

CHAPTER 17

PHYSIOLOGICAL MEASUREMENTS

Healthcare professionals need to assess the health and wellbeing of each individual in their care. To do this, they must understand the meaning of physiological observations, and any changes that occur, to keep people as healthy as possible and to help them choose the kind of care they receive.

17.1 Initial assessments

Assessments or examinations carried out on patients by health professionals include the measurement and recording of physiological indicators called **vital signs (vitals)**. Seven vital signs that provide objective measurements of homeostasis are the respiratory rate, pulse rate (heart rate), oxygen saturation, blood pressure, temperature, urine output and level of consciousness (→ [Box 17.1](#)).

Basic observations

When healthcare professionals are assessing people's health and wellbeing, the usual procedure is to:

- observe their appearance – height, weight, posture, skin texture and colour, pattern of movements
- observe and record vital signs
- listen to the patient's description of their symptoms and history
- carry out a physical examination to look for pointers to any likely underlying problem (→ [Box 17.2](#))
- carry out tests to confirm or dismiss diagnostic suspicions
- determine a course of treatment if disease or disorder is confirmed
- monitor the effectiveness of any treatment.

Signs and symptoms

A **sign** is an indication of a disorder or disease observed by the healthcare professional but not always apparent to the patient. Signs can be measured and observed through the senses, e.g. noticing the yellowing of skin (jaundice) and palpating (feeling for) the pulse.

A **symptom** is an indication of disorder or disease that leads the patient to consult a health professional, e.g. the sensation of pain (→ [9.9](#)). **Pain** is an important symptom of many diseases and disorders and may be:

- somatic, e.g. in the skeletal muscles or body wall
- visceral – in internal organs and tissues
- acute – of sudden onset
- chronic – lasting over a long period of time.

Box 17.1 Homeostatic mechanisms keep parameters in the body within the normal range – at the optimum levels that ensure survival of cells.

Box 17.2 Observations are made by a health professional while taking a case history and finding out more about the patient's symptoms and circumstances. They need to be recorded to provide a framework for considering health problems and levels of wellbeing.

Vital signs can be quantified and compared to the normal "set point" or range. If they are outside the normal range, the information can be used to help diagnose what is the cause of the problem.



Fig. 17.1 A stethoscope is a medical device for listening to sounds inside the body, often lung and heart sounds.

Box 17.3 Pulmonary ventilation is calculated by applying the formula: breathing rate (breaths per minute) multiplied by tidal volume (cm^3 per breath).

17.1.1 Respiratory rate

Healthcare professionals are trained to observe and accurately assess breathing rate, rhythms and sounds as part of a full holistic assessment of health status (→ Fig. 17.1). These signs help to provide information about a person's baseline level of pulmonary ventilation – the cyclical movements of the chest wall (→ Box 17.3). Therefore to understand the process of breathing it is essential to be familiar with the structure and function of the respiratory system (→ Chapter 6).

Changes in respiratory rate

Generally, changes in **respiratory rate** occur automatically, via the autonomic nervous system, in response to changing physiological demands. However, people can also consciously increase or decrease their breathing rate for short periods of time (→ 6.6.9).

Increasing respiratory rate and increased effort by patients to breathe are well recognised as robust indicators for physiological deterioration. The breathing rate increases when people are acutely unwell, in pain or distress. It may also be elevated by physiological disturbance such as metabolic acidosis – a condition that occurs when the body produces too much acid, or when the kidneys are not removing enough acid from the body. Diabetic ketoacidosis occurs in uncontrolled type 1 diabetes due to a build-up of keto-acids (ketones) (→ 16.2.2).

Reduced breathing rate

A reduced breathing rate can sometimes be an indicator of CNS depression – physiological depression that results in reduced brain activity. It can sometimes be caused by the use of depressant drugs such as alcohol, opioids, barbiturates, benzodiazepines, general anaesthetics and some anticonvulsants used to treat epilepsy.

17.1.2 Pulse rate

Every contraction of the ventricles of the heart generates a pulse wave that travels through the arteries. The measurement of pulse rate can therefore be an important indicator of a patient's clinical condition (→ Box 17.4).

A rapid or increasing pulse rate, particularly if accompanied by changes in breathing, skin colour, sweating, and a decreased level of consciousness, can be signs of insufficient circulation.

Tachycardia

Tachycardia (fast heart rate) may be indicative of physical exertion or of circulatory compromise (disturbance), meaning that oxygen is not reaching all of the organs and areas it needs to, which may be due to cardiac rhythm disturbance (→ Box 5.52).

Bradycardia

Bradycardia (slow heart rate) can be an important physiological indicator. A slow heart rate may be normal with athletes or as a consequence of medication, e.g. with beta blockers (→ 18.8). It may also be an important indicator of hypothermia, CNS depression, hypothyroidism or heart block. In heart block, the cardiac impulses that control the heart rate are interrupted and this may cause the heart to beat more slowly.

Box 17.4 Resting **pulse rate** is rapid in babies and children, decreasing into adulthood. Health professionals may use different pulse locations as part of their check, and good practice is to count for one minute. As well as counting the number of pulses, the regularity of the rhythm, force and volume characteristics will be observed (→ Box 5.27). In healthy people, pulse rate equates to heart rate, but this may not always be the case for those with arrhythmias.

17.1.3 Oxygen saturation

It is difficult to determine the haemoglobin and oxygen content of blood by observation alone. A non-invasive, continuous estimate of oxygen levels in pulsing (arterial) blood can be obtained by indirectly measuring the proportion of oxygenated haemoglobin in circulating blood (SpO_2) using a pulse oximeter (→ Fig. 17.2).



Fig. 17.2 A pulse oximeter attached to a finger continuously measures the level of oxygen in a patient's blood throughout an operation.

In critically ill patients, the level of oxygen saturation is measured along with carbon dioxide and acid-base (pH) status using arterial blood gas sampling techniques (→ 6.6.4).

17.1.4 Blood pressure measurement

Blood pressure is usually measured indirectly with a **sphygmomanometer** (blood pressure meter), which is a cuff attached to a pressure-measuring device (→ Fig. 17.3).

Procedure

1. The correct-sized cuff is wrapped around a person's arm covering the **brachial artery** at about the level of the heart.
2. A stethoscope is placed on the **antecubital region** – the region of the arm in front of the elbow – and a healthcare professional listens.
3. A pump is used to inject air into the cuff to inflate it. Raising the pressure in the cuff temporarily occludes (cuts off) blood flow into the person's arm.
4. Initially there is no sound because there is no blood flowing into the arm.
5. As the pressure in the cuff drops, blood begins to spurt into the narrowed artery, creating turbulent flow. This creates the first **Korotkoff** sound which indicates systolic blood pressure (→ Box 17.5).
6. As more air is gradually released from the cuff the blood begins to flow more freely (laminar flow) and the sounds become muffled and inaudible, which indicates diastolic pressure (→ 5.15).

17.1.5 Temperature

Normal range for body temperature is maintained homeostatically by the hypothalamus (→ 3.4). Homeostasis is disturbed by:

- **pyrexia** (fever) – a rise in temperature in response to infection
- **hyperthermia** – e.g. heatstroke
- **hypothermia** – e.g. exposure to cold (→ Box 17.6).

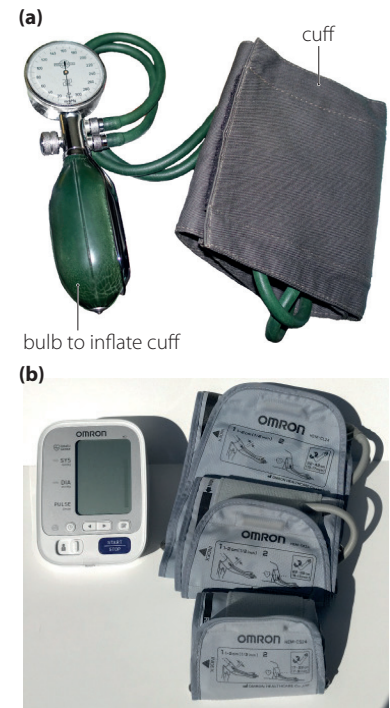


Fig. 17.3 Sphygmomanometers: (a) manual sphygmomanometer; (b) digital sphygmomanometer with three different sizes of sleeve.

Box 17.5 Korotkoff sounds are blood flow sounds that healthcare professionals observe while taking blood pressure. These sounds 'come and go' as the cuff is inflated and deflated.

Box 17.6 Tympanic thermometers have become the most common way to measure body temperature in clinical practice. The device containing a sensor at its tip is carefully positioned in the ear canal. The sensor measures the infrared radiation emitted by the tympanic membrane which is well perfused with blood, and the digital reading provides a rapid result.

Box 17.7 Once collected, a **urine sample** may be tested immediately with a test strip (→ Fig. 17.4) or sent away to a laboratory where a more detailed analysis will be carried out. A clean-catch urine sample is required when the urine is to be tested for microbes. To reduce the risk of contamination from genitalia, they should be washed before a 'mid-stream' sample is collected in a screw-top container which contains boric acid.

17.1.6 Urinalysis

Urinalysis can be used as a screening, diagnostic or monitoring tool (→ Fig. 17.4; Box 17.7). It can detect different metabolic conditions and kidney disorders that may not produce obvious signs or symptoms, e.g.:

- diabetes
- kidney disease
- cystitis
- urinary tract infection (UTI)
- sexually transmitted infections (STIs)
- pregnancy
- illegal drugs
- alcohol consumption
- pre-eclampsia.

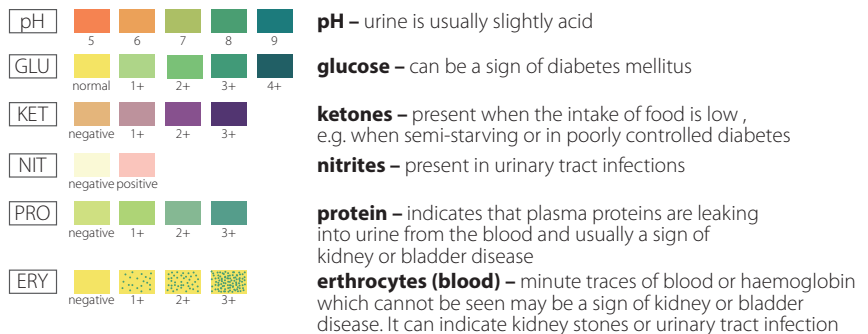


Fig. 17.4 Urinalysis. Different manufacturers may produce slightly different urinalysis dipsticks but they are all capable of detecting 8–10 different parameters.

Urine glucose test

Glucose should not normally be detected in samples of urine as it is filtered by the glomerulus and normally reabsorbed from filtrate as it passes along the nephron (→ 8.2.2).

Hyperglycaemia – high levels of glucose in blood – means that the kidneys cannot completely reabsorb the filtered glucose. It therefore appears in urine called **glucosuria** and is a primary sign of diabetes.

Protein in urine

Protein in urine (**proteinuria**) should not normally be detected because molecules of protein are too large to be filtered by the glomerulus. For this reason, proteinuria is often a sign of disease including glomerular nephritis, nephrotic syndrome, pre-eclampsia or a complication of diabetes.

17.1.7 Level of consciousness

Consciousness is a state of general awareness of oneself and the environment. Changes in the level of consciousness are the earliest and most sensitive indicator of changing neurological status. An initial assessment of neurological functions can be obtained either through:

- using the AVPU scale for a quick review, or as part of a NEWS (→ Box 17.8) assessment
- an ABCDE assessment for emergencies
- more detailed evaluation of the level of consciousness using the Glasgow Coma Scale.

Box 17.8 The **National Early Warning System (NEWS)** provides a standardised track-and-trigger system for the NHS based on the vital signs for patients presenting at hospitals. Results based on NEWS should enable health professionals to collect physiological data regularly (track) and take action to intervene appropriately (trigger) depending on the patients' needs, e.g. for oxygen therapy, fluid resuscitation, blood product transfusion or administration of medication.

AVPU assessment

AVPU stands for **A**lert, **V**oice, **P**ain and **U**nresponsive, which is a quick review of a patient's neurological state.

Alert: The person will be fully awake although not necessarily orientated to time or place, will spontaneously open their eyes, will respond to a voice and be able to move about.

Voice: A casualty may appear to be asleep but makes some kind of response when spoken to, which could be by using the eyes, voice or slight movement of a limb. If there is no response then healthcare professionals move on to 'P'.

Pain: When a painful stimulus is applied, a patient who is not alert and who has not responded to voice is likely to exhibit only withdrawal from pain, or even involuntary flexion or extension of the limbs from the pain stimulus.

Unresponsive: Sometimes referred to as 'unconscious.' This outcome is recorded if the patient does not give any eye, voice or motor response to voice or pain. This means the person is now in a serious condition, the airway may need to be managed and vital signs may need to be monitored.

Agitated and unresponsive: This category is used when a person is conscious but unresponsive. Their agitation may be due to confusion or distress, but could be due to a head injury where the level of consciousness is below that needed to respond to questions. The underlying cause for this condition is potentially serious and warrants urgent investigation.

ABCDE assessment

The ABCDE approach to assessment is a useful aide-memoire because it enables health professionals to quickly assess an individual's health status in a systematic way (→ Fig. 17.5).

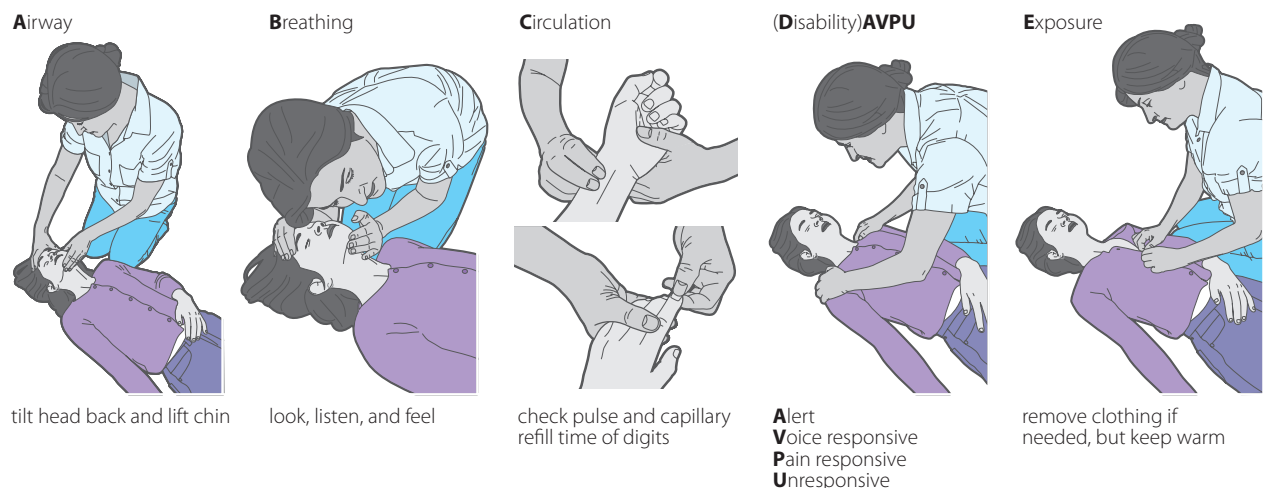


Fig. 17.5 ABCDE assessment – a systematic approach to assess acute illness.

Glasgow Coma Scale assessment

The Glasgow Coma Scale (GCS) assesses the conscious state and degree of neurological impairment of a patient whose brain has been injured (→ Box 17.9). Because the brain is enclosed in the cranium (skull), this rigid bony structure restricts inflammation (swelling) and causes brain

Box 17.9 Paediatric Glasgow Coma Scale is used for infants who are too young to speak.

Box 17.10 When the brain is injured by concussion, stroke or trauma, then the **level of consciousness** will fall, making the person irritable, less able to think clearly or respond normally; they may lose consciousness. This is because the inflammatory response (→ 14.3.3) causes the tissues to swell and the pressure inside the cranium to rise, which can impair normal brain function.

tissue to be compressed. In turn, the rising compression of brain tissue can contribute to further brain injury, loss of consciousness or death.

The three components that contribute to **intracranial pressure (ICP)** – pressure within the cranium – are neural tissue, blood and cerebrospinal fluid. If any one of these components increases, then intracranial pressure (→ 9.10.6) will rise and consciousness deteriorates, as indicated by a fall in the GCS (→ Table 17.1; Box 17.10).

Table 17.1 Glasgow Coma Scale

Eye opening	Verbal response	Motor response
1 = none	1 = none	1 = none
2 = to pain	2 = incomprehensible sounds	2 = abnormal extension
3 = to voice	3 = inappropriate words	3 = abnormal flexion
4 = spontaneously	4 = confused	4 = withdraws from pain
	5 = orientated	5 = localises to pain
		6 = obeys commands

Further measurements

An initial assessment may be followed by further investigations:

- diagnostic **imaging** to produce images of body parts or to watch the internal organs in action and check their efficiency (→ 17.2)
- electrophysiological **measurements** (→ 17.3)
- functional **measurements**, e.g. spirometry (→ 17.4)
- laboratory **tests** to measure component parts of body fluids and bone marrow to determine whether they are within or outside the normal range (→ 17.5)
- microbiological **tests** on body fluids, faeces or tissues to identify pathogens (→ 17.6).

Box 17.11 Radiation is a form of energy that can travel through space at very high speed and which can be absorbed, transmitted or reflected by objects. The radiation spreads out in all directions from its source and includes gravitational waves and the different forms of electromagnetic energy – gamma rays, X-rays, ultraviolet radiation, visible light, microwaves, radio waves and infrared radiation.

Ionising radiation has sufficient energy to cause ionisation in the medium through which it passes, e.g. beta particles, gamma rays and X-rays. Ionising energy converts electrically neutral atoms or molecules into electrically charged atoms or molecules (ions → 20.4.1).

17.2 Diagnostic imaging

Diagnostic imaging allows health professionals to view the internal anatomy without the need for invasive surgery by using:

- images (pictures) of the structures and physiological activities
- data and information in the form of graphs and maps.

Many imaging procedures are painless, although some require the patient to stay still for a long time inside a machine, which can be uncomfortable, and certain imaging tests involve exposure to a small amount of ionising radiation (→ Box 17.11).

Imaging modalities

Imaging modalities are the various technologies used for obtaining images as an aid to diagnosis and treatment, e.g.:

- **endoscopy** uses light energy
- **ultrasound** uses acoustic energy
- **X-rays** and other types of radiography are a form of electromagnetic energy
- **nuclear medicine** uses atomic energy
- **electrophysiology** is based on electrical energy generated by the body.

17.2.1 Endoscopy

Endoscopy is a procedure that uses an **endoscope** to examine the lining of the oesophagus, stomach and duodenum. This long, flexible, fibreoptic tube with a light source and video camera at one end is swallowed by the person. The camera is then moved around to obtain images that are relayed to a television screen (→ Fig. 17.6). The patient is sedated so does not feel any discomfort during the procedure (→ Box 17.12).

Box 17.12 Different types of **endoscopes** are used by surgeons to look inside the hollow organs of the body including airways, bladder, reproductive tract and synovial joints.



Fig. 17.6 Endoscopy.

Colonoscopy

A colonoscopy is when an endoscope is used to detect changes or abnormalities in the colon (large intestine) and rectum.

Laparoscopy

Laparoscopy is a surgical procedure in which the fibreoptic instrument is inserted into the abdomen through a small incision in the abdominal wall. A cutting tool attached at the end of the endoscope allows the surgeon to perform 'keyhole surgery' (laparoscopy), e.g. removal of gallstones, sealing fallopian tubes, repairing hernias or repairing bleeding stomach ulcers.

17.2.2 Medical ultrasound

Ultrasound is a diagnostic imaging technique that uses high frequency sound waves (higher than the human ear can detect) to create an image. This technique can be used to investigate problems with blood circulation, the organs and tissues within the body, to identify some tumours and to take measurements of an unborn baby.

Pregnancy scans

Ultrasound scans use sound waves to build an image of the foetus in the womb from about 6 weeks of pregnancy. Because no ionising radiation is involved (→ Box 17.11), an ultrasound scan has no known side-effects on mother or unborn baby (→ Fig. 17.7).

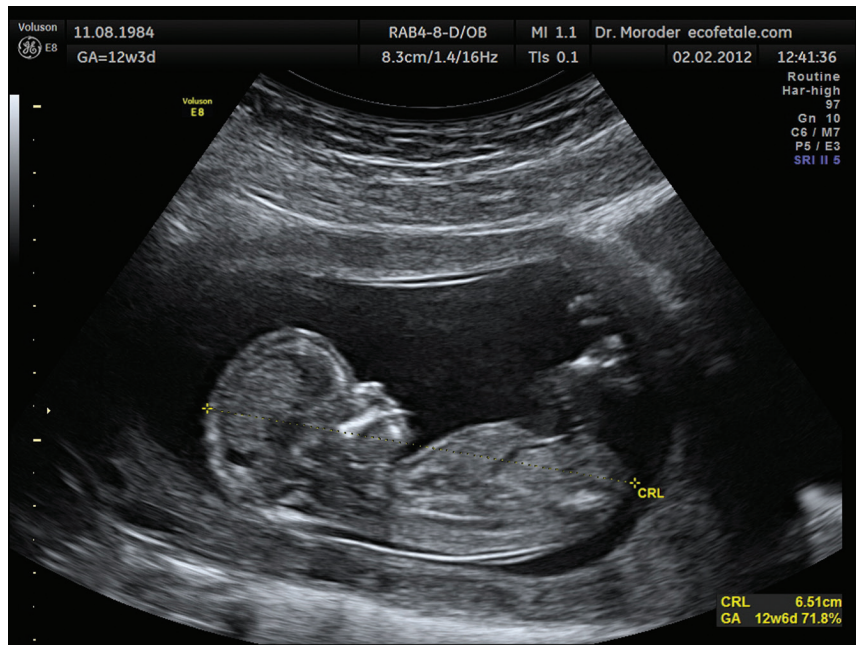


Fig. 17.7 Ultrasound scan of a foetus at 12 weeks.

Echocardiography

Echocardiography (Echo) uses sound waves to build up a detailed picture of the heart. A probe on the skin sends out sound waves that create echoes when they bounce off different parts of the heart (→ Fig. 17.8). The echoes are used to build up images that give information about the heart structure, valves, ejected volumes of blood and pericardial fluid. The procedure may be carried out following a heart attack or heart failure and is also used routinely to assess people with heart valve problems or congenital heart disease (→ Box 17.13).

Box 17.13 An **echocardiogram** is especially useful for diagnosing heart disease in newborn babies and children as it is painless and relatively easy to do.



Fig. 17.8 An echocardiogram being recorded.

Doppler ultrasound

Doppler ultrasound measures blood flow in arteries by bouncing high frequency sound waves (ultrasound) off the red cells. The sound waves are detected by a transducer that converts them to digital signals on a screen. Blood flowing towards the transducer has a higher frequency (hence a different sound) than the blood flowing away from it. This enables the speed and direction of blood flow to be calculated and helps to identify blocked arteries.

17.2.3 X-rays

X-rays are a high energy form of radiation that can penetrate tissues and are recorded as a dark image on a photographic plate (→ Fig. 17.9). When a beam of radiation is directed towards the human body, not all of it passes through, some being deflected or absorbed by dense tissue like bone. It is this difference in absorption that allows body parts to be distinguished from each other; dense bone appears white, soft tissues appear in various shades of grey, and air appears black (→ Box 17.14).

Box 17.14 Cross-sections of the human body are always inferior views, i.e. as if the observer is standing at the feet of the subject and looking up towards their head. Structures on the left-hand side of the body are to be found on the right side of the image.

Computerised tomograph

A computerised tomograph (CT) is a form of X-ray that shows a series of cross-sections ('slices') through the body (→ Fig. 17.10). A narrow beam rotates around the body, moving a short distance every few seconds for about 10–15 minutes and provides a series of images from many angles.

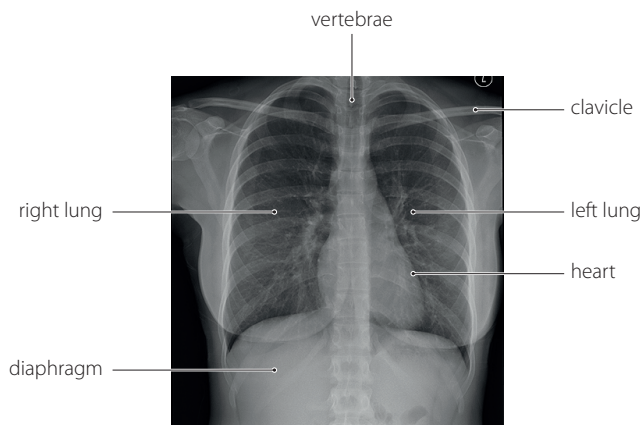


Fig. 17.9 X-ray of an adult thorax (anterior view).

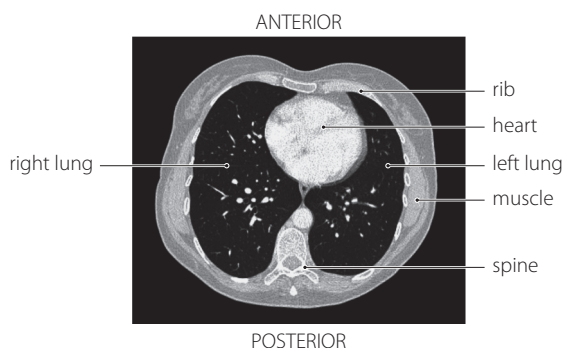


Fig. 17.10 CT scan of a section through the thorax.

The CT is able to show the structure of soft tissue more clearly than X-rays, e.g. inflammation, stroke, blood flow or tumours. In emergency situations it can rapidly reveal haemorrhage.

Barium X-ray

Box 17.15 Some people may have an allergic reaction to barium or other contrast media, e.g. rash or itching, or very rarely an anaphylactic response.

A barium X-ray is an examination of the gastrointestinal (GI) tract using **barium** – a radio-opaque substance – which is swallowed and coats the inside of the GI tract (→ [Box 17.15](#)). The barium shows up on X-rays and provides sharp outlines of the various parts, allowing the condition and movement of the internal organs to be analysed for abnormalities of the intestines and rectum, e.g. tumours, ulcers, polyps, hernias, dysphagia (painful or difficult swallowing), the presence of parasites, and inflammatory disease, e.g. ulcerative colitis, diverticulosis or Crohn's disease (→ [Fig. 17.11](#)).

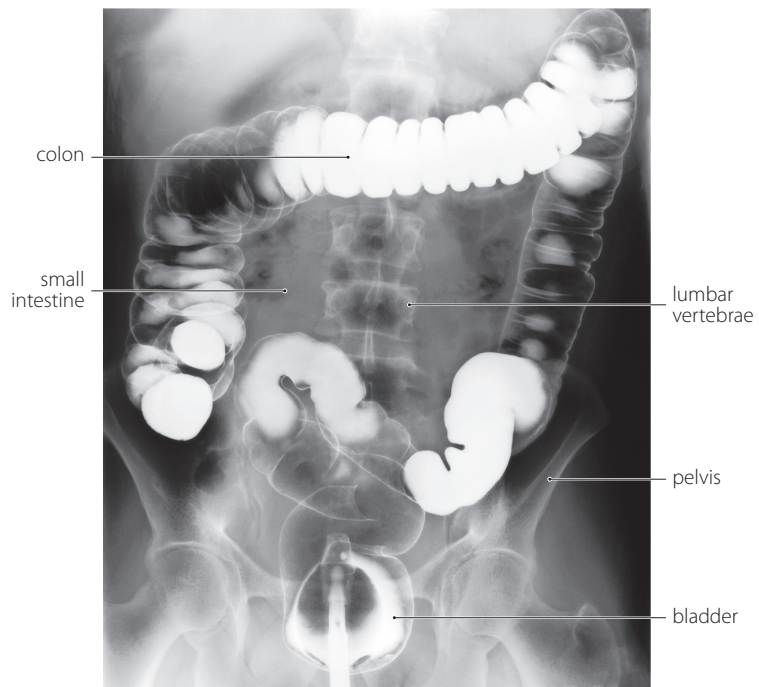


Fig. 17.11 Barium enema: lower bowel examination.

Angiogram

An angiogram is a type of X-ray used to examine blood vessels (→ [Fig. 17.12](#)). They do not show up clearly on ordinary X-rays, so a radio-opaque dye is first injected into the vessels being examined to make them appear white. Angiograms can be used to help diagnose coronary heart disease and aneurysm.

In coronary angiography the tip of a **catheter** (long, thin flexible tube) is inserted into a blood vessel in the wrist or groin and passed up to the coronary arteries. The procedure is used for the insertion of a stent, implanting a pacemaker or to widen blocked arteries.

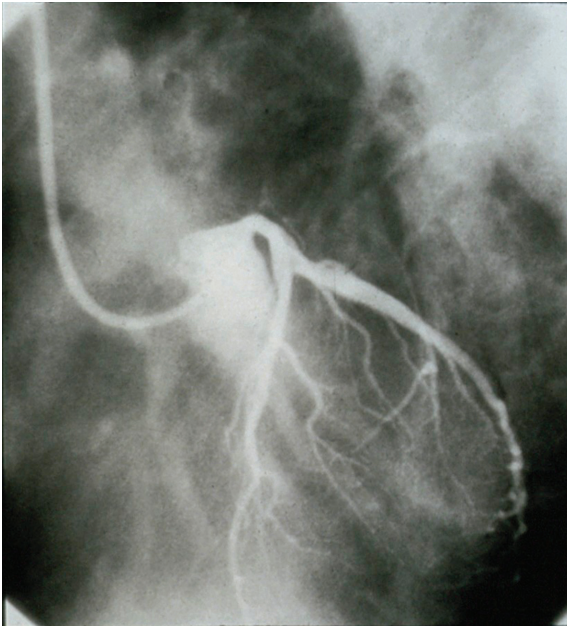


Fig. 17.12 Angiogram of a healthy heart.

17.2.4 Magnetic resonance imaging

Magnetic resonance imaging (MRI) uses radio waves and a very strong magnetic field to produce detailed images of the inside of the body (→ [Box 17.16](#)). The person is placed in a large tube containing powerful magnets and must lie still while the machine scans the body and generates images of organs, tissues and physiological processes (→ [Fig. 17.13](#)).

Box 17.16 The magnetic field in an **MRI scanner** is about 3000 times stronger than the earth's magnetic field. Atomic nuclei (→ [20.3.1](#)) can absorb and emit radio energy when placed in magnetic fields.

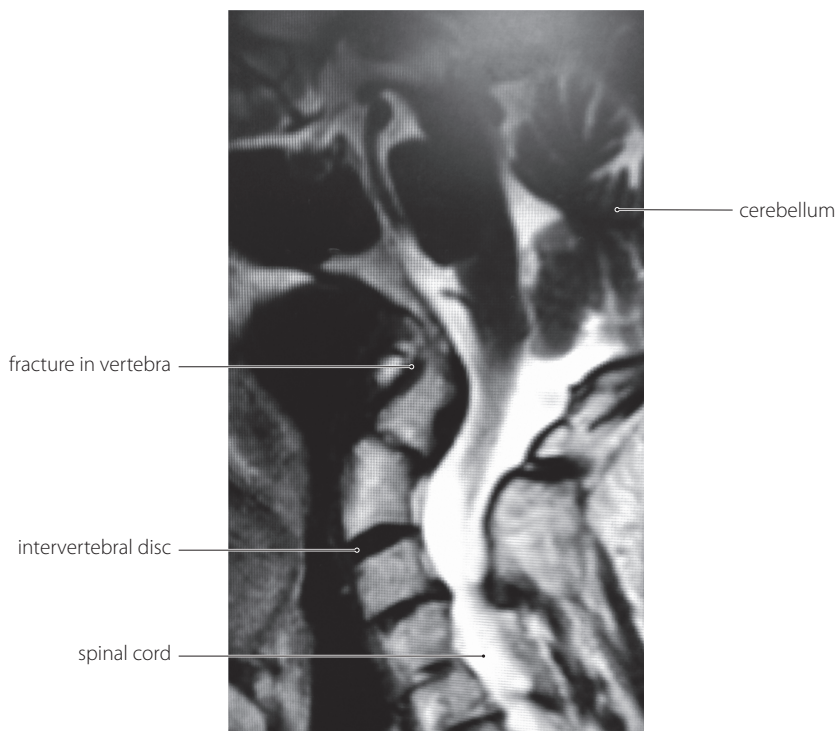


Fig. 17.13 MRI scan of the cervical (neck) region that revealed a fracture in a cervical vertebra.

Box 17.17 MRI scans take between 15 and 90 minutes, depending on the size of the area being scanned and the number of images taken. The process can be claustrophobic, and is noisy when the scanner makes tapping noises as the magnetic coils are being turned on and off.

Box 17.18 Gamma rays are defined as penetrating electromagnetic radiation arising from the decay of atomic nuclei. They pass easily through the body, have no charge and are not deflected by a magnetic field.

Box 17.19 Beta particles are high-energy, high-speed particles emitted by the radioactive decay of an atomic nucleus.

During an MRI scan, the protons in the nuclei of atoms (→ Fig. 20.1) are struck by a pulse of radio waves and absorb energy from them, which forces the protons to line up along the lines of magnetic force. When the pulse of radio waves ends, the protons re-align to their original position. Because protons in different tissues re-align at different speeds, they produce distinct signals which are combined to create a digital image (→ Box 17.17).

Since hydrogen protons are particularly abundant in body fluids and fat, most MRI scanning techniques are based on mapping locations and distribution of soft tissue and adipose tissue.

17.2.5 Nuclear medicine

Nuclear medicine uses the weak nuclear force of radioactivity. It is emitted from the decay of atomic nuclei as high-speed, high-energy nuclear radiation. Two forms are:

- **gamma rays** used in the diagnosis of disease, e.g. as radioactive tracers (→ Box 17.18)
- **beta particles** used for the treatment of disease, e.g. eye and bone cancer (→ Box 17.19).

Radionuclide tracers

A radionuclide (radiopharmaceutical) is a small amount of short-lived **radioactive isotope**. It is attached to carrier molecules, e.g. glucose, and administered by injection, inhalation or orally so that it becomes centred on the organ or tissue to be studied. The path of the radioactive tracer can be followed by a gamma spectroscopy (camera) and recorded.

Positron emission tomography

Positron emission tomography (PET) is a procedure in which a small amount of radioactive glucose is injected into a vein. A scanner is then used to make detailed, computerised 3D images of areas inside the body where the glucose is taken up. This type of scan can be used to help in the diagnosis of a range of different cancers; it can detect how far a cancer has spread or how well it is responding to treatment. PET scans can also be used to help diagnose a number of conditions that affect the normal workings of the brain, such as dementia.

Single photon emission computed tomography

Single photon emission computed tomography (SPECT) uses radionuclides and a special camera to create 3D images of actions taking place in the body, e.g. to show how blood is flowing to the heart, or areas in the brain where most activity is taking place following an epileptic seizure.

17.3 Electrophysiological measurements

Electrophysiology studies the electrical properties of biological cells and tissues, e.g. the electrical activity of the heart can be measured and recorded by electrocardiography, that of the brain by electroencephalography and of the muscles by electromyography.

17.3.1 Electrocardiography

An electrocardiogram (ECG) is a graph (trace or rhythm strip) which represents a visual image of the passage of cardiac impulses through the heart during each cardiac cycle. These cardiac impulses control the rate and pumping activity of the heart (→ 5.11.1). Electrodes placed on the skin pick up the small electrical currents produced by the heart (→ Fig. 17.14). These signals are amplified and converted to a trace on a screen or paper (→ Fig. 17.15). A **clinical ECG** is obtained using ten recording electrodes – six on the chest and four on the limbs – which allow the electrical potential to be measured from 12 different angles (leads) across the body (hence it is called a 12-lead ECG). The correct placement of the recording electrodes on the skin is important to avoid missed or incorrect information.

Interpretation of an ECG

The waves of the ECG represent the sequence of depolarisation and repolarisation (→ Fig. 9.11) of the atria and ventricles. The normal pattern of an ECG is known as **sinus rhythm** because the wave of depolarisation (electrical activity) begins in the sinoatrial node (P wave), spreading via the atrioventricular node, bundle of His and Purkinje tissue of the ventricles (QRS complex) in a characteristic pattern (→ Fig. 5.17). Abnormal wave patterns are created by defects or changes in the cardiac conduction system and are called **arrhythmias**.

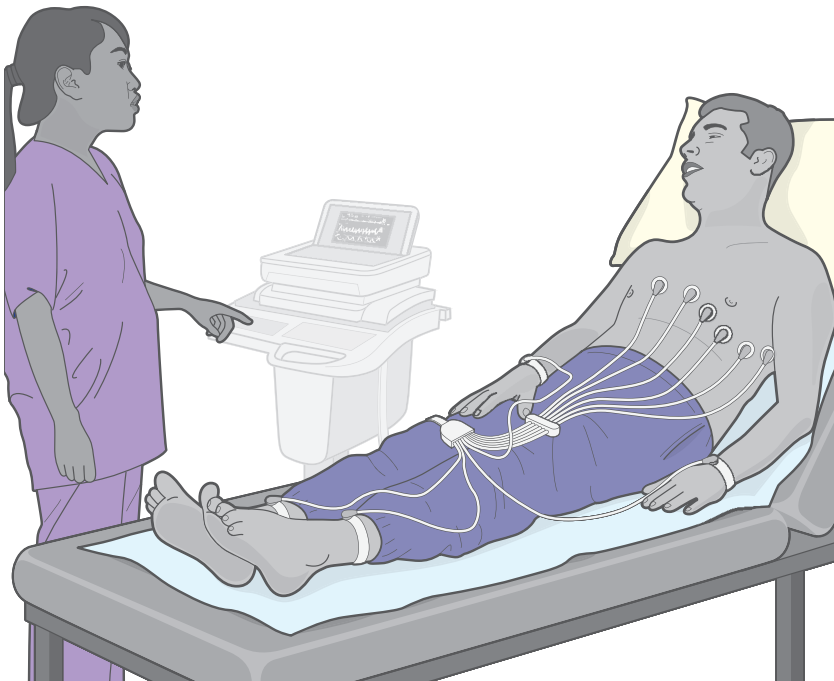


Fig. 17.14 Clinical ECG showing the leads on the front of the body.

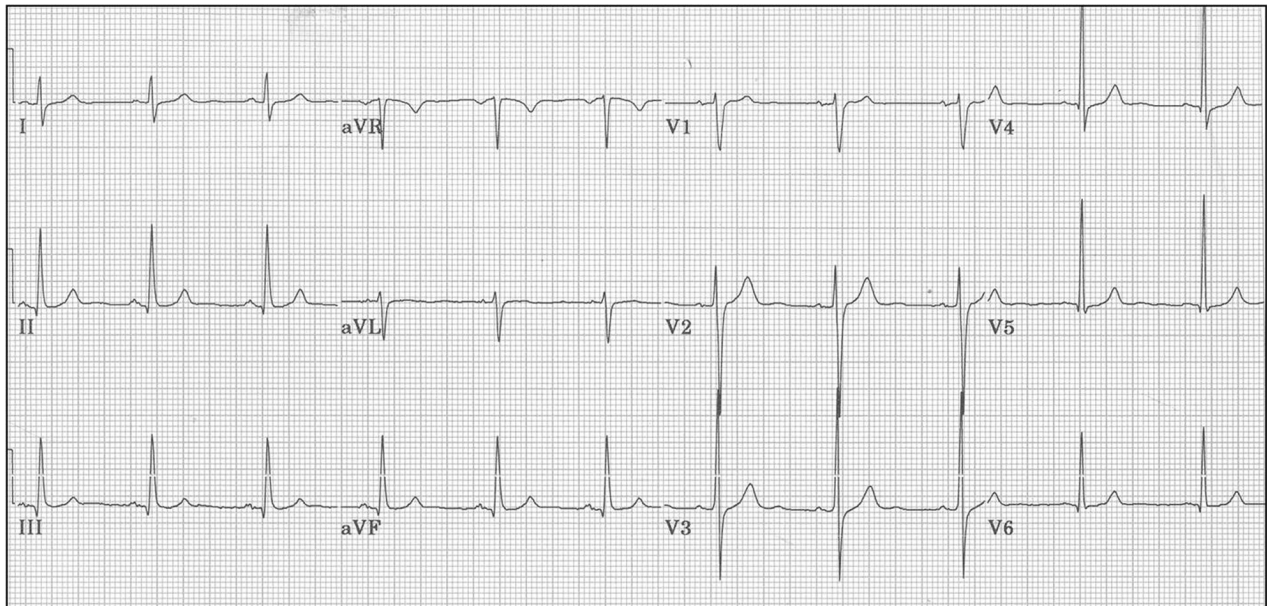


Fig. 17.15 The 12 leads of a clinical ECG recording normal adult sinus rhythm.

In conjunction with a patient's clinical history, an ECG can provide a trained healthcare professional with a great deal of useful information concerning:

- **heart rate** – fewer than 60 beats per minute is known as **bradycardia** while more than 100 beats per minute is **tachycardia**
- **heart rhythm** – used to evaluate the regularity of heart wave components
- the **axis** (overall direction) of the electrical activity through the structure of the heart, e.g. left axis deviation.

17.3.2 Electroencephalography

Electroencephalography (EEG) records and amplifies the spontaneous voltage changes near the surface of the brain that result from action potentials (→ 9.4.1) in networks of neurons. Multiple recording electrodes are precisely positioned on the scalp so that the EEG is the summation of the brain's electrical activity (→ Fig. 17.16). Although the ability of the EEG to identify activity in deeper structures below the surface of the brain is limited, it can sometimes be combined with diagnostic imaging techniques (MRI and PET scans) to improve resolution. Typically the various waves of the EEG change quite distinctively when a person is awake or asleep, during epileptic seizures and at different stages in the lifespan.

Diagnostic applications generally focus on:

- **event-related potentials** which are electrophysiological responses to stimuli, e.g. flashing images on a screen to help assess neurological changes or trauma to the visual system. Timing of these responses is thought to measure the timing of communication and processing in the brain.
- **spectral content** of the EEG, commonly called 'brain waves', which distinguish between phases of sleep and types of epileptic seizure (→ 9.10.4), movement disorders or syncope (fainting).



Fig. 17.16 Recording electrodes would be attached to this cap for EEG.

17.3.3 Electromyography

Electromyography (EMG) is a visual record of muscle activity (→ Fig. 17.17). It detects the action potentials (→ Fig. 9.11) generated by skeletal muscle



Fig. 17.17 Electromyography of skeletal muscle activity in upper arm.

cells when they have been activated by motor neurons. The electrical activity is displayed on a computer screen and can also be converted into an auditory signal which can be heard.

The two types of EMG are:

- **surface EMG** – depends on pairs (or more complex arrays) of recording electrodes which are placed on the skin over the muscle(s) under investigation, e.g. for use by physiotherapists
- **intramuscular EMG** – performed by inserting a needle electrode through the skin into the belly of the muscle.

Recordings of skeletal muscle activity are analysed to see how well the muscles can be activated in terms of mechanical muscle force and the amount of fatigue, which aids the diagnosis of neuromuscular disease (→ [Box 17.20](#)).

Box 17.20 The objective nature of **electrophysiology measurement** techniques can help with diagnosis because they remove the subjective element that is associated with assessment by means of scoring.

17.3.4 Nerve conduction velocity

Nerve conduction velocity (NCV) testing is often done at the same time as an EMG to assess neurological function or to diagnose disease. This procedure involves stimulating a peripheral nerve and recording from the muscle that it innervates:

- the time taken for the impulse to travel from the site of the stimulus to the recording site (in milliseconds)
- the amplitude (measured in millivolts) which reflects the size of the response in terms of mechanical force (tension) generated by the muscle.

17.4 Functional measurements

This section includes examples of physiological tests to give an indication of the type of parameters that might be measured as part of a clinical assessment.

17.4.1 Pulmonary function tests

Pulmonary function tests assess how well the lungs are working by measuring the inspiratory and expiratory air flow – the volume of air breathed in and out from the lungs. Measurement of the flow rates is used:

- to aid diagnosis in people who are experiencing breathlessness, cough, wheeze, other signs of suspected respiratory disease, or whose X-ray is abnormal
- for the monitoring and management of respiratory disease such as asthma, COPD (→ 6.7.3), fibrosis or neuromuscular disorders.

Spirometry

Spirometry is carried out using a **spirometer** – a small device attached by a cable to a mouthpiece that measures how much air can be breathed out in one forced breath (→ Fig. 17.18a). This technique also measures lung volumes against time (→ Fig. 17.18b), and calculations can identify obstructive defects to air flowing out of the pulmonary system. Interpreting the results depends on knowledge of lung capacity (→ 6.5.4) and the reference values for lung function tests which have been established from very large-scale population studies of healthy subjects (→ Table 6.1).

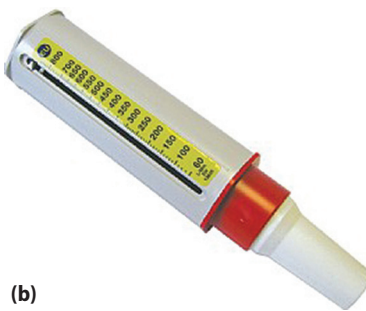


Fig. 17.18 (a) Digital spirometer; (b) peak flow meter.

Peak flow meter

A peak flow meter (→ Fig. 17.18b) measures how rapidly and forcibly air can be exhaled from the lungs following a deep breath. If airways are inflamed and constricted, e.g. by an asthma attack, then peak flow readings will be low. Peak flow tests are often used as part of personal care plans for people with respiratory disorders because regular monitoring indicates the state of lung function. Sometimes people whose asthma is controlled by bronchodilator medication may appear to have normal peak flow values (→ Table 6.1) so they may need to be tested before and after administration of bronchodilators.

Arterial blood gases

Sampling arterial blood gases (ABG) measures the amount of oxygen and carbon dioxide in the arterial blood from the lungs, and may also be used to determine the pH of the blood. The results provide important information about gaseous exchange in the lungs, oxygen delivery to the tissues and acid–base status.

- **Type 1 respiratory failure** occurs when there is hypoxia (low partial pressure of oxygen, P_{O_2}) (→ 6.6.2) with normal partial pressures of carbon dioxide (P_{CO_2}). It may also arise with pneumonia or pulmonary embolism (→ Box 20.4).
- **Type 2 respiratory failure** occurs when hypoxia is accompanied by hypercapnia (high arterial partial pressure of CO_2) which happens when there is poor pulmonary ventilation.

17.4.2 Gastrointestinal observations

Although principles of some common gastrointestinal investigations have been outlined elsewhere in this chapter, key observations are given below.

Abdominal angiograms examine blood flow to organs within the abdomen, e.g. liver or spleen (→ 17.2.3).

Abdominal ultrasound, CT scans and abdominal X-rays can help to find objects that have been swallowed and obstructions in the alimentary canal (→ 17.2.3).

Colonoscopy checks the health of the large intestine (→ 17.2.1).

Endoscopic retrograde cholangiopancreatography (ERCP) provides detailed images of the liver, gall bladder, pancreas and duodenum by combining X-rays with endoscopy (→ 17.2.1).

Bristol stool scale is used to identify the form and characteristics of faeces which are mainly determined by the time taken for food and nutrients to pass through the digestive tract (transit time). The scale is applied to evaluate effectiveness of treatments for constipation or diarrhoea.

Biopsy of the liver or other organs removes tissue samples from the organ, which are then examined under the microscope (→ Box 17.21).

Blood loss (haemorrhage) into the alimentary tract, e.g.:

- upper gastrointestinal haemorrhage, which can lead to vomiting blood (haematemesis) or to 'coffee ground' vomitus
- lower gastrointestinal haemorrhage can result in blood in the faeces, called **haematochezia** when the blood is fresh, but **melaena** when it is dark and tar-like
- **faecal occult blood (FOB)** refers to small amounts of blood in the stools that are not apparent to the naked eye (→ Box 17.22).

17.5 Laboratory tests

Laboratory tests are conducted under controlled scientific conditions in a laboratory or similar setting to help with the diagnosis of medical conditions, plan or evaluate treatments, and monitor diseases. Only a few examples of the many and varied types of parameters that are measured are included here, to highlight some of the more common conditions.

17.5.1 Blood tests

A blood test involves taking a small sample of blood, usually from a vein in a person's arm or by a finger prick. Testing blood does not usually provide a definitive diagnosis of a particular condition, but it can indicate possible health problems.

A **full blood count (FBC)** reveals:

- the **haematocrit** – the number of erythrocytes (red cells)
- **hypoxia** (oxygen deficiency)
- **low haemoglobin** – can indicate anaemia (→ Box 17.23)
- **high haemoglobin** – may be due to an underlying lung disease or problems with the bone marrow
- **proportions of the different leucocytes** (white cells) – reflect the status of the person's immune system
- **high neutrophil count** – usually indicates an infection somewhere in the body
- **platelet count** – provides information about the ability to form the platelet plugs that initiate the clotting mechanisms and the person's risk of thrombosis.

Haemostasis tests

Haemostasis is the process which causes bleeding to stop, so haemostasis tests:

- examine **clotting factors**, e.g. prothrombin and fibrinogen; this test is often used to monitor anticoagulant medication, e.g. warfarin
- screen for haemostatic defects that could cause excessive bleeding.

Box 17.21 In a biopsy, the tissue is examined under a microscope for signs of change, e.g. anaemia, bleeding, inflammation, polyps or tumours. Cells from the sample can be placed in a special culture dish then monitored by microbiologists to determine if microorganisms are present.

Box 17.22 The most commonly used tests for **faecal occult blood (FOB)** are the guaiac smear method (gFOBT) or faecal immunological test. A positive result indicates that bleeding is occurring somewhere along the gastrointestinal tract and would usually be followed by barium X-rays and colonoscopy. FOB tests are also used in screening programmes for early detection of bowel cancer.

Box 17.23 Haemoglobin electrophoresis is a blood test that separates out the different forms of haemoglobin in the blood and can detect abnormal levels of forms associated with sickle-cell disease and thalassaemia (→ 5.9.1).



Fig. 17.19 Blood glucose test meter and lancet.

Box 17.24 High levels of glucose in blood lead to the formation of a complex called **glycated haemoglobin (HbA1c)**. Since the normal lifespan of red cells and hence haemoglobin is 120 days, levels of HbA1c can be used to indicate how well or how poorly managed an individual's plasma glucose levels have been.

Box 17.25 C-reactive protein (CRP) testing is used to identify the presence of inflammation. CRP is a cytokine made by the liver and is released into the bloodstream within a few hours of an injury, at the start of an infection or other acute inflammation. Rising concentrations of CRP may occur before other signs such as fever or pain but is not specific for the location or cause of the problem.

Box 17.26 LDL is sometimes called 'bad cholesterol' because it can accumulate in the plaques that narrow and clog main arteries.

17.5.2 Blood glucose testing

Blood glucose levels are maintained within homeostatic limits in healthy people and values that are outside the normal range may be an indicator of disease, e.g. types 1 and 2 diabetes, gestational diabetes in pregnancy, reactive hypoglycaemia (low blood sugar in reaction to a stressful situation).

Capillary blood glucose test

Routine blood glucose levels can be monitored quickly and immediately using a lancet to obtain a spot of blood from a fingertip. The blood spot is transferred to an analysis strip and a reading obtained (→ Fig. 17.19). The results help people with type 1 diabetes to sustain tight glycaemic control through dietary choices and insulin dosing, thus reducing the risk of serious complications.

Glycated haemoglobin test

A glycated haemoglobin (HbA1c) test uses a small sample of blood:

- to measure the HbA1c – the average blood glucose levels for the last two to three months; a level of 6.5% (48 mmol/mol) or above may indicate type 2 diabetes
- to monitor how well a person's diabetes is being controlled; this requires an HbA1c test at least twice a year (→ Box 17.24)
- as a screening test for people at high risk of diabetes.

Oral glucose tolerance test

An oral glucose tolerance test (OGTT) can help to determine if a person has a problem with homeostasis and metabolising sugars and carbohydrates. During the procedure, a series of blood samples are analysed – before and after drinking a very sweet glucose drink. The results are defined in terms of plasma, glucose and insulin.

Erythrocyte sedimentation rate

The **erythrocyte sedimentation rate (ESR)** is the time it takes for red cells in a sample of blood to fall to the bottom of the test tube. The quicker the red cells fall, the more likely it is that there are high levels of inflammation in the body due to changes in plasma proteins in the blood. An ESR is often used to monitor conditions associated with inflammation such as arthritis and Crohn's disease (→ Box 17.25).

17.5.3 Blood cholesterol test

Cholesterol cannot dissolve in plasma – an aqueous fluid – so it is transported in the blood in combination with lipoprotein carrier molecules – **high density lipoprotein (HDL)** and **low density lipoprotein (LDL)** (→ Box 17.26).

Blood cholesterol is measured in mmol/L. Recommended levels in the UK:

total cholesterol:	5 mmol/L or less for healthy adults 4 mmol/L or less for those at high risk
levels of LDL:	3 mmol/L or less for healthy adults 2 mmol/L or less for those at high risk
levels of HDL:	ideal level is above 1 mmol/L undesirable level is less than 1 mmol/L.

Hyperlipidaemia is the presence of abnormally high levels of lipoproteins in the blood; it is not a disease in itself but the importance of the measurements lies in the increased risk of heart disease and stroke (→ [Box 17.27](#)). Cholesterol levels vary from person to person and elevated levels are characteristic of familial hypercholesterolaemia (→ [Fig. 17.20](#)).

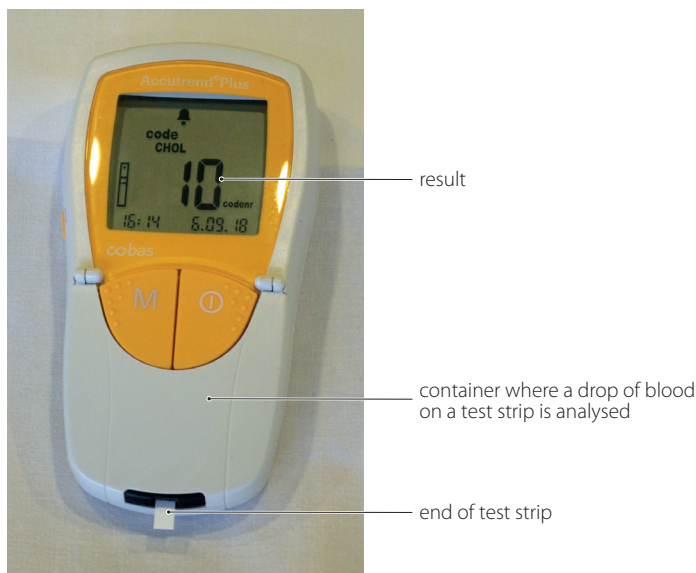


Fig. 17.20 Cholesterol test kit showing a high result.

Box 17.27 The UK has one of the highest average **cholesterol levels** in the world, with two out of three adults having a total cholesterol level of 5 mmol/L or above. In England the average levels are 5.5 mmol/L for men and 5.6 mmol/L for women.

17.5.4 Newborn blood spot test

Newborn blood spot (heel prick) test is carried out by midwives when babies are 5 days old. It is performed on newborn babies to help identify several rare but serious conditions so that treatment can begin early, e.g.:

- congenital hypothyroidism (→ [11.4.2](#))
- sickle-cell disease (→ [13.8.3](#))
- cystic fibrosis (→ [13.8.2](#))
- phenylketonuria (→ [12.7.4](#))
- medium-chain acyl-CoA dehydrogenase deficiency (MCADD)
- maple syrup urine disease (MSUD)
- isovaleric acidemia (IVA)
- glutaric aciduria type I (GA 1)
- homocystinuria (HCU).

17.5.5 Serum electrolyte tests

Electrolytes are minerals that have an electric charge and are present in blood, urine and other body fluids (→ [20.8.2](#)). They are involved in many processes and the body functions best when each is kept in equilibrium (homeostasis). Electrolytes tested include potassium, sodium and chloride; when the level of any of these is raised or lowered outside the homeostatic range, disorder occurs and further assessment and investigation may be needed (→ [Box 17.28](#)).

Box 17.28 Electrolytes in venous blood, plasma or serum are measured using a technique called **potentiometry** that uses ion-selective electrodes and is expressed in mmol/litre or mEq/litre. These tests are used to find the level of various electrolytes in a sample of blood.

Examples of serum electrolyte tests

Potassium is the most abundant intracellular ion. **Homeostasis of potassium** is critical for nerve and muscle function, being regulated by sodium-potassium ATPase active transport pumps in cell membranes (→ [2.2.2](#)).

- **Hyperkalaemia** (high potassium level) in blood has many possible causes, especially in people who have been hospitalised. Some are potentially life-threatening and may require emergency management, e.g. arrhythmias (abnormal heart rhythms) and paralysis.
- **Hypokalaemia** (low potassium level) could be the result of heavy sweating or persistent vomiting or diarrhoea, or be due to certain medications, e.g. diuretics, salbutamol, lithium or some antibiotics.

Sodium homeostasis is essential for fluid balance and homeostasis.

Sodium is the most abundant extracellular ion and is an osmotically active particle that attracts water. It is essential for homeostasis of fluid volume and composition.

- **Hypernatraemia** (high sodium level) in blood results from an inadequate intake of water, e.g. in people who are unable to take in fluid as their thirst dictates or when there is excessive sweating. It can also arise if there is excessive loss of body water via the urinary tract, e.g. glucosuria in diabetes, or via the gastrointestinal tract, e.g. vomiting or diarrhoea (→ Box 17.29).
- **Hyponatraemia** (low sodium level) can result from excess fluid in the body relative to sodium intake, but can also be the result of loss of sodium and fluids due to chronic illness such as congestive heart failure or renal disease.

Chloride homeostasis is essential for normal electrical potential across cell membranes and neuronal excitability.

- **Hyperchloraemia** (high chloride level) in blood may occur as a result of dehydration when too much water is lost in diarrhoea, certain kidney diseases, and sometimes in overactivity of the parathyroid glands.
- **Hypochloraemia** (low chloride level) – chlorine is normally lost in the urine, sweat, and stomach secretions, and excessive loss can occur from heavy sweating, vomiting, and disease of the adrenal glands or kidneys.

17.5.6 Hormone tests

Hormones in blood or urine are present in very small quantities and tests called immunoassays using antibodies (→ 14.6) are needed to measure their level, e.g.:

- thyroid function tests determine the levels of TSH and T4 (→ 11.3.1)
- the level of cortisol if Addison's disease is suspected (→ 14.9.3)
- reproductive hormones in fertility tests, pregnancy tests; and hormone replacement therapy (→ 12.5.2)
- pituitary function tests for the various hormones produced by the anterior pituitary gland (→ 11.3.2).

17.5.7 Liver function tests

Liver function tests (LFTs) provide a very wide range of biochemical measurements that reflect the activity of hepatocytes (liver cells) (→ Fig. 17.21). Abnormal levels of liver markers can be a signal of altered tissue function or altered bile flow, which may or may not be accompanied by signs and symptoms relevant to lifestyle, e.g. misuse of alcohol, recreational drugs and medication. The results of LFTs need to be taken in conjunction with an understanding of patients' life settings (→ Box 17.30).

Box 17.29 Hypernatraemia is a serious condition in bottle-fed babies when the instructions are not followed and too much milk powder is used to mix the feeds. The bottled milk will then have a much higher sodium content than human milk.

Box 17.30 Liver disease is amongst the top global killers and rising – up to about 10% of mortality. Of great concern (to WHO and Public Health England) is that most people who are infected with viral hepatitis do not know it. The rising levels of obesity are also becoming a major concern because it leads to accumulation of fat in the liver. Liver disease is now the third biggest cause of mortality amongst adults.

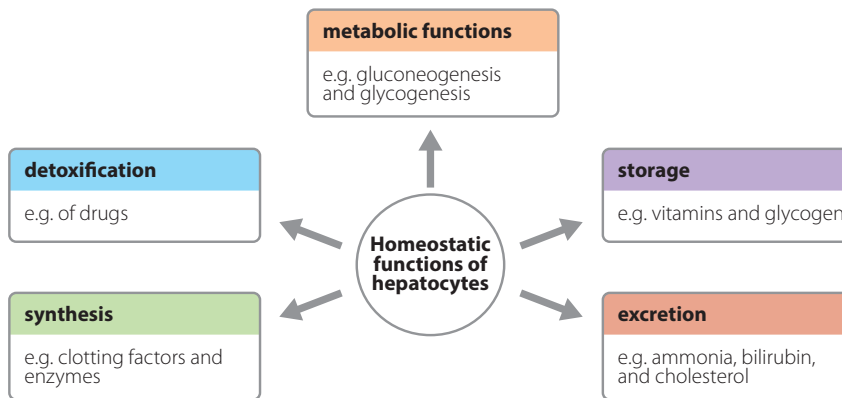


Fig. 17.21 Activities carried out in the liver.

Common liver function tests

- **Albumin** – this plasma protein is made by the liver and its concentration depends on nutritional status, hormonal environment and urinary losses. However, albumin levels tend to fall as liver disease progresses.
- **Bilirubin** is formed from the haem component of erythrocytes and appears in the blood in a form known as unconjugated bilirubin that reflects the balance between its production in the liver and excretion via the bile duct. Therefore high levels often reflect problems with liver tissue or obstruction of the bile duct.
- **Alkaline phosphatase** – high levels of this enzyme can arise from both hepatic and non-hepatic sources, and some increases are physiological, e.g. in adolescence or late pregnancy. The source of alkaline phosphatase needs to be determined as part of the diagnostic process, e.g. increased levels indicate obstruction of the bile duct or the development of malignancy (→ [Box 17.31](#)).
- **Aminotransferases** – these enzymes in the liver cells move amino acids into metabolic pathways and are part of gluconeogenesis; they can be detected in the blood when liver cells are injured.
- **Hepatitis antigens** – a positive result can indicate acute or chronic infection with hepatitis B or hepatitis C, while autoimmune hepatitis is characterised by the presence of antinuclear antibodies.
- **Prothrombin time (PT)** – measures time taken for blood to coagulate. Coagulation of blood depends on clotting factors made by the liver and vitamin K from the diet, so this test measures the effectiveness of their synthesis. It is also used to monitor haemostasis amongst people undertaking anticoagulant therapy, e.g. warfarin. **International Normalised Ratio (INR)** is a means of standardising prothrombin time across different laboratories because it provides a standardised measure of the time taken for blood to clot.
- **Blood urea nitrogen (BUN) to creatinine ratio** – relates to protein metabolism by the liver. This test compares the amount of urea with the amount of creatinine in the blood. These substances are both filtered and then are absorbed from the blood as it passes through the kidneys. The amount of reabsorption of creatinine always remains the same but the reabsorption of urea can be increased or decreased, which changes the ratio and can be an indicator of a likely cause of renal failure.

Box 17.31 Disorders that affect the liver cause enzymes to be released into the blood and the amounts of the various proteins produced by the liver to fall. Measuring the levels of these enzymes and proteins provides information about the state of a patient's liver that is used to help diagnose certain liver disorders such as:

- **hepatitis** (infection of the liver)
- **cirrhosis** (scarring of the liver)
- **alcohol-related liver disease** (caused by excessive alcohol consumption).

17.5.8 Enzyme-linked immunosorbent assay

The enzyme-linked immunosorbent assay (ELISA) test detects specific antibodies that appear in the blood in response to infections or allergies and can be used to check for infections such as HIV, or a specific allergy such as a peanut allergy (→ Fig. 17.22).



Fig. 17.22 ELISA microplate for testing 96 samples.

Box 17.32 Agar is a complex carbohydrate that is extracted from plants then added to a mixture of nutrients to create a solid medium on which to grow colonies and to isolate species. **Nutrient broths** are liquid media with the essential nutritional needs of most microorganisms. Some species, e.g. *Streptococcus* and *Staphylococcus*, demonstrate distinctive characteristics in nutrient broth.

17.6 Microbiological tests

Microbiological tests assist in the diagnosis of infectious diseases. Pathogenic microorganisms – those that cause disease – are certain species of bacteria, viruses, fungi and protozoa. Fungi and protozoa can be identified with a microscope but bacteria and viruses are so small that they need to be **cultured** – that is, grown on, or in, a culture medium – a solid or liquid substance containing nutrients. They are then kept in suitable conditions in which the microorganisms can grow and multiply to a number that can be observed and identified.

17.6.1 Bacterial culture

Bacteria are cultured on agar plates or in a nutrient broth (→ Box 17.32). The cultures are kept at a suitable temperature and, depending on whether the bacteria are aerobes or anaerobes, in the presence or absence of oxygen. Bacteria can be identified by their requirements for growth, colour, shape and whether they are Gram-positive or Gram-negative (→ Fig. 17.23).

Gram stain test

Gram staining is a technique used to differentiate between two large groups of bacteria – Gram-positive and Gram-negative – based on their different cell wall constituents.

Gram-positive and Gram-negative refers to the reaction to Gram stain. A sample is taken from an infected area and placed on a glass slide to which



Fig. 17.23 MRSA colonies growing in a Petri dish.

Gram stain is added. When examined under a microscope, bacteria in the sample will either be purple (Gram-positive) or pink (Gram-negative) (→ Fig. 17.24).

The result helps to identify the type of bacteria that may have caused the infection and allows treatment with appropriate antibiotics (→ Chapter 1) to be started while further tests are carried out to confirm the specific bacteria responsible.

17.6.2 Viral culture

As viruses only grow and multiply in cells, they are cultured in host cells and viral growth is measured by detection of **viral antigens** – substances given off by the virus which cause an immune response in its host (→ Box 17.33).

The advantages of this method are:

- it greatly speeds up detection time
- diagnosis of a viral infection can be obtained in the early stages of a disease
- it is particularly useful for slow-growing types of virus.

Because many clinically relevant viruses are difficult or impossible to grow, molecular techniques including **polymerase chain reaction (PCR)** assays are increasingly providing simple, reproducible identification of viral infection before detectable immunological changes.

17.6.3 Microbial investigations

Cerebrospinal fluid analysis

A sample of cerebrospinal fluid (CSF) is obtained from a **lumbar puncture** and analysed when infections such as meningitis are suspected.

Sputum culture

This test is carried out on **sputum** – the mixture of saliva and mucus coughed up from the respiratory tract. When a sample of sputum is cultured, any microorganisms in it will grow, multiply and can be identified, e.g. in cases of tuberculosis, sputum culture is used to identify the strain of *Mycobacterium tuberculosis* (TB) bacteria involved and whether or not it is drug resistant. As TB bacteria grow slowly, it may take up to 8 weeks to get results.

Stool analysis

A stool analysis is a laboratory test done on a stool (faeces) sample to help diagnose disease affecting the digestive tract, e.g.:

- infectious agents – bacteria, viruses, yeasts, protozoa (→ Box 17.34)
- parasites, e.g. worms and worm eggs
- the presence or absence of occult blood (blood not apparent to the naked eye) due to the small quantity present
- chemical composition, e.g. pH
- poor nutrient absorption, e.g. fat or protein content.

Infected blood

Blood is normally a sterile environment and the presence of bacteria is normally a sign of a severe infection somewhere in the body, e.g. sepsis, pneumonia or meningitis. Blood can also be contaminated during surgery or from a catheter.

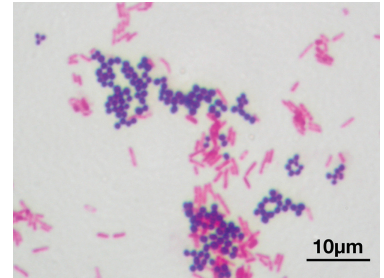


Fig. 17.24 Bacterial reaction to Gram stain.

Box 17.33 Viral immunodiagnostic testing involves the detection and measurement of viral protein.

Box 17.34 Diseases resistant to antimicrobial drugs include tuberculosis, malaria, urinary tract infections, pneumonia, bloodstream infections and hospital-acquired infections such as MRSA (→ 3.2.2).

17.7 Anthropometry

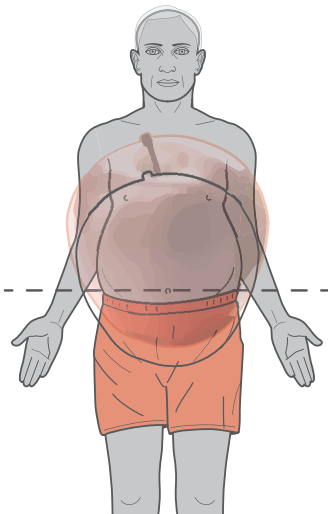
Anthropometry is the study of the proportions and measurements of the human body which relate to body shape. A person's shape is based primarily on genetic make-up adapted by nutrition, lifestyle and medical history.

17.7.1 Body mass index

Body mass index (BMI) calculates the ratio of a person's weight to their height and can be a guide to a healthy weight. BMI charts show the target weight for many men and women but are not intended for pregnant or breastfeeding women, weight-trainers or athletes. BMI can be a useful physiological measure for entire populations but is less useful on an individual basis because its application varies for people of some ethnic groups, e.g.:

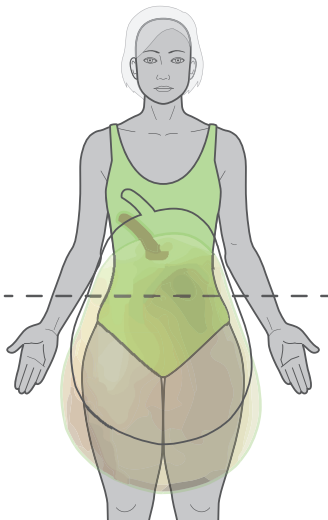
- BMI readings of more than 23 kg/m^2 indicate a greater cardiovascular risk, while BMI above 27.5 kg/m^2 is the threshold for higher risk and may trigger action to prevent type 2 diabetes
- people of south Asian descent are at greater risk of problems related to being overweight, including heart disease and type 2 diabetes
- type 2 diabetes is more likely to develop in people with African and Afro-Caribbean ancestry
- the BMI for children aged two years and over is calculated in the same way as for adults but the results are interpreted using **BMI centiles** as a measure of whether a child is a healthy weight for their height, age and sex
- generally, a 'healthy' BMI does not reflect too much body fat, but 'hidden' adiposity may contribute to metabolic syndrome (→ 16.8) even for people whose BMI lies within the normal range of $18\text{--}25 \text{ kg/m}^2$.

(a) APPLE BODY SHAPE



more adipose tissue around the abdomen

(b) PEAR BODY SHAPE



more adipose tissue below the waist

Fig. 17.25 (a) Apple body shape; (b) pear body shape.

17.7.2 Adiposity measurements

Unlike BMI, these measurements give some indication of the amount of visceral adipose tissue in the body. This is important because where people store fat has an important impact on their health:

- fat stored around the waist (an 'apple-shaped' physique) is associated with a greater risk of diabetes and heart disease (→ Fig. 17.25a)
- fat stored around the hips and thighs (a 'pear-shaped' physique) may be protective against diabetes and hypertension (→ Fig. 17.25b).

Waist circumference

Measurement of the **waist circumference** using a tape measure is an indicator of the amount of abdominal fat present. Ideal waist measurements are:

- men – under 102 cm (40.2 inches)
- women – under 88 cm (34.7 inches).

Measurements greater than these indicate a much increased risk of developing diabetes.

Waist-to-hip ratio

Waist-to-hip (WHR) measures the ratio of a person's waist circumference to their hip circumference and is an indicator of abdominal obesity when:

- WHR for males is >0.90
- WHR for females is >0.85 .

Body Adiposity Index

Body Adiposity Index (BAI) may provide an indication of the percentage of body mass that is composed of fat compared to lean, fat-free mass.

Bioelectrical impedance analysis

Bioelectrical impedance analysis (BIA) sends a safe electrical current through the body. The impedance (resistance to flow) of the current can be used to determine fat-free body mass and body fat. It is based on resistance to alternating current to lean body mass:

- the leaner the individual, the lower the resistance to the current
- the fatter the individual, the greater the resistance to the current.

However, accuracy of this method is affected by body structure, levels of hydration and presence of chronic disease.

Skinfold measurement

Changes in the thickness of the layer of fat that lies beneath the skin are an indication of changes in body composition during athletic training. Specially designed callipers are used to measure the thickness of skinfolds at a minimum of four locations around the body:

- triceps – the back of the arm between shoulder and elbow
- biceps – the front of the arm between shoulder and elbow
- subscapula – just below the shoulder blade
- suprailiac – just above the hipbone.

The reliability and validity of the measurement depend on the skill and experience of the person using the calipers.

Imaging methods

Both CT and MRI scans provide cross-sectional scans of the body and can be used to accurately measure body composition and determine fat (adipose) distribution. They can be used to identify subcutaneous fat, visceral fat, muscle mass and organ composition.

17.8 Dying and death

The process of conception and birth mark the beginning of a person's life on earth and death is the end. It can be brought about by ageing, malnutrition, disease, dehydration, accidents or major trauma that results in terminal injury including suicide, homicide or drowning.

Although healthcare professionals are trained to promote health, prevent disease and preserve life, their training should enable them to:

- **recognise the physiological changes** that are characteristic of the end of life and enable healthcare professionals to work appropriately in the important task of being with the dying and their loved ones
- **understand that death is an integral part of the human life cycle** and does not necessarily represent defeat of the efforts to preserve life
- **realise that death is the final stage of serious illness** which involves the irreversible loss of the essential characteristics of a living person – the capacity for consciousness combined with the capacity to breathe.

Whatever the cause of death, the emphasis of healthcare professionals should always be holistic, enhancing the quality of life and involving the person, their families and carers. Working in multidisciplinary teams (MDT),

Box 17.35 Since members of the healthcare teams are often closest to a sick person in difficult times, or may be the people the family turn to for immediate care, they may also be called upon for explanations about the experience of the dying.

they can be instrumental in supporting those who are dying and their families to go through the emotional, social, ethical and legal aspects of the process of dying and death. This includes being present and explaining the dying process to the person and their loved ones, especially those who have not witnessed a death before (→ [Box 17.35](#)).

17.8.1 Dying

Towards the end of life, frail older people may lose interest in eating; they may experience difficulty in swallowing or coughing properly, as well as being more prone to becoming dehydrated. This is because thirst is often reduced although sips of fluid are often well tolerated while cream applied to the face and lips can provide comfort.

People who are dying may spend a greater part of the day sleeping, so turning to prevent stiffness and pressure ulcers (→ [3.5.2](#)) is important for those who cannot turn themselves and/or find it difficult to communicate what they need. Healthcare professionals should be proactive and notice signs and indications of pain (→ [Box 9.34](#)) so that analgesia (→ [18.12](#)) can be given. Dying itself is not painful, but dying from a painful disease is, so pain should be treated and managed accordingly.

Peripheral shutdown

There are several physiological changes that characterise this stage, which may take 72 or fewer hours. The dying person often knows that they are close to death, maybe sensing that they are on the edge between life and death. Some people experience terminal restlessness or agitation, so keeping a light on in the room day and night can reduce anxiety and help a dying person to become orientated when they are awake, although they may only see and hear at very close range.

- The **skin** on the hands, legs and feet may look noticeably bluish-cold and mottled (blotchy and marbled), because of a lack of blood circulation to the peripheries.
- **Breathing** may become irregular and laboured with apnoea (gasps) in between each breath – known as Cheyne–Stokes respiration.
- **Coughing** may be difficult. People who are frail or dying may have chest or other infections, and lose the ability to cough up secretions, so other measures that may help to provide relief include repositioning, warm or cold pads, elevating and supporting swollen limbs with soft pillows or massage.
- **Hearing** is the last sense to go, and appropriate music can help breathing to become slower, deeper and more relaxed.

17.8.2 Imminent death

When death is imminent, the person is close to dying and may become unresponsive.

- Breathing changes, becoming less laboured but shallow.
- The heart is less able to pump blood effectively, so pulse is thin and thready (→ [5.14.3](#)).
- Less and less oxygen is being delivered to vital centres in the brainstem so blood pressure falls.
- Urinary and bowel changes mean that urine output falls and urine may be discoloured.
- Secretions may gather in the throat, causing a gurgling sound commonly referred to as “the death rattle” which can be distressing for loved ones.

Death

Although it is important to recognise that death is a process, there is a clear societal and professional demand for a reliable means of identifying the moment of death. Death is defined as a physiological process that occurs with:

- loss of capacity for consciousness
- loss of the ability to breathe
- absence of all vital signs (→ 17.1)
- irreversible arrest of brain functions (→ 9.3)
- absence of reflex responses and electrical activity
- loss of ability to maintain cellular homeostasis
- the failure of body organs.

In the first 15–20 minutes following death the person becomes very pale (pallor mortis), the body temperature declines steadily until it matches the environmental temperature (algor mortis) and the limbs of the corpse become stiff and difficult to manipulate (rigor mortis). The process of decomposition begins.

17.8.3 Cardiopulmonary resuscitation

Cardiopulmonary resuscitation (CPR) is the procedure applied following a cardiac arrest, commonly called a heart attack. People who are in cardiac arrest:

- are not breathing properly – noisy, infrequent or gasping breaths is not normal breathing
- have collapsed and are unresponsive
- the heart stops, the blood supply to the brain also stops and the person becomes unconscious.

Typically the brain sustains damage after blood flow has been stopped for about four minutes and irreversible damage after six to seven minutes, therefore CPR is generally only effective if performed within seven minutes of stoppage of blood flow. Blood flow may stop for many reasons, but loss of electrical coordination of the heartbeat (→ 5.11) is usually responsible (→ Box 17.36). The aim of cardiopulmonary resuscitation is therefore to maintain a cardiac output (→ 5.12.1) and provide an open airway in order to oxygenate blood and transport oxygen to vital tissues. The two important skills of CPR are:

- chest compressions that maintain a pressure difference between the arteries and veins that is required to pump blood around the body
- rescue breaths (also known as ‘kiss of life’) to provide oxygen.

Effective CPR can enable enough oxygen to reach the brain to delay brainstem death and may allow the heart to respond to attempts to restart the rhythm. While it may be effective if begun promptly, CPR is an invasive procedure that includes chest compressions, electric shock by an implanted or external defibrillator, injection of drugs and artificial ventilation. However, adverse risks of CPR include rib fracture, hypoxic brain damage and increased physical disability. It may mean that the person dies in an undignified and traumatic way (→ Box 17.37).

17.8.4 Perspectives on death and dying

National guidelines and protocols may guide the coordination of care for the dying, but every family has its own culture and beliefs so, for healthcare professionals, being with the dying is more than just providing physical care

Box 17.36 For many people, including first aiders, CPR refers to the first aid procedures that can be used to keep a person who has collapsed alive until the emergency healthcare team arrives. Effective CPR more than doubles the chance of someone surviving a cardiac arrest so instruction and training are provided by many organisations. It is recommended that training should include practice on a manikin.

Box 17.37 Emergency CPR occurs when healthcare professionals initiate resuscitation in emergency situations either in hospital settings or outside of hospital, e.g. out-of-hospital cardiac arrest (OHCA).

until the point of physiological death. The different rites and habits, as well as mechanisms for coping with death, must be accepted without judgement by healthcare professionals.

- Healthcare professionals understand that, for some people, death is viewed as the end of physical, energetic and spiritual life. For others, it is only the end of life within a physical body, while something immaterial (the spirit; the soul) survives.
- Some people may linger at the brink of death for many days or weeks, and this can be hard for family members who do not care for the dying on a regular basis.
- Since death is the last event of life, and its timing is unknowable, healthcare professionals may therefore need to be able to empower the dying to express their thoughts, feelings and fears before it is too late.
- Healthcare professionals will also understand the need for official, national communication of death and also the notifications related to transplantation.
- Person-centred care values the experiences of people faced with the imminence of the end of life and can pave the way for a dignified and peaceful death (→ [Box 17.38](#)).

Box 17.38 Person-centred care

sees patients as equal partners in planning their care to make sure it is most appropriate for their needs.

Key points

1. Healthcare professionals observe a range of physiological parameters to assess a person's state of health and wellbeing.
 2. Technological advances enable many physiological measurements to be made.
 3. Diagnostic imaging is used to view a person's internal organs.
 4. Electrophysiological techniques help clinicians to understand the transmission of electrical impulses in muscles and neurons and thus, the state of their ability to function.
 5. Laboratory investigations aid diagnosis of patients in healthcare settings and may involve analysis of body fluid composition, assays of molecular biology or genomics and microbiological techniques.
 6. Healthcare professionals are able to care for the dying and provide support for their families.
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