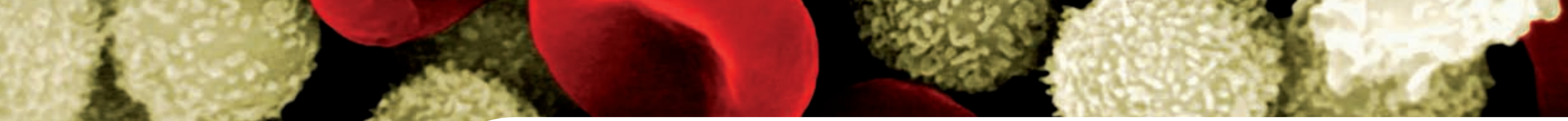


Unit

2A

Chapter 6

# Transport to and from cells

**Figure 6.1** Substances are taken to and removed from cells via the blood, which circulates through arteries, capillaries (shown here) and veins

## Unit content

**Body systems**
The respiratory, circulatory, digestive and excretory systems are specialised to control inputs and outputs in supporting metabolism.

Circulatory system
Structure and function related to:

- role of the heart, arteries, veins and capillaries in the circulation of blood
- roles of plasma and erythrocytes in the transport of materials including oxygen, nutrients and wastes.

**Relevance of human biology to everyday life**
Lifestyle choices can compromise body functioning in the short term and affect future health.

Lifestyle choices that compromise health:

- active or sedentary lifestyle
- use of drugs, including alcohol and smoking
- diet.

The body's main internal transport system is the **circulatory system**. It is the link between the cells inside the body, which have certain requirements, and the environment outside the body, which supplies those requirements. Special organs are needed to extract requirements from the environment. The digestive system absorbs nutrients and the respiratory system absorbs oxygen. Other organs are specialised to pass waste from the body to the environment. The respiratory system excretes carbon dioxide and the kidneys excrete other wastes. The blood is the transport link between the cells of all the body systems. It is also very important in maintaining the internal environment of the body at a constant level. Some of the more important functions of the blood are:

- transport of oxygen and nutrients to all cells of the body
- transport of carbon dioxide and other waste products away from the cells
- transport of chemical messengers, called hormones, to the cells
- maintaining the pH of body fluids
- distributing heat and maintaining body temperature
- maintaining water content and ion concentration of the body fluids
- protection against disease-causing micro-organisms.

This chapter looks at how the transport role of the blood is achieved and how it is regulated to suit the body's needs.

## The blood as a transport medium

Blood is made up of a liquid part, called the **plasma**, and a non-liquid part, consisting of cells and cell fragments, which together are called the **formed elements**. Plasma makes up about 55% of the blood volume, and the formed elements make up the other 45%. The formed elements that are suspended in the blood plasma include the red blood cells, or **erythrocytes**; white blood cells, or **leucocytes**; and platelets, or **thrombocytes** (Fig. 6.2). There are about 4–5 L of blood in an average adult female and about 5–6 L in an adult male.

### *Transport of oxygen*

Oxygen is not very soluble in water, so only about 3% of oxygen is carried in solution in the blood plasma. The other 97% is carried in combination with haemoglobin molecules that are found only in the red blood cells. **Haemoglobin** is able to combine with oxygen to form a compound called **oxyhaemoglobin**. The combination of oxygen and haemoglobin is said to be a *loose* one because oxyhaemoglobin can easily break down to release the oxygen:

$$\underset{\text{haemoglobin}}{Hb} + \underset{\text{oxygen}}{O_2} \rightleftharpoons \underset{\text{oxyhaemoglobin}}{HbO_2}$$

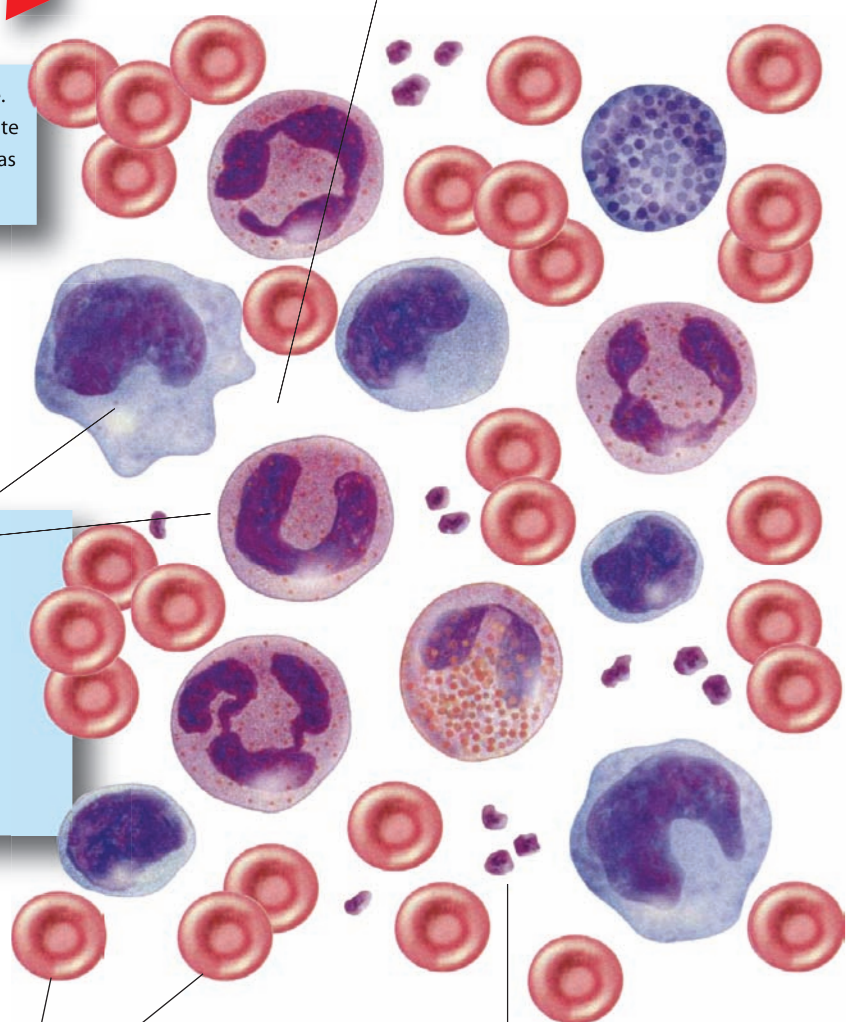
The presence of haemoglobin in the red blood cells increases the oxygen-carrying capacity of the blood by about 60 or 70 times.

Oxygen combines with haemoglobin in situations where the oxygen concentration is relatively high. This would occur in the capillaries in the lungs, where oxygen diffuses into the blood from the air in the air sacs. Oxyhaemoglobin breaks down to haemoglobin and oxygen in situations where the concentration of oxygen is relatively low. As the cells of the body are continually using oxygen, the tissue fluid around the cells has a relatively low oxygen concentration. While flowing through the capillaries between the body cells the red blood cells give up their oxygen, which diffuses into the tissue fluid and then into the cells (Fig. 6.3).

**Blood** is made up of a liquid part, called **plasma**, and cells or cell fragments that are known as the **formed elements**

**Plasma** makes up 55% of the blood volume. Ninety-one per cent is water, with the rest made up of dissolved substances, including nutrients (glucose, amino acids, lipids), ions ($Na^+$, $K^+$, $Ca^{2+}$, $Cl^-$, $HCO_3^-$), gases (oxygen, carbon dioxide), hormones, plasma proteins and wastes (e.g. urea)

**Formed elements** make up 45% of the blood volume. They include the red blood cells, or **erythrocytes**, white blood cells, or **leucocytes**, and cell fragments known as platelets, or **thrombocytes**



**White blood cells**, or **leucocytes**, are larger but much fewer in number than erythrocytes. There are a number of different types:

1. **granulocytes**, which have a granular cytoplasm with a lobed nucleus
2. **monocytes** and **lymphocytes**, which have a spherical nucleus and agranular cytoplasm.

Leucocytes can remove dead or injured cells and invading micro-organisms. They live for a few days

**Red blood cells**, or **erythrocytes**, are biconcave discs —thinner in the middle than at the edges. They have no nucleus, which allows more room for **haemoglobin**, a substance that can combine with oxygen. When combined with oxygen, haemoglobin is red, giving the erythrocytes, and hence the blood, their colour. Erythrocytes live for about 120 days. They are produced in the red bone marrow and destroyed in the liver and spleen

**Platelets**, or **thrombocytes**, are very small cell fragments with no nucleus. They are about one-third the size of an erythrocyte. They are formed in the red bone marrow and last for about 7 days. Thrombocytes are important for normal blood clotting

**Figure 6.2** The structure of blood

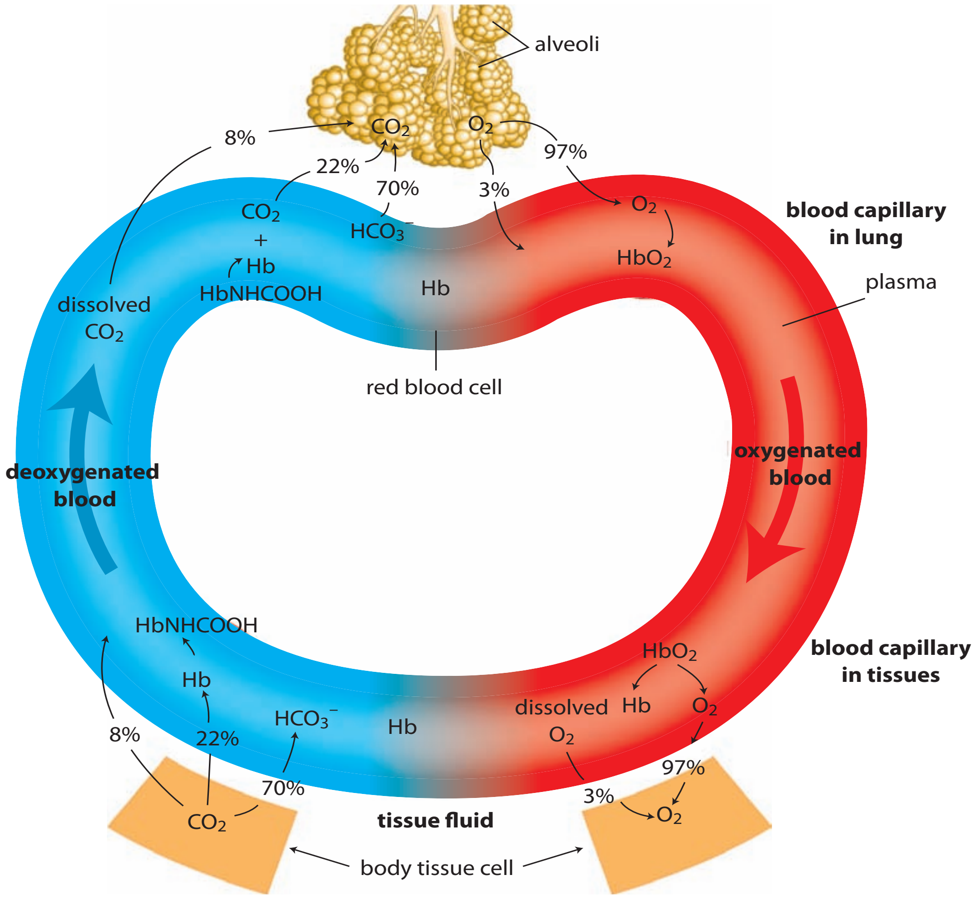



**Figure 6.3** The transport of oxygen and carbon dioxide

**Oxygenated blood** is blood with a high proportion of oxyhaemoglobin. Oxyhaemoglobin is bright red in colour, so the blood in the arteries (except for the arteries to the lungs) is bright red. Haemoglobin is dark red or purplish in colour. The **deoxygenated blood** in the veins (except the veins from the lungs) is therefore dark red.

Red blood cells are well suited to their function of oxygen transport because they:

- contain haemoglobin, which is able to combine with oxygen
- have no nucleus so that there is more room for haemoglobin molecules
- are shaped like biconcave discs—the biconcave centre increases the surface area for oxygen exchange and the thicker edges give a large volume that allows room for the haemoglobin molecules.

## *Transport of carbon dioxide*

The carbon dioxide in the blood is carried in a number of different ways. Some—about 7% or 8%—is dissolved in the plasma and carried in solution. Another 22% or so combines with the globin part of the haemoglobin molecule to form a compound called **carbaminohaemoglobin**. The remainder of the carbon dioxide, about 70%, is carried in the plasma as bicarbonate ions, $HCO_3^-$ (see Fig. 6.3 and Table 6.1).

As the blood is flowing through the capillaries between the body cells, carbon dioxide diffuses into the plasma due to the difference in carbon dioxide concentration. Some carbon dioxide dissolves in the plasma, some combines with haemoglobin, but most reacts with water to form carbonic acid ($H_2CO_3$). Carbonic acid then dissociates into hydrogen ions and bicarbonate ions:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

The air sacs of the lungs, the **alveoli**, are surrounded by a dense network of capillaries. In the blood in these capillaries the reverse occurs. The carbon dioxide dissolved in the plasma diffuses out of the blood into the air in the alveolus. The carbaminohaemoglobin breaks down, and the carbon dioxide molecules released also diffuse into the alveolus. Hydrogen ions and bicarbonate ions recombine to form carbonic acid, which then breaks down under enzyme action into water and carbon dioxide. This carbon dioxide also diffuses into the alveolus (see Fig. 6.3 and Table 6.1).

**Table 6.1** Proportion of oxygen and carbon dioxide transported in the blood in different ways

| Oxygen | Carbon dioxide |
|---|---|
| 3% dissolved in plasma<br>97% as oxyhaemoglobin | 8% dissolved in plasma<br>22% as carbaminohaemoglobin<br>70% as bicarbonate ions |

## *Transport of nutrients and waste*

Nutrients and wastes (apart from carbon dioxide which we have already discussed) are transported dissolved in the blood plasma.

**Nutrients** are the essential elements and molecules that are obtained from the food we eat. Inorganic nutrients are transported as ions. Some of the important ions dissolved in the blood plasma are sodium ions ($Na^+$), calcium ions ($Ca^{2+}$), potassium ions ($K^+$), chloride ions ($Cl^-$) and iodide ions ($I^-$). Organic nutrients dissolved in the blood plasma include glucose, vitamins, amino acids, fatty acids and glycerol.

**Wastes**, or more correctly, **metabolic wastes**, are substances produced by the cells that cannot be used and would be harmful if allowed to accumulate. The most important organic wastes that are transported in solution in the blood plasma are urea, creatinine and uric acid.

# The heart and blood vessels

## *The heart*

The **heart** is the pump that pushes the blood around the body. It is located in the middle of the chest cavity, between the two lungs. Roughly conical in shape, the heart is about the size of a closed human fist—about 12 cm long, 9 cm across the broadest point and about 6 cm thick. Around the heart, and completely enclosing it, is a membrane called the **pericardium**. This membrane holds the heart in place but allows the heart to move as it beats. The pericardium also prevents the heart from overstretching. The wall of the heart itself is made up of a special type of muscle, called **cardiac muscle**. Figure 6.4 summarises the functioning of the heart and blood vessels.

For more on the blood, heart and blood vessels see http://www.fi.edu/learn/heart/index.html

## *Blood vessels*

Blood is pumped by the heart into blood vessels, which carry the blood to the cells of the body or the lungs and then bring it back to the heart again. The same blood flows continuously through the heart, and this movement of blood is referred to as the **circulation**. The blood vessels that are joined together to form the channels through which the blood flows are:

- **arteries**, which carry blood away from the heart
- **capillaries**, which are tiny vessels that carry blood between the cells
- **veins**, which carry blood back to the heart.

**Capillaries** are microscopic blood vessels that form a network, carrying blood close to nearly every cell in the body. This enables the cells to get their requirements from the blood and to pass their waste into the blood. The structure of the capillaries suits them to this function of exchange of materials between the blood and the body cells. Capillary walls have only one layer of cells (Fig. 6.5). This allows substances to pass easily between the blood and the surrounding cells.

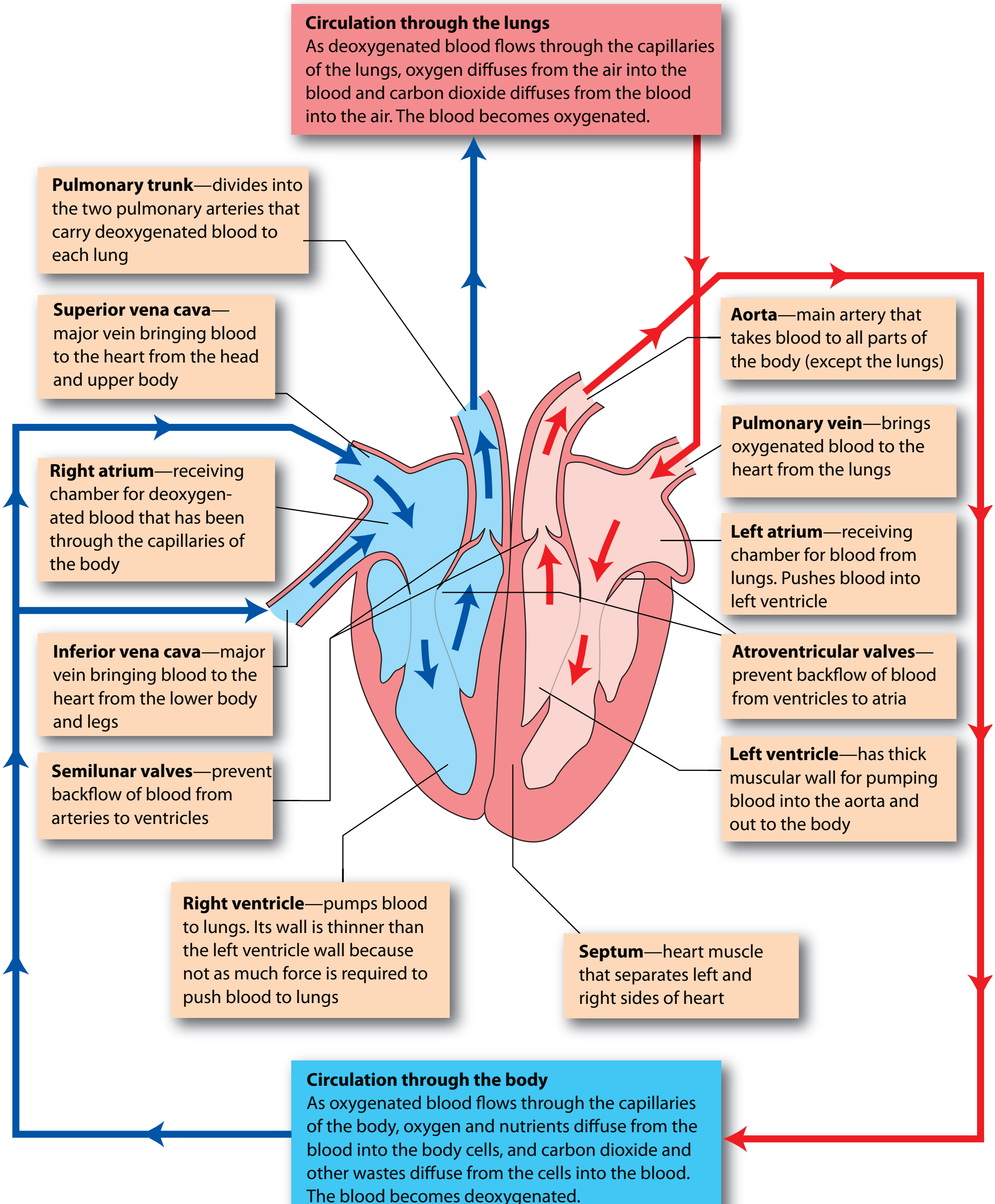



**Figure 6.4** The structure of the heart and the circulation of the blood

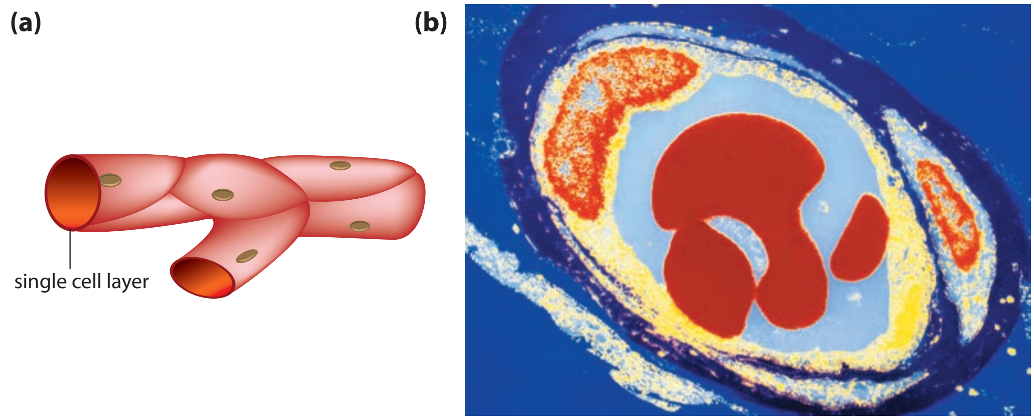



**Figure 6.5** A blood capillary: **(a)** diagram of the wall, which consists of a single layer of cells; **(b)** electron micrograph of a transverse section, showing the single cell that forms the wall of a blood capillary. The dark area at the top left of the cell is the cell nucleus and red blood cells are occupying most of the interior of the capillary

# Blood flow

As we have seen the blood is the transport medium that delivers oxygen and nutrients to cells and carries away their wastes. The requirements of cells will vary depending on their level of activity. For example, when we are actively exercising, the muscles will use up much more oxygen and nutrients, and will produce more carbon dioxide and other wastes, than when we are sitting at rest. To cater for these changes in requirements, the blood flow to and from the cells must be able to change. There are two ways that this can occur: by changing the output of blood from the heart; and by changing the diameter of the blood vessels supplying the tissues.

## *The cardiac cycle*

Animations showing the cardiac cycle can be seen at:

- http://msjensen.cehd.umn.edu/1135/Links/Animations/Flash/0028-swf_the_cardiac_cy.swf
- http://anatimation.com/cardiac-cycle/cardiac-cycle-animation-and-diagram.html

The **cardiac cycle**, or heartbeat, is the sequence of events that occurs in one complete beat of the heart. The pumping phase of the cycle, when the heart muscle contracts, is called **systole**. The filling phase as the heart muscle relaxes is called **diastole**. For a short time both atria and ventricles are in diastole. During this phase the atria fill with blood and the ventricles also receive blood as the valves between them are open. **Atrial systole**, the contraction of the atria, then follows and forces the remaining blood into the ventricles. The atria now relax and refill while the ventricles contract in **ventricular systole**. Ventricular systole forces blood into the arteries (Fig. 6.6). Although the left and right sides of the heart are two pumps, they operate together. Both atria contract simultaneously, as do both ventricles.

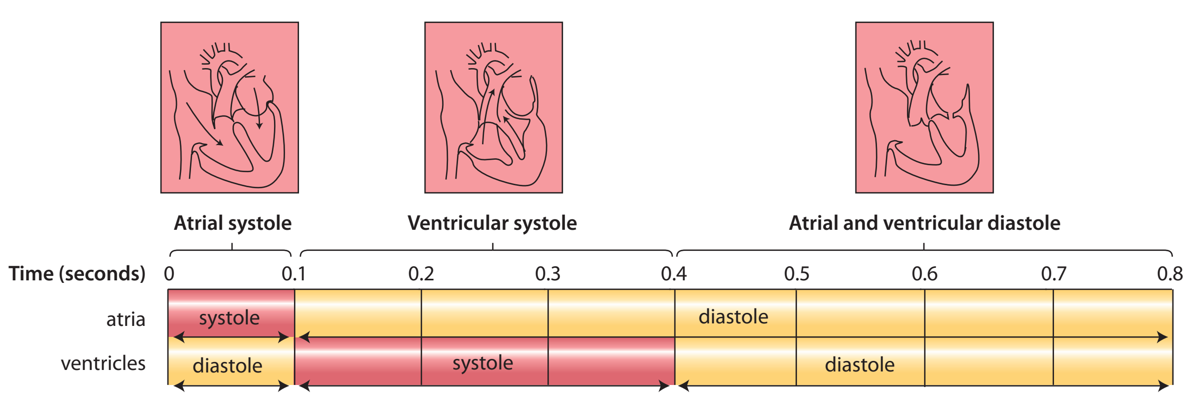



**Figure 6.6** The cardiac cycle

## Cardiac output

The rate of blood flow depends on how fast the heart is beating and how much blood the heart pumps with each beat. The **heart rate** is the number of times the heart beats per minute, while the **stroke volume** is the volume of blood forced from a ventricle of the heart with each contraction. A combination of both of these factors influences the **cardiac output**—the amount of blood leaving one of the ventricles every minute. The cardiac output is equal to the stroke volume multiplied by the heart rate:

$$\text{cardiac output (mL)} = \text{stroke volume (mL)} \times \text{heart rate (beats/minute)}$$

## Blood flow in arteries

**Arteries** are the blood vessels that carry blood away from the heart. The walls of an artery contain smooth muscle and elastic fibres. When the ventricles contract and push blood into the arteries, the walls of the arteries stretch to accommodate the extra blood. When the ventricles relax, the elastic artery walls recoil. This elastic recoil keeps the blood moving and maintains the pressure. The muscle in the artery walls *does not* contract and relax to pump the blood along. However, the muscle can contract to reduce the diameter of the artery and thus reduce blood flow to an organ (Fig. 6.7). Such contraction of a blood vessel is called **vasoconstriction**. Conversely, the muscle may relax to increase blood flow to an organ—**vasodilation**. In this way blood flow may be changed from one organ to another to allow for the changing needs of the body.

The very large arteries that receive blood pumped by the ventricles divide into smaller arteries. These in turn divide into very small arteries, known as **arterioles**. It is the arterioles that supply blood to the capillaries. Like the larger arteries, the arterioles have smooth muscle in their walls. Contraction or relaxation of this muscle is very important in regulating blood flow through the capillaries.

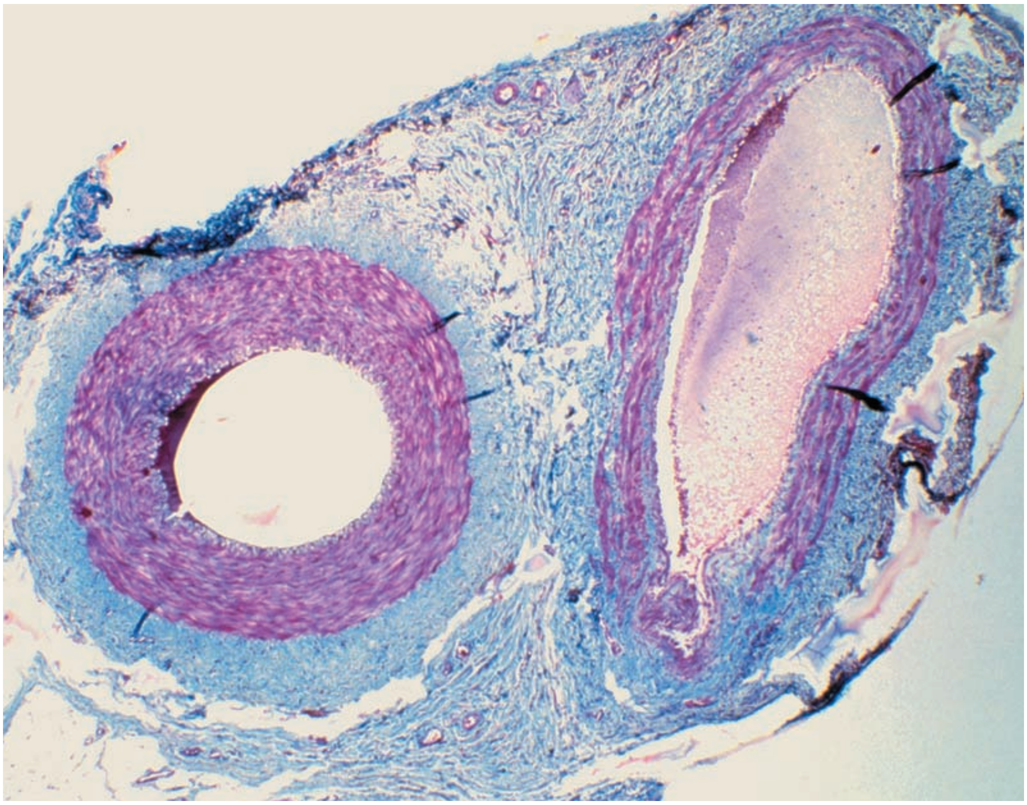


**Figure 6.7** A transverse section of an artery (left) and a vein (right) showing the difference between the walls. The vein has a thinner wall and is being flattened by the surrounding tissue

**Veins**, the blood vessels that carry blood towards the heart, do not have muscular walls and are not able to change their diameter in the way that arteries do. Similarly, **venules**, the tiny veins that carry blood away from the capillaries, do not have muscles in their walls that can change their diameter.

**Table 6.2** Differences between arteries and veins

| Arteries | Veins |
|---|---|
| Carry blood away from the heart | Carry blood towards the heart |
| Have a blood pressure that increases as the ventricles contract and decreases as the ventricles relax | Have a constant, relatively low blood pressure |
| Have thick, muscular, elastic walls | Have thin, relatively inelastic walls with little muscle |
| Have no valves | Often have valves |

# Responding to the body's demands

## *Regulating cardiac output*

The heart has its own inbuilt rhythm of contraction and relaxation, but this can be increased or decreased by nervous stimulation from the cardiac centre in the brain, or by certain chemical substances carried in the blood.

In the wall of the right atrium of the heart is a collection of nerve cells called the **sinoatrial node**, or simply the **SA node**. The SA node acts as a 'pacemaker' for the heart. Left to its own devices the heart would have a constant beat through the activity of the SA node. The SA node begins each cardiac cycle with nerve impulses that spread out over the atria causing them to contract.

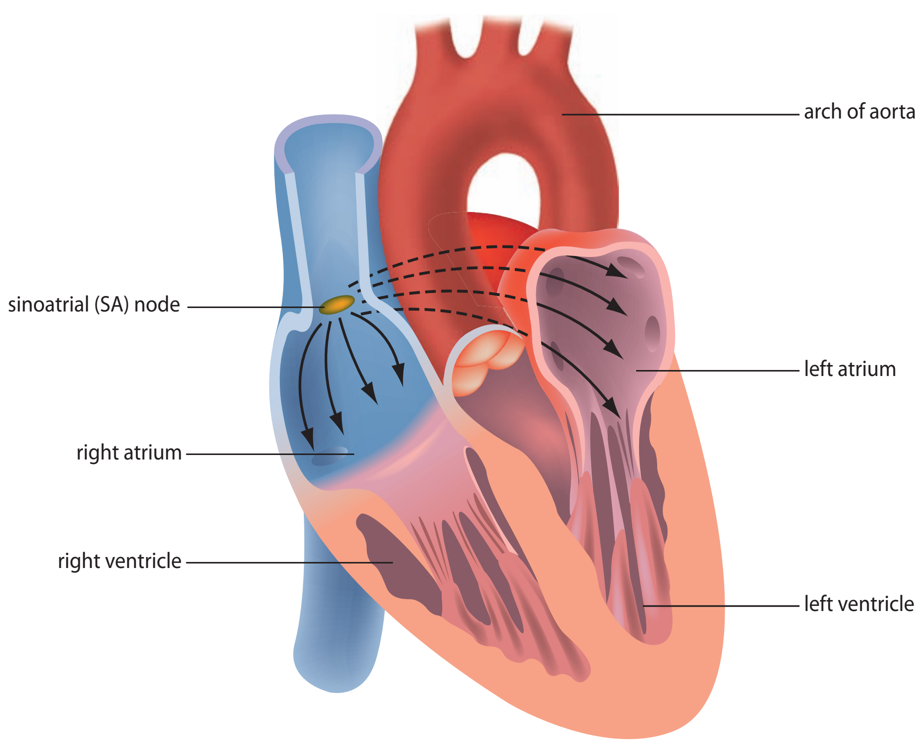



**Figure 6.8** The location of the SA node in the right atrium and how impulses spread across the surface of the atria

Although the node is able to initiate heart muscle contraction on its own, its activities are influenced by the nervous system. Nerve cells from a part of the brain called the **cardiovascular regulating centre** carry nerve impulses to the SA node, causing the heart rate to speed up or slow down.

## Regulating blood flow

**Blood flow** is the amount of blood flowing through an organ or a blood vessel in a given time—usually measured in millilitres per minute (mL/min). Blood flow through the capillary networks of the body's various organs is partly determined by the cardiac output, but also by the diameter of the arteries and arterioles that supply the capillaries. Flow through individual organs will vary from minute to minute as blood is redirected from one organ to another. Such changes in the distribution of blood flow to the organs are accomplished mainly by changing the diameter of arterioles.

A number of factors influence arteriole diameter. The cardiovascular regulating centre in the brain is able to control the diameter of arteries and arterioles throughout the body. Various hormones also affect blood vessel diameter. The best known of these is adrenaline (also called epinephrine). **Adrenaline** causes vasoconstriction of most arterioles but in the skeletal muscles and the heart muscle it causes vasodilation. To a certain extent, these tissues are able to regulate their own blood supply. If skeletal or heart muscle has an inadequate blood flow its waste products will accumulate, which will stimulate vasodilation. This will increase oxygen supply and removal of the waste products, both factors which cause vasoconstriction. These mechanisms achieve a dynamic equilibrium that adjusts blood flow depending on the needs of the tissue.

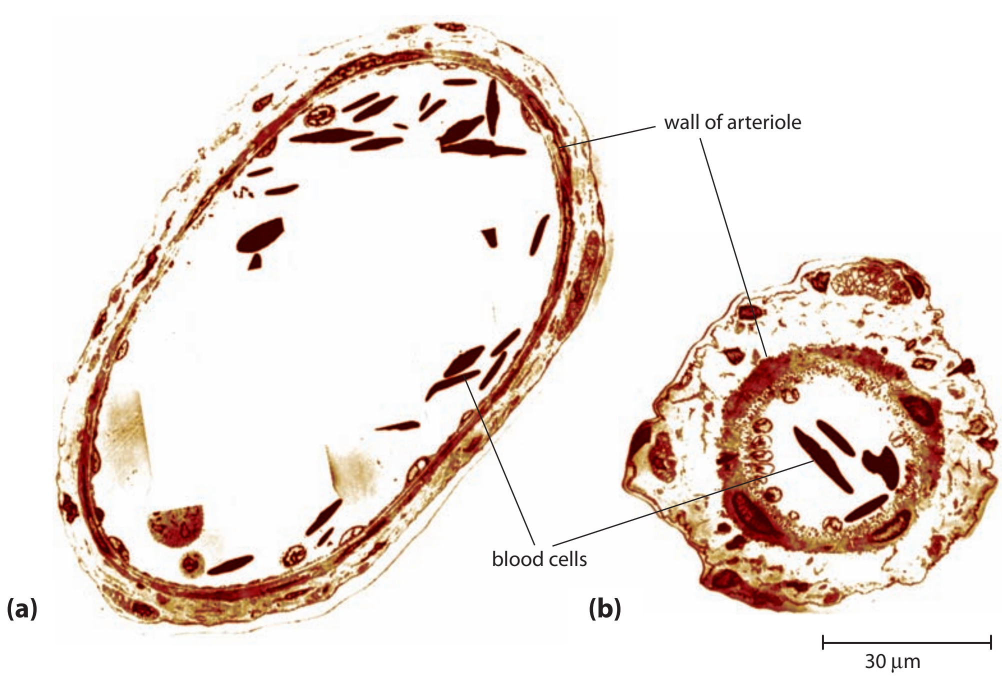



**Figure 6.9** The ability of arterioles to constrict: **(a)** a dilated arteriole; **(b)** the same arteriole constricted, now about one-third the size

## Changes in blood flow during exercise

During exercise, such as running or swimming, the activity of skeletal muscles is greatly increased to bring about the movement of the body. To maintain the activity of the muscle cells a large increase in blood flow is required to ensure an adequate supply of oxygen and nutrients, and to remove the carbon dioxide and heat produced.

Thus, the output of the heart may increase from 5 L/min at rest to a maximum of 30 L/min in a trained athlete.

In physical activity it is the contracting muscles that require the extra blood flow. Other organs do not need extra oxygen and nutrients and do not release extra carbon dioxide. To ensure that blood supply to the muscles is increased, the nervous system and the hormone adrenaline cause constriction of the blood vessels in internal organs such as the stomach and intestines. This is accompanied by a dilation of blood vessels in the muscles. Blood is directed away from those organs that do not require increased blood flow to the contracting muscles that do require more blood.

As a person is about to begin exercising there is an anticipatory response brought about by the nervous system. Heart rate and stroke volume increase and there is an increase in the blood flow to skeletal muscles.

As exercise proceeds, the muscle cells continually require energy. Respiration in the muscle cells makes the energy available but produces large amounts of wastes, including carbon dioxide and lactic acid. These wastes act as **vasodilators**, substances that produce a local widening, or dilation, of arterioles. This results in increased blood flow through the muscle tissues, ensuring that the cells are adequately supplied with oxygen and nutrients for continued functioning. Cellular respiration also releases a lot of heat energy, which tends to increase blood temperature. This also contributes to an increase in heart rate.

## Cardiovascular disease

The heart and blood vessels may be affected by a variety of diseases. These are the **cardiovascular diseases**, although they are often referred to by the general name of 'heart disease'.

Over the past 60 years there has been a steady increase in the importance of cardiovascular disease as a cause of ill-health and death in Australia and other developed countries, such as the United States and the United Kingdom. In Australia, the proportion of deaths from cardiovascular disease rose from 14% in 1923 to 54.6% in 1964 and was still very high, at 34.5%, in 2005.

Cardiovascular disease is at present the most serious health problem in Australian society. There are two reasons why cardiovascular disease has assumed such importance. Firstly, people in developed countries are living longer. Improved nutrition, preventive medicine and the improved treatment of communicable diseases have increased the average life span of people. Since cardiovascular disease is more common in older age groups, increased life expectancy results in a higher rate of such disease. The second reason for the increase in cardiovascular disease is the changes that have occurred in lifestyle over the past 60 years. A reduction in the amount of physical activity, changes in diet and other factors have contributed to the rise in the incidence of heart and blood vessel disease. In more recent times there has been a decline in the proportion of *deaths* through cardiovascular disease. This has been achieved through improved treatment and through educational campaigns aimed at encouraging people to adopt a health-sustaining lifestyle in order to minimise the risk of these diseases.

### *Hypertension*

The most common cause of cardiovascular disease is high blood pressure, or **hypertension**. Blood pressure fluctuates greatly, depending on a person's level of activity, body position and emotional state at any particular time. However, blood pressure that is consistently above the normal level will cause the heart to pump harder, cause damage to the arteries and accelerate the accumulation of fatty deposits in the arteries.

The causes of hypertension are largely unknown. However, it is known that certain factors are associated with the development of the condition. Diet is one important factor: being overweight, having a high salt (sodium chloride) intake, and consuming excessive amounts of alcohol (four or more standard drinks daily for men and two for women) are all associated with hypertension.

Treatment of hypertension involves dietary changes to reduce energy and salt intake; regular exercise; regular relaxation; and not smoking. Simple lifestyle modifications to take these factors into account will often result in a reduction of blood pressure to the normal level. Drug treatment can be used in cases where hypertension cannot be controlled by other methods.

## Arteriosclerosis

**Arteriosclerosis** is a degeneration of the walls of the arteries, which is commonly known as 'hardening of the arteries'. It includes such changes as the loss of elasticity of the artery walls, the narrowing of the diameter of the arteries, and the development of any roughness or obstruction of the artery wall. The roughening and obstruction of the artery wall, called **atherosclerosis**, may lead to a heart attack or stroke.

Atherosclerosis begins with the deposition of fatty substances on the inside walls of the arteries. These fatty deposits are known as **plaques** (Fig. 6.10). In the area of the plaque, fibrous tissue develops, and eventually becomes exposed to the blood. This results in the deposition of calcium salts from the blood. Hard, calcified areas thus develop in the walls of the arteries.

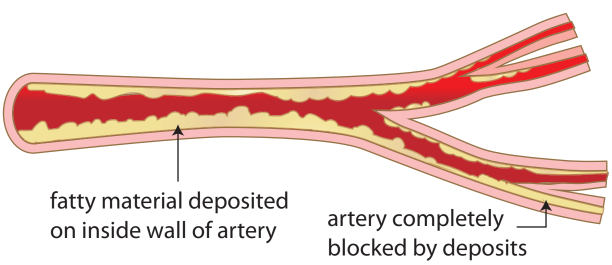



**Figure 6.10** Development of atherosclerosis in arteries

## Coronary heart disease

The arteries that supply blood to the heart muscle itself are the coronary arteries. Atherosclerosis of these arteries results in coronary heart disease (or coronary artery disease). The fatty deposits in the coronary arteries reduce the flow of blood to the heart muscle. This is of particular importance during exercise, when blood flow to the heart muscle is normally increased by several times the resting rate of flow. The presence of obstructing plaques means that the heart muscle supplied by the obstructed blood vessel does not receive enough oxygen to be able to respond to the increased work load during exercise. Severe atherosclerosis of the coronary arteries may result in angina or heart attack.

## Angina

**Angina** (angina pectoris) is pain, or a sensation of heaviness, in the chest. It may occur during physical activity, or at other times when the heart is called upon to increase output. The pain usually subsides when the person rests, and there is no damage to the heart muscle. People with angina can lead relatively normal lives, and drugs can be used to prevent or reduce the pain caused by inadequate blood flow to the heart muscle.

## Heart attack

A **heart attack** occurs when blood flow to a part of the heart muscle is stopped completely. Sometimes this occurs because plaque in the coronary arteries has accumulated to the point where it prevents blood flow through a branch of an artery. At other times the cause of the blockage may be the formation of a blood clot in an artery already narrowed by atherosclerosis. The plaque deposits on the inside of the artery can cause a rough surface on which a clot can form. Whatever the cause, part of the heart muscle is no longer supplied with oxygen, and the muscle in that area dies (Fig. 6.11). This severe injury to the heart, which is accompanied by sudden and severe chest pain, is a 'heart attack'. In medical terms, it is a **myocardial infarction**. Other terms that may be used to describe a heart attack are 'coronary', 'coronary thrombosis' or 'coronary occlusion'.

If the area of heart muscle damaged by lack of oxygen is not large, scar tissue forms and new arterial branches develop to supply blood to the area lacking oxygen (Fig. 6.11). Such healing may occur within a few weeks of a mild heart attack. If the damage to the heart muscle disturbs the normal rhythmic beat of the heart, **cardiac arrest** may occur. The heart pumps little or no blood and may even stop completely. Death then occurs within minutes unless normal rhythm can be restored.

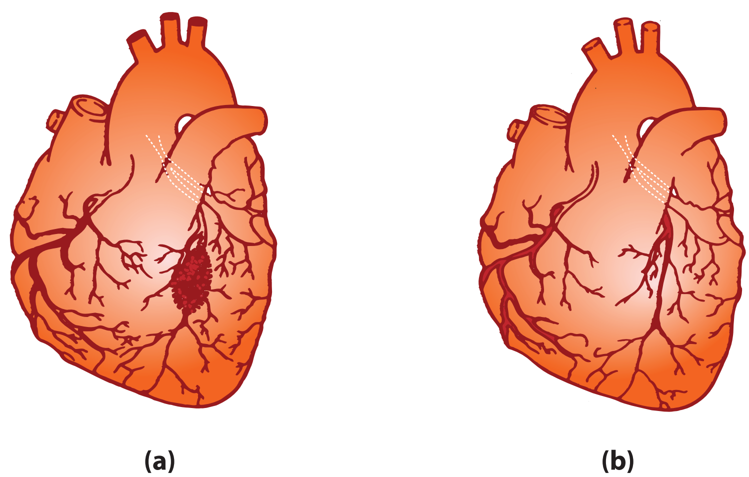


**Figure 6.11** Myocardial infarction: **(a)** in a heart attack, an area of the heart muscle is deprived of its blood supply and the muscle in that area dies; **(b)** after 6–8 weeks scar tissue has formed and new arterial branches develop to supply that area

Although heart attacks may be fatal, many people make a complete recovery from an attack and continue to lead a normal life. The actor Peter Sellers had a rapid series of eight heart attacks in 1964 but continued to make films until he died in 1980.

## Stroke

If atherosclerosis affects the blood vessels supplying the brain, called the **cerebral arteries**, interruption of the blood supply to a part of the brain may occur. That part of the brain receives insufficient oxygen and the nervous tissue dies. This is called a **stroke**. A stroke may occur if plaque blocks an artery in the brain, if a blood clot forms in an artery that is partly blocked (cerebral thrombosis), or if bleeding occurs at a weak point in one of the arteries (cerebral haemorrhage).

The effect of a stroke depends on which part of the brain is affected by the lack of oxygen. Severe strokes can cause death or severe disability; others are mild and recovery is rapid. Often, strokes result in paralysis of one of the limbs or of one side of the body. Speech is sometimes affected. Many people who have strokes recover and lead quite normal lives. Louis Pasteur survived a stroke at the age of 45 and continued to work productively for another 27 years, during which time he had 50 minor strokes.

## Peripheral vascular disease

Cardiovascular disease affecting veins and arteries in the limbs is called **peripheral vascular disease**. It usually occurs in the feet and legs, but sometimes affects the hands and arms. Peripheral vascular diseases include:

- arteriosclerosis in the limb arteries, so that blood supply to part of an arm or leg is slow or absent
- phlebitis, or inflammation of a vein—such inflammation may cause the development of blood clots
- varicose veins—enlarged, lengthened and tortuous veins, which cannot carry blood back to the heart efficiently and may allow blood to accumulate in the lower limbs.

Smoking is a major cause of peripheral vascular disease.

## Factors influencing cardiovascular disease

Research has identified many factors that contribute to cardiovascular disease. Evidence on the relative importance of each factor varies, but medical authorities agree on the following list:

1. *Age*. The incidence of atherosclerosis increases with age, but it is now believed not to be an inevitable part of growing older, provided other risk factors are avoided.
2. *Gender*. Women rarely suffer from cardiovascular disease before the menopause (usually between 45 and 55 years of age). Men may develop cardiovascular disease at a much earlier age.
3. *Diet*. Saturated fats, most of which are of animal origin, result in raised blood cholesterol levels. High salt intake is associated with hypertension.
4. *High blood cholesterol level*. Blood cholesterol level is a measure of the fat content of the blood and, to a large degree, is controlled by the quantity of saturated fats in the diet. Reducing fat intake, especially saturated fats, helps to reduce the cholesterol level of the blood. Exercise is also beneficial.
5. *High blood pressure*. Only regular medical checks can reveal hypertension, but many factors such as smoking, being overweight, or high alcohol consumption contribute to hypertension.
6. *Overweight*. Being overweight, or obese, increases the strain on the heart and lungs.
7. *Smoking*. Smokers are five times more likely to die of cardiovascular disease than non-smokers. Smoking constricts blood vessels, causing hypertension, and the carbon monoxide in smoke combines with haemoglobin to reduce the oxygen-carrying capacity of the blood.
8. *Excessive alcohol consumption*. This is associated with hypertension and may lead to weakness of the heart muscle.
9. *Physical inactivity*. Regular moderate exercise reduces the risk of cardiovascular disease, whereas inactivity definitely increases the risk.
10. *Heredity*. There is a tendency for premature death due to heart disease to occur in families.

It is partly due to increased community awareness of these risk factors that the rate of premature death from cardiovascular disease has declined over the past 20 years.

## *What should I do to reduce the risk of cardiovascular disease?*

Reducing the risk of cardiovascular disease involves avoiding as many of the risk factors as possible. This will not only lessen the possibility of cardiovascular disease but will reduce the risk of other diseases as well (such as lung cancer resulting from smoking). The positive steps everyone should take are listed below.

1. Do not smoke. Smoking is the largest preventable cause of disease and death in Australia.
2. Adopt a healthy diet.
   - **(a)** Eat plenty of plant-based foods (vegetables, fruit and cereal-based foods such as bread, pasta, rice and noodles)
   - **(b)** Eat moderate amounts of lean meat, reduced fat dairy products, skinless poultry and fish.
   - **(c)** Limit intake of saturated (animal) fats—replace with poly- or monounsaturated fats and oils.
   - **(d)** Limit salt intake.
3. Exercise regularly. The National Heart Foundation recommends moderate activity (i.e. activity that slightly raises heart rate) for a total of 30 minutes on most days of the week.
4. Manage your weight. If you consume more energy in food and drink than your body needs the excess energy will be stored as body fat. Regular exercise and a healthy diet is the best way to manage weight.
5. Have regular blood pressure checks, especially as you get older.
6. Consume alcohol only in moderation.

**Figure 6.12** Regular exercise reduces the risk of cardiovascular disease

# Working scientifically

## Activity 6.1 Blood flow during exercise

Table 6.3 shows blood flow through various parts of the body when a person is sitting at rest and during moderate exercise.

**Table 6.3** Blood flow at rest and during moderate exercise

| Part of the body | Rate of blood flow (mL/min) | |
|---|---|---|
| | When resting | When exercising |
| Skeletal muscle | 1000 | 12 500 |
| Digestive system (stomach, intestines, liver) | 1350 | 600 |
| Kidneys | 1100 | 600 |
| Brain | 700 | 750 |
| Skin | 300 | 1 900 |
| Heart muscle | 200 | 750 |
| Other organs | 350 | 400 |

Data from Saladin K, ed. *Anatomy and Physiology*: *The Unity of Form and Function*. 3rd edn. New York: McGraw-Hill, 2004.

The contrast between blood flow to the various organs at rest and while exercising would be more striking if presented in the form of a column graph. Your teacher may want you to draw such a graph.

Use the data in the table, or your graph, to answer the following questions.

1. Calculate the person's cardiac output when at rest.
2. Calculate the person's cardiac output while exercising.
3. What are the two ways in which cardiac output can be increased?
4. For each part of the body listed in the table explain the reasons for any changes in blood flow that occur during exercise.

## Activity 6.2 Measuring blood pressure

Work with a partner to measure one another's blood pressure. Your teacher will explain how to use the sphygmomanometers (instruments for measuring blood pressure) available to your class. Inflate the pressure cuff to about 160 mmHg (do not exceed 180 mmHg) and do not leave the cuff inflated for more than a couple of minutes. Record the systolic pressure, that is, the blood pressure as the ventricles contract. Unless you have an automatic sphygmomanometer, diastolic pressure, the pressure while the ventricles are relaxed, is more difficult to measure without experience.

1. Make a list of all the factors that you think may influence blood pressure.
2. You may like to test the effects of some factors such as posture (e.g. sitting, standing, lying) or exercise on blood pressure.

## REVIEW QUESTIONS

1. Draw up a table with two columns. In one column list the functions of the blood; in the second, describe the importance of each function to the body.
2. (a) Describe the ways in which oxygen is carried in the blood.
   (b) Describe the ways in which carbon dioxide is carried in the blood.
3. (a) What is blood flow?
   (b) Describe the two ways in which blood flow to an organ can be increased.
   (c) What changes occur in blood flow during exercise?
4. Describe the cardiac cycle.
5. (a) Where is the heart's 'pacemaker'?
   (b) Describe how the activity of the pacemaker is regulated.
6. For each of the following describe how its structure is related to its function:
   (a) red blood cell
   (b) artery
   (c) heart
7. (a) Why has cardiovascular disease become the main cause of death in industrialised societies?
   (b) In recent years the proportion of deaths from cardiovascular disease has been declining. Give two reasons to account for this decline.
8. (a) What is hypertension?
   (b) Why is prolonged hypertension dangerous?
   (c) What factors are known to be associated with hypertension?
9. (a) What is atherosclerosis?
   (b) What effects does atherosclerosis have on blood flow?
   (c) What name is given to atherosclerosis of the blood vessels supplying blood to the heart muscle?
10. (a) What is a stroke?
    (b) What part of the body is affected by a stroke?
11. (a) List the factors that contribute to cardiovascular disease.
    (b) Do any of these factors apply to any members of your family? Explain.
12. (a) What positive steps should one take to adopt a lifestyle that minimises the risk of developing cardiovascular disease?
    (b) How does your lifestyle compare with the ideal described in answer to part (a)?

## APPLY YOUR KNOWLEDGE

1. (a) Why is blood red?
   (b) Royalty is sometimes described as having 'blue blood'. See if you can find out why they are described in this way.
2. People living near sea level have about 5 million erythrocytes in 1 $mm^3$ of blood. People living at an altitude of 5500 m above sea level have about 7.5 million erythrocytes per $mm^3$ of blood. Suggest an explanation for this difference.
3. Table 6.4 shows some causes of death in Australia for selected years from 1948 to 2005.

**Table 6.4** Some causes of death in Australia 1948–2005

| Cause of death | Percentage of all deaths | | | |
|---|---|---|---|---|
| | 1948 | 1975 | 1996 | 2005 |
| Cardiovascular disease | 43.4 | 53.9 | 41.9 | 35.3 |
| Malignant tumours | 12.6 | 18.6 | 26.9 | 29.4 |
| Accidents | 5.1 | 6.2 | 3.6 | 4.0 |
| Communicable diseases | 8.3 | 0.8 | 1.3 | 1.3 |

Source: Australian Bureau of Statistics. *Causes of Death*. Canberra: ABS, 2007. Catalogue number 3303.0.

Refer to the data in Table 6.4 to answer the following questions.

**(a)** The decline in deaths due to cardiovascular disease is partly due to improved diagnosis and treatment methods. Use references to find out about modern diagnosis and treatment for cardiovascular disease and discuss some of the methods that would not have been in use 30 years ago.

**(b)** A second reason for the decline in deaths due to cardiovascular disease is that people are becoming more aware of the lifestyle changes that they need to make in order to reduce their risk. Discuss some of the ways in which Australians are being made aware of the risk factors for cardiovascular disease.

**(c)** Suggest why the proportion of deaths due to accidents is now much lower than it was 30 years ago.

**(d)** How can you account for the big decline in the proportion of deaths due to communicable disease in the last 60 years?

**(e)** The proportion of deaths due to communicable disease is now higher than it was 30 years ago. Suggest a reason, or reasons, for the increase.

**4.** A 25% reduction in the cholesterol level of a person's blood reduces their chance of suffering a heart attack by half. Describe the dietary changes that you could make to reduce your blood cholesterol level.

**5.** At one time it was believed that disease was caused by 'bad blood'. Taking large amounts of blood from a patient by bleeding (blood-letting) was widely practised as a cure for disease. Louis XIII of France had blood taken 47 times in six months; Louis XV was bled 38 times and Charles II of England had blood taken numerous times even just before his death. Describe some of the effects that the removal of large quantities of blood would have on a patient.

**6.** Cardiovascular disease and cancer are sometimes called 'lifestyle diseases'. Why is this name given to cardiovascular disease?