CHAPTER

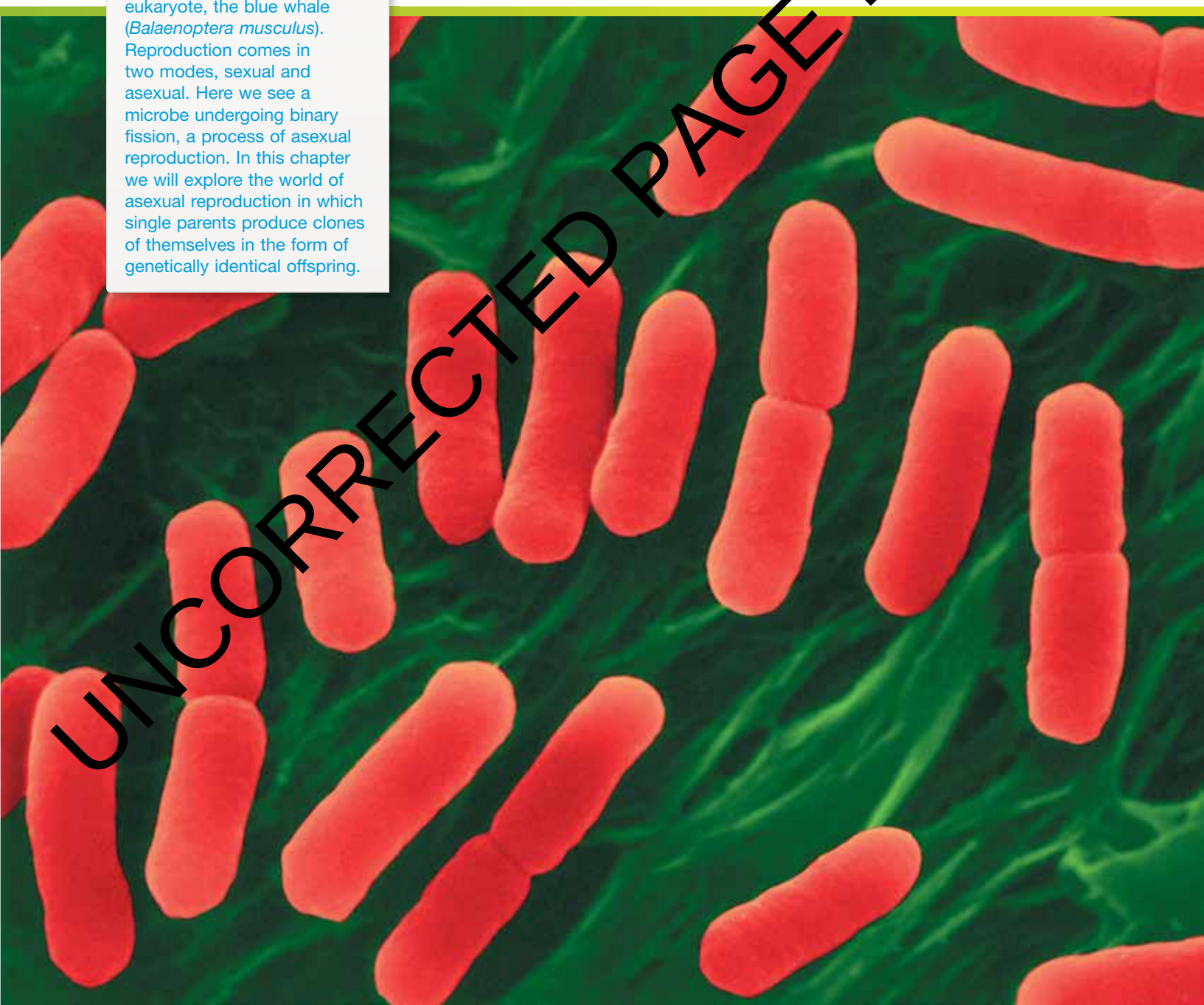
10 Asexual reproduction

FIGURE 10.1 Reproduction is one of the defining characteristics of living organisms, from the smallest microbes, such as *Mycoplasma pneumonia*, about 0.1 µm in diameter, to the largest multicellular eukaryote, the blue whale (*Balaenoptera musculus*). Reproduction comes in two modes, sexual and asexual. Here we see a microbe undergoing binary fission, a process of asexual reproduction. In this chapter we will explore the world of asexual reproduction in which single parents produce clones of themselves in the form of genetically identical offspring.

KEY KNOWLEDGE

This chapter is designed to enable students to:

- understand the concepts of asexual reproduction
- understand that asexual reproduction has biological advantages but also disadvantages
- evaluate the emerging issues concerning cloning



Jake's headache

In the winter of 2001, a young child was not well. Jake had been vomiting, was feverish, and told his parents that he had a headache and that his neck was hurting. Jake's parents initially thought that the boy was coming down with the flu. His parents became increasingly concerned, however, when the young boy became confused and disoriented. They rushed him to the Emergency Department of a public hospital.

The doctors who saw Jake at the hospital quickly assessed the boy and performed some simple tests that led them to suspect that Jake was suffering from **meningitis**. Meningitis is an inflammation of the protective membranes, known as **meninges**, that surround the brain and the spinal cord. A common cause of meningitis is an infection by *Neisseria meningitidis* bacteria. As a precaution, Jake was immediately treated with an antibiotic.

Meninges from *mēning* = membrane

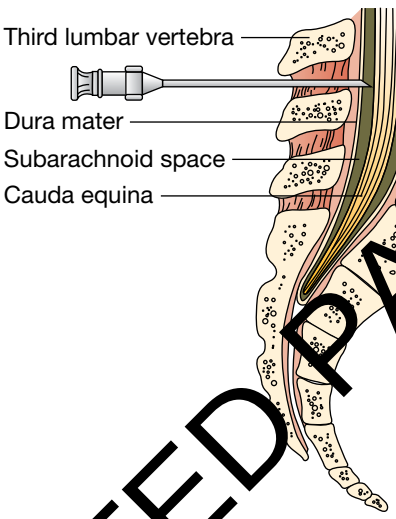


FIGURE 10.2 Simplified diagram showing the lumbar puncture procedure in which a needle is passed between the vertebrae in the lower back into the subarachnoid space. Note that the cerebrospinal fluid is located in the subarachnoid space. The outer boundary of this space is formed by the dura mater, one of the three membranes of the meninges. The cauda equina is a bundle of nerve fibres extending from the end of the spinal cord.

A sample of cerebrospinal fluid (CSF) was taken from Jake in a process known as a **lumbar puncture**. CSF is the fluid that bathes the brain and the spinal cord and it is located in the space between the middle and innermost layer of the meninges (the subarachnoid space).

To obtain a CSF sample, a needle is inserted between two of the lumbar vertebrae in the spinal column (see figure 10.2), either between L3 and L4 or between L4 and L5. The needle passes through two of the layers of the meninges until it reaches the subarachnoid space; a sample of CSF can be taken from this space. (An adult has about 120 to 150 mL of CSF.) The CSF sample from Jake was sent for testing. The CSF of a healthy person is a clear fluid with few, if any, white blood cells present (0 to 5 cells per microlitre). In contrast, the CSF sample from Jake was cloudy and contained high numbers of white blood cells, in excess of 100 cells per microlitre. Further testing showed the presence of bacteria that matched the shape and the biochemical characteristics of *Neisseria meningitidis*, the causative agent of bacterial meningitis.

Once it was confirmed that Jake had bacterial meningitis, he was given appropriate treatment. Happily, Jake recovered with no long-term ill effects and is now a healthy teenager.

ODD FACT

The spinal cord does not extend to the base of the spine. Typically, the spinal cord ends at about lumbar vertebrae L1 or L2. Nerve fibres leaving the end of the spinal cord at that point extend to the hips, legs, anus and bladder.

Meningococcal diseases

Neisseria meningitidis bacteria are natural residents of the mucus that lines the cells of the naso-pharynx (nose and throat) in about 10 per cent of young healthy adults. In a very few people, these bacteria penetrate the mucosal cells and gain entry to the body. These bacteria cause several diseases, including meningitis and **meningococcal sepsis**. The term, **meningococcal disease** (MCD) covers the range of diseases caused by *N. meningitidis*. Meningococcal disease affects mainly young children but it does occur, less commonly, in other age groups (see figure 10.3). Although these diseases are uncommon, they are very serious.

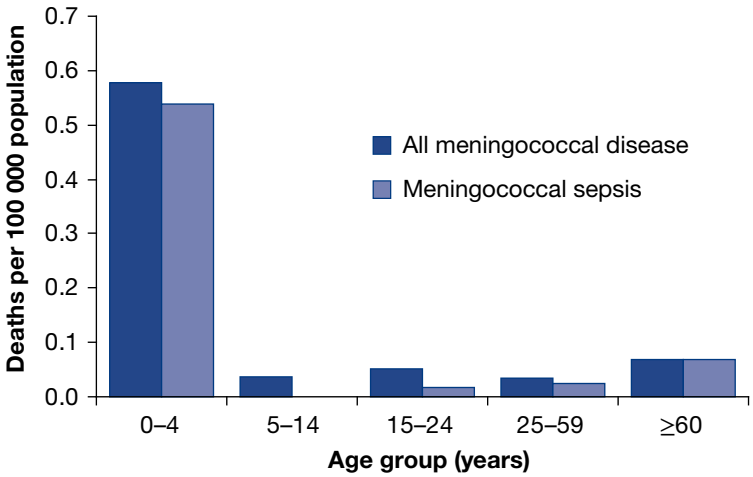


FIGURE 10.3 Graph showing the distribution of deaths from meningococcal disease by age group in the period from 2005 to 2007

ODD FACT

In 1887, the Austrian doctor Anton Weichselbaum (1845–1920) was the first person to identify the bacterium *Neisseria meningitidis* in the spinal fluid of patients with meningitis.

ODD FACT

Many bacteria produce endotoxin. However, *N. meningitidis* produces far more than other bacteria, 100 to 1000 times more.

The *N. meningitidis* bacteria can be spread from an infected carrier to a second person by air droplets from coughing or sneezing, and by close contact with saliva, as may occur from kissing or from sharing drinking vessels.

The *N. meningitidis* bacteria can undergo rapid cell divisions, with a **doubling time** of 40 minutes. This means that in about 6 hours one bacterial cell can undergo 8 cycles of cell division, producing more than 200 daughter cells. Within about 16 hours ongoing divisions of a single bacterial cell can produce more than one million daughter cells.

Meningitis

If *N. meningitidis* reaches the bloodstream, the bacteria can spread to other organs. Meningitis is the disease that results if the bacteria cross the blood–brain barrier and reach the CSF that bathes the brain and spinal cord. If the bacteria become established here, they undergo cell division and cause an inflammation of the protective membranes (meninges) that surround the brain and spinal cord. In some patients, the concentration of living bacteria, either single cells or clumps of cells, was found to be in the range of 10 000 to 100 000/mL of CSF.

The outer surface of each *N. meningitidis* bacterium contains a complex lipopolysaccharide (lipid + polysaccharide), known as **endotoxin**. Endotoxin stimulates the human immune system and activates a range of undesirable and damaging inflammatory responses in human cells. The endotoxin on dead bacterial cells is also active in producing inflammation.

Meningococcal sepsis

The condition of meningococcal sepsis (also termed septicaemia) is the result of an *N. meningitidis* infection in the bloodstream. The bacteria start dividing in an uncontrolled manner, producing more and more bacterial cells. As the numbers of bacteria in the blood grow, an infected person is exposed to ever-increasing amounts of endotoxin. In one study, patients with severe sepsis had bacterial DNA loads of 10^6 to 10^8 DNA copies per millilitre of blood. Yes, that's one million to one hundred million bacterial cells, alive or dead, in every millilitre of their blood. The endotoxin from the massive numbers of living and dead bacteria in the blood causes a condition known as sepsis. This results in system-wide inflammatory changes and may develop into septic toxic shock that damages major organs including the heart, kidneys and liver. This can lead to multiple organ failure and, in some cases, death. (Later in this chapter, we will see how these cells are produced.)

In some cases of meningococcal sepsis, the endotoxin causes septic shock that damages blood vessels and interferes with the blood supply to the limbs. In rare cases, the oxygen-starved tissues of the limbs die and decay. For the patient to have any chance of survival, amputation of part or all of the gangrenous limb or limbs is necessary.

Worldwide, 13 different strains of *N. meningitidis* occur. In Australia, as in other developed countries, the most common strains are C then B. In developing countries, the most common strain of *N. meningitidis* is strain A.

In Jake's case, *N. meningitidis* bacteria resulted in meningitis. In other persons, such as Charlotte Cleverley-Bisman (see figure 10.5), the *N. meningitidis* from her throat became established in her bloodstream and multiplied. The endotoxin from this bacterial load caused meningococcal sepsis that developed further into massive septic shock.

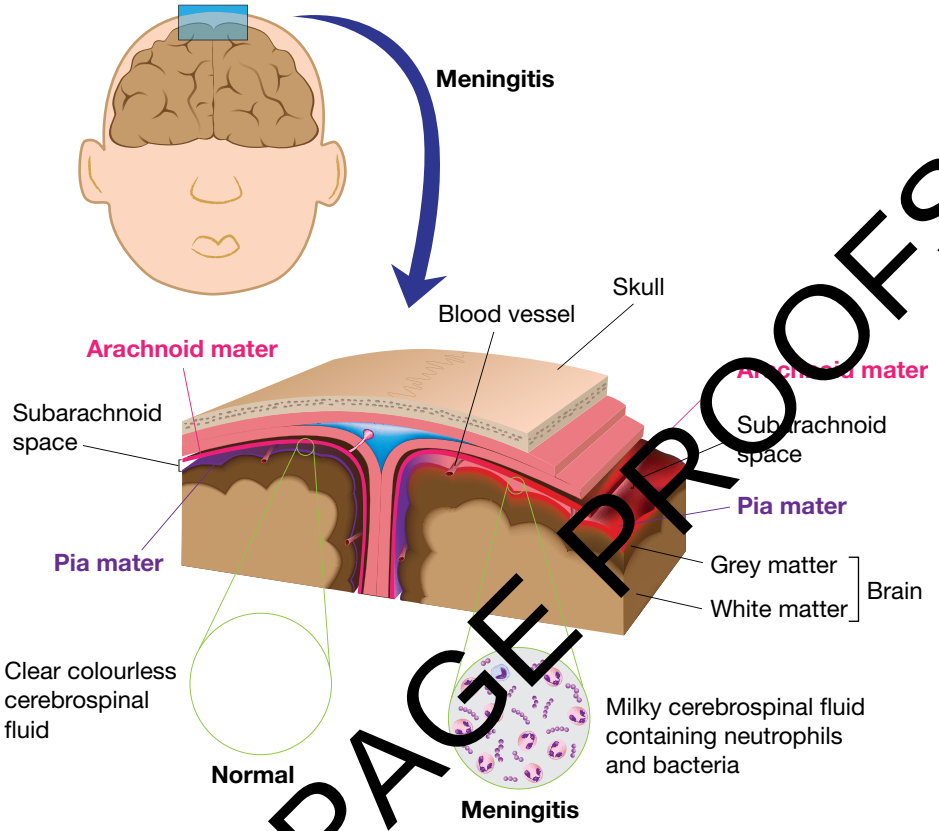


FIGURE 10.4 Meningitis is a result of a bacterial infection of the membranes (meninges) that cover the brain, most commonly caused by *Neisseria meningitidis*. A sample of the cerebrospinal fluid that bathes the brain and spinal cord can reveal the presence of the causative bacteria.

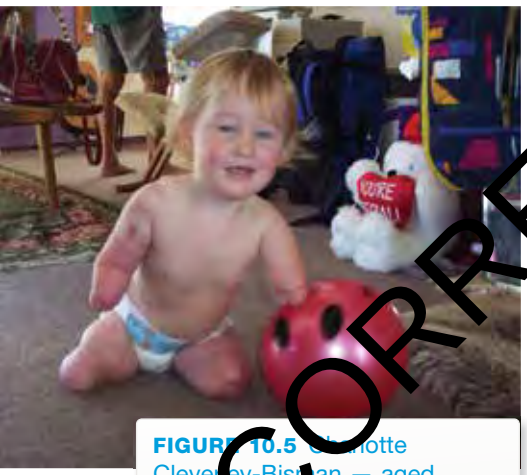


FIGURE 10.5 Charlotte Cleverley-Bisman — aged between 1 and 2 years — following her amputations. Charlotte became the face of the campaign that promotes meningococcal meningitis vaccination in New Zealand and raises awareness of the devastating diseases (meningitis and meningococcal sepsis) caused by *N. meningitidis* bacteria.

Preventive immunisation

The conjugate meningococcal C vaccine was introduced into the National Immunisation Program from 2003 to protect against meningococcal disease caused by *N. meningitidis,* strain C. Immunisation is free for children aged 12 months, and for children from 13 months up to and including 9 years who have not been fully vaccinated. (In the period from 2003 to 2006, a catch-up immunisation was offered to all children and young people aged from 1 to 19 years.) Since the introduction of this immunisation program, the incidence of meningococcal disease has decreased.

In June 2004, Charlotte Cleverley-Bisman (see figure 10.5), then 6 months old, was diagnosed with a meningococcal sepsis infection. The speed of onset of the disease was sickeningly fast; within hours of being taken to a medical centre near her home in New Zealand, little Charlotte's body became covered in swollen, purple areas and her extremities became black — a sign of dead gangrenous tissue. To survive this devastating disease, Charlotte had to undergo the amputation of parts of her four limbs. Charlotte became the 'face' of the campaign that promotes meningococcal meningitis vaccination, launched in New Zealand 1 month after she contracted the disease.

The threatening and serious effects of an infection by *N. meningitidis* bacteria are due to the fact that these bacteria can undergo complete cell divisions within about 40 minutes. (In contrast, a mammalian cell takes about 24 hours for a complete cell cycle (refer to chapter 9, p. 394)). This rapid production of two daughter cells from a single parental cell is just one example of asexual reproduction. Let's now look at this type of reproduction.

Reproduction without sex

Asexual reproduction is a form of reproduction in which one parental organism produces offspring that are genetically identical to each other and to the parent. The daughter cells are **clones**, and asexual reproduction is an example of natural cloning. Another definition of asexual reproduction is that it is a mode of reproduction that produces offspring without the involvement of gametes.

Asexual reproduction occurs in prokaryotes (bacteria and archaea) and in eukaryotes (animals, plants and fungi). The outcome is identical in both prokaryotes and eukaryotes, namely two identical daughter cells, but the process differs in these two groups. In prokaryotes, asexual reproduction involves **binary fission**, while in eukaryotes, asexual reproduction involves **mitosis**.

Table 10.1 compares asexual with sexual reproduction and highlights some key differences between the two modes of reproduction.

TABLE 10.1 Some differences between asexual and sexual reproduction

Feature	Asexual reproduction	Sexual reproduction
number of parents or parental contributions	one	two
processes involved	binary fission (prokaryotes) cell reproduction involving mitosis (eukaryotes)	gamete production involving meiosis (eukaryotes)
fertilisation	absent	fusion of gametes required
offspring	no genetic variability; offspring are clones of single parent	offspring differ from parents and from each other
rate of offspring reproduction	faster	slower

Sexual reproduction will be explored in detail in chapter 11.

ODD FACT

The prefix 'a' in asexual means 'not'. Other comparable words include asymmetrical, atypical and acentric. What does each of these mean?

Seahorses are the only animals where the male gives birth. The female releases her eggs into a brood pouch on the male where they are fertilised and incubated before he later gives birth.

Asexual reproduction: advantages

One advantage of asexual reproduction is that population growth can occur very rapidly. Producing offspring by asexual reproduction is a faster process than by sexual reproduction. Only a single parental organism is required. For various animals, there is no need to spend time looking for a mate and no need for courtship displays; for vascular plants, there is no need to produce pollen and rely on a vector, such as the wind or an insect, to transfer this pollen to another plant for fertilisation.

We have already seen how the cell division of the *Neisseria meningitidis* bacteria can rapidly produce massive numbers of bacteria in the CSF and in the blood of persons with meningococcal diseases.

In addition, in multicellular species that reproduce sexually, the population necessarily consists of two sexes, male and female, but only the females can give birth to offspring. In contrast, in asexually reproducing species, every member of a population can give birth to offspring. This means that, all other things being equal, asexually reproducing organisms can reproduce at twice the rate of sexually reproducing organisms.

If a population suffers a sudden reduction in size as a result of a natural disaster, those species that can reproduce asexually can rebuild their numbers more rapidly than other species that must rely on sexual reproduction.

Another advantage of asexual reproduction is that if a new habitat becomes available for colonisation, those species that reproduce asexually can more quickly exploit the resources of space and energy in this new habitat.

In favourable conditions, asexual reproduction is an advantage because organisms with a successful genetic make-up (genotype) can spread quickly because offspring are exact replicas of the parent. If a parent has already survived in particular conditions, it is highly probable that its offspring will also survive. Such parents can pass their successful genotypes to their offspring, and this will continue, generation after generation. In asexual reproduction, the parental genotype is passed on unaltered to the offspring because this mode of reproduction does *not* involve the processes of genetic shuffling that occurs in sexual reproduction.

Asexual reproduction: disadvantages

The principal disadvantage of asexual reproduction is that it does not create any **genetic variation** in a population because the offspring of each parent are genetically identical clones of that parent. In a population that reproduces asexually no new genotypes are produced. The only genotypes are those that are already present in the population. While conditions are favourable and unchanging, this does not matter, but this feature becomes a clear disadvantage if conditions change and become unfavourable.

In an environment subject to change, the existing genotypes in the population may not be suited to the new conditions. Likewise, the outbreak of a disease could affect all members of an asexually reproducing population. If one member of the population is susceptible to the disease, all will be susceptible.

In summary, asexual reproduction appears to be advantageous when rapid population growth is important or in unchanging stable environments. Sexual reproduction is advantageous where the genetic variation in offspring enables adaptation to unstable and changing environments.

The best of both worlds

Some species have the ability to use both the asexual and the sexual modes of reproduction depending on circumstances (see figure 10.6). These species include various insects (such as aphids), some crustaceans (such as fairy shrimp), algae (such as *Volvox* sp., see figure 10.7), almost all fungal species and many plants.

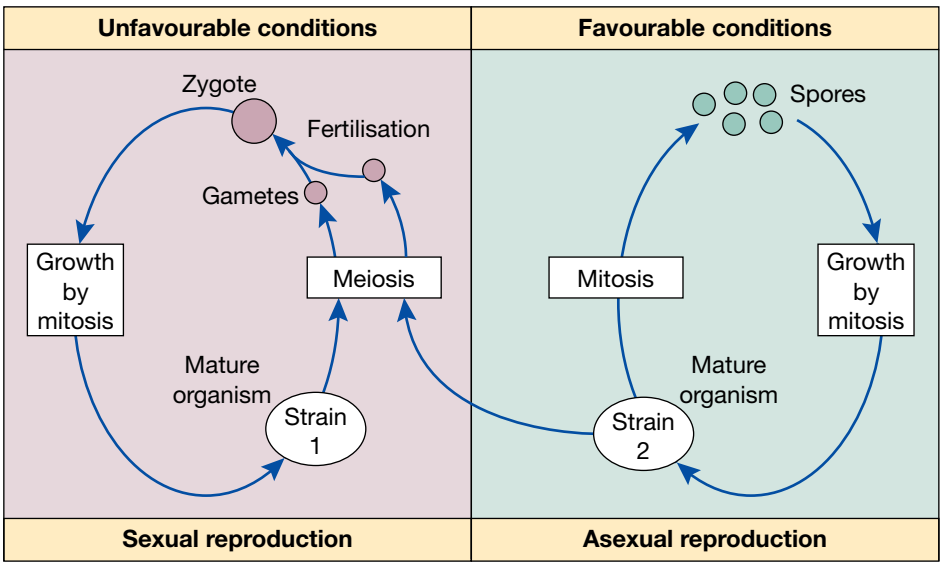


FIGURE 10.6 Some species use both asexual and sexual reproduction depending on circumstances. In preparation for known seasonal changes, such as the onset of winter, these species may switch from asexual to sexual reproduction. Typically, sexual reproduction involves different mating types or strains.

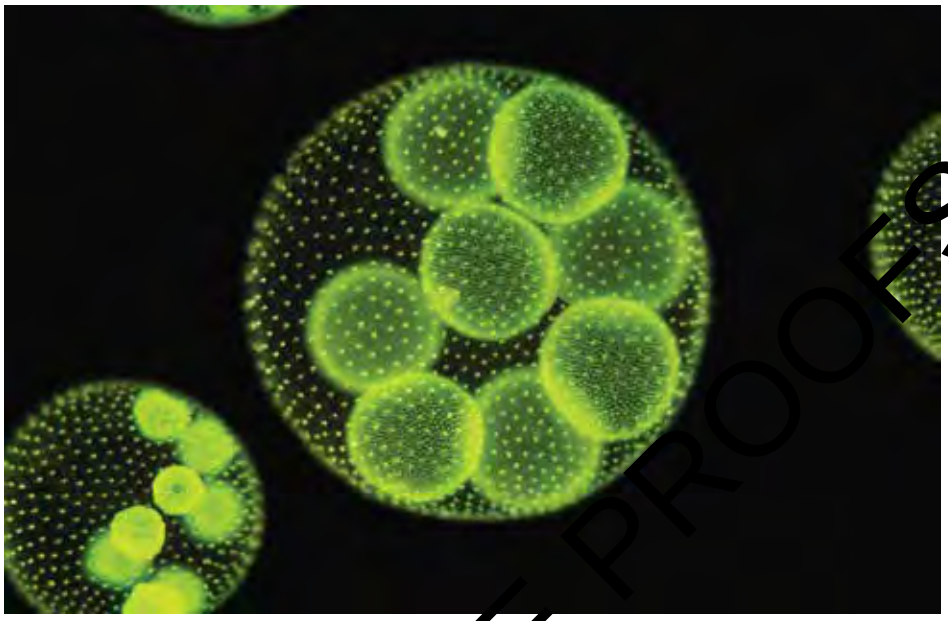


FIGURE 10.7 The freshwater alga *Volvox* sp. is found in temporary ponds and is an example of a colonial organism. *Volvox* can reproduce both sexually and asexually. Daughter colonies produced by asexual reproduction in summer are visible inside the spherical parent colonies. The daughter colonies are released into the water when the parent disintegrates. Because daughter colonies are produced asexually, all the daughter colonies within one parent colony are genetically identical to each other and to the parent colony.

The switch from asexual to sexual reproduction may occur in advance of a seasonal change to less favourable and more unstable conditions. For example:

- *Volvox carteri* is found in shallow pools that form during the spring rains but that dry out during the late summer. When the pools first form, this *Volvox* uses the asexual mode of reproduction to produce offspring that are clones of the single parent. However, not long before the ponds dry out, *Volvox* switches to sexual reproduction that involves genetic contributions (egg and sperm) from two parents. Sexual reproduction produces dormant zygotes that can survive through both the hot dry conditions of the summer and the cold conditions of winter. When the spring rains return and the ponds re-form, these zygotes emerge from their dormant state and give rise to a new generation of *Volvox carteri* that reproduce asexually until the ponds start to dry out again. And so the cycle continues.
- Aphids (see figure 10.8) reproduce asexually when conditions are favourable in terms of temperature and availability of food. When conditions become unfavourable, however, aphids switch to sexual reproduction as the temperatures fall and as the day lengths become shorter.

FIGURE 10.8 Aphids are insects typically found feeding on the sap of plants. Aphids use the asexual mode of reproduction during favourable conditions. When conditions become unfavourable, they switch to sexual reproduction. Note that these aphids are wingless. Remarkably, when aphids need to disperse, such as when their host plant becomes too crowded or when their food supplies are exhausted, they produce wings.

The advantage of sexual reproduction over asexual reproduction is that the offspring resulting from sexual reproduction are genetically variable. This variability equips a population to adapt better to changing conditions, because some of the new gene combinations created by sexual reproduction are likely to contribute to survival of some offspring.

However, when environmental conditions are favourable and resources are in plentiful supply, these species use asexual reproduction. Because the rate of offspring production by asexual reproduction is faster than by sexual reproduction, asexual reproduction can lead to a more rapid increase in population size. However, as noted above the disadvantage of asexual reproduction is that all the offspring of one parental organism are genetically identical to each other and to their single parent because they are the result of mitosis. This genetic uniformity means that, for example, if one offspring is susceptible to an infectious agent, all the offspring will be susceptible, or if one cannot tolerate drought, all will be drought intolerant. **Genetic uniformity reduces the chance of a population adapting to new environmental conditions.**

KEY IDEAS

- Reproduction is an essential characteristic of all living organisms.
- Two modes of reproduction exist: asexual and sexual.
- Asexual reproduction involves a single parental organism that produces offspring which are genetically identical to each other and to the parent.
- Asexual reproduction is faster, requires less energy and can led to rapid population growth in favourable and stable circumstances.
- Asexual reproduction has the disadvantage that it cannot produce any new genotypes to enable adaptation to changing environments.
- Some species can reproduce asexually or sexually depending on circumstances.

QUICK CHECK

1 How many parents are required for asexual reproduction?
2 What is the doubling time of the *N. meningitidis* bacteria?
3 How many new genetic combinations can be produced by asexual reproduction?
4 Name the mode of reproduction that:
   a produces clones of the parent
   b can increase more rapidly under favourable conditions
   c does not involve fertilisation
   d produces offspring that are genetically variable
   e involves mitosis.

Examples of asexual reproduction

Examples of asexual reproduction in which a single parent produces identical offspring include:

- binary fission in prokaryotic microbes
- splitting in single-celled eukaryotic organisms
- spore formation in fungi
- natural cloning in animals, for example
  - budding in sponges and corals
  - 'virgin birth' in insects
- vegetative reproduction in plants, as in runners, cuttings, rhizomes and suckers.

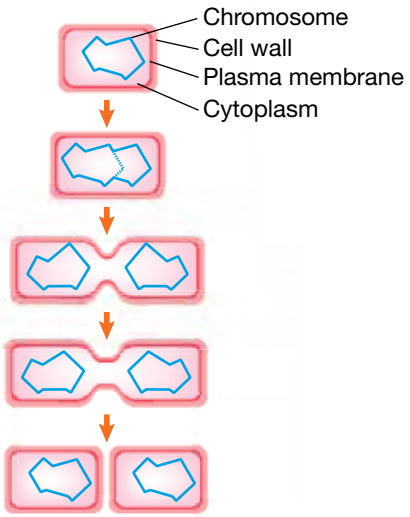


FIGURE 10.9 Binary fission in a bacterial cell. Replication of the circular DNA molecule is followed by cell lengthening and then its division into two. Why is this process an example of asexual reproduction?

Prokaryotes: binary fission

Microbes such as bacteria are unicellular prokaryotic cells. Multiplication of bacterial cells occurs by an asexual process of reproduction known as binary fission (*binary* = two; *fission* = splitting). The binary fission of a bacterial cell involves:

- replication of the circular molecule of DNA of the bacterial cell
- attachment of the two DNA molecules to the plasma membrane
- lengthening of the cell
- division of the cell into two via a constriction across the middle of the cell, so that each new cell contains one circular molecule of DNA (see figure 10.9).

The process of asexual reproduction by binary fission in bacteria is simpler and faster than asexual reproduction in eukaryotic organisms. Asexual reproduction in eukaryotes involves the more complex process of mitosis (refer to chapter 9) followed by division of the cytoplasm (cytokinesis). This process typically takes many hours to complete. Binary fission in some bacteria can be completed in about 20 minutes at room temperature. This means that if resources are available, one bacterial cell, through successive binary fissions over an 8-hour period, could produce 16 million descendants! This is an example of exponential growth and it reminds us why a bacterial infection, if not treated, can have serious outcomes.

Figure 10.10 shows a cell of the bacterial species *Escherichia coli* dividing by binary fission.

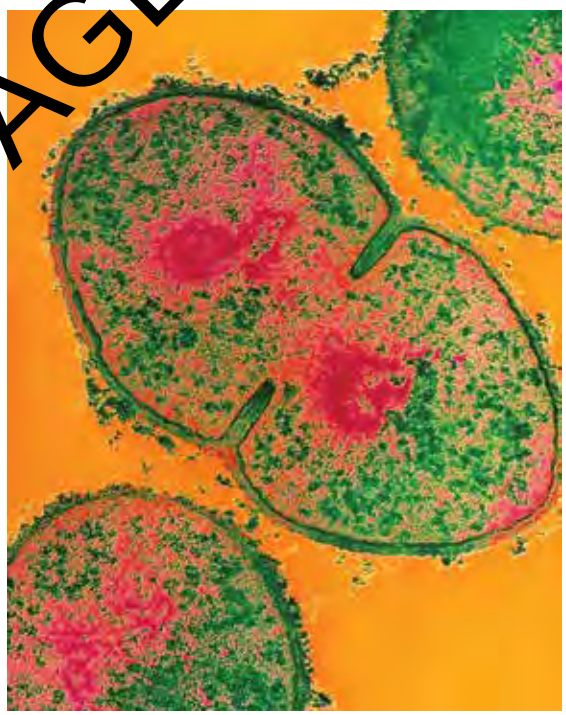


FIGURE 10.10 Transmission electron microscope image of a bacterial cell dividing by binary fission

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Binary fission
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ODD FACT

In prokaryotes the genetic material, DNA, is a naked circular molecule. In eukaryotes DNA is combined with proteins, extensively folded and organised into chromosomes.

Eukaryotes: asexual reproduction

Among the eukaryotic organisms — animals, plants, fungi and protists — many different forms of asexual reproduction occur. Let's look at some examples.

Let's split into two!

Some eukaryotic unicellular organisms, such as *Amoeba* (figure 10.11), *Euglena* and *Paramecium*, live in freshwater ponds and are less than pinhead-size. These unicellular organisms can reproduce asexually by splitting into two (see figure 10.12). Just to confuse matters, this process is also known as binary fission. However, the process of binary fission in these unicellular eukaryotes is different from that which occurs in bacteria. In eukaryotes, the formation of new cells by binary division involves the process of mitosis.

ODD FACT

Amoebae can also undergo **multiple fission**. Mitosis occurs repeatedly and many nuclei form within a single cell. Each nucleus becomes enclosed within a small amount of cytoplasm and forms a **spore**. Spores can later develop into new amoebae.

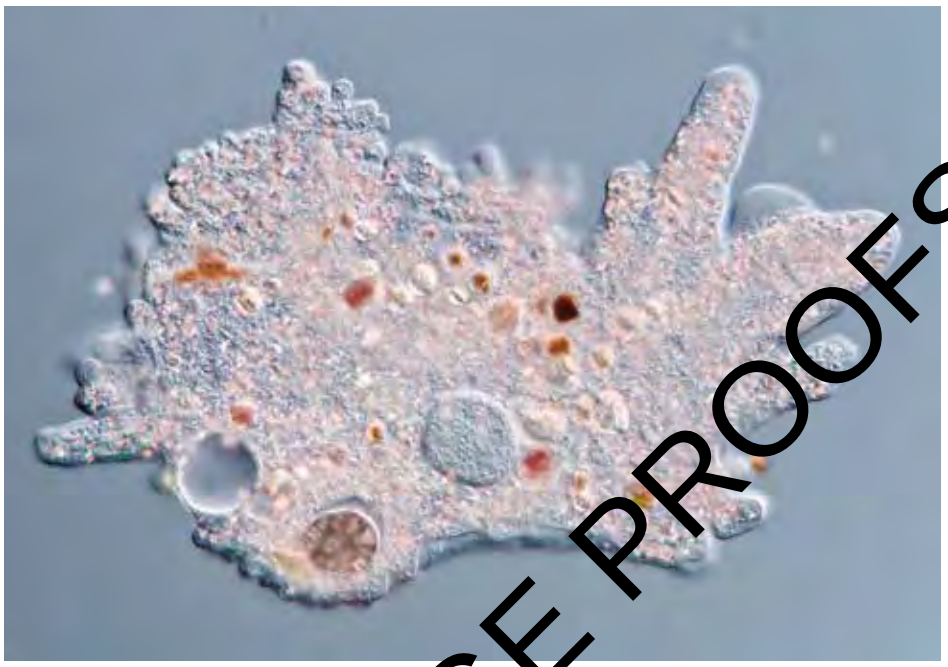


FIGURE 10.11 Phase contrast microscope image of an *Amoeba*

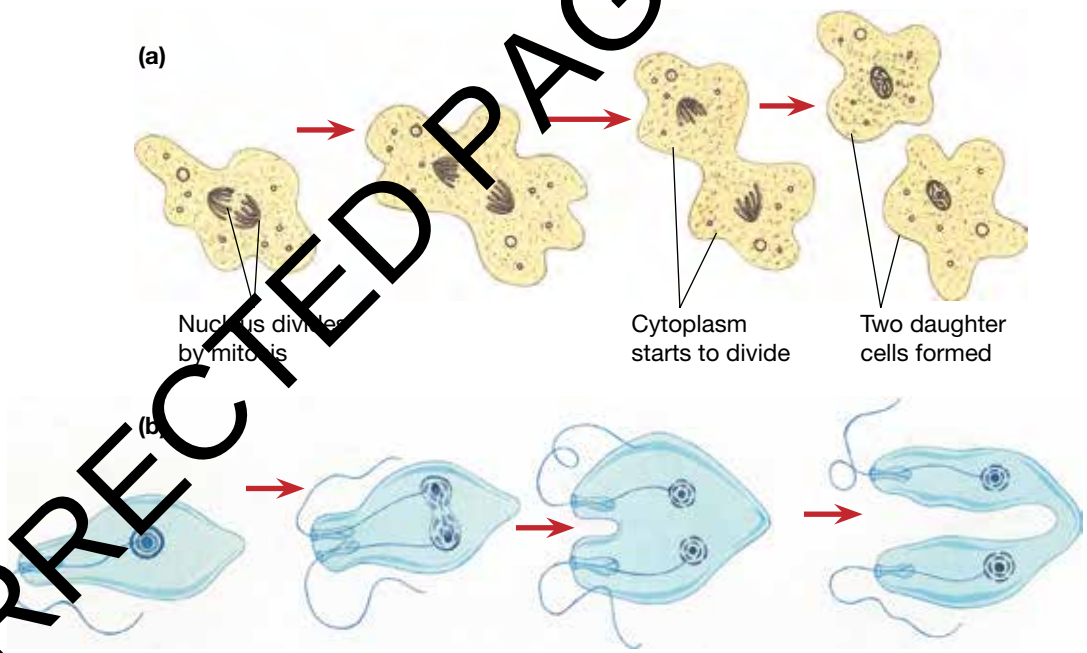


FIGURE 10.12 Binary fission or splitting in simple eukaryotes **(a)** Splitting into two in *Amoeba* sp., a unicellular organism. The cytoplasm divides after the chromosomes have replicated and separated during mitosis. Will the daughter cells be identical to or different from each other? **(b)** Splitting into two along a longitudinal axis, a process known as longitudinal binary fission, occurs in *Paramecium* sp., another unicellular eukaryote.

ODD FACT

Coral polyps can also reproduce asexually. Some bud, others grow new polyps from fragments that break off from a parent polyp and some divide longitudinally to form two new polyps, genetically identical to each other.

Simple multicellular animals, such as flatworms, anemones and coral polyps, can also reproduce asexually by splitting into two (see figure 10.13). Each of the parts then grows into a complete animal. This kind of splitting does not occur in other multicellular organisms because their structure is more complex, being built of many different tissues and organs.

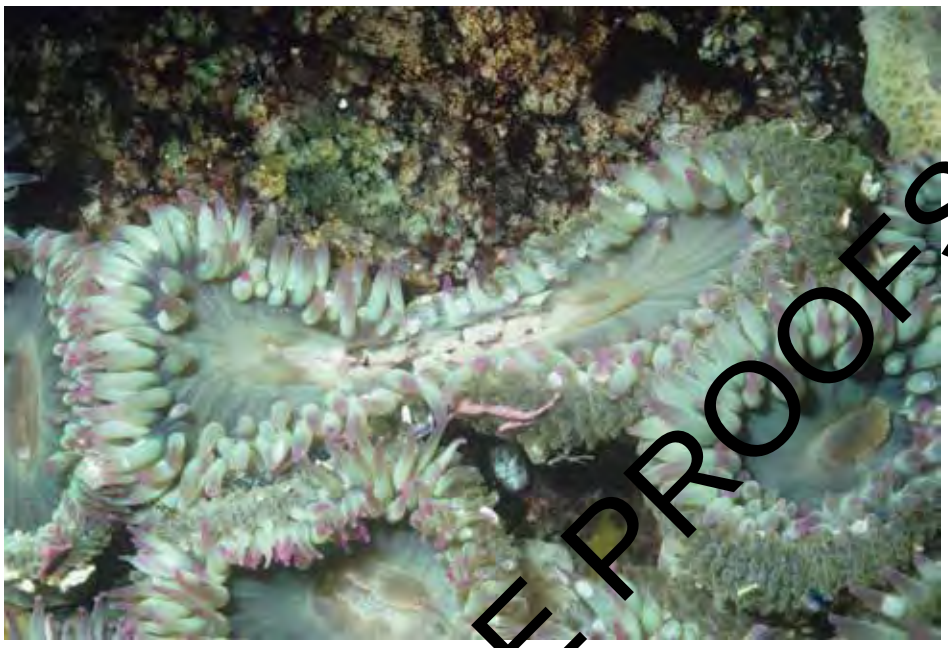


FIGURE 10.13 An anemone (*Anthopleura elegantissima*) in the process of reproducing by splitting in two. Note the narrowing (centre of image) that marks the point where it will split.

Budding to make more

Sponges are common in many marine habitats. Each sponge is made of thousands of cells but has no specialised organs or nervous system. Sponges are able to reproduce asexually from small groups of cells formed by mitosis that bud or break away from the main organism and are carried by currents to other locations where they settle and develop into new sponges. The small group of cells settles on some substrate; the cells reproduce by mitosis and develop into a new sponge. Other simple animals, such as *Hydra*, also undergo **budding** (see figure 10.14).

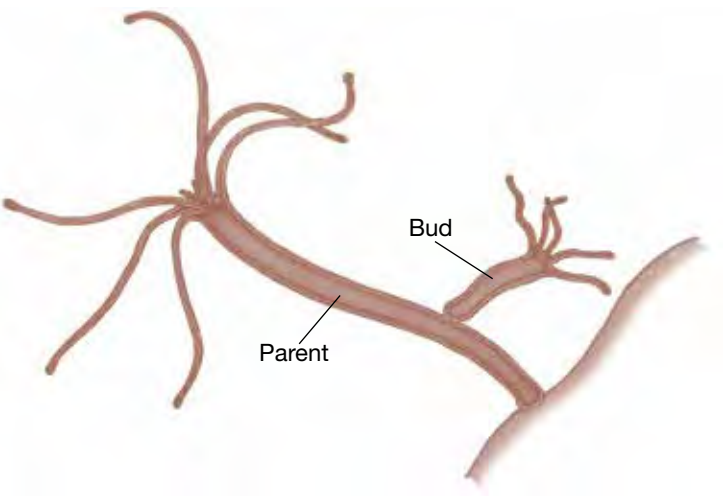


FIGURE 10.14 Asexual reproduction involving budding from one parent occurs in *Hydra*.

FIGURE 10.15 Adult female aphid giving birth. The numerous offspring have developed from unfertilised eggs. What is the name of this kind of reproduction?

Parthenogenesis

An unusual form of asexual reproduction in animals is **parthenogenesis** (*parthenos* = virgin; *genesis* = birth), which is also called virgin birth. Parthenogenesis is defined as reproduction without fertilisation, and almost always involves the development of an unfertilised egg. Offspring are produced from unfertilised eggs — no sperm is necessary. These eggs are produced by mitosis and develop into offspring identical to the female parent. This type of reproduction is seen in aphids when conditions are favourable (see figure 10.15). In contrast to other insects that typically lay eggs, aphids give birth to live young.

Parthenogenesis is seen in many invertebrate animals. It is rare in vertebrate species, but has been reported in several reptile species, such as whiptail lizards (see figure 10.16), and in some shark species.

FIGURE 10.16 *Aspidoscelis tesselata* is one of the many species of whiptail lizard that reproduce by parthenogenesis. Populations of this obligate parthenogen are all female.

Populations that reproduce using parthenogenesis are typically all-female. Parthenogenesis can be **obligate**, meaning that this is the only way in which a species can reproduce. This is the case for about one-third of the 50 plus species of whiptail lizard of the genus *Aspidoscelis*. These obligate unisexual lizard species consist only of females. Other species that show a complete absence of male contribution to reproduction are other reptiles including some snakes, rock lizards (*Lacerta* spp.) and Australian geckos (*Heteronotia* spp.).

In other species, parthenogenesis can be **facultative**, meaning that it is a reproductive strategy that is only used when required, such as when no males are around. When males re-appear, the species return to sexual reproduction. Facultative parthenogenesis has been reported to occur in komodo dragons (*Varanus komodoensis*). Offspring produced by female komodo dragons through parthenogenesis are always male. (We will explore this surprising fact in chapter 11.)

ODD FACT

The komodo dragon is the largest living species of lizard. Dragons can reach lengths of up to 3 m and have a body mass of up to 70 kg.

Spore formation in fungi

Spore formation is an important process in the asexual reproduction of some fungi (and also some algae). These spores produced are true asexual spores produced by mitosis. After dispersal, the spores develop into new organisms that are genetically identical to each other and to the parent.

The bread mould (*Rhizopus stolonifer*) provides an example of asexual spore formation in a fungal species (see figure 10.17). Spores are formed by mitosis in aerial structures called sporangia. When released from a **sporangium**, the spores are carried away by air currents. If a spore lands on a moist location, such as a slice of bread, the spores germinate and form a branching structure and, soon after, new sporangia containing spores develop. And so the cycle is completed.

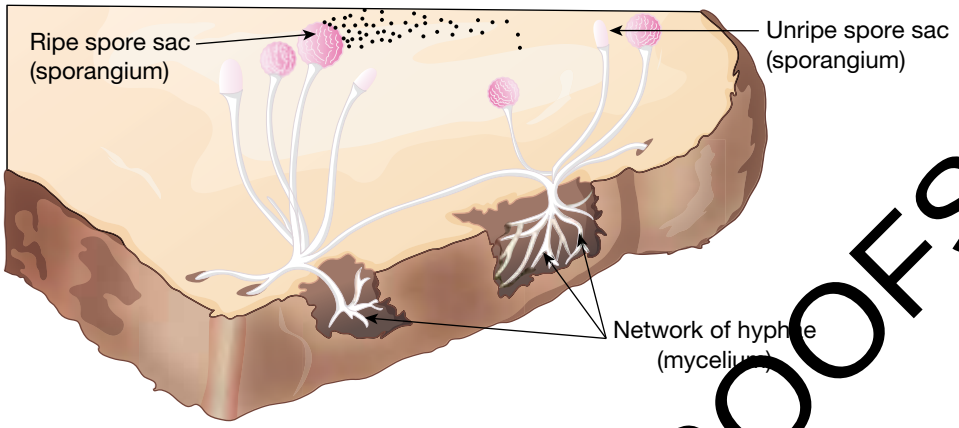


FIGURE 10.17 The bread mould fungus (*Rhizopus stolonifer*) is a common fungus. It reproduces asexually through spores that are windblown. Once a spore lands on a suitable substrate, it germinates and produces the fungal network, or **mycelium**. Note the 'stalks' that raise the sporangia above the substrate surface. Why is this important?

Plants such as mosses and ferns also produce spores as part of their life cycles. However, because the spores are produced by mitosis, not mitosis, the spores produced by one moss or one fern are not genetically identical to the plant that produced them, or to each other. Each spore then develops into a new plant, called a gametophyte, by a process of mitosis.

Asexual reproduction in plants

Asexual reproduction is common in plants. In plants, asexual reproduction is also called **vegetative reproduction**.

Runners

Over 10 years, one strawberry plant (*Fragaria ananassa*) grew into the strawberry patch in figure 10.18. How did one small plant grow into such a large patch? Strawberry plants have **runners**, special stems that grow over the ground. The runner grows away from the parent plant and, at alternate nodes on the runner, new buds give rise to roots, leaves, flowers and fruit (see figure 10.19).

Another example of a plant that spreads by runners — this time in water — is the water hyacinth (*Eichhornia crassipes*) (see figure 10.20). This is a declared noxious weed that infests wetlands, lakes and rivers in Australia.

A variation of 'runners' occurs in blackberry plants (*Rubus* spp.) that propagate when their long stems (canes) bend over and make contact with the ground. Shoots and roots grow from the point where the tips of the stems make contact with the ground.

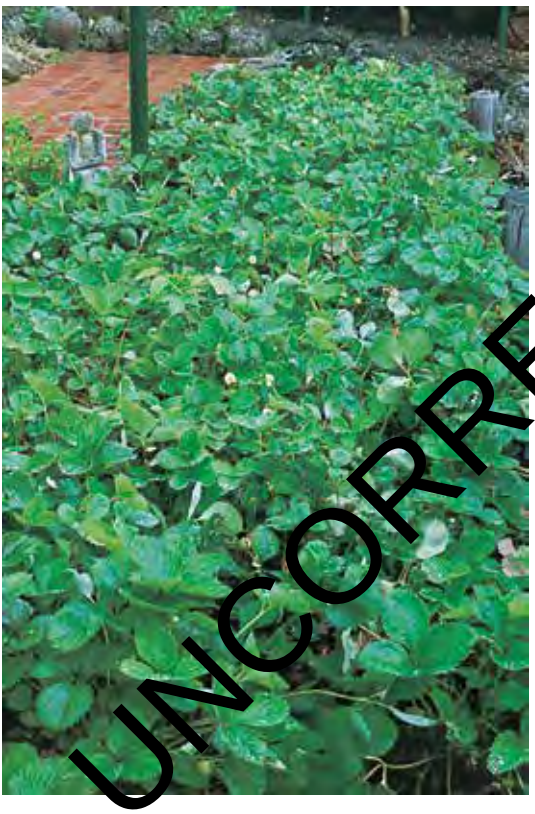


FIGURE 10.18 In 10 years, one strawberry plant grew by asexual reproduction into this strawberry patch.

FIGURE 10.19 The strawberry (*Fragaria ananassa*) has runners, special stems that grow over the ground.

FIGURE 10.20 The water hyacinth

As well as runners, other means of asexual reproduction in plants include:

- **cuttings**
- **rhizomes** (underground stems)
- **tubers** (swollen underground stems)
- **bulbs** (underground structures with short stems and many closely packed, fleshy leaves).

Some of these structures are shown in figure 10.21.

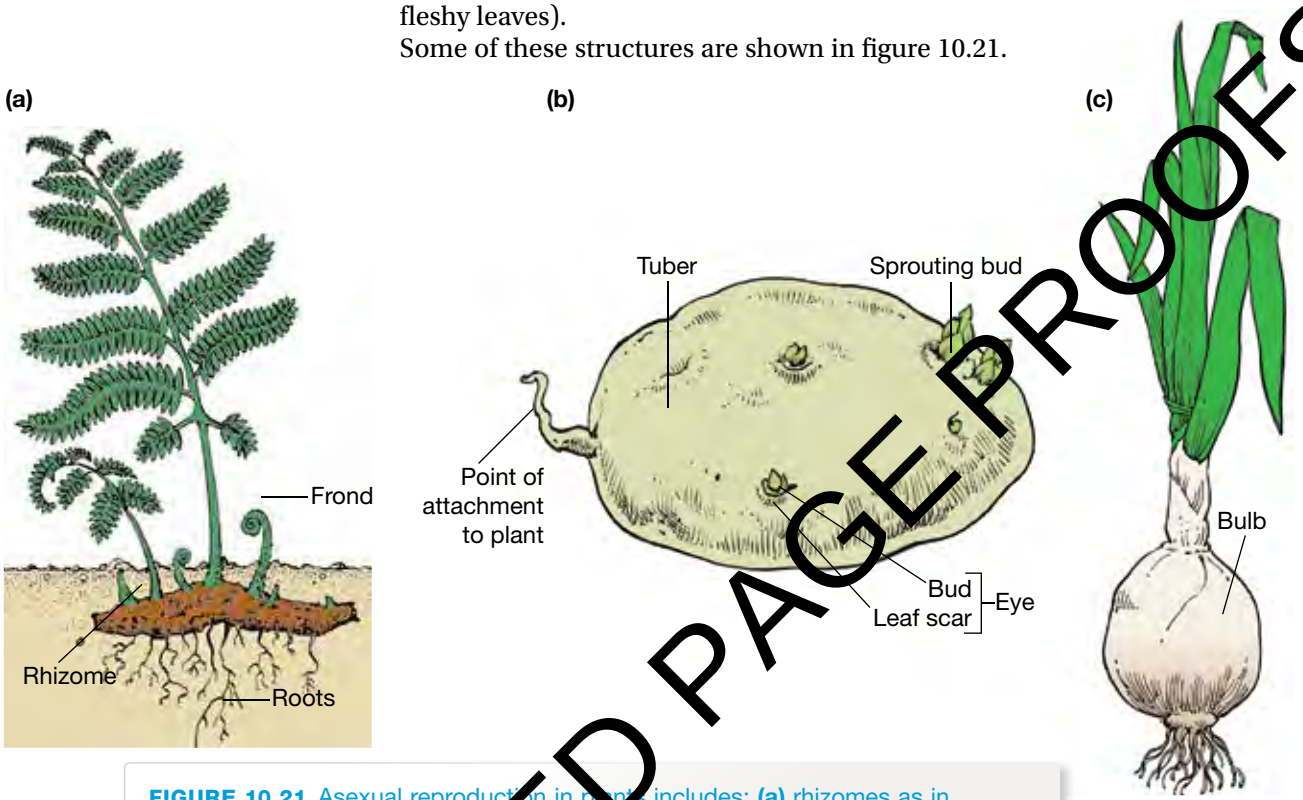


FIGURE 10.21 Asexual reproduction in plants includes: **(a)** rhizomes as in bracken and some grasses; **(b)** tubers as in potatoes; and **(c)** bulbs as in onions. In each case, the new plants are genetically identical to the parent plant.

Cuttings

With some plants, it is possible to clone them by taking cuttings of shoots, roots or leaves and planting them.

Rhizomes

Some plants propagate through underground stems or rhizomes (see figure 10.21a). Buds and roots sprout from nodes along a rhizome and produce new daughter plants. Rhizomes can be distinguished from plant roots by the presence of buds, nodes and often tiny scale-like leaves. Plants that propagate by rhizomes include garden plants, such as irises; grasses, such as kikuyu grass (*Pennisetum clandestinum*) and couch grass (*Cynodon dactylon*); the austral bracken, an Australian fern (*Pteridium esculentum*) (see figure 10.22); and many reeds. Rhizomes are typically thick in structure because they have a food reserve, mainly in the form of starch.

FIGURE 10.22 Austral bracken reproduces asexually from underground stems (rhizomes) when buds from the rhizome develop into new fronds. After a bushfire, austral bracken quickly becomes re-established in a burnt area. Can you suggest why?

ODD FACT

Most ferns are delicate and need moist, shady conditions to reproduce by sexual means. In contrast, austral bracken propagates asexually by rhizomes and thrives in exposed areas.

Suckers

Suckers are new shoots that arise from an underground root at some distance from a parent plant. Blackberry suckers can appear more than 2 m from the parent plant.

Plantlets without sex

The fern *Asplenium bulbiferum*, which is native to Australia and New Zealand, can reproduce asexually. Figure 10.23 shows the small **plantlets** that arise from the fern frond. A similar process also occurs in the plant *Bryophyllum* sp. (see figure 10.24). In both cases, **meristematic tissue** is the source of the cells that grow into plantlets. When they reach a particular size, the plantlets drop from the parent plant and take root.

ODD FACT

In New Zealand, *Asplenium bulbiferum* is commonly known as hen and chickens fern. In Australia, the common name of the same fern is mother spleenwort.

FIGURE 10.23 Asexual reproduction in the fern *Asplenium bulbiferum*. Note the new plantlets on the fern fronds.

FIGURE 10.24 New plants form by asexual reproduction on the leaf margin of *Bryophyllum* sp.

KEY IDEAS

- Asexual reproduction occurs by binary fission in prokaryotes.
- Asexual reproduction in all eukaryotes occurs through mitosis.
- Unicellular eukaryotes reproduce by binary fission that involves mitosis.
- Simple multicellular animals reproduce asexually through budding.
- Parthenogenesis is the development of offspring from unfertilised eggs.
- Certain fungi produce spores as part of their cycle of asexual reproduction.
- Various types of asexual reproduction occur in plants including runners, rhizomes and tubers.

QUICK CHECK

5 What is the key difference between binary fission in a microbe and the binary fission that occurs in an amoeba?
6 Starting with one bacterial cell, how many cells would be expected from six cycles of binary fission?
7 Identify two ways in which a plant might reproduce asexually.
8 What is the key cellular process that is involved in all cases of asexual reproduction in eukaryotic organisms?
9 You are told that a population consists of obligate parthenogens. State two additional correct statements that you could make about this population.

Technology: asexual reproduction

Reproductive technologies such as cloning involve methods of asexual reproduction in which the genetic information of new organisms comes from one 'parent' cell only. For many years, whole plants have been cloned by traditional methods, such as cuttings, but the horticultural industry **now uses the technique of plant tissue culture to clone plants in large numbers**.

Cloning in horticultural practice

Using the technology of plant tissue culture in the laboratory, many identical copies, or clones, of a plant can be produced starting from a small amount of tissue from one plant. This technique is used with ornamental plants, such as orchids and carnations, and Australian native plants, such as bottlebrush (*Callistemon* spp.), the flannel flower (*Actinotus helianthi*) and various eucalypts (*Eucalyptus* spp.). Tissue culturing can also be used with endangered or very rare plants, such as the Wollemi pine (*Wollemia nobilis*) since only a few specimens exist in the wild.

Figure 10.25a shows flannel flowers in tissue culture in a laboratory and figure 10.25b shows mass plantings of flannel flowers propagated by tissue culture.

Tissue culture cloning of plants has several advantages:

- Slow-growing plants can be produced in large numbers.
- Plants can be cultured all year round in controlled conditions of temperature and day length, rather than relying on seasonal growth.
- Virus-free tissue can be used to produce a large number of plants that do not carry the virus. (Viruses are responsible for many plant diseases that can affect commercial crops.)
- Cultured plants can be transported from country to country. The sterile conditions in which they are cultured ensures that the plants are pest free, so that lengthy quarantine periods are avoided.

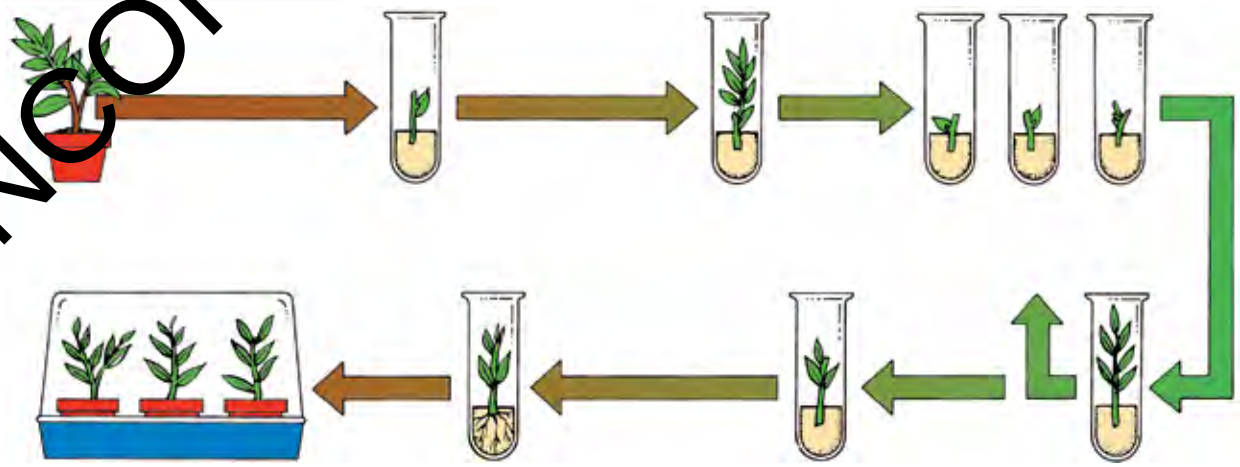
How does tissue culture work? Tissue culture starts with a small piece of a healthy plant such as a piece of leaf or bud or stem. The plant that supplies the tissue is selected because it has particular desirable characteristics, such as flower colour or disease resistance or timber quality.

FIGURE 10.25 **(a)** Flannel flowers in tissue culture **(b)** Large-scale bed plantings of flowers propagated by tissue culture

Pieces of a plant to be cultured must contain meristematic tissue because this is the only plant tissue that is capable of cell division by mitosis. The pieces of tissue are sterilised and placed in sterile test tubes containing a culture medium. The culture medium is a mixture of agar (jelly) and essential nutrients (see figure 10.25a). The pieces are treated with cytokinin, a plant hormone that stimulates shoot formation by mitosis.

The tubes are incubated at controlled temperature and day length. After a few weeks, new shoots appear. Each of these shoots is cut into several pieces and each piece is placed into a fresh culture tube. Again, treatment with cytokinin stimulates these pieces to produce more shoots. This process is called **subculturing** and it can be repeated several times. (If you began your tissue culture with one piece of tissue, after 1 month you could cut the tissue produced by tissue culture into five pieces and grow these in culture. A month later, you could repeat this process, giving you a total of 25 tissue cultures.) The process of subculturing multiplies the output from the original tissue selected. After the shoots have been subcultured a number of times, the hormone auxin is added to stimulate root production. Once roots develop, the small plants are complete with roots, stems and shoots. These small plants are removed from culture and planted in sterile compost and sand.

FIGURE 10.26 Tissue culture procedure. Here many *Eucalyptus* plants are produced from a parent plant selected for its genetically determined timber quality. Will the plants produced by tissue culture be expected to have this quality when they mature?



The success of tissue culturing of plants depends on the fact that asexual reproduction produces genetically identical clones of the parent, whether the parent is a whole organism or a tissue sample or even a single cell. This exact copying is a result of the precision of cell division by mitosis.

Artificial cloning of mammals

Reproduction in mammals in their natural setting is sexual, involving fertilisation of an egg by a sperm, and one fertilisation event typically produces a single offspring.

Artificial cloning of mammals is a recent development and several techniques have been used:

- cloning using **embryo splitting**
- cloning using **somatic cell nuclear transfer**.

Embryo splitting to make identical copies

Cloning by embryo splitting occurs when the cells of an early embryo are artificially separated, typically into two cell masses. This process mimics the natural process of embryo splitting that produces identical twins or triplets. Embryo-splitting technology has been used for stockbreeding for many years. It has become a relatively simple technique, but is limited to twinning. Typically, the embryos to be split are produced through in-vitro fertilisation (IVF), for example, the in-vitro fertilisation of a cow's egg by bull sperm. The parents are chosen because of desirable inherited commercial characteristics that they exhibit, such as high milk yield or high milk fat content in dairy cattle, or muscle formation or fat distribution in beef cattle. Using a very fine glass needle, **an embryo at an early stage of development is divided into two smaller embryos**. The small embryos from the splitting of one embryo are identical, as will be the adults that develop from them. Each small embryo is then implanted into the uterus of a surrogate female parent where embryonic development continues. Figure 10.27 shows an outline of this process.

The two embryos from the splitting of a single embryo can be termed demi-embryos.

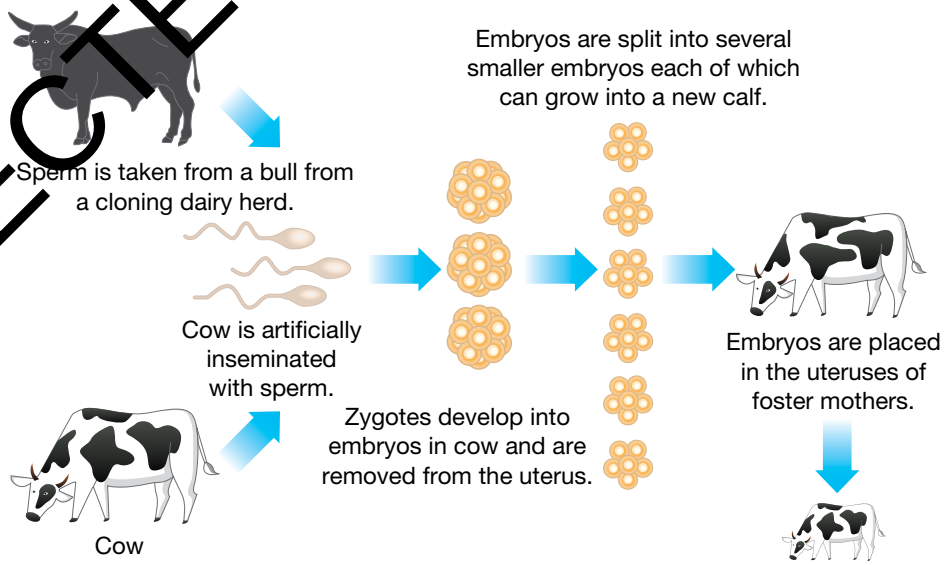


FIGURE 10.27 An outline of the process of embryo splitting to clone dairy cattle. The cow may first be treated with hormones to cause the release of several eggs (superovulation). Does the surrogate mother have any genetic contribution to the embryo?

Embryo splitting has been used for some years in the livestock industry. In cattle, for example, embryo splitting enables the genetic output from several matings of a top bull and a prize cow to be doubled. Instead of just one calf from each such mating, two calves can be produced. This process depends on the use of surrogate mothers.

The two offspring from the splitting of one embryo are *not* genetically identical copies of either the cow that produced the egg or the bull that provided the sperm

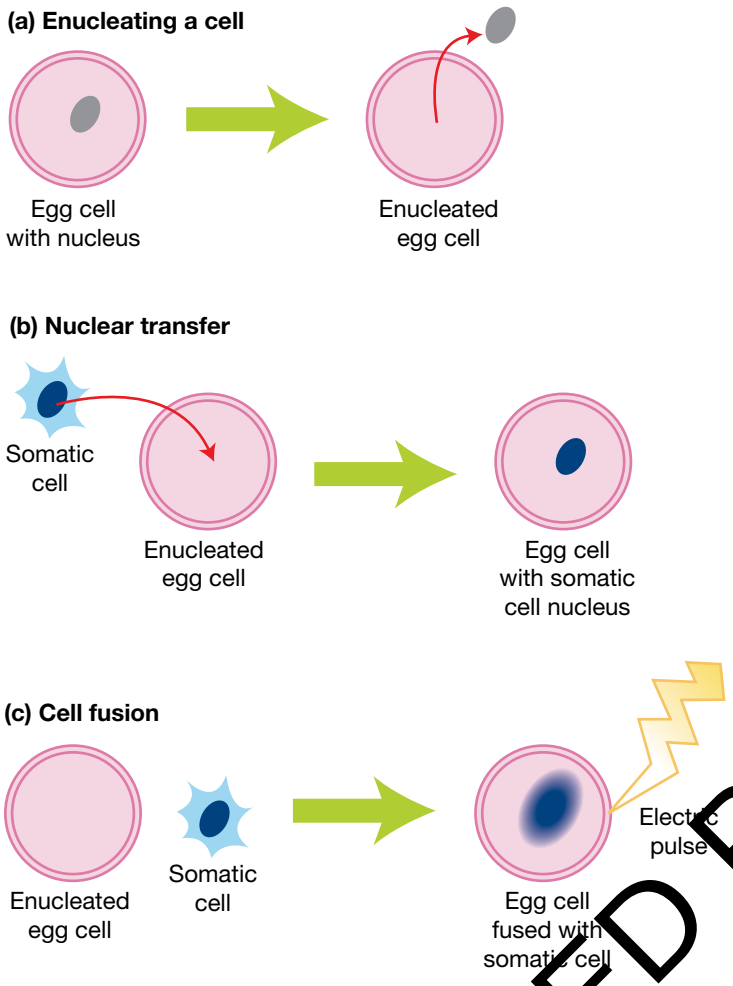


FIGURE 10.28 **(a)** Producing an enucleated cell **(b)** Nuclear transfer between two cells **(c)** Cell fusion. Fusion of two cells is commonly done using a short electric pulse.

used to produce the embryo that was split. The two offspring are genetically identical to each other and are identical copies of the *fertilised* egg from which the embryo came.

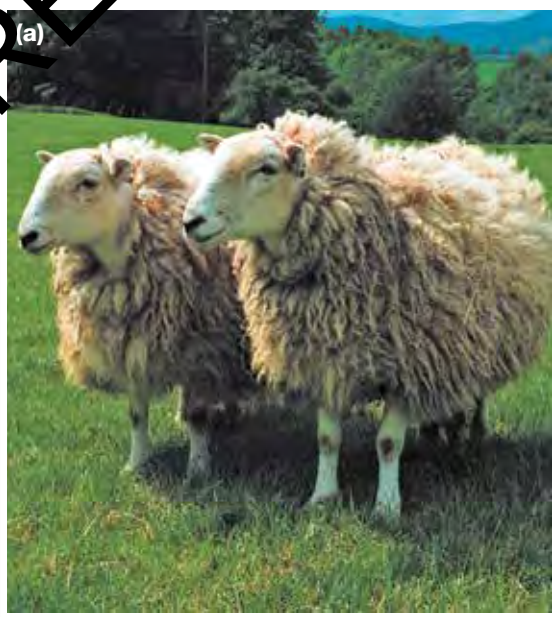
The eggs produced by one cow are not genetically identical to each other, nor are the sperm from one bull. This is because these gametes are produced by meiosis, not mitosis. As we will see in chapter 12, the process of meiosis juggles and re-assorts the genes of eggs and sperm. This means that the offspring from the splitting of embryos derived from different fertilised eggs from the same mating will be genetically different.

Cloning using somatic cell nuclear transfer

Some possibilities exist to manipulate cells and their nuclei. It is possible, for example, to:

- remove the nucleus from a cell (when this occurs the cell is said to be enucleated) (see figure 10.28a)
- transfer the nucleus from one cell to an **enucleated cell** to form a re-designed nucleated cell (see figure 10.28b)
- fuse a somatic cell with an enucleated cell (see figure 10.28c).

The birth of two sheep, Megan and Morag (see figure 10.29), in 1995 marked a significant scientific milestone. These two sheep were the first mammals ever to be cloned using nuclear transfer technology. Each of these **sheep developed from an unfertilised enucleated egg cell that was fused with an embryonic cell that contained its nucleus.** In each case, the embryonic cell used came from the culture of one embryonic cell line; as a result, Megan and Morag were identical twins.



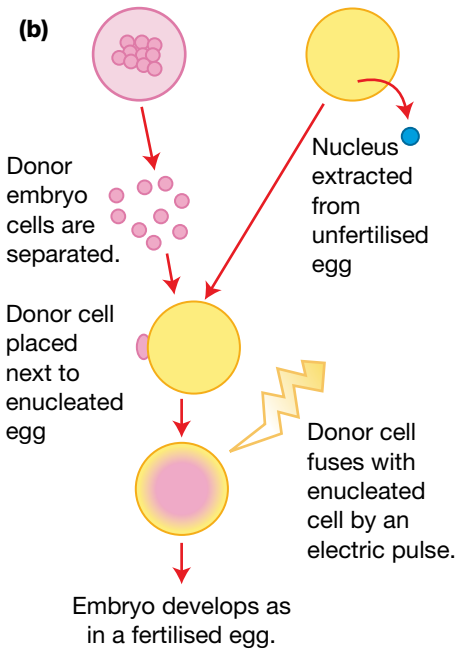


FIGURE 10.29 **(a)** Megan and Morag, two Welsh mountain ewes, born in August 1995 **(b)** Megan and Morag were not born as a result of a normal mating between a ram and a ewe, but were created using nuclear transfer cloning. What cells were involved in their production?

FIGURE 10.30 Dolly and her first lamb, Bonnie. Bonnie was born in April 1998 after a natural mating of Dolly with a Welsh mountain ram.

. . . and then came Dolly!

The scientific world was stunned after the announcement in February 1997 of the existence of Dolly, a Finn–Dorset female lamb born the previous year at the Roslin Institute in Scotland (see figure 10.30). The scientists who created Dolly were Ian Wilmut, Keith Campbell and their colleagues from the Roslin Institute that is part of the University of Edinburgh in Scotland.

Why was Dolly the lamb famous? Read what Ian Wilmut wrote about Dolly:

> Dolly seems a very ordinary sheep . . . yet as all the world acknowledged, . . . she might reasonably claim to be the most extraordinary creature ever to be born . . .
>
> Dolly has one startling attribute that is forever unassailable: *she was the first animal of any kind to be created from a cultured, differentiated cell taken from an adult.* Thus she confutes once and for all the notion — virtual dogma for 100 years — that once cells are committed to the tasks of adulthood, they cannot again be totipotent.
>
> (*Source:* I Wilmut, K Campbell and C Tudge, *The Second Creation: Dolly and the Age of Biological Control*, Harvard University Press, Cambridge, Mass., 2000)

While cloning via nuclear transfer had occurred successfully in the past, those earlier cases involved embryonic or fetal cells, never adult somatic cells. The use of **adult somatic cells**, such as skin cells, to construct new organisms represents remarkable human intervention in the evolutionary processes. Through this means, cells from sterile animals or from animals past their reproductive period, or even stored cells from dead animals, can provide all the genetic information of new organisms. In nature, the normal evolutionary processes would not allow these events to occur.

Totipotent refers to a cell that is able to give rise to all different cell types.

ODD FACT

Dolly was named in fun after Dolly Parton because she was derived from an udder (mammary gland) cell.

How was Dolly created?

The artificial cloning of mammals involves:

- obtaining the nucleus from a somatic (body) cell of an adult animal — this is the 'donor' nucleus
- removing the nucleus from an unfertilised egg cell, typically of the same species — this is the enucleated egg cell
- transferring the donor nucleus into the enucleated egg cell
- culturing the egg cell with its donor nucleus until it starts embryonic development
- transferring the developing embryo into the uterus of a surrogate animal where it completes development.

The genetic information in the cloned animal comes from the nucleus of the adult body cell and so the genotype of the cloned animal is determined by the donor nucleus, not by the egg into which the nucleus is transferred.

The procedure in the case of Dolly is shown in figure 10.31. An unfertilised egg from a Scottish Blackface ewe had its nucleus removed. A cell was taken from the culture of mammary cells derived from the udder (mammary gland) of a Finn–Dorset ewe. Using a short electric pulse, the cultured mammary cell was fused with the enucleated egg cell to form a single cell. This reconstructed cell was cultured for a short time and was then implanted into the uterus of a surrogate Blackface ewe where the embryo developed. At 5 pm on 5 July 1996, this surrogate Scottish Blackface ewe gave birth to Dolly, a Finn–Dorset lamb, the first mammal to be produced by cloning using an adult somatic cell.

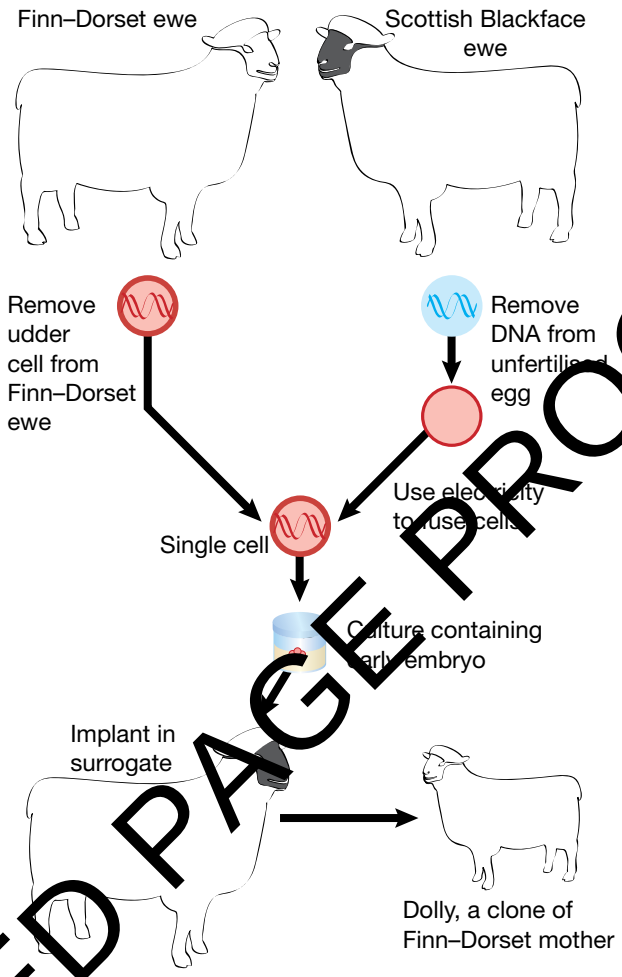


FIGURE 10.31 Technique of animal cloning by somatic nuclear transfer

After Dolly — what next?

Who are Matilda, Suzi and Mayzi, cc and Snuppy?

- Matilda the sheep was the first lamb to be cloned in Australia and was born in April 2000 (see figure 10.32a).
- Mayzi and Suzi (see figure 10.32b) were Australia's first calves to be artificially cloned from the skin cells of a cow fetus. Mayzi and Suzi are identical twins but were born two weeks apart in April 2000. Why were they not born on the same day?
- cc (short for carbon copy) was the first cat to be artificially cloned using a cumulus cell from an adult female cat, Rainbow, as announced by a group of US scientists in February 2002 (see figure 10.32c).
- Snuppy, the Afghan hound, was the first dog to be artificially cloned from an ear cell of a 3-year-old Afghan hound, as announced by a group of South Korean scientists in August 2005 (see figure 10.32d). Snuppy is short for ***S***eoul ***N***ational ***U***niversity pu***ppy***.

study on
Unit 2
AOS 1
Topic 2
Concept 4
Clones in agriculture and horticulture
Concept summary and practice questions

ODD FACT

At the time of birth of the cloned calf Second Chance, the bull First Chance that provided the donor nucleus from one of his somatic cells was dead.

Cloning: the downside

The success rate in initiating development of the egg cell after transfer of the donor nucleus is low. For example, in the case of an artificially cloned calf, known as Second Chance, 189 implantations were made into surrogate cows before a pregnancy was achieved. This case, however, was remarkable because the adult cell that provided the donor nucleus came from a 21-year-old Brahman bull called First Chance. This was an extremely old adult cell to use as the starting point for cloning. Because of testicular disease, First Chance had been castrated so that he was sterile when one of his body cells was successfully cloned.

FIGURE 10.32 A picture gallery of mammalian clones since Dolly: **(a)** Matilda, the first lamb to be cloned in Australia, was born by caesarean section at the Turretfield Research Centre of the South Australian Research and Development Institute (SARDI). She is pictured here with Dr Tania Peura, one of the scientists responsible for the achievement. **(b)** Suzi, one of two genetically identical Holstein calf clones derived from the skin cell of one cow fetus. **(c)** cc, shown on the right at 1 year old, was the world's first cat produced by somatic cell cloning, using a cumulus cell from Rainbow (left). **(d)** Snuppy, the world's first dog produced by somatic cell cloning, is shown with the Afghan dog that supplied the ear cell (left) and his surrogate mother, a Labrador (right).

ODD FACT

One estimate is that the 'ends' (telomeres) of human chromosomes progressively shorten by tens or hundreds of base pairs per year.

ODD FACT

Dolly's stuffed remains are now on display in the Royal Museum in Edinburgh.

The kitten cc, produced by somatic cell cloning, was the only one of 87 embryos implanted into surrogate mothers that survived to term. To get Snuppy, 123 dog embryos were surgically implanted into surrogate females and, of these, only three survived for a significant period, with one dying before birth, one dying soon after birth, and the sole survivor being Snuppy. Dolly was the only live birth from a series of 277 cloned embryos. Clearly, somatic cell cloning is presently far from routine, with fewer than 1 per cent of the cloned embryos surviving beyond birth. Of the clones that survive beyond birth, many have abnormalities that can cause death early in life. One institution reported in 2003 that, for every healthy lamb clone born, about five had abnormalities. Abnormalities reported include impaired immune system function and the 'large offspring syndrome' in which clones have abnormally large organs.

There is evidence that, each time a mammalian cell divides, the specialised 'ends' of their chromosomes lose some DNA base pairs and become shorter. These 'ends', which are known as **telomeres**, do not carry structural genes. Some scientists suggest that the shortening of the chromosome ends is

studyon
Unit 2
AOS 1
Topic 2
Concept 5
Issues associated with cloning
Concept summary and practice questions

associated with ageing. Will ageing be more rapid in a cloned animal that originates from an adult cell that already has shortened chromosome 'ends' than in a normal organism? The death of Dolly in February 2003 suggested that this may be the case. Six-year-old Dolly was put to sleep because of a deteriorating lung disease and arthritis, unusual conditions for a sheep of Dolly's age and one that was housed indoors, since sheep can live for about 12 years. Matilda, the cloned lamb (see figure 10.32a) that was born in March 2000, died less than 3 years later. However, this question remains unanswered.

Attitudes to cloning

Public attitudes to animal cloning are mixed. Some people support the concept because they believe that it will benefit people by providing a source of tissues for transplantation or other products. Other people oppose the concept for various reasons, such as their belief that cloning is interfering with nature.

When people are questioned about the cloning of human beings, there is a very high level of opposition to it. Some governments, including Australia's, have banned experiments directed to producing human clones, and leaders of some religious groups have opposed human cloning. The *Prohibition of Human Cloning Act 2002*, passed by the Australian Parliament in December 2002, bans human cloning. This Act took effect on 16 January 2003 and was amended in 2006.

ODD FACT

Under the *Prohibition of Human Cloning for Reproduction and the Regulation of Human Embryo Research Amendment Act 2006* (Cwlth), the maximum penalty for offences relating to human cloning is 15 years imprisonment.

KEY IDEAS

- Artificial cloning of plants involves subdividing cultured plant tissue.
- Cloning of plants produces organisms that are genetically identical to each other and to the original cultured plant tissue.
- Artificial cloning of mammals is a new technology of asexual reproduction.
- Two types of artificial cloning techniques are embryo splitting and nuclear transfer.
- Embryo splitting involves the artificial separation of embryo cells in vitro.
- Nuclear transfer involves the transfer of a nucleus from an adult somatic cell to an egg cell that has had its own nucleus removed.
- Legislation of the Australian Parliament prohibits human cloning.

QUICK CHECK

10 Identify whether each of the following statements is true or false.
- **a** Cloning mammals involves fusing an intact egg cell with an intact somatic cell.
- **b** The genotype of a cloned mammal is determined by the egg cell.
- **c** An enucleated cell is one that has had its nucleus removed.
- **d** Dolly was produced by a process of embryo splitting.
- **e** Megan and Morag were produced by a process of cloning using nuclear transfer.
- **f** Cloning of mammals uses a different technique from that used in cloning plants.

BIOCHALLENGE

1 Figure 10.33 shows five calves: Lily, Daffodil, Crocus, Forsythia and Rose. These calves are genetically identical and are the same age. These calves were produced through the use of a particular reproductive technology.

FIGURE 10.33 Five genetically identical calves — or more correctly, heifers

a Consider the possible reproductive technology that produced these five calves:
   i Could the five calves be the products of cloning by embryo splitting, where the embryos developed from several fertilised eggs from the mating of the same cow and bull? Give a reason for your decision.
   ii Could the five calves be the products of cloning by nuclear transfer using adult somatic cells of one particular animal? Give a reason for your decision.

b Assume that the calves are indeed the products of cloning by nuclear transfer with a cow or a bull the source of the adult somatic cells used for cloning? Give a reason for your decision.

c Are surrogate animals required in either or both of the procedures referred to in question 1a and b. Briefly explain.

2 Examine figure 10.34. Flatworms have a remarkable power of regeneration. If cut into several pieces, each piece has the ability to regenerate the missing parts of the body.

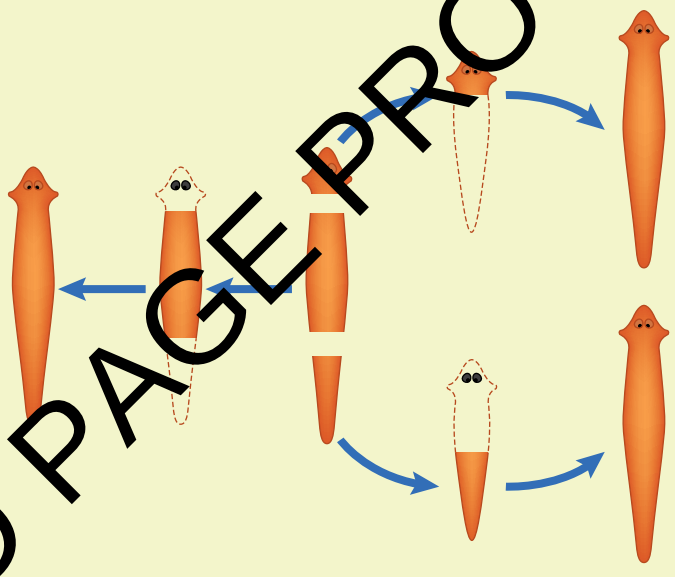


FIGURE 10.34 Regeneration in flatworms

a What cellular process is essential for and underpins this regeneration?

b The degree of regeneration in flatworms is extreme. Other animals can carry out more limited regeneration. Give an example of an animal that can regenerate one part of its body that is lost.

Chapter review

Key words

adult somatic cells
asexual reproduction
binary fission
budding
bulbs
clone
cuttings
doubling time
embryo splitting
endotoxin
enucleated cell
facultative parthenogenesis
genetic variation
lumbar puncture
meninges
meningitis
meningococcal disease
meningococcal sepsis
meristematic tissue
mitosis
multiple fission
mycelium
obligate parthenogenesis
parthenogenesis
plant tissue culture
plantlets
rhizomes
runners
somatic cell nuclear transfer
sporangium
spore
subculturing
suckers
telomeres
totipotent
tubers
vegetative reproduction

Questions

1 **Making connections** ➜ Use at least eight chapter key words to draw a concept map. You may use other words in drawing your map.

2 **Solving problems** ➜ Refer to figure 10.10, which shows binary fission in the bacterial species *E. coli*.

Assume that the time for binary fission in these bacteria is an average of 20 minutes at 15 °C.

Starting with 10 bacteria, about how many bacteria would be present at the end of two hours of binary fission?

The rate of binary fission doubles (or halves) for each rise (or fall) of 10 degrees in temperature. Assume that, at 25 °C, binary fission becomes twice as fast and is completed in 10 minutes. Assume that, at 5 °C, binary fission is slowed and requires 40 minutes for completion.

a At 25 °C, starting with 10 bacterial cells, how many bacterial cells would be present after 2 hours?
b At 5 °C, starting with 10 bacterial cells, how many bacterial cells would be present after 2 hours?
c By what process do these bacteria reproduce?

3 **Demonstrating understanding and communication** ➜ Give an explanation in biological terms for each of the following observations.

a Cooked meats should be stored in a refrigerator, rather than at room temperature.
b After a bushfire, one of the first plants to re-appear is the austral bracken (*Pteridium esculentum*).
c An amoeba can be considered to be immortal (unless it is eaten by a predator).
d Populations of some species of whiptail lizard are entirely female.
e Some species can reproduce without fertilisation.
f An infection of *Neisseria meningitidis* bacteria in the blood can cause a person to go into septic shock within hours after the first symptoms appear.

4 **Demonstrating knowledge** ➜ Give an example of an organism in which you would expect to find or see the following.

Sporangia
b Longitudinal binary fission
c Tubers
d A switch from asexual to sexual reproduction

5 **Demonstrating knowledge and understanding** ➜ Figure 10.35 shows part of a lily (*Canna* sp.) pulled from the ground. The dark purple vertical part is a stem that is almost all above the ground, while the remainder of the structure is below ground.

FIGURE 10.35 Part of a lily (*Canna* sp.) pulled from the ground

a What is this below-ground structure?
b List the evidence that you used to make your decision.
c What function does this structure serve?

6 Applying understanding and evaluating alternatives ➜ The occurrence of facultative parthenogenesis in some reptile populations was unexpected, for example, in the komodo dragon.
a What is facultative parthenogenesis?
b How does it differ from obligate parthenogenesis?
c Identify an example of a reptile that is an obligate parthenogen.
d A female komodo dragon in a zoo has not had recent contact with any males. She produces some eggs and a live baby dragon hatches from one of the eggs. One person said that this birth could be explained as due to sperm that was stored in the female's reproductive tract. Another person said that the birth is a case of parthenogenesis. What data would be needed to decide whether or not the baby dragon was a true 'virgin birth'?

7 Demonstrating knowledge and understanding ➜ A means of reproduction used by some plants is the formation of underground bulbs. Bulbs are formed by parent plants during a growing season and, at the end of that time, the parent plants typically die back.

Examine figure 10.36 that shows the typical structure of a bulb. The apical bud will give rise to leaves and a flower; the lateral buds will produce shoots.

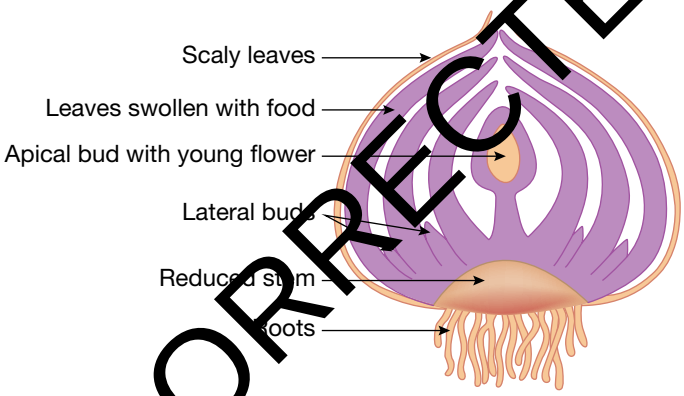


FIGURE 10.36 Typical structure of a bulb

a What parts of the new plant are present in a bulb?
b What mode of reproduction does bulb formation exemplify?
c What role do the leaves within a bulb serve?
d What cellular process will transform the embryonic plant within the bulb into a mature plant?
e Give the name of a bulb that might be part of a meal — raw or cooked.

8 Discussion question ➜ Cloning of mammals using the technique of somatic cell nuclear transfer has a very low success rate. One study has identified the success rate as between 0.1 and 3.0 per cent.
a Consider the various steps involved in this technique, and identify what points the technique could fail.
b Use the success rate given above to identify the maximum number of successful live births expected in 1000 nuclear transfers were carried out. What is the minimum number?
c What were the success rates for the following cloned mammals?
i Snuppy, the dog
ii Dolly, the sheep
iii Second Chance, the bull
iv cc, the cat
d Some people see somatic cell nuclear transfer as a means of contributing to the conservation of endangered mammalian species. Their view is that tissues in cryogenic storage from long-dead mammals of an endangered species may hold valuable genes. Using these cells to clone an endangered mammal might enable the genes to be brought back into the current population. Other persons reject this concept and say that preserving endangered species requires preserving them in their habitats. Discuss these alternatives with your classmates.