3 Functioning systems

KEY KNOWLEDGE

In this topic you will investigate:

Functioning systems

- specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water
- specialisation and organisation of animals cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory.

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PRACTICAL WORK AND INVESTIGATIONS

Practical work is a central component of learning and assessment. Experiments and investigations, supported by a **practical investigation eLogbook** and **teacher-led videos**, are included in this topic to provide opportunities to undertake investigations and communicate findings.

3.1 Overview

Numerous **videos** and **interactivities** are available just where you need them, at the point of learning, in your digital formats, learnON and eBookPLUS at **www.jacplus.com.au.**

3.1.1 Introduction

The first known organisms that appeared on Earth were neither plant nor animal, but were unicellular microbes. Microscopic microbial fossils, found in 3465 million year old rocks in the Pilbara region of Western Australia appear to be the earliest direct evidence of life on Earth. Primitive life existed for another 2800 million years until the appearance of multicellular life on Earth, around 600 million years ago (Mya). Striking evidence of the first complex multicellular organisms came from the diverse fossils unearthed in the Ediacaran Hills of the Flinders Ranges in South Australia (figure 3.1). The nature of these strange Ediacaran creatures was the subject of debate for decades. In 2018, research into preserved steroid lipids recovered from *Dicksonia* fossils provided clear evidence that these Ediacaran organisms were animals.

FIGURE 3.1 Impressions of *Dicksonia,* an Ediacaran fossil animal, preserved in sedimentary rocks from the Ediacaran Hills in South Australia

The evolution of multicellular organisms meant huge increases in the diversity and level of complexity of organisms in addition to extensions in lifespans, as organisms continue to live, even when individual cells die. In a unicellular organism, the single cell must perform all the functions needed to stay alive and their size is limited by the ability of diffusion to provide nutrients and remove wastes. In multicellular organisms, each cell type performs a distinct and specialist role, which gives rise to different levels of organisation: at the cellular level; at the tissue level where cells of one type are organised to specialise in one function; at the organ level where tissues of different types can be aggregated to form organs to carry out a particular function; and the system level where several different organs can be aggregated to form a system that performs a major life-supporting function. The topic opening image shows one such tissue, the glomerulus of the kidneys, showing blood vessels (green) enveloped in podocytes (brown).

LEARNING SEQUENCE

on Resources

eWorkbook — eWorkbook — Topic 3 (ewbk-3158)

Practical investigation eLogbook — Practical investigation eLogbook — Topic 3 (elog-0160)

Digital documents
- Key science skills — VCE Biology Units 1–4 (doc-34326)
- Key terms glossary — Topic 3 (doc-34651)
- Key ideas summary — Topic 3 (doc-34662)

3.2 Specialisation and organisation of plant cells

KEY KNOWLEDGE

- Specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water

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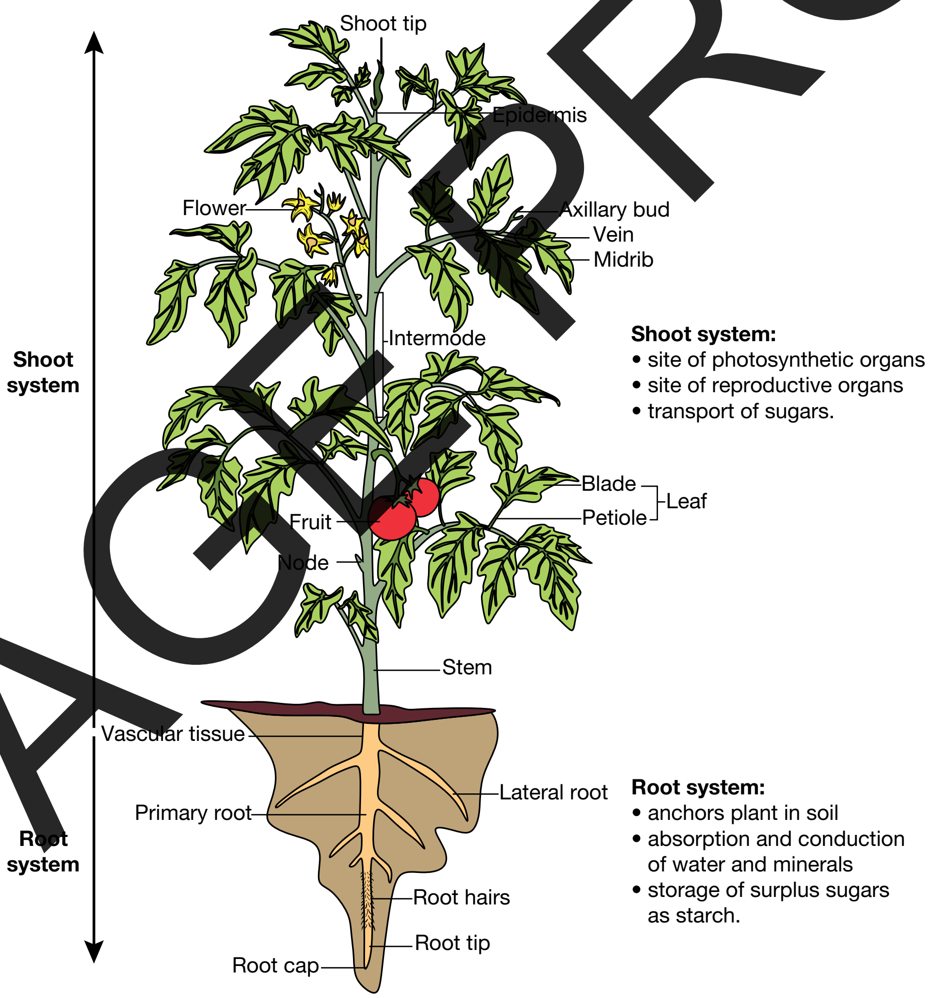
3.2.1 Plant systems, organs and tissues

The multicellular land plants with which people are familiar are the **vascular plants**. Their cells are organised at the system, organ and tissue levels.

Plants have two systems:

- an above-ground **shoot system**
- a below-ground **root system**.

FIGURE 3.2 A typical flowering plant showing its two systems, the shoot and root systems and some of the functions performed by these systems



vascular plants plants with xylem and phloem tissue — the majority being flowering plants and conifers

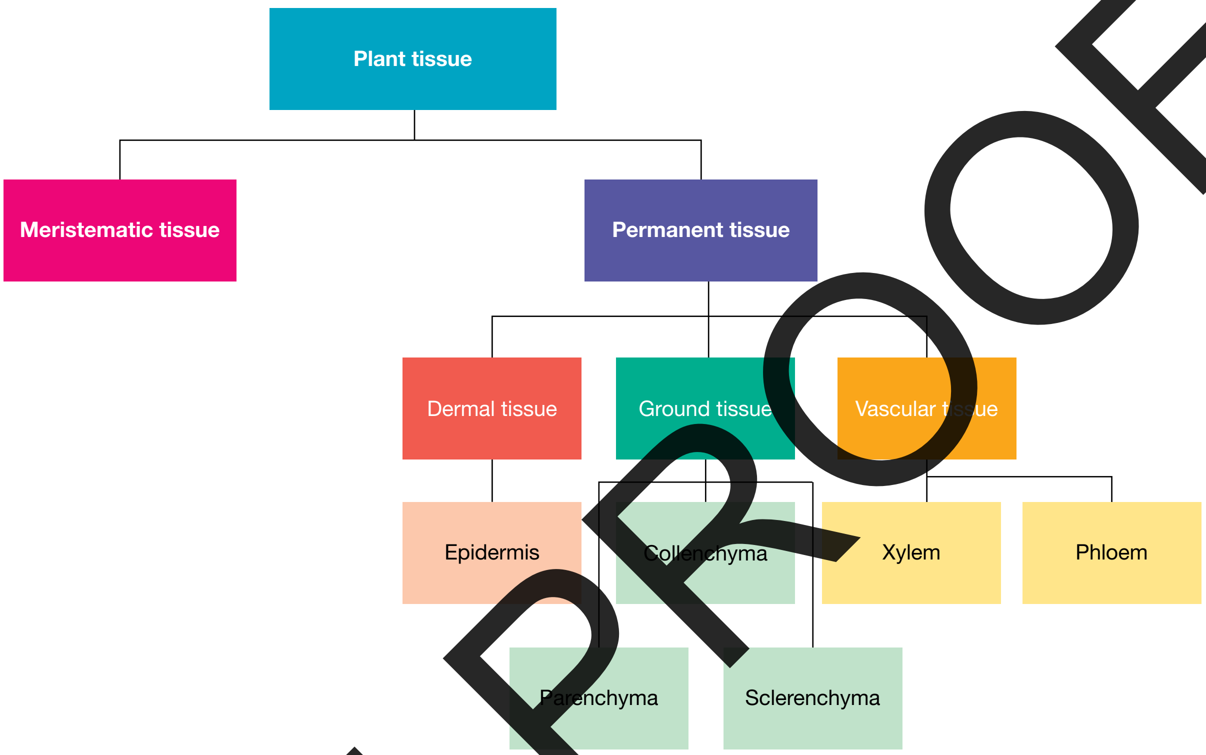
shoot system the above-ground system of plants, the site of photosynthesis, transport of sugars and the site of reproductive organs

root system the below-ground system of plants which anchors the plant in the soil, is responsible for the absorption and conduction of water and minerals, and the storage of excess sugars (starch)

These root and shoot systems consist of different organs:
- shoot system organs — the stem and leaves, plus the reproductive organs, the flowers and fruit
- root system organs — the root, lateral roots and the root hairs.

Plant organs consist of different tissues. A simple classification is shown in figure 3.3.

FIGURE 3.3 A classification scheme of the major types of tissue in vascular plants



Meristematic tissues are made of cells that can undergo cell division and can continue to divide for the life of the plant. Meristematic tissue is usually found in the tips of roots and shoots and is responsible for an increase in the length of the plant stems and roots. (In grass, however, this tissue is located at the leaf base where the leaf blade joins the roots. Meristematic tissue is also present along the length of stems and roots and is responsible for the increase in girth of a plant.)

Permanent tissues are made of cells that can no longer divide. Permanent tissues include several tissue types that differ in their function:
- **Dermal tissue** protects plants and minimises water loss. For example, epidermal tissue made of flattened cells forms the outer layer of stems and leaves. A non-cellular layer of wax on top of the epidermal tissue adds further waterproofing.

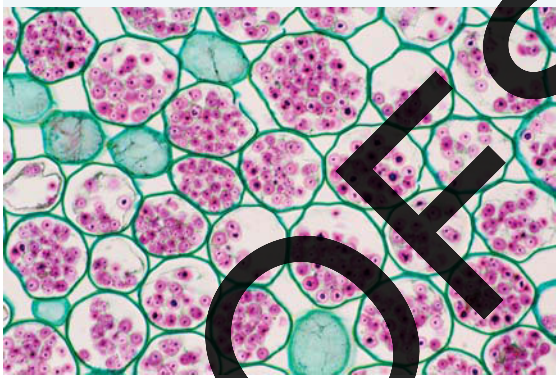
meristematic tissues plant tissue found in tips of roots and shoots that is made of unspecialised cells that can reproduce by mitosis

permanent tissues plant cells that can no longer divide and includes dermal tissue, ground tissue (parenchyma, collenchyma and sclerenchyma) and vascular tissue (xylem and phloem)

dermal tissue tissue that protects the soft tissues of plants and controls water balance

- **Ground tissue** includes the following simple tissues:
  - **parenchyma** tissue — the most common plant tissue and is composed of living thin-walled cells. In leaves, the parenchyma tissue is the site of photosynthesis. In roots, tubers and seeds, the parenchyma tissue is the site of storage of starch (figure 3.4) or oils.
  - **collenchyma** tissue — the main supporting tissue of elongating stems; this tissue is composed of elongated living cells with thick but flexible primary cell walls.
  - **sclerenchyma** tissue — confers rigidity and strength to many plant organs and is composed of cells with thickened secondary cell walls; at maturity, sclerenchyma cells are dead.

FIGURE 3.4 Cross-section through the root of a buttercup (*Ranunculus* sp.) showing the parenchyma tissue. Note the stored starch granules (stained purple).



- **Vascular tissue**, includes the complex tissues:
  - **xylem** tissue — consists mainly of hollow dead cells with thick cell walls hardened by lignin. This tissue transports water and dissolved minerals throughout a plant.
  - **phloem** tissue — consists of living cells that transport sugars, in the form of dissolved sucrose (table sugar), and other organic compounds, including hormones, throughout a plant.

Each plant organ (root, stem and leaf) contains all three tissue types. Figure 3.5 shows the typical arrangements of these various tissue types in vascular plants, with the different types of tissue denoted by different colours. Note the dermal tissue (shown in orange) forms a protective outer boundary of the plant's organs.

FIGURE 3.5 Arrangement of various tissue types in the organs of a vascular plant

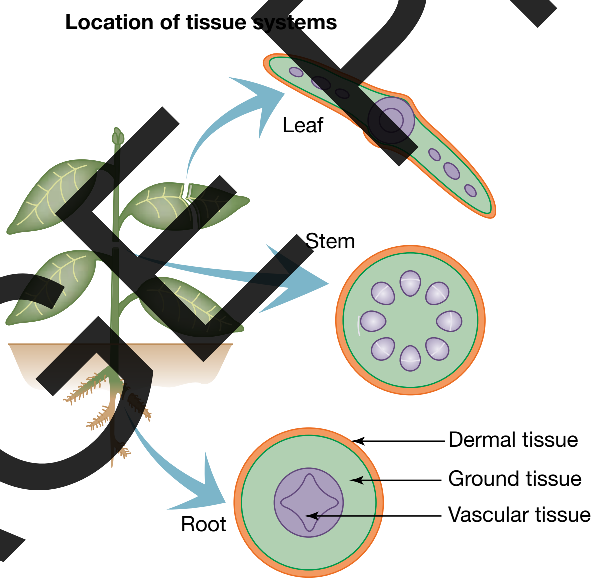


Figure 3.6 is a photomicrograph of a leaf showing the arrangements of different tissues. Note the various tissue types:

- Parenchyma tissue: an example of ground tissue, forms the bulk of the internal structure of the root and the leaf
- Vascular tissue: in the xylem and phloem tissue in both root and leaf
- Epidermal tissue: an example of dermal tissue, forms the upper and lower boundaries of the leaf blade.

ground tissue all plant tissues that are not dermal or vascular

parenchyma thin-walled living plant cells; in leaves the site of photosynthesis and in roots, tubers and seeds the site of stored starch and oils

collenchyma thick, flexible walled cells in plants; the main supporting tissue of stems

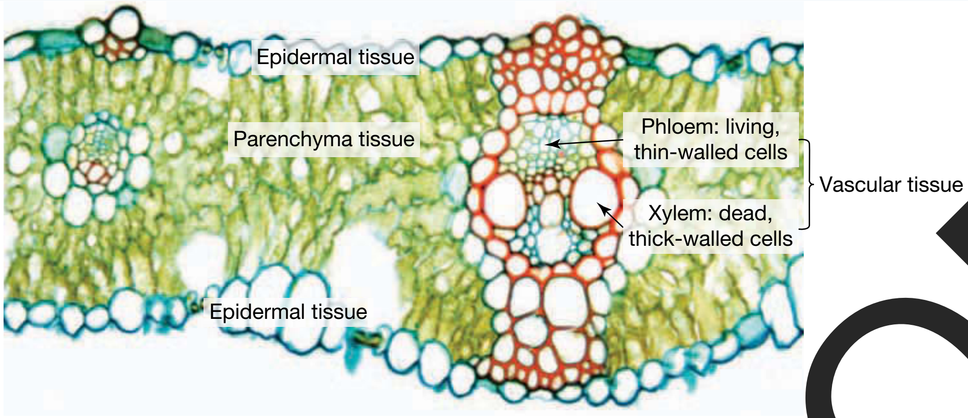
sclerenchyma dead cells with thickened walls for strength and rigidity

vascular tissue plant tissue composed of xylem and phloem

xylem the part of vascular tissue that transports water and minerals throughout a plant and provides a plant with support

phloem complex plant tissue that transports sugars and other organic compounds

FIGURE 3.6 Photomicrograph of a cross-section of part of the leaf of the bread wheat (*Triticum aestivum*). Note the parenchyma tissue that forms the bulk of the leaf.



elog-0254

INVESTIGATION 3.1

online only

A closer look at vascular tissue

Aim

To observe vascular tissue under the microscope

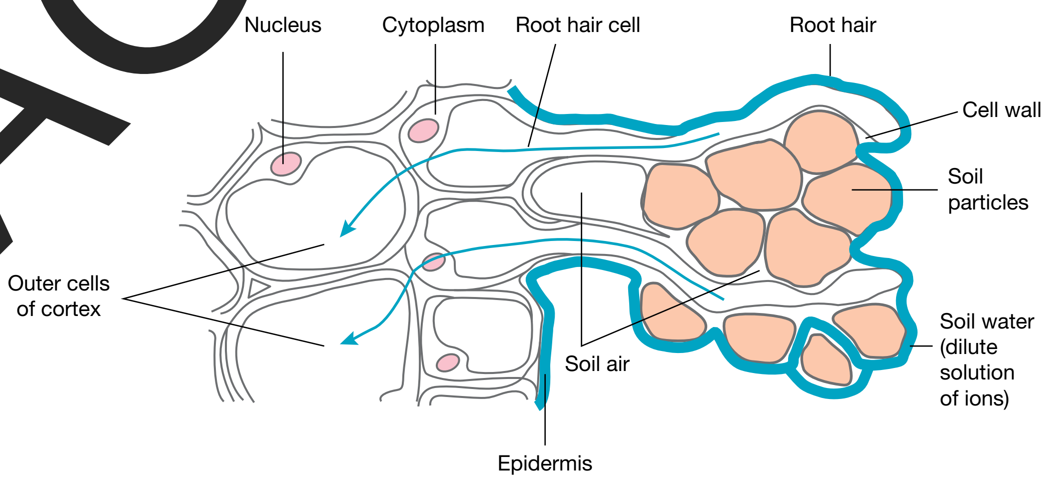
3.2.2 Tissues involved in intake of water

The source of water for terrestrial plants is water in the soil. Soil consists mainly of solid mineral particles and, in dry conditions, the spaces between these particles are largely filled with air. After rain, this space is mainly filled with water.

The absorption and uptake of liquid water by plants takes place through **root hairs**. Root hairs are extensions of cells of the epidermal tissue that forms the outer cellular covering of the root (figure 3.7). Water enters the root hairs from the soil solution by osmosis. From the root hair cells, water moves across the cells of the cortex to the xylem in the vascular bundle from where it will be transported as a fluid to all the living cells of the plant.

root hairs extensions of cells of the epidermal tissue that forms the outer cellular covering of the root; responsible for absorption and uptake of liquid water

FIGURE 3.7 Diagram showing the root hairs that are extensions of the epidermal cells. Water (blue lines) from around the soil particles passes into the root hair cells by osmosis.



Plant tissues involved in the intake of water

- Uptake of water by plants occurs through osmosis by the root hairs.
- Root hairs are extensions of cells of the epidermal tissue that forms the outer cellular covering of the root.

elog-0256

INVESTIGATION 3.2

online only

Root hairs

Aim

To observe the growth of roots and investigate the structure and function of root hairs.

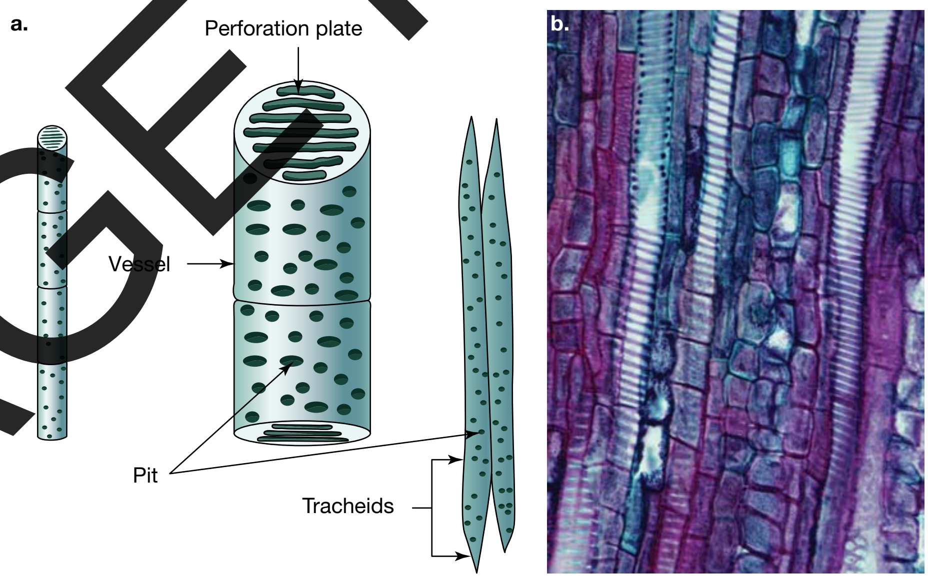
3.2.3 Tissues involved in movement of water

The xylem tissue is responsible for the transport of water and dissolved minerals taken up by root hair cells to the rest of the plant. Unlike most other plant tissues, xylem tissue contains more than one type of cell and, for this reason, xylem is said to be a complex tissue. Present in xylem tissue are the major water-conducting cells called **tracheids** and **vessels**. Both cell types have thickened cell walls and this adds structural support to plants. Other cells types found in this tissue are fibres and parenchyma cells, with the latter being the only living cells in xylem tissue.

tracheids major water conducting cells in the xylem of all vascular plants

vessels major water conducting cells in the xylem of angiosperms

FIGURE 3.8 a. A simplified drawing of xylem vessels (joined end-to-end) and a cluster of tracheids **b.** Longitudinal section of a stem of cottonwood (*Populus* sp.) showing the xylem tissue. The xylem vessels are dead cells with thick walls and lignin thickening in the form of spirals or rings.



The major water-conduction cells in vascular plants are tracheids and vessels.

- Tracheids:
  - are present in all vascular plants
  - are long thin tubular cells with tapered ends
  - have no cell contents and so are no longer living
  - have both a primary and a secondary cell wall
  - have pits in their secondary cell wall enabling lateral movement of water to nearby tissues.
- Vessels:
  - are found only in flowering plants
  - lose their cell contents and are dead
  - form a continuous wide pipe-like structure by the joining of vessels end-to-end
  - have perforation plates that are typically present at the junction between individual vessels in the pipe
  - have both a primary and a secondary cell wall.
  - The secondary cell walls are made even stronger by thick deposits of lignin that forms spirals or rings (figure 3.8b).
  - The walls are perforated by pits — these are spots where the secondary wall of the vessel is thin or absent so that water can move laterally and exit the xylem.

Xylem tissue

- Xylem tissue is responsible for the movement of water and nutrients in a plant.
- It is composed of tracheids, fibres and parenchyma cells, and, in flowering plants only, vessels.

tlvd-1850

SAMPLE PROBLEM 1 Comparing and contrasting tracheids and vessels

Tracheids and vessels are both cells involved in the movement of water. Compare and contrast these cell types. (2 marks)

THINK	WRITE
1. In a compare and contrast question, you need to ensure that you address similarities (compare) and differences (contrast).	
2. Write a statement identifying similarities between the tracheids and vessels.	Both tracheids and vessels are water-conducting cells that are present in xylem tissue, adding structural support (1 mark).
3. Write a statement identifying differences between tracheids and vessels. When identifying differences, ensure you refer to both of the cells.	Tracheids are present in all vascular plants and are long and tubular, whereas vessels are only present in flowering plants and have a wide pipe-like structure (1 mark).

EXTENSION: Growing plants without soil

Hydroponics is a method of growing plants without planting them in soil. Instead, plants are grown with their roots exposed to mineral nutrients in a solution of water.

To access more information on this extension concept please download the digital document.

FIGURE 3.9 Lettuce is a common hydroponic crop.

on Resources

Digital document Extension: Growing plants without soil (doc-35878)

3.2.4 Tissues involved in the loss of water

Plants use less than 5 per cent of the water absorbed by roots for cell functions. The remainder simply passes out of plants directly into the atmosphere in a process called **transpiration**. The loss of water from plant leaves by transpiration can be extensive; for example, one estimate is that a large oak tree can transpire more than 150 000 litres in a year. However, the exact amount of water lost by a plant through transpiration is influenced by temperature, relative humidity of the air, wind movements and the availability of water in the soil. Can you suggest what temperature (hot or cold), wind movements (blowing or still) and relative humidity of the air (high or low) would be expected to result in higher transpiration rates?

Water loss by transpiration occurs in the leaves of plants, and the tissues that are involved include:

- the air spaces in the spongy mesophyll tissue of leaves are usually saturated with water vapour
- the **stomata** (singular = stoma) located mainly in the lower epidermis of leaves are the exit points from where water vapour may diffuse out from the leaves into the air.

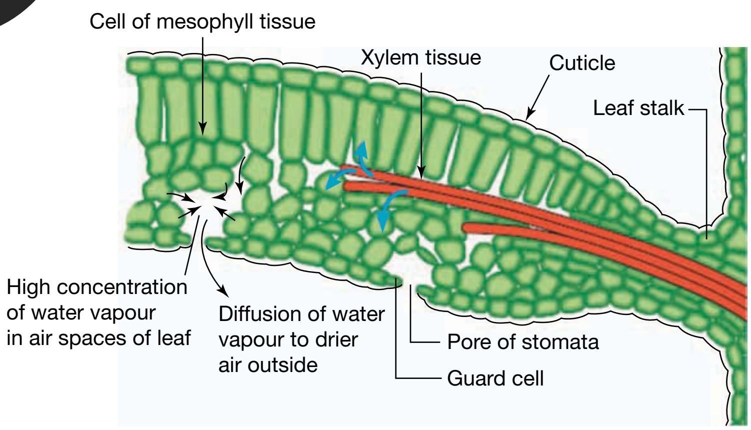
A loss of water vapour will occur, provided:

- a concentration gradient exists between the water content in the leaf spaces (high) and in the air outside the leaf (low)
- the leaf stomata are open.

transpiration loss of water from the surfaces of a plant

stomata pores, each surrounded by two guard cells that regulate the opening and closing of the pores

FIGURE 3.10 Longitudinal section thorough a leaf showing water (blue arrows) being pulled from xylem vessels (orange) into the mesophyll tissue of the leaf. This input of water replaces the water lost from the leaf as vapour through the open stomata.

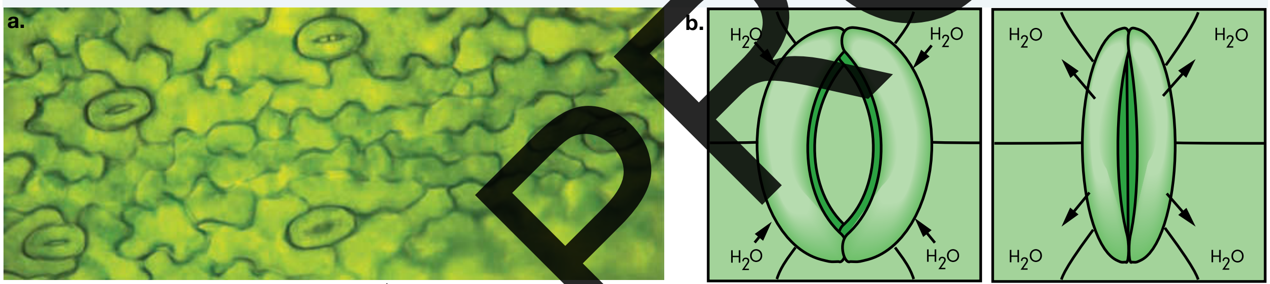


Action of the stomata

Given the extensive water loss that occurs in plants through transpiration, the question might be asked: Why does such an apparently wasteful process of water loss occur? To answer this, you must recall that leaves are the site of the life-sustaining process of photosynthesis. To make sugars during photosynthesis, carbon dioxide is an essential requirement, and this is captured from the atmosphere. So, the entry point of carbon dioxide to a leaf is via the open stomata (figure 3.11). It is not a case of one water molecule out as one carbon dioxide molecule enters a leaf — one estimate is that for each molecule of carbon dioxide taken into a leaf, an average of about 400 water molecules are lost from the leaf. Stopping transpiration means stopping photosynthesis, but when stomata are open, a plant faces the risk of dehydration. However, controls exist over the opening and the closing of plant stomata.

The stomata in the epidermal tissue are pores and each is surrounded by two guard cells. Figure 3.11b shows the inner wall of a guard cell is significantly thicker than its outer wall. In sunlight, when photosynthesis is occurring, guard cells take up water and swell, resulting in the opening of the stomata. This water uptake is triggered by an inflow of potassium ions (K^+) into the guard cells. In the dark, when carbon dioxide is not needed, the reverse reaction occurs: the guard cells lose water and shrink, the stomata close, and water loss is prevented.

FIGURE 3.11 a. Photomicrograph of the epidermal tissue of the lower surface of a leaf where five stomata are visible **b.** Line diagram showing a stoma in the open condition (at left) and the closed condition (at right)



Stomata

- The stomata are the sites of carbon dioxide uptake and loss of water in a plant.
- Stomata are mainly located in the lower epidermis of leaves.
- Water is lost as vapour when a concentration gradient exists between the water content in the leaf spaces (high) and in the air outside the leaf (low) and the leaf stomata are open.

elog-0258

INVESTIGATION 3.3 online only

Leaf epidermal layer

Aim

To observe guard cells, stomata and epidermal cells in plants under the microscope

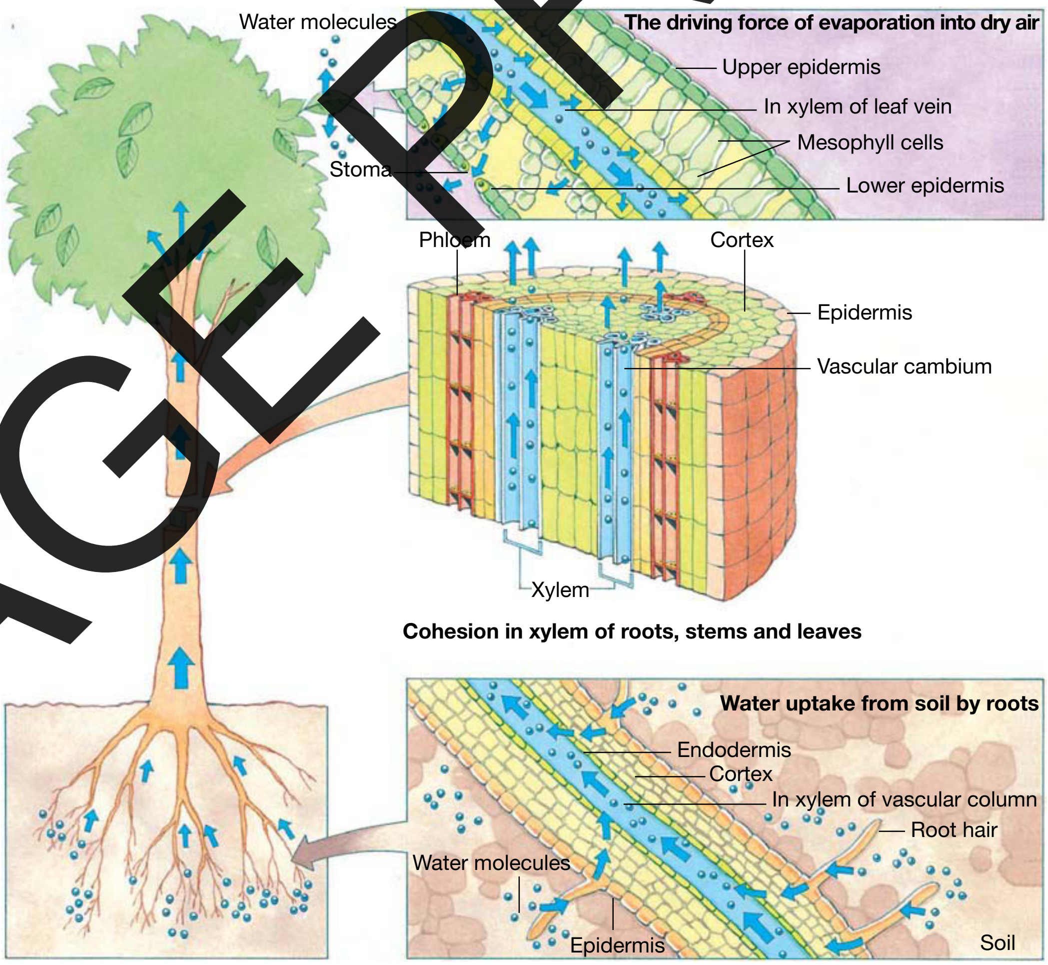
Getting to the top

Plants move water through their xylem tissue from delicate root hairs to the highest leaves in a plant; in the case of trees, this can be quite a height (figure 3.12). How is this achieved? Osmosis certainly can't do it.

The energy provided by the Sun plays a role in this process. When the Sun shines, stomata open and water vapour moves through the stomata into the air surrounding leaves. This water is replaced by water that moves out of the xylem into a leaf, and the water column remaining in the xylem moves up. In effect, water vapour moving out through the stomata sets up a chain reaction in which water in the xylem is moved up through the xylem vessels by the pulling or sucking movement of water ahead of it. This pulling action means that *water in xylem vessels is under tension that affects the entire water column.* The journey of water molecules from the root hairs via the xylem to the leaves depends on intact continuous columns of water in the xylem tracheids and vessels. This journey is shown in figure 3.13, starting with the uptake of water by root hair cells, continuing with this water being transported via the xylem to the leaves and then diffusing as water vapour via the stomata to the air.

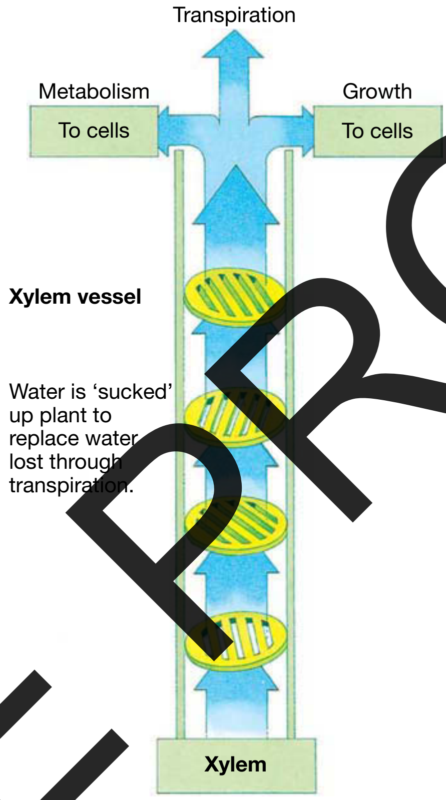
FIGURE 3.12 Water moves through xylem tissue from roots to the highest leaves of plants.

FIGURE 3.13 Water is absorbed from the soil by roots and passes into xylem tissue, which carries it to all parts of the plant. Some of the water is used by cells but much passes through stomatal pores in leaves and is lost by transpiration.



Why does the water column in the xylem not break? Two properties of water molecules help keep the water column unbroken. Water molecules tend to stick together — a property called **cohesion**. Water molecules also tend to stick to the walls of a container — a property called **adhesion**. These combined forces prevent the water column from breaking apart and from pulling away from the walls of the xylem vessels as water is sucked up the many thin tubes in the xylem tissue (figure 3.14). If the water column in one set of xylem tubes breaks, the water is replaced by air and that set of tubes becomes useless for any further water transport.

FIGURE 3.14 Movement of an unbroken column of water through the xylem vessels. This movement is produced by tension in the water column that is kept unbroken by the cohesion and adhesion of water molecules. Blue arrows denote the direction of movement of the water column towards the leaves, and the yellow symbols denote the perforation plates that separate individual xylem vessels.



cohesion tendency of water molecules to stick together through the formation of hydrogen bonds between one another

adhesion attraction of water molecules to other kinds of charged molecules, such as the walls of xylem tubes

elog-0260

INVESTIGATION 3.4

online only

Water movement in the plant

Aim

To observe the movement of water through the xylem in celery and carrots

on Resources

eWorkbook Worksheet 3.1 Systems, organs and tissues in plants (ewbk-3486)

KEY IDEAS

- Plants have two systems: a root system and a shoot system.
- Root system organs (root, lateral roots and root hairs) are responsible for anchoring the plant in the soil, absorbing water and minerals and storing starch.
- Shoot system organs (stem, leaves, flowers and fruit) are responsible for photosynthesis, transport of sugars and water, and reproduction.
- Meristematic tissue can undergo cell division and permanent tissue are cells that can no longer divide.
- Permanent tissue includes dermal tissue, ground tissue and vascular tissue.
- Dermal tissue, such as the plant epidermis, has functions in protection and waterproofing.
- Ground tissues are parenchyma, collenchyma and sclerenchyma and their various functions include photosynthesis, storage, support and protection.
- Dermal tissue and ground tissue are simple tissues, each composed of one cell type only.
- Vascular tissue includes the complex tissues of xylem and phloem, each composed of several different cell types.
- Plant organs are structured with an outer layer of dermal tissue, and inner vascular tissue that is embedded in ground tissue.
- Intake of water and minerals occurs through root hairs by osmosis.
- Root hairs are thin extensions of the epidermal cells that form the outer covering of the root.
- Water and dissolved minerals are transported throughout a plant through the xylem tissue.
- Water loss occurs via transpiration of water vapour through the open stomata of leaves.
- Water loss occurs when the concentration of water vapour within the leaf spaces is higher than that in the air outside the leaves.
- The opening and closing of stomata is controlled by the guard cells that enclose the stomatal pores.
- Transpiration of water from leaves produces the suction or tension in water columns in xylem that can move water up the xylem to the top of trees.
- The cohesive and adhesive properties of water prevent the water columns in xylem breaking.

3.2 Activities

learnON

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at **www.jacplus.com.au.** A **downloadable solutions** file is also available in the resources tab.

3.2 Quick quiz	3.2 Exercise	3.2 Exam questions

3.2 Exercise

1. Explain why root hairs are important to the water transport system of a vascular plant.
2. Describe the mechanism by which water reaches the tops of tall trees.
3. Identify where in a vascular plant you would expect to find:
   a. tracheids
   b. stomata
   c. meristematic tissue
   d. starch granules.
4. Explain the following observation: The epidermis of a root lacks the waterproof cuticle found on the epidermis of most leaves.
5. Identify:
   a. one biological similarity and one difference between collenchyma and sclerenchyma tissue
   b. the mechanism by which water enters root hair cells
   c. the structure that enables water to move laterally out of the water column in xylem tissue.
6. Briefly describe the arrangement of the major types of permanent tissue in a vascular plant.
7. Identify the expected effect — increase or decrease — on the rate of transpiration in a plant of the following:
   a. an increase in the humidity in the air
   b. an increase in wind speed.
   c. the closing of the stomata.

3.2 Exam questions

Question 1 (1 mark)

MC Functional dead cells observed in the vascular tissue of a living plant may be

A. sieve tube elements.
B. parenchyma cells.
C. xylem vessels.
D. companion cells.

Question 2 (2 mark)

Describe functional differences between xylem tissue and phloem tissue.

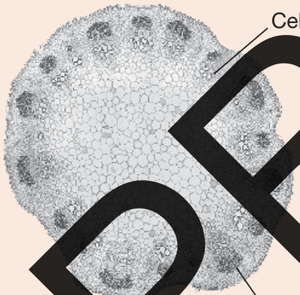
Question 3 (1 mark)

MC The movement of water through a plant

A. requires the plant cells to use the energy in ATP.
B. relies on the forces of attraction between water molecules.
C. slows down when the environment temperature increases.
D. takes place in the phloem tissue.

Question 4 (4 marks)

Consider the following photograph of a cross-section of the stem of a vascular plant.



Name cell type A and describe how the cell is different to cell type B.

Question 5 (4 marks)

In 2010 and 2013 vandals ringbarked a eucalyptus tree referred to as the 'The Separation tree' growing in the Melbourne Botanical Gardens. Ringbarking removes the bark and phloem of the tree.

a. What you would predict to be the fate of the tree in the following years? **1 mark**
b. Explain your prediction by referring to the functioning of the plant. **3 marks**

More exam questions are available in your learnON title.

3.3 Specialisation and organisation of animal cells

KEY KNOWLEDGE

- Specialisation and organisation of animals cells into tissues, organs and systems

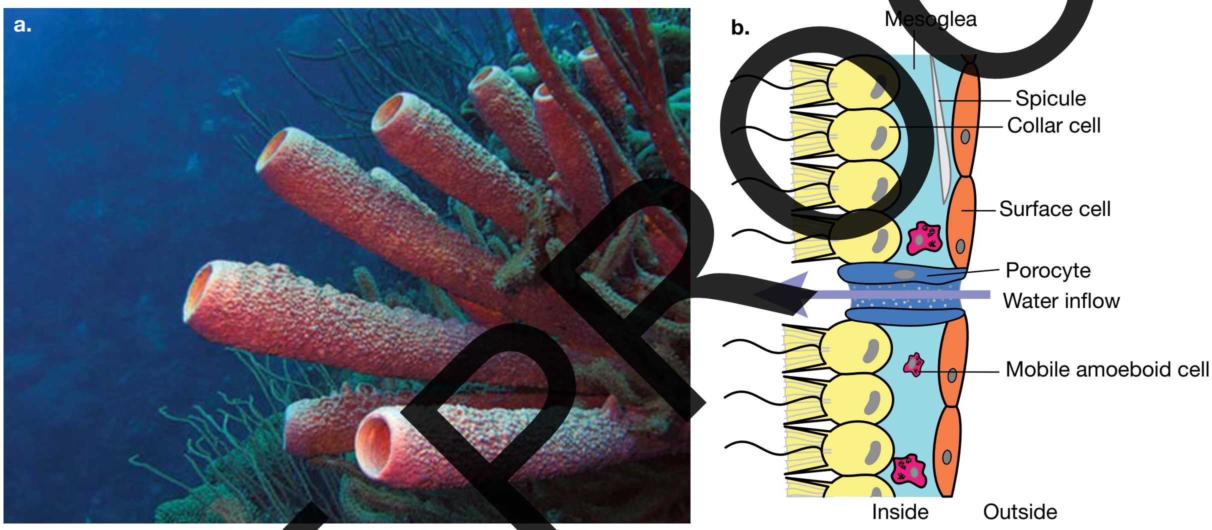
Source: Adapted from VCE Biology Study Design (2022–2026) extracts © VCAA; reproduced by permission.

3.3.1 Cellular level of organisation

Like plants, multicellular animals are arranged at the levels of cells, tissues and organs. Animals with the most simple level of organisation are the sponges, members of phylum *Porifera* (figure 3.15a). Sponges have a structure that is organised at the cellular level — they possess many cell types, but sponges have no definite tissues, organs or systems. Sponges consist of two layers of cells that enclose a space, the spongocoel, that has a single main opening. A non-living gel-like material (mesoglea) separates the two cell layers (figure 3.15b) and a few mobile cells may be present there. Among the specialised cell types in sponges are collar cells that beat their flagella and create incoming water currents that enter the sponge via cells called porocytes. In one study, it was shown that a 10-centimetre-tall sponge filtered about 100 litres of water each day. Tiny plankton and floating organic particles in the water drawn into the sponge are its food and this is digested by enzymes produced by cells of the inner cell layer.

The simplicity of the structure of sponges is illustrated by the fact that if the sponge cells are disaggregated and kept alive, within weeks, the different cell types will re-aggregate into the original structure of the sponge.

FIGURE 3.15 a. A living sponge. Note the single large opening that leads into an internal central space or enteron. Water and wastes both exit via this large opening. **b.** A longitudinal section of the wall of a sponge showing its two cell layers separated by non-living mesoglea. Note that the water enters the enteron via special cells called porocytes.



3.3.2 Tissues in animals

Tissues are formed by groups of cells of similar type — or even a single type — that act in a coordinated manner to perform a common function.

When did the first tissues appear in animals? The first animals to show the tissue level of organisation were the ancestors of jellyfish, corals, sea anemones and hydras that are members of phylum *Cnidaria*. Figure 3.16a shows the basic body plan of a jellyfish that consists of two cell layers, an outer ectoderm (shown in bright pink) and an inner endoderm (shown in blue). These two cell layers are separated by a non-cellular, gel-like mesoglea (yellow). Jellyfish have a single opening that serves as both the entry point for food to the gut and as the exit point for wastes.

Jellyfish have a number of tissues:

- **epithelial tissue**, which forms the ectoderm that lines the outside of the body
- **gastrodermal tissue**, another epithelial tissue, that lines the inner cavity of the body, called the enteron; cells lining this cavity produce digestive enzymes
- nervous tissue in the form of a network of nerve cells in the outer **ectoderm** that can respond to sensory and motor inputs — some researchers liken this to a nervous system

epithelial tissue sheets of cells that cover the external surface of the body and also line internal surfaces that connect to the external environment

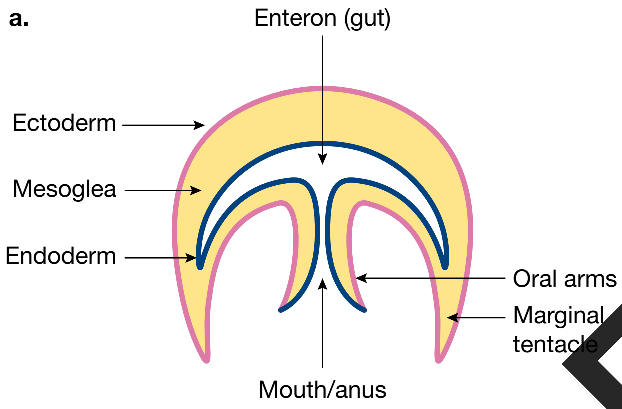
gastrodermal tissue epithelial tissue that lines the inner cavity of the body

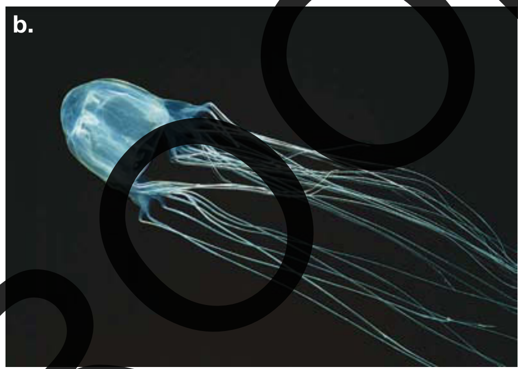
ectoderm epithelial tissue that covers the outer surface of the body

- muscle tissues that enable jellyfish to contract their tentacles and pulsate their bodies; they do this by rhythmically opening and closing their bell-shaped bodies.

Figure 3.16b shows one species of box jellyfish (*Chironex fleckeri*), commonly called the sea wasp, which is considered to be the most venomous animal on this planet. Along the length of its tentacles, the box jellyfish has very large numbers of stinging cells, each of which can discharge a microscopic harpoon-like structure that injects venom into its prey. Contact with two metres or more of the tentacles of this box jellyfish may cause death within a few minutes if the victim is not treated with anti-venom. *C. fleckeri* is distributed in coastal waters in northern Australian, ranging from Agnes Water in Queensland to Exmouth in Western Australia.

FIGURE 3.16 a. Body plan of a typical jellyfish, note the tentacles are not shown **b.** Photo of a box jellyfish (*Chironex fleckeri*), which has tentacles up to three metres long that are covered in millions of stinging cells





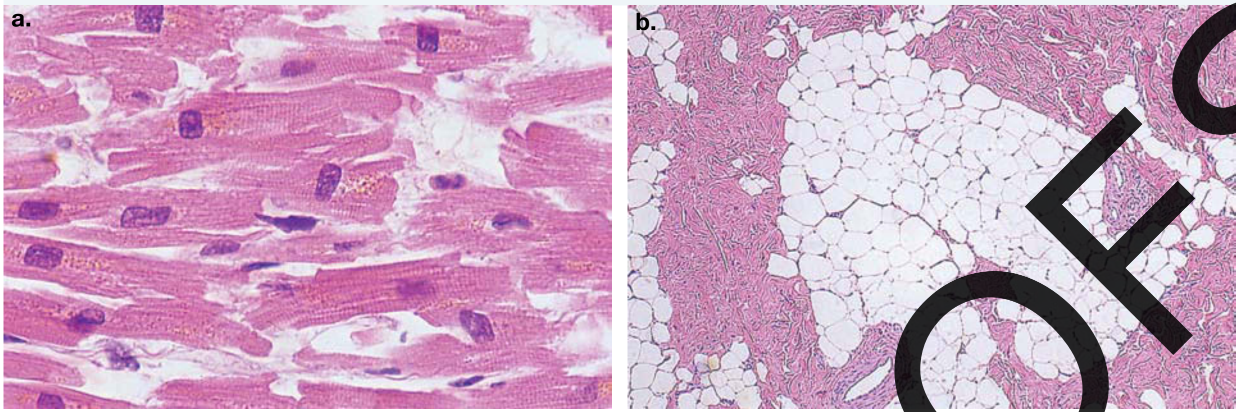
Mammalian tissues

In mammals, as in other animals, four major kinds of tissues are recognised: epithelial, muscle, connective and nervous tissues.

1. *Epithelial tissues*. These are sheets of cells that cover external and internal surfaces — for example, the outermost layer of your skin and the internal lining of tubes and cavities within the body that connect to the external environment, such as the lining of the bladder, lungs and alimentary canal. Epithelial tissues also form the secretory part of glands and their ducts. The functions of these tissues include protection (e.g. skin), absorption (as in the small intestine) and secretion (e.g. glands).
2. *Muscle tissues*. These tissues contract and enable movement — for example, the cardiac muscle tissue of your heart (figure 3.17a), the skeletal (also termed striated) muscles of your arms and legs, and the smooth muscles within the wall of your gut and the walls of your arteries.
3. *Connective tissues*. These provide structural support — for example, the loose **connective tissue** that holds the outer layers of the skin to the underlying muscle layers and the fibrous connective tissue of your bones and cartilage. These tissues also act as energy stores — for example, adipose tissue stores fat (figure 3.17b); and connective tissues transport substances within the body, such as the fluid tissue of your blood.
4. *Nervous tissues*. These tissues are made of different kinds of nerve cells (neurons), such as motor neurons and sensory neurons. Nervous tissue is found in the brain and the spinal cord of the central nervous system and in structures of the peripheral nervous system. An example of nervous tissue is the retina of your eye.

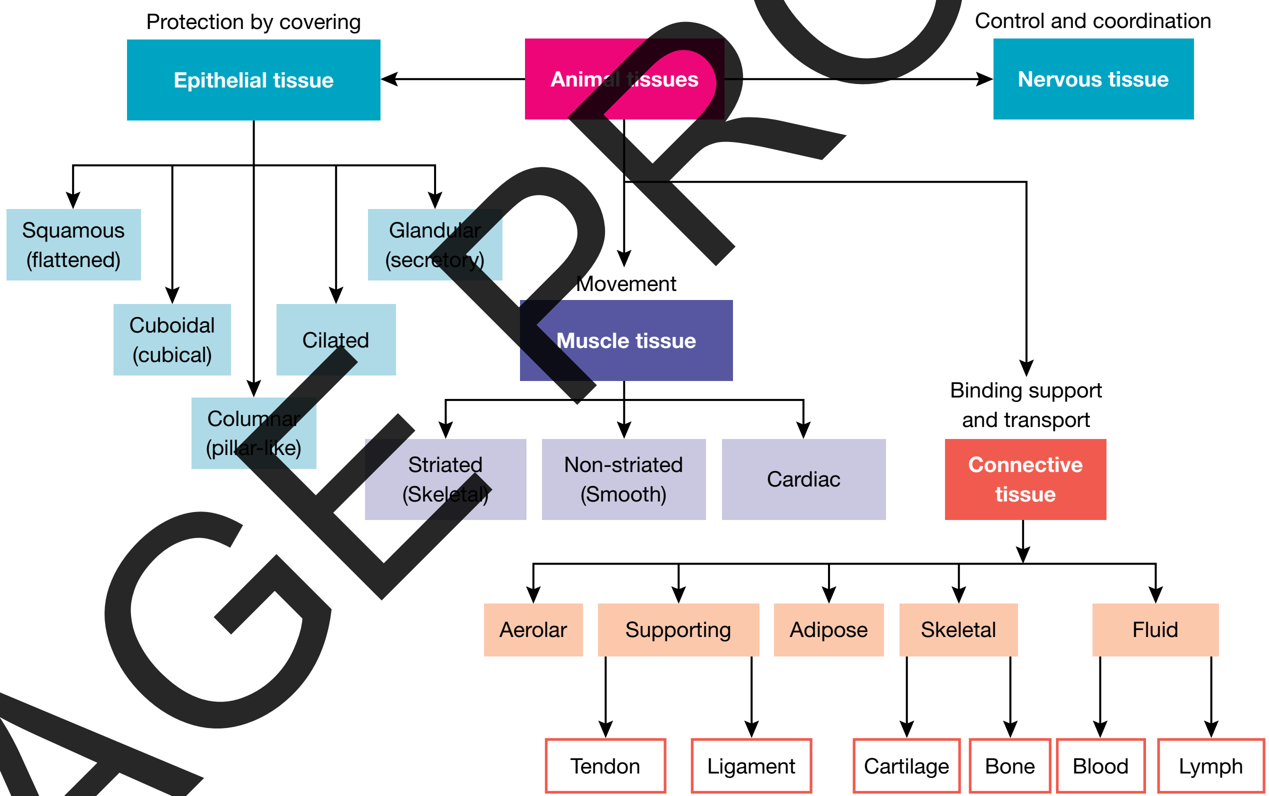
connective tissue diverse solid tissues that connect and support other tissues and organs, or store fat deposits, and fluid tissues that transport materials such as nutrients, wastes and hormones

FIGURE 3.17 **a.** Cardiac muscle tissue responsible for the pumping action of the heart. The purple ovoid shapes are nuclei. **b.** Fat or adipose tissue — an example of connective tissue. The white areas that are fat globules that occupy most of the volume of the fat cells, which are called adipocytes.



The further classification of these four major tissue groups is shown in figure 3.18.

FIGURE 3.18 A classification scheme of the four major tissue types in mammals. What type of tissue is cartilage?



CASE STUDY: Structure and function of connective tissue

Connective tissue is the most abundant tissue type and it is widely distributed throughout the body. The various kinds of connective tissue include areolar tissue, bone, cartilage, ligament, fat tissue and blood.

Connective tissue has three main components: cells, fibres and ground substance.

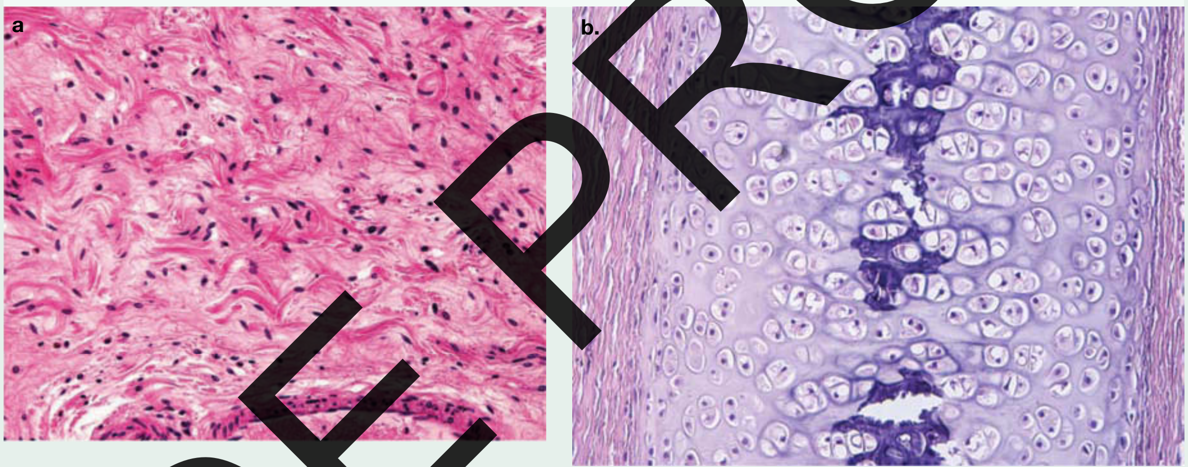
The ground substance is non-cellular and is composed of proteins, polysaccharides and extra-cellular fluid. It may be solid as in bone and cartilage, or viscous as in the gut, or liquid as in blood. The non-cellular fibres include collagen fibres and elastic fibres. Cells present in the matrix include fibroblasts, adipocytes (fat cells) and stem cells; the fibroplasts produces the ground substance.

Connective tissues perform various functions: they bind and support, they protect and insulate, they store reserve energy as fat, and they transport materials.

- Loose (**areolar**) connective tissue provides structural support and binds the cells of tissues and organs together (figure 3.19).
- Dense connective tissues of bone and cartilage provide structural support for the body.
- Fluid connective tissues, blood and lymph, are involved in transport of substances — water, nutrients, wastes and hormones.
- Adipose connective tissue stores fat, an energy reserve.

areolar loose, irregularly arranged connective tissue

FIGURE 3.19 Microscopic views of **a.** areolar connective tissue. Note the nuclei of fibroblasts (red dots), thin elastic fibres and thicker collagen fibres (both pink). **b.** Human cartilage showing chondrocytes (cartilage cells) in a dense ground substance (light purple) that is rich in chondroitin sulfate.



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SAMPLE PROBLEM 2 Tissue types in mammals

Some of the earliest mammals were shrew-like creatures from the *Morganucodon* genus. Like other mammals, they possessed four main types of tissues.

a. Identify each of these tissue types. (1 mark)

b. Select two of these tissue types. Outline the function and structure of each of these tissues. (4 marks)

THINK	WRITE
a. This question is asking you to identify. When you need to identify, you just need to state the relevant term. As this is only worth one mark, you need to identify all four tissues types for the single mark.	• Epithelial tissue • Muscle tissue • Connective tissue • Nervous tissue (1 mark)

b. This question is asking you to outline. This requires a brief summary statement.
In this case, you need to outline both the function and structure of two tissues. As this is worth 4 marks, it is one mark for each point. Outline the structure and function, clearly showing each part of your answer.

Epithelial tissue: The *structure* of the epithelial tissue involves sheets of cells covering surfaces (1 mark).
The *function* of these cells is for protection, absorption and secretion (1 mark).
Muscle tissue: The *structure* of muscle tissue involves tissue and cells that are able to contract (1 mark).
The *function* of muscle tissue is to enable movement and contraction, such as in skeletal, cardiac and smooth muscle (1 mark).

Note: you may have selected connective or nervous tissue instead in your response.

3.3.3 Organs in animals

An organ is a group of different kinds of tissue grouped together to form a discrete structure that works cooperatively to perform a specific function.

The first animals to show organisation at the organ level are flatworms of the phylum *Platyhelminthes*. These animals include free-living marine flatworms (figure 3.20) and parasitic tapeworms and flukes. In contrast to jellyfish with their two-layer body plan, flatworms were the first to have a three-layer body plan: outer ectoderm, inner endoderm and, between them, a cellular mesoderm. Different tissues in flatworms are arranged into organs, as, for example, the brain and the excretory organs (nephridia).

FIGURE 3.20 Marine flatworm (*Pseudobiceros gloriosus*). Its common name is the glorious flatworm. Ancestors of the flatworms were the first animals to show a three-layer body plan.

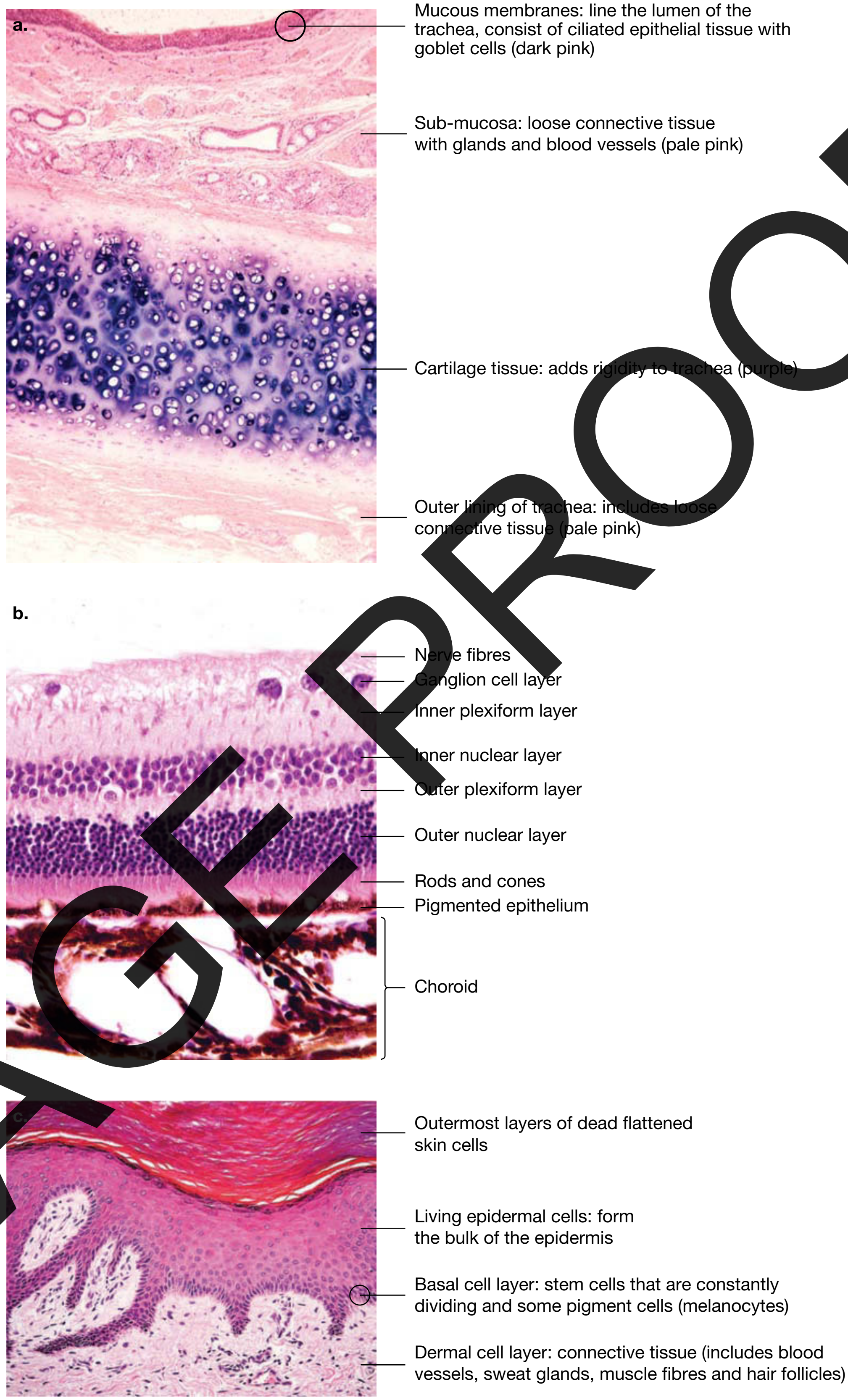
Organs in mammals

Heart, lungs, stomach, kidneys, liver and eyes — these are just some of the organs in not only the human body, but also across a range of organisms. An organ is composed of groups of different tissues that work cooperatively to perform a specific function — the heart pumps blood, the stomach churns and digests food, the kidneys excrete nitrogenous wastes and the eye receives visual signals that are passed to the brain for processing.

The photomicrographs of some organs in figure 3.21 show the different types of tissue that are present in each organ:

- Trachea (windpipe): The cross-section of this organ shows several tissues including ciliated epithelial tissue and cartilage tissue (figure 3.21a).
- Eye: The cross-section of the eye shows the multiple layers of nervous tissue that forms the retina and, below the retina, the connective tissue of the choroid of the eye, including dilated blood vessels, can be seen (figure 3.21b).
- Skin: The section of the skin reveals the epithelial tissue, both dead and living, that forms the outer lining of the skin and the connective tissue of the dermis that lies below it (figure 3.21c).

FIGURE 3.21 Photomicrographs showing different tissues that form the structure of various mammalian organs. **a.** Cross-section of the trachea (windpipe) **b.** Cross-section of the back wall of the eye **c.** Longitudinal section of stained human skin

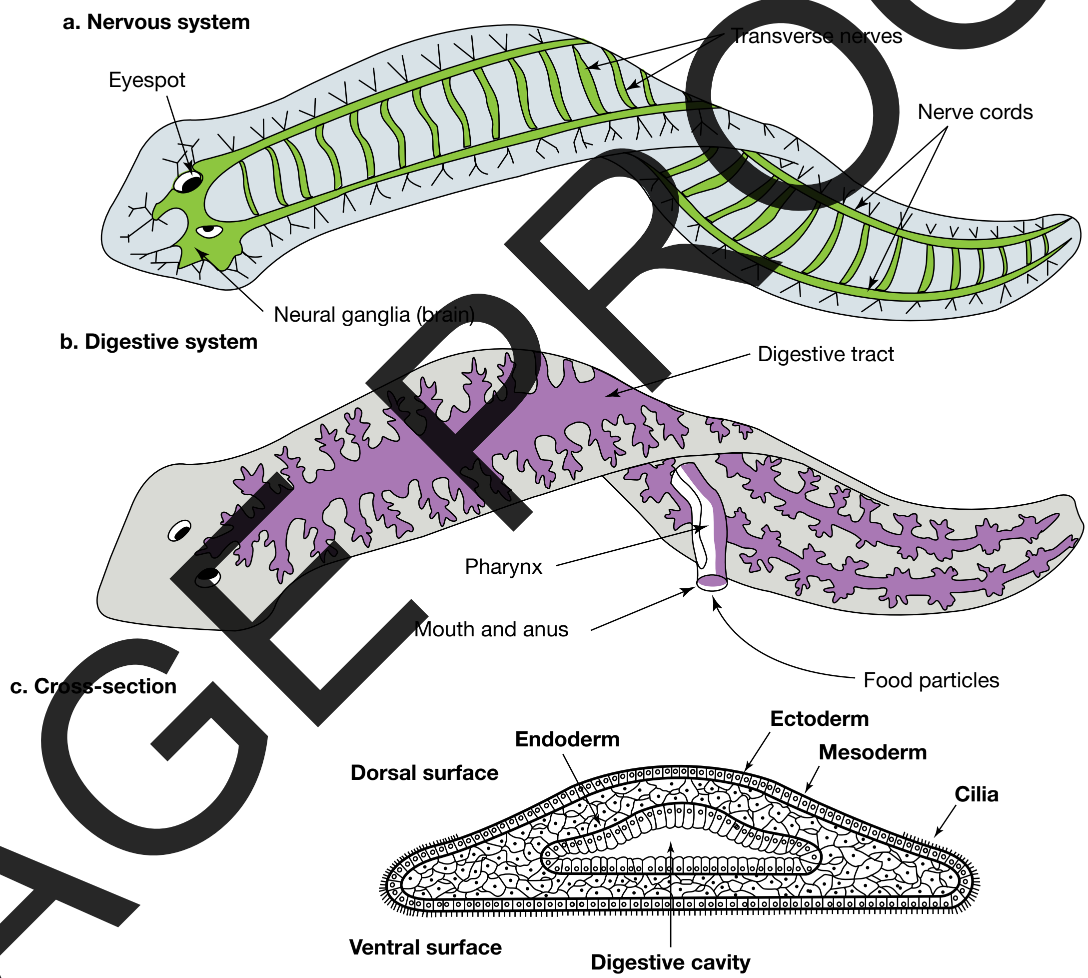


3.3.4 Systems in animals

A system is composed of a group of organs that cooperate to carry out a single life-sustaining function, such as excretion or digestion.

The flatworms of the phylum *Platyhelminthes* not only showed the first organ level organisation, but also the first system level organisation. Flatworms have a nervous system that includes a brain, eyespots and two ventral nerve cords (figure 3.22a). Free-living flatworms have a simple digestive system composed of several different organs, including a pharynx and a highly branched digestive tract (figure 3.22b). (Parasitic flatworms, such as tapeworms and flukes, have no digestive system, so how do they survive?) Flatworms also have organs that form an excretory system and a reproductive system, but they have no respiratory, skeletal or circulatory systems.

FIGURE 3.22 Diagram of a flatworm showing **a.** the nervous system **b.** the digestive system **c.** cross-section showing the three cell layers that form all its tissues, organs and systems. Within the mesoderm are various structures, including muscle fibres and gonads.



The mammalian systems and a brief summary of the major functions that they enable are shown in table 3.1.

In the following sections of this topic, we will look in more detail at the digestive, endocrine and excretory systems. It is important to recognise that systems do not operate in isolation. Instead, to carry out its major function, a system depends on the operation of other systems; for example, the kidneys of the excretory system cannot remove N-containing wastes from the body unless the circulatory system transports them to the kidneys; the lungs cannot excrete carbon dioxide unless it is transported from body cells to the lungs by the circulatory system.

TABLE 3.1 Summary of mammalian systems, some organs and tissues that they contain and their functions

System	Organs and tissues	Major function
Digestive	Oesophagus, stomach, pancreas, duodenum, liver, intestines	Breakdown of food to small products for absorption
Circulatory	Heart, arteries, veins, capillaries and blood	Transport of nutrients to cells and wastes from cells
Endocrine	Hypothalamus and glands (e.g. pituitary, thyroid, adrenal)	Secretion of hormones that regulate cells and organs
Respiratory	Larynx, trachea, bronchi and lungs	Input of oxygen to body and removal of carbon dioxide
Excretory (urinary)	Kidneys, ureters, bladder and urethra	Removal of nitrogenous wastes and compounds in excess from the body
Nervous	Brain, spinal cord, sensory organs (e.g. eye, ear, tongue)	Input of information from senses and coordination of activity
Musculo-skeletal	Muscles, bones, ligaments and tendons	Supports body and enables movement
Reproductive	Ovaries, uterus, vagina testes, penis	Production of gametes, fertilisation and, in females, gestation
Immune	Bone marrow, spleen, thymus	Protection against foreign bodies and pathogens
Integumentary	Skin, and covering such as fur and hair, and nails	Protection and temperature regulation

on Resources

eWorkbook Worksheet 3.2 Systems, organs and tissues in animals (ewbk-3488)

KEY IDEAS

- Multicellular organisms have specialised cells used to perform different functions that serve the needs of the whole organism.
- Multicellular animals may show organisations at the levels of cell, tissue and organ.
- Sponges show the simplest level of organisation — the cellular level.
- Tissues are formed by groups of cells of similar or single type that act in a coordinated manner to perform a common function.
- Jellyfish, corals, sea anemones, hydra (phylum *Cnidaria*) have a two-layer body plan and show tissue level organisation.
- Major tissue types are epithelial, muscle, connective and nervous tissues.
- An organ is a group of different kinds of tissue grouped together to form a discrete structure that works cooperatively to perform a specific function.
- Flatworms have a three-layer body plan and show the first organ level organisation.
- A system is composed of a group of organs that cooperate to carry out a single life-sustaining function, such as excretion or digestion.
- Systems do not act in isolation but are dependent on each other.

3.3 Activities

learnON

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at **www.jacplus.com.au**. A **downloadable solutions** file is also available in the resources tab.

3.3 Quiz quiz on	3.3 Exercise	3.3 Exam questions

3.3 Exercise

1. Consider the following organisms: sponge, jellyfish and flatworm.
   a. Identify, giving a brief reason for your choice, which has the most complex organisation.
   b. Identify, which, if any, has a digestive system and identify whether it is a one-way or two-way system. Explain your answer.
   c. What is the body plan structure, in terms of cellular layers, of each of these animals?
2. Animal M has tissues, but no organs. What kind of animal might it be? Explain your answer.
3. Give an example of a tissue in animals:
   a. that forms a lining
   b. that is an energy store.
4. Identify an organ in which you would expect to find the following:
   a. cartilage tissue
   b. epithelial tissue with outer layers of dead flattened cells
   c. a layer of photoreceptor cells.
5. By which two features can epithelial tissues be classified?

3.3 Exam questions

Question 1 (1 mark)

MC A group of similar cells that perform the same function is referred to as

A. a tissue.
B. an organ.
C. a body system.
D. an organism.

Question 2 (1 mark)

MC An example of an organ in an animal is

A. a muscle cell.
B. a group of epithelial cells.
C. bone tissue.
D. a stomach.

Question 3 (1 mark)

MC Mammalian cells capable of carrying oxygen include

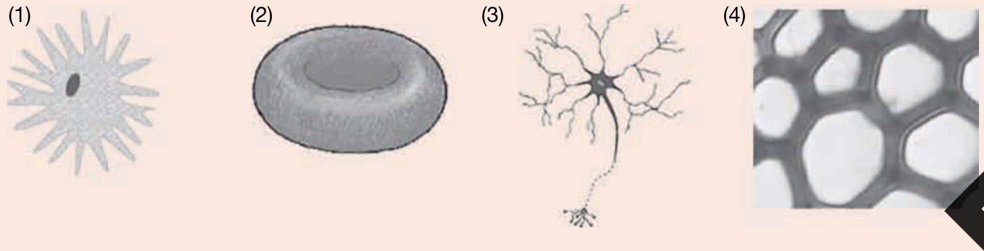
A. platelets.
B. white blood cells.
C. red blood cells.
D. macrophages.

Question 4 (4 marks)

Name four human tissue types and describe the function of each type.

Question 5 (2 marks)

Consider the following diagram that shows several different cell types.



Choose which cell type would be most suited to transmitting messages in an organism. Explain your choice.

More exam questions are available in your learnON title.

3.4 Digestive system in animals

KEY KNOWLEDGE

- Specialisation and organisation of animals cells into tissues, organs and systems with specific functions: digestive

Source: Adapted from VCE Biology Study Design (2022–2026) extracts © VCAA; reproduced by permission.

3.4.1 What is the digestive system?

All animals require a source of chemical energy for living and a supply of organic molecules that are essential for both their structure and their function. The source of chemical energy and organic molecules for animals is their food. Animals exploit a varied range of food sources – paper for silverfish, wool for the larvae of clothes moths, grass and hay for cattle, blood for fleas, skin cells shed by people for dust mites, and eucalyptus leaves for koalas (see figure 3.23).

FIGURE 3.23 Koalas (*Phascolarctus cinereus*) are mainly limited to eating the leaves from 40 to 50 of the 900 species of eucalyptus trees.

To be food for an animal, a substance must contain organic matter that can be broken down and absorbed by the animal and be used to supply it with chemical energy for living, and the organic matter to build and repair its own structures.

Why is a digestive system important for animals? With few exceptions, food that animals ingest is mainly in the form of macromolecules, such as proteins, carbohydrates and lipids (fats). These large molecules must be broken down to small sub-units or monomers before they can be absorbed into the internal environment of an animal's body for use in energy production, and as building blocks for growth, maintenance and repair. That's where the breakdown crew, the digestive system, comes in! The digestive system breaks down large food molecules, chemically and physically, into sub-units small enough to be absorbed into the body. It should be noted that small water-soluble vitamins and minerals that are part of an animal's diet are already small enough so that they do not need to be digested.

The digestive system breaks down macromolecules: proteins, carbohydrates, lipids (fats) into smaller sub-units that can be absorbed and used for energy production, growth, maintenance and repair.

In terms of structure, the digestive system of almost all animals — except sponges, jellyfish and flatworms — is an open hollow tube that takes in food at one end, the mouth, and releases wastes at the other end, the anus. The least complex animals with this one-way digestive system are nematode worms, also called roundworms, of the phylum *Nematoda* that includes both free-living and parasitic species. The parasitic nematodes include heartworms that infect dogs, and pinworms and hookworms that can infect small children. The digestive system of nematodes is a tube that consists of mouth, pharynx, intestine, rectum and anus.

Now let's look at the vertebrates. In terms of structure, the digestive system is made up of two components:

1. The **alimentary canal**, also called the **gastrointestinal tract** (GI tract) or the gut, is an open tube extending from mouth to anus that varies in diameter along its length, and consists of a series of hollow organs including the oesophagus, the stomach and the small intestine.
2. Accessory organs: these are solid organs that include the salivary glands, the liver and gall bladder, and the pancreas. These solid organs release secretions, including enzymes, that are delivered via ducts into the lumen of the alimentary canal.

alimentary canal the whole passage from mouth to anus; see gastrointestinal tract

gastrointestinal tract the whole passage from mouth to anus; see alimentary canal

Accessory organs are essential partners with the alimentary canal in achieving the functions of the digestive system. Refer to figure 3.24, which shows a stylised alimentary canal with its accessory organs (black text) that together form the digestive system (white text).

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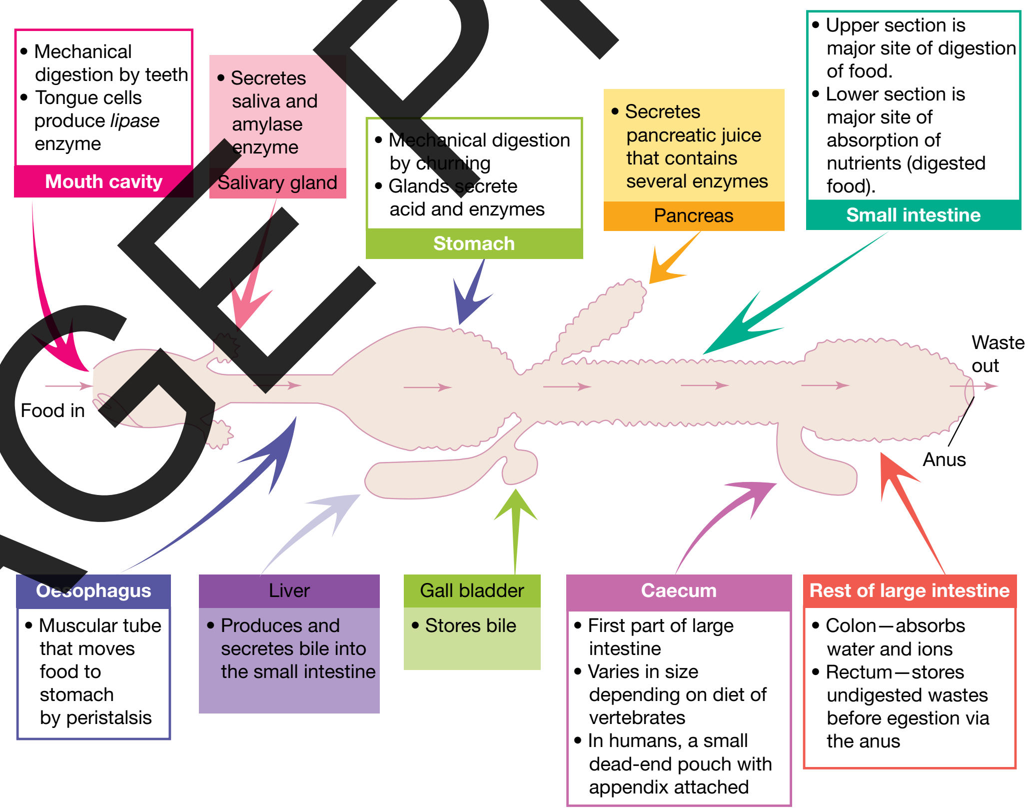
FIGURE 3.24 A stylised representation of the vertebrate digestive system as a one-way passage for the processing of food



However, in vertebrates, the digestive system is not arranged in a straight line within the body. Because of their length, parts of the alimentary canal, such as the small and the large intestines, are coiled or bent in order to be accommodated with the body. This is not surprising, since the total length of the alimentary canal in an adult person is about 9 metres, and most of this involves the small intestine with a length ranging from 3 to 5 metres. The small intestine is not small in length, but it is small in diameter, almost 3 centimetres. The large intestine is about 1.5 metres in length, with a diameter of nearly 5 centimetres. Figure 3.25 shows the major parts and the relative positions of the hollow and solid organs of the human digestive system. Note that the liver has been folded back to show the stomach, pancreas and gall bladder. In reality, the liver is the largest organ within the body and it covers these organs. We will explore the organs of the digestive system in more detail later in this subtopic (section 3.4.4).

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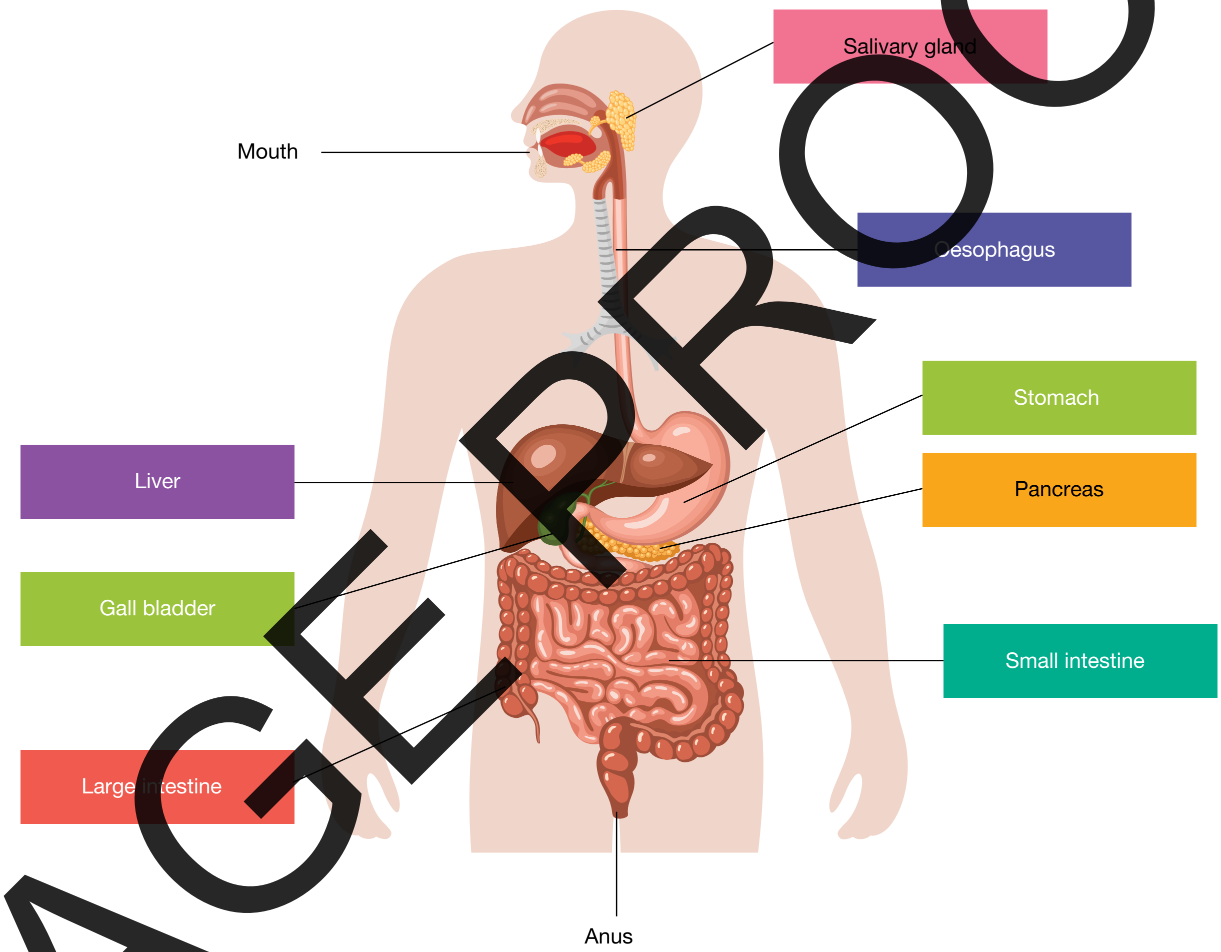
FIGURE 3.25 Line diagram showing the hollow organs of the alimentary canal (GI tract), starting from the mouth and ending at the anus, and its accessory solid organs, the salivary glands, liver and gall bladder, and pancreas



In terms of function, the key activities of the digestive system are shown in table 3.2. **Mechanical digestion** is achieved through chewing and through the churning action of the stomach. Breaking down food into smaller pieces produces an increase in its surface area. As a result, chemical digestion through enzyme action occurs more rapidly on these small food pieces than would occur if the pieces of food were larger. **Chemical digestion** is achieved through the action of enzymes.

mechanical digestion digestion that uses physical factors such as chewing with the teeth

chemical digestion the chemical reactions changing food into simpler substances that are absorbed into the bloodstream for use in other parts of the body

TABLE 3.2 The processes of the human digestive system that make the energy and nutrients in food available for use

Process	Where it occurs	Result
Ingestion	Mouth	Food is taken into the mouth.
Mechanical digestion of food	Begins in mouth; continues in stomach	Food is broken down into small pieces, increasing its surface area.
Chemical digestion of food	Begins in mouth; continues in stomach and small intestine	Macromolecules of food are broken down to smaller and smaller sub-units through the action of enzymes secreted by various glands.
Absorption of digested food	Small intestine	End products of digestion cross the tissue layer that lines the gut and enter the internal environment of the body.
Elimination of undigested wastes	Rectum and anus	Storage and elimination as faeces

Let us now look at the tissues that are part of the digestive system and become aware of how these tissues enable the digestive system to perform its essential functions.

3.4.2 Tissues in the digestive system

The width of the tubular canal of the digestive system differs along its length — it is widest at the stomach and narrowest at the oesophagus. However, the wall of the tubular canal has a similar tissue organisation along its entire length, with the wall of the gut having the same four concentric tissue layers.

Four tissue layers form the gut wall, starting from the inside of the gut cavity or **lumen**. The same four tissue layers form the wall of all the hollow organs of the digestive system as follows:

- Epithelial tissue forms the innermost lining of the digestive system, and it is part of the first tissue layer that is called the **mucosa**. The remainder of this layer is tissue that underlies and supports the epithelial tissue.
- Connective tissue forms the second layer, and it includes blood vessels, lymphatic vessels and nerves; this tissue layer is termed the **sub-mucosa**.
- Muscle tissue forms the third layer; this layer is called the **muscularis**.
- Connective tissue forms the fourth and outside layer that encloses the gut; this tissue layer is called the **serosa**.

lumen the inside space of a tubular structure

mucosa the innermost lining of the digestive system

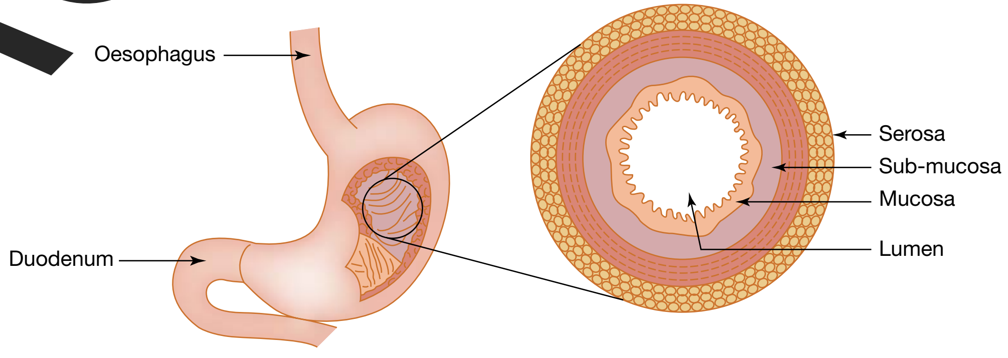
sub-mucosa connective tissue forming the second layer of the gut lining

muscularis muscle tissue of the gut

serosa outer connective tissue which encloses the gut

Figure 3.26 shows a stylised version of the basic pattern of the four tissue layers of the gut wall.

FIGURE 3.26 The stomach, like all the hollow organs of the digestive system, has the arrangement of tissue layers as shown in inset



Don’t worry about the official anatomical names of these tissue layers. They are included here because they are routinely used as labels on diagrams and other images, and they are a convenient shorthand. It is easier to write ‘mucosa’ than ‘the innermost layer of the gut wall’ and ‘muscularis’ rather than ‘a muscle layer consisting of two rings of smooth muscle, the inner ring in a circular arrangement and the ring arranged longitudinally’.

Tissue layers of the digestive tract

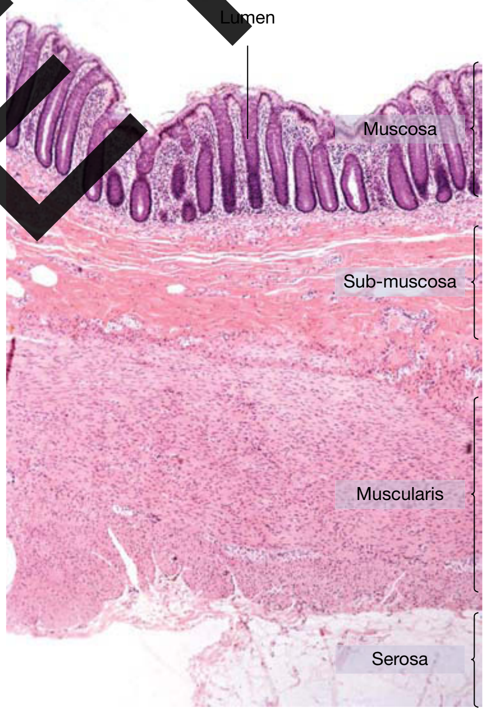
The four layers of tissue that form the digestive system are the muscosa (epithelial tissue), sub-muscosa (connective tissue), muscularis (muscle tissue) and serosa (connective tissue).

Variation in the basic pattern

Different regions of the digestive system are involved in different functions: moving food, churning the gut contents, secretion, digestion and absorption. So, although the basic arrangement of tissue layers in the gut wall is the same throughout the gut, variations exist between different regions of the gut, such as thickness of tissue layers, presence (or absence) of features such as villi (outfoldings) or crypts (infoldings), as well as the specific cell types present in the tissue. In particular, the epithelial tissue of the mucosa that is in direct contact with the gut contents shows some striking regional differences.

Let’s now look at a photomicrograph that shows these tissue layers in one segment of the gut. Figure 3.27 is a photomicrograph of a cross-section through part of a mammal’s small intestine, the jejunum. The four tissue layers are clearly visible. In the small intestine, the epithelial tissue is a single layer of cells that forms the outer surface of the mucosa that is in direct contact with the contents of the gut. Note the extensive folding of the surface of the mucosa to form narrow deep infoldings (called crypts) and finger-like projections (called villi; singular = villus).

FIGURE 3.27 Photomicrograph of a section through the wall of the small intestine in a mammal. Note the four tissue layers that form the wall. In the small intestine, the epithelial tissue of the mucosa forms the gut lining; it is just one cell thick, but it is folded, forming villi and crypts.



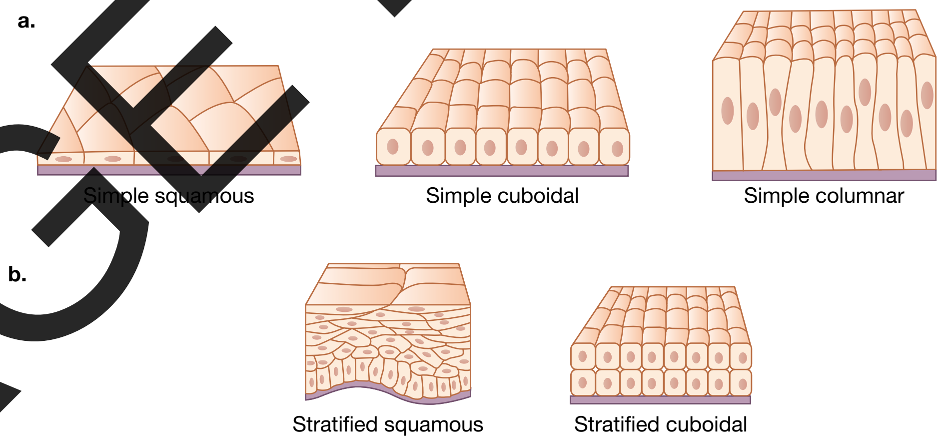
Epithelial tissues: Various types

Some facts about the epithelial tissue in the gastrointestinal tract:

- Epithelial tissue is undergoing constant renewal. Cells are shed in large numbers from epithelial surfaces into the gut lumen, but are replaced just as fast by mitosis of epithelial stem cells. It has been estimated that the epithelial lining of the stomach and that of the small intestine are regenerated every four to five days.
- Epithelial tissue can be classified in terms of the general shape of its cells and also the number of cell layers present.
  - In terms of shape, common cell shapes are squamous, cuboidal and columnar (figure 3.28a).
  - In terms of number of layers, an epithelium can be simple or stratified.
- Simple epithelium is composed of a single layer of cells.
- Stratified epithelium is composed of two or more layers of cells (figure 3.28b).
- Epithelial tissues can be named in terms of these features so, for example, we can talk about 'simple columnar epithelial tissue' or 'stratified squamous epithelium'.
- Different types of epithelial tissues are found in the wall of the alimentary canal, for example:
  - in the oesophagus, the epithelium is stratified and squamous
  - in the stomach, the epithelium is simple columnar and smooth with many infoldings (crypts)
  - in the small intestine, the epithelium is simple columnar with many outfoldings (villi) and infoldings (crypts).
- Epithelial tissues can also be classified in terms of whether they form a lining (lining epithelium) or whether they form a gland — that is, a solid structure below the surface that secretes substances (glandular epithelium).
  - the innermost lining of the GI tract is an example of a lining epithelium
  - the **gastric glands** of the stomach and the intestinal glands (crypts) of the small intestine are examples of glandular epithelium.
- Epithelial tissue itself contains no blood vessels. The epithelial cells obtain their essential requirements by diffusion from blood vessels in the underlying connective tissue of the sub-mucosa.

gastric glands glands of the stomach that contain various epithelial secretory cells, producing neutral mucus, stomach acid and enzymes

FIGURE 3.28 a. Types of simple epithelial tissue that are composed of a single layer of cells **b.** Two types of stratified epithelial tissue that is formed by two or more layers of cells



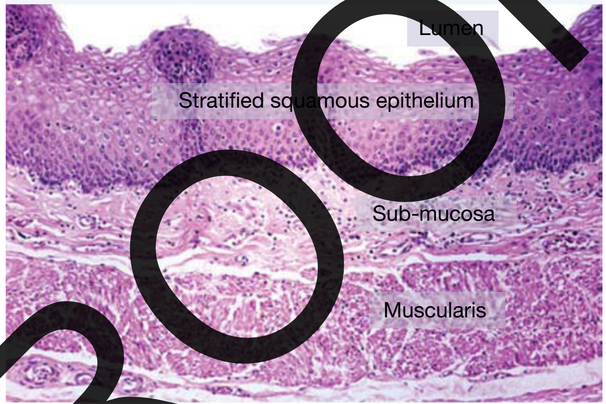
Epithelial tissue: Functions in the digestive system

The functions of the epithelial tissue of the alimentary canal include protection, absorption and secretion.

Protection

The protective role of epithelial tissue is to prevent physical or chemical damage to tissues. For example, the stratified squamous epithelium is present as the inner lining of several regions of the gut — the mouth, the oesophagus and the anal canal — and it protects the underlying tissues from damage. Figure 3.29 shows part of the wall of the oesophagus with its distinctive stratified squamous epithelium, showing many layers of cells. At the base of the tissue are living cells, including stem cells that are constantly producing new cells that push existing cells upwards.

FIGURE 3.29 Photomicrograph of a cross-section of the wall of the human oesophagus (30 x magnification). The squamous stratified epithelium forms the inner lining of the oesophagus and plays a protective role.



Absorption

The end products of digestion are taken up from the gut lumen and transferred across the epithelial tissue of the mucosa to blood and lymph vessels for distribution. Most absorption takes place in the small intestine, where the muscosa is folded into villi, which greatly increases the surface area. The absorptive function is carried out by a layer of simple columnar epithelial cells called enterocytes which cover each villus (figure 3.30).

FIGURE 3.30 Cross-section of part of the wall of the small intestine showing the mucosa folded into villi. and part of the sub-mucosa. Note the finger-like villi projecting into the gut lumen (at top). Also visible are the narrow channels (crypts) at the base of the mucosa.

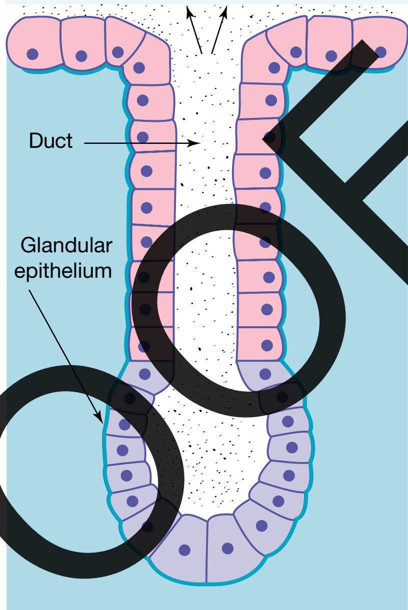
Secretion

Secretion is a function of glandular epithelial tissue and occurs when glands release substances into the lumen of the gut.

- Some glands are single cells, such as goblet cells. These cells are scattered throughout the simple columnar epithelium of the small and the large intestines. Goblet cells secrete mucus that lubricates the inner surface of the gut. Figure 3.31 shows a cross-section through seven villi, each covered by a layer of simple columnar epithelial tissue which forms outer lining around each villus. The bright pink stain identifies the mucus in the mucus-secreting goblet cells.
- Other glands are multicellular and they lie below the epithelial surface to which they are connected by ducts. Various types of gland exist, including the simple tubular glands in the small intestine (figure 3.32), which forms the crypts of the intestinal mucosa. Note the glandular epithelial tissue (shown in dark purple) at the base of the gland that produces the secretion. Secretions from the gland pass to the surface of the gut lining via the duct.

FIGURE 3.31 High power micrograph of a cross-section through seven villi, each covered by simple columnar epithelial tissue that forms the outer lining around each villus. The bright pink stain highlights the mucus secretion present in goblet cells.

FIGURE 3.32 A tubular gland. The glandular epithelial tissue (purple) produces the secretions that pass to the surface of the gut lining via the duct.



Connective tissue: Functions in the digestive system

In the alimentary canal, connective tissue forms the second layer of the gut wall, the sub-mucosa, where it occurs as areolar connective tissue with blood vessels, lymphatics and nerves; it also forms the outermost layer, the serosa. Connective tissue is also present in the solid organs of the digestive system.

Connective tissue in the hollow organs of the alimentary canal provides structural support to other tissues. For example, the connective tissue of the sub-mucosa of the gut wall supports the overlying mucosa and connects it to the underlying muscularis (figure 3.33).

Blood and lymph are also connective tissues. In the sub-mucosa and mucosa, they provide metabolic support by providing nutrients and oxygen, and remove cell wastes. They also transport the end products of digestion after they have been absorbed across the epithelial lining of the gut.

Connective tissue in the solid organs of the digestive system forms a thin surrounding capsule around and within solid organs. For example, a thin layer of connective tissue surrounds the liver and also encloses each functional unit in this organ (see figure 3.34).

FIGURE 3.33 Microscopic view of loose connective tissue in the sub-mucosa of the stomach showing wavy bundles of collagen fibres. Nuclei of fibroblasts appear black.

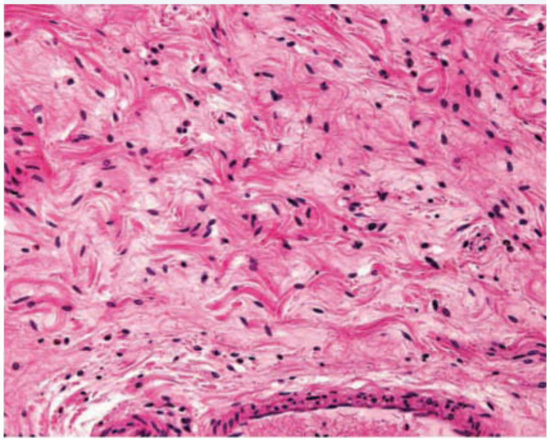
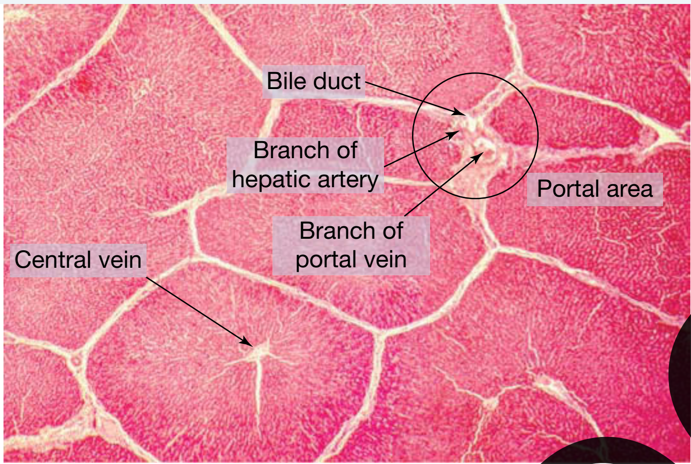


FIGURE 3.34 Photomicrograph of cross-section through the liver showing each of its functional units (lobules) surrounded by connective tissue (white). Note that the bile duct and various blood vessels are also enclosed by connective tissue.



Muscle tissue: Functions in the digestive system

Muscle tissue is important in the structure and function of the digestive system. In almost all parts of the alimentary canal, the muscle tissue is composed of smooth involuntary muscle cells. The exceptions are the muscle tissues of the throat and upper region of the oesophagus and that at the end of the anal canal. In these locations, the muscle tissue is striated (skeletal) muscle that is under voluntary control. As you will be aware, this means that you have conscious control of swallowing food at the start of the gut, and of eliminating faeces at the other end of the gut, but no voluntary control in between.

Smooth muscle tissue forms the third layer (muscularis) of the gut wall in all segments of the gut. Except for the stomach, the muscularis consists of two layers of muscle: an inner smooth muscle that is arranged in a circular pattern and an outer smooth muscle with a longitudinal arrangement (figure 3.35). In the stomach, a third layer of smooth muscle is present with an oblique arrangement (figure 3.36). These three muscle layers act in a coordinated manner to produce the churning movement of food in the stomach.

FIGURE 3.35 Micrograph showing the muscularis layer of the small intestine with of its two layers of smooth muscle

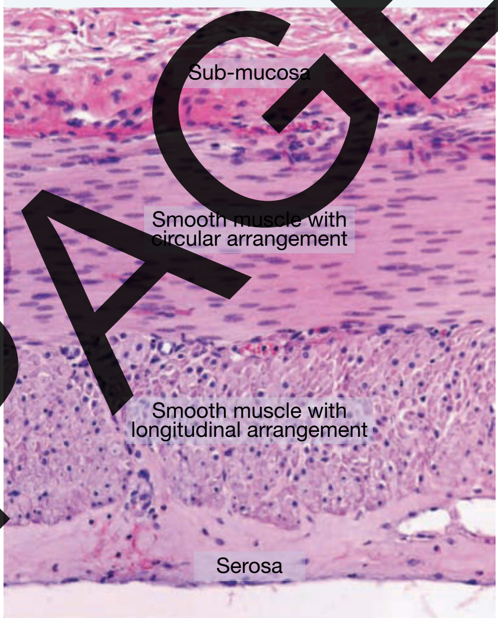
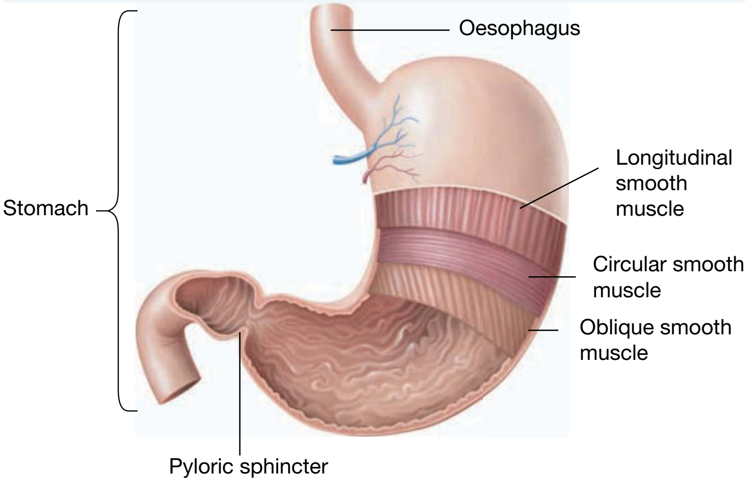


FIGURE 3.36 Illustration of the stomach showing the three layers of muscle tissue that form the musculosa of the stomach wall (Note the pyloric sphincter; you will shortly meet it.)



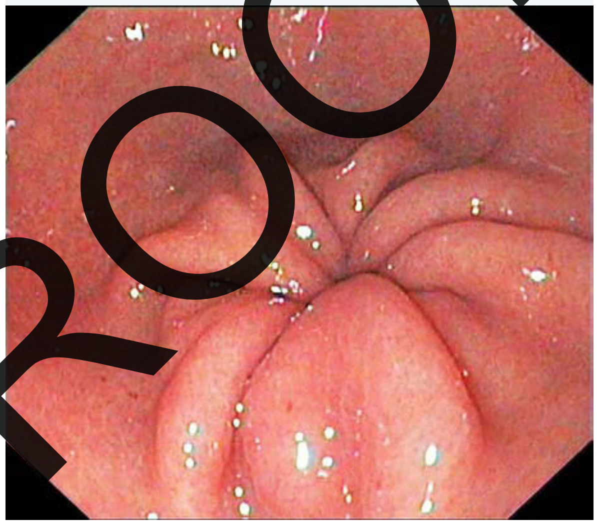
Muscles have the ability to contract (and relax) and they are responsible for various movements in the alimentary canal including:

- coordinated contraction of the musculosa to create the peristaltic movement of the gut content starting at the oesophagus and ending at the anal canal. These movements propel the digested food through the gut and cause mixing.
- regulation of the movement of the gut contents from one segment of the gut to the next. Regulation of the flow of the gut content from segment to segment is achieved through **sphincters**, which are thickened rings of muscle located at the junction of different segments of the alimentary canal. When relaxed and open, the sphincter allows food to pass and, when contract and closed, prevents the forward movement of food.

Sphincters

- A key sphincter is the **pyloric sphincter**, which is present at the junction of the stomach with the duodenum of the small intestine. The stomach contents are large in volume and highly acidic. In contrast, the duodenum is a small segment of the gut and the enzymes that are active in the duodenum require alkaline conditions. An unregulated free flow of **chyme** from the stomach into the duodenum would have negative results. Figure 3.37 shows an endoscopic photo of a normal pyloric sphincter in the closed position.
- Another sphincter in the alimentary canal is present at the junction of the lower end of the oesophagus and the upper region of the stomach — this is the lower oesophageal sphincter that keeps stomach acid from moving up into the oesophagus.
- Another sphincter is located at the anus. This sphincter is in fact, two sphincters: an inner sphincter of smooth muscle that is involuntary and an outer sphincter of striated muscle that is under voluntary control.

FIGURE 3.37 View through an endoscope of a normal pyloric sphincter in the closed position



3.4.3 Organs involved in digestion

Food goes through a series of processes in the period after it enters the mouth and leaves as indigestible wastes via the anus. Each mouthful of food passes from mouth via the oesophagus to the stomach, then through the 3- to 5-metre length of small intestinal tubing into the 1.5 metre of the large intestine before the undigested waste leaves via the anus. The time for the passage from mouth to anus shows variability among healthy persons and is affected by the composition of the meal eaten. However, on average, to totally empty the stomach takes 4 to 5 hours, and the entire trip through the gut may take from 2 to 4 days.

On its journey from mouth to anus, the digestion of food relies on many enzymes to progressively break down large complex nutrients in the food to small monomers or components that can be absorbed from the gut and used by body cells. If this does not happen, the item will be eliminated from the body as undigested waste. Table 3.3 is a list of the enzymes that are key players in the chemical break down of food. The majority of these enzymes operate under alkaline conditions, but the enzymes in the stomach are active under acidic conditions.

sphincters thickened rings of muscle which control the opening and closing of a tube

pyloric sphincter a sphincter at the join of the stomach and the duodenum of the small intestine; it controls the flow of acidic chyme into the alkaline duodenum.

chyme slurry of partially digested food produced in the stomach which passes into small intestine

TABLE 3.3 Enzymes of the digestive system, their sites of production and sites of action, and the result of enzyme activity. End products of digestion that can be absorbed by the enterocytes that line the small intestine are shown in red. The enzymes shown in *italics* are the so-called 'brush border' enzymes.

Macromolecule	Digestive enzyme	Site of enzyme production	Site of enzyme action	Enzyme action
Carbohydrates: broken down to simple sugars (monosaccharides)	Salivary amylase	Salivary glands	Mouth	Starch → sugars + dextrins
	Pancreatic amylase	Pancreas	Duodenum	
	α-dektrinase	Enterocytes of small intestine	Brush border	Oligosaccharides → glucose
	Maltase			Maltose → glucose
	Sucrase			Sucrose → glucose + fructose
	Lactase			Lactose → glucose + galactose
Proteins: broken down to amino adds	Pepsin	Gastric glands	Stomach	Protein → polypeptides & peptides
	Trypsin Chymotrypsin	Pancreas	Duodenum	
	Endopopetidases Aminopeptidases Carboxypeptidases	Enterocytes of small intestine	Brush border	Peptides → amino acids
Fats (lipids): broken down to fatty acids and glycerol or monoglycerides	Lingual lipase	Tongue	Mouth and stomach	Triglyceride → diglyceride + fatty acid
	Gastric lipase	Gastric glands	Stomach	Triglyceride → diglyceride + fatty acid
	Pancreatic lipase	Pancreas	Duodenum	Triglyceride → a monoglyceride + fatty acids
Nucleic acids: broken down to 5-C sugars, phosphate and bases	Deoxyribonuclease	Pancreas	Duodenum	DNA → nucleotides
	Ribonuclease	Pancreas	Duodenum	RNA → nucleotides
	Nucleosidase *Phosphatase*	Enterocytes of small intestine	Brush border	Nucleotides → sugars + phosphates + bases

The mouth — intake of food and start of mechanical and enzymic digestion

Teeth begin the mechanical breakdown of ingested food into smaller particles — this fragmentation increases the surface area of the food that will be exposed to enzymes and other secretions of the digestive system. Saliva contains the enzyme salivary amylase that begins the digestion of carbohydrates such as starch. A fat digesting enzyme, lingual lipase, produced by glandular cells of the tongue, begins the digestion of lipids.

Food leaves the mouth by the conscious act of swallowing — after this, all activity along the digestive tract is involuntary until the anus, where egestion of faeces involves conscious action. As food passes from the mouth into the throat (pharynx), a small flap of tissue called the epiglottis closes over the entry to the trachea (windpipe). Why is this important?

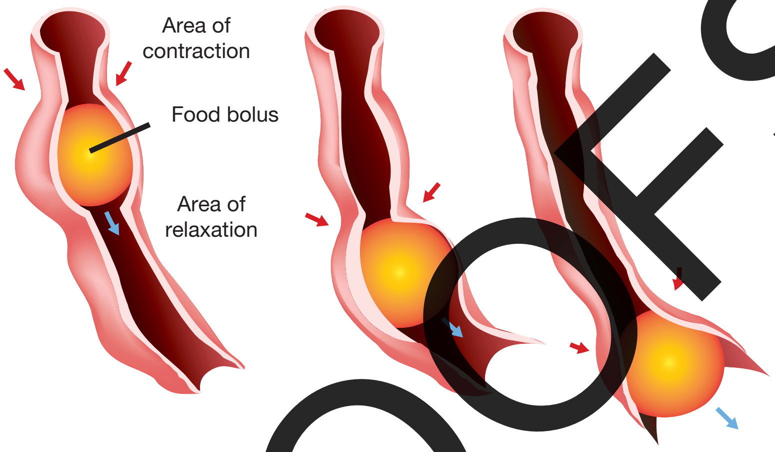
Glands of the mouth include:

- salivary glands that secrete a watery saliva that contains the carbohydrate-digesting enzyme, amylase
- lingual glands on the surface of the tongue that secrete the fat-digesting enzyme, lipase.

The oesophagus — transport of food into stomach

The oesophagus is a narrow tube about 25 centimetres long. Bands of circular muscle tissue are present in the oesophagus wall — near the mouth this muscle is striated muscle but further along the oesophagus, the muscle changes to smooth muscle. Waves of contraction of this muscle progressively move food to the stomach — a process called **peristalsis** (figure 3.38) Peristalsis involves a zone of muscle contraction immediately above the food and a zone of muscle relaxation immediately below the food. Because this movement is due to muscular action and not gravity, a person can swallow food while upside down.

FIGURE 3.38 Diagram showing the movement of food down the oesophagus to the stomach through peristalsis



Glands of the oesophagus include mucus-secreting glands, with the mucus acting as a lubricant and as a neutraliser of acidic **gastric juices** that may flow back up from the stomach.

The stomach — more enzymic and mechanical digestion

The stomach (figure 3.39) is an expandable region of the gut that serves as a temporary holding chamber for ingested food – when empty, in humans, its volume is about 50 millilitres, but it can expand up to several litres when food is present. This ability of the stomach to expand is due to the presence of folds (called rugae) in the stomach wall.

The stomach contains three layers of smooth muscle tissues — longitudinal, circular and oblique — these enable it to actively churn its contents; and contribute to mechanical digestion, which produces a slurry of partly digested food called chyme. Food remains in the stomach for up to four hours, and alcohol and aspirin are two of a very small number of substances that can be absorbed in the stomach.

Enzymic digestion occurs with the release from secretory epithelial cells in gastric glands of gastric juice that is a mixture of mucus, hydrochloric acid, pepsinogen (an inactive **proenzyme**) and the enzyme, gastric lipase. The hydrochloric acid lowers the pH of the lower stomach contents to about a pH of 2 and, in these acidic conditions, inactive pepsinogen is converted to the active enzyme pepsin, that starts the digestion of proteins. Gastric lipase continues the digestion of lipids, and the lingual lipase secreted in the mouth also continues its enzymic breakdown of fats. The passage of chyme from the stomach into the small intestine (duodenum) is controlled by the pyloric sphincter located in the junction.

Glands of the stomach are the gastric glands that contain various secretory cells including:

- parietal cells that secrete hydrochloric acid, which creates the acid conditions of the stomach (pH 2–3)
- **chief cells** that secrete the enzyme gastric lipase and the inactive proenzyme, pepsinogen. In the acidic conditions of the stomach, pepsinogen is converted to the active enzyme pepsin where it begins the digestion of proteins.

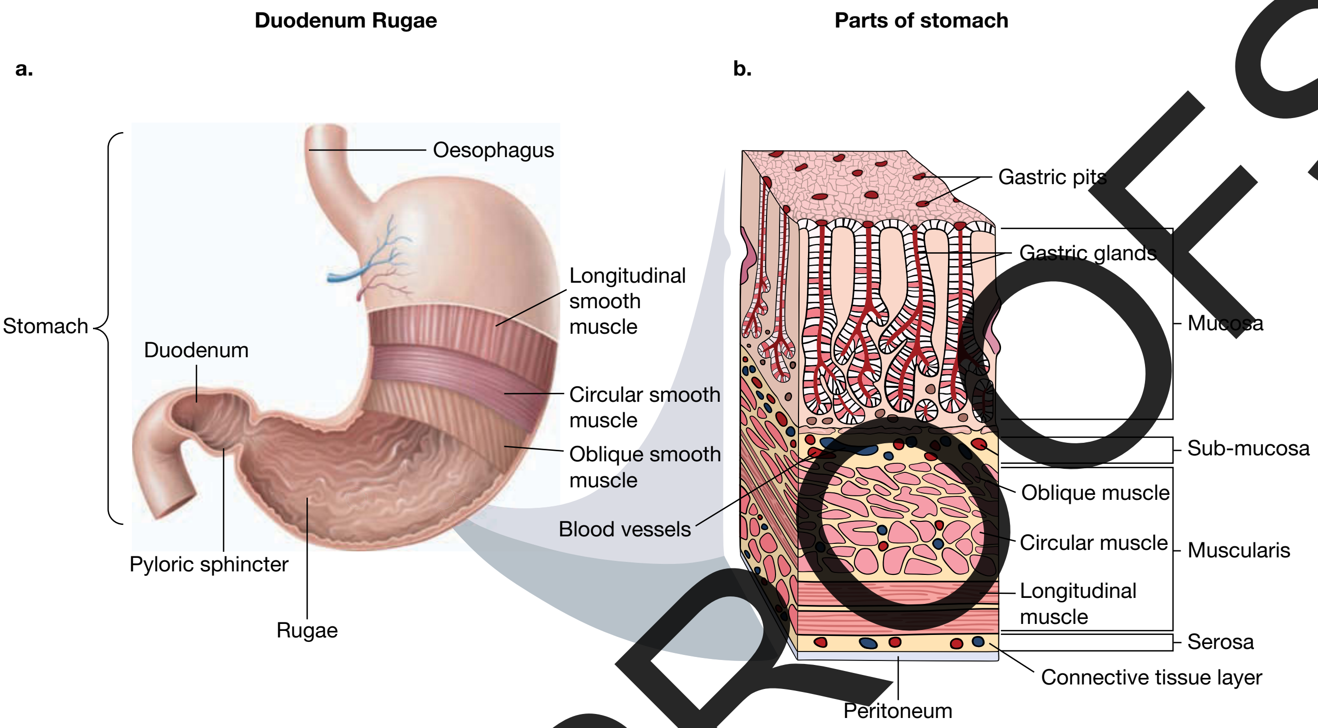
peristalsis involuntary constriction and relaxation of muscles in the alimentary canal to push food to the stomach

gastric juice acid fluid secreted by the stomach glands for digestion in the stomach

proenzyme a precursor of an enzyme that must be activated to form the functional enzyme

chief cells in the parathyroid gland, secretory cells that produce parathyroid hormone (PTH) (Note: different cells with same name are present in the gastric pits of stomach.)

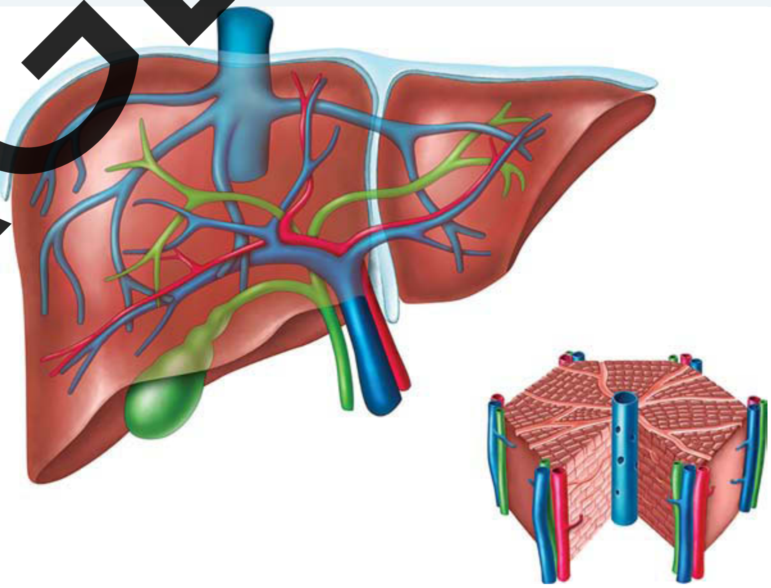
FIGURE 3.39 **a.** Diagram of stomach showing the creases or rugae (singular = ruga) that enable the stomach to expand, and the pyloric sphincter that controls the exit of chyme **b.** A section of the stomach wall showing its four tissue layers. Note in particular the gastric glands located in the mucosa that secrete gastric juice.



The liver — an accessory organ and producer of bile

Bile is secreted by liver cells (hepatocytes) and is transferred via small ducts to the **gall bladder** where bile is either stored or is released via the major bile duct into the duodenum, the first part of the small intestine. The components of bile that are important in digestion are the bile salts. Bile salts are emulsifying agents, not enzymes that disperse fat into smaller particles.

FIGURE 3.40 Illustration of the liver (upper left) and a liver lobule (lower right). Blood vessels are shown as veins (blue) and arteries (red), and the bile-carrying ducts and the expanded gall bladder are shown in green. The liver is organised into many lobules, each built of chains of liver cells (hepatocytes) radiating from a central vein.



gall bladder sac shaped organ which stores the bile after it has been secreted by the liver

The pancreas — an accessory organ and producer of enzymes

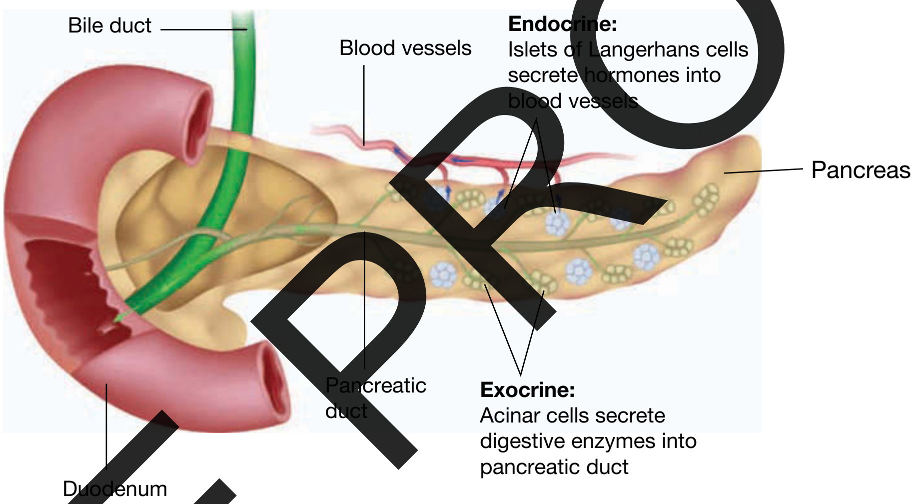
The pancreas secretes and releases pancreatic fluid. Pancreatic fluid leaves the pancreas via the main pancreatic duct. This duct joins the common bile duct from the liver that releases bile and pancreatic fluid simultaneously into the duodenum, the first section of the small intestine (figure 3.41).

Pancreatic fluid contains several enzymes — lipase, amylase and inactive proteases (protein-digesting enzymes) — and it also releases bicarbonate ions into the duodenum that help neutralise the acidic chyme from the stomach.

Glands of the pancreas contain **acinar cells** that secrete:

- trypsinogen, the inactive precursor (proenzyme) of the protein-digestingenzyme, trypsin
- chymotrypsin, the inactive precursor (proenzyme) of the protein-digesting enzyme, chymotrypsin
- pancreatic lipase, a fat-digesting enzyme
- pancreatic amylase, a carbohydrate-digesting enzyme.

FIGURE 3.41 The pancreas showing the junction of the major pancreatic duct with the common bile duct that opens to the duodenum



The small intestine — final stage of digestion and absorption of nutrients

The small intestine has three parts: the duodenum (about 25 centimetres long), followed by the jejunum (up to 2.5 metres long), and then the ileum (about 3 metres long).

The mucosa of the small intestine can be distinguished from that of all other regions of gut by the presence of villi, crypts and microvilli.

- **Villi** are finger-like structures that project into the lumen of the small intestine; villi are covered by absorptive cells (enterocytes) and mucus-secreting goblet cells.
- **Crypts** are narrow depressions that descend into the mucosa and they are intestinal glands (see figure 3.42).
- **Microvilli** are minute outfoldings of the plasma membranes of enterocytes. When viewed using a light microscope, microvilli cannot be individually resolved, and the microvilli-covered surface of these cells is referred to as a 'brush border' (figure 3.43).

acinar cells cells of the pancreas that produce and transport enzymes that are passed into the duodenum where they assist in the digestion of food

villi outfoldings or projections of the mucosa of the small intestine

crypts tube-like depressions of the mucosa located in the intestine and the site of glandular cells

microvilli sub-microscopic outfoldings of the plasma membrane of enterocytes of the small intestine that form the so-called 'brush border' of these cells

FIGURE 3.42 Photomicrograph of a cross-section of the small intestine wall showing its distinctive mucosa.

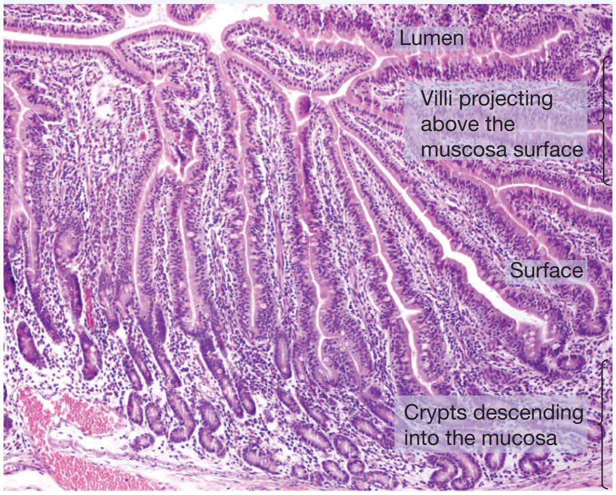


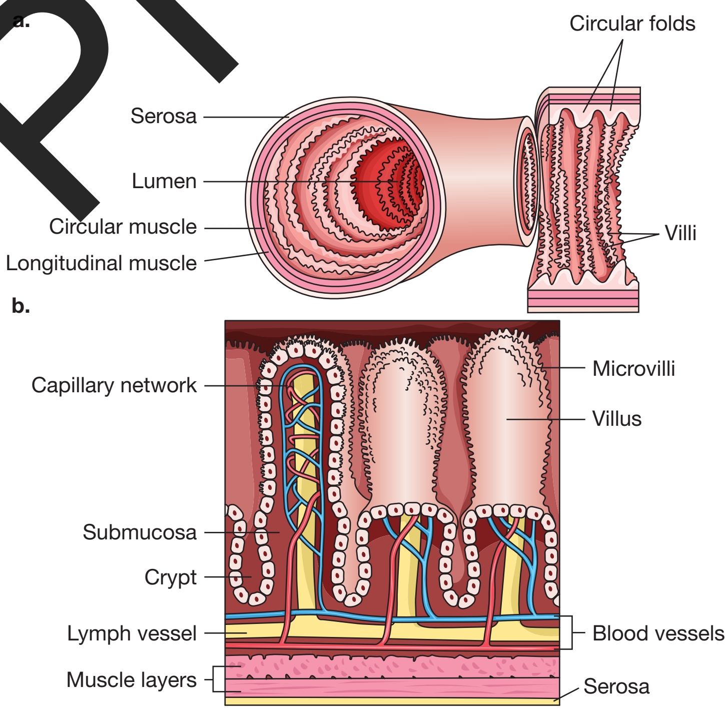
FIGURE 3.43 High power photomicrograph of simple columnar epithelium made of enterocytes that line the villi. The thick upper border of these cells is a brush border (bright purple) of tightly packed outfoldings of microvilli. Note the central mucus-secreting goblet cell.

Compared with a smooth cylinder of similar dimensions, the epithelial surface of the small intestine has a much greater surface area. This increased surface area is due to the presence of regular **circular folds** in the wall of the small intestine, the large numbers of villi on these folds, and the microvilli on the outer surface of enterocytes (figure 3.43). These combined features provide a large surface area over which absorption of digested nutrients can occur. Furthermore, the circular folds means that the intestinal contents flow in a slower spiral manner rather than flowing straight through more rapidly.

Areas of the small intestine that secrete mucus:

- Brunner's gland in the crypts (intestinal glands) of the small intestine, which produces an alkaline mucus that coats the epithelial lining of the duodenum. This alkaline mucus protects the small intestine from the strongly acidic chyme coming from the stomach. This mucus also creates the alkaline conditions required by the enzymes that operate in the duodenum.
- Goblet cells that are part of the surface epithelium also secrete mucus as a protective lubricant.

FIGURE 3.44 **a.** Diagram showing the regular circular folds present in the inner lining of the small intestine. **b.** Diagram at higher magnification showing the large numbers of finger-like villi that are located on either side of these folds



circular folds permanent macroscopic folds (ridges) in the mucosa of the small intestine

Functions of the small intestine: digestion

The duodenum, the first segment of the small intestine, is the site of most of the digestive action that occurs in the alimentary canal. The enzymes involved are:

- pancreatic enzymes that are released by the pancreas into the lumen of the duodenum
- brush border enzymes that are produced by the enterocytes of the duodenum epithelium.

Let's look at a summary of the digestion of fats, carbohydrates and proteins.

Digestion of fats

The duodenum receives bile containing bile salts from the liver via the gall bladder. In the duodenum, bile salts emulsify water-insoluble fats by forming coatings around large droplets of fat and dispersing them into smaller and smaller particles — this process of emulsification increases the surface area of the fat droplets that is available for enzyme action.

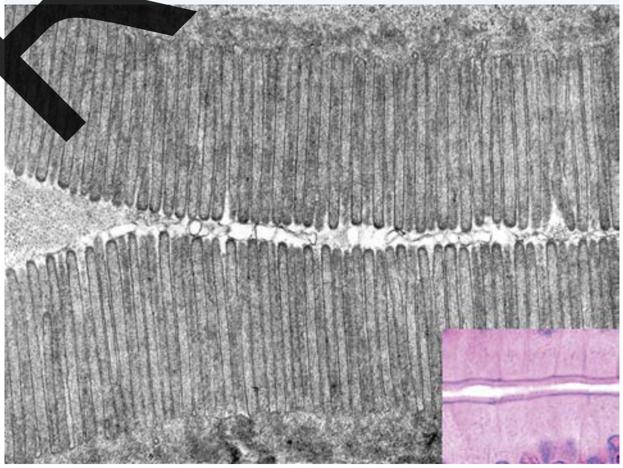
The duodenum also receives pancreatic fluid that contains the enzyme, pancreatic lipase. This enzyme acts on the emulsified fats, breaking them down to monoglycerides and fatty acids that are the end products of fat digestion.

Digestion of carbohydrates

The duodenum receives pancreatic fluid that contains the enzyme pancreatic amylase. This enzyme continues the digestion of carbohydrates that began in the mouth and it breaks carbohydrates down to dextrins (branched oligosaccharides) and various disaccharide sugars — these are all too large to be absorbed.

Various 'brush border' enzymes, including dextrinase, sucrase, maltase and lactase complete the digestion of carbohydrates. These enzymes breakdown dextrins and disaccharide sugars to monosaccharides that are small enough to be absorbed. Brush border enzymes are not free in solution in the intestinal lumen as is the case for other digestive enzymes. They are embedded in the plasma membranes of microvilli of the enterocytes that line the intestinal wall and act on food while in place on the microvilli (figure 3.45).

FIGURE 3.45 TEM showing microvilli on the plasma membrane of two epithelial cells forming the brush border that has enzymes embedded within it. The coloured inset shows the brush border using high power light microscopy.



Digestion of proteins

The duodenum receives pancreatic fluid that contains two inactive proenzymes, trypsinogen and chymotrypsinogen. These proenzymes are converted to the active protein-digesting enzymes, trypsin and chymotrypsin. Proteins are broken down by these enzymes to polypeptides and peptides.

The finishing touches in protein digestion involve the actions of specific brush border enzymes that can breakdown polypeptides and peptides to amino acids that can be absorbed across the epithelial boundary. These brush border enzymes include endopeptidases and aminopeptidases. <u>Endo</u>peptidases cut peptide bonds between amino acids at sites within the chain, while <u>exo</u>peptidases, such as aminopeptidases and carboxypeptidases, cut amino acids off from one end of the chain, either the amino end or the carboxyl end.

Functions of small intestine: absorption

The small intestine is the primary site of absorption of the end products of digestion — that is, the digested nutrients, in addition to water, salts and vitamins.

The various secretions produced by digestive glands — saliva, gastric juice, bile, pancreatic fluid — have a high water content and, each day, they contribute on average about 7 litres of water to the alimentary canal. Our daily fluid and food intake adds about another 2 litres of water. Most, about 80 per cent, of this water is reabsorbed in the small intestine. The structure of the small intestine is well equipped to carry out this function because of the expanded surface area for absorption created by circular folds, villi and microvilli. However, different regions of the small intestine absorb different nutrients:

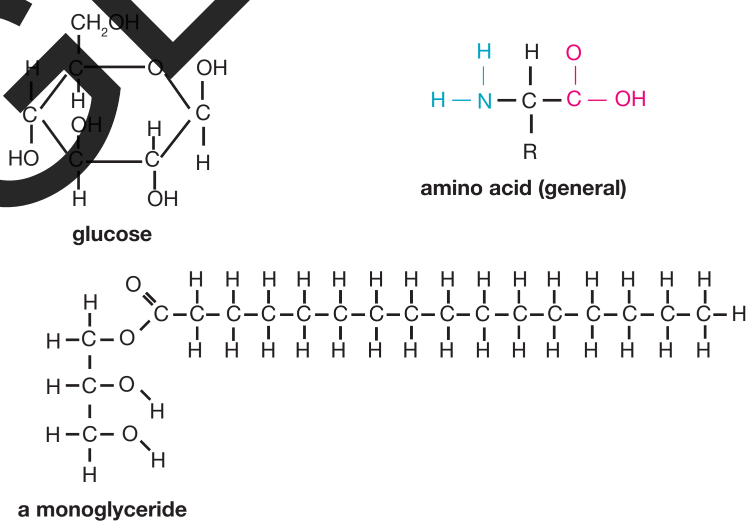
- the duodenum is the primary site of absorption for fatty acids and water-soluble vitamins
- the jejunum is the major region where glucose and amino acids are absorbed
- the ileum absorbs bile salts and vitamin B_{12}.

Absorption of the end products of digestion is a function of the enterocytes that line the small intestine and its villi. Table 3.4 and figure 3.46 shows the various end products of digestion that are able to cross into the enterocytes.

TABLE 3.4 End products of the digestion of carbohydrates, proteins and fats that are able to be absorbed across the epithelial layer of the wall of the small intestine

Input to mouth	Absorbable components
Carbohydrates	Glucose Fructose Galactose
Proteins	Amino acids Dipeptides Tripeptides
Fats	Monoglycerides Fatty acids

FIGURE 3.46 Examples of absorbable end products of digestion. Note the long hydrophobic fatty acid chain that is part of the monoglyceride. Which of these end products of digestion are fat soluble and able to diffuse into enterocytes?

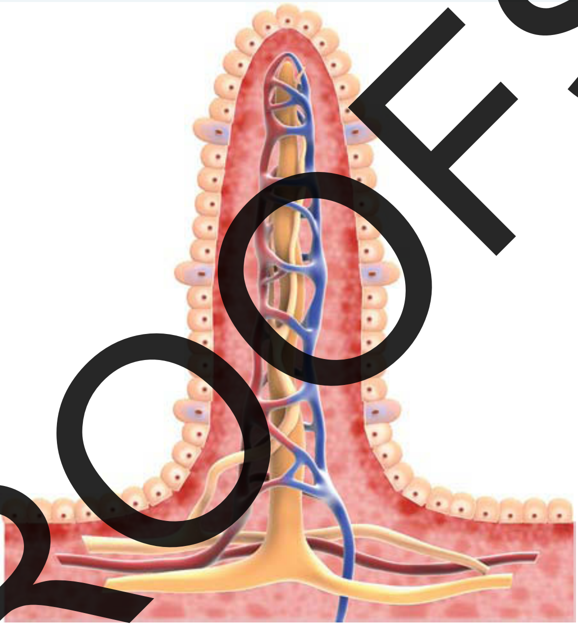


Both diffusion and active transport are needed to absorb digested nutrients into the enterocytes that line the villi. Fat-soluble end products of digestion, such asmonoglycerides and fatty acids, can diffuse across the plasma membranes into the enterocytes. However, the absorption of water-soluble digested nutrients, such as amino acids and monosaccharides, requires some form of energy-requiring active transport.

The amino acids and monosaccharides, such as glucose, fructose and galactose, move the enterocytes into the blood capillary network within the villi. From there, these nutrients are eventually distributed to the rest of the body via the circulatory system.

The absorbed monoglycerides and fatty acids are re-formed into fats and packaged into particles that are moved from the enterocytes into **lacteals**. Lacteals are blind-ending vessels of the lymphatic system (figure 3.47). The fat particles initially travel in the lymphatic system but finally enter the blood circulatory system.

FIGURE 3.47 Longitudinal section through a villus in the small intestine showing its epithelial layer of absorptive enterocytes, a few goblet cells and, within the villus, thin capillaries (shown in red and blue) and a lacteal (shown in yellow) that is a blind extension of the lymphatic system.

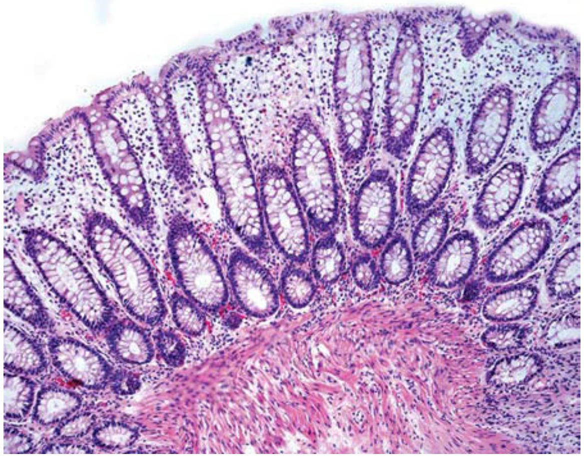


Large intestine — the final stages

The large intestine is the last segment of the digestive tract, and it consists of caecum, colon, rectum and anus. In total, the large intestine is about 1.5 metres long and has a diameter of about 5 centimetres. The longest segment of the large intestine is the colon.

The wall of the large intestine has the same four tissue layers as other regions of the alimentary canal. In contrast to the small intestine with its epithelial layer folded into many villi, the large intestine lacks villi, and is characterised by an abundance of mucus-secreting goblet cells. Figure 3.48 shows the mucosa of the colon with its numerous crypts that lie below the epithelial surface of the mucosa. Goblet cells in the crypt walls can be identified by the clear circular areas — these clear areas occur because the staining technique used here removes the mucus.

FIGURE 3.48 Micrograph of the mucosa of the colon of the large intestine showing the large number of crypts (intestinal glands) that are lined with enterocytes and mucus-secreting goblet cells. Can you suggest why the crypts might have the various shapes visible in this image?



Functions of the large intestine

Reabsorption of water and ions

The large intestine receives mainly water with undigested material from the small intestine. Almost all of the remaining water is removed by the colon along with various ions through osmosis. (We are reminded of the importance of this orderly reabsorption of water if the process goes wrong, as occurs in diarrhoea.)

lacteals the vessels of the lymphatic system which absorb digested fats

Formation and storage of faeces

Water is reabsorbed from the wastes as they are moved along the colon by peristalsis. As this happens, the contents of the colon become more concentrated and solid. By the time they reach the rectum, this solid material has formed faeces. The rectum serves as temporary storage place for the faeces that consist largely of indigestible material, such as cellulose, mucus and bacteria, the last mentioned making up more than half of the dry mass of the faeces. The rectum, like the colon has an epithelium of simple columnar cells with an abundance of goblet cells. Mucus secreted by goblet cells in both the colon and the rectum serves to lubricate the passage of waste material and protect the underlying tissue of the large intestine from damage.

Elimination of faeces

Faeces pass from the rectum and out of the body through the anus. In contrast to the simple columnar epithelium of the colon and rectum, the inner lining of the anus is a stratified squamous epithelium that serves for protection. The external anal sphincter is a band of striated muscle that enables voluntary control of the elimination of faeces.

Maintaining gut bacteria

The colon is home to enormous numbers of bacteria of hundreds of different species – these bacteria form our **gut microbiota** and they are at home in the oxygen-free environment of the colon. People, as hosts, and bacteria, as gut residents, gain benefits from each other. For the bacteria, the benefit is a warm environment and a supply of undigested food that the bacteria can ferment to meet their energy and nutrient needs. For the human hosts, the benefit is access to some of the metabolites that the bacteria produce through fermentation, such as amino acids, short-chain fatty acids that can be converted to glucose, and K and B vitamins that can be used by epithelial cells of the wall of the colon or can be absorbed into the blood and distributed to other tissues.

gut microbiota the population of organisms which live in the gut and play a crucial role in maintaining immune and metabolic homeostasis and protecting against pathogens

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INVESTIGATION 3.5 online only

Digestive systems

Aim

To investigate the role of the digestive system in breaking down food to obtain nutrients

on Resources

eWorkbook Worksheet 3.3 Structure and function of the digestive system (ewbk-3490)
Worksheet 3.4 The ins and outs of digestion (ewbk-3492)

3.4.4 Digestive system in different animals

Earlier in this topic, the digestive cells, tissues or systems of invertebrate animals were introduced, starting with sponges, jellyfish and flatworms. From there, we briefly met the nematodes, the first animals to show the mouth-to-anus one-way digestive tract that is present in all other animals. We have also explored in detail the human digestive system in section 3.4.3. In this section, we will look at the digestive system in some other mammals and birds.

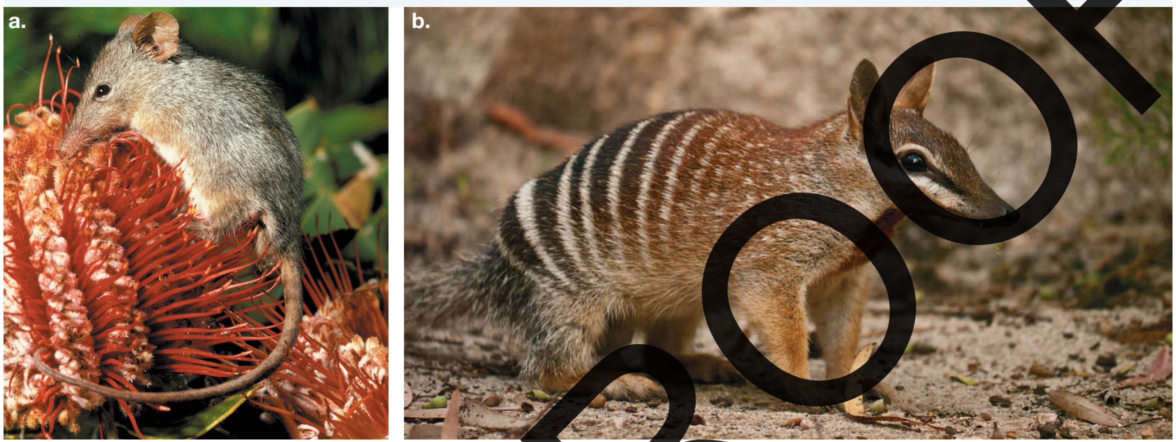
Who eats what?

In terms of the nature of their primary and preferred food source, mammals can be classified as:

- *herbivores.* Primary food source is plant material. Herbivores may be further subdivided into groups, such as fruit eaters, seed eaters, nectar feeders or leaf eaters. Among native Australian fauna, the honey possum (*Tarsipes rostratus*) is a nectar feeder (figure 3.49a) while the eastern grey kangaroo (*Macropus giganteus*) is a leaf eater.

- *carnivores*. Primary food source is the flesh of other animals either hunted as prey or scavenged.
  - the Tasmanian devil (*Sarcophilus harrisii*) that lives on small prey and the carcasses of dead animals (carrion) is Australia's largest carnivorous marsupial. The numbat (*Myrmecobius fasciatus*) is an insectivorous carnivore whose food intake is almost exclusively termites (see figure 3.49b). Like other insect-eating mammals, the numbat has a long tongue that is coated with a sticky saliva secreted by its salivary glands.
- *omnivores*. These animals eat and survive on a mixed diet sourced from both plants and animals.

FIGURE 3.49 a. A honey possum, a herbivore that feeds on nectar, feeding on a *Banksia* flower head **b.** A numbat, an insectivorous carnivore, whose preferred food is termites



To survive, a mammal must be able to access and ingest its preferred food and it must have the means — mechanical and/or enzymic — to break down its food to supply the energy and nutrients it needs for living. The main driver that has influenced the evolution of different features in the digestive system of mammals is the nature of the food on which they rely for their energy and nutrients. Dietary preferences of mammals are indicated in the organisation of their digestive system, such as the length of the digestive tract, the size of the caecum and the characteristics of the teeth, such as types present, sizes, and shapes. Table 3.6 shows some of the variation that exists in the digestive systems of different mammals.

TABLE 3.6 Variation the digestive systems of mammals. Combinations of these features enable mammals to exploit gaining and using particular food sources.

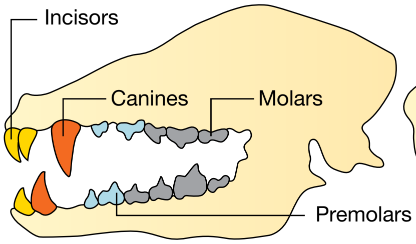
	Variations in mammals	
Mouth	Canine teeth present Continuously growing incisors or molars Gap between incisors and premolars Molar(s) with grinding surfaces High crowned cheek teeth	Canine teeth absent Fixed-size incisors or molars No gap No grinding surfaces on molars Low-crowned cheek teeth
Digestive tract	Long	Short
Stomach	Single-chambered stomach	Multi-chambered stomach
Large intestine	Long caecum	Short or absent caecum
Gut microbiota	Microbiota in foregut	Microbiota in hindgut

Teeth in different mammals

Teeth play an important role in the digestive system. They are a major means by which the mechanical digestion of food is achieved — chewing creates food particles with an increased surface area for enzymic action. Mammals have four kinds of teeth: incisors, canines, premolars and molars. Mammalian teeth can indicate whether a mammal is *most likely* to be a carnivore, a herbivore or an omnivore. Figure 3.50 shows the teeth of four mammals.

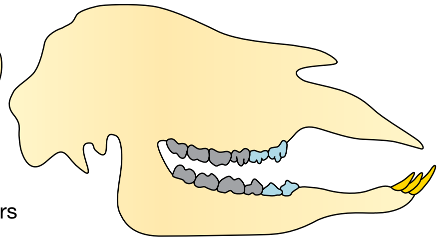
FIGURE 3.50 Diagram showing the teeth of **a.** a carnivore **b.** a herbivore **c.** a gnawing animal **d.** an omnivore. Note the differences between the dentition in these mammals.

CARNIVORE



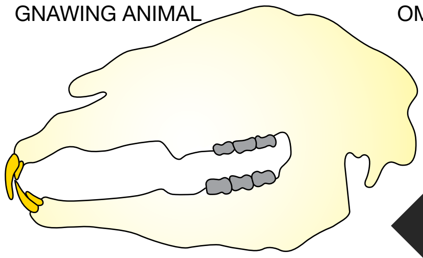
a. Carnivores such as the Tasmanian devil (*Sarcophilus harrisii*) have well-developed canine teeth for tearing meat from bones.

HERBIVORE



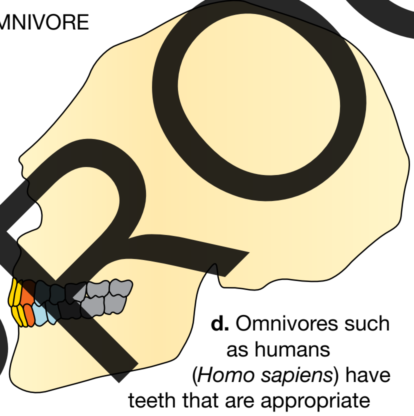
b. Herbivores such as the Merino sheep (*Ovis aries*) have incisor teeth that enable them to clip the grass and other vegetation they eat. Note the absence of canine teeth.

GNAWING ANIMAL



c. Gnawing animals such as the canefield rat (*Rattus sordidus*) have well-developed incisor teeth that enable them to gnaw through heavy grasses, twigs and, in some cases, trees. Their incisors grow constantly to compensate for the heavy wear.

OMNIVORE



d. Omnivores such as humans (*Homo sapiens*) have teeth that are appropriate for a varied diet.

Features of carnivores:

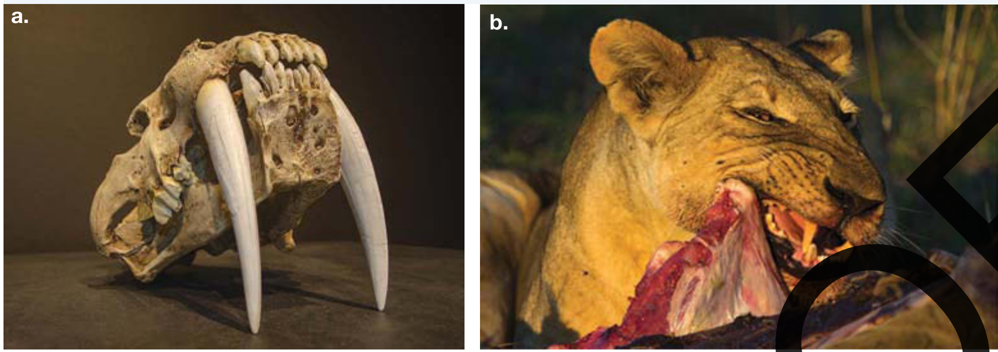
- The presence of large canine teeth and the absence of large grinding molars indicate a flesh-eating carnivore. One such carnivore, now extinct, with very impressive canine teeth was the sabre-toothed cat (*Smilodon fatalis*) (see figure 3.51a).
- Many carnivores, including members of the cat and dog families, have sharp-edged premolars and molars that do not meet on top of each other when the jaw closes. Instead, these teeth, called **carnassial teeth**, produce a shearing or slicing action as their sharp edges move past each other like the blades of scissors. (If you watch a cat eating a strip of fresh meat, it will move the meat to the side of its mouth as it uses its carnassial teeth to slice it.) Figure 3.51b shows a lioness using her carnassial teeth to slice flesh — notice how she has positioned the flesh at the side of her mouth.
- Carnivores cannot move their jaws from side to side when they are chewing.

Features of herbivores:

- The presence of large molars with grinding surfaces indicates that a mammal is herbivorous.
- Herbivores have sharp front teeth (incisors) that are equipped to tear off or nip vegetation. Some species only have lower incisors.
- Canine teeth are often absent from the dentition of herbivores — rabbits and macropods (kangaroos and wallabies) have none.
- They can move their jaws from side to side when chewing.

carnassial teeth paired upper and lower premolars and molars which do not meet, and hence allow a shearing action to tear food

FIGURE 3.51 a. Skull of sabre-toothed cat, an extinct carnivore, showing its massive canine teeth b. A lioness eating flesh which is being sheared by her sharp-edged carnassial teeth (the last upper premolar and the lower molar) as they move past each other



Omnivores, such as pigs, dogs and people, typically have sharp incisors, canines and grinding surfaced molars reflecting a diet that is both animal and plant-based.

Teeth size: fixed size or continuously growing?

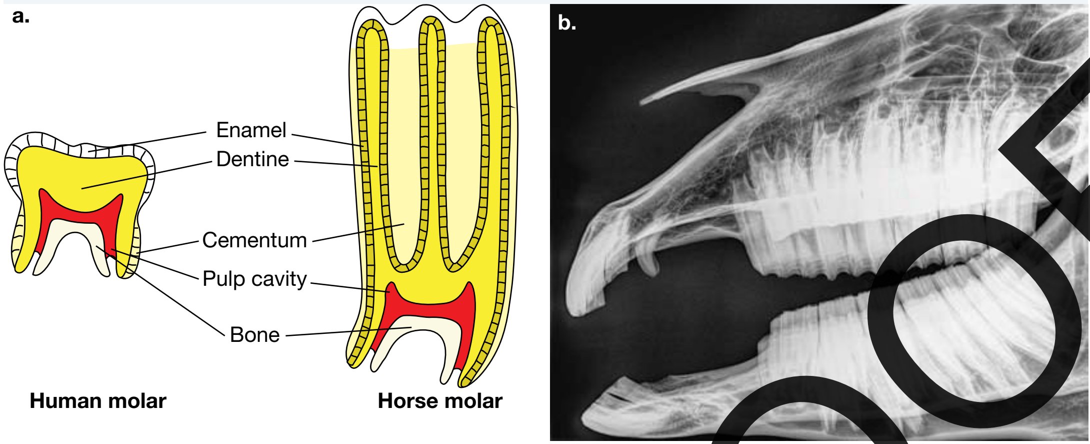
Most herbivores have a diet of tough, fibrous plant material, often with abrasive soil particles attached. Consuming this material over extended periods damages and erodes the structure of their teeth. Various herbivores show adaptations that enable them to deal with this situation.

FIGURE 3.52 The wombat (*Vombatus ursinus*) has a diet of mainly highly fibrous and tough native grasses, sedges and roots.

- *Constantly growing teeth:* Rabbits, hares, rats (but not mice) and wombats have teeth that grow continuously. In rabbits, hares and wombats, it is all their teeth (incisors, premolars and molars), while in rats, it is just the incisors. The roots of these teeth have stem cells that produce dentine and enamel tissues for the growth of new teeth. Continuously growing teeth mean that these herbivores can for their entire lifetimes replace worn and eroded teeth. As teeth wear away at their tips, new teeth material is added at their roots.
- *Fixed size teeth:* Other herbivores also have constant wear and tear on their teeth from their fibrous plant diet, but they do not have constantly growing teeth. Instead, their teeth are fixed in size, but some or all of their teeth have very high crowns. Figure 3.53a shows a comparison of a low-crowned molar tooth, such as occurs in people, cats and dogs, with a high-crowned molar tooth, such as may be seen in horses and in **ruminants**, such as cattle. In the case of the horse, all of its permanent teeth have high crowns, with its premolars and molars being up to 10 centimetres in length. Sounds unlikely? The bulk of these teeth is hidden within the jaw bones and only a small segment is visible (see figure 3.53b). Over time, the grinding surfaces of molars and premolars wear away at the rate of about 2 to 3 millimetres per year. As exposed tooth tissue is eroded, teeth concealed in the jaw bones move equally slowly and replace the lost tooth tissue.

ruminants animals that absorb nutrients by fermenting food in a specialised stomach prior to digestion

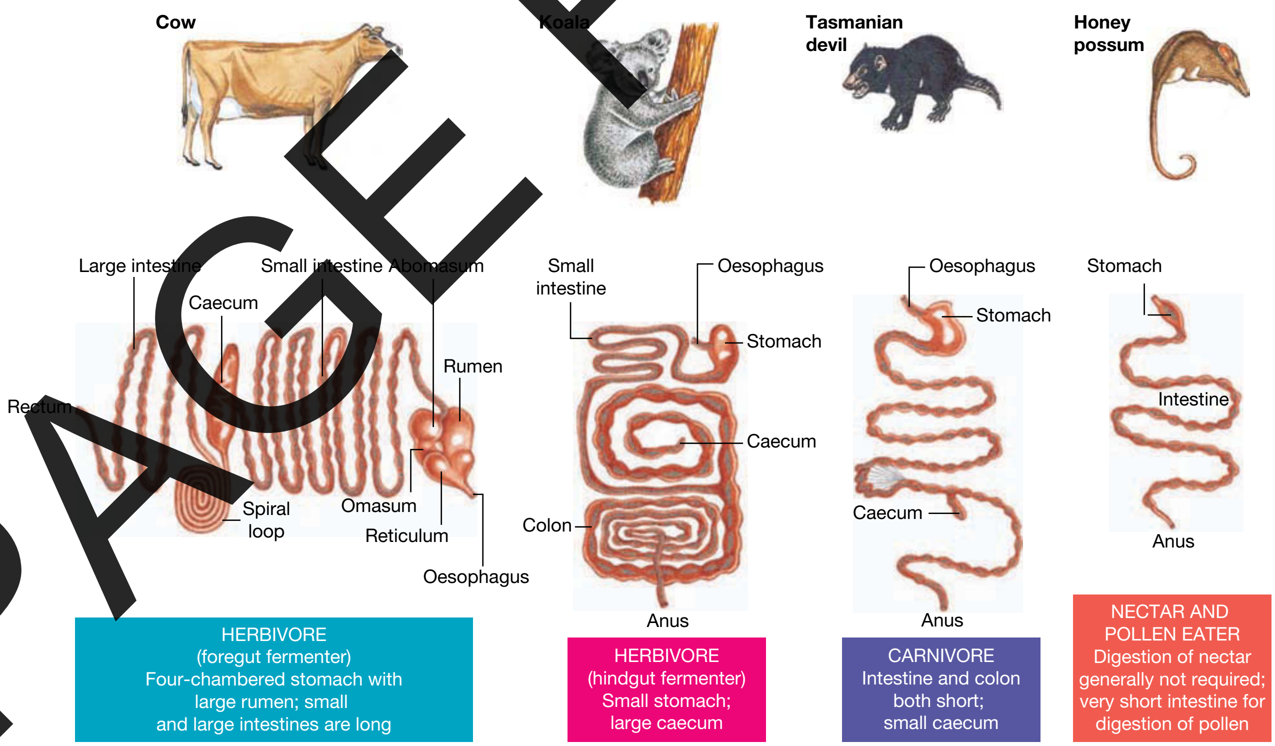
FIGURE 3.53 **a.** A low-crowned molar (as in a person) and a high-crowned molar (as in a horse). Only the pale section at the top of high-crowned molar is visible above the gum margin. **b.** X-ray of the side view of the skull of a horse showing the upper and lower jaws with the prominent cheek teeth (premolars and molars). Only a few centimetres of these teeth appear above the jaw line.



Hollow organs of the digestive tract in different mammals

Figure 3.54 shows drawings of the alimentary canal in several different mammals. In each case, the digestive tract has features that cater for the particular dietary input of the mammal and that ensure that the mammal can obtain the energy and nutrients it needs. Examine this figure and note the differences.

FIGURE 3.54 The alimentary canals of a cow, a koala, a Tasmanian devil and a honey possum. Notice the differences in the comparative sizes of some segments of the gut, such as the colon and the caecum.



Length of the alimentary canal

- The shortest gut is that of the honey possum with its diet of nectar and pollen. Nectar is essentially a solution of sugars, (glucose, fructose and sucrose), and only the sucrose disaccharide requires digestion.
- The longest alimentary canals are those of the herbivorous cow and koala. The digestion of plant material such as the cellulose in fibrous grass and eucalyptus leaves is a more complex process than the digestion of protein. *Mammals do not themselves produce enzymes that can digest cellulose.* Instead, they depend of the action of their gut microbiota to do this for them in a mutually beneficial arrangement.
- The alimentary canal of the carnivore, in comparison with that of the herbivores is very short. The protein of animal flesh is more easily digested than the cellulose in plants since mammals are equipped with a family of protein-digesting enzymes.
- The length of the alimentary canal indicates the difficulty or otherwise of digesting the preferred food of a mammal — the shorter the canal, the simpler the digestive processes; the longer the canal, the more elaborate the digestive processes.

Number of chambers in the stomach

Many mammals have a stomach with a single chamber that is like an expandable sac. However, the group of mammals termed ruminants (from Latin = 'to chew again') have a stomach with a more complex structure consisting four chambers, with the first of these chambers being the **rumen**. The more than 200 species of ruminant mammals include cattle, sheep, deer, antelopes, giraffes and gazelles.

Microbial fermentation

The grass-eating cow and the leaf-eating koala each have a chamber in their alimentary canals where their gut microbiota carry out fermentation. We all have microbes in our gut, but in the case of herbivores, there is typically a very large concentration of bacteria and other microbes in one particular segment of their alimentary canals.

For example:

- Cows: fermentation site is the very large first chamber of its stomach, the rumen. The rumen has a capacity of up to 150 litres and is said to be 'one of the most dense microbial habitats in the world'. In comparison, the human stomach when distended has a capacity of 2 to 4 litres.
- Koalas: fermentation site is the caecum. Note the long caecum in the koala that is about 2 metres in length and houses the microbiota that are essential for leaf digestion. In comparison, the adult human caecum is about 6 centimetres long and can be removed surgically with no effect on digestion.

In the fermentation chambers of herbivores, gut microbes ferment ingested cellulose to produce volatile fatty acids, microbial proteins and the gases hydrogen and methane.

Mammals that accommodate their microbiota in the stomach are said to be *foregut fermenters*, with the biggest group being the ruminant mammals. Mammals with their microbiota housed in the caecum are said to be *hindgut fermenters*. As well as the koala, this group of mammals includes horses, rhinos, elephants, rodents and rabbits.

rumen first part of the stomach of a ruminant where digestion occurs with the aid of gut microbiota

CASE STUDY: Digestion in the cow

Like all other ruminants, cows depend on their gut microbiota to convert the grasses and hay that they eat into compounds that they can used to meet their energy and nutrient needs, such as proteins.

Cows have a stomach with four separate compartments (figure 3.55), each having its own role in the digestive process.

The four compartments are:

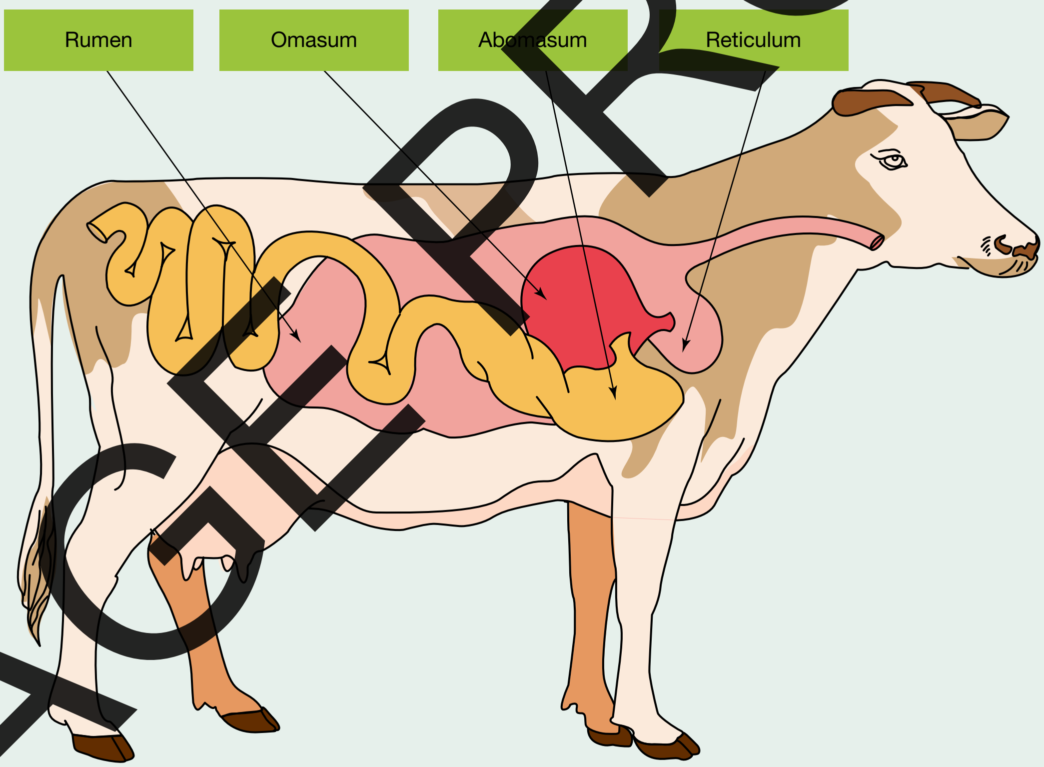
- the rumen
  - houses the enormous numbers of microbes (mainly bacteria and protozoa) and serves as a large fermentation vat
  - can hold 50 to 150 litres of food and fluid, depending on the size of a cow
  - is the site where the breakdown (digestion) of grass and hay occurs through fermentation by rumen microbes
- the **reticulum** (from French *reticule* 'small purse')
  - is a pouch-like chamber that is the smallest of the four chambers. As the cow eats, any dense feed and any heavy foreign objects, such as screw or nails, that the cow might ingest in its hay, drop into this chamber.
- the **omasum** (from Latin *omasum* 'tripe') is the third chamber with a volume of about 8 litres. This compartment is where much of the water is absorbed from the stomach contents, and it also acts as a filter that allows only fine particles of food to pass to the final compartment.
- the **abomasum** (*ab* = away from *omasum*) is the final chamber of the stomach, with a volume of about 27 litres. The abomasum is the only chamber of the stomach where the cow's own enzymes are secreted and used in digestion. The inner lining of the abomasum is a glandular epithelium that secretes hydrochloric acid and enzymes, including the precursor (proenzyme) of the protein-digesting pepsin.

reticulum second part of the stomach of a ruminant that is the smallest of the four chambers; collects any heavy objects

omasum third part of the stomach of a ruminant which acts as a filter and where water is absorbed

abomasum final part of the stomach of a ruminant where enzymes are secreted and used in digestion; food then passes to the small intestine.

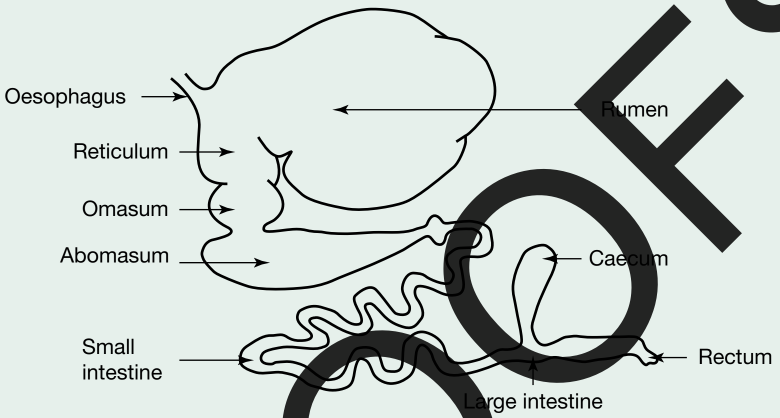
FIGURE 3.55 The four-chambered stomach of a cow. This illustrates the mass of the rumen, which is the fermentation chamber, and shows the size of the rumen relative to the size of the cow.



Let's follow the path of a mouthful of hay that a cow has just ingested (figure 3.56).

An outline of the steps in the pathway of a mouthful of ingested hay is as follows:

FIGURE 3.56 Line diagram showing the hollow organs of the digestive tract of a cow, including its four-chambered stomach



1. Mechanical breakdown of the hay begins in the cow's mouth where the hay mixes with saliva and is fragmented by the cow's side-to-side chewing action.
2. The hay moves down the oesophagus to the rumen. Mechanical digestion continues through the churning action of the rumen walls.
3. Microbes in the rumen start the breakdown (digestion) of the hay through a process of fermentation**.** All digestion in the rumen is carried out by microbes.
4. Partly digested hay, called cud, is returned to the mouth for further chewing. This process is popularly referred to as 'chewing the cud' or, more scientifically, as rumination.
   - Chewing the cud grinds the hay into smaller fragments and causes the release of more saliva — up to 75 litres daily.
   - The more fibrous the cud, the more time is spent chewing it, and a cow may spend up to 10 hours per day in this activity.
   - Multiple cycles occur of the cud being chewed, returned to the rumen, regurgitated to the mouth and so on.
5. En-route to its return to the rumen, the food passes via the reticulum and any heavy food particles or other solid objects are filtered out and drop out the bottom of this compartment, while lighter material returns to the rumen.
6. On reaching the rumen again, digestion of the cud by gut microbes continues.
7. The end products of the microbial fermentation of cellulose, starch, sugars and proteins in the rumen are:
   - *volatile fatty acids*. These are used by the cow as its major source of energy; they are absorbed across the epithelium of the rumen and transferred into the cow's blood circulatory system.
   - *gases, such as methane and carbon dioxide*. About 30 to 50 litres of these gases are produced each hour and they are largely burped into the atmosphere.
   - *microbial proteins*. Nitrogen-containing compounds in the hay are broken down by microbes and are re-synthesis ed into microbial proteins.
8. The watery suspension of fine particles along with masses of microbial cells move from the rumen into the omasum where water is absorbed and the residue, including the microbial cells, flows into the next chamber, the abomasum.
9. In the abomasum, its lining of glandular epithelium releases hydrochloric acid and the precursor of a protein-digesting enzyme that is activated to the enzyme pepsin in the acid conditions. In the abomasum, digestion is carried out by the cow's own enzymes. Among the proteins digested here are the millions of microbial cells carried from the rumen, and these are the major source of protein for the cow. This microbial protein will be broken down to amino acids and used to synthesise cow protein.
10. From the abomasum, the digested nutrients move into the small intestine where other digestive enzymes and bile are present that break down protein to amino acids. Absorption of digested nutrients also occurs in the small intestine.
11. The large intestine (caecum and colon) is where water and minerals are absorbed. Undigested material passes in the rectum and is eliminated as faeces.

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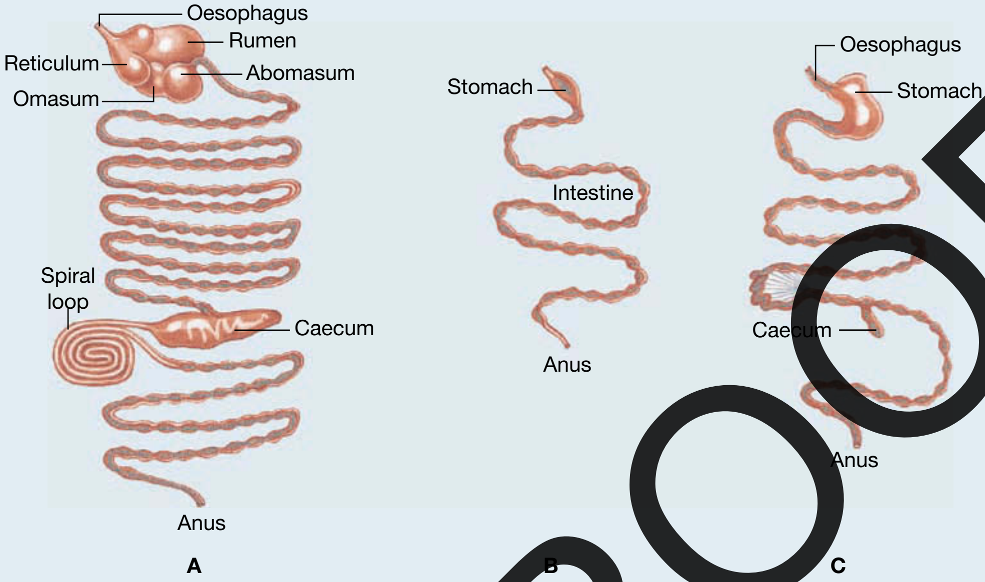
SAMPLE PROBLEM 3 Comparing digestive systems

The following diagram shows the digestive system of three different organisms: a herbivore, a carnivore and a pollen eater.



a. **Identify which digestive system belongs to which organism. Justify your response.** **(2 marks)**

b. **Herbivores can be either a foregut or hindgut fermenter. Provide two clear pieces of evidence that suggest that this herbivore is foregut fermenter.** **(2 marks)**

c. **Explain the role of microbes in the digestion of herbivores.** **(2 marks)**

THINK

a. 1. This question is asking you two things for 2 marks. Firstly, you need to identify which digestive system belongs to a herbivore, carnivore and pollen eater. Consider what you know about digestive systems:
- Herbivores often have a caecum and longer digestive system to breakdown plant matter.
- Pollen eaters have very simple digestive systems.

WRITE

A. Herbivore
B. Pollen eater
C. Carnivore (1 mark)

2. For the second mark, you are required to justify your response. Ensure you highlight the evidence that allowed you to determine your answer.

A. was determined to be the digestive system of a herbivore, due to the presence of a large caecum, spiral loop and longer, more complex digestive system.
B. was determined to belong to a pollen eater due to its short length and simplicity.
C. was determined to be a carnivore due to having a more complex digestive system than the pollen eater, but a much smaller, less pronounced caecum than the herbivore (1 mark).

b. This question requires evidence to justify the answer that was provided. Consider features that are seen in foregut fermenters and select the two that best support the diagram:
- structure of the stomach
- size of the caecum
- presence of a spiral loop.

Two pieces of evidence that suggest this digestive system belongs to a foregut fermenter:
- Foregut fermenters have larger, more complex, multi-chambered stomach, including a rumen. This is seen in the digestive system shown (1 mark).
- The presence of a spiral loop and a smaller caecum (compared to a hindgut fermenter) also supports the statement that this is a foregut fermenter (1 mark).

c. This is an explain question. You need to provide a detailed response that outlines the relationship between microbes and digestion.

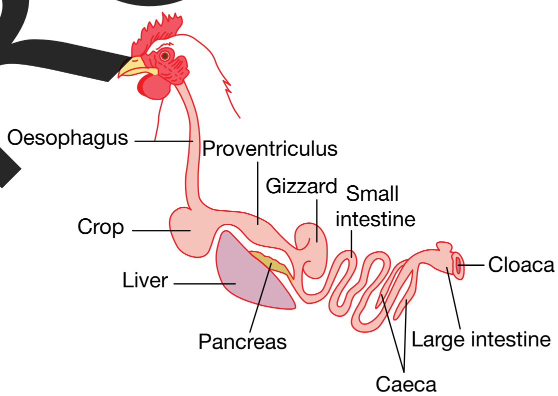
Herbivores eat plant material that contains cellulose. This cellulose cannot be broken down by mammals as they do not possess the appropriate enzymes (1 mark). The microbes in the gut allow for cellulose to be broken down and digested, enabling the nutrients to be obtained by the herbivore (1 mark).

Digestive system in birds

The saying ‘as rare as hen’s teeth’ reminds us that modern birds do not have teeth. The lack of teeth means that key differences can be seen between the digestive systems of birds and of mammals. However, as in mammals, the walls of the alimentary canal are composed of four major tissue layers: mucosa, sub-mucosa, muscularis and serosa.

Figure 3.57 shows the digestive system of a typical bird. Let’s look at its components, starting with the mouth and ending with the cloaca.

FIGURE 3.57 The components of the digestive systems of birds



Mouth

The beak consists of the upper and lower jaws covered by a layer of keratin, the same material that forms your fingernails. Beaks vary greatly in shape and size in different species. The beak size and shape may provide an indication of the diet of the bird, such as seed eaters with their short thick beaks for cracking seeds versus nectar-feeders with their long slender beaks for probing flowers.

Birds have no teeth. The absence of teeth means that no mechanical digestion occurs in a bird’s mouth. Their preferred food items must be swallowed whole — OK for seeds, but not so easy for a fish (figure 3.58).

FIGURE 3.58 A bird with its preferred dietary item of fish. The absence of teeth means that the fish must be swallowed whole.

For most birds, the beak is their only means of obtaining and holding their food — the exceptions are raptors (birds of prey) and parrots that can also use their feet.

Oesophagus

The oesophagus in birds is a muscular and flexible tube that transports food from the mouth to the crop. It is relatively large in diameter compared to mammals, especially in those birds that swallow large prey whole, such as cormorants.

Crop

In birds the crop is an out-pocketing of the oesophagus located in the lower neck region and is capable of stretching. It provides temporary storage for food before it is passed to the stomach for digestion — this enables birds to consume large amounts of food quickly and then move to a safer location for digestion to occur.

Stomach

The stomach in birds consists of two parts: the proventriculus and the gizzard.

The proventriculus is the first part of the stomach and its function is enzymic digestion, especially of protein. It is lined by thick glandular epithelium that secretes mucus, hydrochloric acid and the inactive proenzyme, pepsinogen. As in the human stomach, pepsinogen is converted to active pepsin enzyme in the acid condition of the proventriculus.

The gizzard is the second part of the stomach and consists of a strong muscular sac that functions in mechanical digestion (figure 3.59).

It grinds, mashes and mixes foods, a function that is very important for animals without teeth, and creates a much larger surface area for enzyme action. It may contain grit and small stones (gastroliths) that birds swallow to assist the gizzard function.

FIGURE 3.59 Chicken gizzard. Note the strong muscular sac which may contain small stones to aid in mechanical digestion.

The gizzard has a structure that includes several layers of smooth muscle, a glandular epithelium, and a thick lining of tough non-cellular material (cuticle) that protects the underlying tissues from the acidic conditions within. As the cuticle lining is worn away by the grinding action of the gizzard, it is replaced by fluid material secreted by the glandular epithelium. This fluid moves to the surface of the cuticle where it hardens.

The gizzard is also present in the digestive tract of other animals, including crocodiles, and evidence for its existence in dinosaurs has been found. (What might that evidence be?)

Food moves back and forth between the two parts of the stomach creating cycles of digestion, grinding, more digestion, more grinding.

Small intestine

The small intestine is similar to that of mammals and is composed three segments: duodenum, jejunum and ileum. A single layer of columnar epithelium together with mucus-secreting goblet cells form the inner lining of the small intestine. Its functions are similar to those in the mammalian digestive tract.

The duodenum receives digestive enzymes from the pancreas and bicarbonate (to neutralise the acid from the proventriculus), and receives bile from the liver and pancreatic fluid from the pancreas. It is the site where most of the digestion of food by enzymes produced by a bird occurs and where digestion is completed.

The jejunum and ileum are the major sites of absorption of digested nutrients and water.

Large intestine

The large intestine consists of a pair of caeca and a colon.

The caeca are two blind pouches located at the junction of the small and large intestine. They are sites for microbial fermentation of any remaining matter that has not been digested in the duodenum, such as cellulose. Products generated through this fermentation can be used by birds as an energy source.

The colon is a short tube that ends at the cloaca. Its primary function is the absorption of water and electrolytes.

The cloaca is a wide tube that is the common opening of the digestive, reproductive and urinary systems. It opens to the outside of the bird through the vent.

on Resources

eWorkbook Worksheet 3.5 Different digestive systems in animals (ewbk-3494)

Weblink Health conditions of the digestive system

KEY IDEAS

- Food for an animal must contain organic matter that can be broken down and absorbed and used as chemical energy for living and the organic matter to build and repair its own structures.
- The digestive system typically breaks down macromolecules (proteins, carbohydrates, lipids (fats) to be absorbed and used for energy production, growth, maintenance and repair.
- The vertebrate digestive system includes:
  - alimentary canal (gastrointestinal tract) and the hollow organs of oesophagus, stomach and small intestine
  - accessory organs (solid organs): salivary glands, liver, gall bladder, pancreas.
- Tissues of the digestive system include:
  - muscosa (epithelial tissue)
  - sub-mucosa (connective tissue)
  - muscularis (muscle tissue)
  - serosa (connective tissue).
- Epithelial tissue has a number of types; its functions include protection, absorption and secretion.
- Connective tissues perform various functions: they bind and support, they protect and insulate, they store reserve energy as fat and they transport materials.
- Muscle tissues in the digestive system are largely smooth involuntary muscle cells — the exceptions are the muscle tissues of the throat and upper region of the oesophagus and that at the end of the anal canal.
- Coordinated contraction of muscle tissues controls peristalsis along the length of the system from oesophagus to anus.
- Regulation of movement between segments of the gut are controlled by sphincters.
- The pyloric sphincter separates the large acidic stomach from the smaller alkaline duodenum.
- Digestion of food relies on many enzymes throughout the digestive system.
- Organs of the digestive system include:
  - Mouth: teeth provide mechanical breakdown; enzymes in saliva begin chemical breakdown.
  - Oesophagus: transports food to the stomach via peristalsis
  - Stomach: temporary holding chamber for food; three layers of muscle actively churn the contents, acidic conditions and active enzymes continue digestion of fats and start digestion of proteins.
  - Liver (accessory organ): produces bile which aids in digestion
  - Pancreas (accessory organ): produces enzymes
  - Small intestine: the final stage of digestion and absorption of nutrients; mucosa distinguished by villi, crypts and microvilli.
  - Large intestine: includes the caecum, colon, rectum and anus. Functions include reabsorption of water, formation and storage of faeces, elimination of faeces and maintenance of gut bacteria.
- Animals can be classified as herbivores, carnivores and omnivores; their teeth and digestive systems reflect their diet, including length of alimentary canal, number of stomach chambers and the microbial fermentation processes.
- Digestive system of birds includes mouth (beak, no teeth), oesophagus, crop, stomach (proventriculus and gizzard), small intestine and large intestine.

3.4 Activities

learnON

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at **www.jacplus.com.au. A downloadable solutions file is also available in the resources tab.**

3.4 Quick quiz on	3.4 Exercise	3.4 Exam question

3.4 Exercise

1. What is an accessory organ in the digestive system?
2. Identify the substances that contribute to the digestion process from the salivary gland and the liver.
3. Name the following:
   a. The structure that controls the flow of chyme from stomach to duodenum
   b. The enzyme that can function in both a neutral and acidic environment
   c. The least complex kind of animal that has a one-way digestive system
   d. The two major locations where mechanical digestion of food occurs
   e. The organ where most digestion of food occurs
   f. The organ where most reabsorption of water occurs
4. a. List the four tissue layers of the alimentary canal starting from the lumen of the gut.
   b. Identify the type of epithelium that is present in the mucosa of the oesophagus and small intestine, and their major function(s).
5. a. You examine two light microscope images of a cross-section of the wall of the alimentary canal. Image A shows a mucosa with many villi and crypts. Image B shows a smooth mucosa with many crypts. Identify which region the images of the alimentary canal might have come from.
   b. You are told that gastric pits are present in the surface of the organ of image B. Would you now revise your answer to part a or not?
6. Most people with the inherited disorder cystic fibrosis show various symptoms, including what is termed exocrine pancreatic insufficiency (EPI). EPI shows as a progressive loss of acinar tissues in the pancreas. Treatment includes enzyme replacement capsules.
   a. Would you expect that these enzymes would be enzyme precursors (proenzymes)?
   b. What enzymes might be present in these capsules?
7. a. What is a brush border?
   b. Identify where the brush border occurs in the alimentary canal.
   c. Identify one role of the brush border.
8. After they are absorbed, how are the following digested nutrients transported from the alimentary canal?
   a. Amino acids
   b. Fats
9. What is a benefit to the mammalian host of its gut microbiota?
10. What reasonable statements may be made about an animal that displays the following features? Justify your responses.
    a. High-crowned molars with large grinding surfaces
    b. An extremely short alimentary canal
    c. A multi-chambered stomach
    d. Carnassial teeth
    e. A gizzard
11. Which animal would be expected to have the longest alimentary canal relative to its body size: a grass-eating herbivorous mammal or a flesh-eating carnivorous mammal? Explain.

3.4 Exam questions

Question 1 (1 mark)

MC In humans, mechanical digestion of food

A. occurs in the mouth, stomach and small intestine.
B. occurs only in the mouth and stomach.
C. requires the presence of an enzyme.
D. occurs best at a temperature of 37 °C.

Question 2 (1 mark)

MC The major type of macromolecule broken down in the stomach is
A. carbohydrate.
B. protein.
C. lipid.
D. nucleic acid.

Question 3 (1 mark)

MC Humans do not have digestive enzymes capable of acting on
A. starch in potato.
B. sucrose in peaches.
C. polypeptides in meat.
D. cellulose in breakfast cereals.

Question 4 (1 mark)

MC Most monomers of organic compounds are absorbed from the digestive system and into the blood stream when in the
A. oesophagus.
B. stomach.
C. small intestine.
D. large intestine.

Question 5 (2 marks)

People with cystic fibrosis produce abnormally thick mucus that can block the ducts of the pancreas. Explain how this disease affects the human digestive system.

More exam questions are available in your learnON title.

3.5 Endocrine system in animals

KEY KNOWLEDGE

- Specialisation and organisation of animals cells into tissues, organs and systems with specific functions: endocrine

Source: Adapted from VCE Biology Study Design (2022–2026) extracts © VCAA; reproduced by permission.

3.5.1 What is the endocrine system?

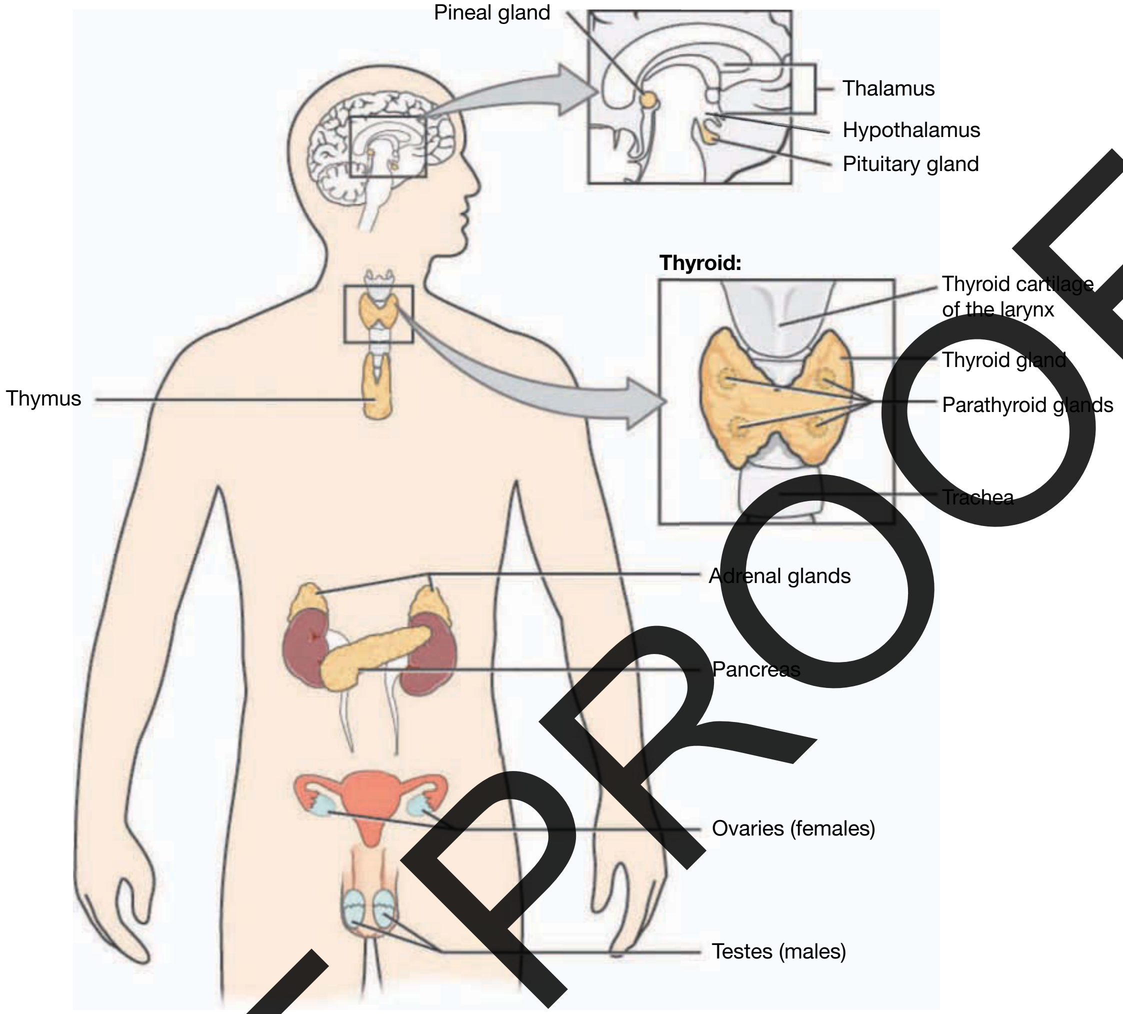
The endocrine system is composed of a network of **endocrine glands** and it functions as a chemical messenger system. Among the many glands of the endocrine system are the pituitary gland, the adrenal glands, the thyroid gland and the parathyroid glands (figure 3.60).

endocrine glands ductless glands that distribute hormones via the bloodstream

The endocrine system and the nervous system are both major communicators of messages to body cells. One difference is that the nervous system uses nerves to transmit information, while the endocrine system uses blood vessels to deliver its chemical messages. Which types of message — nervous or hormonal — would be expected to be acted on more quickly? Which would be expected to be longer-lasting?

int-5766

FIGURE 3.60 Diagram showing the glands of the endocrine system



Hormones are the chemical messengers produced by the endocrine glands of the endocrine system. They can be:

- proteins, polypeptides or amino acid derivatives such as antidiuretic hormone. Protein hormones are **hydrophilic** and so cannot diffuse easily across the plasma membrane. Hence, their complementary receptors are on the plasma membrane.
- steroids, which are synthesised from cholesterol and include cortisol and aldosterone (figure 3.61). Steroid hormones are **hydrophobic** and so can easily diffuse across the plasma membrane. Hence, their complementary receptors are in the cytosol/nucleus.

Hormones regulate many body functions, such as metabolism, growth, the concentration of glucose and electrolytes in body fluids, and sexual development.

Hormones carry messages to their target tissues. For example:

- 'secrete T3 and T4 hormones' — a message to the thyroid carried by thyroid-stimulating hormone
- 'reabsorb more calcium' — a message to cells of the small intestine carried by parathyroid hormone.

The target cells have specific receptors for their respective hormones that enable them to receive and respond to the message carried by the hormone (figure 3.62). Receptors for protein hormones are located on the surfaces of their target cells, while receptors for steroid hormones are located within the target cells.

hormones chemical messengers, released by endocrine glands, that regulate the function of distant organs, each with a specific receptor for its hormone

hydrophilic substances that dissolve easily in water; also called polar

hydrophobic substances that tend to be insoluble in water; also called non-polar

FIGURE 3.61 a. Cortisol: a steroid hormone released by the adrenal glands **b.** Antidiuretic hormone (ADH): a peptide hormone released by the pituitary gland that regulates the water content of blood

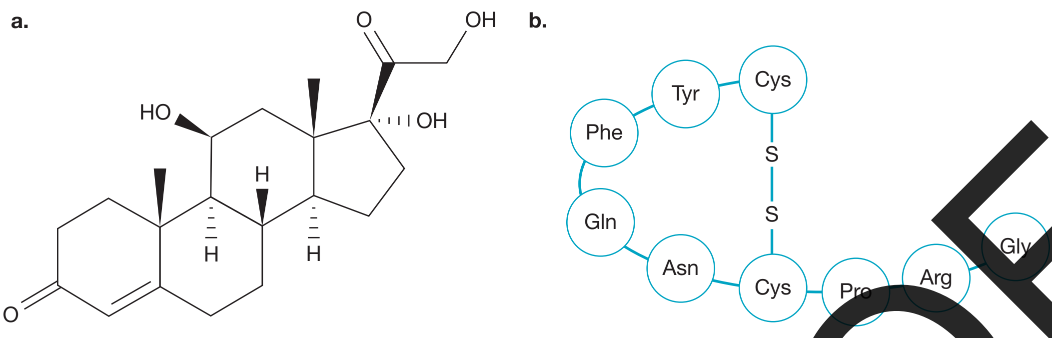
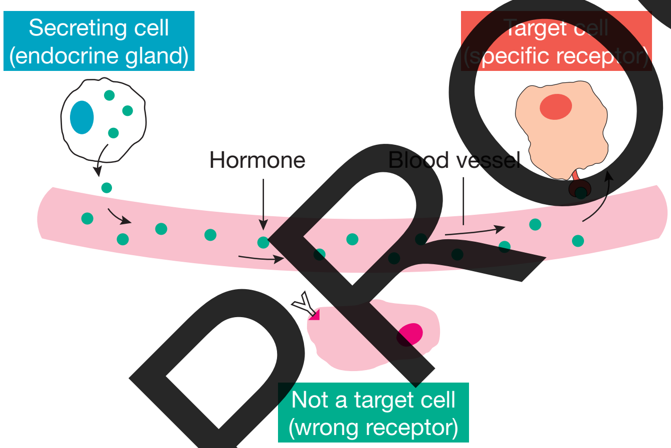


FIGURE 3.62 The delivery of a hormone via the bloodstream to its specific target cell that carries on its surface the correct receptor. Only cells with the matching receptor can accept the messenger.



Endocrine glands:

- release hormones *directly* into the bloodstream that carries them to their distant target cells
- do not have ducts and so differ from the type of gland found in the digestive system that releases its secretions via a duct to a surface, such as the skin or the mucosal surface of the gut (figure 3.63)

FIGURE 3.63 a. Exocrine gland such as an intestinal crypt in the small intestine that releases its secretion to the surface via a duct **b.** Endocrine gland that releases its hormone directly into a blood capillary

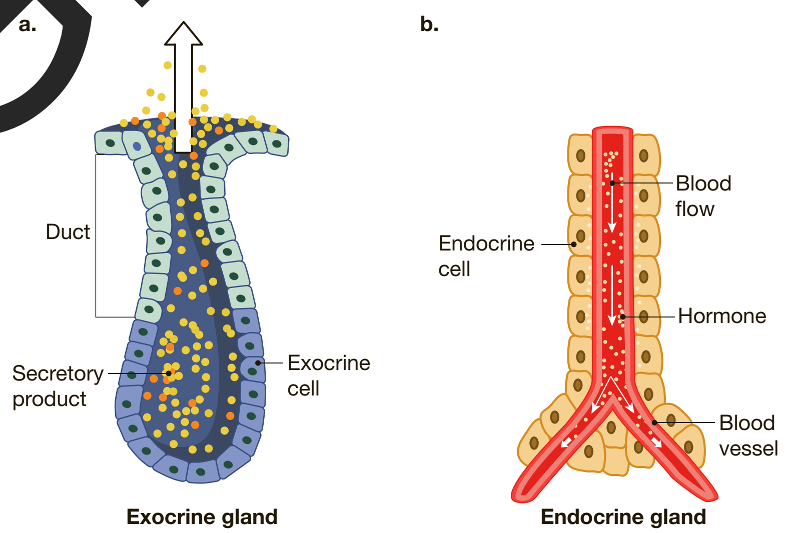


Table 3.7 shows some of the glands of the endocrine system, the hormones they release, the target organ of each hormone and the signal that it communicates.

TABLE 3.7 Summary of hormones produced by some glands of the endocrine system, their target organ and the signals or messages each hormone communicates

Endocrine gland	Hormone released	Target organ	Signal to target
Hypothalamus	Thyrotropin-releasing hormone (TRH)	Anterior pituitary gland	Start releasing thyroid-stimulating hormone (TSH)
	Growth-hormone releasing hormone (GHRH)	Anterior pituitary gland	Start releasing growth hormone (GH)
	Growth-hormone inhibitory hormone (GHIH)	Anterior pituitary gland	Stop releasing growth hormone (GH)
	Corticotitropin-releasing hormone (CRH)	Anterior pituitary gland	Start releasing ACTH (adreno-corticotropic hormone)
	Gonadotropin-releasing hormone (GnRH)	Anterior pituitary gland	Start releasing FSH or LH
Anterior pituitary gland	Growth hormone (GH)	Liver, fat Muscle and bone tissues	Release IGF-1 Build more tissue
	Adrenocorticotropic hormone (ACTH)	Adrenal glands	Secrete cortisol
	Thyroid-stimulating hormone (TSH)	Thyroid gland	Secrete T3 and T4 hormones
	Prolactin (PRL)	Mammary glands	Produce milk
	Follicle-stimulating hormone (FSH)	Ovaries/Testes	Produce gametes (eggs or sperm)
	Luteinising hormone (LH)	Ovaries/Testes	Produce sex hormones (oestrogens or testosterone)
Posterior pituitary gland	Antidiuretic hormone (ADH)	Kidneys	Raise blood pressure by increasing water reabsorption
	Oxytocin (OXT)	Uterus	Increase birth contractions
Thyroid gland	T3 and T4 hormones	Many organs	Raise the metabolic rate
	Calcitonin (CT)	Bones and kidneys	Lower blood calcium levels
Adrenal glands	Aldosterone	Kidneys	Control blood pressure by selective reabsorption of water and ions
	Cortisol	Ovaries and testes	Activate the stress response
	Androgens	Many organs	Convert precursor androgens to female or male sex hormones
	Adrendaline and noradrenaline	Many organs	Begin the 'fight or flight' response: increase heart rate and blood pressure
Parathyroid glands	Parathyroid hormone (PTH)	Bones and kidneys	Raise the blood calcium level

IGF-1 = insulin like growth factor 1, a hormone that promotes growth of muscle and bone

Note that:
- the hypothalamus produces hormones that target various cells of the anterior pituitary gland
- hormones released by the anterior pituitary gland target other endocrine glands
- the pathway to the final action of one hormone may involve earlier action by other hormones; for example, the release of the thyroid hormones, T3 and T4, requires the prior action of two hormones as shown.

Interrelationship between thyroid hormones

The release of thyroid hormones, T3 and T4, requires the prior action of other hormones as shown in the pathway provided.

Hypothalamus $\xrightarrow{\textit{Thyroid–releasing hormone}}$ Anterior pituitary $\xrightarrow{\textit{Thyroid–stimulating hormone}}$ Thyroid $\xrightarrow{\textit{T3 and T4}}$ Muscle, bone and other body tissues

Resources

Digital document Extension: Hormones in the digestive system — without a gland (doc-35879)

3.5.2 Tissues in the endocrine system

Each of the organs of the endocrine system are composed of different tissue types which are discussed with reference to their particular organ below. The role of each of these organs will be examined in section 3.5.3.

Pituitary gland

The pituitary gland:

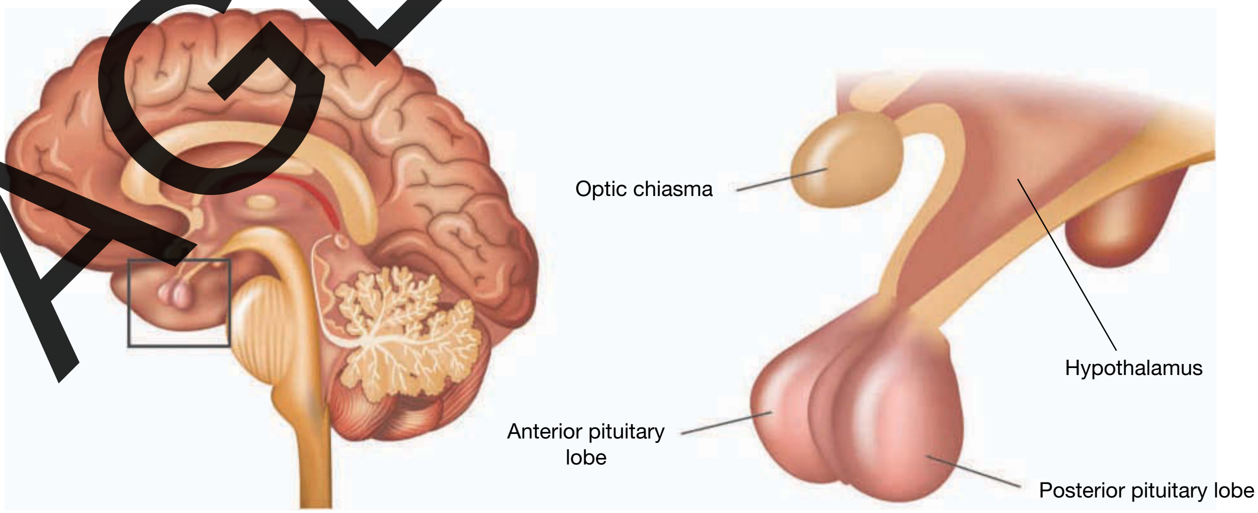
- is located at the base of the brain immediately below the hypothalamus
- is composed of two major lobes: the **anterior pituitary** and the **posterior pituitary**, that are separated by a thin strip of tissue.

Figure 3.64 shows the two lobes of the pituitary gland and their close proximity to the hypothalamus. The anterior and the posterior lobes differ markedly in their structure and function and are discussed separately below.

anterior pituitary anterior lobe of the pituitary gland; it is made of glandular tissue that synthesises and secretes several releasing hormones that activate other endocrine glands.

posterior pituitary posterior lobe of the pituitary gland; it is made of neural tissue that stores and releases hormones sent from the hypothalamus.

FIGURE 3.64 Simplified diagram showing the two major lobes of the pituitary gland: the anterior and the posterior



Anterior pituitary

The anterior pituitary is composed of winding cords of glandular epithelial cells with capillaries interspersed throughout. When sections of this tissue are treated with hematoxylin and eosin stain (H&E) a light micrograph shows three different types of cells:

- acidophil (acid-loving) cells with pink cytoplasm — these cells produce and secrete hormones
- basophil (base-loving) cells with bluish cytoplasm — these cells produce and secrete hormones
- chromophobes (colour-hating) — these cells are fewer in number, take up little stain and do not produce any hormone.

FIGURE 3.65 Light micrograph of a section through the anterior pituitary gland showing acidophil cells (bright pink cytosol) and basophils (blue cytosol). Small red blood cells can be seen in the blood vessels.

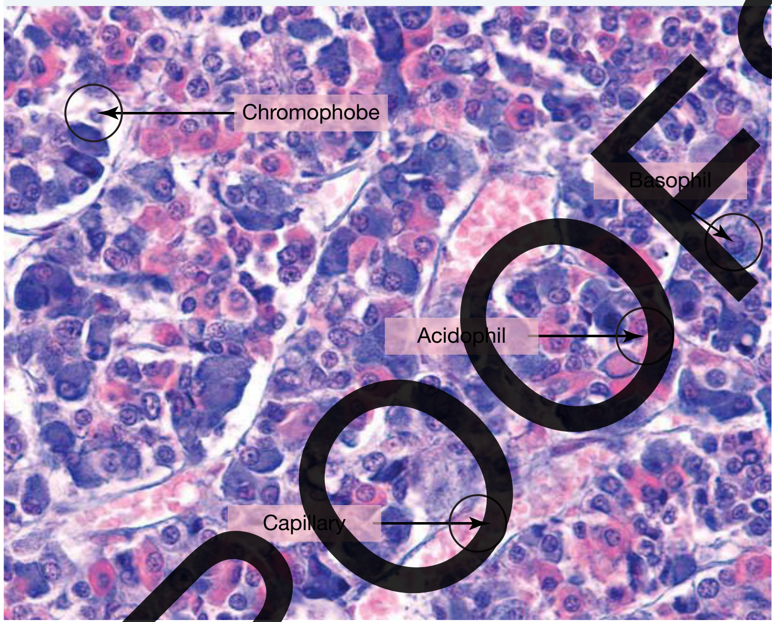


Figure 3.65 is a cross-section through the anterior pituitary gland stained with H&E that shows the hormone-producing acidophils and basophils. Note the presence of many capillaries, which transport the hormone released by each type of cell to its target tissue.

The H&E stain does *not* identify the type of hormone produced by an individual secretory cell in the anterior pituitary. However, more specialised staining techniques show that each individual acidophil and basophil produces just one hormone, as follows:

- acidophils that produce either growth hormone (GH) or prolactin (PRL)
- basophils that produce one of thyroid-stimulating hormone (TSH), follicle-stimulating hormone (FSH), luteinising hormone (LH) or adrenocorticotropic hormone (ACTH).

The hormones produced by these various cells are stored in granules in their cytosol; the size and the location of the granules differs in these various cells. The release of stored hormones is triggered by a specific hormone from the hypothalamus; for example, thyrotropin-releasing hormone (TRH) released from the hypothalamus stimulates specific basophil cells to release their stored thyroid-stimulating hormone (TSH).

FIGURE 3.66 False colour TEM showing several endocrine cells of the anterior pituitary. The orange profiles belong to a support cell.

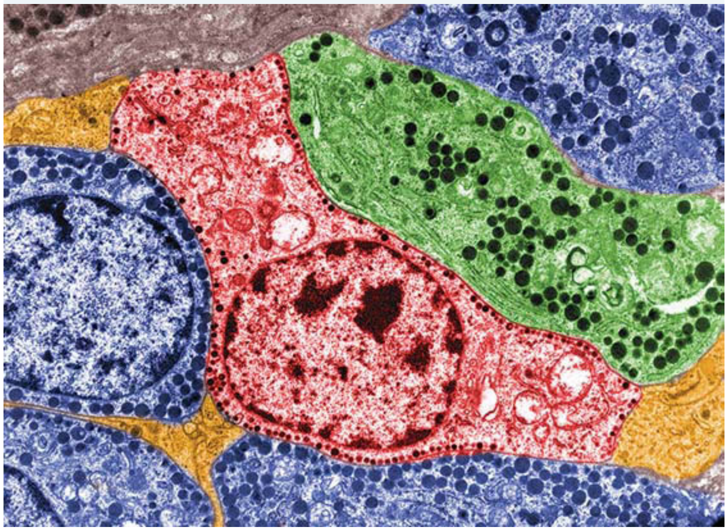
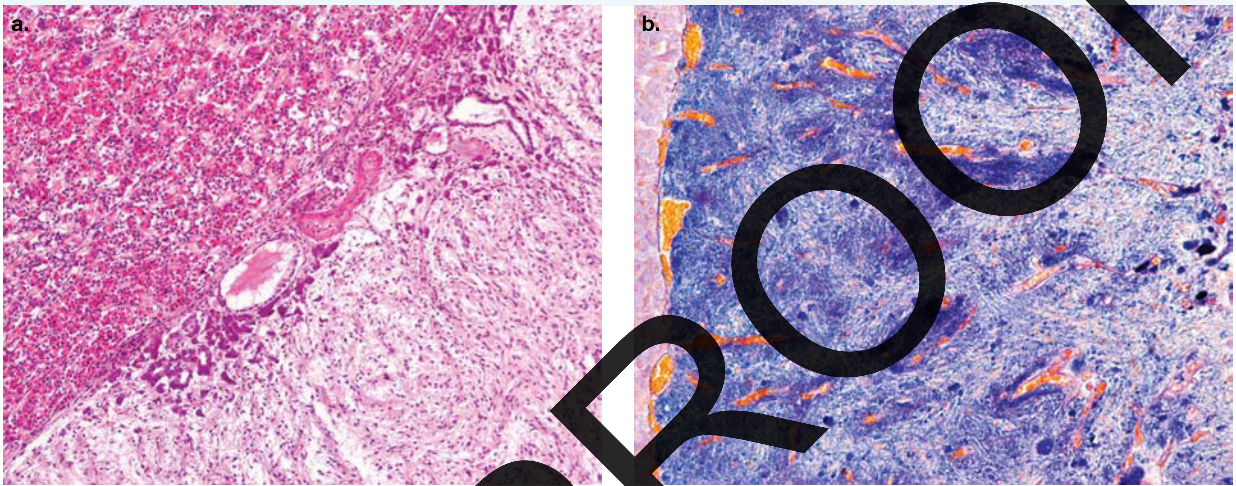


Figure 3.66 shows a transmission electron micrograph of several cells of the anterior pituitary. Note the variation in the size of their granules and their location within these cells. The red-coloured cell is a basophil that produces thyroid-stimulating hormone (TSH), the green-coloured cell is an acidophil that produces prolactin (PRL), and blue-coloured cells are basophils that produce growth hormone (GH). Note that the colours used in this micrograph are not related to the colours of cells in H&E-stained tissue.

Posterior pituitary

In light microscope views, the posterior pituitary looks very different from the anterior pituitary — the posterior lobe is much paler. Figure 3.67a shows a cross-section through a human pituitary gland stained with H&E. The posterior pituitary is in the lower area, the anterior pituitary is in the upper area and they are separated by a thin strip of tissue. The areas of white in the posterior pituitary are nerve fibres (axons) and nerve endings that are packed with secretory granules — no acidophils and basophils. Figure 3.67b shows a section of the posterior pituitary treated with a special stain that reveals its neurosecretory elements and shows their activity.

FIGURE 3.67 a. H&E stained posterior pituitary at lower right and the anterior pituitary at upper left **b.** Section of the posterior pituitary showing the areas of activity of neurosecretory cells (blue) and the blood-filled capillaries (orange)

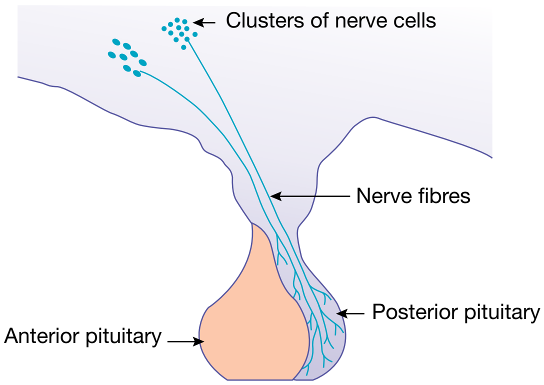


The posterior pituitary is composed of tissue that differs from the glandular epithelial tissue of the anterior pituitary. This is nervous tissue that consists of nerve fibre (axons) and nerve endings that originate in nerve cells located in the hypothalamus (figure 3.68). These cells are **neurosecretory cells** — that is, they receive nerve impulses from the brain and respond by releasing hormones. The tissue includes support cells and contains many capillaries.

The posterior pituitary does not produce hormones itself; instead it receives hormones — oxytocin (OCT) and antidiuretic hormone (ADH), which are produced by clusters of nerve cells in the hypothalamus. These hormones are transported to the posterior pituitary via nerve fibres. The hormones are stored in granules in the nerve endings.

neurosecretory cells cells that receive nerve impulses and respond by a chemical stimulus

FIGURE 3.68 Line diagram showing the nerve connection between the hypothalamus and the posterior pituitary. The OCT and ADH hormones from the hypothalamus move to the posterior pituitary via these nerve fibres.



Adrenal glands

The **adrenal glands** are paired endocrine glands that are located on the top of the kidneys.

Each adrenal gland is enclosed in a fibrous connective tissue capsuleand has two distinct regions:

- an outer cortex
- an inner medulla.

Both regions are richly supplied with blood capillaries, and, in addition, the medulla has many nerve fibres and nerve endings.

Figure 3.69 is a cross-section of an adrenal gland showing the medulla with blood vessels in the centre of the gland surrounded by the outer cortex. Note, in particular, that the cortex is not uniform and shows some layering. Also visible is the fibrous capsule that encloses the gland.

FIGURE 3.69 Light micrograph of a section of the adrenal gland showing the medulla with blood vessels in the centre of the gland and the surrounding cortex

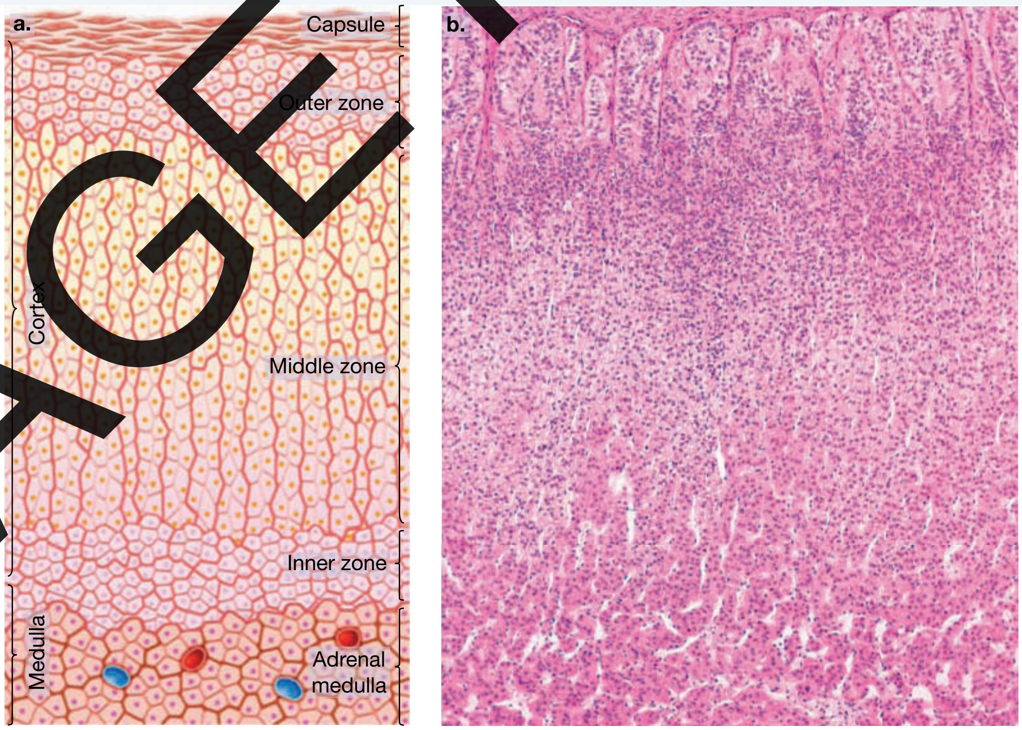
adrenal glands small endocrine glands located on top of the kidneys that produce various hormones

corticoid hormones steroid hormones, including aldosterone and cortisol, produced by cells of the cortex of adrenal glands

The adrenal cortex

The adrenal cortex is composed of glandular tissue. It produces and releases various **corticoid hormones** — these are produced in the cortex of adrenal glands and are steroids.

FIGURE 3.70 a. The arrangement of the cells of the adrenal cortex to form three distinct zones that lie between the capsule and the medulla **b.** Light micrograph of a section of the adrenal gland showing the zonation of the adrenal cortex



The adrenal cortex is not uniform in microscopic appearance, and three zones can be identified based on the different organisation of the cells, which each produce specific hormones:

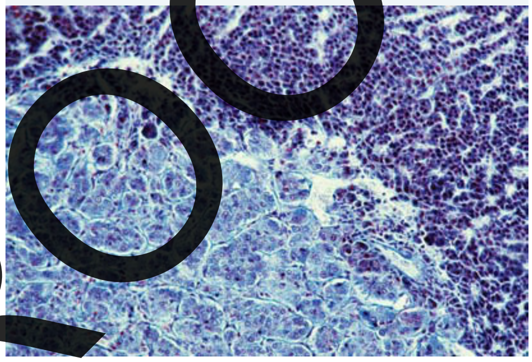
- the outer zone: cells are cuboidal to columnar in shape and are arranged in clusters. These cells cells produce **aldosterone**, which regulates blood pressure and the salt and water balance in the body.
- the middle zone: cells produce **cortisol**, which plays a role in regulating blood sugar levels and in recovery from the **stress response**
- the inner zone: the thinnest zone, with small cells arranged in clusters that cross and intersect creating a net-like appearance. These cells secrete androgens, the precursors of sex hormones.

The adrenal medulla

The adrenal medulla forms the central part of the adrenal gland and is composed of cells called chromaffin cells that are highly modified nerve cells.

Chromaffin cells produce the hormones, adrenaline and noradrenaline, which are very rapidly released in physically and emotionally stressful situations. These hormones are released in response to impulses from nerves connected directly to them. The release of hormones in response to nerve impulses occurs much more rapidly than for hormones released in response to signals carried to their endocrine glands via the bloodstream.

FIGURE 3.71 Light micrograph of a section of an adrenal gland showing innermost zone of the adrenal cortex (upper right) and the cells of the medulla (lower left)



The flood of adrenaline into the bloodstream starts the ‘flight or fight’ response that has several effects, including an increase in heart rate and the release of glucose into the bloodstream to provide fuel for cells. (You will no doubt have felt that flood of adrenaline when you received a sudden fright.)

Figure 3.71 is a light micrograph of a section through the adrenal gland at the junction of the medulla (at lower left) with inner zone of the cortex (at upper right). The cells of the inner zone of the cortex are dark-stained secretory cells that produce sex hormone precursors. The paler chromaffin cells of the medulla are organised into clumps of nervous tissue that secrete adrenaline and noradrenaline.

Thyroid gland

The **thyroid gland**, commonly described as a butterfly-shaped organ, is located in the neck around the trachea and below the larynx.

The thyroid gland has a rich blood supply with capillaries in close association with its secretory cells. It is composed of many structural units called **follicles**. They are lined with a single layer of cuboidal epithelial cells called follicular cells. The follicles are filled with **colloid** which consists of thyroglobulin, which is needed to produce the major thyroid hormones, T3 and T4. The thyroid gland has the only cells of the body that can absorb iodine, which is needed to produce T3 and T4.

aldosterone a steroid hormone produced by the adrenal cortex that regulates levels of salt and water and so controls blood pressure

cortisol a steroid hormone produced by the adrenal cortex that has many roles, including control of blood glucose levels during stress and the body’s recovery from the stress response

stress response combined physiological reactions to stress, also known as the ‘fight or flight’ response, that results from release of the hormones, adrenaline and noradrenaline from the adrenal medulla

thyroid gland endocrine gland located in throat that produces and secretes the hormones including T3 and T4

follicles secretory cells that enclose the thyroid follicles and that synthesise and release the hormones, T3 and T4

colloid gel-like material inside follicles that is the source of thyroglobulin, a prohormone of the T3 and T4 thyroid hormones

The thyroid gland also contains a number of cells called **parafollicular cells** which produce and secrete calcitonin, another thyroid hormone. Parafollicular cells are typically found among groups of cells in regions between follicles.

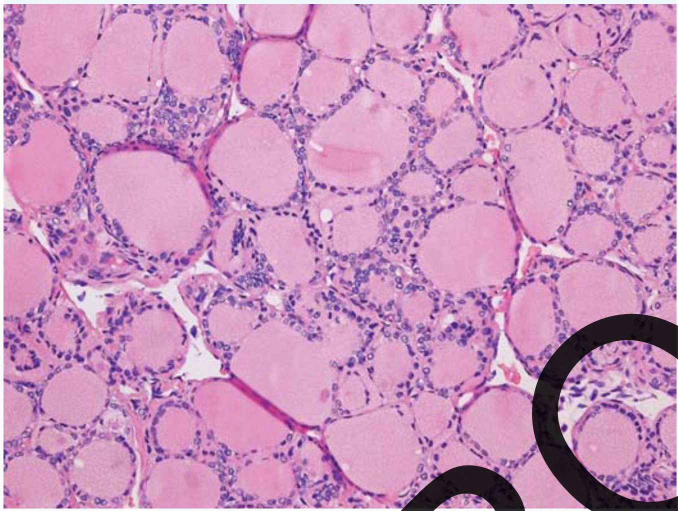
parafollicular cells secretory cells, located in small areas between follicles, that produce the thyroid hormone, calcitonin

chief cells in the parathyroid gland, secretory cells that produce parathyroid hormone (PTH) (Note: different cells with same name are present in the gastric pits of stomach.)

parathyroid hormone a protein hormone synthesised and secreted by the parathyroid glands in response to a falling blood calcium levels

adipocytes cells with large deposits of stored fat

FIGURE 3.72 Light micrograph of a cross-section of thyroid gland showing its many follicles, each filled with colloid, that is used by follicle cells to produce T3 and T4



Parathyroid glands

The parathyroid glands are endocrine glands located on the rear surface of the thyroid gland. The parathyroid glands are surrounded by a thin fibrous capsule and have networks of capillary vessels throughout their tissue.

The glandular tissue of the parathyroid glands contains several types of cell, including:

- **chief cells** that produce **parathyroid hormone** (PTH), which regulates calcium levels; PTH is secreted in response to falls in blood calcium levels — these are the smallest and most numerous cells and have with intensely-stained nuclei
- fat cells (**adipocytes**), which are large cells with clear contents
- other cell types of unknown function.

FIGURE 3.73 Light micrograph showing parathyroid gland tissue (right half) embedded within and attached to the thyroid gland tissue (left half). The thin red areas in the parathyroid tissue are blood capillaries.

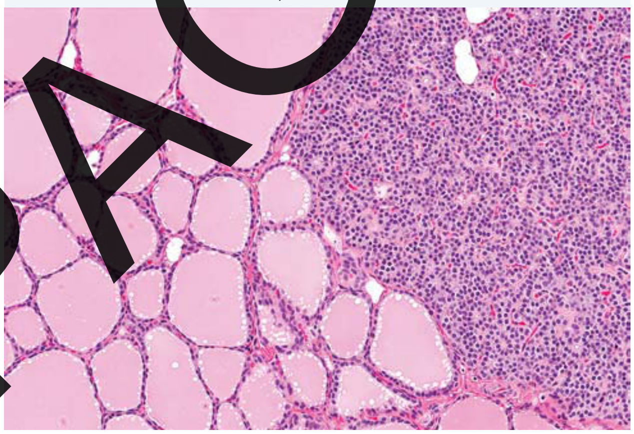
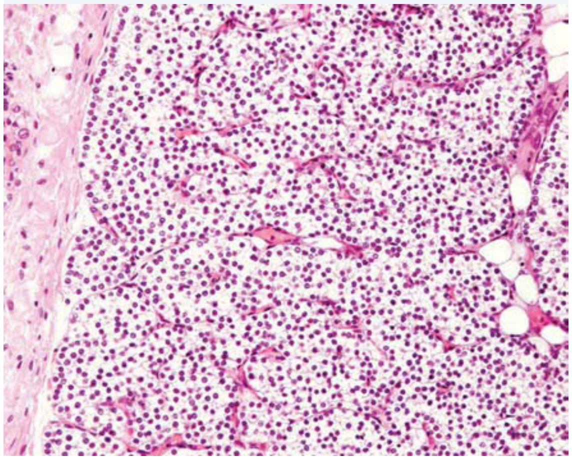


FIGURE 3.74 High power micrograph of a section through a parathyroid gland stained with H&E. Note the large fat cells and the numerous hormone-secreting chief cells.



3.5.3 Organs involved in the endocrine system

Pituitary gland

The pituitary gland is a pea-shaped endocrine gland, about 1 centimetre in diameter, that is located at the base of the brain immediately below the hypothalamus (figure 3.75). Two major components of the pituitary gland are its anterior and posterior lobes. The lobes are both formed from epithelial tissue during embryonic development: the anterior lobe is formed from surface tissue while the posterior lobe is formed from nerve tissue.

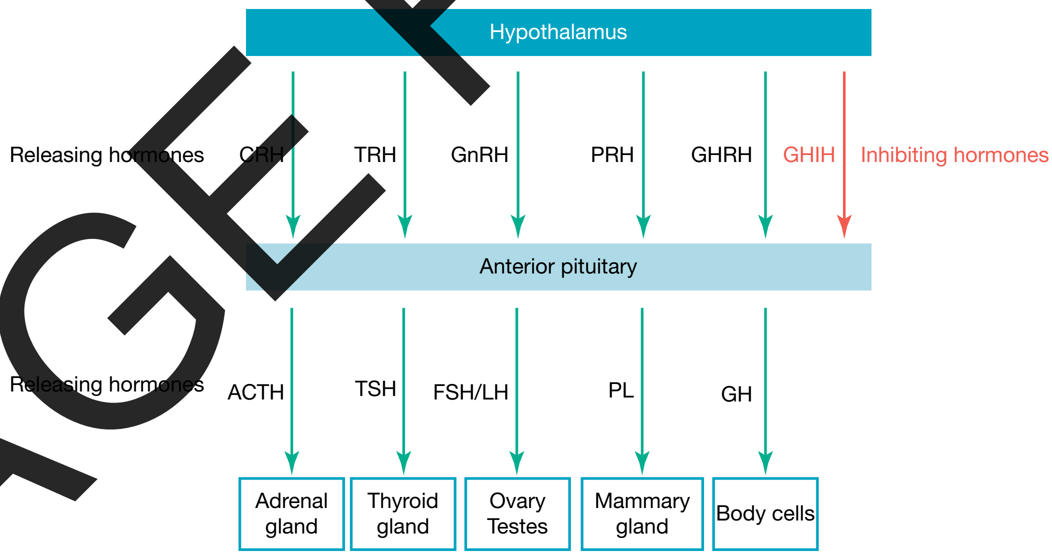
FIGURE 3.75 Image showing the pituitary gland linked to the hypothalamus

The function of the pituitary gland is to form the link between the brain and other endocrine glands through a series of hormones (see figure 3.76). As a result, it is the target of a number of hormones produced in the hypothalamus of the brain:

- some are *releasing hormones* that stimulate the anterior pituitary to produce and secrete a specific hormone
- one is an *inhibiting hormone* that stops the secretion of a specific hormone by the anterior pituitary
- some are stored in the posterior lobe for later release.

Note that in the case of the anterior pituitary, its targets include other endocrine glands (adrenal cortex and thyroid) as well as other body organs. For the posterior pituitary, its targets are the kidney and the uterus.

FIGURE 3.76 Diagram showing the link between the hormones of the hypothalamus, the anterior pituitary and the final targets (Hormone abbreviations are shown in table 3.7.)



The level of any hormone must be carefully regulated since an oversupply or undersupply will cause serious problems. For example:

- Oversupply: if an excess of growth hormone occurs in childhood when growth plates of the long bones are still unfused, gigantism will result, as seen in Sultan Kösen (see Case study below). If an oversupply occurs in adulthood, it will result in acromegaly, with excessive growth of hands, feet, jaw and nose.
- Undersupply: if a deficiency of growth hormone occurs, it results in growth retardation or dwarfism.

Control systems are normally in place to ensure that the levels of circulating hormone in the blood are maintained within narrow limits. For most of the hormones of pituitary gland, a key mechanism for hormone regulation is through negative feedback. In negative feedback, a hormone inhibits its own further production by blocking the glands(s) that produce it when the hormone concentration or its effects exceed or drop below the normal range. Feedback is discussed in detail in topic 4, section 4.4.3.

Adrenal glands

The adrenal glands are a pair of organs, each located on the upper margin of a kidney (figure 3.77).

The adrenal glands are composed of two parts — the cortex and the medulla — which synthesise and secrete different hormones. The cortex produces the steroid hormones cortisol and aldosterone. The medulla produces the hormones adrenaline and noradrenaline, which are derived from amino acids.

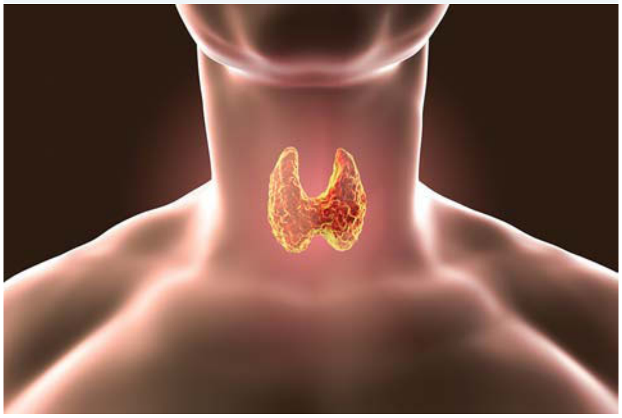
The secretion of cortisol and aldosterone is regulated by a system comprising the hypothalamus, the anterior pituitary and the adrenal glands and involves the actions of corticotropin-releasing hormone (CRH) and adrenocorticotropic hormone (ACTH). The regulation of hormone levels involves negative feedback (see section 4.4.3).

FIGURE 3.77 The location of the adrenal glands on the top of the kidneys

Thyroid gland

The thyroid gland consists of two lobes, joined by connecting tissue, located in front of the trachea in the lower neck. The size of the thyroid varies with age and sex, but for an adult, the length is 40 to 60 millimetres and the antero-posterior diameter is 13 to 18 millimetres.

FIGURE 3.78 The thyroid gland with its two lobes near the base of the throat



The thyroid gland secretes three hormones:

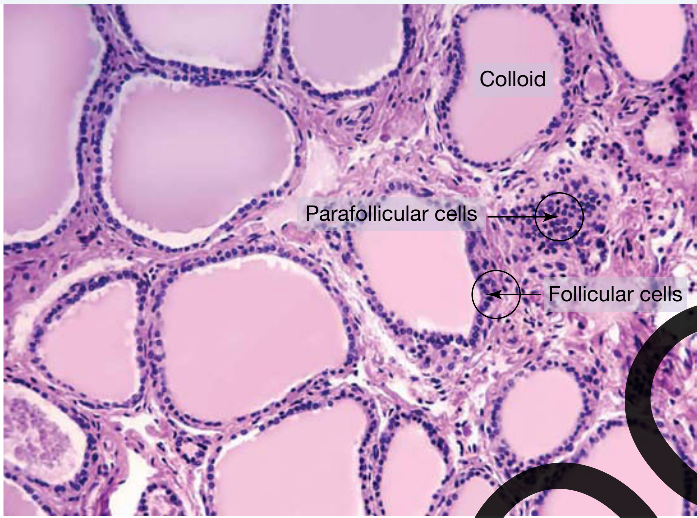
- T4 (thyroxine) and T3 are produced by its follicular cells. Note that the label, thyroid hormone (TH), is a convenient term to encompasses both hormones.
- calcitonin is produced by its parafollicular cells in response to a rise in blood calcium levels.

Figure 3.79 is a high-power light micrograph image showing the relative locations of these cells. Note the blood vessels that are in close association with the thyroid cells — these will carry the hormone messengers to their target tissues.

The T3 and T4 thyroid hormones regulate metabolism, growth and development. They have an effect on almost all body systems, including:

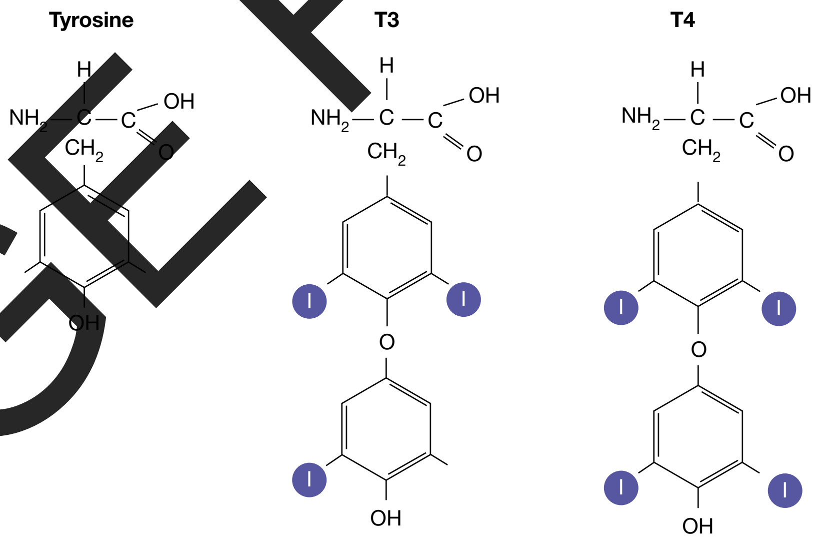
- increasing basal metabolic rate (see section 4.4.2)
- mobilising fat from adipocytes (fat cells)
- increasing cardiac output
- increasing blood flow to the skeletal muscles, liver and kidney
- increasing glomerular filtration rates.

FIGURE 3.79 High-power light micrograph showing a section of thyroid that identifies the follicular cells that produce the hormones T4 and T3 and the parafollicular cells that produce calcitonin



These thyroid hormones are critical for brain development in the developing foetus and during childhood. Figure 3.80 shows the structure of the amino acid tyrosine, and those of the T3 and T4 thyroid hormones. Note the presence of iodine atoms. A normal thyroid gland produces about 80 per cent T4 and about 20 per cent T3. T3 has a much stronger physiological effect than T4. T4 is enzymically converted to T3 in the thyroid and in other tissues including the liver.

FIGURE 3.80 Structural formulas of tyrosine, the amino acid that is a building block of the thyroid hormones T4 and T3. Note the presence of iodine atoms in the hormone structures.



T3 and T4 hormones are produced in a series of steps by the follicular cells of the thyroid. They are the only hormones that contain iodine and this is obtained through a person's dietary intake.

Thyroid hormone production is regulated to ensure that T3 and T4 levels are neither too high nor too low. The elements in the regulation of the thyroid activity include the hypothalamus, which secretes thyrotropic-releasing hormone (TRH) and the anterior pituitary, which secretes thyroid-stimulating hormone (TSH). The mechanism of this regulation is negative feedback, which is discussed in section 4.4.2.

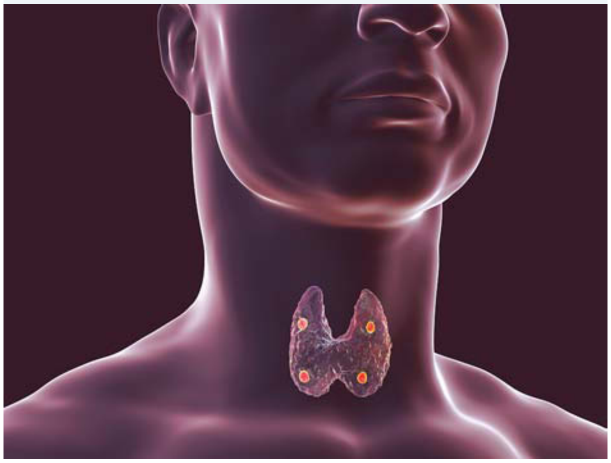
FIGURE 3.81 Production of T3 and T4 hormones

Thyroglobulin synthesis	Thyroglobulin, a protein, is synthesised by follicular cells and transferred into the colloid in the thyroid follicles.
Uptake and concentration of iodide (I^-)	Iodide from dietary sources is actively taken up from the blood by follicular cells, accumulates and is then transported into the follicle adding to the colloid.
Oxidation of iodide (I^-) to iodine (I)	In the colloid, iodide is converted to iodine.
Iodination of thyroglobulin	Iodine atoms form bonds with one particular amino acid residue (tyrosine) that is present in multiple numbers in the polypeptide chain of thyroglobulin.
Formation of MIT and DIT	MIT (mono-iodo-tyrosine) is a tyrosine residue with one iodine attached. DIT (di-iodo-tyrosine) is a tyrosine with two iodines attached. MIT + DIT = T3 and DIT + DIT = T4.
Digestion and secretion	Thyroglobulin with its iodinated tyrosine amino acids is taken from the colloid into the follicular cells where proteases cut the MITs and DIT molecules free and they join, forming T3 and T4 hormones.

Parathyroid glands

The parathyroid glands are endocrine glands on the posterior surface of the thyroid gland. Typically, a person has four parathyroid glands, each about 5 millimetres long, 3 millimetres wide and 1 to 2 millimetres thick. Two parathyroid glands lie behind each lobe of the thyroid gland (figure 3.82).

FIGURE 3.82 The parathyroid glands are located on the surface of the thyroid.



The parathyroid glands produce a hormone called parathyroid hormone (PTH), which is involved in the regulation of calcium blood levels — that is, the maintenance of calcium homeostasis. Secretion of calcitonin, a thyroid hormone, is stimulated by increases in the serum calcium concentration. Calcitonin protects against the development of hypercalcemia.

The main target organs of parathyroid hormone are bones and the kidneys. When calcium levels are low, parathyroid hormone (PTH) is released into the blood, causing the calcium levels to return to normal. Mechanisms by which this is achieved include:

- loss of calcium from bone — this is achieved when bone cells (called osteoclasts) are stimulated by the hormone to resorb bone from the surface of particular bones, releasing that calcium into the blood.

- decreased loss of calcium in urine — this is achieved through increased reabsorption of calcium by cells of the kidney tubules.
- increased conversion of inactive vitamin D in the kidney to its active form, namely 1, 25-dihydroxy vitamin D; this, in turn, increases calcium absorption in the intestine.
- increased absorption of calcium in the intestine. In the absence of vitamin D, dietary calcium is not absorbed very efficiently.

Some people suffer from excessive secretion of parathyroid hormone, which leads to structural damage to bone and excess calcium in the blood. In many cases, this condition is due to a parathyroid tumour.

Note that the actions of a thyroid hormone, calcitonin, are opposite to those of parathyroid hormone. Its targets are bone and kidneys. Calcitonin acts to decrease blood calcium levels and it does this by inhibiting the activity of osteoclasts so preventing bone being absorbed, and it inhibits the resorption of calcium in the kidney tubules.

CASE STUDY: Sultan Kösen — the world's tallest man

In 2009, the name of a Turkish man was entered the *Guinness Book of Records* as 'the world's tallest living man'. He is Sultan Kösen, born in 1982, and his recorded height is now 2.51 metres. As a comparison, the Building Code of Australia identifies 2.4 metres as the minimum ceiling height for most rooms in new houses. Figure 3.83 shows a photo of Sultan Kösen and his brother taken in 2009. Sultan's abnormal growth spurt began during childhood and was the result of a non-cancerous tumour on his pituitary gland that caused it to release excessive growth hormone, which affected his bone and muscle growth. Surgery on the tumour in 2010 stopped the excessive production of growth hormone by his pituitary gland and this prevented Sultan from becoming any taller. Reading about Sultan Kösen reminds us that the hormones that are the products of the endocrine system exert major influences on the functioning of the human body. When the production of a particular hormone is either in excess or in deficit, negative and, in some cases fatal, effects on body function follow.

FIGURE 3.83 Sultan Kösen and his brother

tlvd-1853

SAMPLE PROBLEM 4 Explaining the role of iodine

A 9-year old patient was admitted to hospital with an enlarged thyroid gland. Through various tests, they were diagnosed as having an iodine deficiency.

a. Why is iodine important for the proper functioning of the endocrine system? (2 marks)
b. Suggest the impact of an iodine deficiency on the production of the T3 and T4. (2 marks)
c. With reference to both the pituitary and thyroid gland, propose a reason why an iodine deficiency may lead to an enlarged thyroid gland. (2 marks)
d. Outline some of the symptoms that may result from a poorly functioning thyroid. (3 marks)

THINK	WRITE
a. The question requires simple statements. As the question is worth 2 marks, you should highlight two key points: the function of the endocrine system and why iodine is important for this function.	The endocrine system is a chemical messaging system that uses hormones to regulate body functions (1 mark). Iodine is required to produce some of these hormones (1 mark).

b. You are asked to suggest, which involves providing a logical explanation with reasoning. This question requires two key points. You should consider your answer around the need for iodine to produce T3 and T4.

Iodine is found in both the T3 and T4 hormones, which are produced in the thyroid gland from the amino acid tyrosine (1 mark). Without iodine, T3 and T4 would not be able to be produced, leading to a reduction in the production of these hormones (1 mark).

c. Carefully read the question. You need to propose a reason for an enlarged thyroid gland. The question specifically states that you need to link to both the pituitary and the thyroid glands in your response to achieve both marks.

As the hormones are not being produced, more thyroid stimulating hormone will be released from the pituitary gland (1 mark). As the thyroid gland is unable to make enough T3 and T4 hormones, it is likely that the thyroid gland will enlarge to try to increase and amplify the production of the T3 and T4 hormones (1 mark).

d. This is an outline question, so brief statements are required. T3 and T4 act to increase basal metabolic rate, cardiac output, blood flow and glomerular filtration. They also mobilise fat and aid in brain development. Use these points to consider what a deficiency would lead to. **TIP:** As the question is worth 3 marks, you should make 3 clear points. These may be written as a bulleted list. If you make 5 points, but some are incorrect, you will lose marks, so pick 3 points that you are most confident with.

T3 and T4 have an effect on metabolism, growth and development. Some of the symptoms of a deficiency in these hormones for a poorly functioning immune system may include:

- a lower than normal body temperature (due to a lower metabolic rate) (1 mark)
- low blood flow to muscles, liver and kidney (1 mark)
- reduced brain development and possible intellectual disability (1 mark).

on Resources

eWorkbook Worksheet 3.6 The human endocrine system (ewbk-3496)

3.5.4 Endocrine systems in different animals

Communication in the form of chemical signalling between cells is present in *all* animals. Chemicals that carry a signal from one cell to other cells include hormones and nuerotransmitters.

The first cells involved in chemical communication were probably neurosecretory cells, that is, nerve cells that when stimulated release a chemical signal (hormone). The least complex means of endocrine communication is the individual cells that produce and release chemical signals that travel by diffusion to neighbouring target cells — there are no specialised endocrine glands and no involvement of a circulatory system. The most complex means of endocrine communication is an endocrine system with specialised glands, closely associated with the nervous system and the circulatory system — as seen, for example, in the endocrine system of vertebrates.

Insects are among the first animal groups in which specialised endocrine organs can be seen.

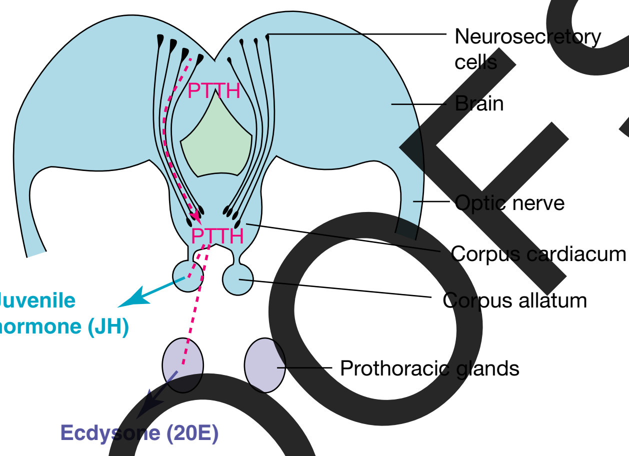
Communication through chemical signalling occurs in all animals via hormones.
The simplest form of intercellular communication is by the diffusion of a chemical signal released by one cell that diffuses neighbouring target cells, with no endocrine glands or involvement of the circulatory system.

Endocrine system of insects

The insect endocrine system produces a large number of hormones. These hormones are mainly synthesised by the glandular cells and the neurosecretory cells of endocrine glands. Many of the hormones are small peptides, but some are steroids, and they regulate growth, development, homeostasis, reproduction and behaviour.

Figure 3.84 shows a stylised representation of the major organs of the insect endocrine system. The hormones identified are those that regulate moulting and development.

FIGURE 3.84 Stylised representation of the major organs of the insect endocrine system and some major hormones



The major organs of the insect endocrine system are:

- the brain, which has clusters of neurosecretory cells that produce hormones, including prothoracicotropic hormone (PTTH), allotropin and allostatin
- corpora cardiaca (singular = corpus cardiacum), which are paired neuroglandular bodies that produce their own neurohormones. They receive, store and release neurohormones produced in the brain, including PTTH.
- corpora allata (singular = corpus allatum), which are paired glands. Their glandular cells produce and secrete **juvenile hormone** (JH) in response to stimulation by the hormone allotropin. Another hormone, allostatin, inhibits the production of JH by the corpora allata.
- prothoracic glands, which are paired diffuse glands located partly in the thorax. Their glandular cells produce and secrete the hormone ecdysone (a steroid hormone derived from cholesterol). Ecdysone is a prohormone and is converted to its active form, 20E (20-hydroxy ecdysone) after its release into the hemolymph (body fluid).

The signal to produce ecdysone originates in neurosecretory cells in the brain that release PTTH and this hormone stimulates the prothoracic glands to secrete **ecdysone**.

juvenile hormone insect hormone in the nymphal and larval stage of all insects; it is a lipid, derived from a fatty acid.

ecdysone steroid hormone which controls moulting in insects

moult in insects, the periodic event during development of larvae or nymphs which involves growth in epidermal cell numbers, shedding of the noncellular outermost cuticle and production of a new expanded cuticle

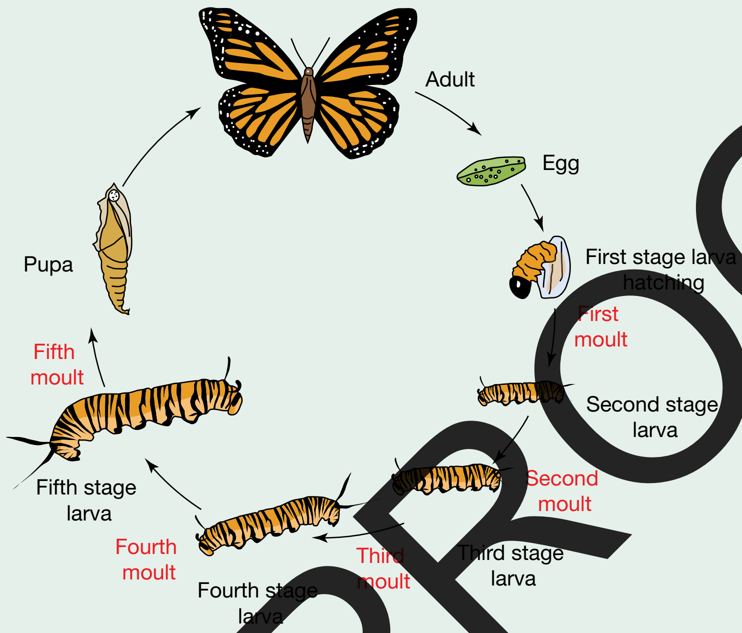
CASE STUDY: Hormones and moulting in insects

In the immature stages of their life cycle, insects (either larvae or nymphs) are voracious eaters but they do not increase in size in a smooth fashion. Instead, they grow in discrete steps that are separated by **moults**. Before moulting, a larva or a nymph enlarges its epidermis by growth in cell numbers. It then sheds the noncellular outermost layer (cuticle) and produces a new enlarged cuticle. This provides space for an increase in size (figure 3.85).

FIGURE 3.85 Black Swallowtail butterfly larva *(Papilio polyxenes)* eating the cuticle that it has shed in the process of moulting

Figure 3.86 shows the life cycle of a butterfly, including the stages egg, larva, pupa and adult. After hatching, the larva undergoes five moults. The first four moults are 'larva in–larva out', but the fifth moult is 'larva in–pupa out'. Within the pupal case, an extraordinary process of **metamorphosis** occurs, with a butterfly emerging from the pupal case. Think about how a caterpillar and a butterfly differ in their shape, diet, appendages and motor capabilities. Moulting and metamorphosis in insects are complex processes that are governed by hormones.

FIGURE 3.86 The life cycle of a butterfly including the five larval stages



Two of the insect hormones involved in moulting are ecdysone (20E) and juvenile hormone (JH).

The 'larva in–larva out' moults occur in the presence of both ecdysone and JH. The role of ecdysone is to:

- initiate and coordinate the moult
- initiate the changes in gene expression needed for metamorphosis.

The role of JH is to prevent these changes in gene expression.

So in these moults, the presence of JH limits the action of ecdysone. The epithelial cells of the larval integument (skin) are stimulated to detach from the overlying old cuticle and secrete to a new cuticle. By swelling up, the larva splits the old cuticle and extracts itself as a next-stage larva.

The 'larva in–pupa out' moult occurs in the presence of ecdysone only. The production of JH is blocked by the release of a neurohormone, allatostatin, from the brain to the corpora allata (CA). The role of ecdysone in this stage is to initiate a moult that inactivates larval genes and stimulates the pupa-specific genes, shifting the insect from larva to pupa.

The metamorphosis from larva to adult occurs within the pupal cuticle. Most of the larval cells are destroyed by apoptosis, and new adult tissues and organs develop from special clusters of undifferentiated cells in the larva. Ecdysone plays a major role in regulating the genes involved in these processes and in cell growth and division. Figure 3.88 shows the changes in concentration of ecdysone during the insect life cycle of the fruit fly, *Drosophila*. Far from being a 'moulting hormone' that is active during larval life, ecdysone plays a major coordinating role in the pupa-to-adult metamorphosis. Note that the release of ecdysone is not constant, but occurs in pulses, with the largest being during embryonic development, at the larva-to-pupa moult and during metamorphosis.

metamorphosis process of transformation — in insects (holometabolous) and amphibians — from an immature form to an adult that involves major changes in body structure and physiology

FIGURE 3.87 Diagram showing the hormones involved in moulting in insects. Organs are shown in boxes, hormones in ovals, excitatory hormone pathways in green and inhibitory pathways in red.

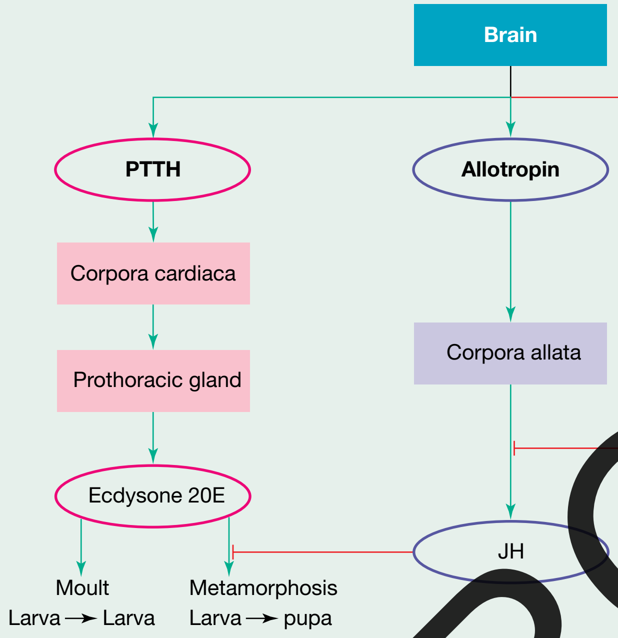
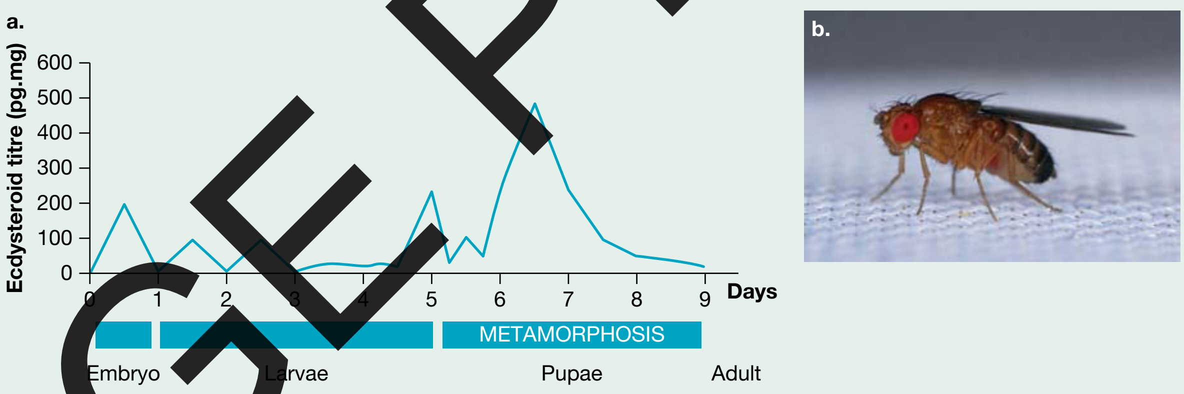


FIGURE 3.88 a. Graph showing the release of pulses of ecdysone during development of the fruit fly *Drosophila*, over its embryonic, larval and pupal stages **b.** *Drosophila melanogaster*, the common fruit fly



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INVESTIGATION 3.6

online only

Observing the life cycle of a butterfly

Aim

To observe the life cycle of a butterfly including the various moulting stages

CASE STUDY: Thyroid hormones in amphibians

Most vertebrates — mammals, birds, reptiles, bony fish, sharks — have a simple life cycle. They have young that are born or hatch, are similar to their parents and over their lifetimes grow into adults.

The life cycle of most amphibians — frogs, toads and newts — is more complex. Their young are not similar in structure and function to their parents. Their young are aquatic animals, lacking legs, that use their gills to obtain oxygen from water, while the adults are terrestrial animals that obtain their oxygen via lungs.

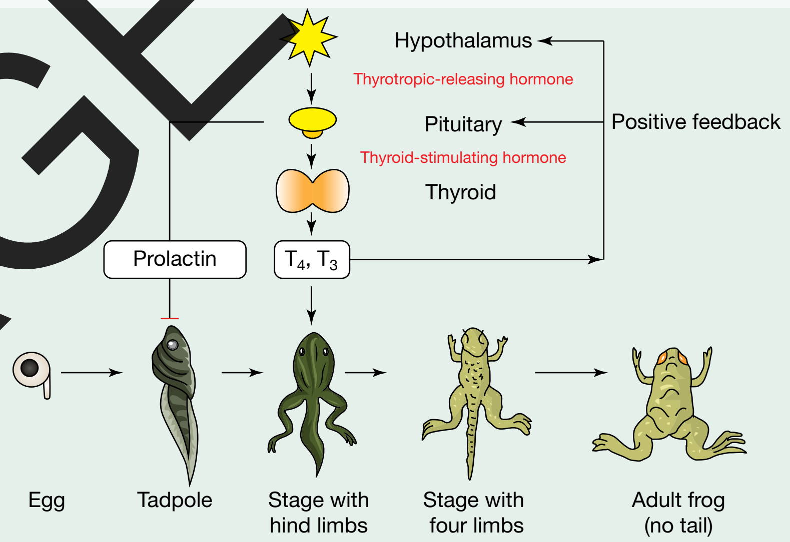
Metamorphosis is process of transformation of young to adult in most of these amphibians. The developmental changes include:

- total removal of the tissues of tail and gills by programmed cell death (apoptosis)
- development of new tissues of limb buds and lungs
- remodelling of their long digestive tract to accommodate the switch from a largely herbivorous lifestyle to that of a carnivore
- induction of urea cycle enzymes in the liver in the switch from excretion of N-wastes as ammonia to excretion as urea.

Metamorphosis in *Amphibia* has now been shown to involve the interaction of endocrine glands and the hormones they secrete. Figure 3.89 shows the hormonal system that is regulates metamorphosis. Does it look familiar? It is the hypothalamus–pituitary–thyroid system that was introduced in section 3.5.1.

- The hypothalamus releases thyrotropic-releasing hormone (TRH), which travels via the blood stream to the pituitary.
- In response to the TRH signal, the anterior pituitary releases thyroid-stimulating hormone (TSH), which travels via the blood stream to the thyroid gland.
- The TSH signal from the anterior pituitary activates the dormant thyroid gland that responds by secreting thyroid hormone (T3 and T4) that enters the blood stream and travels to body cells. Body cells with receptors for the thyroid hormone respond by initiating the particular biochemical and physiological changes of the metamorphic process for their tissue.
- Note that:
  1. Positive feedback occurs in this system. The output of the system, thyroid hormone, enhances the original signals by stimulating the anterior pituitary and the hypothalamus to release more of their hormones (see topic 4).
  2. Prolactin released from the anterior pituitary inhibits the metamorphic actions of thyroid hormone.

FIGURE 3.89 Schematic representation of the metamorphosis of a tadpole to a frog and the hormones involved in the regulation of this process



Resources

eWorkbook Worksheet 3.7 Endocrine system in other animals (ewbk-7379)

Weblink What is endocrinology?

KEY IDEAS

- The endocrine system is a network of endocrine glands that deliver chemical messages through hormones in the blood stream to target tissues.
- Hormones regulate body functions, including metabolism, growth, the concentration of glucose and electrolytes in body fluids, and sexual development.
- Target cells have specific receptors for their respective hormones to receive and respond to messages.
- The hypothalamus produces various releasing hormones that target various cells of the anterior pituitary gland.
- The pituitary gland is composed of the anterior pituitary and the posterior pituitary.
- The glandular tissue of the anterior pituitary contains acidophil and basophil cells that release various stimulating hormones that target other endocrine glands.
- The posterior pituitary gland is composed of nervous (neural) tissues and does not produce hormones but stores and releases hormones produced by the hypothalamus.
- Adrenals are paired endocrine glands on the top surface of the kidneys.
- The cortex of the adrenal gland has three zones, the cells of each one producing different hormones.
- The adrenal medulla produces the hormones adrenaline and noradrenaline that are involved in the stress response, also known as the fight-or-flight response.
  - Colloid-containing follicles, enclosed by follicular cells, form the structure of the thyroid gland.
  - Follicular cells of the thyroid gland synthesise the hormones T3 and T4 and its parafollicular cells produce the hormone calcitonin.
- Parathyroid glands are located on the rear surface of thyroid gland and secrete the parathyroid hormone.
- Regulation of hormone action typically involves negative feedback.
- Communication between cells through chemical signalling occurs in all animals.
- The simplest form of intercellular communication is via a chemical signal produced by one cell that moves by diffusion to a nearby cell.
- Insects were among the first animal groups to develop specialised endocrine systems.
- The main organs of insect endocrine system are the corpora cardiaca, corpora allata and prothoracic glands.
- Important hormones in moulting and metamorphosis in insects are PTTH, JH and ecdysone (20E).

3.5 Activities

learnon

To answer questions online and to receive **immediate feedback** and **sample responses** for every question go to your learnON title at **www.jacplus.com.au**. A **downloadable solutions** file is also available in the resources tab.

3.5 Quiz quiz on	3.5 Exercise	3.5 Exam questions

3.5 Exercise

1. MC The thyroid gland
   A. requires iodine to produce the hormones T3 and T4.
   B. releases calcitonin to increase calcium levels when they fall too low.
   C. is located just above the kidneys.
   D. releases growth hormones during development.
2. What is an endocrine gland?
3. Briefly identify:
   a. the chemical nature of hormones
   b. the general function of hormones
   c. their mode of delivery to their target organs.
4. Describe how a hormone finds its correct target cells.
5. Consider the hormones that are produced and released by the anterior pituitary gland. Which of these hormones has as its target another endocrine gland that it stimulates to release its hormones?

6. Compare and contrast the anterior pituitary and the posterior pituitary in terms of:
   a. their ability to synthesise hormones
   b. the composition of their tissue.
7. Briefly identify the role of follicular and parafollicular cells of the thyroid gland.
8. Where in the endocrine system would you find the following?
   a. Chief cells
   b. Cells that secrete aldosterone
   c. Cells that synthesise thyroglobulin
9. List three actions by which parathyroid hormone acts to increase calcium levels in the blood when the concentration falls below the normal range.
10. The hormones ecdysone (20E) and juvenile hormone (JH) are both involved in the insect life cycle.
    a. Which are involves in larva in–larva out moults?
    b. Which are involves in the larva in–pupa out moult?
    c. At which stage of the insect life cycle are 20E levels at their highest?

3.5 Exam questions

Question 1 (1 mark)

MC Certain tumors of the adrenal gland cause high production of the hormone aldosterone. This change in production of aldosterone will most likely affect blood

A. carbon dioxide concentration.
B. cell count.
C. glucose concentration.
D. pressure.

Question 2 (2 marks)

Source: *VCAA 2013 Biology Section B, Q3a, 3b*

A signalling molecule, epinephrine (adrenaline), is released from the adrenal gland when a human feels threatened. The molecule is transported in the bloodstream and initiates responses in cells in other parts of the human body.

a. To which group of signalling molecules does epinephrine belong? **1 mark**
b. Receptors for epinephrine are found on the exterior surface of the plasma membrane of cells. What does this suggest about the nature of the epinephrine molecule? **1 mark**

Question 3 (3 marks)

Source: *VCAA 2007 Biology Exam 1, Section B, Q1b, Q1ci-ii*

A hormone was produced in one cell, entered the bloodstream and travelled to two groups of cells adjacent to each other. One group of cells responded to the hormone but the neighbouring group did not.

a. What is the most likely reason for this difference in response by cells to the same hormone? **1 mark**
b. Consider one hormone you have studied this year that is transported through the blood to one or more types of cells.
   i. Name the hormone. **1 mark**
   ii. Name the tissue or gland that produces the hormone. **1 mark**

Question 4 (1 mark)

Source: *VCAA 2008 Biology Exam 1, Section B, Q6c*

Hormones are found in all multicellular organisms.

A hormone is sometimes defined as 'a chemical that is produced in one organ and transported by the blood to other cells where it causes a specific change'.

We now understand that this definition fails to account for all hormones found in multicellular organisms.

Write a new definition for a hormone, covering the majority of situations in which we know hormones are involved.

Question 5 (4 marks)

Compare and contrast the location and hormones released by the thyroid gland and the parathyroid gland. **4 marks**

More exam questions are available in your learnON title.

3.6 Excretory system in animals

KEY KNOWLEDGE

- Specialisation and organisation of animals cells into tissues, organs and systems with specific functions: excretory

Source: Adapted from VCE Biology Study Design (2022–2026) extracts © VCAA; reproduced by permission

3.6.1 What is the excretory system?

Living organisms carry out life-sustaining metabolic reactions in their cells all the time. Some of these reactions generate left-over products that are toxic, or substances that disturb the homeostatic balance of the body if their concentration build to too high levels, or substances that cannot be stored but are in excess of immediate needs.

Leftover products that must be removed include harmful nitrogenous wastes (N-wastes) such as:
- ammonia and urea from the metabolism of protein
- guanine from the breakdown on nucleic acids
- creatine and creatinine from the metabolic activities of skeletal muscle.

Substances that must be removed when they are in excess include water and inorganic ions, such as Na^+, K^+ and Cl^-.

These various types of wastes are removed in a process known as **excretion**. In vertebrates, the key organ of the excretory system is the kidney. (Organs in other systems also contribute to excretion of wastes — lungs excrete gaseous carbon dioxide, skin excretes excess salt and water in sweat, the liver excretes a product of the breakdown of red blood cells in bile — but that is not their primary function.)

Figure 3.90 is a simple diagram of the human excretory system showing its four organs — kidney, ureters, urinary bladder and urethra — and its major blood vessels. (We will explore these organs and their functions in section 3.6.3.) Note that the kidney is a solid organ, while the **urinary tract** is composed of the three hollow organs: ureters, urinary bladder and urethra. The urinary tract is also known as the excretory passage.

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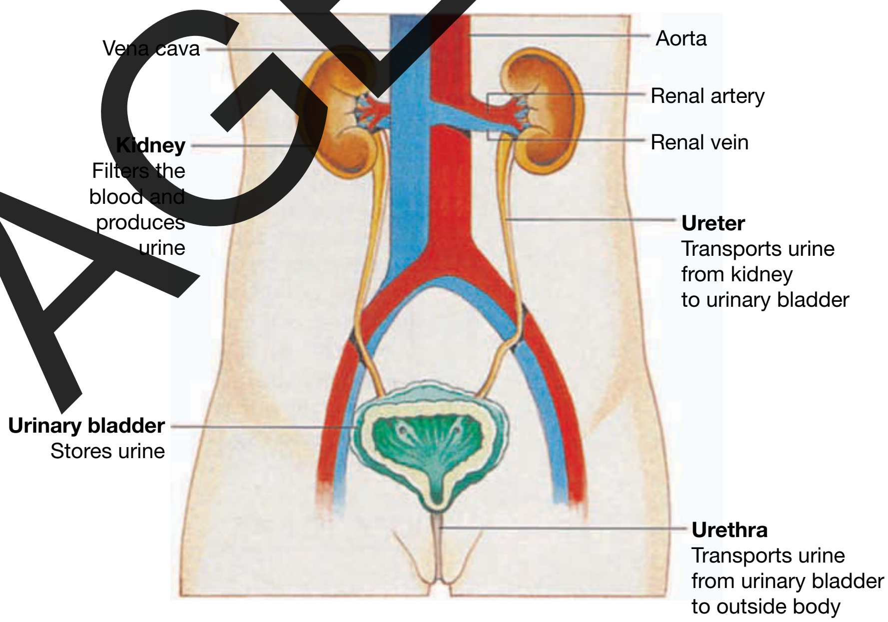
FIGURE 3.90 A diagram showing the four organs of the excretory (urinary) system: kidneys, urinary bladder, ureter, and urethra



excretion process of removal from the body of various types of waste material arising from its metabolic activities

urinary tract a series of hollow organs comprising ureters, bladder and urethra that transport urine to the outside of the body

3.6.2 Tissues in the excretory systems

Epithelial tissues

Epithelial tissue is important in the mammalian excretory system where it forms the linings of the hollow organs of the urinary tract — ureters, bladder and urethra — and the linings of various tubules within the kidney.

Linings of the hollow organs

The linings of the hollow organs are formed by **transitional epithelium**, which occurs nowhere else in the human body. All the cell layers in transitional epithelium are living cells.

The apical cells, that is, the cells that face into the lumen, have distinctive rounded outer surfaces that can be seen in light micrographs.

Transitional epithelium provides a waterproof barrier so that no component of the urine can pass out of the urinary tract into surrounding tissues, nor can anything enter. It can also expand and contract — this is particularly important in the urinary bladder that, when full, can expand to hold 400 to 600 mL. When empty the epithelial lining forms folds and the bladder shrinks.

FIGURE 3.91 High-power light micrograph of a section of the mucosa of the human bladder. The transitional epithelial tissue is underlaid by dense connective tissue. Note the rounded outer surfaces of the apical cells of the transitional epithelium.

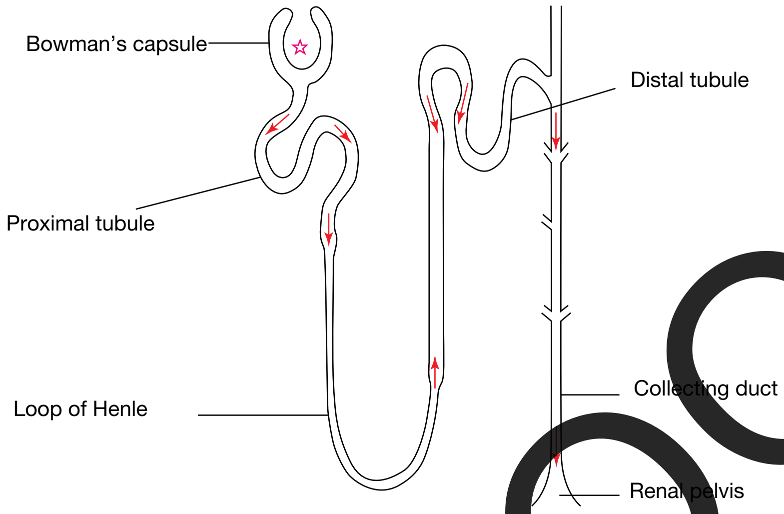
Linings of the tubules

The lining of various tubules of the kidney are composed of simple epithelial tissue. These various tubules in the kidney form part of the basic functional unit of the kidney, the **nephron**. Figure 3.92 shows these tubules and the collecting duct into which they empty. What is not shown here are the blood vessels that are intimately associated with the tubules.

transitional epithelium type of stratified epithelium present only in the hollow organs of the excretory system

nephron functional unit of the kidney

FIGURE 3.92 Line diagram showing the structures (Bowmans's capsule and tubules) that form part of the nephron. Arrows indicate the direction of movement of the filtrate through tubule. The star ✭ shows the location of the cluster of capillaries from where the process of excretion starts.



The linings of all the Bowman's capsule, kidney tubules and the collecting duct are various types of simple epithelium (single layer of cells).

- The Bowman's capsule (figure 3.93) encloses a space with an outer wall composed of simple squamous epithelium. The inner wall consists of a layer of special epithelial cells called podocytes that are closely associated with the cluster of capillaries (glomerulus) enclosed within Bowman's capsule. The simple squamous epithelium of the outer wall of the capsule is very thin, but the nuclei of some of its cells are visible (arrowed).
- Proximal tubules have a lining of simple low columnar epithelium, with each cell having a brush border of microvilli (figure 3.94).
- The loop of Henle has a lining of simple squamous epithelium, while distal tubules have a lining of simple cuboidal cells, with no brush borders.
- The lining of the collecting duct is simple cuboidal to columnar epithelium.

FIGURE 3.93 Micrograph of a cross-section of the kidney cortex. The Bowman's capsule encloses a cluster of capillaries (glomerulus). Surrounding the Bowman's capsule are cross-sections of tubules.

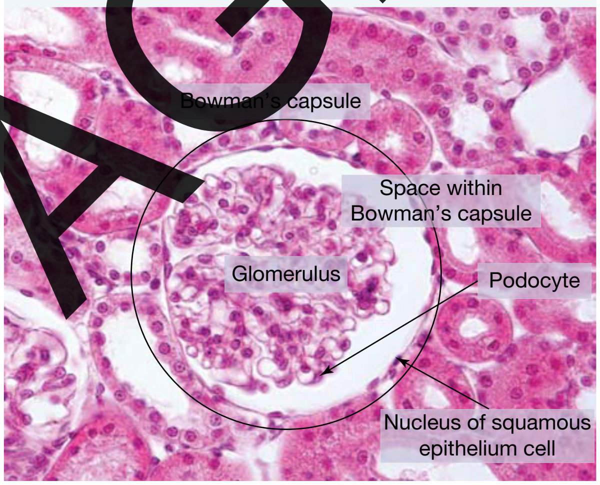
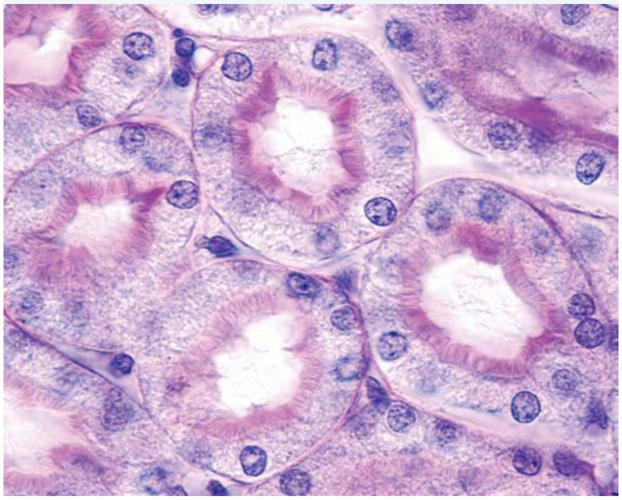


FIGURE 3.94 Micrograph of a cross-section of proximal tubules of the kidney. The specific stain used in this preparation distinguishes the brush border from the rest of the proximal tubule cells.



Connective tissue

Fibrous connective tissue is present in the hollow organs of the excretory system where it underlies and supports the transitional epithelium.

Muscle tissue

Muscle tissue is present in all the hollow organs of the urinary tract. Typically two layers are present, an inner layer of circular smooth muscle and an outer layer of longitudinal smooth muscle. Smooth muscle is not under voluntary control.

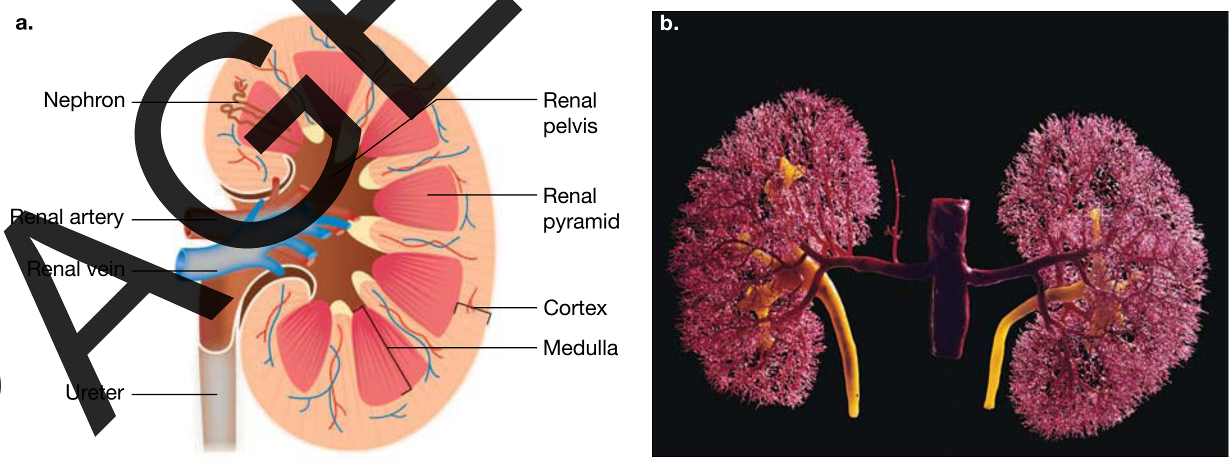
In the ureter walls, smooth muscle layers continually contract and relax in a peristaltic movement that forces urine away from the kidneys and towards the bladder. In the bladder wall, relaxation of the muscle layers enables the bladder to expand as the volume of stored urine increases. When the bladder empties, its walls contract and flatten, emptying urine into the urethra. At the junction of the bladder and the urethra are sphincter muscles, which are circular muscles that keep urine from leaking by closing tightly like a rubber band around the opening of the bladder.

3.6.3 Organs involved in the excretory system

Kidneys

All vertebrates depend on an excretory system to remove various wastes. In humans, each kidney weighs only approximately 150 grams and is about 11 centimetres long, 5 to 7.5 centimetres wide and about 2.5 centimetres thick (figure 3.95a) but they receive about 25 per cent of the blood output by the heart. This very rich blood supply highlights their importance as organs that remove wastes, and regulate the water and electrolyte balance of body fluids. The cortex is the location of Bowman's capsules and glomeruli and they give it a granulated appearance. The renal pelvis is the intersection of all the collecting ducts. Figure 3.95b shows the blood vessels within the kidney tissue, two renal arteries (purple), branching from the aorta, that supply blood to the kidney. The network of blood vessels within the kidney includes clusters of capillaries that form the glomeruli and the capillaries that surround the rest of the tubules.

FIGURE 3.95 a. The basic features of the anatomy of the human kidney **b.** A resin cast showing the rich blood supply of the kidney. The urine produced by the kidney leaves via the two ureters (yellow) and travels to the bladder.



The functional unit of the kidney is the nephron. Each kidney has a large number of nephrons — an average normal human kidney contains about 1 million nephrons. Figure 3.96a shows a simplified diagram of a kidney nephron that starts at Bowman's capsule and ends where the tubule joins the collecting duct. The blood flow from the renal artery to the renal vein is indicated.

Figure 3.96b shows a more detailed picture of a nephron. Each tubule consists of five parts: Bowman's capsule, the proximal tubule, the loop of Henle, the distal tubule and the collecting duct. In this diagram, trace the tubule from its start at Bowman's capsule to its end where it joins the collecting duct. The intimate contact between the tubule and the surrounding peritubular capillaries enables material to be moved from within the tubule to the blood, and vice versa. In both diagrams note the associated blood vessels: the cluster of capillaries of the glomerulus in Bowman's capsule and the peritubular capillaries that coil around the rest of the kidney tubule.

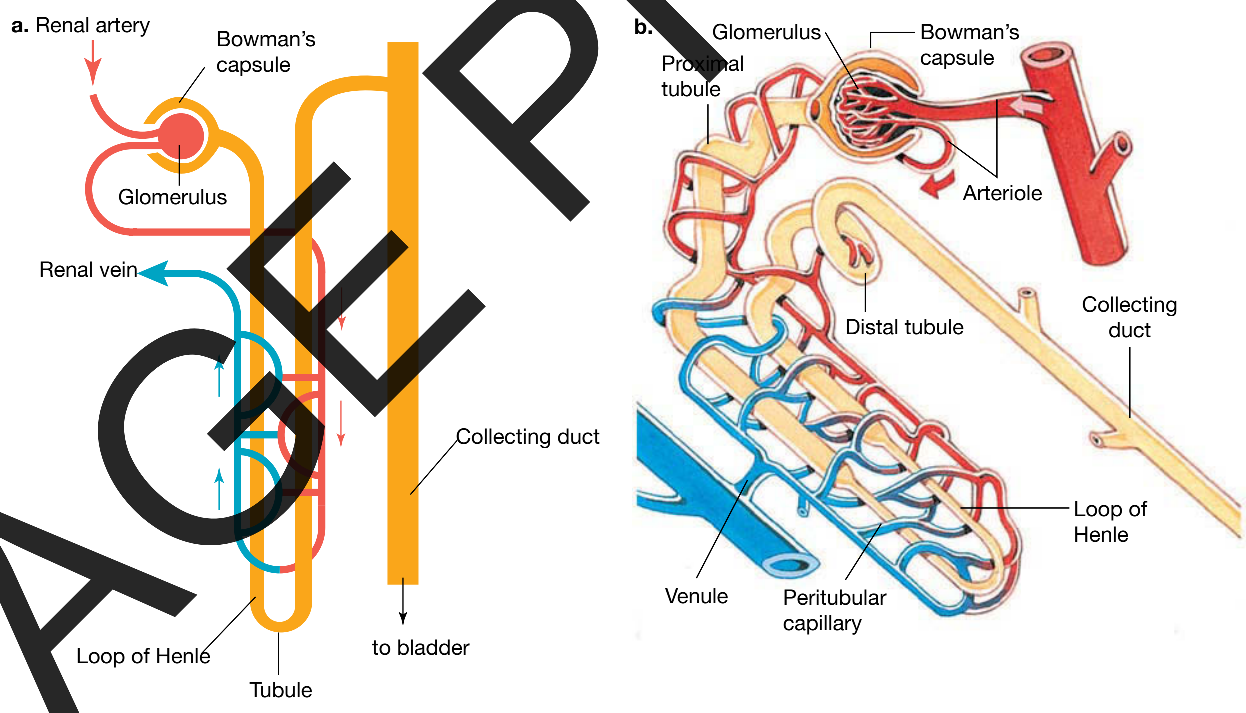
The basic functions performed by the nephrons are:

- filtration
- reabsorption
- secretion
- excretion.

It is through these processes that the kidneys:

- remove metabolic wastes from the blood to the outside while conserving useful substances (glucose and other nutrients) — this is its excretory function.
- conserve salts and water so that the balance of water and ions in the body and the pH of the blood is maintained within narrow limits — this is its osmoregulatory function.

FIGURE 3.96 a. Simplified diagram of a kidney nephron **b.** Detailed structure of a nephron



Functions of the kidney: filtration

The site of filtration is Bowman's capsule and the cluster of capillaries (glomerulus) that it encloses. Filtration is the mass movement of the fluid component of the blood from the glomerular capillaries into the space within the Bowman's capsule (see figure 3.96b).

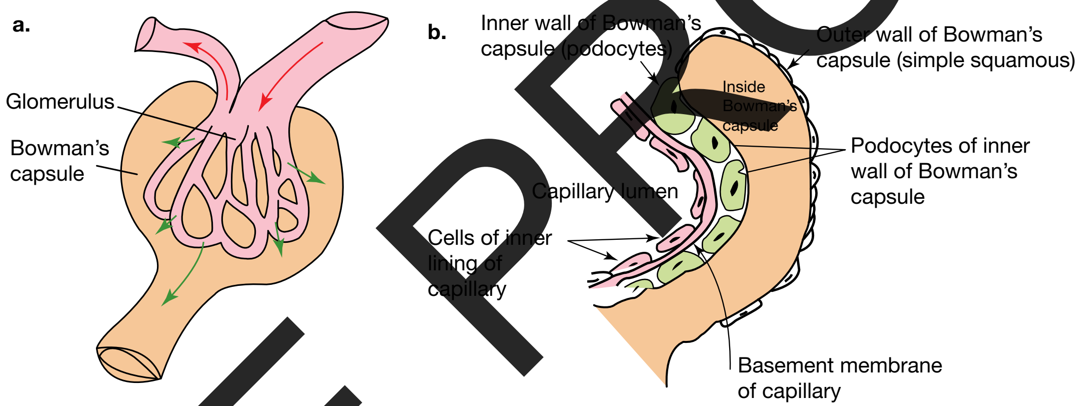
Blood cells and macromolecules (molecular weight > 60 000) cannot cross the barrier that consists of the lining of the capillary walls, the underlying basement membrane and the podocytes that surround the capillaries. The image on the opening page of this topic is a false-coloured scanning electron micrograph of some glomerular capillaries (shown in green) enveloped by podocytes with their multi-branched cytoplasmic extensions (shown in brown).

Plasma is the liquid portion of the blood, minus blood cells and large plasma proteins, and, once inside the space within the Bowman's capsule, it is called the **filtrate**. About 180 litres of plasma is filtered from the blood into the kidney each 24 hours, that is, about 125 mL of plasma per minute. Since the plasma volume of the blood is about 3 litres, this means that the entire plasma of the blood is filtered 60 times per day.

filtrate fluid composed of blood plasma minus large proteins that is filtered into Bowman's capsule from the glomerulus

The force that drives the movement of plasma into the space in the Bowman's capsule is blood pressure created in the glomerulus because the exit arteriole is smaller in diameter than the arteriole that enters glomerulus (figure 3.97a). Because filtration only stops blood cells and macromolecules from moving into the space in Bowman's capsule, this means that the filtrate contains useful molecules as well as wastes including glucose and amino acids.

FIGURE 3.97 a. The glomerular capillaries within Bowman's capsule; red arrows show blood flow, green arrows show filtrate forced from glomerulus. **b.** The close association of the inner wall of Bowman's capsule and the wall of a glomerular capillary. This is the path the plasma is filtered across.

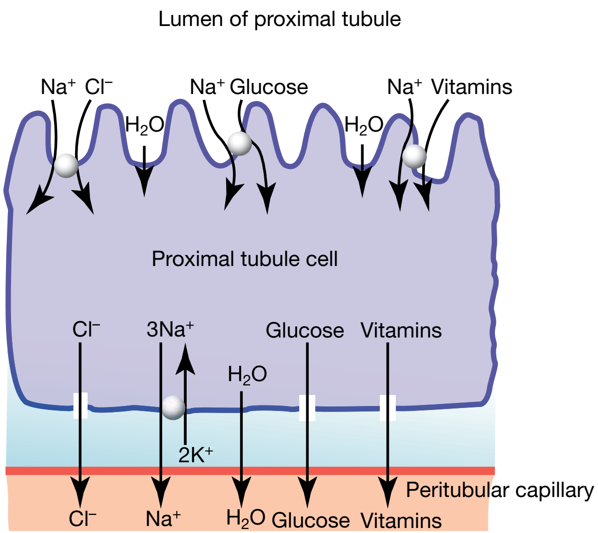


Functions of the kidney: tubular reabsorption

Reabsorption is the process by which water and useful solutes are removed from the filtrate and returned to the blood. The major site of reabsorption is the proximal tubule, with more than 70 percent of reabsorption occurring here. The brush border of microvilli increases the surface area available for reabsorption. Other segments of the tubule are involved to a lesser extent in reabsorption of water and inorganic ions.

All nutrients, such as glucose and amino acids, and most of the water and inorganic ions, such as sodium, potassium, phosphate and calcium are reabsorbed across the wall of the proximal tubule and enter the peritubular capillaries of the blood stream (figure 3.98). Reabsorption occurs by diffusion, facilitated diffusion and active transport (see topic 1).

FIGURE 3.98 Reabsorption in a proximal tubule cell. Substances are taken up from the filtrate in the tubule lumen, transferred across the tubule cell and are returned to the blood in the peritubular capillary.



Reabsorption from the proximal tubule to the blood is enhanced by the presence of microvilli on the epithelium that greatly increase the surface area available for reabsorption.

Functions of the kidney: tubular secretion

Secretion is the process of transporting specific compounds, typically waste products, out of the blood of the peritubular capillaries into the tubular filtrate that will eventually become urine. Secretion occurs mainly in the proximal tubule, but some also occurs in other regions of the tubules.

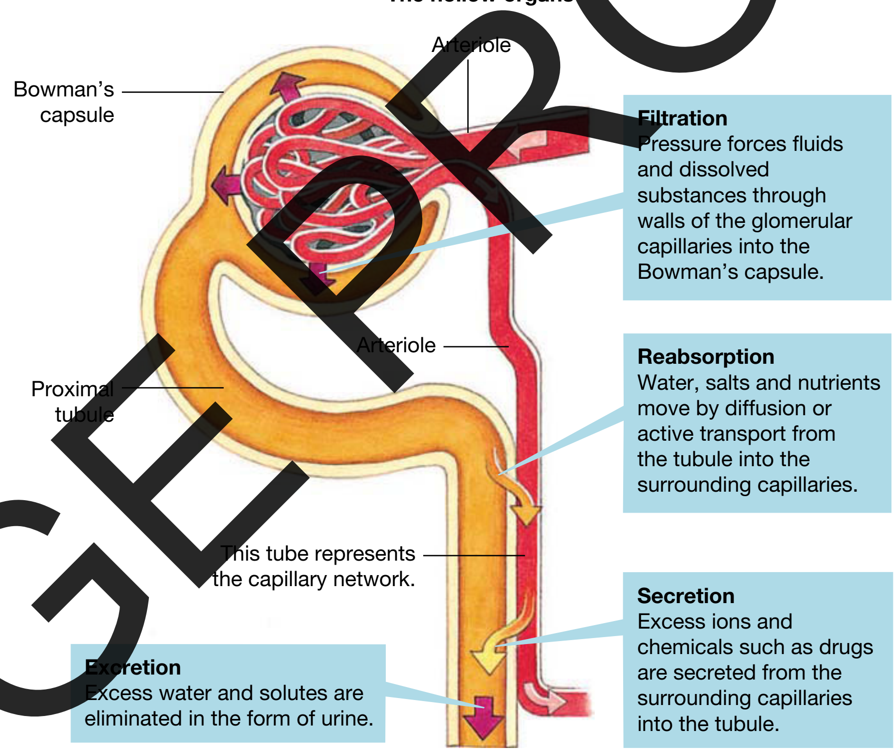
Substances secreted from the blood into the tubule filtrate include urea, potassium ions, ammonia (NH_3), creatinine, and foreign substances taken into the body, such as various pharmaceutical drugs. Secretion occurs mainly by active transport, but some also occurs by passive diffusion.

Functions of the kidney: excretion

Of the 180 litres of filtrate that enters Bowman's capsule each daily, the excretory output of the kidney of an average person on a healthy diet is only 1 to 2 litres of urine daily. Urine is a watery solution containing organic wastes: urea, uric acid, ammonia and creatinine, as well as sodium and chloride ions. Urine is transferred out of the kidneys via the collecting ducts in the ureters.

eles-2644

FIGURE 3.99 Summary of urine formation in mammals



elog-0800

INVESTIGATION 3.7 online only

Kidney dissection

Aim

To dissect a kidney and observe its structure

The hollow organs

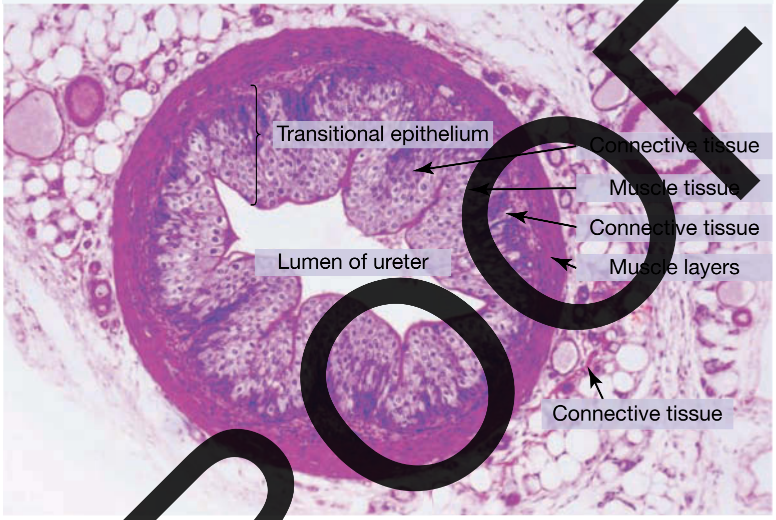
The hollow organs of the excretory system — ureters, urinary bladder and urethra — function in transporting urine from the kidney to the outside after storage in the bladder. No change in the composition of the urine occurs during its passage through the urinary tract.

Ureter

Two ureters form the first part of the urinary tract. They are tubes and their sole function is the transport of the urine made in the kidney to the bladder. Figure 3.100 shows a photomicrograph of the cross-section of the ureter of a mammal. Moving out from the central lumen, the following layers may be seen:

- the mucosa that includes a wide layer of transitional epithelium that is folded (light purple layers) of cells with prominent nuclei
- a thin layer of connective tissue that under lies the epithelium
- a layer of circular muscle, an inner longitudinal and an outer circular layer of smooth muscle (bright purple)
- on the outside, a layer of connective tissue that include fat tissue and blood vessels.

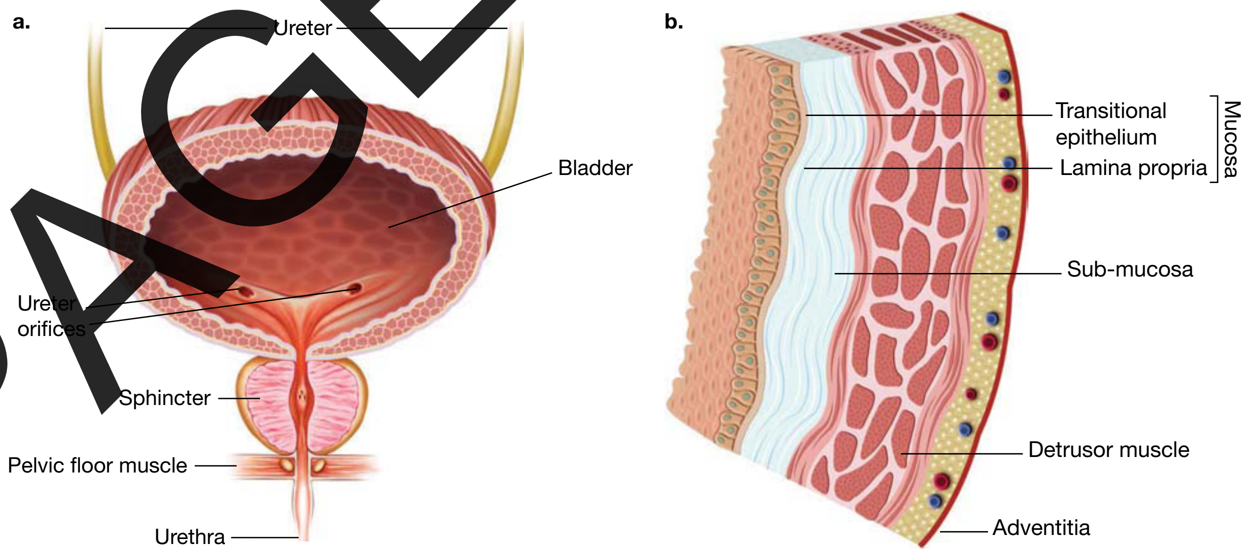
FIGURE 3.100 Low power light micrograph of a mammalian ureter



Urinary bladder

The urinary bladder is a sac-like structure that serves as a temporary storage for urine (figure 3.101a). The inner lining of the bladder is the mucosa that is composed of transitional epithelium. Below this is a thin layer of connective tissue, followed by two layers of smooth muscle, one longitudinal and the next circular (figure 3.101b).

FIGURE 3.101 a. Line diagram showing the bladder in a female **b.** The layers in the bladder wall



Urethra

The urethra is a tube that allows urine to pass outside the body. Because it passes through the penis, the urethra is longer in human males (18–20 cm) than in human females (3 cm).

Urination occurs when a signal from the brain causes the bladder muscle layer to squeeze urine from the bladder. At the same time, a signal goes to the sphincter muscles at the junction of the bladder and the urethra to relax and enable urine to flow from the bladder to the exterior.

EXTENSION: Kidney disease in humans

Kidney disease occurs in humans when the filtration rate of the kidneys falls, resulting in the kidneys becoming less efficient. While diet can help with early stage kidney disease, more advanced kidney disease requires haemodialysis. Without haemodialysis, nitrogenous wastes from the breakdown of proteins build up in the patient's blood, causing tiredness and nausea. The excess fluid in the blood causes swelling and raises blood pressure. High concentrations of sodium ions in the blood further elevate blood pressure and excess potassium ions can result in a decrease in heart muscle activity.

For more information on the results of kidney failure, and how haemodialysis works, please see the digital document.

on Resources

Digital document Extension: Kidney disease in humans (doc-35877)

FIGURE 3.102 A dialyser used to treat kidney disease

elog-0802

INVESTIGATION 3.8 online only

Modelling kidney filtration and dialysis

Aim

To model kidney filtration and investigate how the process of dialysis works

tlvd-1855

SAMPLE PROBLEM 5 Describing excretion

a. **The kidneys are a vital component in the excretory system. Identify the functional unit of the kidney. (1 mark)**

b. **Outline the four main steps involved in the production of urine. (4 marks)**

c. **Two individuals have consumed vastly different amounts of water. Explain what differences you would expect in the urine of these individuals. (2 marks)**

d. **Some species such as the kangaroo rat have structural adaptations in the loop of Henle that allow them to better survive in dry conditions and reduce water loss through urine. Identify and explain what adaptation they would likely have in regard to the loop of Henle. (2 marks)**

THINK	WRITE
a. This is an identify question, and worth only 1 mark. It requires only a simple one word answer.	Nephron (1 mark)
b. This question requires an outline of each step, which is a brief statement. You should make sure that you name each of the four steps of: • filtration • reabsorption • secretion • excretion.	The four main steps are as follows: • Filtration: the movement of the fluid component (plasma) of the blood within the from the glomerulus at the Bowman's capsule to form the filtrate (1 mark). • Reabsorption: the process in which water and useful solutes from the filtrate in the proximal tubule (1 mark). • Secretion: the secretion of waste products, excess ions and chemicals from the surrounding capillaries into the tubule (1 mark). • Excretion: The removal of excess water and solutes in the form of urine (1 mark).
c. This is an explain question. You need to provide a detailed response that describes the differences between the urine of two individuals — one who drinks less water and one who drinks more water. Urine would likely contain much more water in individuals who drink high volumes of it.	An individual who drinks large volumes of water will have more water removed from the blood during secretion and will therefore have very dilute urine (lighter in colour, lower urea concentration) (1 mark). An individual who drinks less water will have less water removed from the blood (and likely water will be reabsorbed from the proximal tubule) resulting in more concentrated and darker urine (1 mark).
d. This question requires you to identify the feature of the loop of Henle for one mark and explain the adaptation for the second mark. Remember that part of the loop of Henle is used to reabsorb water.	The loop of Henle is associated with the reabsorption of water. An animal in dry conditions would likely have a long loop of Henle (1 mark). This would allow for more water to be reabsorbed from the urine, reducing water loss, therefore allowing it to survive in drier conditions (1 mark).

on Resources

eWorkbook Worksheet 3.8 The excretory system in mammals (ewbk-7381)

3.6.4 Excretory systems in different animals

Getting rid of the nitrogenous wastes (N-wastes) produced in various metabolic reaction is a problem for animals. The means by which animals excrete N-waste and the form in which it is excreted — ammonia, urea or uric acid — reflect an animal's evolutionary history, its body plan structure and its habitat. All vertebrates have kidneys similar to those of mammals. Let's now consider excretory systems in invertebrate animals.

Excretory systems in invertebrates

Ammonia (NH_3) is the initial N-waste produced from the breakdown of protein and other N-containing compounds, such as nucleic acids. Some animals excrete their N-wastes in the form of ammonia. Ammonia can be converted into urea (NH_2CONH_2) or uric acid ($C_5H_4N_4O_3$) but these conversions require an investment of energy. Many animals carry out these conversions and excrete their N-wastes as either urea or as uric acid. Why not save energy and excrete ammonia? See the Extension box below for a clue.

Diffusion of ammonia

Diffusion of ammonia is the least complicated means of excreting N-wastes. This does not require any specialised tissues or organs — all that is needed is lots of water to dilute the ammonia and carry it away. However, diffusion of any substance across cells or tissues can only operate over short distances, and when a high surface area to volume ratio exists.

A few animal groups can excrete ammonia by diffusion, and they are the sponges of phylum *Porifera* and all members of phylum *Cnidaria* that includes jellyfish, corals, and sea anemones (see section 3.3.2). Neither of these animal groups has distinct excretory cells or tissues.

Sponges, the least complex animals, have a two-layered body structure — this means that no sponge cell is far from the external environment. N-wastes in the form of ammonia simply diffuse across the cell surfaces of the sponge into the external environment, which is, for almost all sponges, the sea.

Jellyfish and other members of the phylum *Cnidaria* with their two-layered body structure also rely on diffusion of ammonia for excretion of their N-wastes into their marine environment.

FIGURE 3.103 The simple two-layered body structure of jellyfish relies upon ammonia diffusion for excretion.

As the body size of animals increases, diffusion becomes inefficient. In more complex multicellular animals with a three-layer body structure, most of their cells are too far removed from the external environment for these animals to rely on diffusion as an excretory mechanism. These multicellular animals have special tissues and organs that enable them to collect and excrete N-wastes efficiently and rapidly as ammonia, urea or uric acid. The first animal group with excretory organs are the flatworms (planarians) and the other members of phylum *Platyhelminthes*. Other groups of invertebrates developed different systems for excreting N-wastes but they include similar features such as tubules and cells with cilia.

EXTENSION: Forms of N-wastes

Nitrogenous wastes (N-wastes) are a by-product mainly of the metabolism of proteins. Some animals can excrete their N-waste as ammonia. Others convert ammonia to urea, yet other animals convert ammonia to uric acid. Both of these conversions are energy-requiring reactions. Why use this energy?

To access more information on this extension concept please download the digital document.

on Resources

Digital document Extension: Forms of N-wastes (doc-35880)

FIGURE 3.104 A colony of cormorants (*Phalacrocorax aristotelis*). The extensive white areas are the uric acid droppings of these birds.

CASE STUDY: Flame cells of planarians

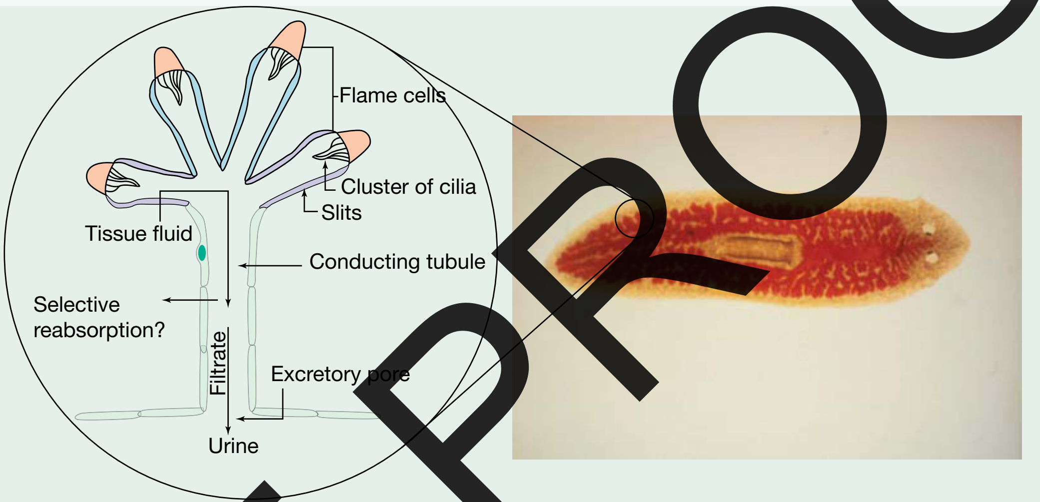
Planarians are free-living flatworms that live in fresh water. Their ancestors were the first animals to have an excretory system.

The planarian excretory system consists of a large number of units (protonephridia), each containing excretory cells called **flame cells** and connecting tubules that join to a main excretory canal that opens to the exterior through excretory pores. Two excretory canals are located on either side of the planarian (figure 3.105).

The flame cells are cup-shaped and have long strands of cilia on their inner surface. When viewed with a microscope the moving cilia look like a flickering flame, and hence the cells are called flame cells.

Beating of the cilia draws tissue fluid into the flame cells where water and waste materials are removed through filtration. The beating cilia then drives waste matter into the excretory tubules that terminate at excretory pores where wastes pass to the outside. The pores open at the body surface along both sides of the flatworm's body.

FIGURE 3.105 Dugesia planarian are one of the simplest animals to have an excretory system. Inset shows a stylised representation of one unit of their excretory system.



CASE STUDY: Malpighian tubules of insects

The Malpighian tubule system is the excretory system present in insects, and also in millipedes, centipedes, spiders and scorpions.

The Malpighian excretory system consists of a number of thin blind-ending tubules (Malphighian tubules) located in the abdomen of the insect. They are bathed in **hemolymph** of the insect.

The open ends of the tubules join the digestive system at the junction between the midgut and the hindgut.

The tubules are lined with a single layer of epithelial cells. The number of tubules varies between species and range from a few to more than 100. Tubule cells remove N-wastes in the form of uric acid and other solutes from the hemolymph.

flame cells excretory cells with flagella present in members of phylum *Platyhelminthes*

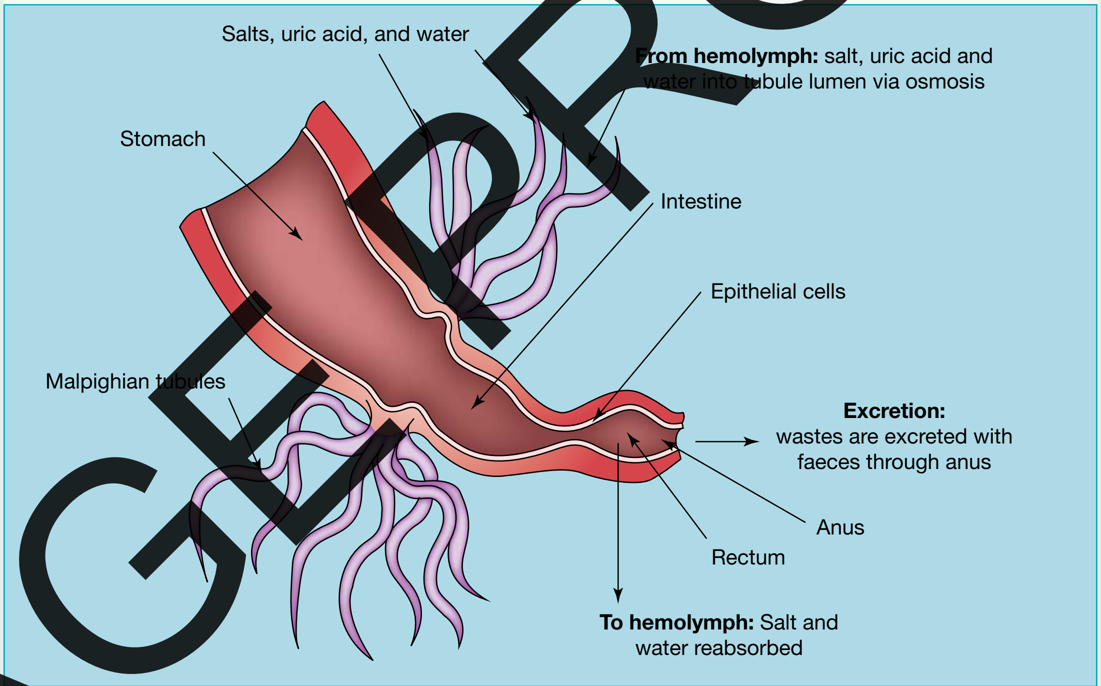
hemolymph the internal fluid of insects, analogous to blood in vertebrates; mostly water; it also contains ions, carbohydrates, lipids, glycerol, amino acids, hormones and some cells.

Urine is formed by a process of secretion. In this process, tubule cells secrete Na^+ ions into the fluid of the lumen of the tubule by active transport and this inflow of ions increases the osmotic concentration of the enclosed fluid. This change causes water, uric acid and other solutes to flow into the tubule lumen, forming urine. In contrast, in the mammalian kidney, fluid enters the nephron by a process of filtration.

The urine passes from the Malpighian tubules into the rectum of the hindgut where water and ions are reabsorbed while the almost solid uric acid is expelled along with faeces. Water is reabsorbed to a level to maintain the organism's water balance. However, larvae of some insect species are aquatic, such as mosquito larvae ('wrigglers'), and they reabsorb useful solutes in the hindgut, but do not need to reabsorb water.

FIGURE 3.106 SEM image of a mosquito (*Anopheles* sp.) midgut (at centre) and, immediately behind it, the five Malpighian tubules. Together these form the excretory system of this insect.

FIGURE 3.107 A diagrammatic representation of the excretory system in insects and other animals. In these animals, excretion also involves action by the digestive system.



CASE STUDY: Nephridia of the earthworm

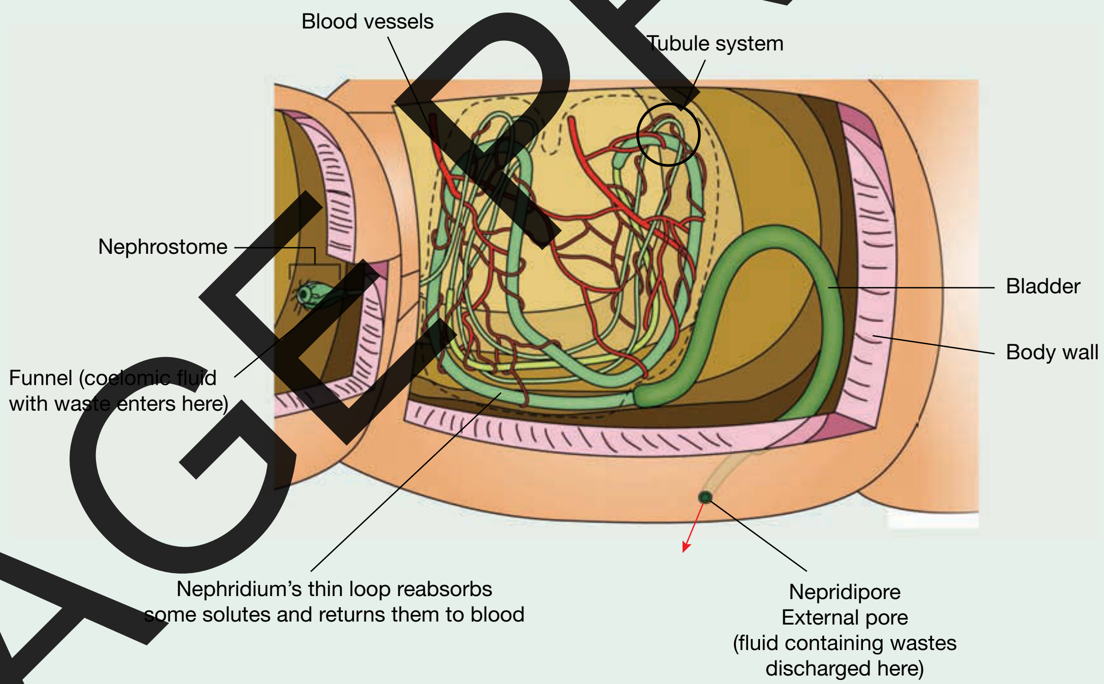
The common earthworm (*Lumbricus terrestris*) is a segmented worm belonging to the phylum *Annelida* that also includes polychaete worms and leeches. The main form in which N-waste excreted by earthworms is urea. The unit of excretion is the nephridium and each segment of the earthworm, except for the first two, has a pair of nephridia.

In the process of excretion (see figure 3.107):

1. Body fluid with wastes from one segment is taken into a ciliated funnel (nephrostome) by the beating of its cilia, from where the fluid enters a long narrow ciliated tube
2. Fluid is carried in this tube through the dividing wall into the next segment where the tube forms a series of loops.
3. The loops of the tube are enveloped in blood capillaries and more wastes are transferred from the blood into the tube.
4. Useful substances, including water, glucose, amino acids and salts, are reabsorbed from the fluid in the tube and returned to the blood.
5. The residual fluid containing the N-wastes passes into a thick portion of the tube that forms a bladder-like sac.
6. From the sac, the excretory wastes are released through a pore on the worm's side that opens to the outside.

FIGURE 3.108 The common earthworm *(Lumbricus terrestris)*

FIGURE 3.109 Segments of the body of a common earthworm and its excretory organ, the nephridium



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eWorkbook Worksheet 3.9 Excretion in other animals (ewbk-7383)

Weblink Keeping kidneys healthy

KEY IDEAS

- In unicellular microbes, protists and the simplest animals, wastes are removed by a process of simple diffusion across the plasma membrane.
- Animals with complex multicellular structures use specialised tissues, organs and systems for waste removal.
- In mammals, the excretory system is responsible for removing metabolic and other wastes from the blood and plays a role in water balance.
- N-wastes include:
  - ammonia and urea from the metabolism of protein
  - guanine from the breakdown of nucleic acids
  - creatine and creatinine from the metabolic activities of skeletal muscle.
- In vertebrates, the excretory (urinary) system is the kidneys and urinary tract.
- The urinary tract comprises the ureters, urinary bladder and urethra.
- Tissues in the excretory system include:
  - epithelial tissue in the linings of the hollow organs of the urinary tract and in the various tubules within the kidney
  - connective tissue
  - muscle tissue.
- Organs of the excretory system include the kidneys and the hollow organs of the ureters, urinary bladder and urethra.
- The main organ is the kidney; the functional unit of the kidney is the nephron.
- The functions of the nephron are filtration, reabsorption, secretion and excretion.
- Diffusion of ammonia is the simplest way to get rid of N-wastes. It does not require specialised organs but is limited by availability of water and animal size.
- End stage kidney disease is a serious and life-threatening condition.
- Haemodialysis is a medical intervention that can replace some of the defective kidney functions.
- The planarian excretory system relies on flame cells and excretory canals.
- The Malpighian excretory system in insects consists of thin blind-ending tubules which remove uric acid and solutes from the hemolymph; urine is formed by changes on osmotic pressure, and is then excreted with other wastes.
- Earthworms excrete N-wastes using the nephridia, which absorb useful substances into the body. The residual fluids are excreted.
- N-wastes may be excreted as ammonia, urea or uric acid that differ in their solubility, toxicity and energy cost of production.
- Aquatic invertebrates, bony fish and amphibian larvae excrete their N-wastes as ammonia.
- Birds, reptiles and some terrestrial invertebrates, including insects and spiders, excrete their N-waste as uric acid.

3.6 Activities

learnon

To answer questions online and to receive **immediate feedback** and **sample responses** for every question, go to your learnON title at **www.jacplus.com.au**. A **downloadable solutions** file is also available in the resources tab.

3.6 Quick quiz on	3.6 Exercise	3.6 Exam questions

3.6 Exercise

1. a. Identify the key organs of the mammalian excretory system.
   b. What is the functional unit of the kidney?
2. In the human kidney:
   a. What produces the pressure that forces filtrate from the glomerulus into the space within Bowman's capsule?
   b. What type of tissue lines:
      i. the proximal tubules of the kidney
      ii. the urethra of the urinary tract?

3. Identify the key difference between the members of the following pairs.
   a. Secretion and reabsorption
   b. Filtrate and urine
4. Think about the passage of filtrate through the kidney tubules and that of urine through the urinary tract. Does either the filtrate or the urine undergo a change in composition as it moves along its particular route? Briefly justify your decisions.
5. Explain the following observations:
   a. The tubular filtrate in a healthy kidney contains no red blood cells.
   b. Healthy people have glucose in their blood, but no glucose in their urine.
6. Identify two sources of nitrogenous waste in mammals.
7. By what means to the following animals excrete their nitrogenous and other wastes?
   a. Jellyfish of phylum *Cnidaria*
   b. Flatworms of phylum *Platyhelminthes*
   c. Insects of phylum *Arthropoda*
   d. Earthworms of phylum *Annelia*
8. Jellyfish and all other members of the phylum *Cnidaria* excrete their nitrogenous waste in the form of ammonia. Is it reasonable to predict that the next species in that phylum to be discovered might excrete its waste as uric acid rather than ammonia?

3.6 Exam questions

Question 1 (1 mark)

MC A major role of the kidneys is

A. the removal of carbon dioxide.
B. maintaining blood glucose levels.
C. eliminating nitrogenous wastes.
D. balancing fat-soluble vitamin blood levels.

Question 2 (1 mark)

MC Antidiuretic hormone (ADH) acts by increasing the reabsorption of water from the collecting duct.
In the presence of ADH, what would be expected?

A. Urine would contain more glucose.
B. Urine would be more diluted.
C. Urine production would cease.
D. Urine solutes would be more concentrated.

Question 3 (1 mark)

MC Which of the following molecules would not be found in the filtrate of a nephron?

A. Urea
B. Glucose
C. Amino acids
D. Large plasma proteins

Question 4 (2 marks)

Inflammation of the glomeruli in the kidneys can lead to the presence of blood proteins and blood cells in the urine. Explain why blood protein and blood cells are not normally found in urine.

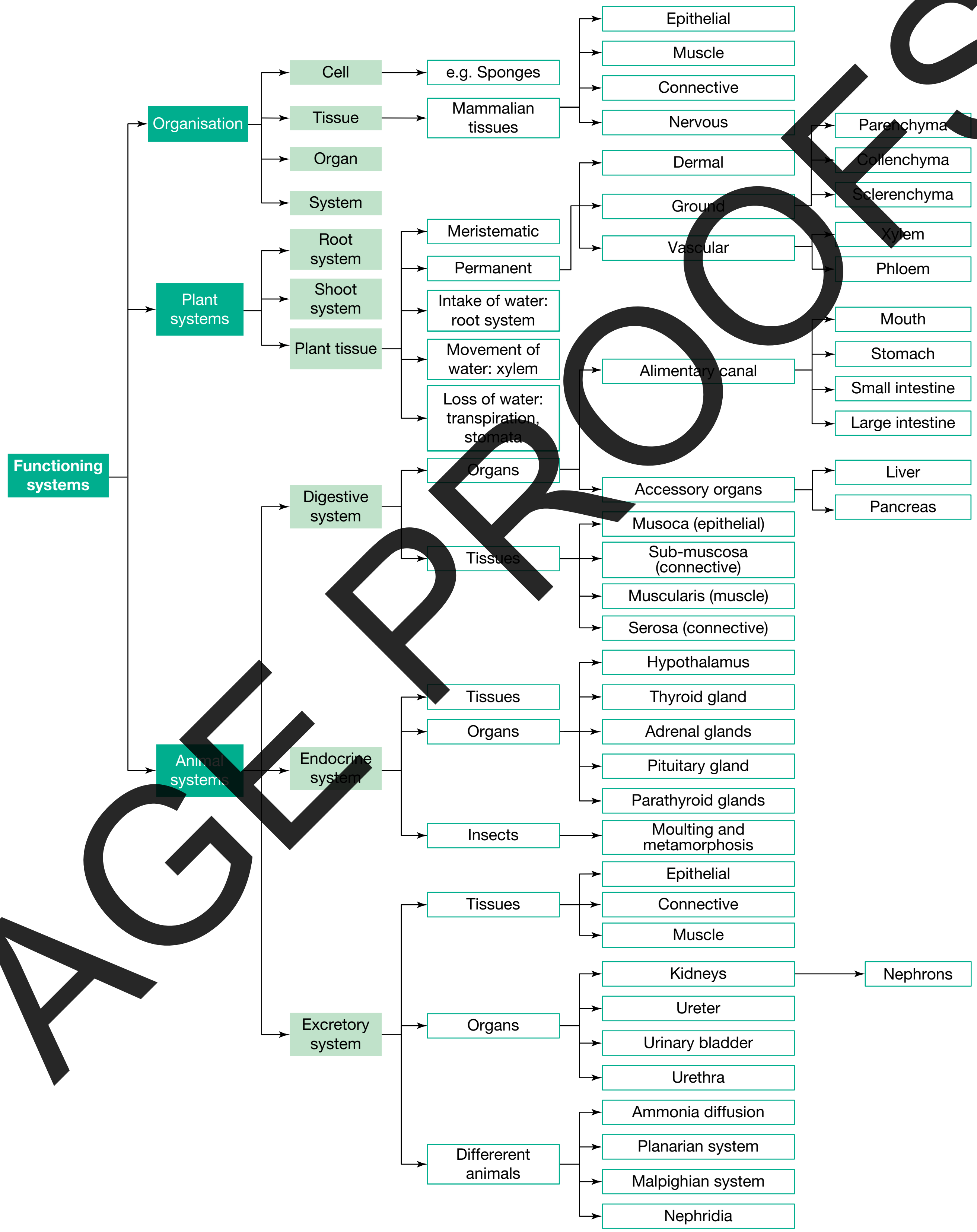
Question 5 (2 marks)

Proximal tubule cells lining the beginning of a renal nephron in the kidneys have a folded plasma membrane and contain many mitochondria. Explain the significance of each of these structures.

More exam questions are available in your learnON title.

3.7 Review

3.7.1 Topic summary



on Resources

eWorkbook	Worksheet 3.10 Reflection — Topic 3 (ewbk-7387)
Practical investigation eLogbook	Practical investigation eLogbook — Topic 3 (elog-0160)
Digital documents	Key terms glossary— Topic 3 (doc-34651) Key ideas summary — Topic 3 (doc-34662)

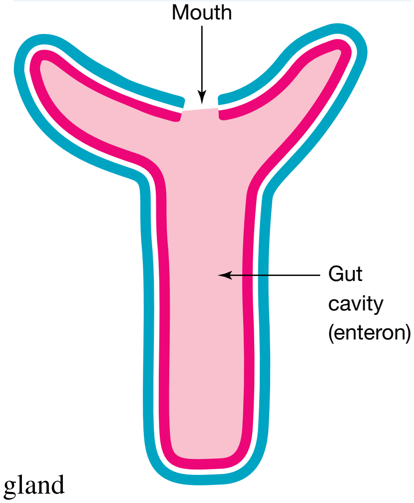
3.7 Exercises

To answer questions online and to receive **immediate feedback** and **sample responses** for every question go to your learnON title at **www.jacplus.com.au**. A **downloadable solutions** file is also available in the resources tab.

3.7 Exercise 1: Review questions

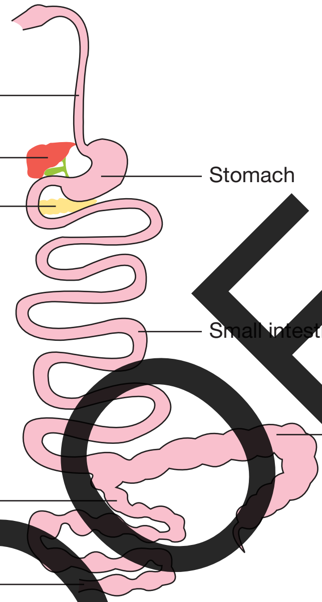
1. Comment on or briefly explain the following observations.
   a. The release of a hormone from the anterior pituitary gland in response to a stimulus detected in the brain occurs more slowly than the release of a hormone from the posterior pituitary gland.
   b. Only very few animals can excrete ammonia by simple diffusion.
   c. Of the 180 litres of filtrate that enters Bowman's capsule every day, the excretory output of the kidney of an average person eating a healthy diet is only 1 to 2 litres each day.
2. Comment on, or briefly explain, the following observations:
   a. When a plant is transplanted, root hairs are often damaged, so before transplanting a gardener usually removes many of the leaves.
   b. When florists shorten the stems of a bunch of flowers, they take care to cut each stem under water and not in the air.
3. Consider a tiny living organism, known as a hydra — just visible to the unaided eye — that lives in freshwater. The figure shows a diagram of its body plan: it has a two-layer body wall separated by mesoglea. Several different cell types are present in this organism including cells with flagella that line the gut cavity and several kinds of stinging cells (cnidocytes) with a mini-harpoon that fires, penetrating and paralysing the prey on which this organism feeds.
   a. What kind of organism is a hydra?
   b. On what information did you base your decision?
   c. Does a hydra show evidence of cell specialisation?
   d. What is the mesoglea?
   e. Would you predict that organs are present in a hydra? Explain.
   f. What level of organisation does a hydra show (cellular, tissue, organ or system)?

FIGURE Simplified body plan of a hydra with its two main cell layers: an outer ectoderm and an inner endoderm



4. What is a key difference between members of the following pairs?
   a. Cohesion and adhesion of water molecules
   b. Parenchyma and sclerenchyma tissues in vascular plants
   c. Calcitonin and calcitriol
   d. Tissue of the anterior pituitary gland and that of the posterior pituitary gland
   e. Follicular cells and parafollicular cells of the thyroid gland
   f. A releasing hormone and a stimulating hormone

5. The figure shows the alimentary canal of a mammal.
   a. Based on this diagram, what conclusion might reasonably be drawn about the preferred diet of this mammal. Explain your choice.
   b. Suggest two features (either presence or absence) that might be expected to be seen in the teeth of this mammal. Explain your decision.
6. Identify two key differences between ammonia and uric acid and relate them to the types of animal that have ammonia as their excretory product and those that have uric acid.



3.7 Exercise 2: Exam questions

on Resources

Teacher-led videos Teacher-led videos for every exam question

Section A — Multiple choice questions

All correct answers are worth 1 mark each; an incorrect answer is worth 0.

Question 1

An example of permanent tissue in plants is

A. collenchyma tissue.
B. xylem tissue.
C. dermal tissue.
D. sclerenchyma tissue.

Question 2

The internal lining of the oesophagus and the anal canal is composed of

A. simple squamous epithelial cells.
B. stratified columnar epithelial cells.
C. stratified squamous epithelial cells.
D. multi-layered transitional epithelial cells.

Question 3

Processes that occur during formation of urine by the mammalian kidney include

A. blood from the glomerular capillaries enters Bowman's capsule and becomes the tubular filtrate.
B. reabsorption of water and useful solutes occurs mainly in the proximal tubules.
C. secretion of drugs into the collecting ducts.
D. about half the filtrate that enters Bowman's capsule is finally excreted as urine.

Question 4

Which of the following events take place in the human digestive system?

A. Protein digestion is completed in the stomach; digestion of fats and carbohydrates occurs later in other regions.
B. The digestive enzyme trypsin is release by acinar cells of the pancreas.
C. Secretion of hydrochloric acid by the pancreas provides the optimal pH for enzymes that act in the duodenum.
D. End products of fat digestion are carried from the alimentary canal in lacteals.

Question 5

A calcium-sensing receptor in the parathyroid gland detects a fall in the calcium concentration in the blood. This would likely lead to

A. the release of calcitonin from the parathyroid gland.
B. a signal being sent to the adrenal glands to stimulate the release of cortisol.
C. the inactivation of the T3 and T4 hormones.
D. the release of the parathyroid hormone (PTH) from the parathyroid gland.

Question 6

In vascular plants, identify the best description of the parenchyma tissue.

A. It forms the bulk of the cells in xylem tissue.
B. It is composed of living cells with thickened cell walls.
C. It acts as a major storage site for starch in roots and stems.
D. Its primary function is as support and protection in leaves.

Question 7

Identify the generation of the major force that pulls water up the xylem tissue.

A. The loss of water by transpiration in the leaves
B. The closing of the stomata of the leaves
C. The pressure by soil particles on the root hairs
D. The lateral movement of water through pits in the walls of xylem vessels

Question 8

All animals are multicellular, but various animals show different levels of organisation of their cells. It is reasonable to state that

A. animals at the cellular level of organisation could have tissues but not organs.
B. animals at the organ level of organisation include members of the phylum *Cnidaria.*
C. animals at the system level of organisation would be expected to have organs and tissues.
D. animals at the cellular level of organisation include flatworms of phylum *Platyhelminthes.*

Question 9

Enzymes involves in digestion include

A. amylases that are secreted by the salivary glands and the stomach chief cells.
B. maltase that is embedded in the microvilli of enterocytes of the small intestine.
C. pepsin that is secreted as a proenzyme pepsinogen by the pancreas into the duodenum.
D. lipases that are secreted by the liver and pancreas.

Question 10

As occurs in vertebrates, excretion in invertebrate animals is also concerned with the removal of waste products from within their cells. It is reasonable to state that

A. all invertebrates excrete their nitrogenous waste as ammonia.
B. flame cells are the functional excretory cells in flatworms.
C. the Malpighian tubules of insects open directly to the external environment.
D. the nephridia of earthworms lack the ability to secrete substances.

SECTION B — Short answer questions

Question 11 (10 marks)

a. Identify the first two enzymes to which ingested food is exposed. **2 marks**
b. After being swallowed, food travels to the stomach.
  i. Descibe the mechanism how food moved. **1 mark**
  ii. Identify the organ and kind of tissue involved in bringing about this movement of food to the stomach. **2 marks**
c. Describe the difference between a foregut fermenter and a hind gut fermenter. **2 marks**
d. Identify one principal site of protein digestion in the alimentary canal. **1 mark**
e. Suggest, giving a reason, which amylase enzyme — from the salivary glands or the pancreas — would be expected to be more effective in digesting carbohydrates? **2 marks**

Question 12 (8 marks)

a. Consider the structure of the wall of the digestive tract.
  i. Identify the four layers, starting from the gut lumen, that are typically visible in a cross-section of the digestive tract. **2 marks**
  ii. Identify the specific type of tissue that is present in the layer in immediate contact with the gut contents. **2 marks**
  iii. List the two major functions that are served by this type of tissue in the small intestine. **2 marks**
b. Identify a structural feature of the lining of the small intestine that contributes to or facilitates its function. **1 mark**
c. Explain why protease digestive enzymes are released into the gut as inactive proenzymes. **1 mark**

Question 13 (13 marks)

a. Identify two key functions of the excretory system. **2 marks**
b. What is the functional unit of the mammalian kidney? **1 mark**
c. Briefly describe the process by which the kidney filtrate is formed. **2 marks**
d. **i.** What is the key difference between the tubular processes of reabsorption and secretion? **2 marks**
  ii. Explain why the process is termed *reabsorption* rather than *absorption*? **1 mark**
e. Briefly describe the structure of the lining of the proximal tubules that are in contact with the filtrate and link this structure of its function. **2 marks**
f. Identify the excretory organ of insects, their major excretory product and the means by which it is formed. **3 marks**

Question 14 (10 marks)

a. In addition to secreting hormones, what is a distinctive feature of the endocrine glands? **1 mark**

b. What kind of tissue forms the bulk of the endocrine glands? **1 mark**

c. You examine a light microscope view of an endocrine gland that has been stained with standard hematoxylin and eosin stain (H&E). You are told that it is a cross-section of either the thyroid gland or the anterior pituitary gland. For each possibility, identify two distinguishing features that you would expect to see that would allow you to identify the gland. **4 marks**

d. Identify the change in the body (or the stimulus) that would lead the release of the following hormones:

i. The thyroid hormones T3 and T4 **1 mark**

ii. Parathyroid hormone (PTH) **1 mark**

e. Identify and provide an example of a way in which the production of a hormone by an endocrine gland can be blocked. **2 marks**

Question 15 (9 marks)

a. The blood (plasma) concentration of calcium is regulated and in a healthy person is maintained within a narrow range.

i. Which hormones are involved in maintaining calcium levels of the blood within normal limits? **2 marks**

ii. For each hormone, identify one target tissue and one action on this tissue. **4 marks**

b. Alcohol consumption interferes with the normal secretion of antidiuretic hormone (ADH) by inhibiting its release.

i. Identify the gland that releases ADH. **1 mark**

ii. ADH acts on the kidneys, increasing water reabsorption from the collecting tubules back into the blood. Explain how alcohol consumption would affect the volume of urine. **2 marks**

3.7 Exercise 3: Biochallenge online only

on Resources

eWorkbook Biochallenge — Topic 3 (ewbk-8073)

Solutions Solutions — Topic 3 (sol-0648)

teachon

Test maker

Create unique tests and exams from our extensive range of questions, including practice exam questions.
Access the assignments section in learnON to begin creating and assigning assessments to students.

Online Resources

onResources

Below is a full list of **rich resources** available online for this topic. These resources are designed to bring ideas to life, to promote deep and lasting learning and to support the different learning needs of each individual.

eWorkbook

- 3.1 eWorkbook— Topic 3 (ewbk-3158)
- 3.2 Worksheet 3.1 Systems, organs and tissues in plants (ewbk-3486)
- 3.3 Worksheet 3.2 Systems, organs and tissues in animals (ewbk-3488)
- 3.4 Worksheet 3.3 Structure and function of the digestive system (ewbk-3490)
  - Worksheet 3.4 The ins and outs of digestion (ewbk-3492)
  - Worksheet 3.5 Different digestive systems in animals (ewbk-3494)
- 3.5 Worksheet 3.6 The human endocrine system (ewbk-3496)
  - Worksheet 3.7 Endocrine system in other animals (ewbk-7379)
- 3.6 Worksheet 3.8 The excretory system in mammals (ewbk-7381)
  - Worksheet 3.9 Excretion in other animals (ewbk-7383)
- 3.7 Worksheet 3.10 Reflection — Topic 3 (ewbk-7387)
  - Biochallenge — Topic 3 (ewbk-8073)

Solutions

- 3.7 Solutions — Topic 3 (sol-0648)

Practical investigation eLogbook

- 3.1 Practical investigation eLogbook — Topic 3 (elog-0160)
- 3.2 Investigation 3.1 A closer look at vascular tissue (elog-0254)
  - Investigation 3.2 Root hairs (elog-0256)
  - Investigation 3.3 Leaf epidermal layer (elog-0258)
  - Investigation 3.4 Water movement in the plant (elog-0260)
- 3.4 Investigation 3.5 Digestive systems (elog-0796)
- 3.5 Investigation 3.6 Observing the life cycle of a butterfly (elog-0798)
- 3.6 Investigation 3.7 Kidney dissection (elog-0800)
  - Investigation 3.8 Modelling kidney filtration and dialysis (elog-0802)

Digital documents

- 3.1 Key science skills — VCE Biology Units 1–4 (doc-34648)
  - Key terms glossary — Topic 3 (doc-34651)
  - Key ideas summary — Topic 3 (doc-34662)
- 3.2 Extension: Growing plants without soil (doc-35878)
- 3.5 Extension: Hormones in the digestive system — without a gland (doc-35879)
- 3.6 Extension: Kidney disease in humans (doc-35877)
  - Extension: Forms of N-wastes (doc-35880)

Teacher-led videos

- Exam practice questions — Topic 3
- 3.2 Sample problem 1 Comparing and contrasting tracheids and vessels (tlvd-1850)
- 3.3 Sample problem 2 Tissue types in mammals (tlvd-1851)
- 3.4 Sample problem 3 Comparing digestive systems (tlvd-1852)
- 3.5 Sample problem 4 Explaining the role of iodine (tlvd-1853)
- 3.6 Sample problem 5 Describing excretion (tlvd-1855)

Video eLesson

- 3.4 Digestive system (eles-2643)
- 3.6 Urine formation in the kidney (eles-2644)

Interactivities

- 3.4 Digestive system (int-3080)
  - The digestive system (int-3398)
- 3.5 Endocrine glands (int-5766)
- 3.6 Labelling the kidneys (int-8234)

Weblinks

- 3.4 Health conditions of the digestive system
- 3.5 What is endocrinology?
- 3.6 Keeping kidneys healthy

Teacher resources

There are many resources available exclusively for teachers online.

To access these online resources, log on to **www.jacplus.com.au**.