of secondary sexual characteristics:

- deepening of the voice due to growth of the larynx (voice box)
- production of pubic, axillary and facial hair
- enlargement of the penis and testicles
- increased muscle mass and bone density
- broadening of the shoulders

Hormonal role in spermatogenesis

Spermatogenesis requires the coordinated action of FSH, LH and testosterone:

- FSH stimulates cells in the seminiferous tubules to support sperm cell maturation. These cells release a hormone called inhibin, which provides negative feedback to the pituitary gland, inhibiting production of FSH, thus regulating FSH levels.
- LH stimulates Leydig cells to produce testosterone.
  Testosterone promotes spermatogenesis and maintains sex drive and secondary

To produce sperm, stem cells lining the seminiferous tubules of the testes undergo mitotic divisions to expand their population. Some of these cells then differentiate into primary spermatocytes and enter meiosis:

- Meiosis I forms haploid secondary spermatocytes (23 chromosomes).
- Meiosis II produces spermatids, each genetically unique due to crossing over and

Spermatids travel to the epididymis, where they transform into mature spermatozoa with acrosomes. They are stored for up to several weeks.

This process produces large quantities of sperm, each genetically distinct from each

Evolutionary reasoning for continuous sperm production

Continuous sperm production reflects an evolutionary strategy where sperm p
(egg cell production), requires less energy, fewer nutrients and fewer hormon
produce millions of sperm daily throughout adult life.

Male fertility benefits from being unrestricted by reproductive cycles. In huma
reproduction is regulated by female physiology, due to the greater demands o
postnatal care – the majority of resources are required for the female.

As a result, the male strategy of continuous sperm production increases the lik
males can father multiple offspring.

This evolutionary pattern has further selected traits such as high sperm counts
competitiveness, and secondary sexual characteristics, including muscular dev
hair, which shape sexual selection and competition for mates.

Together, these adaptations reflect a reproductive model adapted for maximis
while minimising resource and energy requirements per gamete.

Recall questions

1. List the main hormones involved in male sexual dev
where they are produced and their main roles.
2. Describe how these hormones work together to reg
male sexual development.
3. Describe the process of spermatogenesis and expla
sperm is significant.
4. Outline the evolutionary advantages that continuou
males in terms of reproductive success.

Role of hormones in intersex individuals

Hormones play a central role in shaping the development and physiology of in
hormones depend not only on their levels, but also on the existing gonad struc
receptor sensitivity. In intersex individuals, the type and responsiveness of go
hormones are produced and how they act (see page 148).

Recall questions

1. Describe why the hormones produced and the effec
intersex individuals.

3.3.3. Reproductive changes during ageing

Ageing brings a range of physiological changes, including slower tissue repair,
hormone regulation. As the body becomes less capable of supporting gestatio
females, biological mechanisms have evolved to limit reproduction to the mos

In females, menopause marks the end of natural fertility, reflecting a shift tow
over continued ovulation. This enables females to support others in pregnancy

Male reproductive function also declines with age, though less abruptly. Chang
and motility, lower testosterone levels, affecting sex drive and sexual function,
in the prostate gland, which can impair both ejaculation and urination.

This chapter explores how reproductive systems change through ageing and c
contribute to overall biological and evolutionary fitness.

Menopause

Menopause is defined as the permanent ending of menstruation, diagnosed after 12 without a period. It typically occurs between the ages of 45 and 55, with an average

It is caused by ovarian ageing and hormonal changes. Specifically, a decline in the nu ovarian follicles, and the reduction in secretion of oestrogen and progesterone.

Symptoms of menopause vary, but include hot flushes and night sweats, vaginal dry pain and osteopenia, thinning hair and dry skin. These symptoms can be managed by including hormonal, non-hormonal and surgical approaches.

Hormone replacement therapy (HRT) replaces declining oestrogen and progesterone flushes, vaginal dryness and mood changes. It also helps prevent osteoporosis but m breast cancer, blood clots and stroke, depending on the type of therapy and for how

Non-hormonal therapies include antidepressants to help control mood and hot flush vaginal lubricants for dryness.

Surgical responses seek to preserve and reimplant ovarian tissue, thus delaying men hormone production, but is experimental.

Lifestyle interventions like a well-balanced diet, sufficient exercise, and stopping smo timing of menopause and the severity of symptoms.

Your turn

1. State the average age at which menopause usually occurs and the conditions tha menopause to be diagnosed.
2. Describe the main physiological changes that occur during menopause and how
3. Discuss the benefits and potential risks associated with hormone replacement th menopausal symptoms.

Pregnancy later in life

In Britain, the trend over recent decades has been towards delayed parenthood. The mothers in the UK has risen from approximately 23 years in the 1950s, to 29.2 years the average number of children per woman was around 2.4, but this has fallen to 1.7 pattern is mirrored across many developed nations.

Risks associated with later pregnancy

Pregnancy at older maternal ages is associated with increased risks, including:

- reduced fertility due to declining egg quality and quantity
- higher chance of miscarriage
- increased likelihood of complications during pregnancy, such as gestational diab
- foetal chromosomal abnormalities (e.g. Down's syndrome)
- greater chance of delivery by Caesarean section, which carries greater risk than recovery time and temporary impairment of mobility and function while the su
- lower energy levels, which can affect day-to-day caregiving

Advantages of later parenthood

Despite the risks, later-life parenting offers several potential benefits:

- emotional maturity and a greater psychological readiness
- stable relationships and increased likelihood of co-parenting support
- financial security, which makes childcare, education and enrichment acti
- life experience, which may enhance resilience and problem-solving in pa
- cognitive stimulation, which may lead to impro bal memory and e demands of parenting

Recall questions

1. Describe some potential advantages and disadvanta later in life, and how this might impact family dynam

Changes in the male reproductive system

As males age, the reproductive system undergoes gradual structural and funct hormonal shifts of female menopause, male reproductive ageing is typically s affect fertility, sexual function, and urinary health.

One notable change is a reduction in testicular volume and the number of Ley testosterone. From around the age of 30, testosterone levels decline at an av contributing to several effects. Along with fewer germ cells (cells that give ris testosterone slows spermatogenesis, leading to reduced sperm count and mo

Damaged DNA in sperm increases with age, raising the risk of miscarriage and Achondroplasia (unusually short stature), autism spectrum disorders, and Do to increased paternal age.

Declining testosterone levels may red drive and impair sexual function due to decreased blood flow th s, which also increases ejaculation tim

In addition e and vas deferens lose elasticity, reducing the effic storage, ntributing to reduced semen volume.

Prostate hypertrophy

Benign prostatic hyperplasia (BPH) affects about one in every two men over t hypertrophy (excessive growth) of prostate tissue, leading to enlargement of t compresses the urethra, resulting in urinary symptoms such as difficulty start urine stream and incomplete bladder emptying, causing more frequent urinat

An enlarged prostate may also reduce semen flow, or cause dry ejaculation, w released. Additionally, it may increase the risk of urinary tract infections, due t to colonise the urethra. In severe cases, this can lead to kidney complications bladder and ureter.

Recall questions

1. State the population fr cy nd approximate ag prostatic hype as (BPH).
2. Des e symptoms and possible complications ing males.
3. Explain how age-related changes in the male repro fertility and sexual function.

Practice questions: Reproductive changes during ageing

1 Analyse the advantages and disadvantages of becoming a parent later

Topic 4: Basics of microbiology

4.1. Microbes

4.1.1. Features of bacteria found in human

Certain species of bacteria can colonise various regions of the human body, sometim
disease. However, not all bacteria are harmful and many have essential roles in dige
maintaining a healthy microbio

A deeper unde ing of bacterial structure and function helps us to interpret how
diagnosis after ion, and determines which treatments are likely to be most suc
explores the key features of bacterial cells and how they are classified.

Cell components of bacteria

Bacterial cells consist of several components, although not all features are present i
Each component has a specific role in the survival, adaptation, and reproduction of

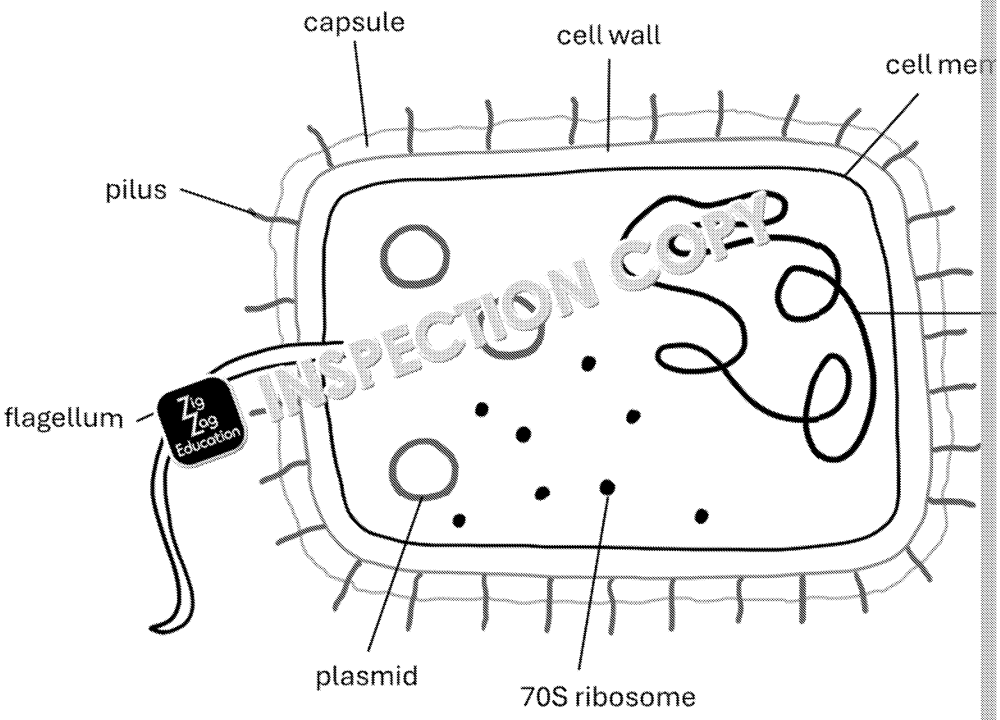


Figure F4.1. *Prokaryotic subcellular structure.*

Capsule / Slime layer

Some bacteria produce an outer capsule or slime layer. This provides protection aga
immune responses and helps adhere to surfaces.

Peptidoglycan cell wall

The bacterial cell wall, mainly made of peptidoglycan, provides mechanica
It protects aga vi mental fluctuations in pH, water availability and salinity. G
Gram-negative ages 158–159) bacteria differ in wall thickness and membrane

Cell surface membrane

Located beneath the cell wall, this phospholipid bilayer contains embedded protein
waste removal, and intercellular signalling. It also facilitates attachment to host cell

Cytoplasm

The cytoplasm is the site of metabolic activity. It contains water, dissolved so
reactions, including respiration and biosynthesis.

70S ribosomes

Bacterial ribosomes, which are smaller (70S) than those in eukaryotes (80S), c
translating mRNA into polypeptides. Their similarity to
supports endosymbiotic theory.

DNA loop

Bacterial DNA forms
genes re
function and replication.

Plasmids

Plasmids are small circular DNA fragments carrying non-essential but advanta
resistance. They are widely used in genetic engineering due to their ease of m

Mesosomes

Mesosomes appear as membrane infoldings in electron micrographs but are
to be **artefacts** from sample preparation. Historically, they were considered
functional structures, but their existence and function are now debated.

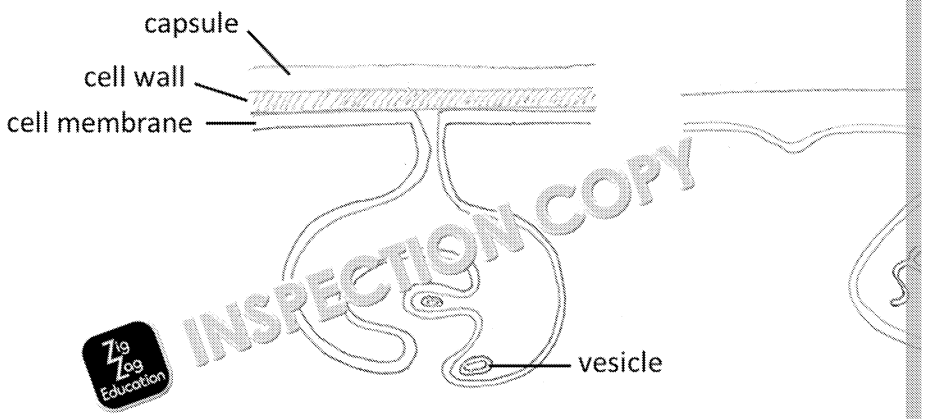


Figure F4.2. *Mesosomes appear as membrane infoldings but are*

Rotary-like flagellum

Flagella are very fine threads called filaments, driven by a rotatable motor em
which enables motility without the 9+2 microtubules structure seen in eukary

Gram staining

Gram staining is a staining technique used to classify bacteria based on the cell wall structure. Gram-positive and Gram-negative bacteria differ in their appearance under the microscope and their susceptibility to antibiotics.

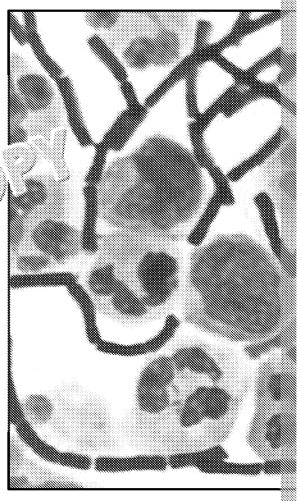


Figure F4.3. *A*
anthrax ba

Gram-positive bacteria

Gram-positive bacteri
rich cell
retains
appear p
These bacteria are usually susceptible to the antibiotic penicillin, which inhibits peptidoglycan synthesis. Common examples include *Bacillus*, *Clostridium*, *Staphylococcus* and *Streptococcus*.

Gram-negative bacteria

Gram-negative bacteria have thinner peptidoglycan walls, but a high lipid content in membrane, similar to the inner cell membrane.

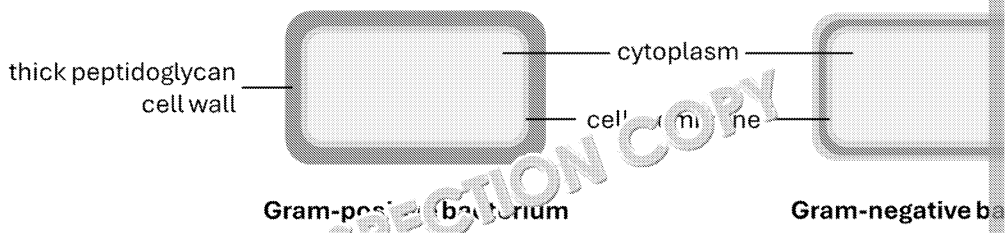


Figure F4.4 *...g... showing the differences in the cell wall and membranes of Gram-positive*

As a result, the crystal violet stain is lost during alcohol wash, and a second counterstain, typically safranin, is used to stain them red or pink (see Staining specimens, page 22). These bacteria are resistant to penicillin because of their cell wall so other antibiotics must be considered. Examples include *Salmonella*, *Escherichia* and *Azotobacter*.

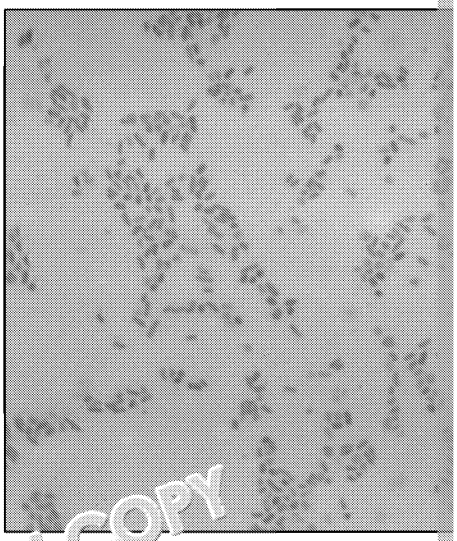


Figure F4.5. *A photomicr... Bacteroides fragilis ss. vulgat...*

Classification of bacteria

Bacteria are classified based on their **morphology**, specifically the shape and arrangement of their cells:

- Coccus (plural: cocci) – spherical or oval
- Bacillus (plural: bacilli) – rod-sh...
- Spiral – twisted or curv...

This allows ide...ion and understanding of their environmental adaptations and behaviour, and to quickly determine their pathogenic significance.

Cocci

Cocci bacteria are spherical or oval, and may be arranged individually (*Monococcus*), in pairs (*Diplococcus*), in chains (*Streptococcus*), or in clusters (*Staphylococcus*) like grape bunches.

These bacteria are often involved in respiratory, skin and bloodstream infections, and include *Streptococcus pneumoniae,* which causes pneumonia, and *Staphylococcus aureus*, responsible for many infections including skin infections, sepsis and toxic s...k syndrome (a ra...t su...s condition often associate...prolonged use of menstrual tampons).

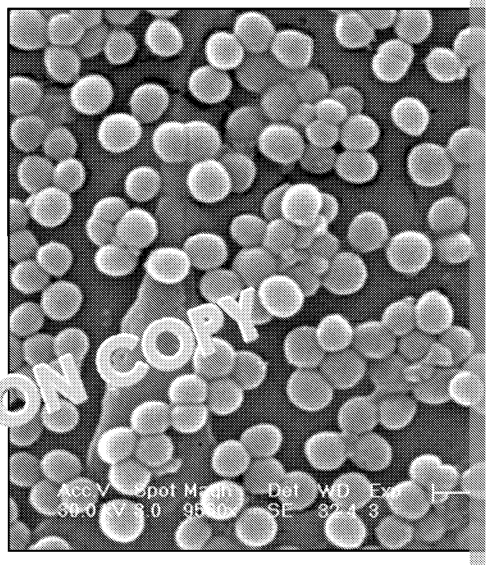


Figure F4.6. *Scanning electron microgr... Staphylococcus aureus (MRSA)*

Bacilli

Bacilli bacteria are rod-shaped and may be found individually or in chains. They are found in gut flora (*Bacillus subtilis*), but some species cause food poisoning (*Escherichia coli*) or anthrax (*Bacillus anthracis*).

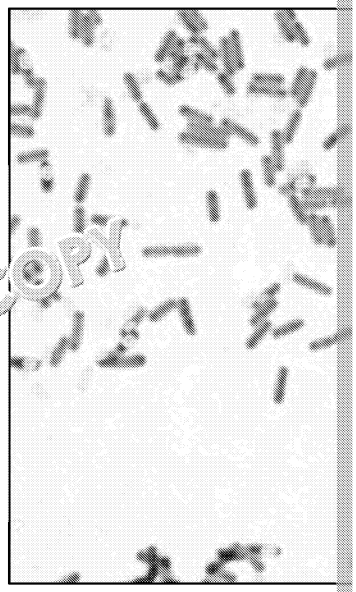


Figure F4.7. *Light micrograph o*

Spiral

Spiral bacteria may form rigid spirals with external flagella (*Spirillum*), flexible spirals with internal flagella (*Spirochete*), or comma-shaped (*Vibrio*).

These bacteria are often motile because of the presence of flagella, and are associated with chronic infections, such as syphilis (*Treponema pallidum*) and cholera (*Vibrio cholerae*).

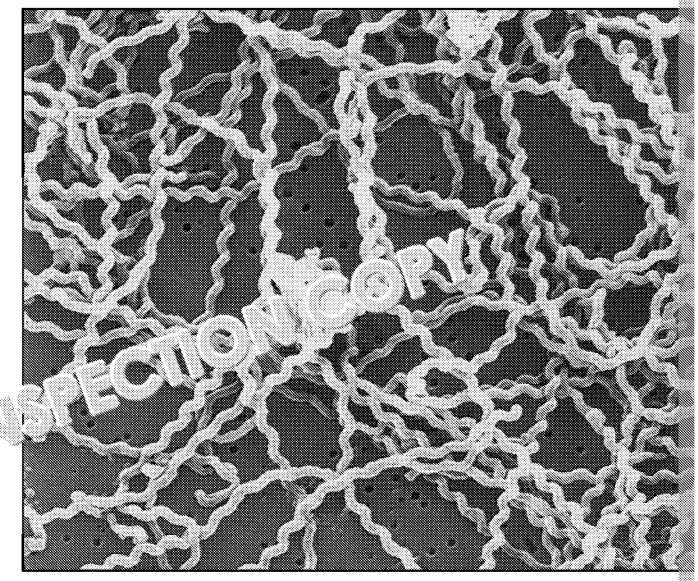
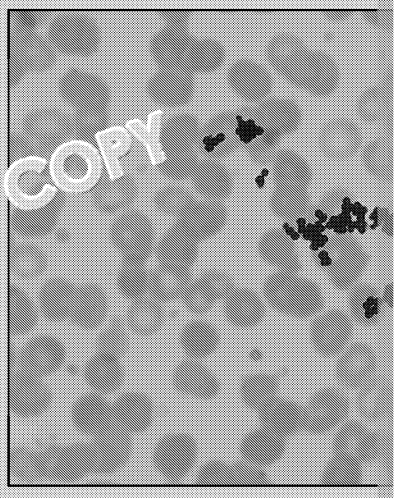


Figure F4.8. *Scanning electron micrograph of Leptospira sp. bacteria, a f*

Apply your knowledge

1. State what a plasmid is.
2. Describe how Gram staining distinguishes between Gram-positive and Gram-negative bacteria and how structural differences in their cell walls leads to this.
3. Describe the different bacterial shapes used for classification and provide an example of a disease condition associated with each type.
4. Use classification information to identify the type of bacteria in the image of a blood smear.



Practice questions: Features of bacteria found in humans

1 The bacteria in the image below is commonly found within the gut microbio
collected from the environment, such as soil or water.

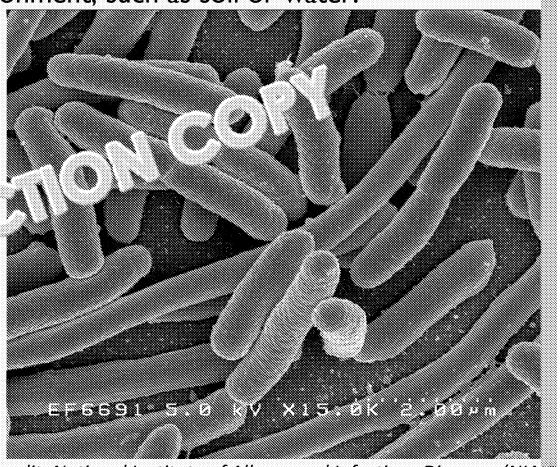


Image credit: National Institute of Allergy and Infectious Diseases (NIAID)

Classify the bacteria according to its shape [1].

4.1.2. Features of fungi found in humans

Fungi may be unicellular or multicellular eukaryotic organisms, and they play v
pathogens and symbionts. They digest organic material extracellularly using s
nutrients across their cell surfaces.

This chapter explores the cellular structure and function of fungal component
common fungal infections relevant to human biolo

Structure and function of fungal components

Fungal cells share se a d tinctive components, each with specialised roles
survival h, reproduction.

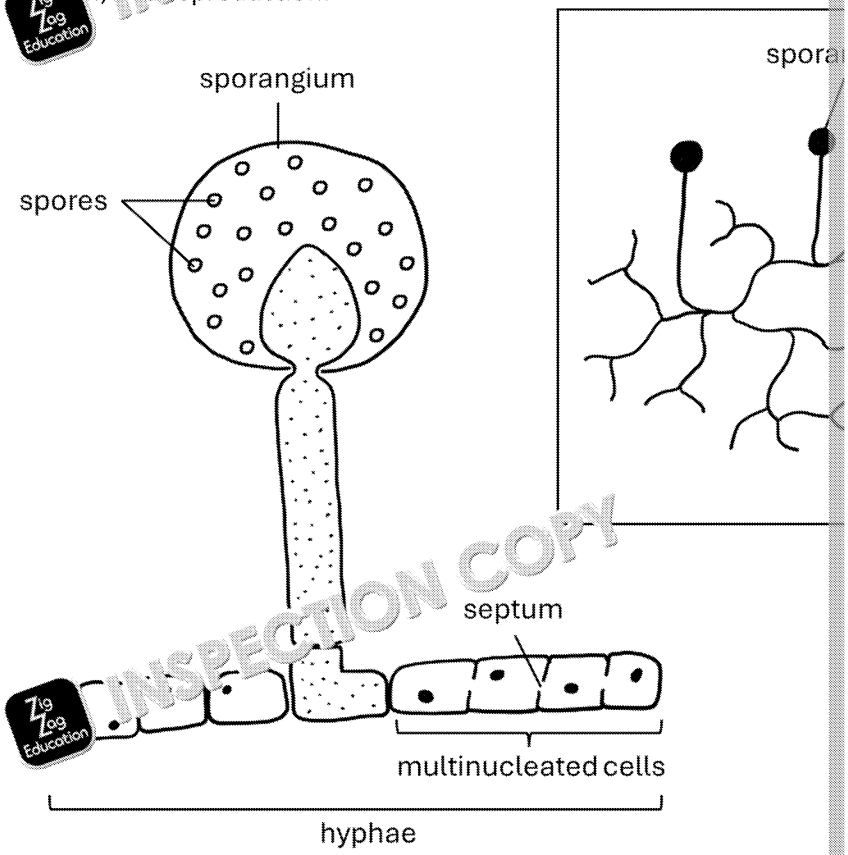


Figure F4.9. *The parts of a fungus in overview and close-u*

Cytoplasm

The cytoplasm contains essential organelles such as nucleus, mitochondria an
action, nutrient processing and intracellular transport, while also helping to m
metabolic functions.

Chitin cell wall

Fungal cell walls are primarily composed of chiti a ug polysaccharide als
This provides rigidity, structural integrity d rotection from environmental
availability and salinity.

Septum

Septa (si septum) are internal cross-walls that separate hyphae into co
allow cytoplasm to move between cells (called cytoplasmic streaming), enabli
organelles, molecules, and ions. They also enable the isolation of damaged re
fungal network.

Hypha

Hyphae (singular: hypha) are thread-like filaments that form the basic structure of m
colonise substrates, secreting hydrolytic enzymes to digest organic matter, which is t

Hyphae may be septate (divided) or aseptate (undivided).

Mycelium

A mycelium (plural: mycelia) is a dense, interconnect ... et ... rk of hyphae. It forms
and provides a large surface area for enzym... ...es... ...n and nutrient absorption. It
structures and serve as a base for sp... ...tion.

Spores

Spores are spe... reproductive units, produced sexually or asexually. They are d
animals. The spore's outer layers protect it from extreme conditions, increasing surv
and enabling colonisation in new habitats.

Recall questions

1. State the main role of chitin in fungal cell walls.
2. Describe the function of hyphae and explain how they con
survival of fungi in their environment.
3. Explain how septa benefit fungi.

Types of fungi

Fungi may be parasitic or saprophytic:

- Parasitic fungi – live off a living host:
  - endoparasitic – living inside the host ... d... e nutrients from host tissues
  - ectoparasitic – living outsid... ..., colonising external surfaces of the b
- Saprophytic fungi – dec... ..., digesting dead organic matter, sometimes o

However, class... ...ns overlap, for example *Candida albicans* is both saprophytic a
on context.

Type of fungus	Location in/on body	Key characteristics
Endoparasitic	• Deep tissues • Bloodstream • Lungs	• Invasive growth • Causes systemic (body-wide) infections • May evade immune detection
Ectoparasitic	• Skin • Nails • Hair	• Digest keratin • Cause superficial infections • Often transmissible by contact
Saprophytic	• Skin surfaces • Mucous membra...	• ...na... harmless ... become pathogenic when immune defences are low

...F... Details of endoparasitic, ectoparasitic and saprophytic fu

Recall questions

1. Use the key characteristics of fungal type to explain why e
are less harmful than endoparasitic fungi.
2. Explain why people taking immunosuppressant drugs or w
may succumb to a saprophytic fungal infection.

Common fungal diseases

Fungal infections in humans vary in severity and location, ranging from superf
threatening systemic illnesses.

Aspergillosis

Aspergillosis refers to a group of diseases caused by inhaling spores from *Aspe*
moulds commonly found in soil, compost, decaying v tation and dust. These
healthy individuals but may opportunistically colonise the respiratory system i
conditions or weakened immune fu ction.

Common symptoms i t persistent cough which may include blood or thi
and whee fe fatigue, and weight loss.

Allergic bronchopulmonary aspergillosis (ABPA)

ABPA results from an allergic reaction to inhaled spores and primarily affects t

Chronic pulmonary aspergillosis (CPA)

CPA is a long-term lung infection that may lead to cavity formation or fibrosis (
those with COPD or a history of tuberculosis.

Aspergilloma

This condition results from a fungal ball growing in a pre-existing lung cavity. It
affects those with other past lung infections.

Invasive pulmonary aspergillosis (IPA)

IPA occurs when a lung infection spreads into lung tissue and beyond. It is a lif
generally affects immunocompromised individuals, su h as those receiving che
immunosuppressed post-transplant.

Vaginal candidiasis

Vaginal candidiasis, also known as vaginal thrush, is a very common fungal infe
especially *Candida albicans*. Usually, this fungus exists harmlessly as part of the vagin
overgrowth cause infection if the balance is disturbed. Antibiotics, hormonal
suppression may all cause disruption.

Symptoms include itching and soreness of the vulva and vagina with a thick, w
usually odourless. Individuals can experience a burning sensation during urinat
be redness or swelling in more severe cases.

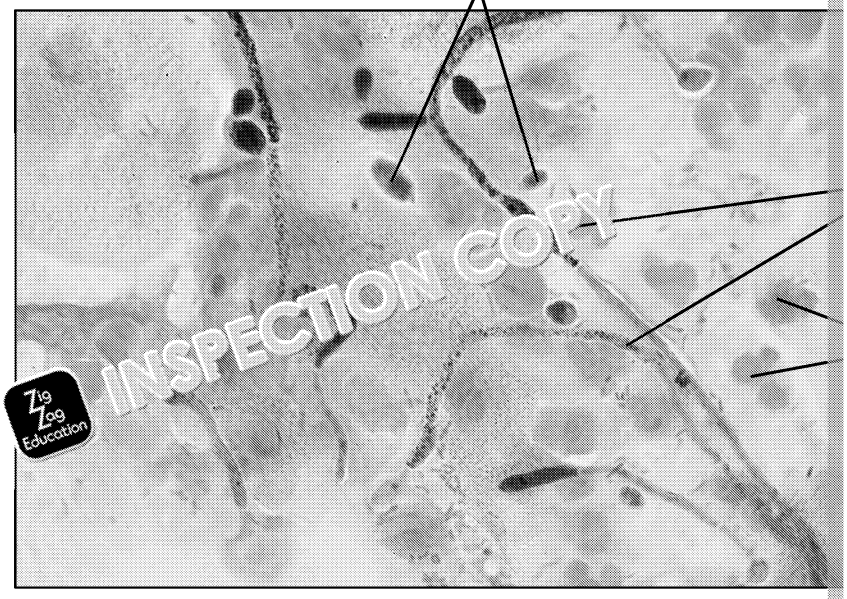


Figure F4.10. *A high-powered light photomicrograph of Candida albicans fr*

Athlete's foot

Athlete's foot, or tinea pedis, is a highly contagious skin infection, caused by the *Tine* in damp, warm environments, and digest keratin. It is common in individuals who fre and use communal areas like gyms, pools or changing rooms.

It is spread by direct skin contact or contact with contaminated surfaces such as sho

Symptoms include an itchy, white or red scaly rash, with cracked or peeling skin. It m of the feet or toenails, and in severe cases can cause blisters.

Recall ques

1. Describe the factors that can increase an individual's risk o aspergillosis and explain how the various forms of this co in severity.
2. Describe the causes and typical symptoms of vaginal candi why this infection might occur even in healthy individuals.
3. Explain how athlete's foot is spread among people and de conditions that make transmission more likely.

4.1.3. Bacteria of the human body and beyond

Recognising the normal distribution of bacteria within the human body is crucial for u diagnosing infection. Equally, being aware of where bacteria are in our surroundings, and water, helps us minimise exposure to harmful strains.

This chapter explores the locations of bacteria in and around the human body and h collected and cultured from the external environment. By the end, you will appreciat organisms are essential to human biology and impact our environment, and key mic

Bacteria in the human body

The human body hosts trillions of bacteria, collectively known as the human microbi communities are essential for digestion, immune function and protection against pat they are harmless or beneficial, but disruption can lead to infection or disease.

Skin surface

The surface of the skin is colonised mainly by Gram-positive bacteria, including *Staph Corynebacterium* and *Cutibacterium acnes*. They are adapted to dry, salty and acidic competitive barrier that prevents colonisation by harmful bacteria. Imbalances in the contribute to skin conditions such as acne.

Conjunctiva

The conjunctiva forms the surface of the eye and provides an important barrier betw environment and the delicate internal eye structures. It is hostile to microbes due to tears and mechanical cleaning by blinking.

However, some bacteria including *Staphylococcus aureus*, *Staphylococcus epidermid* sparsely colonise the surface, and disruption to the microenvironment can lead to co the conjunctiva or keratitis (inflammation of the cornea).

Mucous membranes

Mucous membranes are present in the mouth, nasal passages, respiratory tra
surfaces are covered in mucus which traps pathogens and supports antimicro
has specific adaptations:

- oral cavity – saliva contains enzymes and antimicrobial peptides
- nasal passages – lined with hairs which filter incoming particles
- trachea – lined with ciliated epithelial cells which ... mucus up to the
- vagina – acidic environment (~pH 4.5)

These adaptations are enh... by the microbiome – rich in *Lactobacillus, Str*
Veillonella species ... compete potential pathogens for space and nutri

Teeth a... cavity

The teeth and mouth are constantly exposed to microbes from food, air or co
saliva incorporates pH buffers which resist changes in pH and contains antimi

However, bacteria persist as **biofilms** called dental plaque, which contain *Streptococcus mutans, Lactobacillus* and *Actinomyces*. These bacteria quickly colonise teeth and gums because carbohydrates from food provide energy fo bacterial metabolism, which leads to acid production, causing dental decay.

Gastrointestinal tract (colon)

The colon hosts one of the densest microbiomes in the body, including *Bacter Clostridium, Firmicutes* and *Lactobacillus*. These have essential functions, inclu carbohydrates, synthesising some vitamins (e.g. the B and K groups), and sup to identify pathogens.

Disruption in the microbiome is linke... ...ammatory bowel diseases and ga

Reproductive tra...

The vagi...int... a protective microbiome dominated by *Lactobacillus*. Th which ke... vaginal pH at around pH 4.5. This environment discourages p with organisms like *Candida* and *Gardnerella*. The flora composition fluctuates menstrual cycle and sexual activity.

Renal tract

The renal tract is normally sterile from the kidneys to the bladder, although th have low numbers of harmless bacteria. Urinary tract infections (UTIs) usually *Klebsiella* species of bacteria and their presence is normally indicated by a bu coupled with increased frequency and urgency.

Your turn

1. List the types of bacteria that commonly c...lo... the skin surface.
2. Describe the role that skin ba... a... ...n protecting against harmful mic
3. List the adaptations th... ...el... ...ucous membranes defend against pathog
4. Explain the i... ...t the oral microbiome has on dental health.
5. Exp... ...w the composition of the vaginal microbiome changes and why ... for m... ...aining a healthy environment.

Bacteria in the external environment

Bacteria inhabit virtually all environments on Earth, including some of the most extre
pathogenic, many have essential ecological roles such as nutrient cycling and decom

Air

Most airborne bacteria actually spend most of their life in wate the soil or attached
travel attached to dust particles, skin cells or droplets and include *Micrococcus*, *Sta*
Airborne transmission can spread respiratory d se like tuberculosis, caused by *M*

Water

Aquatic bacteri b ed for freshwater, seawater or wastewater, and are u
habitats. They olved in nutrient cycling, nitrogen fixation, and the breakdown
called bioremediation), and include *Pseudomonas* and photosynthetic *Cyanobacteri*
green algae).

Pathogens like *Vibrio cholerae* may cause gastrointestinal infections marked by seve

Soil

Soil is one of the richest and biologically diverse habitats in the world, containing bil
Soil bacteria support plant growth, nitrogen fixation, nutrient cycling, decompositio
Rhizobium species attach to legume root nodules in nitrogen-fixing plants, but many
exist in soils, including *Actinomycetes*, *Streptomyces* and *Bacillus*.

Clostridium species are anaerobic that can survive harsh conditions. Some are notab
C. botulinum that causes botulism, *C. tetani* that develops into tetanus, and *C. perfri*
poisoning and gas gangrene.

Plant surfaces

Leaves and roots host **epiph** a. They often work symbiotically with the ho
to assist nutrient tak as at root nodules), protect against pathogens or
support growt mon species include *Pseudomonas*, *Agrobacterium* and *Erwini*

Animal surfaces

All animals host harmless or symbiotic bacteria on their feathers, fur, skin, or mucou
only become pathogenic if displaced – for instance, gut bacteria on the conjunctiva

Zoonotic pathogens such as *Salmonella, Campylobacter* and *Brucella* can be transferred between animals and humans through direct contact or contaminated materials.

z
tra

Your turn

1. Create a summary table comparing the habitats, ge ra bles and pathogenic po different bacteria.

Collecting environment bacterial samples

When analysing bacteria from the environment, samples must be collected and st

- contamination by microorganisms not present at the sampling site (e.g. p when the soil is the environment being sampled)
- exposure to potentially pathogenic organisms, especially anaerobic speci during culture

Therefore, to protect the reliability of the sam le and reduce the risk to healt carefully and thoroughly applied.

Collecting samples

To collect samples from the environment:

Sample source	Collection method	
Water	Use a sterile pipette or sampling syringe to transfer the water into a sterile screw-cap tube (e.g. McCartney bottle or Falcon tube)	• Ensure t clearly l • Transpo
Surfaces	• Wipe the surface using a sterile cotton swab in firm strokes • Avoid touching other objects	• Place in transpo • Refrige
Soil	Use a sterile corer or spatula to extract a soil sample from beneath the surface layer	Store in steri exposure if a

Table F4.2. Methods for collecting samples from water, surface

Aseptic technique in sampling

Aseptic means without contamination. Aseptic techniques aim to prevent the introduction of microorganisms to the sample other than those that were pre within the environment originally, thus not contaminating the sample.

The key principles of aseptic technique when sampling are:

- Using sterile equipment, including all tools (swabs, tubes, pipettes, co
- Good personal hygiene, including wearing disposable gloves, tying back hair, and avoiding touching sample areas unnecessarily.
- Accurate sample labelling and storage, including labelling with date, locat and sampling method, and transporting the sample promptly back to the overgrowth or death of **fastidious species** that have complex and specific

Advantages and disadvantages of sampling bacteria from the enviro

Sampling bacteria from the environment can be challenging but provides usef

Advantages	D
• Helps study biodiversity and ecological roles of microbes • Supports identification of pathogenic or beneficial species • Enables monitoring of pollution levels and microbial contamination • Provides data for bioremediation, antibiotic research or soil	• Environmental v difficult to contr • Some species ca conditions • Risk of culturing anaerobes • May require spe sustain growth

Table F4.3. Advantages and limitations of sampling bacteria from th

Recall questions

1. List the key steps and precautions required to maint when collecting bacterial samples from different en
2. Identify and explain two advantages and two disadv bacteria from the environment.

4.1.4. Reproduction and culture of bacteria

Microorganisms reproduce extremely quickly, sometimes in as little as 20 minutes, a
too. Understanding how bacteria replicate and exchange genetic information is esse
growth, antibiotic resistance, and industrial culturing practices.

In this chapter, we explore binary fission and asexual reproduction in bacteria, and i
environmental conditions influence growth dynamics. We also explore horizontal ge
an important evolutionary mechanism that allows bacteria to share survival-enhanc
underpin laboratory techniques such as culturing bacterial cells on agar and liquid m
microbiology, biotechnology, and medical diagnostics.

Bacterial reproduction

Bacteria reproduce asexually through a process called binary fission. Unlike mitosis i
simpler but still involves DNA replication, cytokinesis and cell separation. Binary fiss
identical offspring, unless mutation occurs during DNA replication.

The steps of binary fission are:

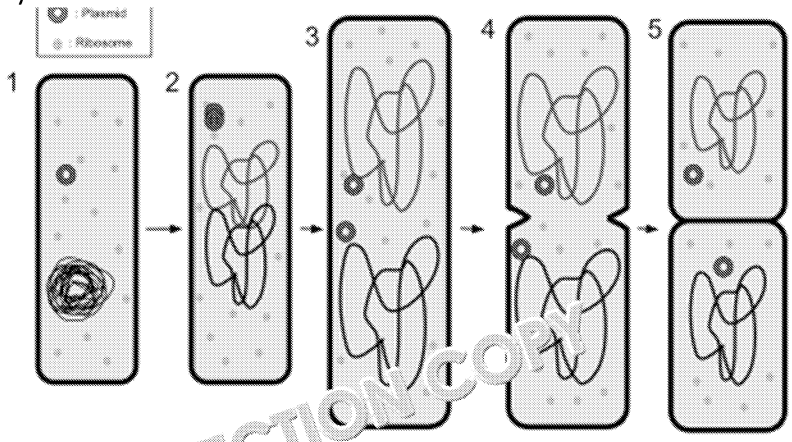


Figure F4.11. *The steps of binary fission.*

1. Bacterial cell contains DNA stored as a circular nucleoid and in plasmids.
2. The circular DNA molecule replicates once; plasmids replicate at least once.
3. The copies of the circular DNA molecule move to opposite poles of the cell. Plas
   randomly between the poles.
4. Cell elongates and the membrane pinches inwards.
5. A new cell wall forms between the two DNA molecules.
6. Cytoplasm divides into two roughly equal daughter cells, containing the same D
   of plasmids.

Estimating population size

If each bacterium divides at regular intervals, we can estimate future population size

$$\text{number of bacteria} = 1 \times 2^n$$

where n = number of divisions

Worked example:

A bacterium takes 1 hour to reproduce. Calculate the population size after 9 hours

1. Calculate number of divisions:
   9-hour window ÷ 1-hour reproductive period = 9
2. Calculate population size:
   $1 \times 2^9 = \underline{512}$

Sex pili and conjugation

Although binary fission is asexual, bacteria evolve quickly due to high replicat
and horizontal gene transfer (conjugation). Mutations may have no effect on s
reduce viability or cause cell death, or be beneficial and enhance survival, suc

Some Gram-negative bacteria, such as *E. coli*, possess sex pili (singular: pilus) or
hair-like appendages that enable horizontal gene trans usually plasmids, by a

Conjugation involves several stages:

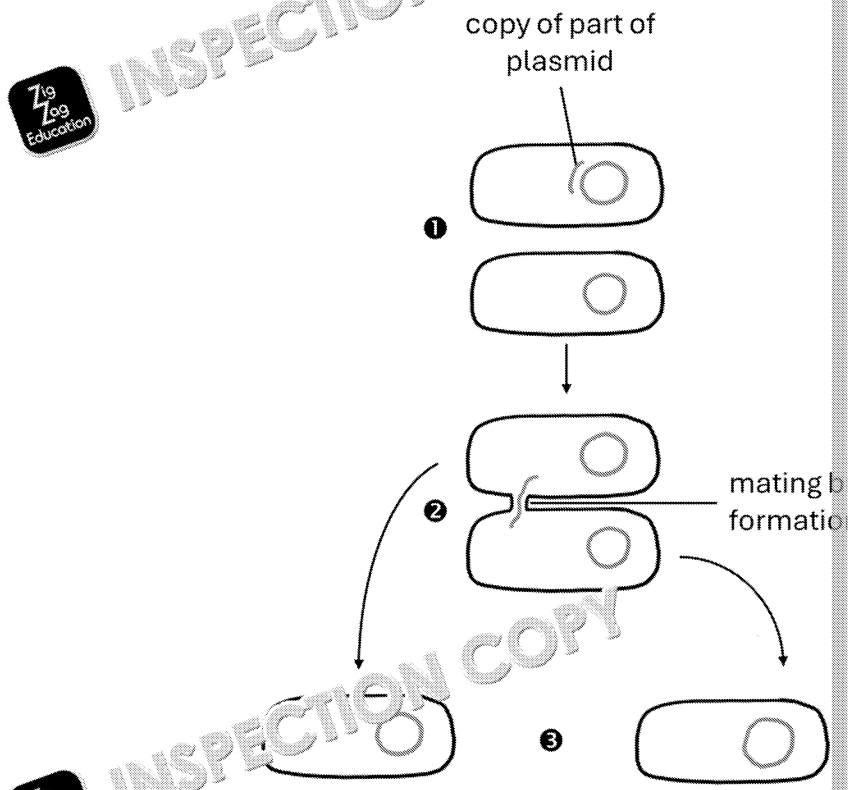


Figure F4.12. *The process of horizontal gene transfer between bacteria*

1. Donor cell replicates part or all of a plasmid.
2. Mating bridge forms between the two bacteria with a pilus. The copy of D
   pilus from donor to recipient.
3. The recipient now contains a copy of the plasmid, and both cells can go o

This allows bacteria to share adaptive traits, such as antibiotic resistance, viru
capabilities. Conjugation causes genetic diversity without reproduction, sexua
between different species of bacteria, making it an important factor in microb

Apply your knowledge

1. Estimate the bacterial population size after three days with a reproductive rate
2. Outline the stages in binary fission and explain how conjugation serves a differ
   reproduction.

Culturing bacteria in the lab

Bacterial populations can be cultured in the laboratory using agar plates or nutrient b
essential nutrients for growth and allow controlled observation of colony developme

- Agar is a solid medium formed from seaweed-derived polysaccharides. It has a
with carbon, nitrogen and trace minerals. It provides a stable surface for growi
bacterial colonies.
- Nutrient broth contains similar ingredients but rem[illegible] liquid, supporting gro
planktonic (free-floating) or aquatic bacteria[illegible] ideal for studying populatio
turbidity, and metabolic activity.

Figure F4.13. *An agar plate with bacterial [illegible] and a bacterial broth cultur*

Phases of population growth in culture

Bacterial growth in [illegible] system (e.g. nutrient broth) follows a predictable patter

- lag phase – [illegible] are metabolically active but not dividing; adapting to new cond
- exponential phase – rapid cell division; population doubles at regular intervals
- stationary phase – nutrient depletion and waste accumulation slow growth; ce
- death phase – cell death exceeds cell formation because resources have been u

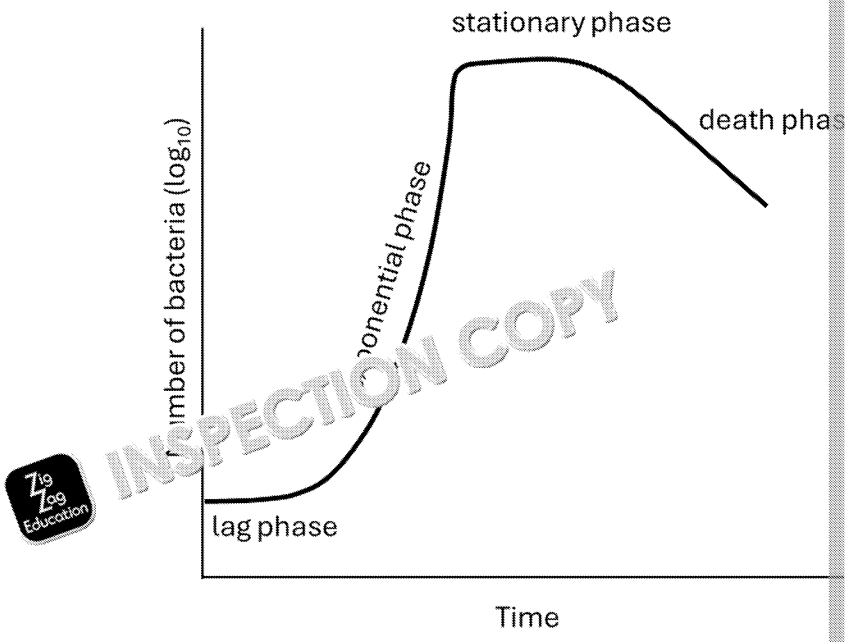


Figure F4.14. *A graph outlining bacterial growth phases.*

Environmental factors affecting growth

The phases of cultured bacterial growth are affected by various environmental factors that can be adjusted and controlled within the lab.

Factor	Effect on growth
Temperature	Affects enzyme activity so can restrict or promote gr Optimal range varies by species
pH	Influences enzyme function and cell membrane stabil Most bacteria prefer pH 6.5–7.5
Salinity	High salt concentrations cause osmotic stress as wate is usually harmful to growth Halophiles thrive in salty environments
Nutrient availability	Key nutrients include carbon, nitrogen and trace min Lack of nutrients limits population expansion
Oxygen levels	Aerobes require oxygen; anaerobes may be harmed b tolerate both

Table F4.5. Details of environmental factors and the effect they have o

Bacterial species require specific growth conditions. *E. coli*, *Bacillus subtilis* and
commonly studied:

Species	Temperature range (°C)	Optimal pH	Oxygen requirement	Growth medi
Escherichia coli	20–48 (optimum ~37)	6.5–7.5	Facultative anaerob	LB broth/agar, nutrient agar
Bacillus subtilis	18–43 (optimum 30–37)	6.8–7.4	**Obligate** aerobe	Nutrient broth, LB broth, molasses + yeast extract
Clostridium perfringens	12–50 (optimum 3–47)	6.0–7.0	Obligate anaerobe	Cooked meat medium, thioglycolate broth

Table Specific growth conditions for various species o

Obligate – bacteria that must live in the condition stated, e.g. an obligate must live in oxygen-poor air.

LB broth – lysogeny broth – a nutrient-rich medium which provides b like amino acids needed for growing many forms of bacteria.

Aseptic technique

Aseptic technique prevents contamination of cultures and protects the handler from
involves sterile handling procedures before, during and after sample collection and c

Obtaining bacterial samples

When obtaining bacterial samples from patients or the environment (see page 167)

- use sterilised swabs or pipettes
- label and repackage samples immediately
- wear disposable gloves and avoid t[illegible] in[illegible]n-sterile surfaces

Working within the l[illegible]y

When working[illegible] the laboratory to grow or observe cultures, aseptic techniques

- Sterile han[illegible]g:
  Open containers only when needed.
  Avoid talking, coughing or sneezing near open materials.
  Use a flame or alcohol wipes to sterilise surfaces, especially in the laboratory.
  Used autoclaved equipment, sterile water, and gloves.
- Environmental controls:
  Work near a Bunsen burner or in a **laminar flow cabinet** where possible.
  Keep windows closed to minimise airborne contamination.

Creating bacterial suspensions

Aseptic techniques necessary when creating bacterial suspensions include:

- working near a Bunsen burner or in a laminar flow hood
- closing windows and minimising air movement
- using autoclaved equipment, sterile water, and glov[illegible]

Creating streak plates

When streaking agar plates, [illegible]niques to observe include:

- flame-steril[illegible] th[illegible]ulating loop before and after use
- avoiding g[illegible] the agar
- keeping Pe[illegible]dish lid ajar but covered during streaking to limit airborne contam
- securing lid with tape in an X-shape to allow airflow while preventing accidenta
- labelling with name, date, sample, and type of growth medium

Incubation and disposal

The incubation and destruction of bacterial cultures must be carried out with care t
controlled growth, and responsible disposal.

Aerobic or facultative anaerobic bacterial samples should be incubated at 25 °C in co
oxygen availability. This helps prevent the unintended growth of pathogenic species
body temperature (37 °C).

Obligate anaerobic bacteria must be incubated at 25 [illegible]a[illegible]ght containers or anae
and maintain appropriate atmospheric condi[illegible] Anaerobic packs can be used to a
Some clinical samples may need cult[illegible]uman body temperature (35–37 °C) fo

Cultures are ty[illegible]m[illegible]ed for no more than 7–8 days to prevent overgrowth a
contamination[illegible]cultures, media and equipment must be sterilised using a high t
(e.g. 121 °C for 15–20 minutes under pressure) before disposal. Disposed contents m
recorded, in line with biosafety protocols.

Health and safety recording

Maintaining comprehensive health and safety records protects personnel and

A complete aseptic procedure record should include:

- date and results of mandatory staff training
- maintenance logs for laminar flow hoods and autoclaves
- sample and culture details, including organism, ... ions, disposal meth

Benefits and limitations

There are benefits and limi... ons ... aseptic techniques:

Benefits	Li
• Prevents contamination from external microbes • Protects microbiologists from exposure to unknown or pathogenic strains • Ensures integrity of experimental results • Reduces risk of laboratory-acquired infections	• Requires careful co • May require expens sterilisation proced • Human error (misse compromise the cul • Enhanced protectio risk samples

Table F4.7. Benefits and limitations of aseptic techniq

Recall questions

1. Outline the key steps involved in aseptic technique in the laboratory and explain why each step is impo
2. Describe the main phases of bacterial population g and explain the fact... ha... influence each phase.
3. Compar... ...e... ...th requirements and characteristi ... *Clostridium perfringens*.

...ctice questions: Bacteria of the human body and beyo

1 a. Plot the data of bacterial growth in a flask and draw a smooth line growth. (2)

Time (hours)	Population
0	1 x 105
2	1.2 x 105
4	5 x 105
6	2 x 106
8	8 x 106
10	1 x 107
12	1 x 107
14	5 x 106
16	1 x 106
18	2 x 105

b. Label the ph... gr... ...h on your graph. (4)

4.1.5. Viruses

Viruses are often described as biological contradictions. They possess genetic mater
the cellular structures and metabolic machinery required for independent life. For e
contains only eight genes, yet it can cause devastating disease.

Because viruses cannot carry out metabolism or replicate on their own, they do not
living organisms; however, they are capable of infecting
es
oying cells with ex

Structure and classification of viruses

Viruses consist of a protein
coat called a c
wi
bedded
glycoprotein sp
at aid attachment to
specific receptors on host cells. They have a central core containing either DNA or RNA, which may be single- or double-stranded.

Most viruses are extremely small, typically 20–300 nm, far smaller than bacteria, and only visible under an electron microscope.

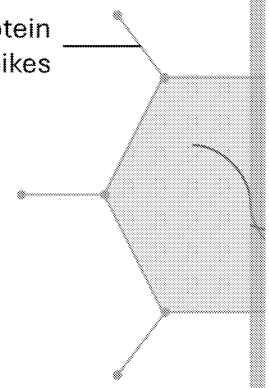


Figure F4.15. A

Bacteriophages

Bacteriophages, or simply phages, are viruses that infect and replicate within bacteri
s.
addition to the capsid which ho
viral
genome, they have a tail
achnes and
penetrates the
all
o inject genetic material, and tail fibres t
cognise specific receptors on the bacterial cell surface and confer high specificity – phages usually target only one species of bacteria, even down to the strain.

Phage reproduction may occur lytically or lysogenically. In the lytic cycle, the phage invades the bacterial cell, uses the machinery to replicate the virus, then lyses the cell to release new phages. Lysogenic reproduction involves DNA integration with the host genome to form a prophage, which then replicates passively until it is triggered into the lytic cycle.

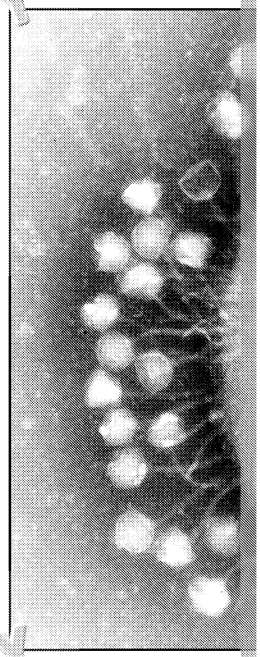


Figure 4.10. Electron micrograph o
to a bacterial cell wall, at approxi

Recall ques

1. Describe the structure of a typical virus.
2. Describe how phages reproduce in bacterial cells and exp
essential for their survival.

Viral reproduction in eukaryotic cells

Viruses reproduce by invading host cells and using their biochemical machine
1. Attachment – viral glycoproteins bind to specific host cell receptors
2. Penetration – virus enters the cell via endocytosis or membrane fusion
3. Use of host machinery
   - Inhibits normal cell functions
   - Replicates viral genetic material and synthesises viral proteins
   - May direct host to produce proteins or modify immune signals
4. Assembly and release – new viruses are assembled and released by lysis (
   (cell membrane bursts and breaks off with virus inside, in a process simila
   vira

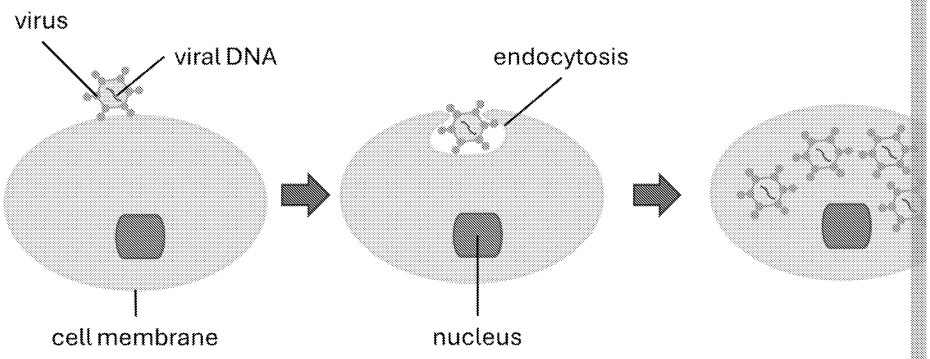


Figure F4.17. *Viral replication in eukaryotic cells.*

Living or not living?

Viruses differ fundamentally from cells because they lack a cell membra
organelles or enzymes for metabolism, cannot reproduce without a host, and
their environment.

However, because they carry genetic material and evolve over time, they are
particles, rather than living organisms.

Your turn

1. Describe viral replication in eukaryotic cells and explain why using host ce
   essential for this process.
2. Discuss whether viruses should be considered living organisms or remain

The human microbiome is a vast community of microorganisms, including bacteria, a
and protozoa, that live in and on the human body. They inhabit nearly every surface
complex ecosystems that are essential for our health, development, and physiologic

The human microbiome

The many microbial communities throughout the body contribute actively to digesti
metabolic efficiency. They can influence our mood, behaviour, and neurological hea
when imbalanced.

Site	Role
Gut, especially colon	Digestion, vitamin synthesis, immunity
Skin	Barrier protection, pH regulation
Oral cavity	Enzymatic activity, pathogen defence
Respiratory tract	Immunity
Urogenital tract	pH maintenance, protection against infe
Conjunctiva	Antimicrobial defence

Table F4.8. Details of the site and role of microbial communities in the b

Benefits of the human microbiome

The human microbiome performs essential functions. In many sites, the microbiome
through destruction of pathogenic bacteria through the production of antimicrobial
invading bacteria, and preparing the immune system.

Within the digestive system, the microbiome is essential for breaking down undiges
fibres, and for synthesising vitamins that contribute to energy metabolism and nervo
vitamins), or blood clotting and bone health (vitamin K).

The microbiome can also influence mood and brain function, and the balance of mic
essential for overall health. When the balance is disrupted, conditions like inflamma
obesity, diabetes mellitus, autoimmune diseases, and mental health disorders may o

Maintaining and enhancing the human microbiome

Microbiome composition is shaped by our diet, environment, medications, lifestyle,
microbiome balance is vital, it is possible to enhance our microbiome to improve mi

Probiotic foods

Eating a healthy, balanced diet is important for maintaining a good gut microbiome,
and active cultures that can increase our gut microbiome if consumed in sufficient q

Common probiotic-rich foods include yoghurt and kefir, soy-based drinks, fermente
kimchi and miso, and aged cheeses. These typically contain *Lactobacillus* or *Bifidoba*
support digestion, strengthen immune defences and increase the variety of microbes

Rectal probiotic implants

Rectal probiotic implants, or probiotic enemas, deliver beneficial microbes dir
(GI) tract, bypassing digestive enzymes and acids that may degrade oral probio

Implants are typically administered after colonic hydrotherapy and involve ins
live *Lactobacillus* or *Bifidobacterium* species into the colon.

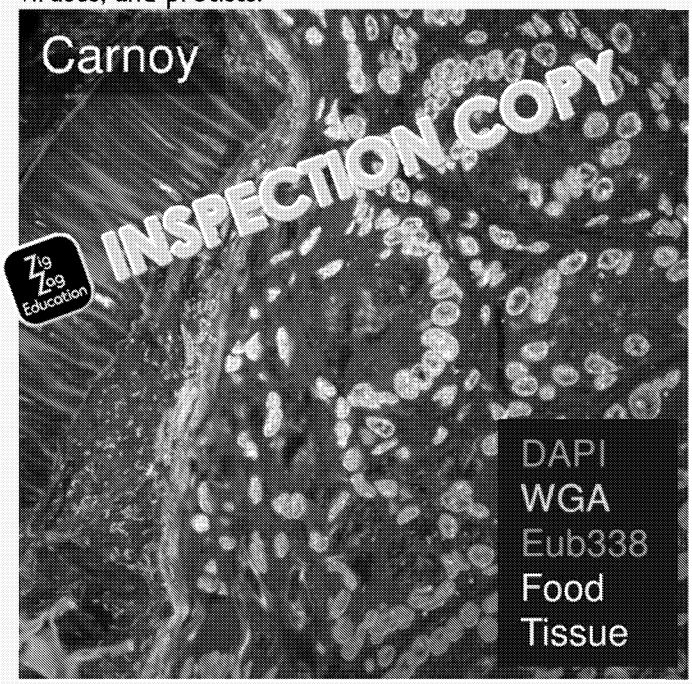
They have been shown to improve the colon m[illegible]e and form part of a t
obese or have disorders of the GI trac[illegible]as ulcerative colitis. However, it is
should only be implemented by qu[illegible]d professionals.

Recall questions

1. List three microbiome sites in the human body and
microorganisms at these locations.
2. Describe everyday activities that can be easily compl
gut microbiome.
3. Explain how medical interventions can be used to i

Practice questions: Beneficial Microbes

1 The gut microbiome is one of the densest microbiomes in the human
viruses, and protists.



The image shows mucus, microbes, host tissue, and food in an area a

a. Name two bacteria commonly fou[illegible]d w[illegible]n the large intestine mic

b. Describe the es[illegible]tial r[illegible]es that the microbiome has within the g