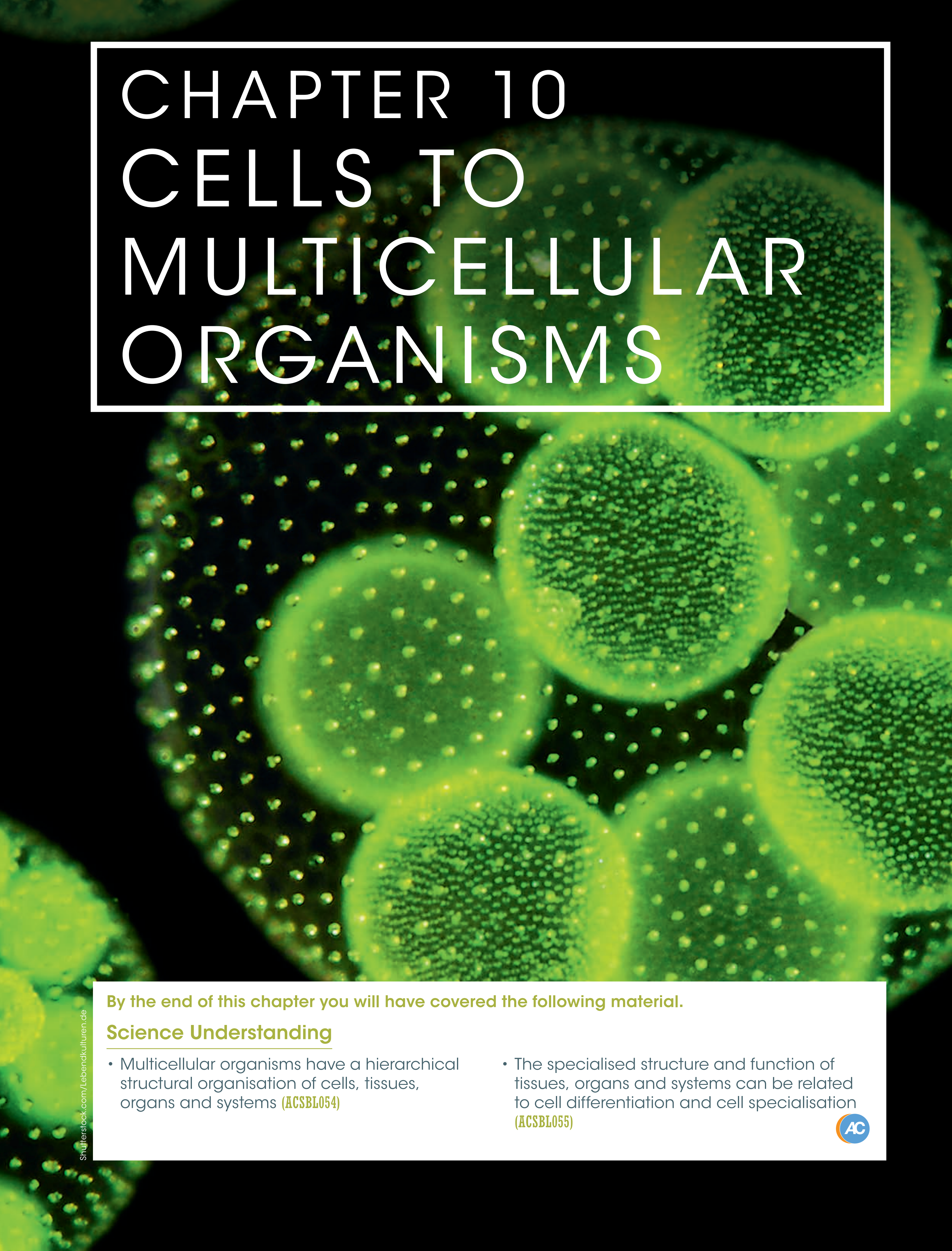
CHAPTER 10 CELLS TO MULTICELLULAR ORGANISMS



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By the end of this chapter you will have covered the following material.

Science Understanding

- Multicellular organisms have a hierarchical structural organisation of cells, tissues, organs and systems (ACSBL054)
- The specialised structure and function of tissues, organs and systems can be related to cell differentiation and cell specialisation (ACSBL055)

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Figure 10.1 ▶ Spirals and chambers in this nautilus shell can be seen as patterns elsewhere in life.

Have you noticed patterns in the world around you? What about the 'world' inside you? How simple or complex are these patterns? Are there reasons for these patterns? If you were to look very carefully at the patterns of life, you would see that they all share some similarities. Some of these patterns are related to their shape and size. Other patterns can be found within the internal structures they possess.

Not only can there be patterns in the structures of organisms, but there can also be patterns in what they do and how they do it. Some of the reasons for the patterns in structures are so that they can function more effectively. By functioning more effectively, the cell or organism may have an increased chance of surviving. The organism may even be able to survive long enough to reproduce and pass on its genetic material to the next generation.

What about these patterns of life within you? How are they similar to other living things? Why are they similar? Patterns of both structure and function can be used to provide a framework of how we perceive the world around us. These patterns can also help us to appreciate the history of life, and to understand how life exists and what we have in common with other organisms on our planet.

Increasing complexity: from unicellular to multicellular

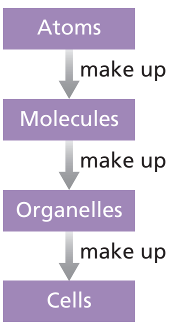


Figure 10.2 ▲ Hierarchy of atoms to cells

See Chapter 7 for detail on the structure of cells.

When observing the structural features of living things, you can get hints of what their function may be. Throughout this chapter take special note of any patterns that you recognise and try to relate these patterns to specific functions of the organism.

Cells are organised in a hierarchy of structural levels. All matter is composed of **atoms** that can be organised into complex biological molecules. These molecules can be organised into the **organelles** found in **cells**.

Aside from the number of cells that make up organisms, there are also patterns in the basic structural organisation of cells. These patterns are used to classify cells as either **prokaryotic** or **eukaryotic**.

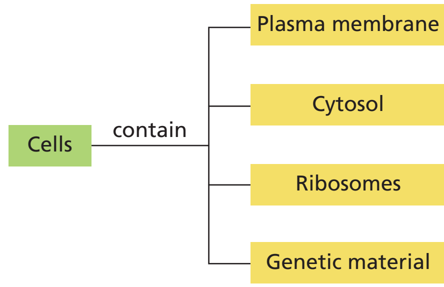
While there can be structural differences between cells, they all share a similar overall pattern. All cells possess a **plasma membrane**, which encloses a semi-fluid substance called the **cytosol**. Cells also contain genetic material and ribosomes.

Although all living things are made of cells, they can vary in their shape, size, structural complexity and their organisation. Organisms that are made up of a single cell are referred to as being **unicellular** and those made up of many cells as being **multicellular**. The early forms of life on our planet were most likely unicellular. Multicellular organisms arrived comparatively recently in our evolutionary history.

Unicellular organisms

As discussed in Chapter 7, simple unicellular prokaryotes such as Archaea and Bacteria are thought to be the earliest organisms to inhabit Earth. They lived in our oceans between 3.5 and 4 billion years ago in very different environmental conditions to those we currently live in. From 3.5 to 2 billion years ago, these prokaryotes dominated Earth's evolutionary history.

Prokaryotes are still the most widespread organisms on Earth. They are still evolving and adapting; however, their small size and simplicity also comes with limitations. A key limitation is related to the number of metabolic activities that can be performed within the cell at one time.



▲ **Figure 10.3**
Cells contain genetic material, a plasma membrane, cytosol and ribosomes.

See Chapter 2 for more information on the classification of organisms.

Chapter 8 discusses the role of the cell membrane and how the surface-area-to-volume ratio affects the ability of the cell to interact with its environment.

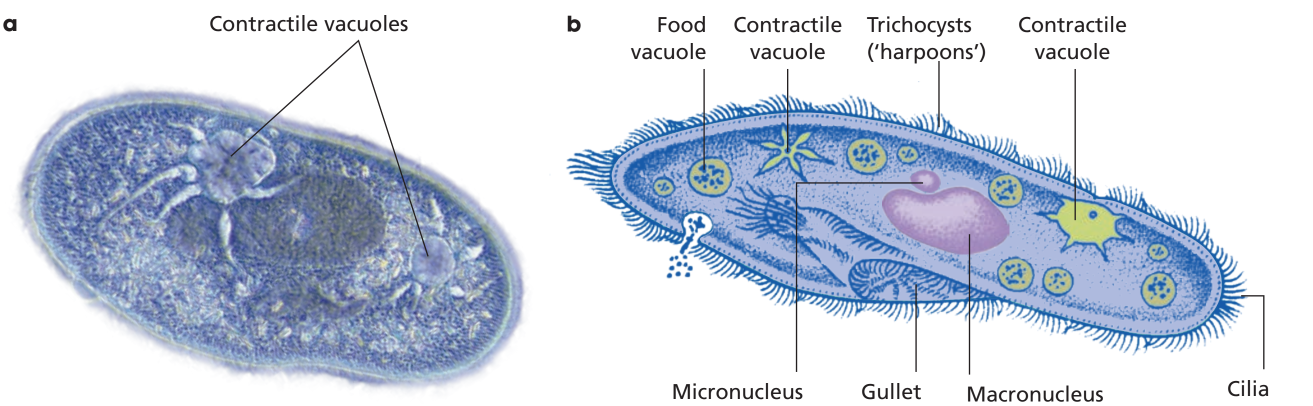
On the other hand, eukaryotic cells can perform many more processes due to their more complex structure. If ancestral unicellular eukaryotic organisms were alive today, they may resemble some of the organisms that are currently classified as protozoan ('proto' = first, 'zoa' = animals). Protozoans are a group of heterotrophic unicellular eukaryotes belonging to the Kingdom Protista. They are the oldest known group of heterotrophic life that convert complex food particles into energy.

Unicellular organisms such as protozoans are complete functioning organisms. All the needs of the organism (e.g. nutrients, energy and water) and functions (e.g. intake of nutrients and energy, processing of nutrients to release energy, and expulsion of waste products) take place within the boundary of the cell. The microscopic size of the cell allows these processes to occur efficiently.

A single cell has a high surface-area-to-volume ratio. This means that the size of the plasma membrane (its surface area) is sufficient to service the total volume of the cytoplasm. Oxygen, nutrients and carbon dioxide can diffuse directly across the plasma membrane in amounts sufficient to meet the needs of the entire cell.

Paramecium

Within the Protista Kingdom, there are many forms of cells that meet their survival needs in many different ways. *Paramecium* is an example of a relatively simple-structured unicellular eukaryotic organism. Paramecia are usually found in ponds, slow-moving streams or any enclosed area containing water. They are able to obtain all their requirements for survival directly from their surroundings.



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▲ **Figure 10.4**
a) *Paramecium*;
b) sketch of *Paramecium* showing structures

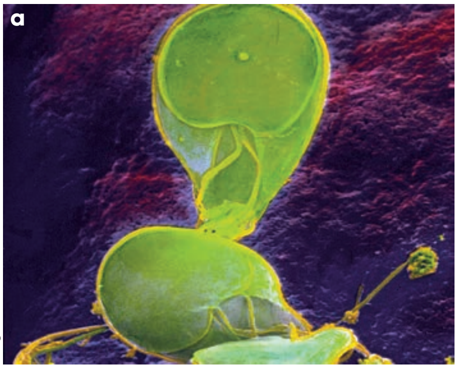

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Figure 10.5 ▲
The diversity in structure of unicellular organisms: a) *Giardia lamblia*, b) *Trichomonas vaginalis* and c) *Trypanosoma brucei*.

The unicellular *Paramecium* is shaped like a football and covered in cilia. The movements of the cilia are synchronised, allowing for the movement of the organism through the water. One feature that sets *Paramecium* apart from some other protists is that it gathers its organic nutrient requirements, such as bacteria, algae and yeasts, from its surroundings. By using its cilia, it sweeps food, along with some water, into its oral groove and then into the mouth of the cell. The food travels through the cell mouth into the gullet, which is a temporary holding area for the food. When there is enough food in the gullet, the food breaks away and forms a food vacuole. Throughout this process, the vacuole is making its way to the back end of the cell. Expulsion of wastes from the food vacuole occurs through an anal pore. The *Paramecium* collects the excess water that enters the cell with the food in a contractile vacuole and from there the water is expelled back into the environment.

WOW

Little animals in water

Anton van Leeuwenhoek (1632–1723) was the first human being to see living protozoans and bacteria. The son of a basket-maker in Delft, Holland, he received little education, but became a prosperous linen-draper. His friends included the painter Jan Vermeer. Drapers used magnifying glasses to inspect cloth, and van Leeuwenhoek took to grinding his own lenses from glass globules and constructing microscopes. With these he observed protozoans and bacteria in fresh water, the bile of various animals, the human mouth and his own excrement. He nearly blinded himself watching the explosion of gunpowder under a microscope. His descriptions, communicated to the Royal Society in London in a series of 190 letters spanning 50 years, are so precise that modern bacteriologists can identify with certainty many of the micro-organisms he saw.

Colonies of cells

One of the simplest forms of life where many cells cooperate to meet the needs of all the cells is *Volvox*. *Volvox* is a hollow whirling sphere of 500 to 60 000 flagellated cells embedded in a gelatinous wall; each sphere of cells makes up a **colony**. Each colony is only one cell thick. Every cell in the colony contains chloroplasts, though some of the colonies may obtain what they need by absorption of nutrients from their environment. Volvocids, members of the group containing *Volvox* (Figure 10.6), are a form of freshwater, green algae. Each cell in the colony is capable of independent functioning if that is required.

In some colonies, cells may continue to be functionally independent of each other. In other colonial forms, their activities may be coordinated. This cooperation makes the organism more efficient in performing functions than individual cells.

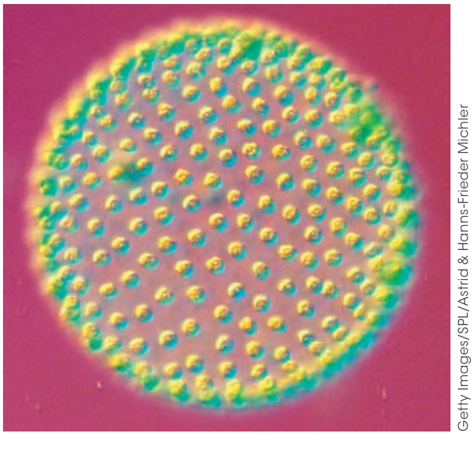

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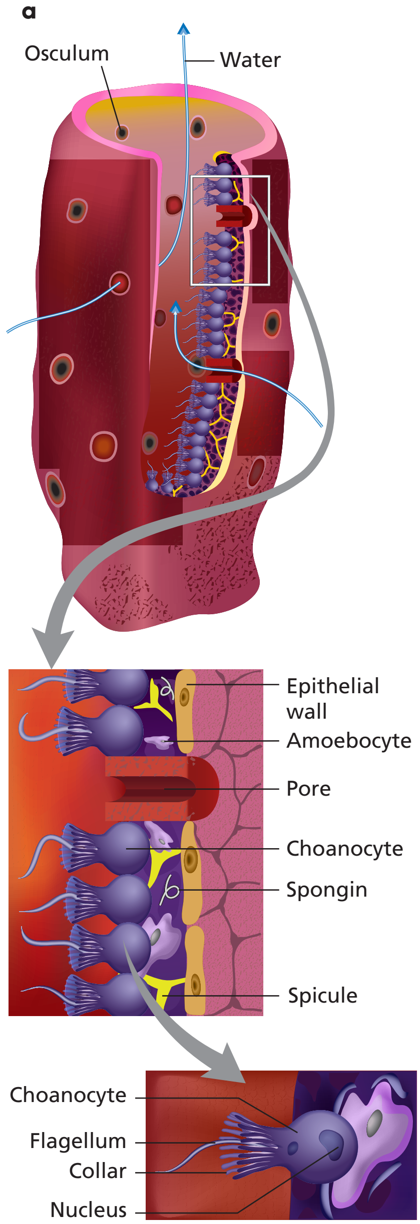
Figure 10.6 ▶
Volvox

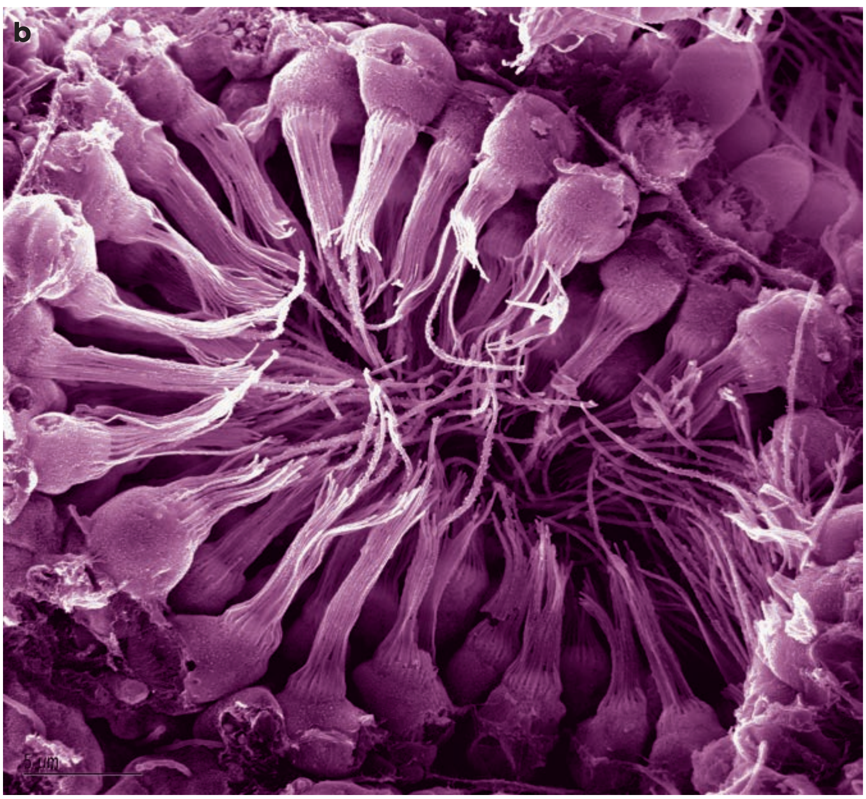
Development of multicellularity

The transition from unicellular organisms to multicellular organisms was a huge leap in the evolution of life on our planet. There is also evidence that suggests it occurred more than once, and that fungi, plants and animals are all descendants of separate transitions to multicellular life. The evolutionary step from a colony of unicellular organisms to a multicellular organism can be illustrated in one group of living organisms: the sponges. When you think of a sponge, you most likely think of material to mop up spills in the kitchen or to clean a car. Real sponges are animals that live in our oceans. They are amazing in their diversity and are problematic in their classification. Sponges also are important because they were one of the first multicellular animals on our planet.

The surface of a sponge is covered with a layer of cells and pores through which water enters the sponge. Inside the sponge, small cells line the cavity (Figure 10.7). These cells are called choanocytes. The flagella on these cells create a current of water inside the sponge from which plankton are extracted. A third group of cells wander around the walls and supply this food to the rest of the sponge.

The choanocytes that line the sponge cavity resemble protozoans called choanoflagellates. It could be that ancestors of these unicellular protozoans clustered together, finding cooperation an advantage. How could such a cooperative of unicellular organisms later lead to them being inherited together as a multicellular organisation? An event such as this could have laid the foundations of the ancestral tree of complex animal life.





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▲ **Figure 10.7**
a) Sponges do not have a definite head, tail or body organs. If a sponge was broken into fragments, each individual fragment could go on living and growing.
b) The feeding cells of sponges resemble choanoflagellates.

If simple sponges have resulted from choanoflagellates joined by a number of other kinds of cells, a framework was needed to support these cells into a single structure. Observations of sponges provide evidence of different solutions to this challenge. Some sponges (e.g. bath sponge) use a material called spongin (a variety of collagen) that result in wonderfully interlinked microscopic frameworks. Other sponges use calcium carbonate (similar to that in many invertebrate skeletons) and yet others use a glass-like framework made of silica that look like they have been spun by a magical geometer.

SULTAN OF SLIME

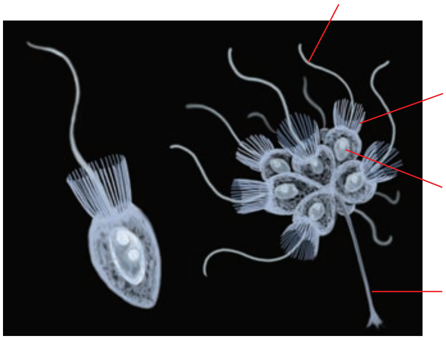
Professor John Bonner (known as the 'Sultan of Slime') has been fascinated by slime moulds and has studied them for more than 70 years. Watch his video to see the weird and wonderful behaviour of slime moulds.

Chapter 12 discusses the structure and function of plants.

WOW

Choanoflagellates: a possible link between unicellular and multicellular organisms

Choanoflagellates (collared flagellates) are eukaryotic organisms that consist of an ovoid or spherical cell body with a single collared flagellum. They can be observed as both free-living unicellular organisms and in colonies. Interest in these organisms as evolutionary ancestors of animals has previously been supported by microscopic similarities in cells. In 2008, research from mapping of the genome of choanoflagellates showed that these ancient organisms possess similarities in proteins that more complex organisms (such as humans) use to communicate with each other. This research further supports their role as an evolutionary link between unicellular and multicellular organisms.



▲ **Figure 10.8**
Protists such as choanoflagellates are thought to be important to the evolution of multicellular organisms such as animals.

WOW

Living up to their 'slimy' name

Slime moulds continue to confound scientists. Rather than solving puzzles, new technologies and research often lead to more questions and fascination about these amazing organisms. Once considered to be fungi, they are currently classified as protists, but even that classification is causing some debate. These unicellular organisms can 'join' together to form a multicellular fruiting body and they can even form a type of tissue, once believed to be unique to animals. Observations of their complex behaviour, continues to intrigue scientists.

Complex multicellular organisation

All eukaryotic cells share features that are indicative of their common ancestry. However, not all of the cells within a multicellular organism are the same. While the cell of a unicellular organism undertakes all living functions (e.g. respiration, digestion, reproduction and excretion), this is not the case in multicellular organisms. In multicellular organisms, there are different types of cells, each type with a specialised structure and function. These cells are so specialised they cannot exist independently of other cells.

The evolution from unicellular organisms to multicellular organisms required three organising principles. These were the ability of cells to divide, specialise and communicate with other cells.

Branching out into plants, animals and fungi

It is thought that multicellular plants evolved from primitive algal organisms. These were initially only in the oceans, but eventually some were also able to survive on land. These ancestors of modern-day plants needed features that controlled water loss and allowed them to reproduce without the need for water. They also needed to be able to support their weight in the air, anchor themselves, internally transport materials, and possess structures that could absorb light and manufacture their food.

It was once thought that fungi arose from primitive algae that had lost their ability to photosynthesise. More recently, they are thought to have evolved from ancestral flagellates, such as the choanoflagellates, and that they are more closely related to animals than to plants.

In terms of **specialisation**, there is more diversity found in animal cells than plant cells. Unlike plants, most animals have the ability to move around in their environments. Such mobility requires a flexible framework (which may include **muscle tissue**), and a fast and effective way to communicate between cells. Such additional structural and communication requirements provide a possible explanation as to why animals possess a nervous system and plants do not.

The transition from unicellular organisms to multicellular organisms was a huge leap in the evolution of life on our planet. As daunting as this jump may be, it didn't happen just once. This type of cellular organisation evolved a number of different times. Evidence suggests that fungi, plants and animals are all descendants of separate transitions to multicellular life.

Case study

Sponges and evolution of organised multicellular organisms with 'Sponge Hoops': Doctor John Hooper

Fancy a career in which the scientific discoveries in one field influence understanding in other fields and have implications in evolution research, medical biotechnologies and sustainability? Dr John Hooper is currently Head of the Natural Environments Program at the Queensland Museum. He is responsible for the museum's collections of living and fossil biodiversity, rocks and minerals, with a focus on the natural history of Queensland. Dr Hooper's specific research interests include taxonomy, systematics, biogeography, diversity and conservation biology, or biodiversity and marine conservation in general. Dr Hooper's key focus has been on discovering new species of sponges using morphology (e.g. SpongeMaps) and molecular tools (e.g. the Sponge Barcoding Project), their species level and higher taxonomy (e.g. World Porifera Database). He applies this information to discover new compounds of potential pharmaceutical benefit and other bioactivity (e.g. Eskitis Institute).

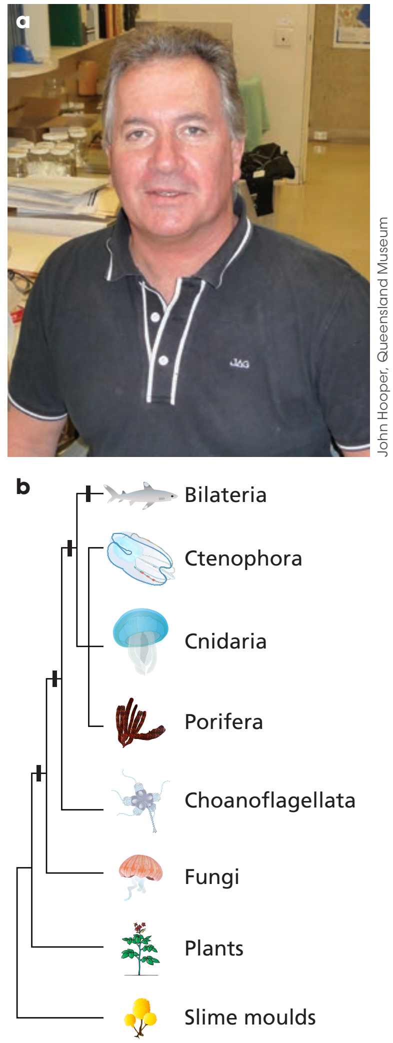
Collaborations with a variety of pharmaceutical companies have provided Dr Hooper with unique opportunities to investigate the reefs across tropical Australia, South-East Asia, Indo-Malay Archipelago and the Pacific Islands. He has contributed to the discovery of more than 35 000 specimens in more than 5000 species of sponges, many new to science, and tripling our previous biodiversity estimates of these organisms. Since 1982, he has named or renamed more than 600 new species, 10 new genera, 2 new families and suborders of sponges.

Because sponges are early-branching multicellular animals in the tree of life, they can reveal insight into the evolution of later multicellular organisms. As Dr Hooper said, 'For me, they are remarkable in being seemingly indiscriminate blobs as an adult – which is also a "strength", in that their flexibility of growth forms enables them to colonise just about any aquatic habitat'.

Sponges have no organs, nervous system (or any sensory system to speak of) or even tissues. Their sophisticated symmetrical larvae, however, are phototactic (move directionally in response to a light source), respond to chemical signals and can recognise their own cells from those of others. They can also undergo complex **cellular differentiation** by which the adult can fully regenerate from (theoretically) a single cell. Demonstrating just about all forms of reproductive and development strategies, they possess 70% of the genes that occur in the higher animals, or should that be vice versa?

All this makes sponges a most useful model organism to understand metazoan (muticellular animal) evolution and developmental processes, character evolution and interpretation of shared characters (homologies) among all animals, and the genomic innovations necessary to become more complex multicellular organisms.

Developments in genomics technologies are linked to some ongoing debates over the relationships between animals at the base of the metazoan evolutionary tree. These technologies are advancing so quickly that what is 'taught' is very quickly out-of-date.



▲ Figure 10.9
a) Dr John Hooper is an international authority on sponges. These multicellular eukaryotic organisms are members of the Phylum Porifera. b) Genetic technology RNA can be used to suggest the relationships between animals (metazoans), choanoflagellates, fungi, plants and cellular slime moulds.

Questions

1 Outline Dr Hooper's key research interests.

2 Suggest and discuss ways in which scientific knowledge gained through his research may be used to:

a develop or evaluate projected economic, social and environment impacts.

b design an action for sustainability.

c influence other areas of science, technology and engineering.
d develop new models or theories across scientific disciplines.
e offer reliable predictions and explanations.

3 Discuss how scientific knowledge that may be gained through such research can have beneficial and/or unintended outcomes.

4 If sponges have no organs or nervous system:
   a how can they sense and respond to their environment?
   b do they have the same ethical rights as more complex multicellular animals?

Justify and discuss your responses.

ACTIVITY 10.1

GET YOUR FEET WET WITH SPONGES!

What to do

Research sponges using the weblinks and soak up more knowledge about these often ignored-animals.

What did you discover?

1 Find out more about and report on:
   a links between choanoflagellates and animal evolution.
   b cellular differentiation in sponges.
   c reproductive and development strategies of sponges.
   d the debate over the relationships between basal metazoans with other non-bilateral groups (e.g. cnidarians and ctenophorans) and their relationship with bilaterians (e.g. other animals).

2 Explore evidence that could be used to determine whether sponges should be considered as a colony of cells or a simple multicellular animal. Based on your research, what is your opinion? Justify your view to others.

SPONGEMAPS

SpongeMaps is an online community with a focus on sponge taxonomy. It provides an opportunity to find out more about sponges and to collaborate with others who find them fascinating.

SPONGE BARCODING

Awareness of the Sponge Barcoding Project will increase your appreciation of the diversity of sponges and difficulties associated with classifying them.

WORLD PORIPHERA DATABASE

The World Poriphera Database provides current updates on the classification of sponges.

EXPERIMENT 10.1

THE LEAP TO MULTICELLULAR ORGANISATION

The transition from unicellular organisms to multicellular organisms was a huge leap in the evolution of life on our planet. If ancestral unicellular eukaryotic organisms were alive today, they may resemble some of the organisms that we currently classify as being protozoan. Many protozoans, such as *Amoeba*, *Paramecium*, *Chlamydomonas* and *Euglena*, are relatively structurally simple unicellular eukaryotic organisms. Not only are they able to perform all life's functions within their single cells, but they also show diversity in how they can achieve this.

Some unicellular organisms, such as *Volvox*, are able to form colonies and work together with other cells, with each cell taking on a specialised function. This specialisation and cooperation of cells, taken to its full potential, can be observed in multicellular organisms.

Aim

To use a light microscope to observe and record the features of different types of cells, and relate the differences to the evolutionary transition from unicellular to multicellular organisms

Materials

- light microscope
- plastic ruler marked in mm or mini-grid (optional)
- concave slides
- coverslips
- lens cleaning tissue
- paper towelling
- large beaker of water for used microscope slides and coverslips
- pipettes
- fresh specimens of

  Protists: *Euglena*, *Amoeba*, *Vorticella*, *Paramecium*, *Volvox*

  Plant cells: red onion epidermal cells, *Elodea* leaf or *Spirogyra*
- prepared slides of

  Animal cells: ciliated epithelial cells (e.g. trachea), glandular epithelial cells (e.g. inner lining of small intestine), human red and white blood cells, human nerve cells

  Plant cell: root hair cells
- annotated diagram or poster of a bacterial cell

Procedure

Note: Before you begin, make sure you familiarise yourself with how to correctly use a microscope, determine the field of view, determine the size of specimens and prepare a wet mount.

1 Observe each of the specimens provided. For each of your observations, draw a diagram ensuring you include the following details.
   - Give your diagram a title.
   - If there is more than one cell, select two or three representative cells.
   - Draw cells that are approximately $\frac{1}{3}$ to $\frac{1}{2}$ of an A4 page.
   - State the magnification used.
   - Include an estimate of the size observed (including units).
   - Draw in grey lead pencil, with no colour or shading.
   - Annotate your diagrams and include any relevant information (such as the presence of cell structures, size, shape, movement).

Results

1 Categorise the specimens observed into increasing levels of evolutionary complexity: unicellular prokaryote, unicellular eukaryote, colonies of cells or multicellular organisms.

2 Copy and complete Table 10.1 to summarise the estimated size measurements and key features recorded for each cell specimen. Also include information about the bacterial cell from the provided diagram.

Table 10.1 Summary of cells observed

Category of complexity	Specimen	Estimated size (μm)	Summary comments on the features of the cell

3 Construct a graph to show the difference in the size of the cells observed.

Analysis of results

1 a Identify any patterns in your observations of the cell structures present.
   b Suggest reasons for these observed patterns.
2 a Identify any patterns in your observations of the shape of the different cells.
   b Suggest reasons for these observed patterns.
3 No bacterial specimens were provided. Suggest the difficulties in observing these types of cells in the classroom.
4 From your observations, compare the complexity of the cells of unicellular organisms with those cells from the multicellular organisms.
5 Construct a conclusion that uses the relevant biological theory of evolutionary transitions of life (see the experiment introduction) to explain your observations.

QUESTION SET 10.1

Remembering

1 State whether each of the following statements are true or false. Justify each of your decisions.
   a The earliest forms of life on our planet were most likely multicellular organisms.
   b *Volvox* colonies show simple multicellular organisation.
   c Cells within a multicellular organism can live independently of other cells.
   d Fungi evolved from ancestral algae that lost its ability to photosynthesise.
   e Multicellular organisation occurred only once in the evolutionary history of Earth.
2 Suggest what group of organisms alive today would resemble ancestral unicellular eukaryotic organisms. Describe their general characteristics.
3 Identify an advantage and a disadvantage of being (a) unicellular and (b) multicellular.
4 List three organising principles that were required for the evolution from unicellular organisms to multicellular organisms.

Understanding

5 Draw a flow chart to show the relationship between the following terms: organisms, molecules, cells, atoms and organelles.
6 Identify and explain the feature of unicellular organisms that allows them to gain all their oxygen, nutrients and carbon dioxide needs.
7 Explain how *Paramecium* gains its nutrients.
8 Provide an example of a colony made up of eukaryotic cells and suggest an advantage of the cells being organised in such a pattern.

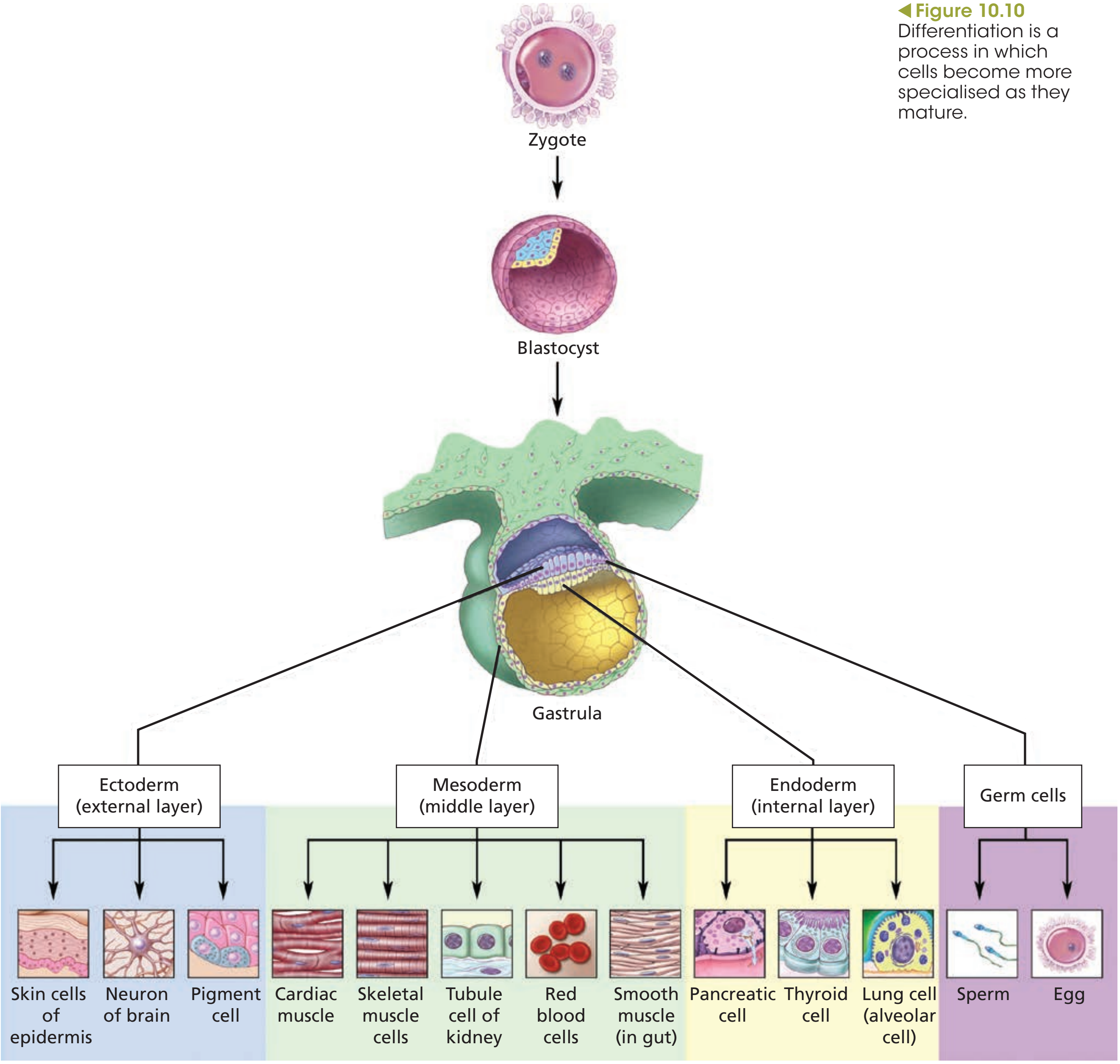
Evaluating

9 'Sponges may be an evolutionary link between unicellular and multicellular organisms.' Evaluate this statement using evidence of the structural characteristics of sponges.

Cell specialisation and differentiation

The amazing diversity of cell shape and structure reflects the evolutionary adaptations of cells to different environments. In multicellular organisms, these differences usually relate to their specific function. This specialisation can increase the efficiency in which the organism functions and can be essential for its survival. The process of specialisation is called cellular differentiation.

All **specialised cells** originate from **stem cells**. Stem cells differ from other cells in the body in three important ways. The first difference is that they are unspecialised (have not yet specialised into a particular type of cell). The second difference is that they have the potential to divide and replicate for long periods of time. The third difference is that these relatively unspecialised cells can differentiate to form different specialised cells.



◀ **Figure 10.10**
Differentiation is a process in which cells become more specialised as they mature.

Unit 3 Biology discusses the transfer of genetic material via mitosis.

Same, but different

With the exception of sex cells (such as sperm and ova) eukaryotic cells are produced by a type of cell division called **mitosis**. Mitosis produces cells that are genetically identical to each other and to the original cell. This means that all of the non-sex cells within a multicellular organism should be genetically identical to each other. But if various specialised cells all contain the same genetic instructions, why don't they look the same? How are they able to perform different functions?

While the genetic information is the same in all cells of a multicellular organism, not all of this information is used in every cell. Only a small portion is actively 'switched on' in each cell. The specific genetic instructions (located within genes in the chromosomes) that will be 'switched on' and expressed to make specific protein will be dependent on the function of the specific cell.

It is the immediate environment of the differentiating cell and its location in the developing organism that determines which genes will be activated ('switched on'). This causes the cell to differentiate and become specialised. As a specialised cell, it will have a specific shape and function. In humans, this differential gene expression can result in more than 200 different cell types.

Being special comes at a price

While specialised cells increase efficiency and reduce duplication of effort, there is a cost. Within a multicellular organism, this specialisation brings about the need for communication and coordination between cells. Specialised cells are totally dependent on activities of other cells to perform tasks that they cannot. Nerve cells, for example, effectively transport nerve impulses, but they rely on red blood cells to deliver oxygen, heart muscles to pump the oxygenated **blood** to them and other cells to provide nutrients and to remove their wastes. If a nerve cell was isolated from the organism of which it is part, unlike a unicellular organism, it will not be able to function on its own and will die.

QUESTION SET 10.2

Remembering

1 State whether each of the following statements are true or false. Justify each of your decisions.
   - a The process of specialisation is called cellular differentiation.
   - b Different types of specialised cells contain different DNA.
   - c All specialised cells originate from stem cells.

2 Outline three ways in which stem cells are different from other cells in the body.

Understanding

3 All cells within a multicellular organism contain the same genetic information, but the structure and function of specialised cells differs. Explain how this is possible.

4 Discuss the advantages and disadvantages of a cell becoming specialised.

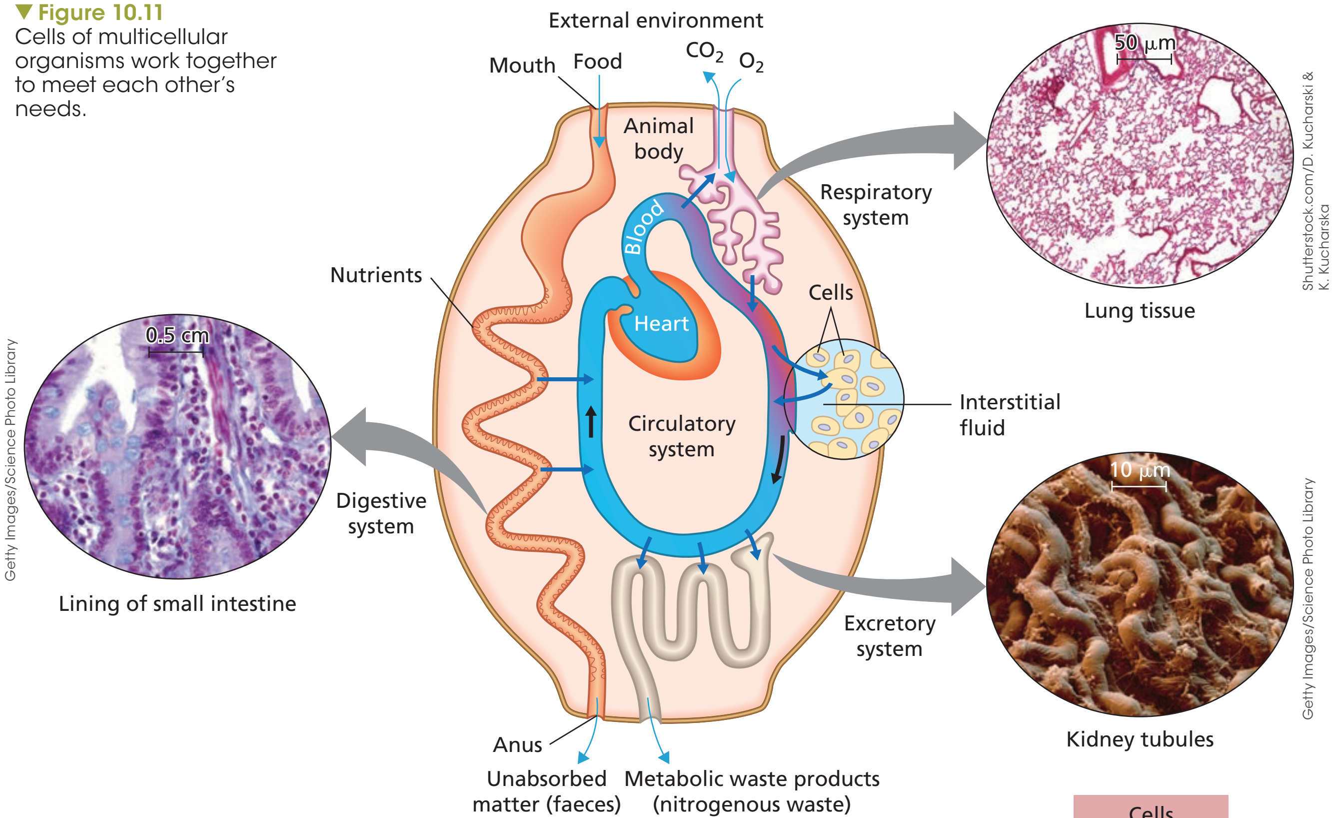
5 Explain the importance of communication and connections between cells of a multicellular organism.

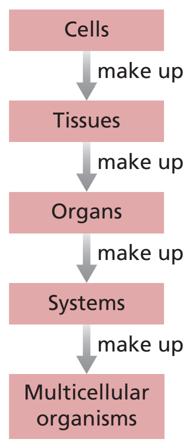
Applying

6 Stem cells are the cause of great excitement in medical research. They are also the cause of many ethical and scientific debates. Key reasons for such excitement and debate relate to how stem cells differ from other body cells, their source, how they are being used in research, and why they are being used. Investigate these reasons and construct a PMI chart (Plus, Minus, Interesting) on the use of stem cells in medical research.

Patterns in levels of organisation

▼ **Figure 10.11**
Cells of multicellular organisms work together to meet each other's needs.





▲ **Figure 10.12**
Hierarchy of cells to multicellular organisms

There are patterns in how cells of multicellular organisms are organised and how they work together. Groups of specialised cells working together to perform a similar function make up tissues. Likewise, a collection of different types of **tissues** working together to perform a particular function is called an **organ**. Your heart is an organ. It consists of cardiac muscle tissue, which uses **nervous tissue** to direct its contractions. Chambers of the heart are lined with **epithelial tissue** that prevents leaking and also **connective tissue** to add strength and elasticity.

In a similar pattern, a collection of organs that work together to perform a particular function is called a **system**. Each organ system contributes to the survival of all living cells in the body. You might think this is stretching things. For example, how could muscles and **bones** help each small, individual cell stay alive? Yet it is the interactions between the skeletal system and the muscular system that allow us to move toward sources of nutrients and water. Parts of these organ systems help keep blood circulating to cells, such as when contractions of leg muscles help move blood in veins back to the heart. The circulatory system rapidly transports oxygen and other substances dissolved in blood to cells, and moves metabolic products and wastes away from them. The respiratory system swiftly delivers oxygen from the air to the circulatory system and takes up carbon dioxide wastes from it. Skeletal muscles assist the respiratory system, and so it goes throughout the entire body.

Chapters 11 and 12 discuss the role of these various systems in animals and plants, respectively.

While the skeleton helps support and gives shape to your body, it is merely one of the many systems that work together to keep you alive. Each of these systems is made up of different organs, which are made up of different types of tissue, which are made up of collections of specialised cells. While sharing some features with the other cells in the body, the cells in the skeleton also possess different features, which suit them to their specific function. These cells have become so specialised that they cannot live independently of other types of cells of your body.

In multicellular organisms cells of similar shape and function are organised into tissues. Different tissues are organised into an organ that carries out a particular function. Groups of organs working together to achieve a particular function make up a system.

Animal cell specialisation and organisation

Balaenoptera musculus, the blue whale, is the largest mammal on the planet. Reaching an average weight of 100 000 kg and length of approximately 25 m, it feeds almost entirely on a tiny shrimp-like crustacean called krill. The krill provides all its nutritional needs. The whale is able to move through the oceans at an average speed of 20 km h^{-1} but can reach speeds close to 50 km h^{-1} when necessary. Due to this speed, they were not hunted much by whalers before 1868. It was at that time that a Norwegian whaler, Svend Foyn, developed an exploding harpoon gun, and revolutionised the whaling industry.

©Luis Quinta/naturepl.com

Figure 10.13 ▶ The blue whale has cells similar in shape and function to humans despite being considerably larger.

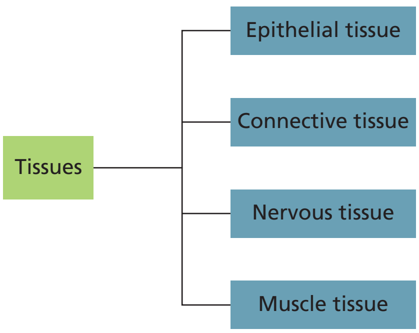


Figure 10.14 ▲ Complex animals consist of four basic tissue types.

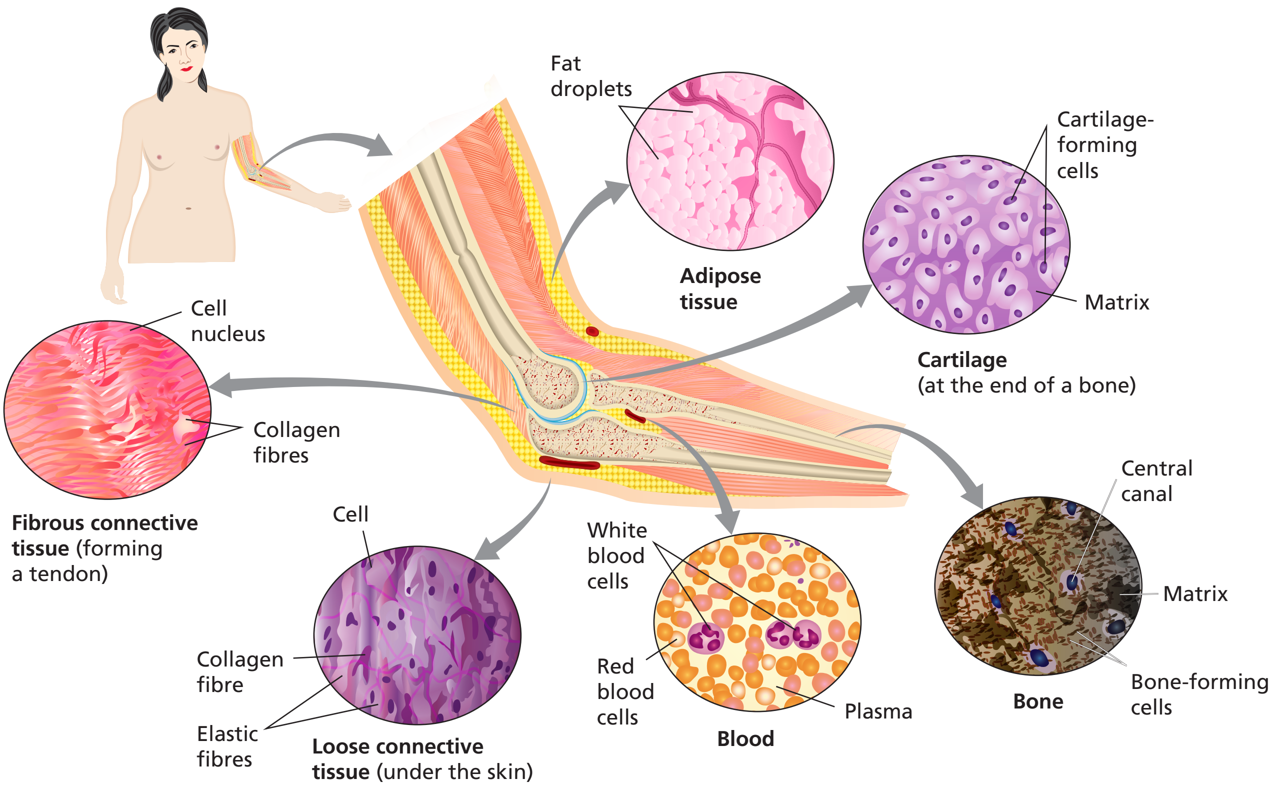
B. musculus is able to dive and remain submerged for up to 20 minutes at a time, surfacing with the expulsion of air forcibly through blowing air via the blowhole 8–15 times. They reach sexual maturity between 6–10 years, and are able to produce calves once every 2–3 years after a 12-month gestation period. The young are weaned at 7–8 months when they have reached 16 m in length and weigh 21 000 kg. If you zoom in on the blue whale and look at it at the microscopic level, you would see that it is made up of trillions of cells working cooperatively together.

Blue whale cells, like human body cells of similar shape and function, are organised into tissues. Amazingly, the body of all complex animals consists of only four basic types of tissues. These are epithelial, connective, muscle and nervous tissues.

Connective tissue

Connective tissue provides support and holds various parts of the body together. It plays a key role in binding and supporting other tissues, and protects against damage, infection and heat loss.

Cells in connective tissue are sparsely scattered through a non-living material called the semi-fluid extracellular matrix. There are different types of connective tissue and they can vary in their density of cells and ways in which cells are specialised. The main types of connective tissue in vertebrates are **loose connective tissue**, **fibrous connective tissue**, **adipose tissue**, **cartilage**, bone and blood. Differences in the structure of each of these types of connective tissue are related to their specialised functions. For example, human red blood cells are small (around 10 µm), enabling them to easily move through capillaries. Loss of their nucleus as they mature also gives these cells more space to carry oxygen.

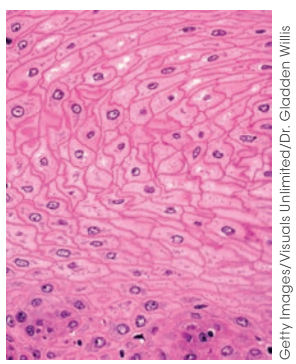


▲ **Figure 10.15**
Pinch and pull some of the skin on the back of your hand. The collagen in the connective tissue is involved in stopping your skin from tearing away from your bone. The elastic fibres function to restore your skin back to its original place and shape. This figure shows examples of different types of connective tissue.

Epithelial tissue

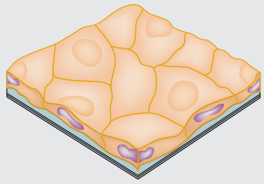
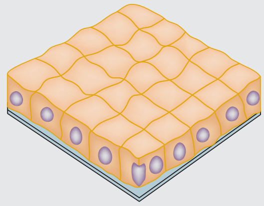
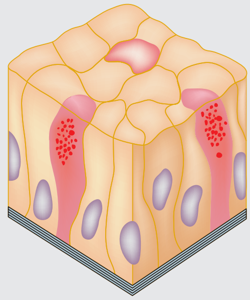
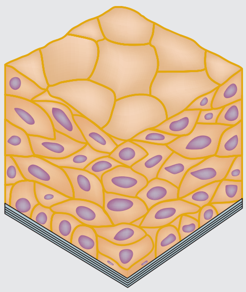
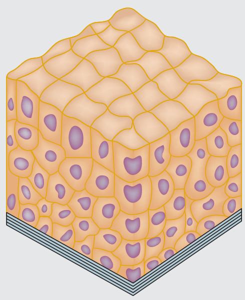
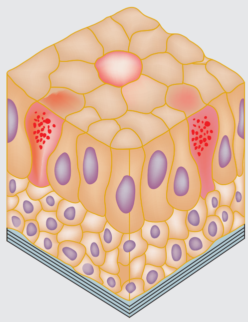
Epithelial tissue is a covering that protects organs, lines body cavities and covers the surface of the body. Epithelial cells line internal and external surfaces such as blood vessels, digestive organs, kidney tubules, skin and airways. Epithelial cells are usually organised into tightly packed single or layered sheets. This cell organisation increases their effectiveness as barriers that protect against mechanical injury, invasive micro-organisms and loss of fluid.

As well as providing a barrier and protecting organs, some epithelial tissue may be specialised to function in absorption, secretion or excretion. For example, the epithelium tissue that lines the respiratory tract secretes mucus that lubricates the surface and keeps it moist. The possession of cilia enables the mucus to move along the surface, trapping particles and sweeping them back up the trachea. This helps to keep lungs clean and healthy. Table 10.2 (page 256) summarises the different types of epithelial cells and their functions.



▲ **Figure 10.16**
A human tongue with stratified squamous epithelial cells

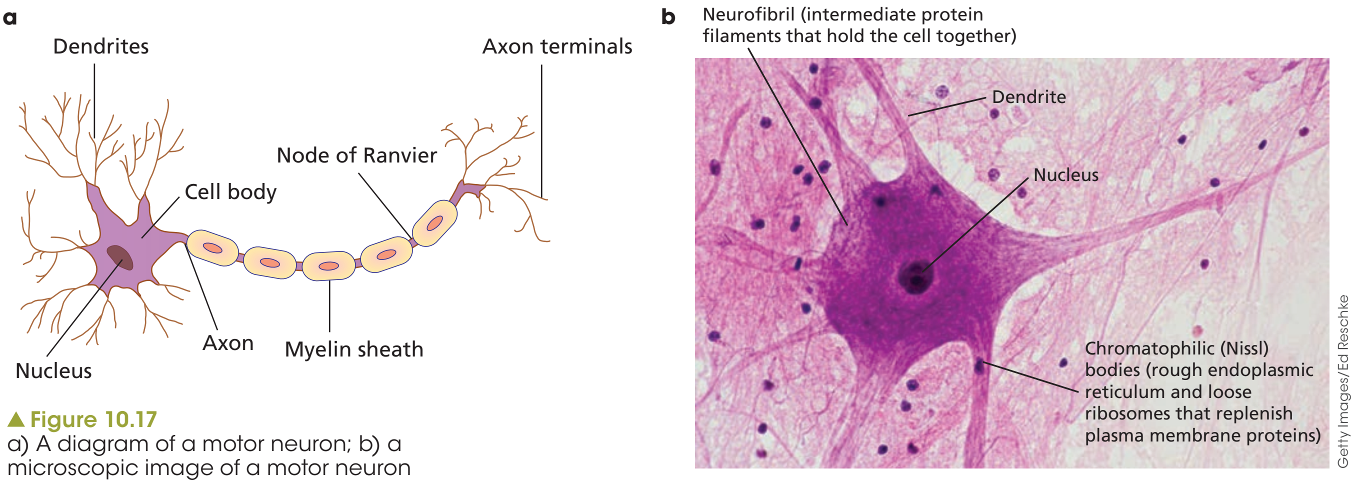
Table 10.2 Epithelial tissue plays a key role in lining or covering surfaces and body cavities. The number of cell layers and shape of the cells on their surface are two criteria used to classify epithelial cells.

	Types of epithelial cells		
	Simple squamous	**Simple cuboidal**	**Simple columnar**
Structure			
Location	Lining of blood vessels and alveoli of lungs	Kidney tubule lining	Most digestive organ lining
Function	Lines blood vessels and air sacs of lungs Permits exchange of nutrients, wastes and gases	Lines kidney tubules and glands Secretes and reabsorbs water and small molecules	Lines most digestive organs Absorbs nutrients, produces mucus Goblet cell
	Stratified squamous	**Stratified cuboidal**	**Stratified columnar**
Structure			
Location	Outer layer of skin, vagina, mouth	Sweat gland duct lining	Mammary gland, epididymis and larynx lining
Function	Protects against abrasion, drying out, infection	Lines ducts of sweat glands Secretes water and ions	Lines epididymus, mammory glands, larynx Secretes mucus Basement membrane

Nervous tissue

Nervous tissue provides the means of communication between all body structures, and the cells in nervous tissue are highly specialised. For example, the elongated shape and the extensions of motor neurons is well-suited to their function of passing messages between the nervous system to other parts of the body. **Neurons** consist of extensions called dendrites, a cell body and an axon.

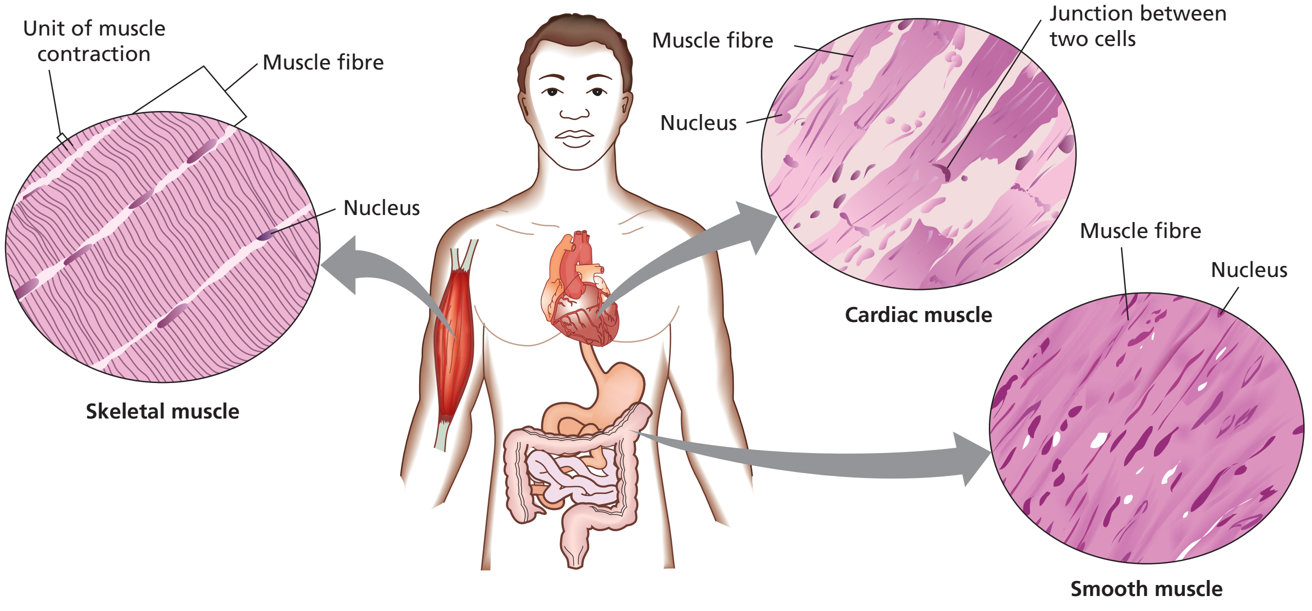
The shape of the dendrites increases the surface area for message detection. The electrical message (impulse) is then carried along the axon to the axon terminal where it is converted into a chemical message (neurotransmitter), which is released into the synapse. The message may either interact with another neuron or an effector (e.g. muscle or gland) to bring about a response.



▲ Figure 10.17
a) A diagram of a motor neuron; b) a microscopic image of a motor neuron

Muscle tissue

Muscle tissue is made up of thin and very long thread-like cells called muscle fibres. These fibres are capable of contracting when stimulated by nerve impulses. Contraction of these fibres accounts for much of the energy requirements in an active animal.



▲ Figure 10.18
Muscles are classified both functionally (e.g. voluntary or involuntary) and structurally (e.g. striated or smooth). The contraction and relaxation of voluntary muscles (such as skeletal muscle in biceps) requires conscious thought. On the other hand, involuntary muscles (such as in cardiac muscle in your heart and smooth muscle in your stomach) contract and relax without conscious thought.

Scientific literacy: Who controls differentiation?

Regulatory genes and the environment in which the cells are located have an impact on the type of cell it will become. We have the ability as humans to manipulate and regulate, not just the differentiation of the cells of our own species, but also that of others, but should we? Should this manipulation of genetic material be regulated? If so, by who and how?

Such scientific dabbling has implications not just for our species but also for others on our planet. After all, we all share the same genetic language and many of these differentiation switches may have evolved along shared lineage.

Need replacement tissue? Just press 'print'!

Scientists have developed a custom-made printer that can make material that is similar to living tissue. In the future, this new technology may be used replace damaged tissue and to test new drugs – replacing or reducing the requirement to test these on living animals.

These new breakthroughs are also accompanied by increased public awareness. The potential applications and implications of these have also broadened the debate about the direction, ethics and responsibility of science and its new technologies – especially when they have potential applications that involve human health and reproduction, and experimentation on other animal species.

Mix 'n' match … crossing the species boundaries

Not just a myth any more, some scientists are involved in human–animal chimera research. This research involves the transfer of human stem cells into other animal species. Concern has been expressed with regards to the crossing of nature's boundaries and the creation of genetically mixed organisms.

Some scientists have now created 'para-humans'. Human body parts have also been grown in other animals, such as Chinese scientists mixing human cells and rabbit eggs and allowing them to grow and divide prior to collecting the stem cells that resulted. Human hearts and livers are being grown inside sheep, and there is even research being performed to get pigs to produce human blood.

Questions

1 Suggest how the development of new technologies could result in replacing or reducing the numbers of animals required for medical testing.

2 If humans have the ability to manipulate and regulate the differentiation of cells of (**a**) their own species and (**b**) different species, should they? Justify your responses.

3 Suggest an advantage and a disadvantage of life on our planet having shared evolutionary histories.

4 Should some types of stem cell clinical trials on animals be allowed and others not? Suggest criteria that could be used to decide.

ACTIVITY 10.2

WHOSE RIGHTS?

Tissue engineering was first conceived in the 1980s when possibilities of synthetic scaffolds for cell implantation were being explored. In 1997, one of the first public introductions of this new technology was of 'Auriculosaurus' (a mouse with a human ear). Even though in this instance there was no actual mixing of genes between species, this image has cast a shadow on future tissue engineering of this type.


AAP/AP Photo/Xinhua

▲ **Figure 10.19**
Auriculosaurus: tissue engineering in mice

What to do

Read through the following questions and consider your responses for each.

If we are able to grow not just human cells and tissues but also organs, at what point does the object being grown have rights? When does it become human? What are the criteria that define 'human'? Is there a difference between organs growing separately between systems? Do some organs, such as brains, have more 'rights' than others? Does the nervous system have more 'rights' than other systems?

What about a human organ grown in the body of another species? If a human brain was grown within a monkey or a dog, would this be regulated in the same way that an ear, eye, heart or lungs would be? Who decides these issues? Who regulates, why, and how?

What did you discover?

1. Share and discuss your opinions with your partner.
2. Consider each question again and construct a list of ethical and legally responsible guidelines for scientists to use in the future.
3. Share and justify your guidelines with others in the class.

Plant cell specialisation and organisation

While plants do not possess all of the same systems that multicellular animals do, they do have specialised cells that make up tissues with specific functions to assist in their survival. Again, the individual cells are organised into tissues (such as photosynthetic tissue), which form the organs (such as the leaf) of the plant body. Each of these tissues is specialised to perform important functions that support the life of the organism. These include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases. Figure 10.20 illustrates and describes the main parts of a growing plant.

The structure of a **vascular** plant ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs. The organs are grouped as systems and in plants there are two systems.

1. The shoot system is comprised of all parts of the plant found above ground. This includes the plant stem as well as the leaves and reproductive organs that grow from the tips of actively growing stems. The shoot system is responsible for supporting the plant physically and the transportation of resources, as well as the absorption of oxygen and carbon dioxide, reproduction, and carrying out photosynthesis in leaves.
2. The root system is generally below ground and is responsible for absorbing water and nutrients from the soil. The roots and **root hairs** are part of the root system.

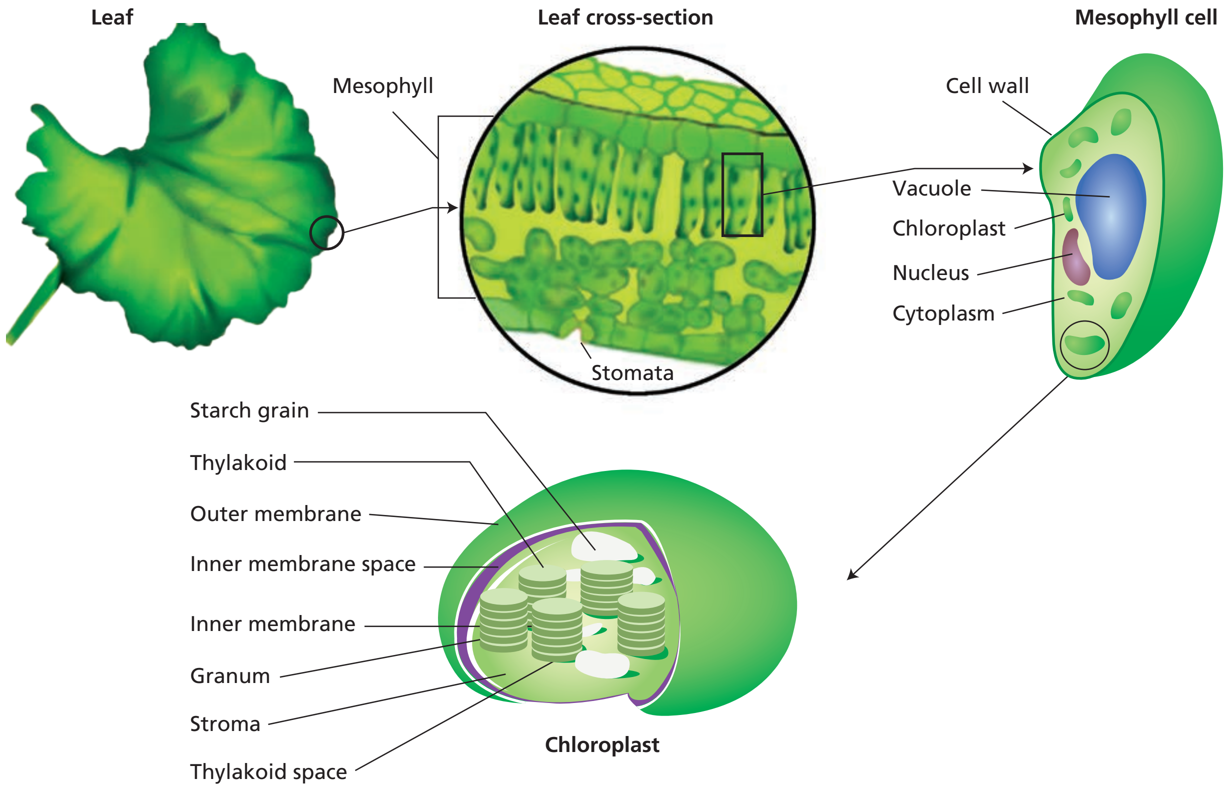


Figure 10.20 ▲ Plants possess a wide variety of cell types that are organised into tissues, organs and systems. A leaf, for example, is an organ that contains specialised cells organised in particular patterns within it.

The initial division of labour occurs due to the presence of different tissues performing different tasks. In a vascular plant, there are four main types of plant tissues. These tissues perform specialised functions such as storage, transportation, photosynthesis and growth.

Meristematic tissue is composed of cells that undergo cell division by mitosis, the process by which plants grow. **Meristems** are the only places in a plant where cells divide; they are found at the tips of roots and shoots, and in a ring around the inside of stems and branches. This enables growth in length as well as width. Some meristematic cells differentiate after division.

Dermal tissue is composed of the outermost cell layers of a plant. The **epidermis** is the outermost part of the dermal layer. As for animals, the dermal layer protects the plant from cuts, invasion by micro-organisms and water loss. On leaves and stems, these cells usually produce a waxy **cuticle**. This wax is vital to the prevention of water loss from leaves and other delicate tissues. Epidermal cells also produce fine hairs on the surfaces of many leaves and stems. In many plants, these discourage plant eaters. Some contain harmful irritants that are released into the skin when touched. Epidermal root tissue produces large numbers of extremely fine extensions called root hairs. These hairs aid in the absorption of water and minerals. In woody plants, a bark layer forms when layers of specialised cells that soon die replace the epidermis.

Ground tissue is composed of all the internal cells of a plant other than **vascular tissue**. This tissue consists of a variety of different cell types that are specialised for storage, support and photosynthesis. Examples of ground tissue include the fleshy portions of apples, pears, potatoes and carrots.

Vascular tissue is involved in the transport of substances in the plant. You will find out much more about the types of tissues making up the vascular tissue in Chapter 12.

The cell is greater than the sum of its parts

Each of the different parts of a cell has a specialised function, which can give rise to new abilities due to interactions among components with increasing organisation. These new abilities can be seen in multicellular organisms when individual cells cooperate to form tissues, tissues work together in organs, organs work together to form a particular function in systems, and these combined systems cooperate to maintain life. The interaction and cooperation between cells, tissues, organs and systems provides multicellular organisms with abilities that are beyond the limitations of a single cell. In other words, you really are more than just the components of which you are made.

QUESTION SET 10.3

Remembering

1 List the four basic types of tissues in complex animals. Describe the function of each type.

2 Provide an example of how the respiratory, circulatory, digestive and excretory systems can work together.

3 Name the four major tissue types in plants, and briefly describe their functions.

Understanding

4 Starting with cells, list the hierarchy of organisation within a complex multicellular organism.

5 Create a concept map that summarises the relationship between the different types of tissues, organs and systems in a typical vascular plant.

6 Explain how the function of the dermal tissue is similar in both a plant and an animal.

7 Describe the relationship between specialised cells, tissues, organs and systems.

8 While your skeleton provides a framework for your structure, your life depends on much more than your skeleton. Explain why you should be considered as being more than just your skeleton.

Applying

9 A scientist discovers that the shells of nuts contain thick-walled cells of ground tissue. Suggest a conclusion she might reach about the function of this tissue.

CHAPTER SUMMARY

- Patterns can help us to appreciate the history of life, and understand how life exists and what humans have in common with other forms of life on our planet.
- There can be patterns in the sizes and shapes of living things so that they can function more effectively. By functioning more effectively, the cell or organism may have an increased chance of surviving and passing its genetic material to the next generation.
- All matter is composed of atoms that can be organised into complex biological molecules.
- Molecules can be organised into structures called organelles, which are found in cells.
- Unicellular organisms are made up of a single cell that can perform all of the necessary functions to keep it alive. Their small size allows for easy diffusion of oxygen, carbon dioxide and nutrients.
- The association of unicellular organisms to form colonies is an early step in the evolution of multicellular organisms.
- The evolution from unicellular organisms to multicellular organisms required the ability of cells to divide, specialise and communicate with other cells.

- Multicellular organisms are made up of many cells, which are specialised so that they have specific tasks. Cells within a multicellular organism need to cooperate with each other as their survival is dependent on it.
- There is evidence to suggest that fungi, plants and animals are all descendants of separate transitions to multicellular life.
- All specialised cells originate from stem cells. Stem cells differ from other cells in the body – they are unspecialised, capable of self-renewal and can differentiate to form different specialised cells.
- Specialisation can increase the efficiency with which an organism functions and can be essential for its survival. Specialised cells are dependent on the activities of other cells to perform tasks that they cannot.
- Cellular differentiation is a process by which cells become specialised so that they perform specific functions.
- Specialisation within a multicellular organism brings about the need for communication and coordination between cells.
- Groups of specialised cells working together to perform a similar function make up tissues.
- A collection of different types of tissues working together to perform a particular function is called an organ.
- An organ system is a collection of different types of organs that work together to perform a function.
- There are four main types of tissues in animals. These are epithelial tissue, connective tissue, nervous tissue and muscle tissue.
- Plants have two major organ systems: the shoot system and the root system.
- Plant structure is based on four tissue types: meristematic, dermal, ground, and vascular tissues.
- The cell is a living unit greater than the sum of its parts. New properties emerge as a result of interactions among components at lower levels with each step up.

CHAPTER GLOSSARY

adipose tissue a type of connective tissue (e.g. fat droplets)

atom the fundamental particle of matter; is composed of protons, neutrons and electrons

blood a type of connective tissue (e.g. red blood cells)

bone a type of connective tissue that holds the body together (e.g. skeleton)

cartilage a type of connective tissue that holds the body together (e.g. at the end of a bone)

cell the basic structural unit of all life on Earth

cellular differentiation the process by which an unspecialised cell develops into a specialised cell

colony an organised association of unicellular organisms

connective tissue holds the body together and protects against infection

cuticle the non-cellular protective layer on the surface of a plant

cytosol the fluid part of the cytoplasm containing highly organised fluid material with dissolved substances; excluding the organelles

epidermis the surface layer of plant or animal cells, generally responsible for separating and protecting the organism from its environment

epithelial tissue cells that line the internal and external surfaces such as blood vessels, digestive organs and airways

eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

fibrous connective tissue a type of connective tissue that holds the body together (e.g. forming a tendon)

loose connective tissue a type of connective tissue that holds the body together (e.g. found under skin)

meristem a localised area of plant tissue in which cells actively divide to form new tissues; includes the growing tips of roots and stems

mitosis a type of nuclear division that maintains the parental number of chromosomes for daughter cells; it is the basis of bodily growth and asexual reproduction in many eukaryotic species

multicellular describes an organism consisting of more than one cell

muscle tissue tissue made up of thin, very long thread-like cells called muscle fibres that contract when stimulated

nervous tissue tissue containing cells (e.g. neurons) that are highly specialised for transmission of nerve impulses

neuron a nerve cell

organ a collection of different types of tissues working together to perform a particular function

organelle a specialised structure or compartment within a cell that has a specific function

plasma membrane the insoluble boundary of all living cells that maintains the contents of the cell and regulates movement of substances in and out of the cell

prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of Domains Archaea or Bacteria

root hair a tube-like outgrowth of a root epidermal cell that increases the surface area of the root; responsible for absorbing water and nutrients

specialisation describes the possession of specific features that relate to a specific role or function

specialised cell a cell that possesses specific features that well-suit it to its specific function

stem cell an unspecialised, immature cell capable of being transformed into different kinds of specialised, differentiated cells

system a collection of organs that work together to perform a particular function

tissue a group of specialised cells working together to perform a specific function

unicellular an organism made up of a single cell

vascular describes vessels that conduct fluid

vascular tissue (in plants) the plant tissue devoted to the bulk transport of water, nutrients, sugars and other substances, comprising the xylem and phloem

CHAPTER REVIEW QUESTIONS

Remembering

1 Copy and complete the table, inserting the most appropriate word from the list given.

leaf	connective tissue	systems	neurons	stomach	plants
tissues	excretory system	atoms	cells	oxygen	specific
within	digestive system	mitochondria	root cells		

Level of organisation	Description	Examples
Organisms	The sum of all of the organ ________ working together	Animals, ________, Fungi
Organ systems	Different types of organs working together to perform ________ functions	Reproductive system, circulatory system, ________, respiratory system, ________
Organs	Different types of ________ working together to perform a specific function	Brain, heart, lung, ________, ________
Tissues	Different types of ________ working together to perform a specific function	Skin tissue, epidermal tissue, muscle tissue, ________
Cells	Building blocks of life	Blood cells, ________, skin cells, bone cells, ________, root hair cells
Organelles	Structures ________ the cell with a specific function	Nucleus, ribosomes, chloroplasts, ________
Molecules	Combinations of ________	Proteins, carbohydrates, nucleic acids, lipids
Atoms	Combine to make up molecules	Carbon, hydrogen, ________

2 Name:
- a four main types of tissues in humans.
- b three examples of human body systems.
- c two types of specialised cells.
- d one example of connective tissue.

Understanding

3 Explain why cells in a multicellular organism cannot survive independently of other cells.

4 Distinguish between specialisation and differentiation.

5 If all cells of a multicellular organism contain the same genetic material, explain why they don't all look the same.

6 Explain why multicellular organisms are made up of different types of cells.

Applying

7 Construct Venn diagrams to compare:
  a unicellular organisms, colonies of unicellular organisms and multicellular organisms.
  b stem cells and specialised cells.

8 Construct a PMI chart (Plus, Minus, Interesting) of being (a) unicellular and (b) multicellular.

9 A student noticed bugs eating the tips of shoots in a plant in her garden.
  a Name the type of tissue found in the tips of the plant.
  b List other places this tissue would be found.
  c Suggest the effect of the loss of the tips to the plant.

Analysing

10 Provide arguments that possession of specialised cells in multicellular organisms is:
  a advantageous to the survival of the organism.
  b disadvantageous to the survival of the organism.

11 Discuss what is meant by 'The cell is a living unit greater than the sum of its parts'.

Evaluating

12 Evaluate, explain and justify the following statements.
  a Patterns can help us to appreciate the history of life, understand how life exists and what we have in common with other forms of life on our planet.
  b There is a relationship between the patterns in the sizes and shapes of living things to their function.

Creating

13 In 2007, scientists announced the development of a technology that induced fully mature specialised cells (e.g. human skin cells) to mimic embryonic stem cell characteristics. Stem cells are cells that can differentiate into other types of cells. These altered stem cells could provide a source of cells for replacement and regeneration after damage due to disease or injury, or even to reduce the effects of normal ageing. While these cells have great potential, there is still a lot that is unknown about these cells and their usefulness. Research stem technology to answer the following questions. If these technologies are not safe enough for humans, how can they be tested? How can the study of their potential be continued? Who or what should they be tested on? What sorts of guidelines should scientists follow in this type of research? Present your findings to your teacher.

14 Primitive multicellular organisms that in many ways resemble the first multicellular organisms that existed about a billion years ago can still be found on Earth. Find out what they are, and their structure, function and history. Present your findings in a multimedia format and highlight features that may be related to survival success of these organisms.