Cell division

Maintenance of organisms requires growth and repair

How does a single fertilised egg cell become a large, complex, **multicellular** organism? How did we develop from the tiny embryo inside our mothers? This is the result of both growth and development.

Growth

Growth of an organism occurs as a result of increasing the *number* of cells in the body (**cell division**) and increasing the *size* of each cell already there (*cell enlargement* or *elongation*). Growth and development involves four phases:

1. cell division
2. cell enlargement
3. assimilation
4. differentiation.

(Some of these we have already addressed in earlier chapters. This chapter will concentrate mainly on cell division and tie it in with the other phases.)

Cell division

Cells can only arise from pre-existing cells. Cell division is essential for the *maintenance* of organisms, both for the continued *growth* of organisms and also for the *repair* of damaged or worn out cells within them. Cell division is the process by which cells give rise to other cells. One cell replicates its genetic nuclear content exactly and then divides to become two cells, distributing one full set of genetic material to each cell—it is essential for every body cell in an organism to contain the full complement of genetic material if it is to function properly.

Assimilation

These new cells now need to enlarge until they are equal in size to the original cell. *Assimilation* of material from the products of digestion in animal cells, or from photosynthesis in plant cells, supplies new cells with the material that they need for cell enlargement.

Cell enlargement

Most cells increase in size as a result of the assimilation of new materials into the boundaries and cytoplasm. In plant organs such as the root, this cell *enlargement* or *elongation* takes place in a particular area, the zone of elongation, just behind the dividing cells near the tip of a root. Cell elongation may also involve the intake of water, particularly in plant cells, resulting in an increase in the size of the vacuole. If the increase in size is due only to water absorption, it may be temporary, but if it is accompanied by assimilation, it is permanent. Growth refers to a permanent increase in the size of living things.

To scientifically measure growth in an organism, the most accurate method involves measuring an increase in its dry mass. Because it is unethical to maintain large colonies of animals and then kill and dry them, *dry mass* is used to measure growth in plants, and an increase in *height and wet mass* in animals is measured.

Differentiation

The differentiation of cells follows cell enlargement, resulting in an increase in the complexity of an organism, as cells with different structural features develop to enable them to perform their functions more effectively. As a result, a variety of different tissues form, each with a special function; that is, a *division of labour* occurs amongst the cells.

Repair

Cells in our bodies constantly need repair or replacement. If we fall and graze our skin, or the heat of the sun in summer burns the leaves of plants, or a tail is ripped from a lizard, the need for *repair* of these tissues is evident. Continuous *maintenance* of the body parts of an organism may not seem as obvious, but is easier to understand if we think of our own bodies. For example, in humans, red blood cells have a life span of only three months and so they need to be replaced on an ongoing basis; skin cells near the surface of the skin die and slough off continuously (each time we rub our hands together we lose thousands of dead skin cells), and these are only a few of the cell types that need to be constantly replaced. Therefore cell division is important not only for growth, but also for repair and maintenance to replace old, worn-out cells in living organisms.

Where mitosis occurs

5.1

- ***identify the sites of mitosis in plants, insects and mammals***

TR

Where mitosis occurs worksheet

Although every cell in an organism has the potential to divide by **mitosis**, in reality, cell division occurs only in certain cells in mature multicellular organsisms. Living bodies have control mechanisms to ensure that only those cells required to divide do so. If cells divide in an uncontrolled manner, tumors or cancer may result.

Embryos

Most multicellular organisms start life as a single fertilised egg cell which grows into an embryo. It continues its development and eventually grows into an adult. During embryonic development, there is continual mitotic division and growth of all cells, starting with the division of a single fertilised egg into two identical cells which then divide into four and so on, until a ball of cells results. This ball of cells continues to divide by mitosis and eventually a variety of tissues begin to differentiate, until the young organism begins to closely resemble the adult it will eventually become. This growth and development or *life cycle* may occur in a continuous manner, or it may involve very noticeable changes in form—**metamorphosis** in some animals, such as insects, or an alternation of generation in plants. In all forms, *mitosis* followed by *differentiation* is the driving force behind embryo growth and development.

In mature organisms not all cells continue to divide. As cells differentiate and specialise, some lose the ability to divide by mitosis. Those cells that are able to divide occur at particular locations within the adult body. The tissue involved is known as **meristem** in plants, but is not given a generalised term in animals, although some cells are referred to as stem cells. Growth occurs in two directions: growth in length (height) is termed *primary growth*, whereas growth in girth (width or diameter) is termed *secondary growth*. Particular dividing cells give rise to these forms of growth in mature organisms. (See Fig. 5.2.)

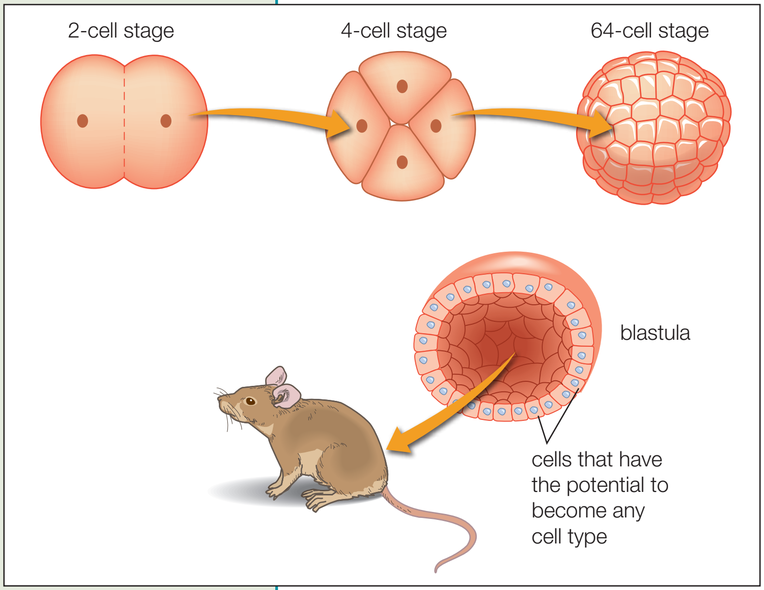

Figure 5.1
Early stages of mammalian embryonic development: Division of embryonic stem cells at early stages

Plants

Localised cells which are actively involved in mitotic division in plants, termed *meristematic tissue* or *meristems* are found at the following locations (see Fig. 5.2a):

- **apical meristems** are growing points near the tips of roots and stems (*apex* = top or tip). They result in *growth in length* (primary growth)
- *buds* near the tip contain meristematic tissues that divide by mitosis and give rise to *lateral branches*
- **cambium** is meristematic tissue that divides by mitosis, resulting in growth in diameter (secondary growth) in both stems and roots and allows young leaves to grow. There are two types:
  —*vascular cambium*, which occurs between xylem and phloem of vascular bundles in stems and gives rise to the woody tissue common in many trees and shrubs
  —*cork cambium*, which occurs just below the epidermis of stems and gives rise to cork cells and the bark of woody trees
- **pericycle** is a special layer of meristematic tissue in plant roots and is responsible for the development of *branch roots*.

(A tip for remembering the above tissues—you simply need to remember your 'abc': *a* is for apical mersitem, *b* for bud meristem, *c* for cambium and well, perhaps *d* could be an upside down *p* for pericycle!)

Mammals

Some parts of mature mammalian bodies require constant replacement, while others require no replacement or are unable to be replaced. For example, skin cells are constantly being replaced, but if a nerve cell is destroyed, it is not replaced because nerve tissue cannot divide once it has fully differentiated. Active centres of cell division occur at several locations in mature mammalian bodies. The fastest cell replacement rates occur in dividing tissue in the following locations (see Fig. 5.2c):

- cells in the basal layer of the *skin* and *protective layers* (such as cells that give rise to hair, scales, fingernails, feathers, cornea of the eye)
- *bone marrow* which produces blood cells
- cells lining the *digestive tract*.

Cells which divide, but have a slower replacement rate, are:

- liver cells
- bone cells—growth plates in bones result in an increase in the length of long bones, and therefore height in upright mammals like humans, until they become sexually mature, at which stage primary growth shuts down and secondary bone growth occurs. Once adulthood is reached, living bone and cartilage cells found in clusters within bone tissue and cartilage can also divide to repair damaged or broken bones.

As cells age, their ability to divide is impaired and cell division slows down as a natural part of ageing.

Insects

Insects show a different type of development to that of plants and mammals. As mentioned before, their growth and development involves metatmorphosis, a change in form (and a change in organs when one stage of the life cycle changes into another). (See Fig. 5.2b.) The transformation of an insect larva into an adult is illustrated by two typical examples outlined below:

- *complete metamorphosis*—e.g. the total transformation of a caterpillar into a pupa (cocoon) and then into a butterfly
- *incomplete metamorphosis*—e.g. the gradual transformation of a young grasshopper into an adult, through a series of stages or instars, each separated by a period of moulting (when the insect sheds its outer skin and forms a new one), with an increase in size at each stage until adulthood.

In both types of metamorphosis the change in form relies on the death of some cells and the division of other cells. During a *complete metamorphosis*, because the larval and adult forms are so different from each other, most of the larval tissues inside the pupa are destroyed by the action of lysosomes. Zones of embryonic tissue, made up of cells that have the potential to divide and differentiate occur in the larva. Growth hormones stimulate these larval cells to divide and begin to differentiate. Moulting hormones then act on the cells stimulating them to become new adult tissues, larval growth decreases and moulting and change occur. Just as the nucleus of a cell controls cell division, so it is thought to control cell death during the metamorphosis of pupae into adults. (See Fig. 5.2b.)

In insects which have an *incomplete metamorphosis*, less cell death occurs. A large proportion of the larval tissues remain and the cells simply enlarge to form the corresponding tissue in the adult. Mitosis is involved in the addition of certain adult body parts; for example, the growth of wings in mature locusts, grasshoppers and cockroaches from embryonic cells present in *wing buds*.

In insects mitosis also plays a role in the normal repair and maintenance of body tissues.

STUDENT ACTIVITY

The information in the remainder of this chapter deals with the process of mitosis. Once you have read through this information, answer these questions.

1. Draw a fully-labelled diagram to distinguish between the following terms:
   - *chromosome*
   - *chromatid*
   - *centromere*.
2. Observe the photographic images in Figure 5.5 and identify each of the stages shown.
3. Are the cells in Figure 5.5 plant or animal cells? Justify your answer using evidence visible in the images.
4. Draw a fully-labelled diagram of one of the images in Figure 5.5 showing cytokinesis and one image showing the chromosomes lined up in the centre of the cell. (Your diagram should resemble the images actually shown.)
5. Explain, giving examples, how mitosis plays a role in the addition of adult body parts to an immature (larval stage) insect during metamorphosis.

Word search gird

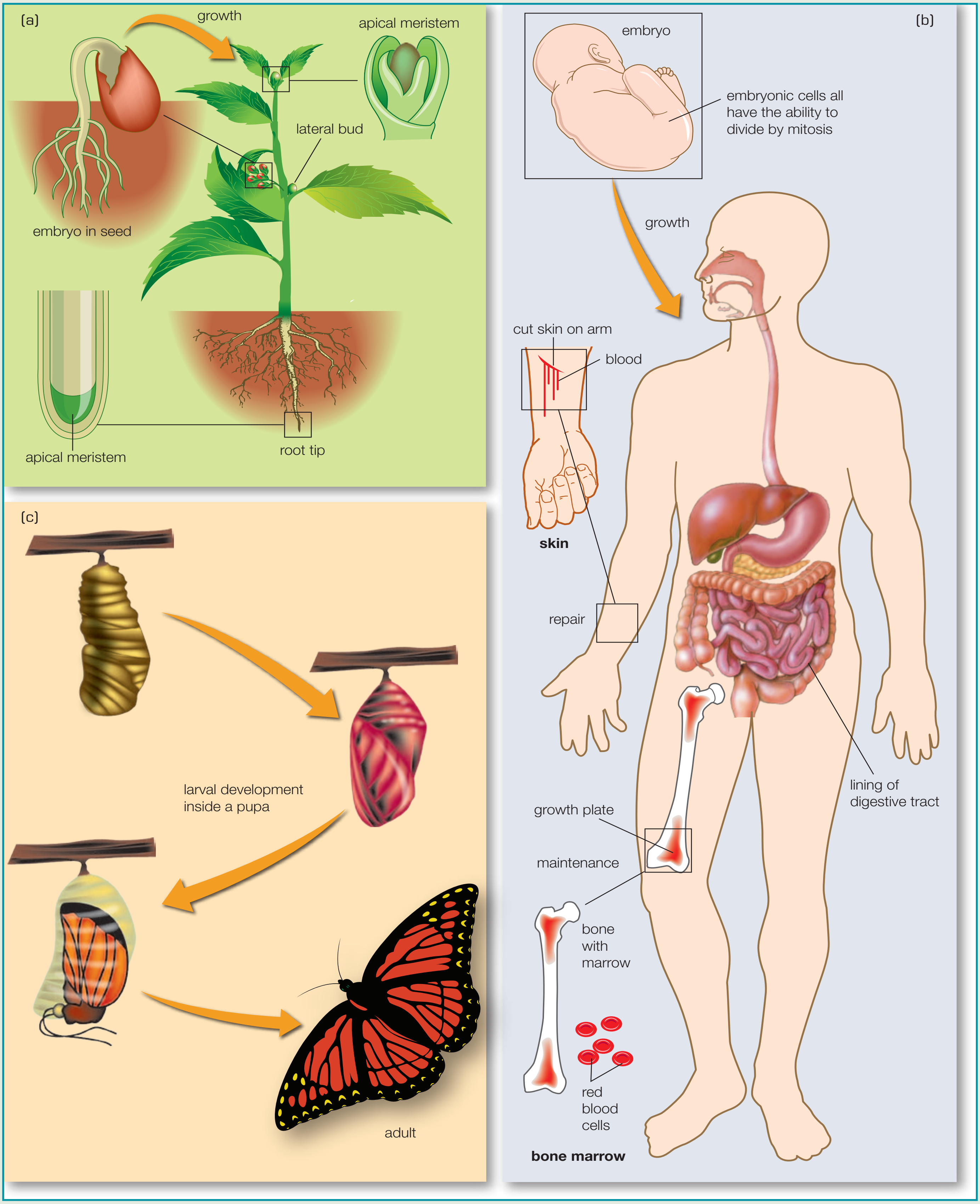

Figure 5.2 Where mitosis occurs in plants, humans and insects: (a) positions of meristems in plants; (b) position of meristems in humans (mammals); (c) complete metamorphosis in insects—transformation brought about by the division of some cells and the death of other cells

Mitosis: the process and its importance

5.2

- ***identify mitosis as a process of nuclear division and explain its role***

The role of mitosis

If cell division occurs in **unicellular** organisms, it results in asexual reproduction—one organism becomes two, but no sex cells or gametes are involved. (This will be dealt with in more detail in the last module.) In multicellular organisms, cell division is a process that leads to the formation of new cells that form part of the organism and, as a result, contribute to the growth of the organism or the repair of damaged tissue.

The role of mitosis in multicellular organisms can be summarised as follows:

- *growth*
- *repair* of damaged tissue and replacement of worn out cells
- *genetic stability*: mitosis ensures the precise and equal distribution of chromosomes to each daughter nucleus, so that all resulting cells contain the same number and kind of chromosomes as each other and as the original parent cell
- *asexual reproduction*: e.g. *growing plants from cuttings* (more detail in the last module) and *cloning*—an artificially-induced form of asexual reproduction in multicellular organisms that relies on human intervention and genetic modification (more detail in the HSC course).

The process of mitosis

The growth or repair of tissue begins with the formation of new, identical cells by the process of cell division. Cell division occurs in a cycle and involves two main steps:

1. mitosis—the division of the nucleus
2. **cytokinesis**—the division of the cytoplasm.

The cell cycle

Cell division and enlargement occur in a repetitive sequence called the **cell cycle**, with one complete cell cycle taking about 18 to 22 hours in many species (see Fig. 5.3). Mitosis is only one part of this cell cycle and usually takes about an hour or two. Before a cell divides, it undergoes preparation for division and this preparation phase, called **interphase** takes much longer.

Interphase is subdivided into three stages, G_1, S and G_2:

- G_1 is a gap phase during which cell enlargement takes place before the DNA replicates
- S phase is a synthesis period when DNA replicates—that is, the DNA in the cell makes an identical copy of itself, so that each dividing cell has two copies at the start of mitosis. When the cell divides, one full copy ends up in each resulting daughter cell
- G_2 is a second gap phase after replication, when the cell prepares for division.

Mitosis (division of the nucleus) then occurs, followed by cytokinesis (division of the cytoplasm).

Mitosis is a highly co-ordinated process, ensuring that the replicated chromosomes separate and are equally distributed to the daughter cells. Mitosis is a gradual and continuous process, but is usually described in four phases to make it easier to understand. (It is not necessary for students to know the names of these phases, but learning them may make it easier to remember the process.)

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Websites that show cell division and the cell cycle

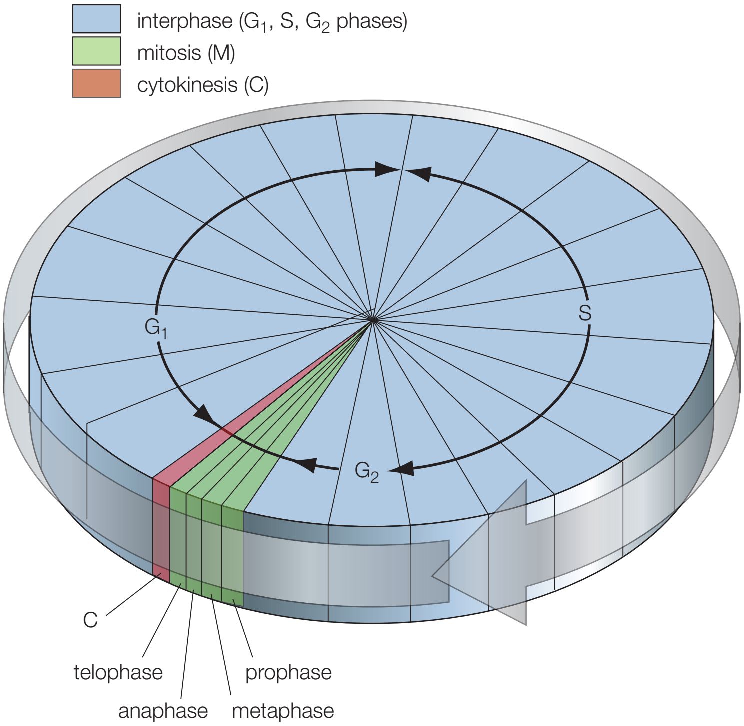


Figure 5.3 The cell cycle: each wedge represents 1 hour of the 22-hour cycle in human liver cells growing in culture

Mitosis: introduction to terminology

- **Chromosomes** (see page 90) contain linear sequences of genes, the units of heredity that code for the inherited characteristics of an organism; for example, in humans chromosomes code for our eye colour, hair colour and height.
- Each organism has a set number of chromosomes (e.g. humans have 46 chromsomes, a platypus has 52 and a lettuce has 18).
- In a non-dividing cell, the DNA and protein occurs as chromatin material, but once the DNA has replicated the chromatin material separates into short, thick individual rod-shaped structures called chromosomes.
- Each chromosome consists of two identical copies of a DNA sequence.
- Each chromosome splits longitudinally and the duplicated arms of the chromosome are held together by a structure called a **centromere.** These two identical arms are termed **daughter chromatids** (see Fig. 5.4) and their segregation to opposite poles occurs during mitosis. Following this, the cytoplasm divides, separating the two daughter nuclei from each other.

Mitosis: stages

Although mitosis is a continuous process, it is easier to understand it if we analyse the process and name identifiable stages within the process. There are four main stages of nuclear division in mitosis: following on *interphase* are the stages *prophase*, *metaphase*, *anaphase* and *telophase*. The late stages of nuclear division are accompanied by the start of cytokinesis. The process of cell division is summarised in Table 5.1 on page 189.

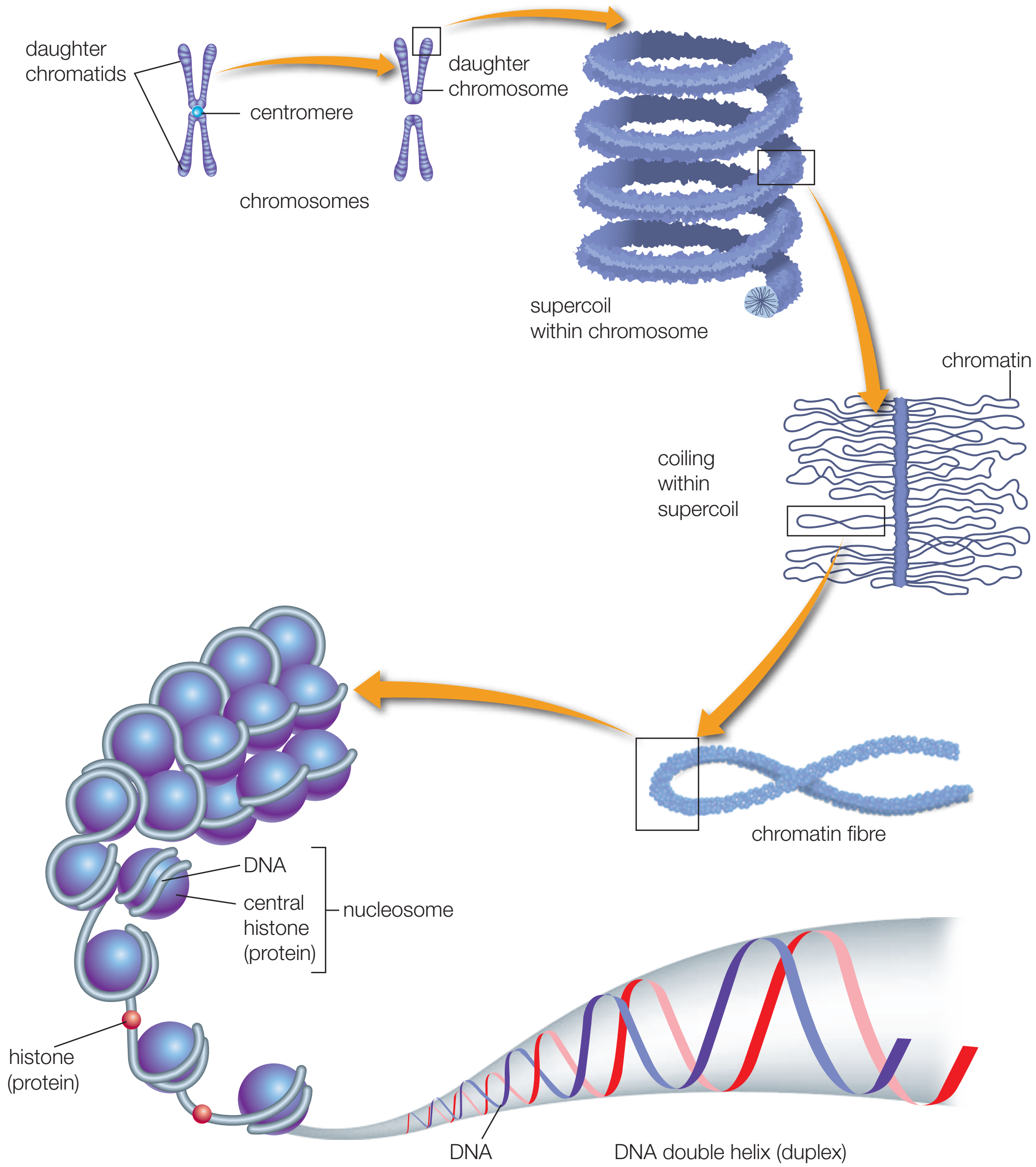
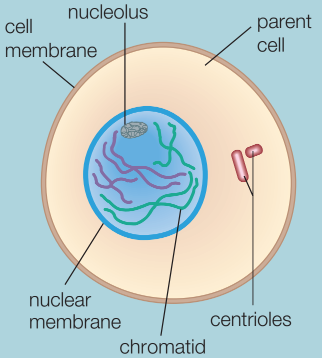
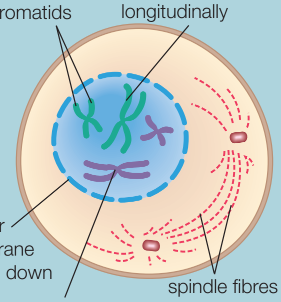
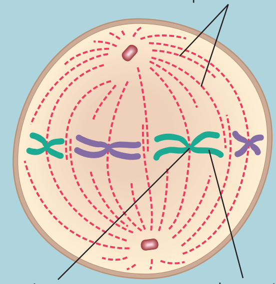
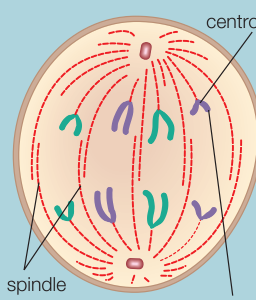
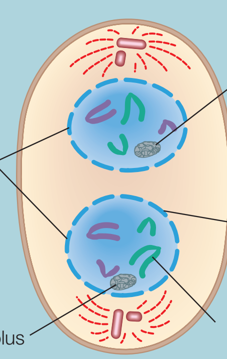


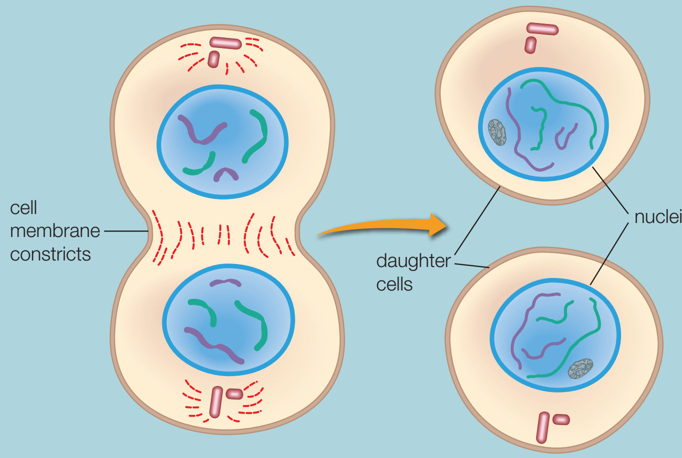
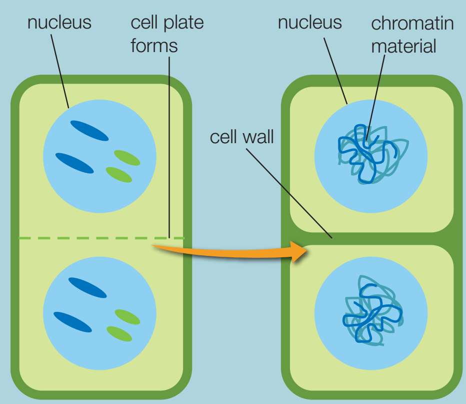
Figure 5.4 Diagram representing the changes to chromatin material in dividing cells

Table 5.1 Mitosis in an animal cell

Stage	Description: Mitosis	Diagram
Interphase	This is the S phase of the cell cycle, where DNA synthesis occurs: ■ *DNA replicates* (makes an identical copy of itself). ■ It appears to diffuse (spread out) and is termed **chromatin material**. ■ It is not yet recognisable as individual chromosomes.	 (a) G_2, late interphase: cell completes DNA replication

continued . . .

Stage		Description: Mitosis	Diagram
Mitosis	Prophase	■ Chromatin material shortens and thickens by spiralling and separates out into individual chromosomes. ■ Each chromosome contains two copies of the DNA. ■ The *chromosomes split longitudinally* into two arms, the daughter chromatids, held together.by a centromere. Each chromatid contains one copy of the DNA. ■ The nuclear membrane begins to break down and is no longer visible; a spindle begins to form from the broken down material and extends across the cells (like the imaginary lines of longitude that are drawn on a globe of the world).	 (b) Prophase: chromosomes condense, become visible and spindle apparatus forms
	Metaphase	■ The *chromosomes line up across the centre* or the 'equator' of the cell, each attached to the spindle fibres by a centromere. ■ The *centromere divides* horizontally.	 (c) Metaphase: chromosomes align along the equator of the cell
	Anaphase	■ The spindle fibres contract, and as the daughter chromatids begin to separate, they are now termed **daughter chromsomes**. They are *pulled towards opposite poles* of the cell and their movement is assisted by the centromere.	 (d) Anaphase: sister chromatids separate to opposite poles of cell
	Telophase	■ The daughter chromatids gather at opposite poles of the cell. ■ The spindle breaks down. ■ The nuclear membrane and nucleolus reappear. ■ Nuclear division or mitosis is now complete. The result is two nuclei that have the identical chromosomes to each other and to the original nucleus in the parent cell.	 (e) Telophase: nuclear membranes assemble around two nuclei

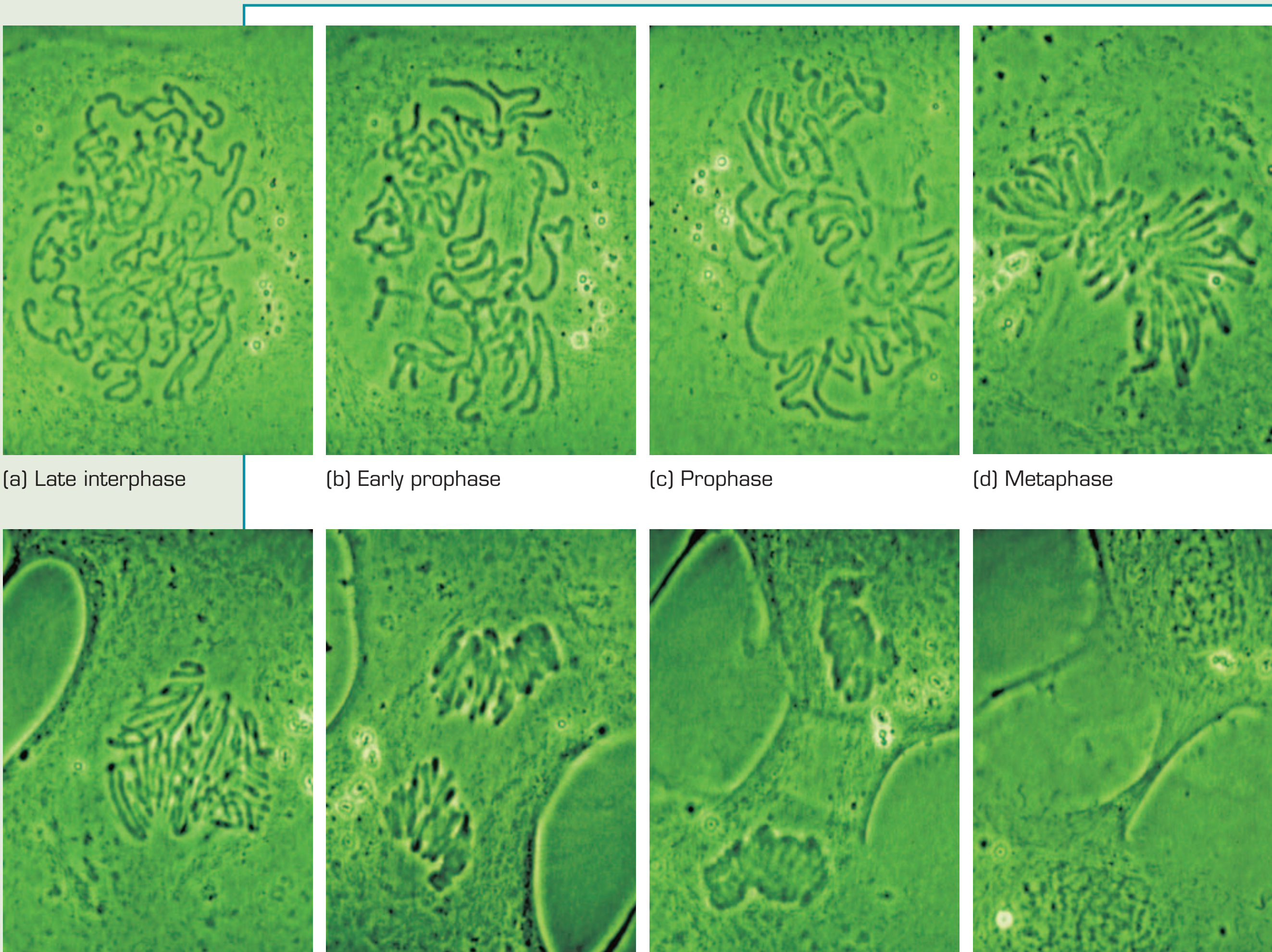
Stage	Description: Cytokinesis	Diagram
Cytonkinesis	■ Division of the cytoplasm, separating the two daughter nuclei so that each is in its own cell. Cytokinesis differs in plant and animal cells: —*animal cells*: the cytoplasm constricts in the centre of the cell, between the two daughter nuclei and it 'pinches off' (similar to squeezing a round balloon in the centre until the edges meet and then giving it a twist to separate it into two bubbles!)	 (f) Cytokinesis: division of cytoplasm into two; G_1, early interphase of daughter cells
	—*plant cells*: cytokinesis involves the formation of a cell plate while the nucleus is still in telophase; thickenings appear on the spindle fibres in the region of the equator and they join up to form a cell plate made of pectin compounds. Cellulose is then deposited on either side, forming a cell wall to separate the two daughter nuclei.	 (g) Cytokinesis in plant cells

Note: As we already know, the number of chromosomes varies from one species to another. To keep the diagrams simple, the diagrams show a progressive sequence of events in a cell with two pairs of chromosomes.

Cytokinesis

■ *explain the need for cytokinesis in cell division*

Cytokinesis is the final step in cell division. It is the division of the cytoplasm and begins while the nucleus is completing its division. Cytokinesis is important to separate the newly formed daughter nuclei, *to ensure that each cell has only one nucleus*. The outcome at the end of mitosis and cytokinesis is *two daughter cells* that have the *identical chromosomes* to each other and to the original parent cell. The daughter cells will then enlarge until they are the same size as the original adult cell (assimilation as well as cell enlargement occurs). The nucleus of each cell controls all the cell activities; it is interesting to note that the ratio between the proportion of nucleus and cytoplasm is kept constant. If the cytoplasm exceeds a certain proportion of the cell, the ability of the nucleus to control it decreases and this may be involved in triggering the cell to divide.



(a) Late interphase
(b) Early prophase
(c) Prophase
(d) Metaphase
(e) Anaphase
(f) Telophase
(g) Cytokinesis
(h) Early interphase of daughter cells

Figure 5.5 Images of a living cultured newt lung cell dividing, showing nuclear division followed by cytokenesis

5.3 DNA outside the nucleus

■ *identify that nuclei, mitochondria and chloroplasts contain DNA*

When the cytoplasm divides, the organelles such as mitochondria and chloroplasts are distributed to the daughter cells in approximately equal numbers. It is then necessary for the organelles in the cytoplasm to replicate so that they are not reduced in quantity. Assimilation is important in the growth of many organelles, but mitochondria and chloroplasts contain their own small amounts of DNA and so they are able to *replicate* themselves. By the time the daughter cells have grown to the size of the original cell, they have a similar number of organelles as the original cell had.

Investigating mitosis using a microscope

FIRST-HAND INVESTIGATION

BIOLOGY SKILLS

P12: 12.1; 12.2; 12.4
P13: 13.1

SR TR

For interactive websites

- ***perform a first-hand investigation using a microscope to gather information from prepared slides to describe the sequence of changes in the nucleus of plant or animal cells undergoing mitosis***

Introduction

Mitosis can be observed relatively easily in cells in the growing region of a root tip. These cells have been specially dyed, using a stain (such as acetic orcein) which is specifically taken up by chromosomes. The prepared slides that you will look at show stained tissues that are no longer living, but with current, more advanced microscopy techniques, living tissue can be recorded today actively dividing. There are a number of videos available to demonstrate this process, some of which can be downloaded from the Internet.

Aim

To gather information on the sequence of changes in the nucleus of plant cells undergoing mitosis.

Background information

In this first-hand investigation, the first step is to identify the part of the plant organ where you would expect to find dividing cells.

If you are looking at root tips, this would be in the meristematic region immediately behind the root cap at the very tip of the root (see Fig. 5.2a).

Because the tissue is no longer living, you will see the cells in the stages of division that they were in when the root tip was killed with a fixative. The division of cells at any one time is not synchronised—different cells will be in various stages of division. The phase that is most commonly represented is probably the longest phase. Look at the cell cycle and predict which phase you would expect this to be.

Procedure

- Using the correct microscope technique, observe a prepared slide of a root tip under the compound microscope.
- Locate and identify the apical meristem (just behind the root cap) under low power and then look for cells with darkly-stained chromosomes, indicative of mitosis occurring.

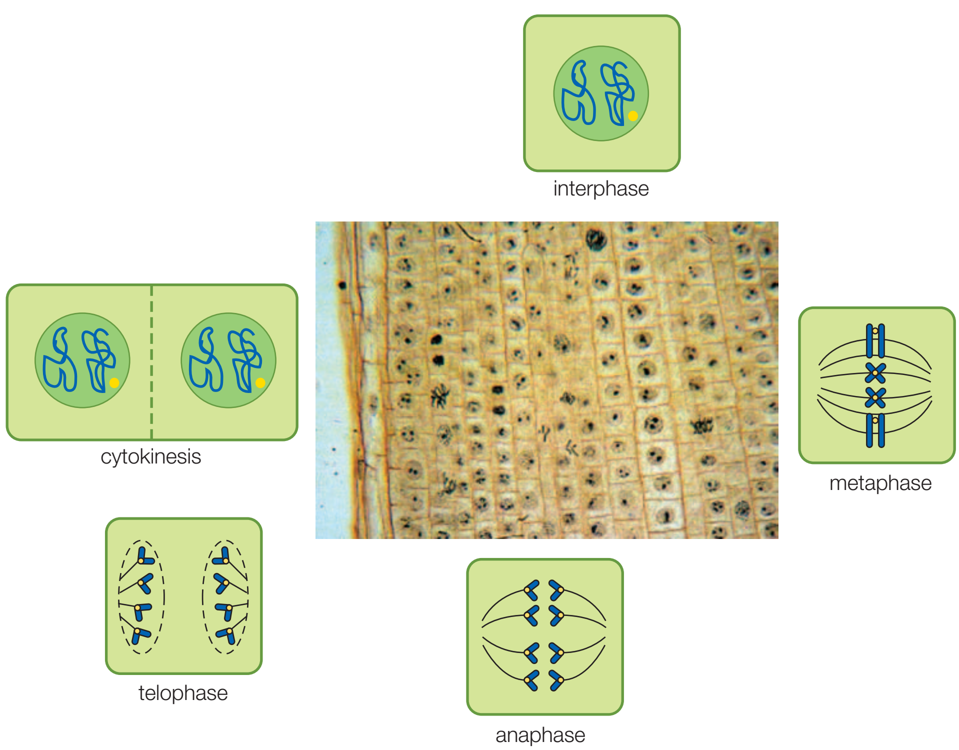


Figure 5.6
A photomicrograph of root tip cells undergoing mitosis

- Change to higher power and identify cells in at least four different stages of division.
- Record your results in the form of fully-labelled diagrams. Remember to include a heading for each diagram and state the magnification used. Write a brief description of what is happening at each stage in the diagram.
- Write out a practical report using a procedure text type, under the headings Aim, Materials, Method, Results and Conclusion.
- Answer all questions at the end of this chapter.

REVISION QUESTIONS

1. Distinguish between the terms *cell division* and *mitosis.*
2. (a) Describe the main difference in the role of mitotic cell division in unicellular organisms, as opposed to multicellular organisms.
   (b) State two other important roles of mitosis in multicellular organisms.
3. Some meristems in plants result in growth in height (length), but other meristems result in growth in diameter. Give one example of each of these types of meristematic tissues and describe where it occurs in plants.
4. (a) Define *metamorphosis* and explain the role of both cell division and cell death in insects with a complete metamorphosis.
   (b) In the development of frogs from tadpoles, a tadpole loses its tail and grows legs. Apply what you have learnt from insect metamorphosis to explain how this change may come about.
5. Identify where, in mature mammals, dividing cells may be located.
6. Describe what is meant by each of the following terms:
   - centromere
   - chromosome
   - chromatin material.
7. Compare cytokinesis in plant cells with that in animal cells.
8. By means of a fully-labelled comparative diagram, compare early prophase with metaphase of mitotic division in an animal cell.
9. Explain the difference between a daughter chromatid and a daughter chromosome.

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Answers to revision questions