Surfing

Senior Science

Medical Technology: Bionics

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Science Press

Contents

Use the table of contents to record your progress through this book. As you complete each topic, write the date completed, then tick one of the three remaining columns to guide your revision for later. The column headers use the following codes:

?? = Don't understand this very well at all. RR = Need to revise this. OK = Know this.

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Introduction

Each book in the 'Surfing' series contains a summary, with occasional more detailed sections, of all the mandatory sections of the syllabus, along with questions and answers.

It is envisaged this book will be useful in class for both initial understanding and revision, while the more traditional textbook can remain at home for more detailed analysis.

All types of questions — multiple choice, short response, structured response and free response — are provided. Questions are written in exam style and use the verbs specified by the Board of Studies so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions, including multiple choice and free response questions. These cover every aspect of the topic, and are useful for revision and exam practice. Marking guidelines are supplied where appropriate.

Verbs To Watch

When you are answering questions in this book, your textbook or any examinations, make sure you answer what the question is asking. To do this you will have to know what each of the terms below means — they dictate what sort of an answer is required. It is essential that you learn their meanings as required by the Board of Studies. Your exam answers will be marked according to what these terms indicate your answer should be saying.

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.
analyse Identify components and the relationships among them, draw out and relate implications.
apply Use, utilise, employ in a particular situation.
appreciate Make a judgement about the value of something.
assess Make a judgement of value, quality, outcomes, results or size.
calculate Determine from given facts, figures or information.
clarify Make clear or plain.
classify Arrange into classes, groups or categories.
compare Show how things are similar or different.
construct Make, build, put together items or arguments.
contrast Show how things are different or opposite.
critically (analyse/evaluate) Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to an analysis or evaluation.
deduce Draw conclusions.
define State the meaning of and identify essential qualities.
demonstrate Show by example.
describe Provide characteristics and features.
discuss Identify issues and provide points for and against.
distinguish Recognise or note/indicate as being distinct or different from, note difference between things.
evaluate Make a judgement based on criteria.
examine Inquire into.
explain Relate cause and effect, make the relationship between things evident, provide why and/or how.
extract Choose relevant and/or appropriate details.
extrapolate Infer from what is known.
identify Recognise and name.
interpret Draw meaning from.
investigate Plan, inquire into and draw conclusions about.
justify Support an argument or conclusion.
outline Sketch in general terms; indicate the main features.
predict Suggest what may happen based on available information.
propose Put forward (a point of view, idea, argument, suggestion etc.) for consideration or action.
recall Present remembered ideas, facts or experiences.
recommend Provide reasons in favour.
recount Retell a series of events.
summarise Express concisely the relevant details.
synthesise Put together various elements to make a whole.

1 History of Biomaterials and Implants

A prosthesis is an artificial replacement for a missing part of the body, such as a substitute hand, leg, eye or denture. Many of the simpler prostheses are attached to the outside of the body, such as glasses, hearing aid, an artificial leg or hand. Others are implanted into the body. Some, such as an artificial eye made from glass or plastic, fit into an existing socket. Others, such as plastic lenses used to replace the eye's natural lens, have to survive within the bodies tissues. Table 1.1 lists a range of biomedical devices and their uses.

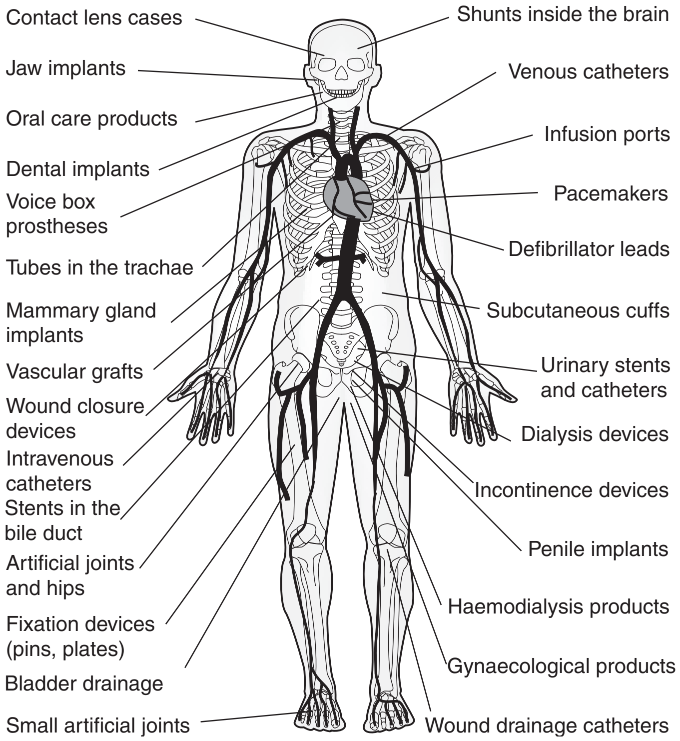

Figure 1.1 **Biomaterials and implants** The huge range of body parts provided by modern medicine and technology

The environment of the body is moist, salty and corrosive. Many early implants did not last long as they corroded or fractured. Some caused the bodies immune system to react, producing inflammation and an immune response. **Biocompatibility** is the ability of a material to function within a human or other organism without the material being damaged or causing damage. Table 2 lists many of the materials used in various biomedical devices.

Prosthesis and Human Hearing

Aids to improve hearing have been used for thousands of years. Cupping the hands over the ears is a help. Even better is an ear trumpet that can gather sound and feed it into the ear. Versions of the ear trumpet ranging from bull's horns to seashells have most likely been used by humans for a long time. The invention of the transistor allowed the development of practical hearing aids. Modern electronic hearing aids are able to assist some forms of hearing loss, but not all.

The idea of directly stimulating the nerves of the inner ear began two hundred years ago. Alessandro Volta carried out a dangerous experiment when he inserted metal rods attached to his newly invented battery into his ears. He described the sensation as similar to the sound of boiling water. Although other attempts continued throughout the next 50 years, by the mid 1800s, the idea of using electrical stimulation to improve hearing was rejected.

It wasn't until the 1930s that the effects of electrical stimulation on hearing were studied again. It was found that deaf individuals could achieve hearing sensation when they received electrical stimulation to the middle ear. The limits of technology at the time did not allow this idea to be developed further.

By the late 1950s, scientists in France using microsurgical techniques reported the first successful electrical stimulation of hearing nerves by inserting an electrode in a deaf subject's cochlea or inner ear. The patient perceived the rhythm of speech and reported that the stimulation provided assistance with lip-reading. This was the beginning of the development of modern **cochlear** implants.

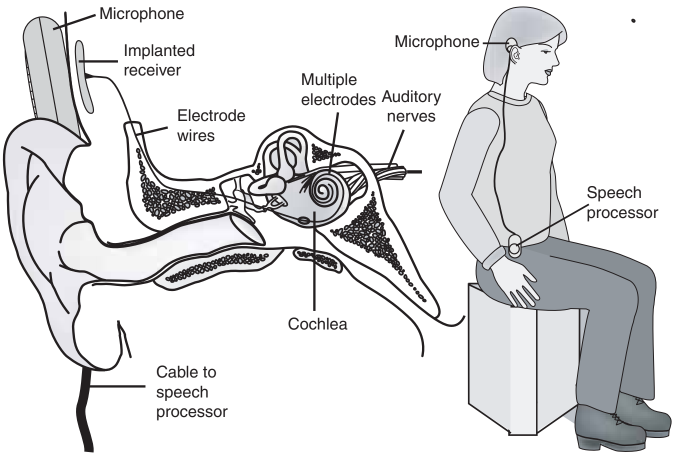

Figure 1.2 **Prothesis** A modern cochlear implant

Throughout the 1960s, a large amount of time and effort went into studying and developing cochlear implants. By 1970s the first practical cochlear implants were inserted. They were simple devices that sent information to only one small site in the cochlea. They helped patients to know that people were speaking and they could detect loud sounds that warned of danger. The implants helped people with lip-reading but generally did not allow them to recognise speech.

The miniaturisation of electronics allowed the introduction of multichannel cochlear implants in the 1980s and was a major advance in cochlear implant technology. Multichannel cochlear implants stimulate hearing nerve fibres at many locations along the length of the cochlea and thus allow many frequencies to be detected. The introduction of the multichannel implant allowed people to understand speech without lip-reading. Improvements have continued and since 1990 Australia has led the world in the development and production of cochlear implants.

Biomaterials

Biomaterial is a substance used in a medical device intended to interact with biological systems. Some biomaterials are intended to last for as long as possible. It is both expensive, painful and a danger to health to have to replace an artificial hip or pacemaker. Other biomaterials are made to last a short time — it is intended that the body dissolve or remove them in some way. Thus sutures (stitches) naturally dissolve over time so they don't need to be removed, while bone plates are incorporated into normal bone.

Table 1.1 Biomedical devices

Device	Use
Plates, pins and screws	Used to protect damaged areas in the skull and to hold parts of the leg together as shattered bones heal. Pins and screws used in dental work to hold crowns in place.
Artificial joints	Replace joints such as those in fingers, knees and hips.
Pacemakers	Replace or assist the natural pacemakers that control the beating of the heart.
Hearing aid	Small microphone, amplifier and loudspeaker increases the intensity of sound for those hard of hearing.
Cochlear implants	A type of hearing aid for the profoundly deaf where the electrical signals are transmitted to a coil implanted at the back of the ear and sent through wires to electrodes implanted into the cochlea of the inner ear.
Artificial valves	Replace the valves between the chambers of the heart, or in the arteries leaving the heart.
Crowns	Replace the outer surface of a damaged tooth.
Dentures	Replace the whole tooth row.
Lenses	Supplement the eyes' lenses with glasses or contact lenses, or replace the lens of the eye with one made from plastic.
Prosthetic limbs	Replace hands, arms or legs.

Table 1.2 Biomedical materials and devices

Part of the body	Device	Materials used
Skeletal system	Joint replacement (hip, knee)	Titanium, Ti-Al-V alloy, stainless steel, polyethylene
	Bone plate for fracture fixation	Stainless steel, cobalt-chromium alloy
	Bone cement	Poly(methyl methacrylate)
	Bony defect repair	Hydroxylapatite
	Artificial tendon and ligament	Teflon, dacron
	Dental implant for tooth fixation	Titanium, alumina, calcium phosphate
Cardio-vascular system	Blood vessel prosthesis	Dacron, teflon, polyurethane
	Heart valve	Reprocessed tissue, stainless steel, carbon
	Catheter	Silicone rubber, teflon, polyurethane
Organs	Artificial heart	Polyurethane
	Skin repair template	Silicone-collagen composite
	Artificial kidney	Cellulose, polyacrylonitrile
	Heart-lung machine	Silicone rubber
Senses	Cochlear replacement	Platinum electrodes
	Intra-ocular lens	Poly(methyl methacrylate), silicone rubber, hydrogel
	Contact lens	Silicone-acrylate, hydrogel
	Corneal bandage	Collagen, hydrogel

A wide range of biomaterials have been found suitable for use within humans.

- **Metals** must be corrosion-resistant so that alloys such as stainless steel and newer 'superalloys' are mostly used. They are required where strength is needed, such as in hip replacements.
- **Plastics** have to sometimes withstand considerable forces. For this reason UHMWPE, a form of polyethylene, is often used. Teflon and dacron can be used for fabrics, while other plastics have to act as a glue. Some plastics are designed to be degraded and absorbed by the body after they have served their function.
- **Ceramics** are used with bones while others are tooth replacements. They are very strong when compressed, but they are brittle.

- **Biological tissue** is used during transplants, especially with heart valves.

Not all materials used in prostheses have to survive the harsh conditions inside the body. Hearing aids have a plastic outer covering with miniature microphones, speakers, amplifiers and batteries inside. Hand and leg prostheses are again made of plastic and metal able to withstand the weight they support.

For You To Do

1. What name is given to an artificial replacement for a massing part of the body?
   (A) prothesis
   (B) implant
   (C) plastic
   (D) protease
2. Which of the following materials could be classed as a biomaterial?
   (A) aspirin
   (B) dioxin
   (C) strychnine
   (D) titanium
3. What does the word biocompatibility mean?
   (A) The ability of a material to be implanted within a human being.
   (B) The ability of a material to function within a human without the material causing damage.
   (C) The ability of a material to function within a human without the material being damaged.
   (D) The ability of a material to function within a human without the material being damaged or causing damage.
4. What is UHMWPE?
   (A) A new ceramic used to replace damaged bone.
   (B) A modern 'superalloy' used in heart pacemakers.
   (C) A plastic used in artificial hips.
   (D) A reprocessed biological material used to replace damaged heart valves.
5. Surgeons use stitches to tie together human tissues so that they will grow together and heal. A surgeon has removed a tumour from the small intestine and stitched the parts together with a suture. Which of the materials listed below would make the best material for the suture?
   (A) A strong metal like titanium so that it won't corrode.
   (B) A flexible plastic that dissolves slowly inside the body.
   (C) A strong and long-lasting plastic.
   (D) A flexible ceramic that dissolves slowly inside the body.
6. Use the Internet and other resources to draw a timeline to trace the historical development of artificial legs and dentures.
7. Use a timeline to trace the historical development of cochlear implants.
8. Use Figure 1.1 to answer the questions below.
   (a) Which part of the body has most implants?
   (b) How many of the implants are tubes?
   (c) Name one implant that may be used for reasons of appearance rather than health.
   (d) Name one implant not shown in the diagram.
9. Use the information in this unit, your textbook and other sources to complete Table 1.3.

Table 1.3 Biomedical devices

Device	Material used	Use
Plates, pins and screws		
Artificial joints		
Pacemakers		
Hearing aid		
Cochlear implants		
Artificial valves		
Crowns		
Dentures		
Lenses		
Prosthetic limbs		

10. Below is a list of biomedical devices that can be used to replace damaged or diseased body parts.
    (a) pins, screws and plates
    (b) artificial joints
    (c) pacemakers
    (d) cochlear implants
    (e) artificial valves
    (f) crowns
    (g) dentures
    (h) lenses
    (i) prosthetic limbs
    Match each of the parts in the list with where they would be used in Figure 1.3.
11. Here is a short history of the artificial eye.

    Artificial eye-making has been practised since ancient times. The first ocular prostheses were made by Roman and Egyptian priests as early as the fifth century BC. In those days artificial eyes were made of painted clay attached to cloth and worn outside the socket.

It took about twenty centuries for the first in-socket artificial eyes to be developed. At first, these were made of gold with coloured enamel. Then, in the latter part of the sixteenth century, the Venetians started making artificial eyes out of glass. These early glass eyes were crude, uncomfortable to wear, and very fragile. Even so, the Venetians continued making them and kept their methods secret until the end of the eighteenth century.

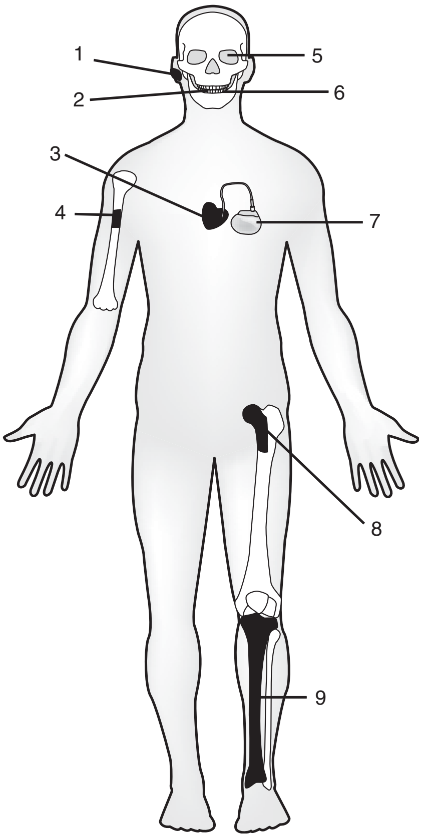

Figure 1.3 Biomedical devices

After that, the centre for artificial eye-making shifted to Paris for a time, but by the mid nineteenth century German glass blowers had developed superior techniques, and the centre for glass eye-making moved to Germany.

(a) How did the first artificial eyes differ from those made in the sixteenth century?
(b) Would you expect artificial eyes to be solid or hollow glass? Why?
(c) Suggest a class of materials that may have replaced glass for artificial eyes.

12. Here is a short history of the dentist's drill.

One of the earliest forms of prosthesis was the dental filling. When a tooth develops a cavity, the decayed tissue must be removed. The earliest devices for doing this were metal picks and enamel scissors. When two-edged cutting instruments were designed, they were twirled in both directions between the fingers. It was not until the later 1700s that a foot powered drill was developed. A foot-treadle spinning wheel was adapted to rotate a drill. By the mid 1800s mechanically powered dental drills were in use with the first electric powered drills used in the late 1800s.

What about the pain? The first anaesthetic was nitrous oxide. It was not widely used until the mid 1800s. Until that time you had decide which was worse — the pain from the tooth or the pain getting it repaired.

(a) Explain why twirling the two-edged cutting instrument is better than using it as a 'pick'.
(b) What advantage does a foot-powered drill have over one twirling one between the palms of the hand?

2 Circulatory System

The circulatory system is vital in maintaining humans as functioning organisms. It distributes food from the digestive system to the cells of the body. It also carries oxygen from the lungs to the tissues. It then returns wastes produced by the cells. Urea and other wastes are filtered from the blood by the kidneys. Carbon dioxide is returned to the air by the lungs.

Circulatory System

The **circulatory system** is composed of a pump called the heart and a series of tubes used to carry the blood to the tissues (Figure 2.1). The **heart** acts as a double pump. The first pump forces used blood to the lungs where carbon dioxide is released and oxygen absorbed. After the blood returns to the heart, the second pump forces the blood to the tissues of the body.

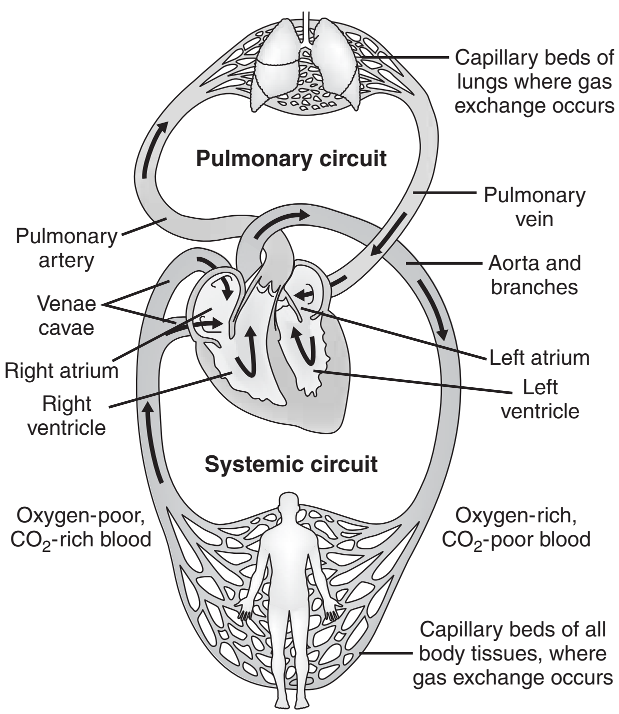

Figure 2.1 **Circulatory system** Blood leaves the heart in arteries, reaches the tissues in capillaries and returns to the heart in veins

Blood leaves the heart in **arteries**. These thick walled tubes must be quite strong and elastic. This is because the blood is under high pressure so that it will reach the extremities of the body. As the blood moves towards the tissues the arteries become smaller and smaller. The smallest tubes are called **capillaries**. With walls one cell thick, capillaries pass close to most cells of the body. This allows chemicals to pass freely from the blood to the cells. After passing through the capillaries, the blood returns to the heart along veins. These tubes do not have walls as thick as arteries as the pressure is not as high. The veins also contain valves to prevent the blood from flowing backwards.

The Heart

The human heart has four chambers — two on each side of the heart (Figure 2.2). The **atria** act as receiving chambers and are thin walled. The **ventricles** are the pumps, and have thick muscular walls. Between the atria and ventricles are **valves** to stop blood flowing backwards. The left side of the heart pumps blood to the body while the right side pumps it to the lungs. The **cardiac muscles** that make up about half the heart can never stop!

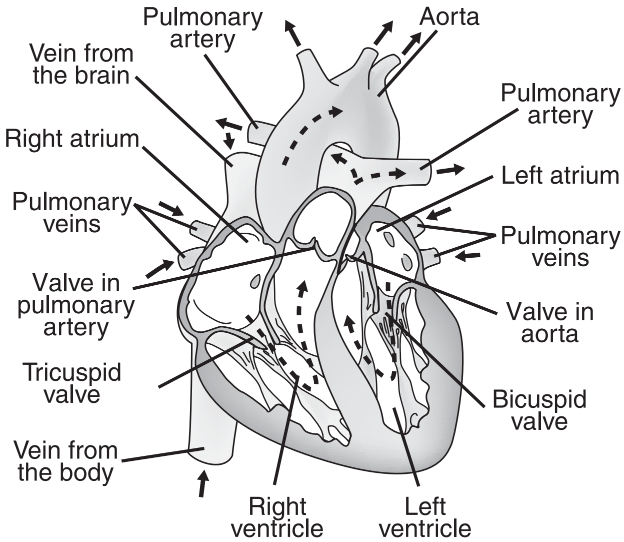

Figure 2.2 **Structure of the heart** The heart has four chambers separated by one-way valves

Blood from the body arrives are the right atrium in veins (Figure 2.2). As the ventricles relax, the right atrium contracts and forces the blood through the **tricuspid valve** into the right ventricle. When the ventricle contracts the valve closes shut and the blood is forced along the **pulmonary artery** to the lungs. A valve in this artery prevents blood flowing backwards. After passing through the lungs, the now oxygenated blood returns to the left atrium. When the ventricles relax, the left atrium contracts and forces the blood through the **bicuspid valve (**also called **mitral** valve) into the left ventricle. When the ventricles contract, the valve closes and the blood is forced out through an artery called the **aorta** to the cells of the body. There is a valve at the beginning of this artery to stop the blood flowing back into the heart.

Electrical Activity of the Heart

The contractions of the heart are controlled electrically. A device called an electrocardiograph can record these electrical impulses (Figure 2.3). Metal electrodes are attached to the skin on a person's arms, legs and chest. The electrodes detect the electrical activity and record it on moving paper or electronically to produce an **electrocardiogram** (ECG). Doctors can use the patterns produced to help diagnose heart problems.

When we look closely at the electrocardiogram we can match the graph with what is going on in the heart (Figure 2.3). The P-wave is produced by the electrical signals that cause the atria to contract, forcing blood into the ventricles. The QRS-wave represents the signals that bring about the contraction of the ventricles. The T-wave represents the recovery wave as the electrical signals spreads back over the ventricles in the opposite direction.

We can relate the sounds made by the pumping heart to the pattern on the electrocardiogram (Figure 2.3). The louder first sound (lub) is due to the valves between the atria and ventricles closing, just after the ventricles begin the contract. The second sound (dub) is the valves in the arteries closing to stop the backward flow of blood as the ventricle starts to relax.

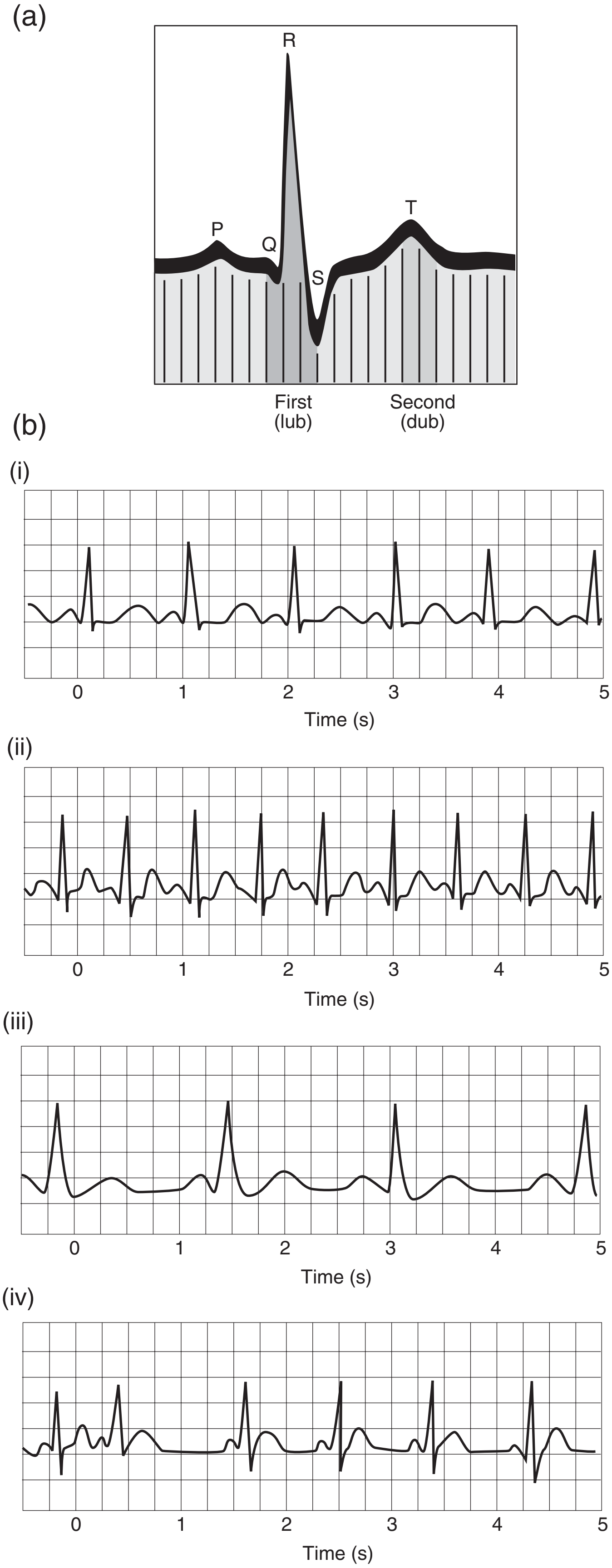

Figure 2.3 **Electrocardiograms** (a) The electrical activity and sound of the heart (b) How the heartbeat changes

Heart and Exercise

As the heart beats, the pressure surges along the arteries which we feel as our **pulse**. We can measure the rate at which the heat is beating by measuring this pulse rate. A resting pulse is normally around 60 to 80 beats per minute. People who are out of condition and rarely exercise can have a resting pulse rate up to 100 beats/minute. A trained athlete can have a pulse rate below 60 beats/minute.

The change in pulse rate with exercise is shown in Figure 2.4. A treadmill is used as this allows better control of the subject's speed and sensors can remain attached as they exercise. The greater the physical activity, the faster the heart must pump to supply oxygen to the cells and to remove carbon dioxide. There is also a maximum pulse rate that can be achieved. As a very rough guide, you can estimate your maximum pulse rate using the formula:

Maximum pulse rate = 220 – age in years

For You To Do

1. Which of the following is the correct order for blood flowing around the circulatory system?
   (A) heart → arteries → capillaries → veins → heart
   (B) heart → capillaries → arteries → veins → heart

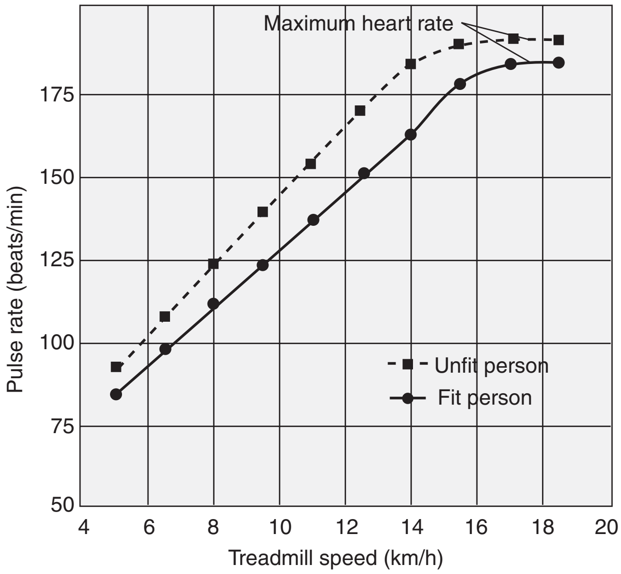

Figure 2.4 **Heartbeat and physical activity on a treadmill** The heart rate increases in direct proportion to the increase in speed, eventually reaching a maximal rate

(C) heart → arteries → veins → capillaries → heart
(D) heart → veins → capillaries → arteries → heart

2. Which of the following is the correct order for blood flowing through the heart?
   (A) artery → left atrium → left ventricle → lungs → right atrium → right ventricle → vein
   (B) vein → right atrium → right ventricle → lungs → left atrium → left ventricle → artery
   (C) vein → left atrium → left ventricle → lungs → right atrium → right ventricle → artery
   (D) artery → right atrium → right ventricle → lungs → left atrium → left ventricle → vein
3. Which part of the circulatory system prevents blood from flowing backwards?
   (A) atria
   (B) capillaries
   (C) valves
   (D) ventricles
4. Look at Figure 2.3 (b). Which of the following is closest to the pulse rate for the fastest heart?
   (A) 40 beats/min
   (B) 60 beats/min
   (C) 80 beats/min
   (D) 100 beats/min
5. Figure 2.4 shows the pulse of a fit and a not-so-fit person as recorded on a treadmill. Which of the conclusions is correct?
   (A) The fit person has the fastest pulse.
   (B) The unfit person has the fastest pulse.
   (C) The maximum pulse rate of the fit person is higher than the unfit person.
   (D) The pulse rate of the fit person increases at a faster rate than the unfit person.
6. An electrocardiogram of a single heartbeat is shown in Figure 2.5.

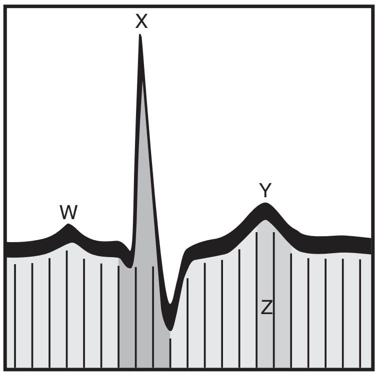

Figure 2.5 **Heartbeat**

   (a) What is happening at W?
   (b) Suppose that X was missing. Which part of the heartbeat would not have taken place?
   (c) What is happening at Y?
   (d) A sound is produced at Z. Describe what causes the sound.
7. There is a relationship between the structure and function of the parts of the heart and circulatory system.
   (a) Explain why the walls of the arteries are thicker than the walls of the veins.
   (b) Explain why there are valves between the atria and the ventricles.
   (c) Explain why the walls of the ventricles are thicker than the walls of the atria.
8. Athletes who intend to run long-distance events will undergo extensive training. Figure 2.6 shows the effect this training has on their pulse rate of an athlete. Use the graph to answer the questions below.

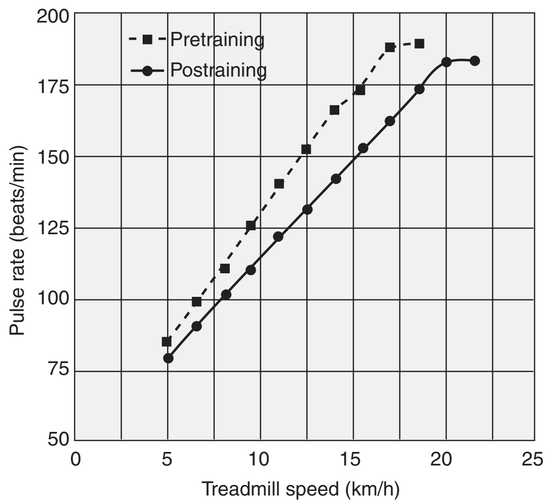

Figure 2.6 **Training and the heart**

(a) By how much does the pulse rate change after training when the treadmill speed is 10 km/h?
(b) Describe the effect that training has on the maximum pulse rate.
(c) Is the effect of training on pulse rate greater for slow speeds or for higher speeds?
(d) Describe the overall effect that training has on pulse rate.

9. After heavy exercise, it takes some time for the pulse rate to return to normal. The effect of training on the heart recovery rate is shown in Figure 2.7 Use the graph to answer the questions.

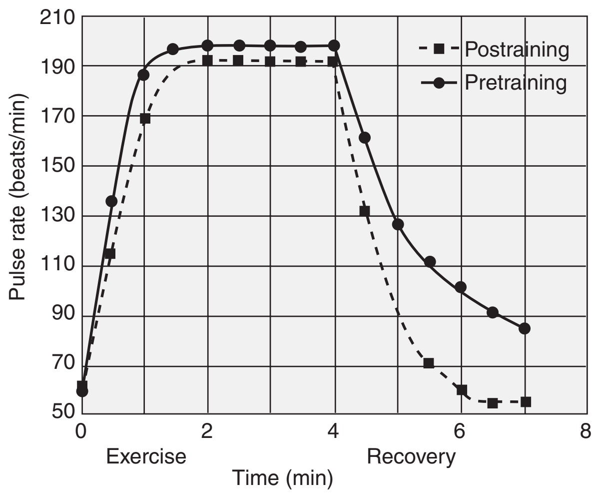

Figure 2.7 Pulse rate recovery time

(a) How long does the pulse rate remain unchanged until it starts to decrease?
(b) What was the maximum heart rate before and after training?
(c) Describe the effect that training has on the maximum heart rate.
(d) Describe the overall effect that training has on pulse rate recovery time.

10. Describe the role of the circulatory system in maintaining humans as functioning organisms.