Chapter 13
Cell division and growth

Unit
1B

Unit content

Cells, metabolism and regulation
The primary role of the cell cycle is for growth and repair.

The cell cycle:
- chromosome changes in mitosis (including microscopic examination)
- introduction to the differentiation of cells which result in different tissues
- basic introduction to stem cells and their uses.

The relevance of human biology to everyday life
Interest in the human body has often resulted from trying to explain body dysfunction; in maintaining health; and trying to improve human performance. Modern medical methods and alternative therapies differ in their effectiveness and each has its risks, ethical concerns and benefits.

Body dysfunction:
- types of dysfunctions *e.g. cancer*
- requirements for maintaining health *e.g. diet, exercise and hygiene.*

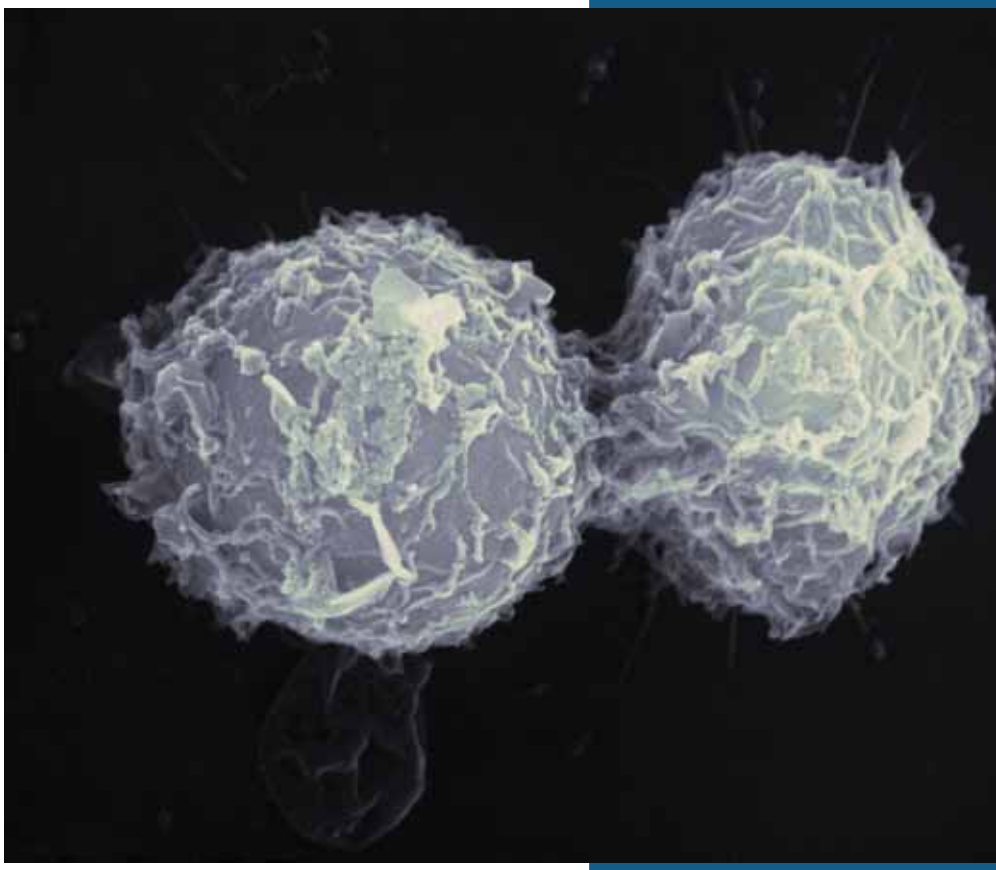


Figure 13.1 A scanning electron micrograph of a human colon cancer cell dividing

Growth is one of the life processes that are characteristic of all living things. Growth is achieved by producing new cells from existing cells. The existing cells divide and then grow until they are similar in size to the original cell.

Most cells are microscopic so that the surface area is large in relation to the volume. This is because the surface area must be large enough to take in the oxygen and nutrients required, and at the same time remove any wastes. In Chapter 3, the importance of the surface area to volume ratio was discussed. Remember that anything that goes into or out of a cell must pass through the cell membrane. For the effective exchange of substances across the membrane, it must have a large surface area.

You have increased in size a lot since you were born. This growth was not due to an increase in the size of your cells, but was due to an increase in the number of cells. In this chapter we examine the process by which new cells are produced for growth, and to replace cells that have died or have been damaged. This process of cell division is called **mitosis**.

Mitosis

Even though our bodies stop growing once we reach maturity, some of our cells go on reproducing throughout life. Some cells have a very short life span because they are in places where there is a lot of wear and tear. The cells lining the intestine, for example, have an average life span of less than two days. On the other hand, most of the nerve cells in the brain will last for a lifetime. Table 13.1 shows the life span of a number of different types of cell.

Table 13.1 Average life span of human cells

Cell type	Average life span (days)
Intestinal lining	1.3
Stomach lining	2.9
Tongue surface	3.5
Cornea of the eye	7
Outer skin of the abdomen	7
Inside of the cheek	10
Air sac in the lung	21
Red blood cell	about 120
Kidney	170
Lining of the bladder	330
Liver	450
Nerve cell in the brain	29 200+ (80+ years)

The cell cycle

Cell division provides replacements for dying cells and also new cells in parts of the body where growth is occurring. The events that take place from one cell division to the next are called the **cell cycle**. It is called a cycle because the events keep repeating themselves as the cell divides again and again.

The events that occur in the cell cycle have been divided into a number of phases:

- The **G_1 phase** or first growth phase: during this phase the cell produces new proteins, grows and carries out its normal tasks for the body. The G_1 phase ends when the cell's DNA begins to duplicate.
- The **S phase** or synthesis phase: during this phase the DNA molecules in the cell nucleus form exact duplicates of themselves.
- The **G_2 phase** or second growth phase: this relatively short phase involves preparation for cell division.
- The **M phase** or mitotic phase: during this phase the cell divides into two daughter cells.

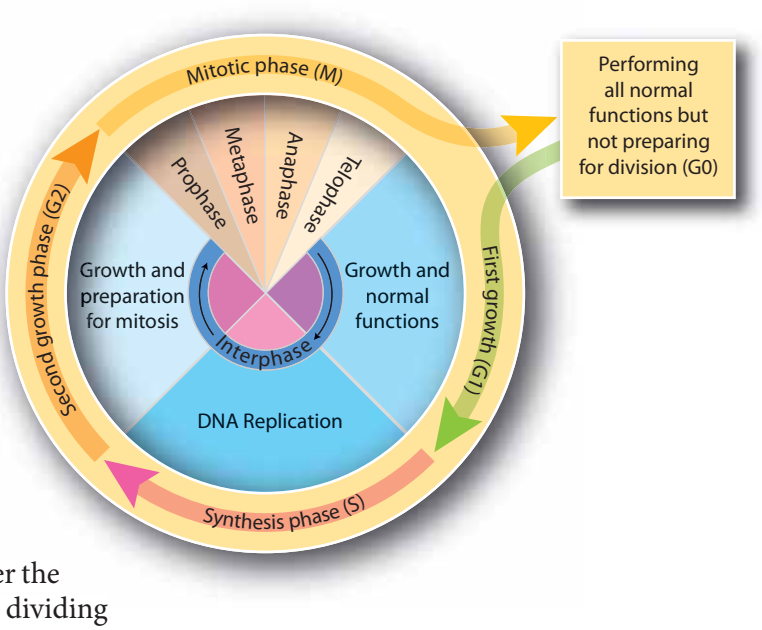


Figure 13.2 The cell cycle

After cell division cells may continue the cycle and enter the G_1 phase again. Some cells leave the cell cycle and stop dividing for days, years or even for the rest of the person's life. These cells are in the **G_0 phase**.

The phases of mitosis

Each new cell must contain the same genes as the parent cell. The genes are in the cell's DNA so each new cell must contain exactly the same DNA as its parent. This is achieved by the division of the nucleus known as mitosis.

For convenience, biologists describe mitosis in four phases (see Table 13.2): prophase, metaphase, anaphase and telophase. However, the process is continuous; it does not occur in steps.

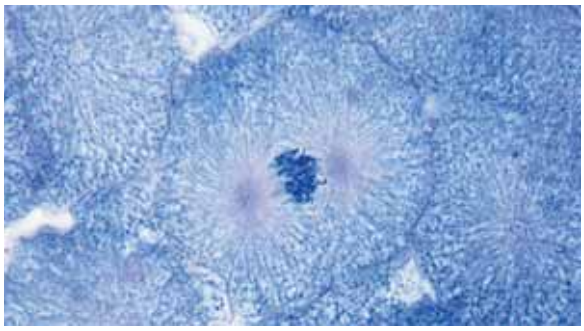
Interphase

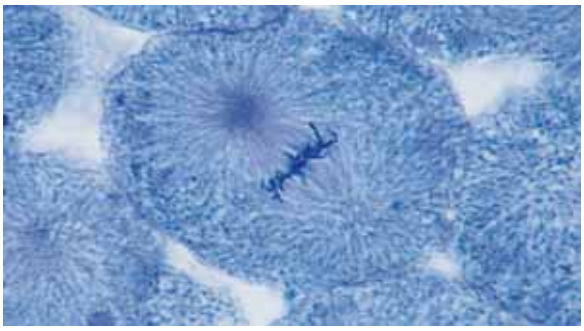
Interphase is when the cell is not dividing—the period between divisions of the nucleus. During interphase the cell goes through the G_1, S and G_2 phases of the cell cycle listed above. In the S phase the DNA molecules in the nucleus form exact copies of themselves. Thus, in the period between one cell division and the next, the quantity of DNA in the nucleus doubles.

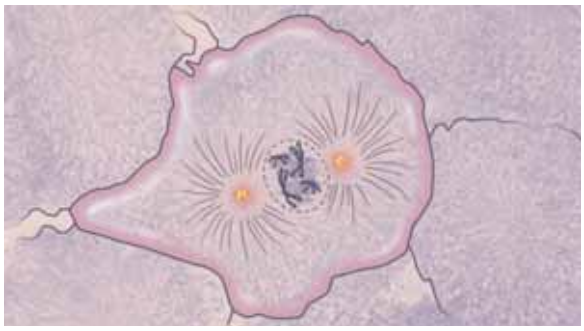
Prophase

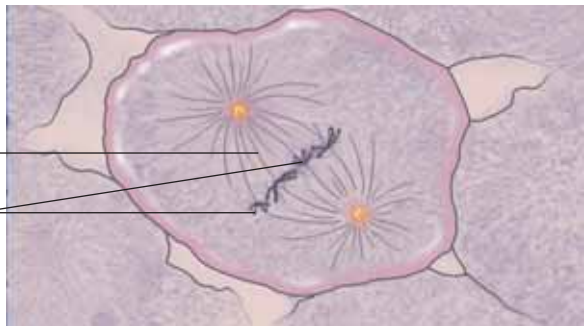
Prophase is the first phase of mitosis. Microtubules begin to grow from the ends of the cell. By the end of prophase the microtubules will have joined in the middle of the cell to form a structure called a **spindle** (see Fig. 13.3). While the spindle is forming the nucleus disappears and the nuclear membrane begins to break down. The thread-like DNA molecules become tightly coiled, and can be seen as **chromosomes**. Because the DNA has been duplicated, each chromosome consists of two **chromatids**, which are joined at a point called the **centromere** (see Fig. 13.4). The two chromatids that make up a chromosome are identical, tightly coiled DNA molecules.

By the end of prophase the spindle is fully formed and the nuclear membrane has completely disappeared. The chromatid pairs move towards the centre (or equator) of the cell (see Fig. 13.3).



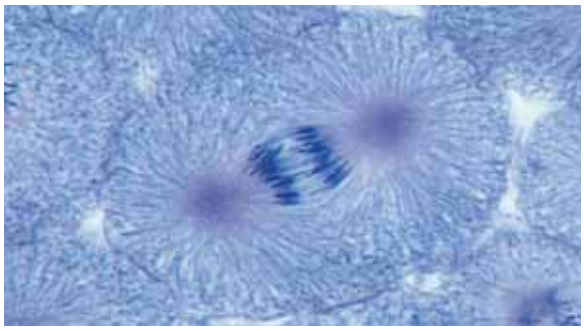


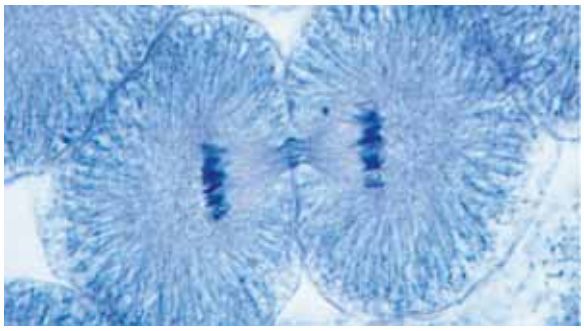


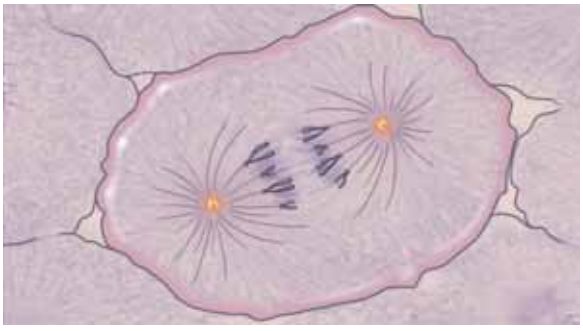


Prophase
DNA becomes tightly coiled to form chromosomes.
Chromosomes are visible as a pair of chromatids.
The nucleus disappears and the nuclear membrane breaks down.
Spindle fibres form.

Metaphase
The pairs of chromatids move to the middle of the cell.
Spindle fibres attach to centromeres.







Anaphase
Chromatids separate at the centromeres.
Spindle fibres contract pulling the chromatids (now chromosomes) to the opposite ends of the cell.

Telophase
The two sets of chromosomes form tight groups at the ends of the cell. The cytoplasm begins to divide. A new nuclear membrane begins to form around the chromosomes at each end of the cell. The spindle begins to disappear.

Figure 13.3 The events of mitosis

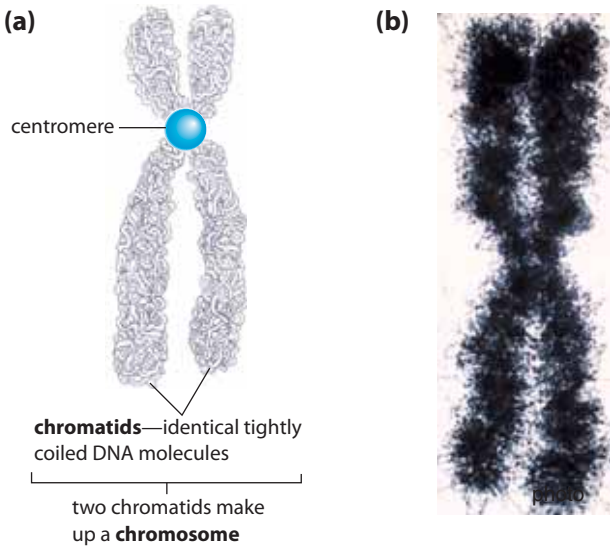


Figure 13.4 **(a)** During prophase, chromosomes become visible as pairs of chromatids; **(b)** scanning electron micrograph of a chromosome consisting of a pair of chromatids

Metaphase

During **metaphase**, the chromatid pairs line up on the middle of the spindle. The centromere of each pair becomes attached to a spindle fibre (see Fig. 13.3).

Anaphase

In **anaphase**, each pair of chromatids separates at the centromere. As the chromatids have become independent of each other, they are now called chromosomes. Each new chromosome has its own centromere that is still attached to the spindle fibres. The spindle fibres contract and pull the chromosomes apart towards opposite ends of the cell (see Fig. 13.3).

Telophase

In **telophase**, the two sets of chromosomes form tight groups at each end of the cell. A nuclear membrane forms around each group. The spindle fibres disappear and the chromosomes gradually uncoil to become chromatin threads once more.

Cytokinesis

Telophase is the last phase of the nuclear division and it is usually during this phase that the cytoplasm begins to divide. Division of the cytoplasm is called **cytokinesis**. A furrow develops in the cytoplasm between the two nuclei. The furrow gradually deepens until it cuts the cytoplasm into two parts, each with its own nucleus (see Fig. 13.3). Note: mitosis is the process of division of the cell nucleus but the word is often used to describe the whole process of cell division.

Mitosis, and the division of the cytoplasm into two parts, has thus resulted in the formation of two **daughter cells**. Because each chromosome was duplicated, and because the duplicates have separated into daughter cells, *each daughter cell has exactly the same number and type of chromosomes as the parent cell*. The original DNA, and therefore the genes, is passed on without any change from parent cell to daughter cells.

There are many websites where you can see animations of mitosis, including:

- http://www.cellsalive.com/mitosis.htm
- http://www.johnkyrk.com/mitosis.html
- http://micro.magnet.fsu.edu/cells/mitosisjava/mitosisjava.html
- http://www.sumanasinc.com/webcontent/animations/content/mitosis.html

Table 13.2 A summary of cell division

Stage	Events occurring
Interphase	DNA molecules duplicate
Prophase	Nuclear membrane breaks down; chromosomes appear as pairs of chromatids; spindle forms
Metaphase	Chromosomes line up on the spindle in the middle of the cell
Anaphase	Centromeres divide; daughter chromosomes are pulled apart by the spindle
Telophase	Spindle disappears; nuclear membranes form; centrioles divide; chromosomes uncoil and disappear; during this phase cytokinesis occurs
Cytokinesis	Cytoplasm of the cell divides into two, each with a nucleus

Cell differentiation

See a video of cell differentiation at http://www.teachersdomain.org/resources/tdc02/sci/life/stru/different/index.html

Mitosis ensures that each daughter cell receives the same genes that were in the parent cell. Therefore every cell in a person's body must have the same genetic information. However, as we saw in Chapter 4, cells are specialised so that they can carry out particular tasks. The process by which cells become specialised is called **differentiation**. It seems that as the cells undergo division by mitosis, different genes become activated. This makes the cells differentiate into specialised cells that are able to perform particular functions.

Through the process of differentiation, recently formed cells may become specialised into stomach cells that secrete enzymes, muscle cells that can contract or red blood cells that can carry oxygen. These are only a few examples of the way cells can become specialised. Over 200 types of cells make up a mature human body.

Stem cells

The cells that undergo differentiation are called stem cells. They are very different from other cells. **Stem cells** are not specialised for any particular role and are capable of repeated division by mitosis. Given the right conditions, they can differentiate into specialised cells. Because of their ability to develop into any cell type, stem cells could potentially provide an unlimited source of cells for repair of tissues such as bone, muscle, liver or the blood.

Stem cells are already used in a limited way to treat a few diseases. In Australia and many other countries, a lot of scientific research is directed at finding ways of using stem cells to produce new tissues and organs.

There are three sources of stem cells.

- **Umbilical cord blood and placental stem cells**: stem cells are present in the blood in a baby's umbilical cord and in the placenta. Once a baby is born, these cells can be recovered from the discarded tissue. They can then be used for the benefit of children and adults who suffer from bone marrow and blood diseases. These stem cells are obtained after the baby is born. There is no harm to the mother or child.
- **Embryonic stem cells**: these are cultured from frozen embryos that have been produced by in-vitro fertilisation (fertilisation in a test tube, outside the female's body). The embryos have been donated for research because the donors no

longer wish to have additional children. An advantage of using embryonic stem cells is that they can become any of the cell types of the body.

- **Adult stem cells**: these occur in many kinds of tissue. An important potential advantage of using adult stem cells to treat disease is that a patient's own cells could be used for treatment. Risks would be reduced because the patient's body would not reject its own cells. A disadvantage of most adult stem cells is that their ability to differentiate is limited. That is, blood stem cells make only blood cells, and brain stem cells make only brain cells. It appears that most organs of the body have stem cells so that dead or damaged cells can be replaced. For example bone marrow, where blood cells are made, contains stem cells that give rise to all the cells of the blood and is, therefore, a good source of adult stem cells.

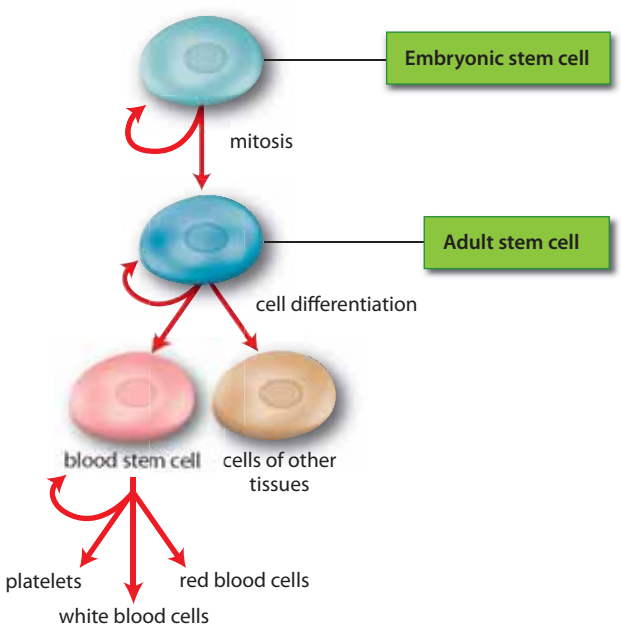
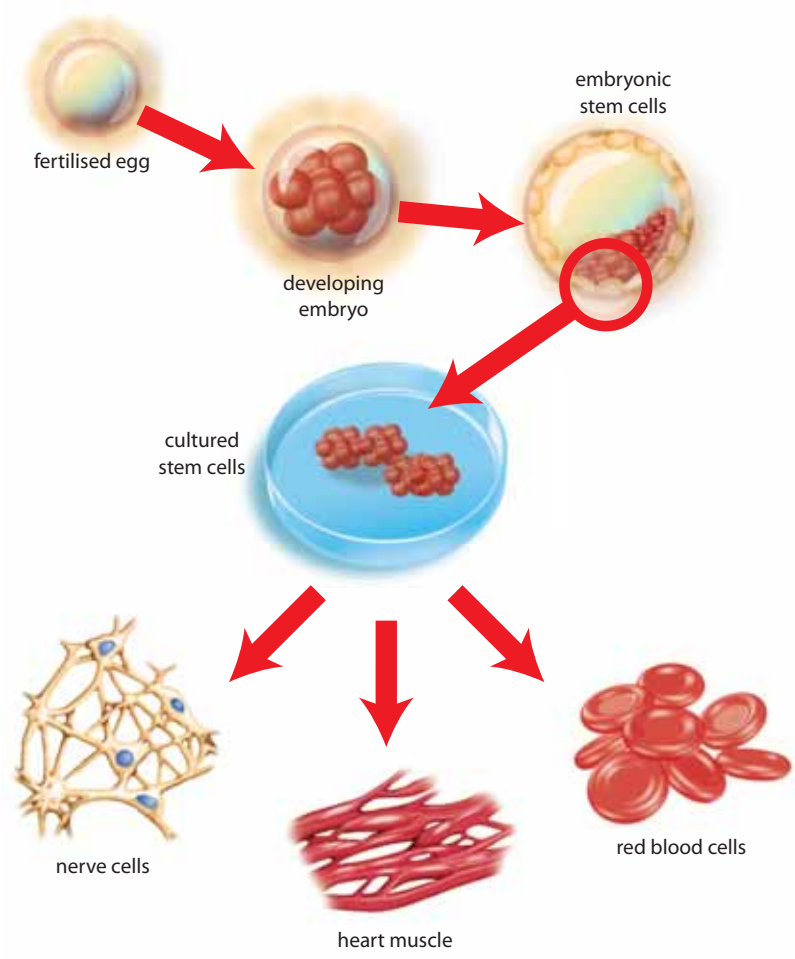


Figure 13.5 Cell differentiation



Learn more about stem cells in a fun way at http://learn.genetics.utah.edu/units/stemcells/whatissc

Figure 13.6 Culturing embryonic stem cells may allow medical scientists to grow replacement tissues and organs for patients

Cancer

What is cancer?

Cancer is not just one disease, but many. However, all cancers have certain characteristics in common. They all result from a situation where the normal differentiation of cells goes wrong.

An abnormal mass of tissue, called a **tumour**, results from uncontrolled division of cells. Cancer cells do not differentiate into the normal tissue cells that surround the tumour. They can therefore be easily identified with a microscope. Some tumours are **malignant**, which means the tumour cells are able to spread to other parts of the body. This is known as **metastasis**. In this way, **secondary tumours** may develop in parts of the body well away from the original tumour.

A website with lots of information on different types of cancer is http://www.medicalonline.com.au/medical/cancer/index.html

Some tumours are not malignant. The cells in the dividing mass are not able to invade normal tissues or blood or lymph vessels and so do not spread to other parts of the body. These tumours are called **benign**. Benign tumours grow and press on surrounding tissues. Such tumours can be dangerous if they exert pressure on vital organs such as the brain. However, because a capsule often surrounds them, they are usually easily removed.

Causes of cancer

The cause of some cancers is unknown but we do know that certain environmental factors can trigger malignant tumours. Such factors are known as **carcinogens**. Cancer usually occurs only after long exposure to a carcinogen, and the cancer may develop many years after the exposure has ended.

Carcinogens

A great many substances and forms of radiation have been found to be associated with cancers.

- **Ultraviolet (UV) radiation**, which is a part of sunlight, produces cancer of the skin, especially in people with light-coloured skin. Sunburn and overexposure to UV radiation are the main causes of skin cancer.
- **X-rays** are known to cause cancer. The exposure to X-rays is limited and controlled in Australia. The amount of radiation produced by modern machines poses little risk to patients from routine medical use.
- **Ionising radiation**, such as that produced by radium and ores of uranium, can cause cancer. A single exposure to a high dose may result in leukaemia. Radiation from the atomic bombs dropped on Hiroshima and Nagasaki in Japan at the end of World War II caused a significant increase in the incidence of cancers in the people of those cities.
- **Viruses** have been found to cause some forms of cancer. For example the human papilloma virus (HPV) causes cancer of the cervix in women (the cervix is the neck of the uterus). A vaccine called Gardasil that protects young women against some forms of HPV was introduced in Australia in 2007.
- **Chemical carcinogens** are widespread in modern society, but simple precautions can usually be taken to avoid excessive exposure. Some known

chemical carcinogens are alcohol (excessive consumption), asbestos, soot and tar, organic solvents in glues and paints and tobacco tar.

Prevention of cancer

Many cancers are associated with lifestyle factors, such as exposure to UV radiation, smoking, alcohol consumption and diet (lifestyle diseases are discussed further in Chapter 21).

In Australia the incidence of cancer has been reduced in two ways:

- **Education**: The public has been made aware through advertising and other education programs of the need to limit exposure to carcinogens. An example is the very successful 'Slip! Slop! Slap!' program to make people aware of the need to limit exposure of the skin to UV radiation.
- **Legislation**: Australian governments have passed laws to control exposure to carcinogens. For example, smoking is banned in most public places and advertising of tobacco is not permitted. Standards have been imposed for the manufacture and operation of X-ray machines, and products containing asbestos have been banned. These and other measures have helped to reduce the incidence of cancer, but each of us still has a responsibility to minimise the risks as far as possible.

Some positive steps that you can take to reduce the risk of cancer later in life are:

- avoid smoking
- use sunscreens, sunglasses, long-sleeved clothing, shade and hats to reduce exposure to UV radiation
- if possible, stay out of sunlight between 10 am and 3 pm
- ensure that your diet has adequate fibre and is low in fat
- avoid being overweight or obese
- limit alcohol intake, if you choose to drink
- use protective clothing and face masks when handling chemicals such as organic solvents or vinyl chlorides.

Early detection is critical for the successful treatment of cancer.

Australian women should:

- have a Pap test to check for cervical cell changes every two years
- if aged about 50 or over, women should have a mammogram every two years.

To help reduce cervical cancer incidence, girls and women should discuss the cervical cancer vaccine with their doctor.

Australian men should if over 50, talk to their doctor about regular tests for prostate cancer.

Both women and men over the age of 50 should have regular screening for bowel cancer.

Everyone should be familiar with their bodies and see a doctor if they notice changes, for example, a breast lump, a lump in a testicle, a change in a mole, a change in bowel habits, and others. More information is available from the Cancer Council (see website addresses later in this chapter).

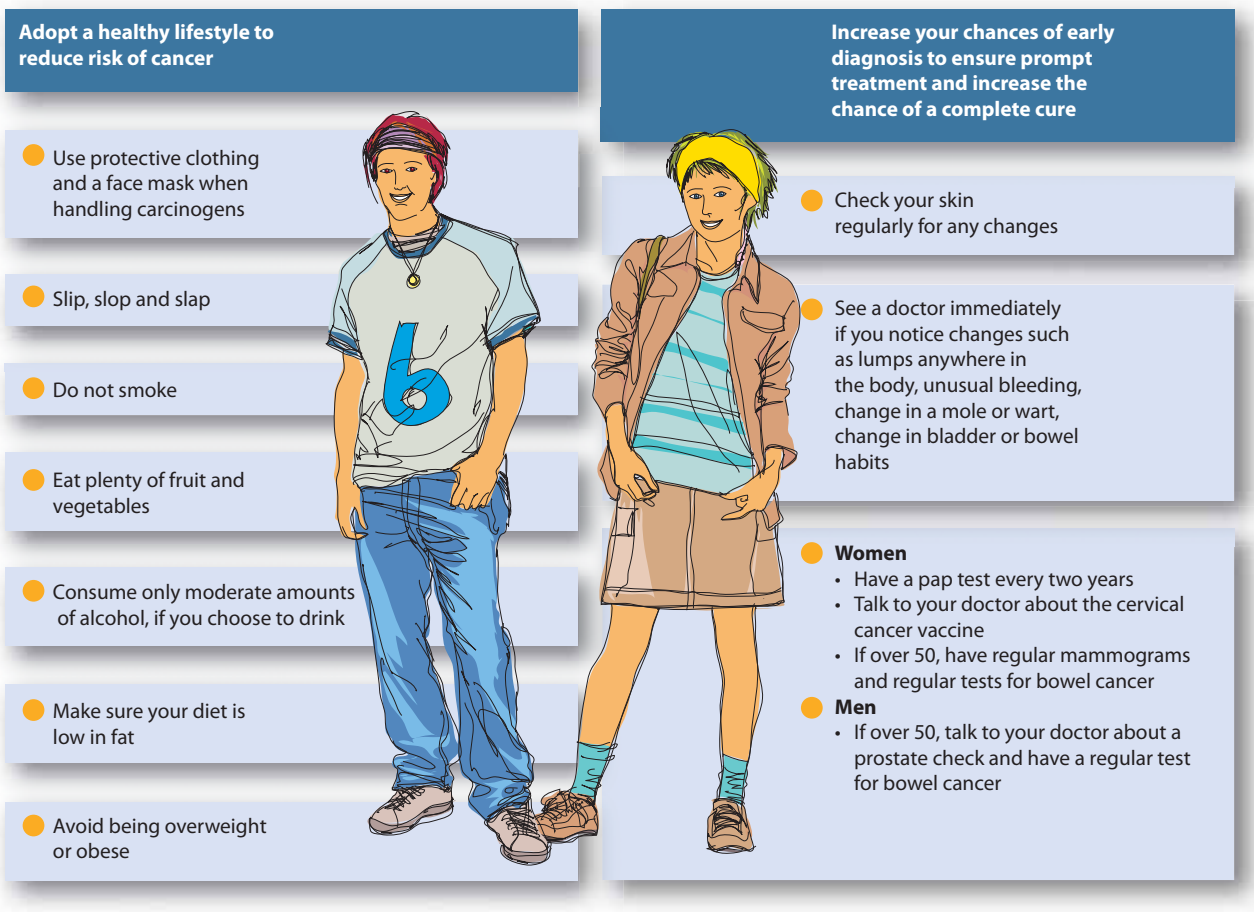


Figure 13.7 Take responsibility for your own health: reduce your risk of getting cancer later in life and increase the chance of early diagnosis so that any cancer can be treated

Working scientifically

Activity 13.1 Modelling mitosis and cytokinesis

In science a model is a simplified version of a complex process. You could model the events that occur when a cell divides.

Draw a cell in pencil on a large sheet of paper, or you could use a whiteboard marker to draw on a laminated board or bench top. To represent the chromosomes/chromatids you could use strings of beads or some other suitable materials. Use different lengths to represent different chromosomes. The centromeres holding the chromatids together could be paperclips or elastic bands. (Have only three chromosomes in your cell so that the process does not become too complicated.)

Use the description of cell division on pages 157–9 and Figure 13.3 to work through the phases of mitosis. As changes occur in the cell, lines on your paper or board can be erased and replaced.

Activity 13.2 Observing mitosis

You can observe the phases of mitosis by looking at dividing cells under a microscope. Your teacher will provide prepared slides of dividing cells. Often these will be cells from the root tip of an onion. Mitosis in plant and animal cells follows the same sequence of events but mitosis is often easier to observe in plant cells.

If you have forgotten how to use a microscope correctly, refer to Activity 3.1 on page 31.

Look for cells that are in prophase, metaphase, anaphase and telophase of mitosis.

1. Draw a cell that is in each of the four phases.
2. Notice that you cannot see the spindle in any of the cells. Suggest why it cannot be seen.
3. Estimate the number of chromosomes in the cells you are observing. How does your estimate compare with that of others in your class?
4. If you observed onion cells, what major difference did you see between those cells and the animal cells we have discussed in this chapter?

Activity 13.3 Developments in stem cell research

There is a considerable amount of information being published in the media about progress with stem cell research. Find out:

- the lines of research that are currently being carried out
- the latest information on the use of adult stem cells
- the diseases that could potentially be cured as a result of the research
- arguments against stem cell research.

Activity 13.4 The incidence of cancer in Australia

Many people are treated successfully for cancer each year but cancer is still a major cause of death in Australia. Use references to find out:

- which cancers are most common in Australia
- whether there is any relationship between the type of cancer and where people live in Australia
- the age groups at which particular cancers are more common in Australia
- whether there are any upward or downward trends in the incidence of particular cancers in Australia.

There are many websites with information about cancer such as:

- The Cancer Council Australia: http://www.cancer.org.au
- The Cancer Council WA: http://www.cancerwa.asn.au
- The Cancer Council NSW: http://www.cancercouncil.org.au
- The Cancer Council Victoria: http://www.cancervic.org.au

There are also sites for organisations that deal with specific types of cancer. As with any information that you use from the Internet, make sure that it has come from a reliable source.

REVIEW QUESTIONS

1. **(a)** What is the cell cycle?
   (b) Describe what happens in the four phases of the cell cycle.
2. Using a diagram, explain the difference between a chromatid and a chromosome.
3. Draw up a table (similar to Table 13.2) to summarise, in your own words, the events of mitosis. Include in your table a column with a drawing showing a cell in each of the phases of mitosis.
4. Refer to Table 13.1 and name three places where cells would be reproducing rapidly in the body of a healthy adult human. Explain why cell reproduction is necessary in these places.
5. Use a diagram to explain how mitosis ensures that each daughter cell has exactly the same genes as the parent cell.
6. Describe three sources of stem cells.
7. Explain the difference between a benign and a malignant tumour;
8. **(a)** What is a carcinogen?
   (b) Give five examples of carcinogens.

APPLY YOUR KNOWLEDGE

1. Skeletal muscle cells and most nerve cells remain in the G_0 phase of the cell cycle. Is it likely that these cells would be dividing? Explain your answer.
2. What do you think would happen if the spindle fibres did not form in a cell that was undergoing mitosis?
3. Research into disease treatments using stem cells is occurring in many laboratories around the world, with new advances being made all the time. Find out the latest information available with particular reference to those diseases that are most likely to benefit from such research.
4. **(a)** List as many reasons as you can for the fact that Australia has the highest incidence of skin cancer in the world.
   (b) How can you change your habits to reduce the risk of skin cancer?
   (c) Describe any recommended changes in beach wear that are aimed at reducing exposure to UV radiation.
5. List reasons why our exposure to carcinogens is greater today than it has been in the past.
6. Think carefully about your own lifestyle.
   (a) What aspects of your lifestyle are already reducing your risk of developing cancer later in life?
   (b) How could you change your lifestyle to further reduce your risk of developing cancer?