CHAPTER 16

The musculoskeletal system

ANIMATIONS

The musculoskeletal system consists of the bones of the skeleton, their joints and the skeletal (voluntary) muscles that move the body. The characteristics and properties of joints, and of bone and muscle tissue, are discussed in this chapter. The effects of ageing on the musculoskeletal system are listed, and the illnesses section at the end of the chapter describes some disorders of bone, muscle and joints.

Bone

Learning outcomes

After studying this section, you should be able to:

- state the functions of bones
- list five types of bones and give an example of each
- outline the general structure of a long bone
- describe the structure of compact and spongy bone tissue
- describe the development of bone
- explain the process of bone healing and the factors that complicate it
- outline the factors that determine bone growth.

Although bones are often thought to be static or permanent, they are highly vascular living structures that are continuously being remodelled.

Functions of bones

The functions of bones include:

- providing the body framework
- giving attachment to muscles and tendons
- allowing movement of the body as a whole and of parts of the body, by forming joints that are moved by muscles
- forming the boundaries of the cranial, thoracic and pelvic cavities, and protecting the organs they contain
- haemopoiesis, the production of blood cells in red bone marrow (p. 64)
- mineral storage, especially calcium phosphate – the mineral reservoir within bone is essential for maintenance of blood calcium levels, which must be tightly controlled.

Types of bones

Bones are classified as long, short, irregular, flat and sesamoid.

Long bones. These consist of a shaft and two extremities. As the name suggests, these bones are longer than they are wide. Most long bones are found in the limbs; examples include the femur, tibia and fibula.

Short, irregular, flat and sesamoid bones. These have no shafts or extremities and are diverse in shape and size. Examples include:

- short bones – carpals (wrist)
- irregular bones – vertebrae and some skull bones
- flat bones – sternum, ribs and most skull bones
- sesamoid bones – patella (knee cap).

Bone structure

Long bones

These have a *diaphysis* (shaft) and two *epiphyses* (extremities) (Fig. 16.1). The diaphysis is composed mainly of compact bone with a central medullary canal, containing fatty yellow bone marrow. The epiphyses consist of an outer covering of compact bone with *spongy* (*cancellous*) *bone* inside. The diaphysis and epiphyses are separated by *epiphyseal cartilages*, which ossify when growth is complete.

Long bones are almost completely covered by a vascular membrane, the *periosteum*, which has two layers. The outer layer is tough and fibrous, and protects the bone underneath. The inner layer contains osteoblasts and osteoclasts, the cells responsible for bone production and breakdown (see below), and is important in repair

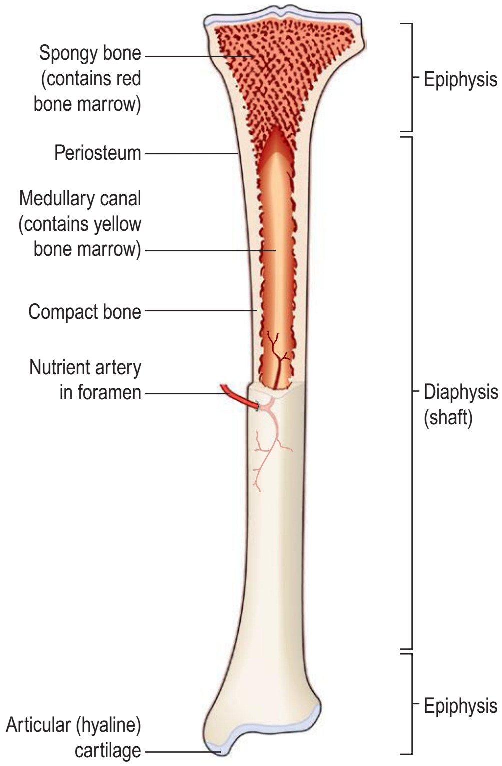

Figure 16.1 A mature long bone: partially sectioned.

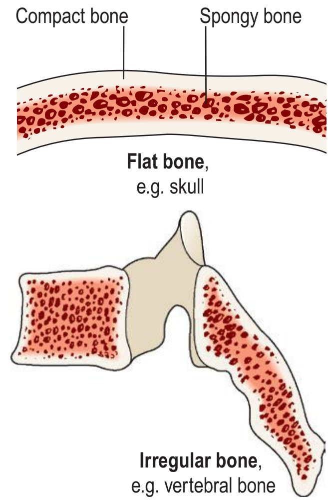

Figure 16.2 Sections of flat and irregular bones.

and remodelling of the bone. The periosteum covers the whole bone except within joint cavities, allows attachments of tendons and is continuous with the joint capsule. *Hyaline cartilage* replaces periosteum on bone surfaces that form joints. Thickening of a bone occurs by the deposition of new bone tissue under the periosteum.

Blood and nerve supply

One or more nutrient arteries supply the bone shaft; the epiphyses have their own blood supply, although in the mature bone the capillary networks arising from the two are heavily interconnected. The sensory nerve supply usually enters the bone at the same site as the nutrient artery, and branches extensively throughout the bone. Bone injury is, therefore, usually very painful.

Short, irregular, flat and sesamoid bones

These have a relatively thin outer layer of compact bone, with spongy bone inside containing red bone marrow (Fig. 16.2). They are enclosed by periosteum except the inner layer of the cranial bones where it is replaced by dura mater.

Microscopic structure of bone

Bone is a strong and durable type of connective tissue. Its major constituent (65%) is a mixture of calcium salts, mainly calcium phosphate. This inorganic matrix gives bone great hardness, but on its own would be brittle and prone to shattering. The remaining third is organic material, called *osteoid*, which is composed mainly of collagen. Collagen is very strong and gives bone slight flexibility. The cellular component of bone contributes less than 2% of bone mass.

Bone cells

There are three types of bone cell:

- osteoblast
- ostecyte
- osteoclast.

Osteoblasts

These bone-forming cells are responsible for the deposition of both inorganic salts and osteoid in bone tissue. They are therefore present at sites where bone is growing, repairing or remodelling, e.g.:

- in the deeper layers of periosteum
- in the centres of ossification of immature bone
- at the ends of the diaphysis adjacent to the epiphyseal cartilages of long bones
- at the site of a fracture.

As they deposit new bone tissue around themselves, they eventually become trapped in tiny pockets (*lacunae*, Fig. 16.3) in the growing bone, and differentiate into *osteocytes*.

Osteocytes

These are mature bone cells that monitor and maintain bone tissue, and are nourished by tissue fluid in the *canaliculi* that radiate from the *central canals*.

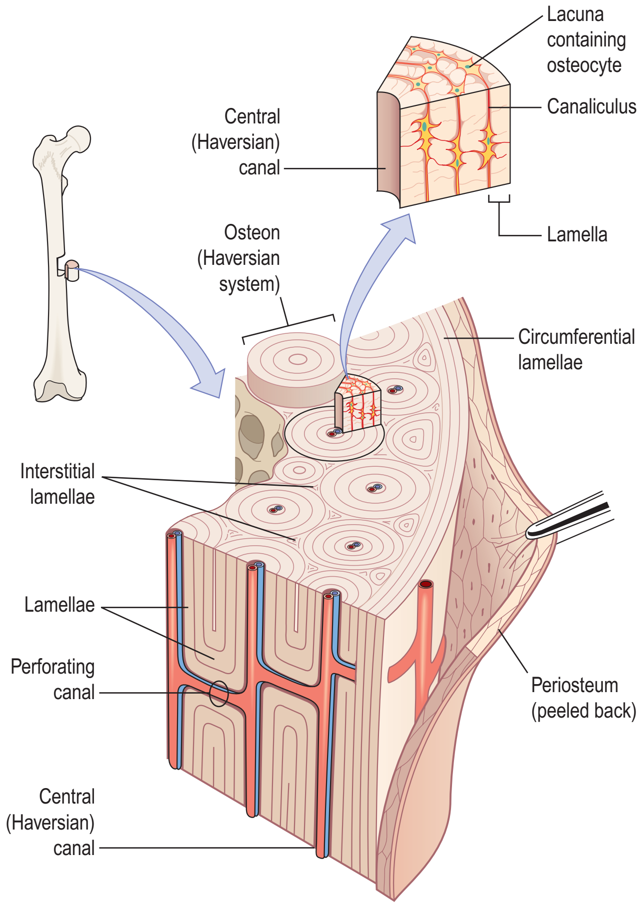

Figure 16.3 Microscopic structure of compact bone.

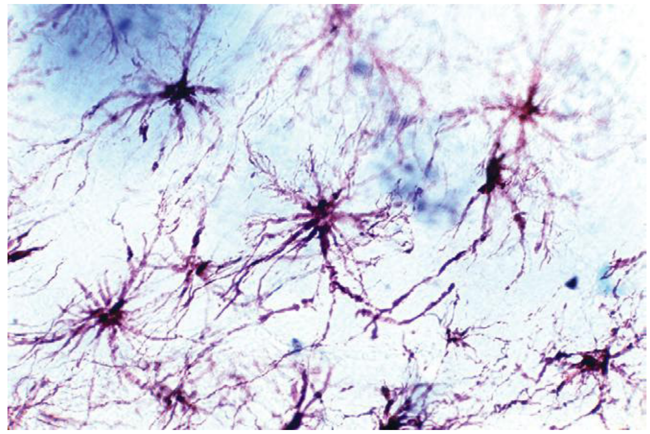

Figure 16.4 Light micrograph of osteocytes, showing the multiple fine processes that extend through bone canaliculi and allow each cell to communicate directly with its neighbours.

Osteoclasts

These cells break down bone, releasing calcium and phosphate. They are very large cells with up to 50 nuclei, which have formed from the fusion of many monocytes (p. 69). The continuous remodelling of healthy bone tissue is the result of balanced activity of the bone's osteoblast and osteoclast populations. Osteoclasts are found in areas of the bone where there is active growth, repair or remodelling, e.g.:

- under the periosteum, maintaining bone shape during growth and to remove excess callus formed during healing of fractures (p. 394)
- round the walls of the medullary canal during growth and to canalise callus during healing.

Compact (cortical) bone

Compact bone makes up about 80% of the body bone mass. It is made up of a large number of parallel tube-shaped units called *osteons* (Haversian systems), each of which is made up of a central canal surrounded by a series of expanding rings, similar to the growth rings of a tree (Fig. 16.3). Osteons tend to be aligned the same way that force is applied to the bone, so for example in the femur (thigh bone), they run from one epiphysis to the other. This gives the bone great strength.

The central canal contains nerves, lymphatics and blood vessels, and each central canal is linked with neighbouring canals by tunnels running at right angles between them, called *perforating canals*. The series of cylindrical plates of bone arranged around each central canal are called *lamellae*. Between the adjacent lamellae of the osteon are strings of little cavities called *lacunae*, in each of which sits an osteocyte. Lacunae communicate with each other through a series of tiny channels called *canaliculi*, which allows the circulation of interstitial fluid through the bone, and direct contact between the osteocytes, which extend fine processes into them (Fig. 16.4).

Between the osteons are *interstitial lamellae*, the remnants of older systems partially broken down during remodelling or growth of bone.

Spongy (cancellous, trabecular) bone

To the naked eye, spongy bone looks like a honeycomb. Microscopic examination reveals a framework formed from *trabeculae* (meaning 'little beams'), which consist of a few lamellae and osteocytes interconnected by canaliculi (Fig. 16.5). Osteocytes are nourished by interstitial fluid diffusing into the bone through the tiny canaliculi. The spaces between the trabeculae contain red bone marrow. In addition, spongy bone is lighter than compact bone, reducing the weight of the skeleton.

Development of bone tissue 16.1

Also called *osteogenesis* or *ossification*, this begins before birth and is not complete until about the 21st year of life. Long, short and irregular bones develop in the fetus from rods of cartilage, *cartilage models*. Flat bones develop from *membrane models* and sesamoid bones from *tendon models*.

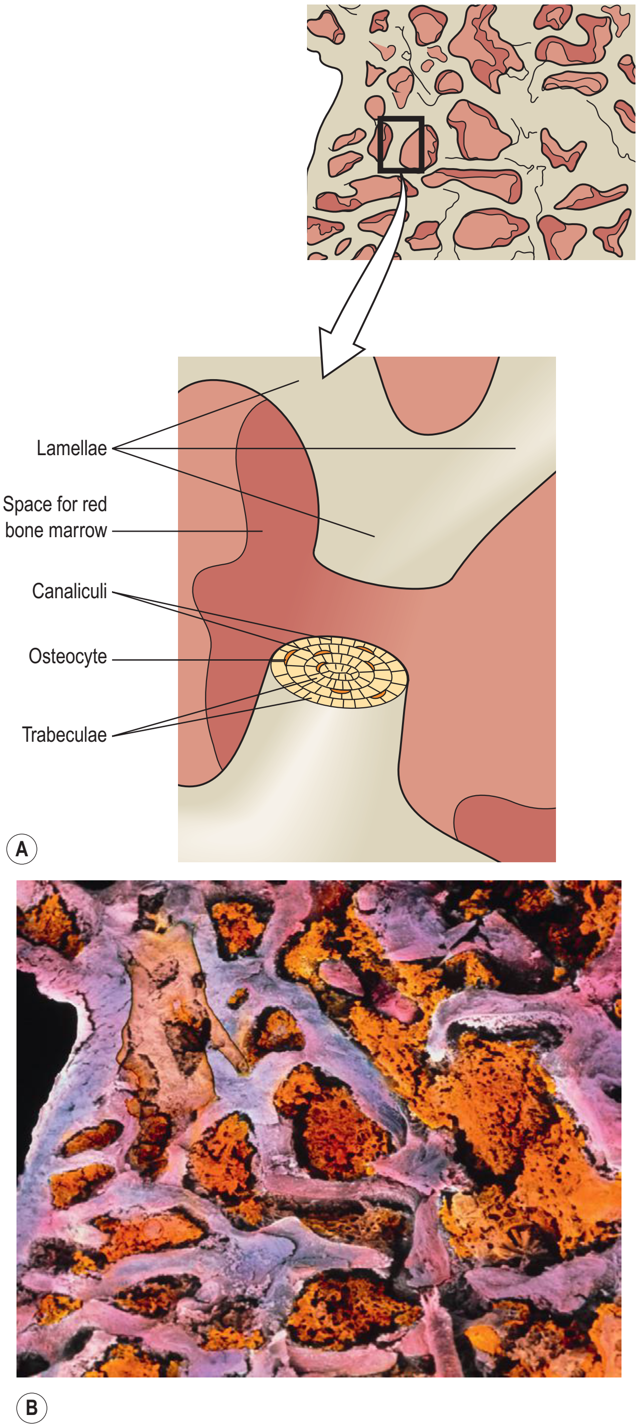

Figure 16.5 Spongy bone. A. Microscopic structure of spongy bone. **B.** Electron micrograph of spongy bone showing bone marrow (orange) filling the spaces between trabeculae (grey/blue).

During ossification, osteoblasts secrete osteoid, which gradually replaces the initial model; then this osteoid is progressively calcified, also by osteoblast action. As the bone grows, the osteoblasts become trapped in the matrix of their own making and become osteocytes.

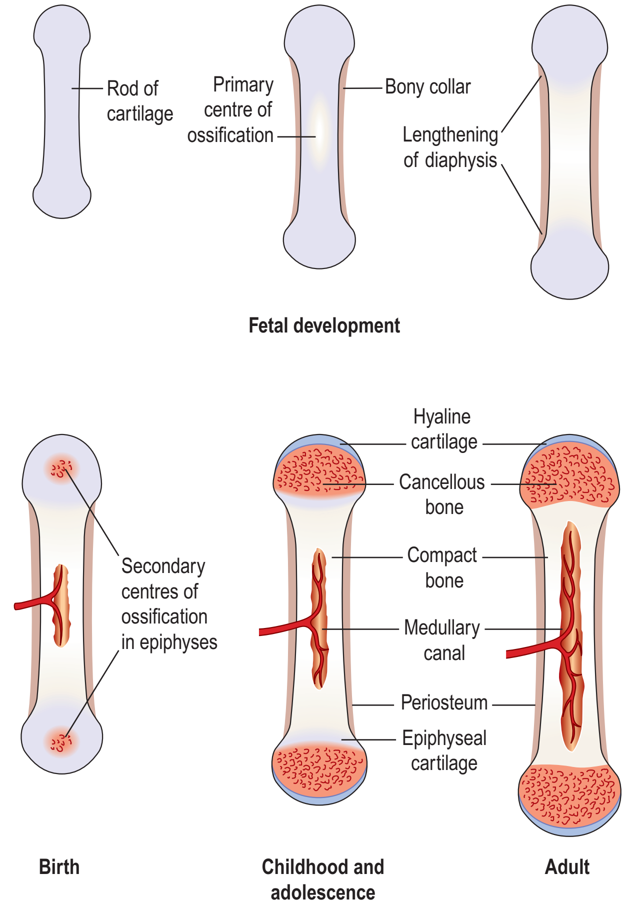

Figure 16.6 The stages of development of a long bone.

In mature bone, a fine balance of osteoblast and osteoclast activity maintains normal bone structure. If osteoclast activity exceeds osteoblast activity, the bone becomes weaker. On the other hand, if osteoblast activity outstrips osteoclast activity, the bone becomes stronger and heavier.

Development of long bones

In long bones the focal points from which ossification begins are small areas of osteogenic cells, or *centres of ossification* in the cartilage model (Fig. 16.6). This is accompanied by development of a bone collar at about 8 weeks of gestation. Later the blood supply develops and bone tissue replaces cartilage as osteoblasts secrete osteoid in the shaft. The bone lengthens as ossification continues and spreads to the epiphyses. Around birth, secondary centres of ossification develop in the epiphyses, and the medullary canal forms when osteoclasts break down the central bone tissue in the middle of the shaft. During childhood, long bones continue to lengthen because the epiphyseal plate at each end of the bone, which is made of cartilage, continues to produce new cartilage on its diaphyseal surface (the surface facing the shaft of the bone, Fig. 16.7). This cartilage is then turned to bone. As long as cartilage production matches the rate of ossification, the bone continues to lengthen. At puberty, under

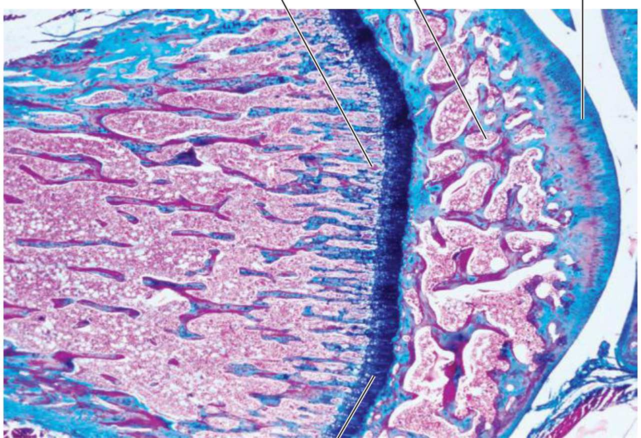

Figure 16.7 Light micrograph of the end of a growing bone, showing the epiphyseal plate.

the influence of sex hormones, the epiphyseal plate growth slows down, and is overtaken by bone deposition. Once the whole epiphyseal plate is turned to bone, no further lengthening of the bone is possible.

Hormonal regulation of bone growth

Hormones (see Ch. 9) that regulate the growth, size and shape of bones include the following.

- *Growth hormone* and the thyroid hormones, *thyroxine* and *tri-iodothyronine*, are especially important during infancy and childhood; deficient or excessive secretion of these results in abnormal development of the skeleton (p. 223).
- *Testosterone* and *oestrogens* influence the physical changes that occur at puberty and help maintain bone structure throughout life. Rising levels of these hormones are responsible for the growth spurt of puberty, but later stimulate closure of the epiphyseal plates (Fig. 16.7), so that bone growth lengthways stops (although bones can grow in thickness throughout life). Average adult male height is usually greater than female, because male puberty tends to occur at a later age than female puberty, giving a male child's bones longer to keep growing. Oestrogens are responsible for the wider female pelvis that develops during puberty, and for maintaining bone mass in the adult female. Falling oestrogen levels after menopause can put postmenopausal women at higher risk of bone fracture (osteoporosis, p. 431).
- *Calcitonin* and *parathyroid hormone* (p. 224) control blood levels of calcium by regulating its uptake into and release from bone. Calcitonin increases calcium uptake into bone (reducing blood calcium), and parathormone decreases it (increasing blood calcium).

Although the length and shape of bones does not normally change after ossification is complete, bone tissue is continually being remodelled and replaced when damaged. Osteoblasts continue to lay down osteoid and osteoclasts reabsorb it. The rate in different bones varies, e.g. the distal part of the femur is replaced over a period of 5 to 6 months.

Exercise and bone

Although bone growth lengthways permanently ceases once the epiphyseal plates have ossified, thickening of bone is possible throughout life. This involves the laying down of new osteons at the periphery of the bone through the action of osteoblasts in the inner layer of the periosteum. Weight-bearing exercise stimulates thickening of bone, strengthening it and making it less liable to fracture. Lack of exercise reverses these changes, leading to lighter, weaker bones.

Diet and bone

Healthy bone tissue requires adequate dietary calcium and vitamins A, C and D. Calcium, and smaller amounts of other minerals such as phosphate, iron and manganese, is essential for adequate mineralisation of bone. Vitamin A is needed for osteoblast activity. Vitamin C is used in collagen synthesis, and vitamin D is required for calcium and phosphate absorption from the intestinal tract.

Bone markings

Most bones have rough surfaces, raised protuberances and ridges that give attachment to muscle tendons and ligaments. These are not included in the following descriptions of individual bones unless they are of particular note, but many are marked on illustrations. Bone markings and related terminology are defined in Table 16.1.

Healing of bone 16.2

There are a number of terms used to classify bone fractures, including:

- *simple*: the bone ends do not protrude through the skin
- *compound*: the bone ends protrude through the skin
- *pathological*: fracture of a bone weakened by disease.

Following a fracture, the broken ends of bone are joined by the deposition of new bone. This occurs in several stages (Fig. 16.8).

1. A haematoma (collection of clotted blood) forms between the ends of bone and in surrounding soft tissues.
2. There follows development of acute inflammation and accumulation of inflammatory exudate, containing macrophages that phagocytose the haematoma and small dead fragments of bone

Table 16.1 Anatomical terminology related to bones

Term	Meaning
Articulating surface	The part of the bone that enters into the formation of a joint
Articulation	A joint between two or more bones
Bony sinus	A hollow cavity within a bone
Border	A ridge of bone separating two surfaces
Condyle	A smooth rounded projection of bone that forms part of a joint
Facet	A small, generally rather flat, articulating surface
Fissure or cleft	A narrow slit
Foramen (plural: foramina)	A hole in a structure
Fossa (plural: fossae)	A hollow or depression
Meatus	A tube-shaped cavity within a bone
Septum	A partition separating two cavities
Spine, spinous process or crest	A sharp ridge of bone
Styloid process	A sharp downward projection of bone that gives attachment to muscles and ligaments
Suture	An immovable joint, e.g. between the bones of the skull
Trochanter, tuberosity or tubercle	Roughened bony projections, usually for attachment of muscles or ligaments. The different names are used according to the size of the projection. Trochanters are the largest and tubercles the smallest

(this takes about 5 days). Fibroblasts migrate to the site; granulation tissue and new capillaries develop.

3. New bone forms as large numbers of osteoblasts secrete spongy bone, which unites the broken ends, and is protected by an outer layer of bone and cartilage; the new deposits of bone and cartilage is called a *callus*. Over the next few weeks, the callus matures, and the cartilage is gradually replaced with new bone.
4. Reshaping of the bone continues and gradually the medullary canal is reopened through the callus (in weeks or months). In time the bone heals completely with the callus tissue completely replaced with mature compact bone. Often the bone is thicker

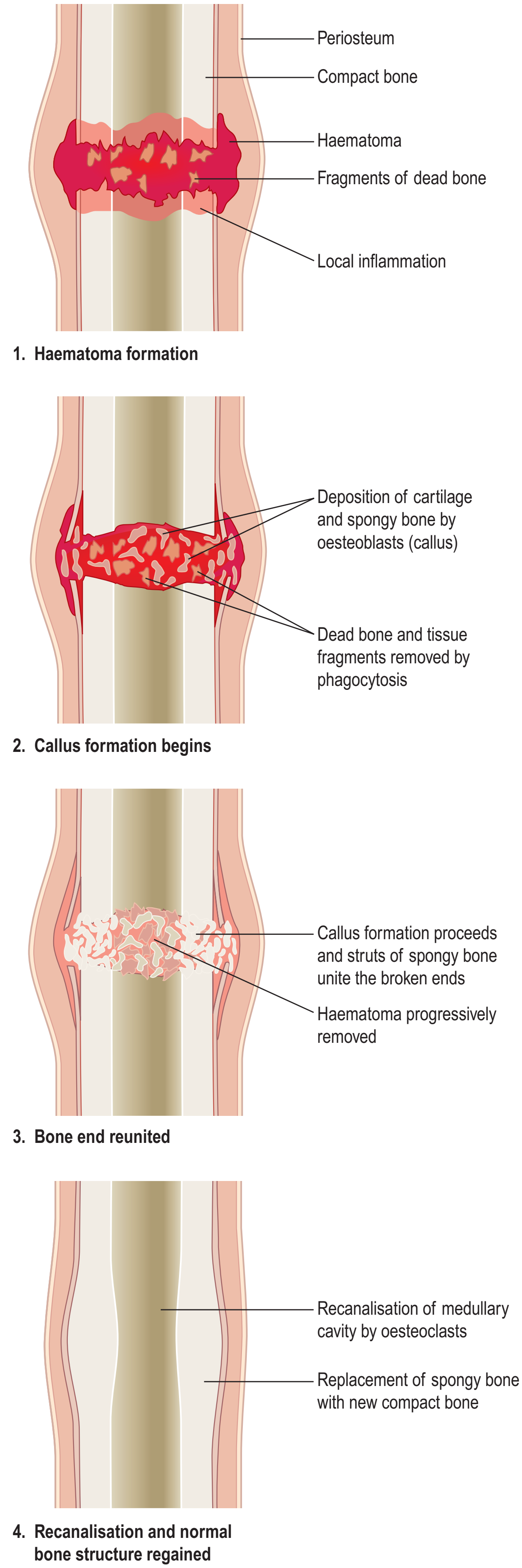

Figure 16.8 Stages in bone healing.

and stronger at the repair site than originally, and a second fracture is more likely to occur at a different site.

Factors that delay healing of fractures

Tissue fragments between bone ends. Splinters of dead bone (*sequestrae*) and soft tissue fragments not removed by phagocytosis delay healing.

Deficient blood supply. This delays growth of granulation tissue and new blood vessels. Hypoxia also reduces the number of osteoblasts and increases the number of chondrocytes that develop from their common parent cells. This may lead to cartilaginous union of the fracture, which results in a weaker repair. The most vulnerable sites, because of their normally poor blood supply, are the neck of femur, the scaphoid and the shaft of tibia.

Poor alignment of bone ends. This may result in the formation of a large and irregular callus that heals slowly and often results in permanent disability.

Continued mobility of bone ends. Continuous movement results in fibrosis of the granulation tissue followed by fibrous union of the fracture.

Miscellaneous. These include infection (see below), systemic illness, malnutrition, drugs, e.g. corticosteroids and ageing.

Complications of fractures

Infection (osteomyelitis, p. 432**).** Pathogens enter through broken skin, although they may occasionally be blood-borne. Healing will not occur until the infection resolves.

Fat embolism. Emboli consisting of fat from the bone marrow in the medullary canal may enter the circulation through torn veins. They are most likely to lodge in the lungs and block blood flow through the pulmonary capillaries.

Axial skeleton

Learning outcomes

After studying this section, you should be able to:

- identify the bones of the skull (face and cranium)
- list the functions of the sinuses and fontanelles of the skull
- outline the characteristics of a typical vertebra
- describe the structure of the vertebral column
- explain the movements and functions of the vertebral column
- identify the bones forming the thoracic cage.

The bones of the skeleton are divided into two groups: the *axial skeleton* and the *appendicular skeleton* (Fig. 16.9).

The axial skeleton consists of the *skull*, *vertebral column*, *ribs* and *sternum*. Together the bones forming these structures constitute the central bony core of the body, the axis. The appendicular skeleton consists of the shoulder and pelvic girdles and the limb bones.

Skull (Figs 16.10 and 16.11)

The skull rests on the upper end of the vertebral column and its bony structure is divided into two parts: the cranium and the face.

Sinuses

Sinuses containing air are present in the sphenoid, ethmoid, maxillary and frontal bones. They all communicate with the nasal cavity and are lined with ciliated mucous membrane. They give resonance to the voice and reduce the weight of the skull, making it easier to carry.

Cranium

The cranium is formed by a number of flat and irregular bones that protect the brain. It has a *base* upon which the brain rests and a *vault* that surrounds and covers it. The periosteum lining the inner surface of the skull bones forms the outer layer of dura mater (p. 152). In the mature skull the joints (*sutures*) between the bones are immovable. The bones have numerous perforations (e.g. foramina, fissures) through which nerves, blood and lymph vessels pass. The bones of the cranium are:

- 1 frontal bone
- 2 parietal bones
- 2 temporal bones
- 1 occipital bone
- 1 sphenoid bone
- 1 ethmoid bone.

Frontal bone

This is the bone of the forehead. It forms part of the *orbital cavities* (eye sockets) and the prominent ridges above the eyes, the *supraorbital margins*. Just above the supraorbital margins, within the bone, are two air-filled cavities or *sinuses* lined with ciliated mucous membrane, which open into the nasal cavity.

The *coronal suture* joins the frontal and parietal bones and other sutures are formed with the sphenoid, zygomatic, lacrimal, nasal and ethmoid bones. The frontal bone originates in two parts joined in the midline by the *frontal suture* (see Fig. 16.18).

Parietal bones

These bones form the sides and roof of the skull. They articulate with each other at the *sagittal suture*, with the frontal bone at the coronal suture, with the occipital bone

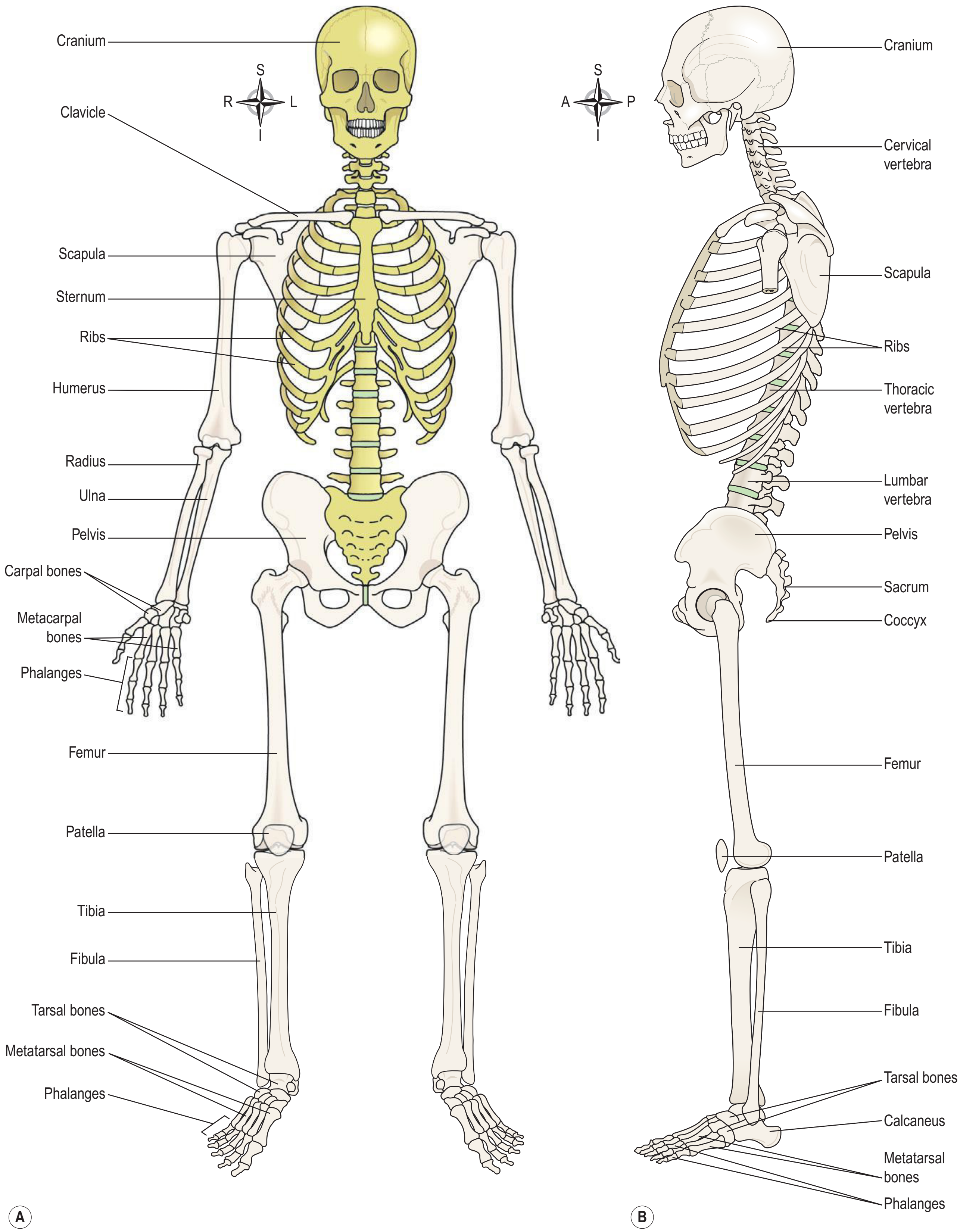

Figure 16.9 The skeleton. Axial skeleton in gold, appendicular skeleton in brown. **A.** Anterior view. **B.** Lateral view.

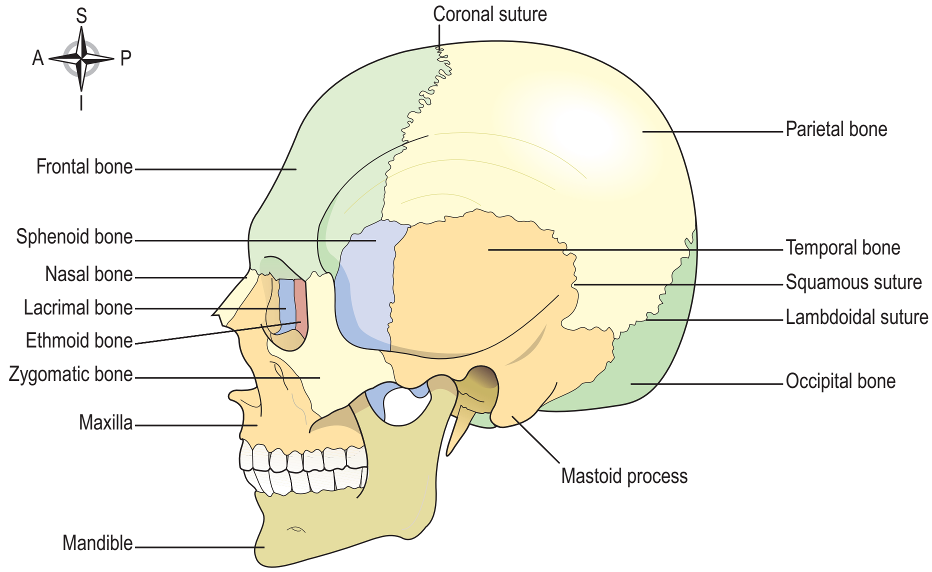

Figure 16.10 The bones of the skull and their sutures (joints).

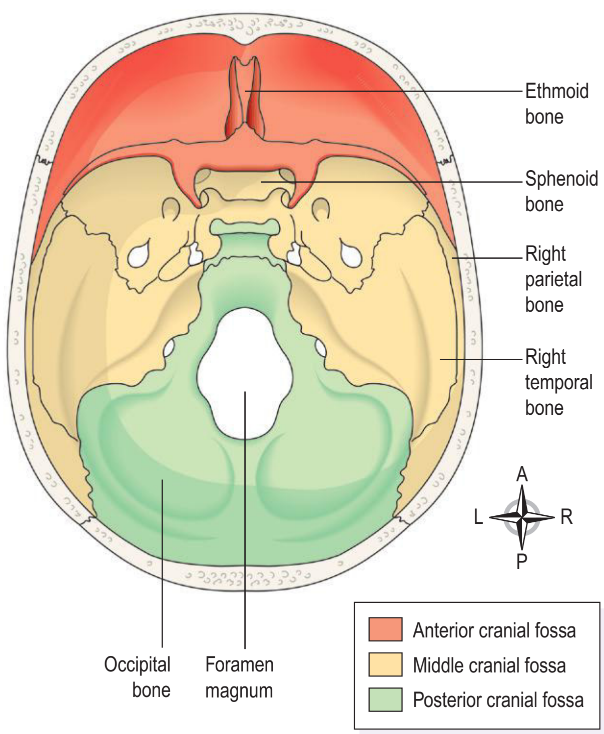

Figure 16.11 The bones forming the base of the skull and the cranial fossae. Viewed from above.

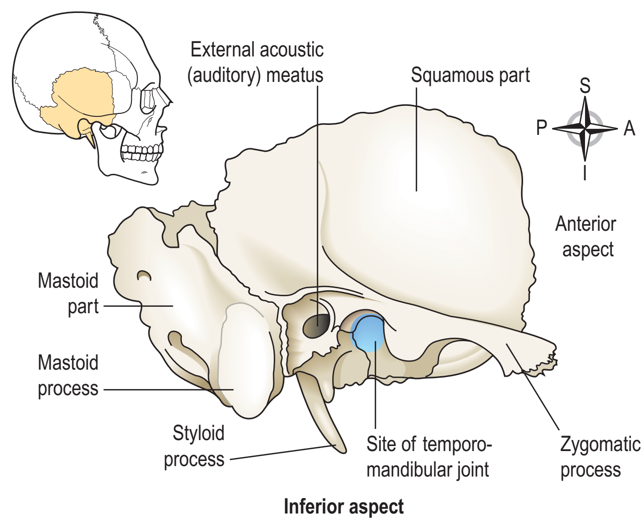

Figure 16.12 The right temporal bone. Lateral view.

at the *lambdoidal suture* and with the temporal bones at the *squamous sutures*. The inner surface is concave and is grooved to accommodate the brain and blood vessels.

Temporal bones (Fig. 16.12)

These bones lie one on each side of the head and form sutures with the parietal, occipital, sphenoid and zygomatic bones. The *squamous part* is the thin fan-shaped area that articulates with the parietal bone. The *zygomatic process* articulates with the zygomatic bone to form the zygomatic arch (cheekbone).

The *mastoid part* contains the mastoid process, a thickened region easily felt behind the ear. It contains a large number of very small air sinuses that communicate with the middle ear and are lined with squamous epithelium.

The *petrous portion* forms part of the base of the skull and contains the organs of hearing (the spiral organ) and balance.

The temporal bone articulates with the mandible at the *temporomandibular joint*, the only movable joint of the skull. Immediately behind this articulating surface is

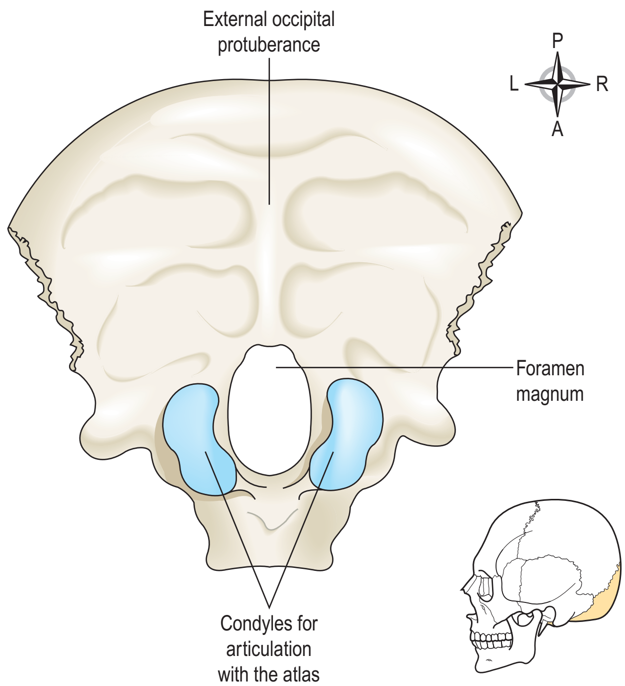

Figure 16.13 The occipital bone. Viewed from below.

the *external acoustic meatus* (auditory canal), which passes inwards towards the petrous portion of the bone.

The styloid process projects from the lower process of the temporal bone, and supports the hyoid bone and muscles associated with the tongue and pharynx.

Occipital bone (Fig. 16.13)

This bone forms the back of the head and part of the base of the skull. It forms sutures with the parietal, temporal and sphenoid bones. Its inner surface is deeply concave and the concavity is occupied by the occipital lobes of the cerebrum and by the cerebellum. The occiput has two articular condyles that form condyloid joints (p. 414) with the first bone of the vertebral column, the *atlas*. This joint permits nodding movements of the head. Between the condyles is the *foramen magnum* (meaning 'large hole') through which the spinal cord passes into the cranial cavity.

Sphenoid bone (Fig. 16.14)

This bone occupies the middle portion of the base of the skull and it articulates with the occipital, temporal, parietal and frontal bones (Fig. 16.11). It links the cranial and facial bones, and cross-braces the skull. On the superior surface in the middle of the bone is a little saddle-shaped depression, the *hypophyseal fossa* (*sella turcica*) in which the *pituitary gland* rests. The body of the bone contains some fairly large air sinuses lined with ciliated mucous membrane with openings into the nasal cavity. The optic nerves pass through the *optic foramina* on their way to the brain.

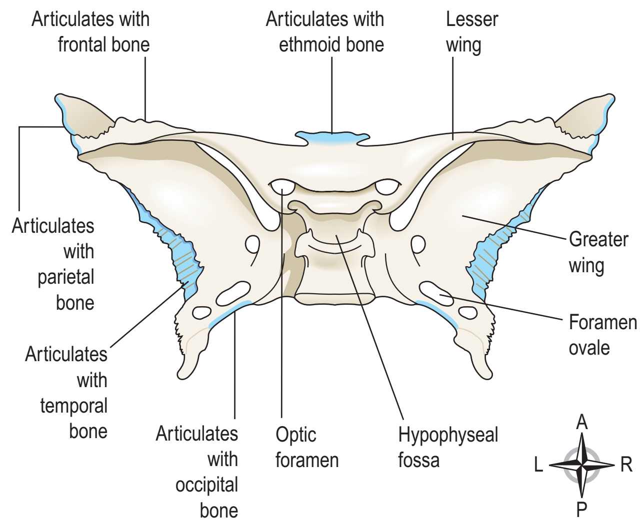

Figure 16.14 The sphenoid bone. Viewed from above.

Ethmoid bone (Fig. 16.15)

The ethmoid bone occupies the anterior part of the base of the skull and helps to form the orbital cavity, the nasal septum and the lateral walls of the nasal cavity. On each side are two projections into the nasal cavity, the *superior* and *middle conchae* or *turbinated processes*. It is a very delicate bone containing many air sinuses lined with ciliated epithelium and with openings into the nasal cavity. The horizontal flattened part, the *cribriform plate*, forms the roof of the nasal cavity and has numerous small foramina through which nerve fibres of the *olfactory nerve* (sense of smell) pass upwards from the nasal cavity to the brain.

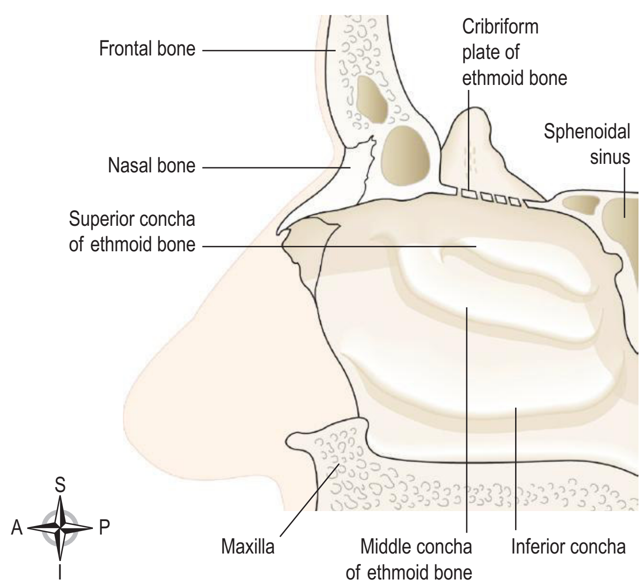

Figure 16.15 Lateral view of the right nasal cavity. Viewed from the left.

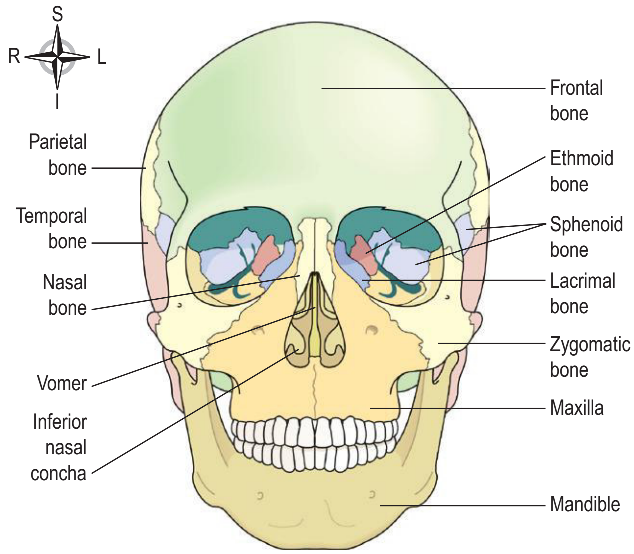

Figure 16.16 The bones of the face. Anterior view.

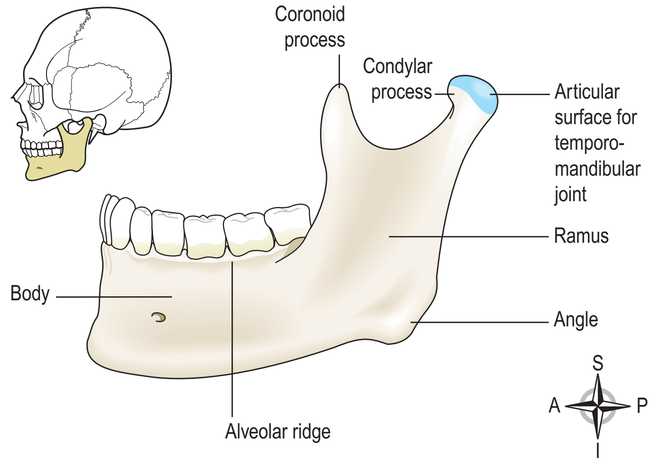

Figure 16.17 The left mandible. Lateral view.

There is also a very fine *perpendicular plate* of bone that forms the upper part of the *nasal septum*.

Face

The skeleton of the face is formed by 13 bones in addition to the frontal bone already described. Figure 16.16 shows the relationships between the bones:

- 2 zygomatic (cheek) bones
- 1 maxilla
- 2 nasal bones
- 2 lacrimal bones
- 1 vomer
- 2 palatine bones
- 2 inferior conchae
- 1 mandible.

Zygomatic (cheek) bones

The zygomatic bone originates as two bones that fuse before birth. They form the prominences of the cheeks and part of the floor and lateral walls of the orbital cavities.

Maxilla (upper jaw bone)

This originates as two bones that fuse before birth. The maxilla forms the upper jaw, the anterior part of the roof of the mouth, the lateral walls of the nasal cavity and part of the floor of the orbital cavities. The *alveolar ridge*, or *process*, projects downwards and carries the upper teeth. On each side is a large air sinus, the *maxillary sinus*, lined with ciliated mucous membrane and with openings into the nasal cavity.

Nasal bones

These are two small flat bones that form the greater part of the lateral and superior surfaces of the bridge of the nose.

Lacrimal bones

These two small bones are posterior and lateral to the nasal bones and form part of the medial walls of the orbital cavities. Each is pierced by a foramen for the passage of the *nasolacrimal duct* that carries the tears from the medial canthus of the eye to the nasal cavity.

Vomer

The vomer is a thin flat bone that extends upwards from the middle of the hard palate to form most of the inferior part of the nasal septum. Superiorly it articulates with the perpendicular plate of the ethmoid bone.

Palatine bones

These are two small L-shaped bones. The horizontal parts unite to form the posterior part of the hard palate and the perpendicular parts project upwards to form part of the lateral walls of the nasal cavity. At their upper extremities they form part of the orbital cavities.

Inferior conchae

Each concha is a scroll-shaped bone, which forms part of the lateral wall of the nasal cavity and projects into it below the middle concha. The superior and middle conchae are parts of the ethmoid bone. The conchae collectively increase the surface area in the nasal cavity, allowing inspired air to be warmed and humidified more effectively.

Mandible (lower jaw bone, Fig. 16.17)

This is the lower jaw, the only movable bone of the skull. It originates as two parts that unite at the midline. Each half consists of two main parts: a *curved body* with the *alveolar ridge* containing the lower teeth and a *ramus*, which projects upwards almost at right angles to the posterior end of the body.

At the upper end the ramus divides into the *condylar process* which articulates with the temporal bone to form

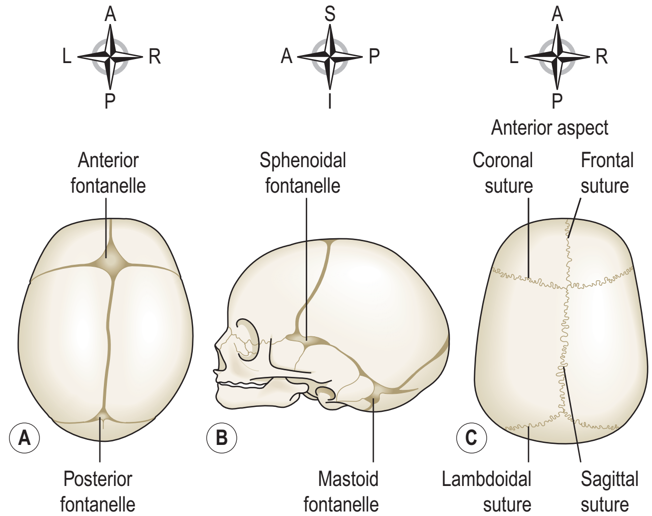

Figure 16.18 The skull showing the fontanelles and sutures. **A.** Fontanelles viewed from above. **B.** Fontanelles viewed from the side. **C.** Main sutures viewed from above when ossification is complete.

the *temporomandibular* joint (see Fig. 16.12) and the *coronoid process*, which gives attachment to muscles and ligaments that close the jaw. The point where the ramus joins the body is the *angle* of the jaw.

Hyoid bone

This is an isolated horseshoe-shaped bone lying in the soft tissues of the neck just above the *larynx* and below the *mandible* (see Fig. 10.4). It does not articulate with any other bone, but is attached to the styloid process of the temporal bone by ligaments. It supports the larynx and gives attachment to the base of the tongue.

Fontanelles of the skull (Fig. 16.18)

At birth, ossification of the cranial sutures is incomplete. The skull bones do not fuse earlier to allow for moulding of the baby's head during childbirth. Where three or more bones meet there are distinct membranous areas, or *fontanelles*. The two largest are the *anterior fontanelle*, not fully ossified until the child is between 12 and 18 months old, and the *posterior fontanelle*, usually ossified 2–3 months after birth.

Functions of the skull

The various parts of the skull have specific and different functions:

- the *cranium* protects the brain
- the *bony eye sockets* protect the eyes and give attachment to the muscles that move them
- the *temporal bone* protects the delicate structures of the inner ear
- the sinuses in some face and skull bones give resonance to the voice
- the bones of the face form the walls of the posterior part of the nasal cavities and form the upper part of the air passages
- the *maxilla* and the *mandible* provide alveolar ridges in which the teeth are embedded
- the mandible, controlled by muscles of the lower face, allows chewing.

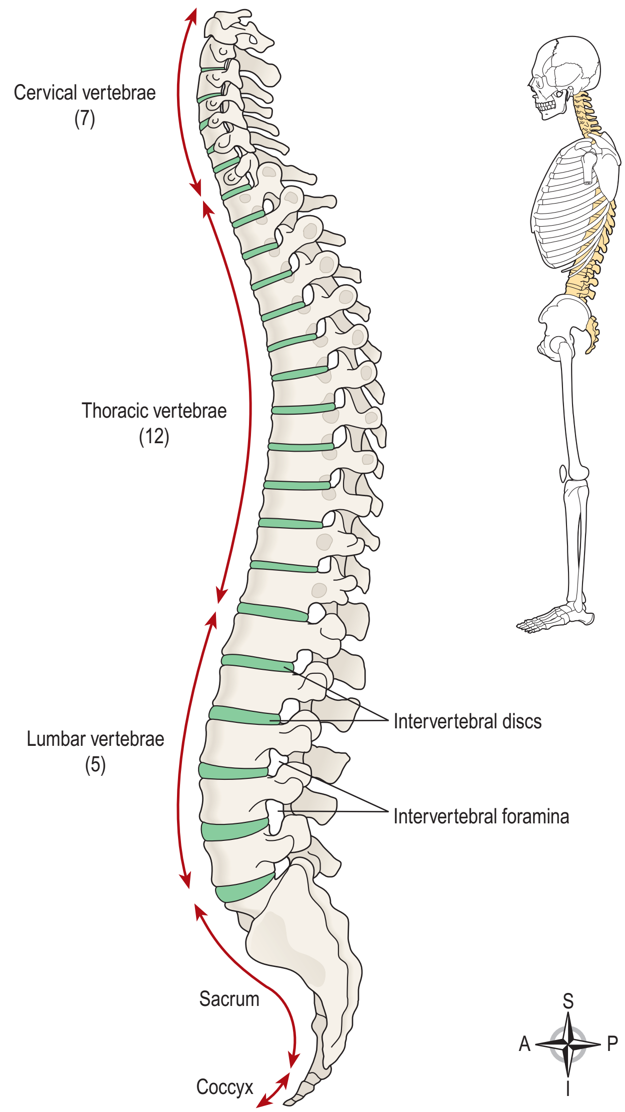

Figure 16.19 The vertebral column. Lateral view.

Vertebral column (Fig. 16.19) 16.3

There are 26 bones in the vertebral column. Twenty-four separate vertebrae extend downwards from the occipital bone of the skull; then there is the *sacrum*, formed from five fused vertebrae, and lastly the *coccyx*, or tail, which is formed from between three and five small fused vertebrae. The vertebral column is divided into different regions. The first seven vertebrae, in the neck, form the cervical spine; the next 12 vertebrae are the thoracic spine,

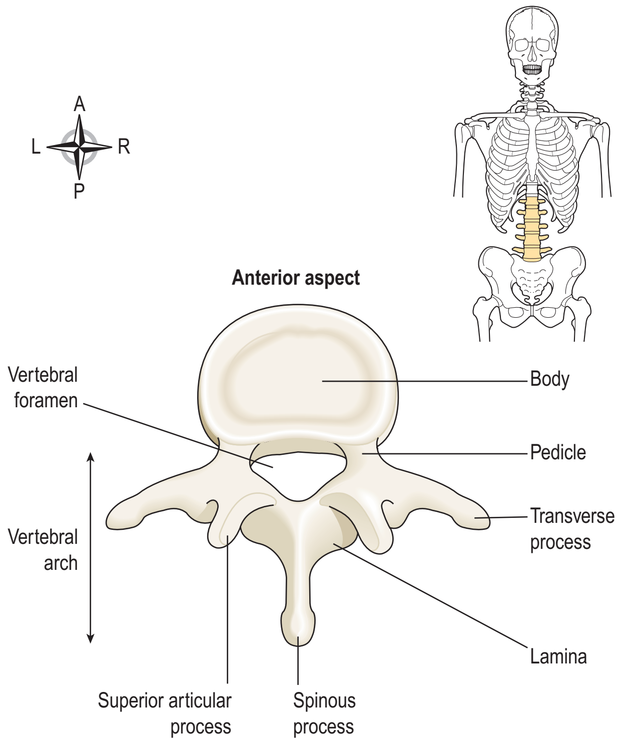

Figure 16.20 A lumbar vertebra showing the features of a typical vertebra. Viewed from above.

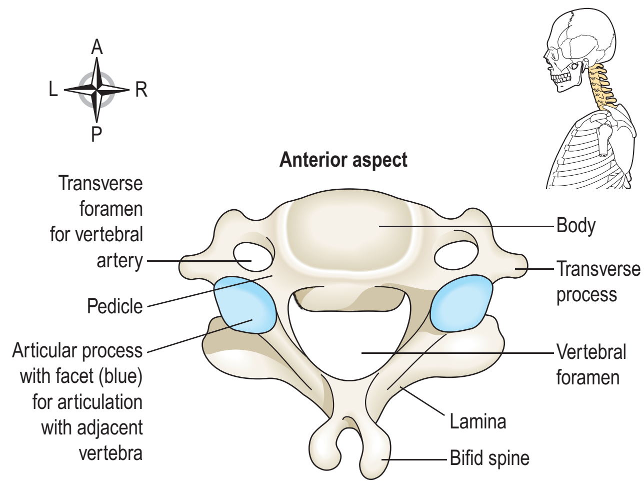

Figure 16.21 A cervical vertebra, showing typical features. Viewed from above.

and the next five the lumbar spine, the lowest vertebra of which articulates with the sacrum. Each vertebra is identified by the first letter of its region in the spine, followed by a number indicating its position. For example, the topmost vertebra is C1, and the third lumbar vertebra is L3.

The movable vertebrae have many characteristics in common, but some groups have distinguishing features.

Characteristics of a typical vertebra (Fig. 16.20)

The body. This is the broad, flattened, largest part of the vertebra. When the vertebrae are stacked together in the vertebral column, it is the flattened surfaces of the body of each vertebra that articulate with the corresponding surfaces of adjacent vertebrae. However, there is no direct bone-to-bone contact since between each pair of bones is a tough pad of fibrocartilage called the *intervertebral disc*. The bodies of the vertebrae lie to the front of the vertebral column, increasing greatly in size towards the base of the spine, as the lower spine has to support much more weight than the upper regions.

The vertebral (neural) arch. This encloses a large *vertebral foramen*. It lies behind the body, and forms the posterior and lateral walls of the vertebral foramen. The lateral walls are formed from plates of bone called *pedicles*, and the posterior walls are formed from *laminae*. Projecting from the regions where the pedicle meets the lamina is a lateral prominence, the *transverse process*, and where the two laminae meet at the back is a process called the *spinous process*. These bony prominences can be felt through the skin along the length of the spine. The vertebral arch has four articular surfaces: two articulate with the vertebra above and two with the one below. The vertebral foramina form the vertebral (neural) canal that contains the spinal cord.

Region-specific vertebral characteristics

Cervical vertebrae (Fig. 16.21)

These are the smallest vertebrae. The transverse processes have a foramen through which a vertebral artery passes upwards to the brain. The first two cervical vertebrae, the *atlas* and the *axis*, are atypical.

The first cervical vertebra (C1), the *atlas*, is the bone on which the skull rests. Below the atlas is the *axis*, the second cervical vertebra (C2).

The atlas (Fig. 16.22A) is essentially a ring of bone, with no distinct body or spinous process, although it has two short transverse processes. It possesses two flattened facets that articulate with the occipital bone; these are condyloid joints (p. 414) and they permit nodding of the head.

The axis (Fig. 16.22B) sits below the atlas, and has a small body with a small superior projection called the *odontoid process* (also called the dens, meaning tooth). This occupies part of the posterior foramen of the atlas above, and is held securely within it by the transverse ligament (Fig. 16.22C). The head pivots (i.e. turns from side to side) on this joint.

The 7th cervical vertebra, C7, is also known as the *vertebra prominens*. It possesses a long spinous prominence terminating in a swollen tubercle, which is easily felt at the base of the neck.

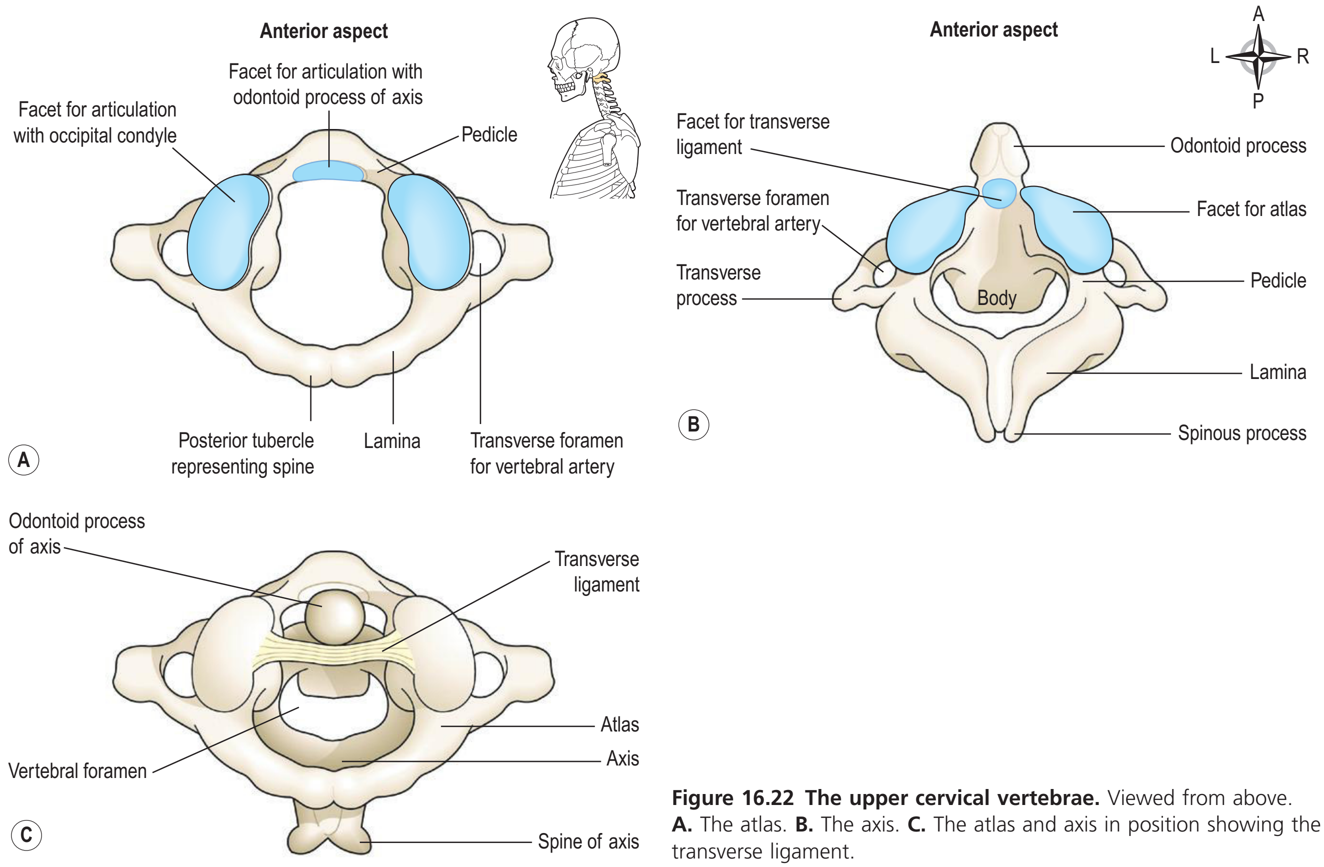

Figure 16.22 The upper cervical vertebrae. Viewed from above. **A.** The atlas. **B.** The axis. **C.** The atlas and axis in position showing the transverse ligament.

Thoracic vertebrae (Fig. 16.23)

The 12 thoracic vertebrae are larger than the cervical vertebrae because this section of the vertebral column has to support more body weight. The bodies and transverse processes have facets for articulation with the ribs.

Lumbar vertebrae (Fig. 16.20)

These are the largest of the vertebrae because they have to support the weight of the upper body. They have substantial spinous processes for attachment of the muscles of the lower back.

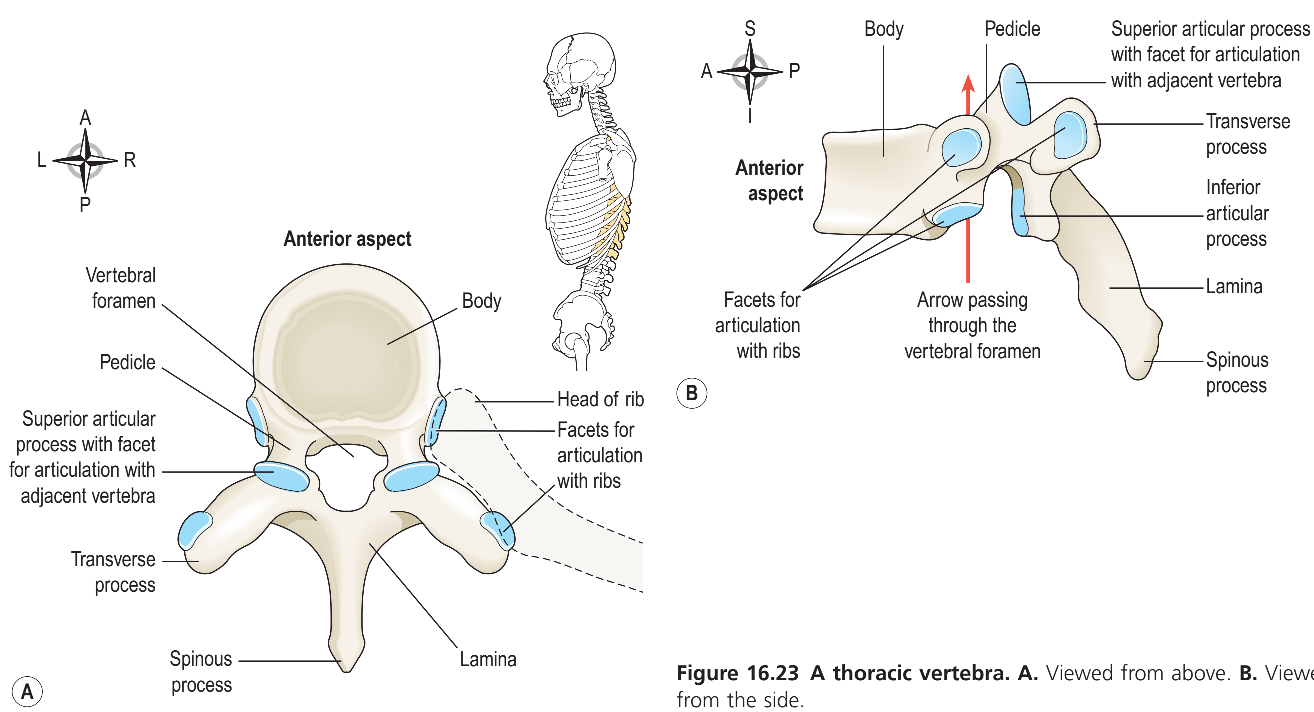

Figure 16.23 A thoracic vertebra. A. Viewed from above. **B.** Viewed from the side.

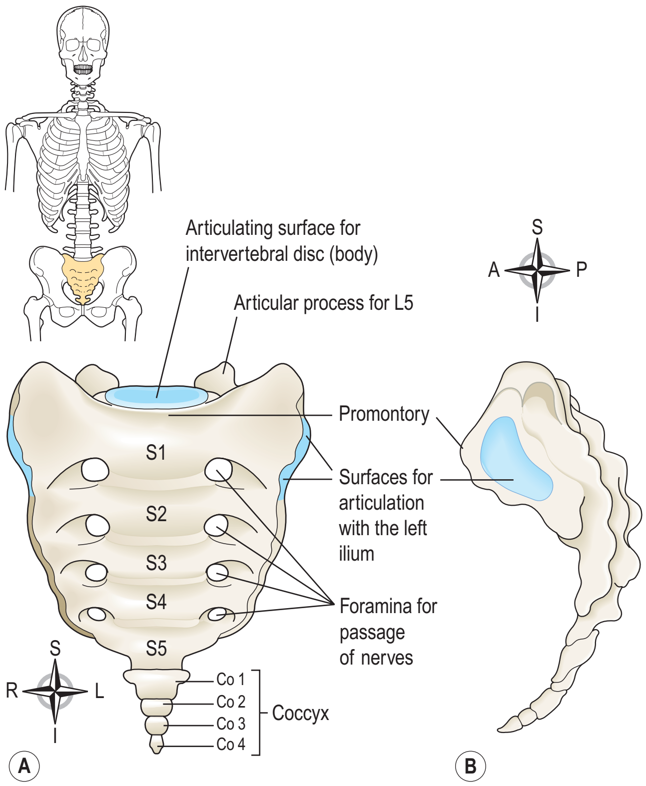

Figure 16.24 The sacrum and coccyx. A. Anterior view. **B.** Lateral view.

Sacrum (Fig. 16.24)

This consists of five rudimentary vertebrae fused to form a triangular or wedge-shaped bone with a concave anterior surface. The upper part, or base, articulates with the 5th lumbar vertebra. On each side it articulates with the ilium to form a *sacroiliac joint*, and at its inferior tip it articulates with the coccyx. The anterior edge of the base, the *promontory*, protrudes into the pelvic cavity. The vertebral foramina are present, and on each side of the bone there is a series of foramina for the passage of nerves.

Coccyx (Fig. 16.24)

This consists of the four terminal vertebrae fused to form a very small triangular bone, the broad base of which articulates with the tip of the sacrum.

Features of the vertebral column

Intervertebral discs

The bodies of adjacent vertebrae are separated by *intervertebral discs*, consisting of an outer rim of fibrocartilage (*annulus fibrosus*) and a central core of soft gelatinous material (*nucleus pulposus*) (Fig. 16.25). They are thinnest in the cervical region and become progressively thicker towards the lumbar region, as spinal loading increases. The posterior longitudinal ligament in the vertebral canal helps to keep them in place. They have a shock-absorbing function and the cartilaginous joints they form contribute to the flexibility of the vertebral column as a whole.

Intervertebral foramina

When two adjacent vertebrae are viewed from the side, a foramen formed by a gap between adjacent vertebral pedicles can be seen.

Throughout the length of the column there is an intervertebral foramen on each side between every pair of vertebrae, through which the spinal nerves, blood vessels and lymph vessels pass (Fig. 16.26).

Ligaments of the vertebral column (Fig. 16.25)

These ligaments hold the vertebrae together and keep the intervertebral discs in position.

The *transverse ligament* holds the odontoid process of the axis in the correct position in relation to the atlas (Fig. 16.22C).

The *anterior longitudinal ligament* extends the whole length of the column and lies in front of the vertebral bodies.

The *posterior longitudinal ligament* lies inside the vertebral canal and extends the whole length of the vertebral

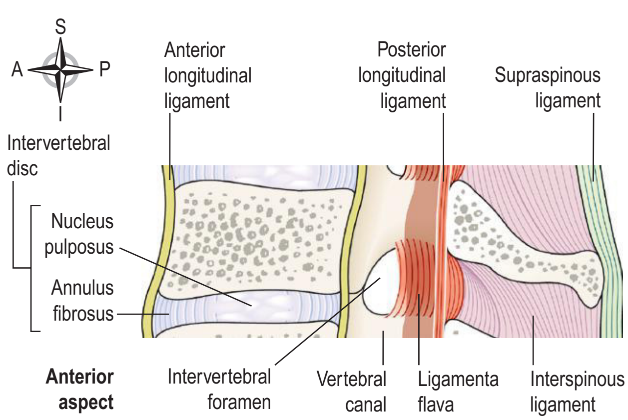

Figure 16.25 Section of the vertebral column showing the ligaments, intervertebral discs and intervertebral foramina.

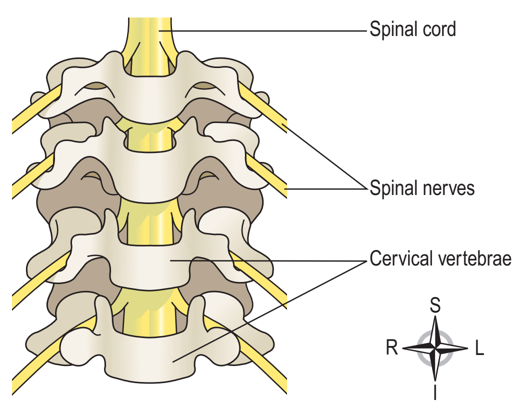

Figure 16.26 Lower cervical vertebrae separated to show the spinal cord and spinal nerves emerging through the intervertebral foramina. Anterior view.

column in close contact with the posterior surface of the bodies of the bones.

The *ligamenta flava* connect the laminae of adjacent vertebrae.

The *ligamentum nuchae* and the *supraspinous ligament* connect the spinous processes, extending from the occiput to the sacrum.

Curves of the vertebral column (Fig. 16.27)

When viewed from the side, the vertebral column presents four curves: two *primary* and two *secondary*.

The fetus in the uterus lies curled up so that the head and the knees are more or less touching. This position shows the *primary curvature*. The secondary *cervical curve* develops when the child can hold up their head (after about 3 months) and the secondary *lumbar curve* develops when able to stand (after 12–15 months). The thoracic and sacral primary curves are retained.

Movement of the vertebral column

Movement between the individual bones of the vertebral column is very limited. However, the movements of the column as a whole are quite extensive and include *flexion* (bending forward), *extension* (bending backward), *lateral flexion* (bending to the side) and *rotation*. There is more movement in the cervical and lumbar regions than elsewhere.

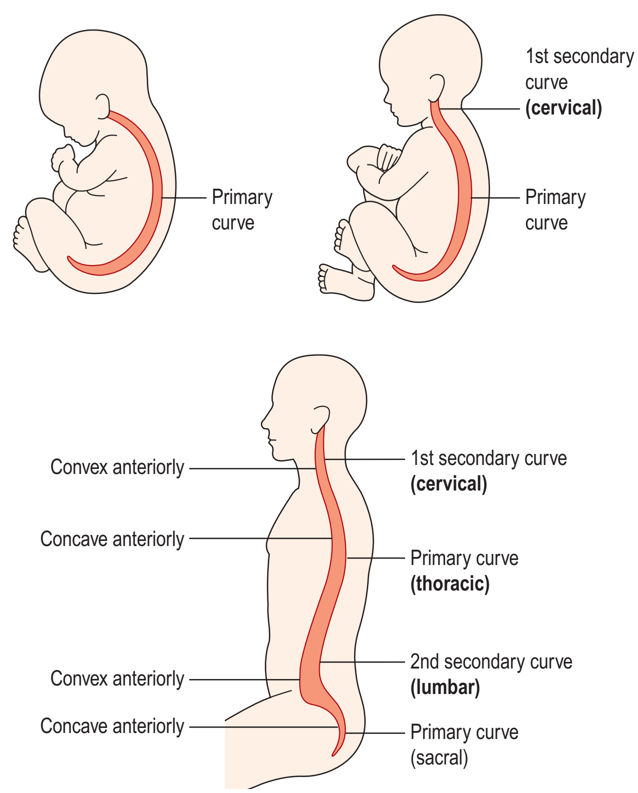

Figure 16.27 Development of the spinal curves.

Functions of the vertebral column

These include:

- collectively the vertebral foramina form the vertebral canal, which provides a strong bony protection for the delicate spinal cord lying within it
- the pedicles of adjacent vertebrae form intervertebral foramina, one on each side, providing access to the spinal cord for spinal nerves, blood vessels and lymph vessels
- the numerous individual bones with their intervertebral discs allow movement of the whole column
- support of the skull
- the intervertebral discs act as shock absorbers, protecting the brain
- formation of the axis of the trunk, giving attachment to the ribs, shoulder girdle and upper limbs, and the pelvic girdle and lower limbs.

Thoracic cage (Fig. 16.28)

The thorax (thoracic cage) is formed by the sternum anteriorly, twelve pairs of ribs forming the lateral bony cages, and the twelve thoracic vertebrae.

Sternum (breast bone, Fig. 16.29)

This flat bone can be felt just under the skin in the middle of the front of the chest.

The *manubrium* is the uppermost section and articulates with the clavicles at the *sternoclavicular joints* and with the first two pairs of ribs.

The *body* or *middle portion* gives attachment to the ribs.

The *xiphoid process* is the inferior tip of the bone. It gives attachment to the diaphragm, muscles of the anterior

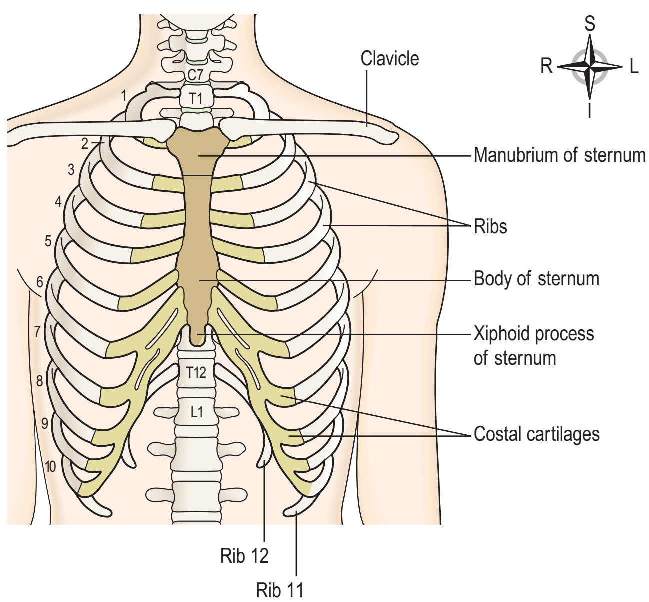

Figure 16.28 The thoracic cage. Anterior view.

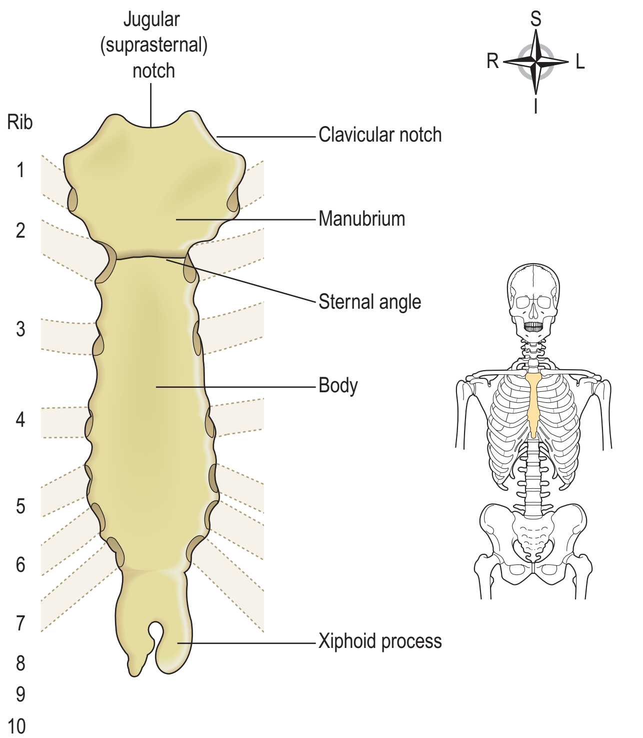

Figure 16.29 The sternum and its attachments. Anterior view.

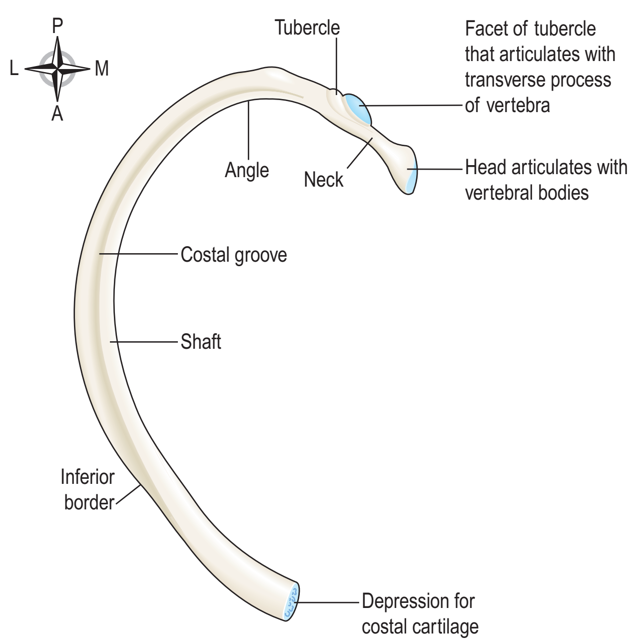

Figure 16.30 A typical rib. Viewed from below.

abdominal wall and the *linea alba* (literally 'white line'; Fig. 16.62).

Ribs

The 12 pairs of ribs form the lateral walls of the thoracic cage (Fig. 16.28). They are elongated curved bones (Fig. 16.30) that articulate posteriorly with the vertebral column. Anteriorly, the first seven pairs of ribs articulate directly with the sternum and are known as the *true ribs*. The next three pairs articulate only indirectly. In both cases, *costal cartilages* attach the ribs to the sternum. The lowest two pairs of ribs, referred to as *floating ribs*, do not join the sternum at all, their anterior tips being free.

Each rib forms up to three joints with the vertebral column. Two of these joints are formed between facets on the head of the rib and facets on the bodies of two vertebrae, the one above the rib and the one below. Ten of the ribs also form joints between the tubercle of the rib and the transverse process of (usually) the lower vertebra.

The inferior surface of the rib is deeply grooved, providing a channel along which intercostal nerves and blood vessels run. Between each rib and the one below are the intercostal muscles, which move the rib cage during breathing.

Because of the arrangement of the ribs, and the quantity of cartilage present in the ribcage, it is a flexible structure that can change its shape and size during breathing. The first rib is firmly fixed to the sternum and to the 1st thoracic vertebra, and does not move during inspiration. Because it is a fixed point, when the intercostal muscles contract, they pull the entire ribcage upwards towards the first rib. The mechanism of breathing is described on page 225.

Appendicular skeleton

Learning outcomes

After studying this section, you should be able to:

- identify the bones forming the appendicular skeleton
- state the characteristics of the bones forming the appendicular skeleton
- outline the differences in structure between the male and female pelves.

The appendicular skeleton consists of the:

- shoulder girdle with the upper limbs
- pelvic girdle with the lower limbs (Fig. 16.9).

Shoulder girdle and upper limb

The upper limb forms a joint with the trunk via the shoulder (pectoral) girdle.

Shoulder girdle

The shoulder girdle consists of two clavicles and two scapulae.

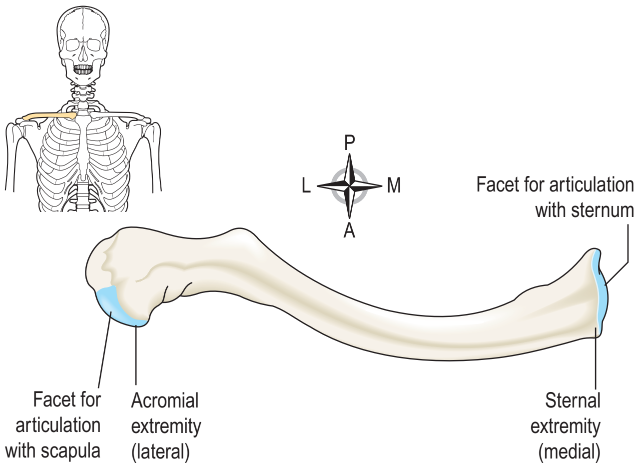

Figure 16.31 The right clavicle. Viewed from above.

Clavicle (collar bone, Fig. 16.31)

The clavicle is an S-shaped long bone. It articulates with the manubrium of the sternum at the *sternoclavicular joint* and forms the *acromioclavicular joint* with the *acromion process* of the scapula. The clavicle provides the only bony link between the upper limb and the axial skeleton.

Scapula (shoulder blade, Fig. 16.32)

The scapula is a flat triangular-shaped bone, lying on the posterior chest wall superficial to the ribs and separated from them by muscles.

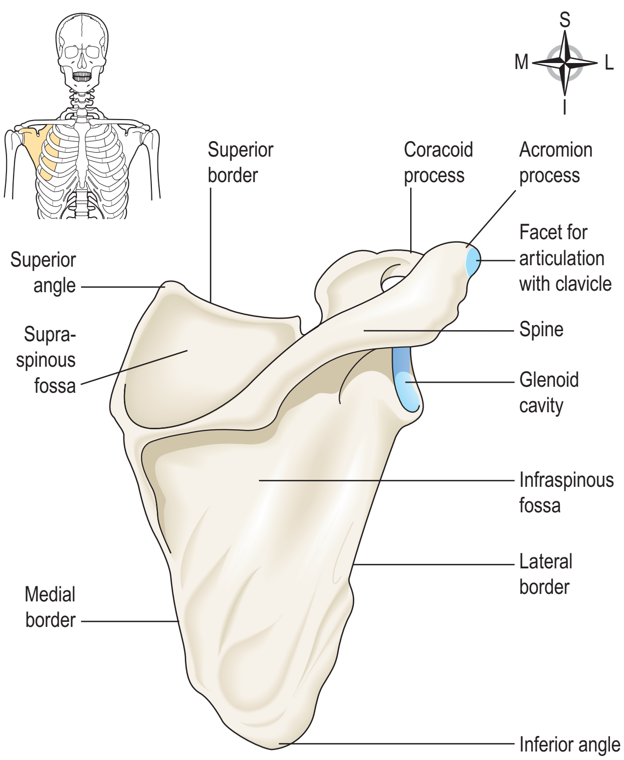

Figure 16.32 The right scapula. Posterior view.

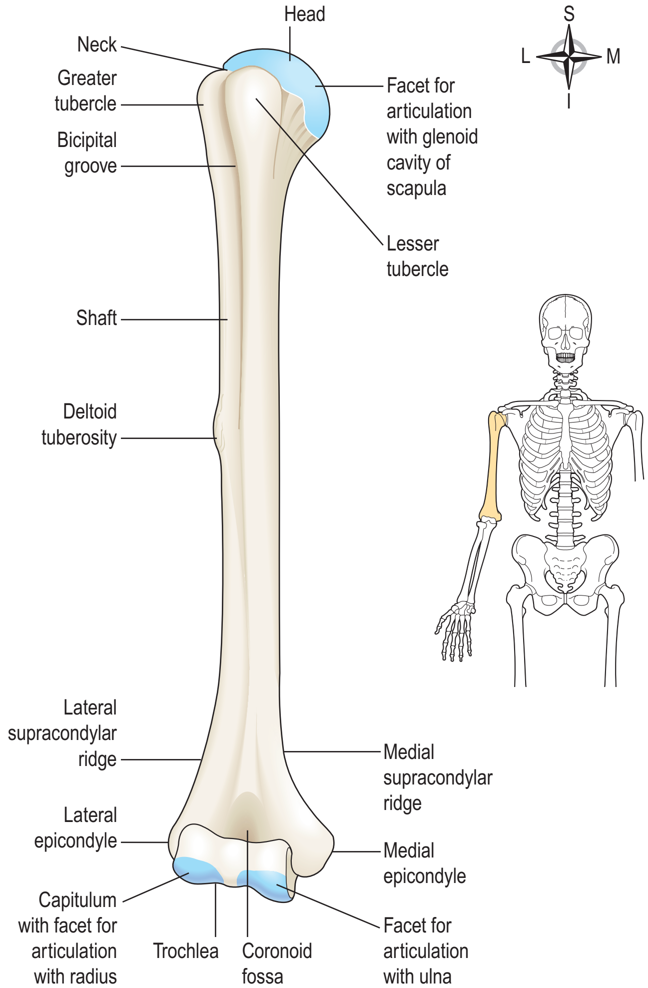

Figure 16.33 The right humerus. Anterior view.

At the lateral angle is a shallow articular surface, the *glenoid cavity*, which, with the *head of the humerus*, forms the *shoulder joint*.

On the posterior surface runs a rough ridge called the *spine*, which extends beyond the lateral border of the scapula and overhangs the glenoid cavity. The prominent overhang, which can be felt through the skin as the highest point of the shoulder, is called the *acromion process* and forms a joint with the clavicle, the *acromioclavicular joint*, a slightly movable synovial joint that contributes to the mobility of the shoulder girdle. The *coracoid process*, a projection from the upper border of the bone, gives attachment to muscles that move the shoulder joint.

The upper limb

Humerus (Fig. 16.33)

This is the bone of the upper arm. The head sits within the glenoid cavity of the scapula, forming the shoulder joint. Distal to the head are two roughened projections of bone, the *greater* and *lesser tubercles*, and between them there is a deep groove, the *bicipital groove* or *intertubercular*

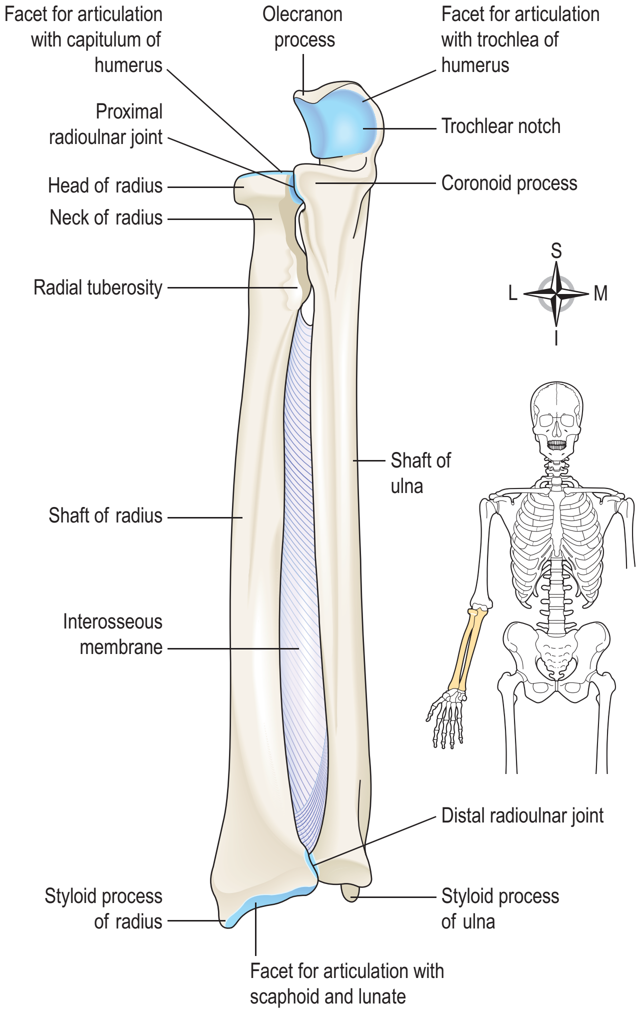

Figure 16.34 The right radius and ulna with the interosseous membrane. Anterior view.

sulcus, occupied by one of the tendons of the biceps muscle.

The distal end of the bone presents two surfaces that articulate with the radius and ulna to form the elbow joint.

Ulna and radius (Fig. 16.34)

These are the two bones of the forearm. The ulna is longer than and medial to the radius and when the arm is in the anatomical position, i.e. with the palm of the hand facing forward, the two bones are parallel. They articulate with the humerus at the *elbow joint*, the carpal bones at the *wrist joint* and with each other at the *proximal* and *distal radioulnar* joints. In addition, an interosseous membrane, a fibrous joint, connects the bones along their shafts, stabilising their association and maintaining their relative positions despite forces applied from the elbow or wrist.

Carpal (wrist) bones (Fig. 16.35)

There are eight carpal bones arranged in two rows of four. From outside inwards they are:

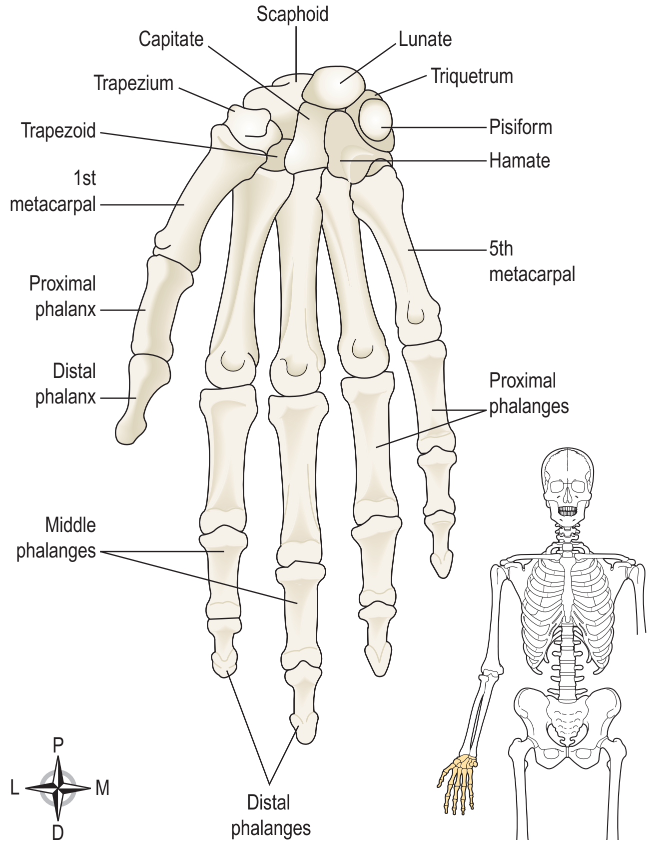

Figure 16.35 The bones of the right hand, wrist and fingers. Anterior view.

- *proximal row*: scaphoid, lunate, triquetrum, pisiform
- *distal row*: trapezium, trapezoid, capitate, hamate.

These bones are closely fitted together and held in position by ligaments that allow a limited amount of movement between them. The bones of the proximal row are associated with the wrist joint and those of the distal row form joints with the metacarpal bones. Tendons of muscles lying in the forearm cross the wrist and are held close to the bones by strong fibrous bands, called retinacula (see Fig. 16.50).

Metacarpal bones (bones of the hand)

These five bones form the palm of the hand. They are numbered from the thumb side inwards. The proximal ends articulate with the carpal bones and the distal ends with the phalanges.

Phalanges (finger bones)

There are 14 phalanges, three in each finger and two in the thumb. They articulate with the metacarpal bones and with each other, by hinge joints.

Pelvic girdle and lower limb

The lower limb forms a joint with the trunk at the pelvic girdle.

The pelvic girdle

The pelvic girdle is formed from two innominate (hip) bones. The *pelvis* is the term given to the basin-shaped structure formed by the pelvic girdle and its associated sacrum.

Innominate (hip) bones (Fig. 16.36)

Each hip bone consists of three fused bones: the *ilium*, *ischium* and *pubis*. On its lateral surface is a deep depression, the *acetabulum*, which forms the hip joint with the almost-spherical head of femur.

The *ilium* is the upper flattened part of the bone and it presents the *iliac crest*, the anterior curve of which is called the *anterior superior iliac spine*. The ilium forms a synovial joint with the sacrum, the *sacroiliac joint*, a strong joint capable of absorbing the stresses of weight bearing and which tends to become fibrosed in later life.

The *pubis* is the anterior part of the bone and it articulates with the pubis of the other hip bone at a cartilaginous joint, the *symphysis pubis*.

The *ischium* is the inferior and posterior part. The rough inferior projections of the ischia, the *ischial tuberosities*, bear the weight of the body when seated.

The union of the three parts takes place in the *acetabulum*.

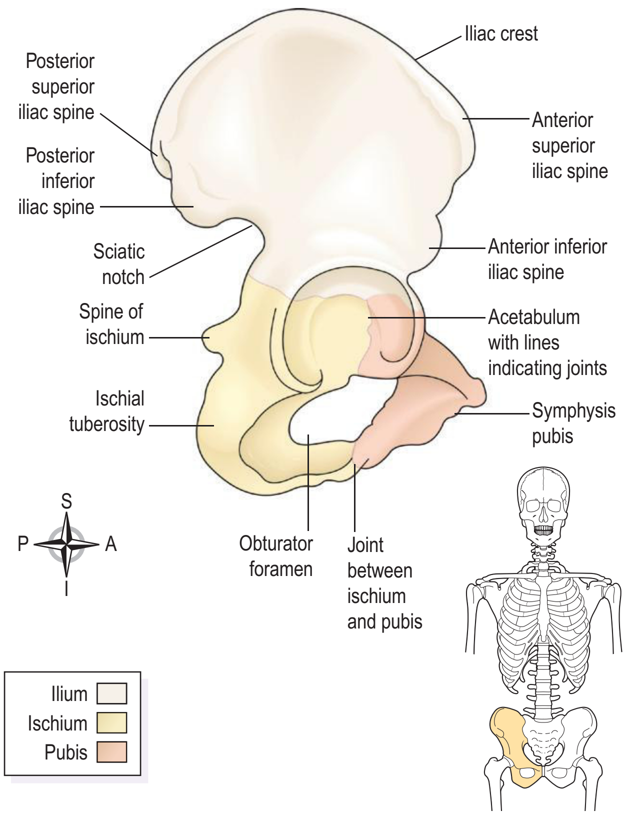

Figure 16.36 The right hip bone. Lateral view.

The pelvis (Fig. 16.37)

The pelvis is formed by the hip bones, the sacrum and the coccyx. It is divided into upper and lower parts by the *brim of the pelvis*, consisting of the promontory of the sacrum and the iliopectineal lines of the innominate bones. The *greater* or *false pelvis* is above the brim and the lesser or *true pelvis* is below.

Differences between male and female pelves (Fig. 16.38)**.** The shape of the female pelvis allows for the passage of the baby during childbirth. In comparison with the male pelvis, the female pelvis has lighter bones, is more shallow and rounded and is generally roomier.

The lower limb

Femur (thigh bone, Fig. 16.39)

The femur is the longest and heaviest bone of the body. The head is almost spherical and fits into the *acetabulum*

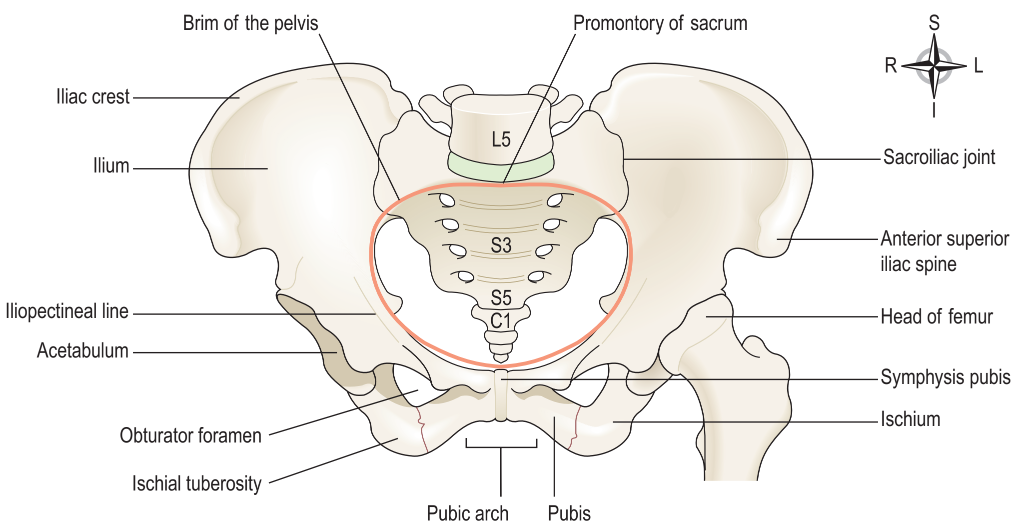

Figure 16.37 The bones of the pelvis and the upper part of the left femur.

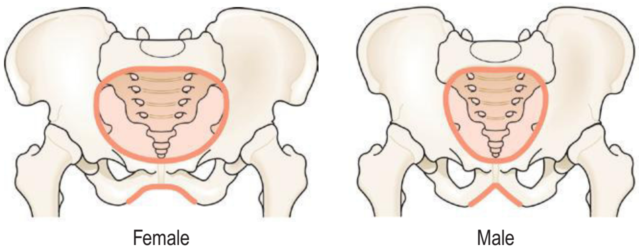

Figure 16.38 The difference in shape of the male and female pelves.

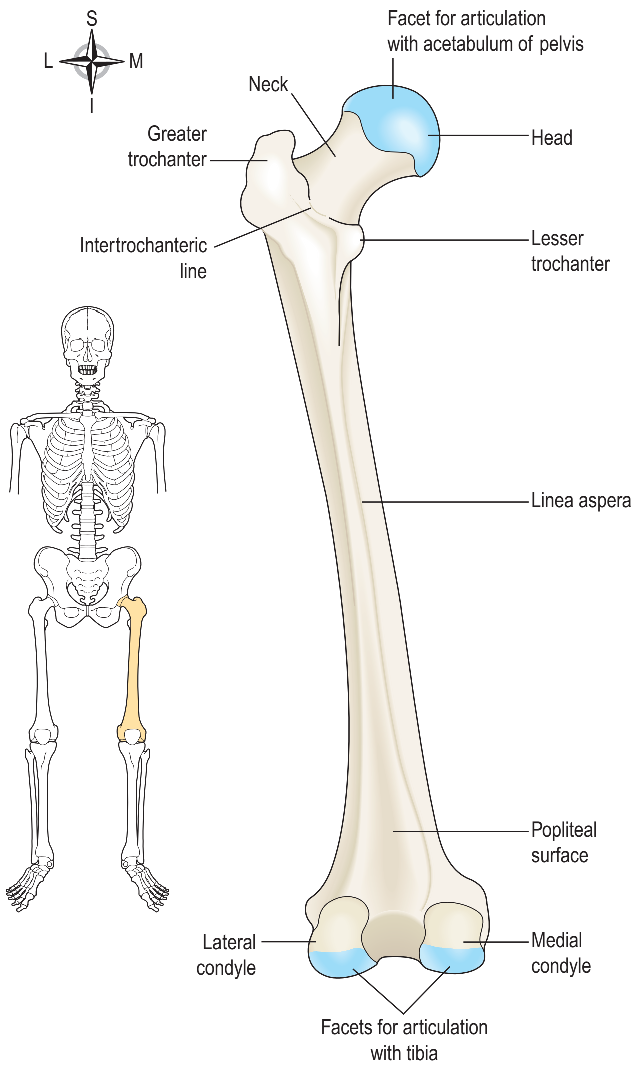

Figure 16.39 The left femur. Posterior view.

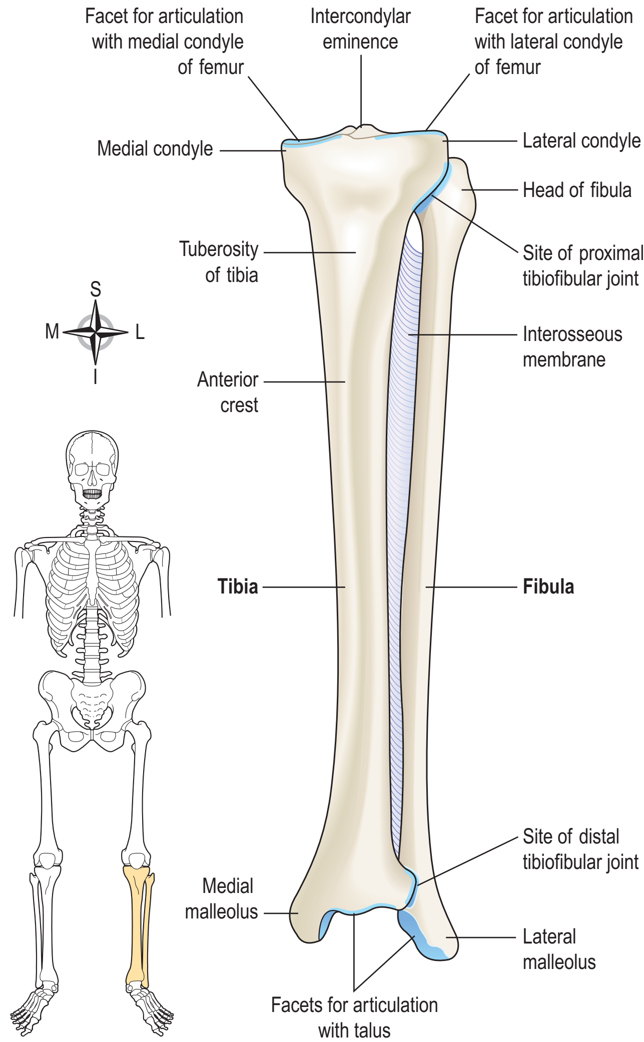

Figure 16.40 The left tibia and fibula with the interosseous membrane. Anterior view.

of the hip bone to form the *hip joint*. The neck extends outwards and slightly downwards from the head to the shaft and most of it is within the capsule of the hip joint.

The posterior surface of the lower third forms a flat triangular area called the *popliteal surface*. The distal extremity has two articular *condyles*, which, with the tibia and patella, form the knee joint. The femur transmits the weight of the body through the bones below the knee to the foot.

Tibia (shin bone, Fig. 16.40)

The tibia is the medial of the two bones of the lower leg. The proximal extremity is broad and flat and presents two *condyles* for articulation with the femur at the knee joint. The head of the fibula articulates with the inferior aspect of the lateral condyle, forming the proximal tibiofibular joint.

The distal extremity of the tibia forms the *ankle joint* with the talus and the fibula. The *medial malleolus* is a downward projection of bone medial to the ankle joint.

Fibula (Fig. 16.40)

The fibula is the long slender lateral bone in the leg. The head or upper extremity articulates with the lateral

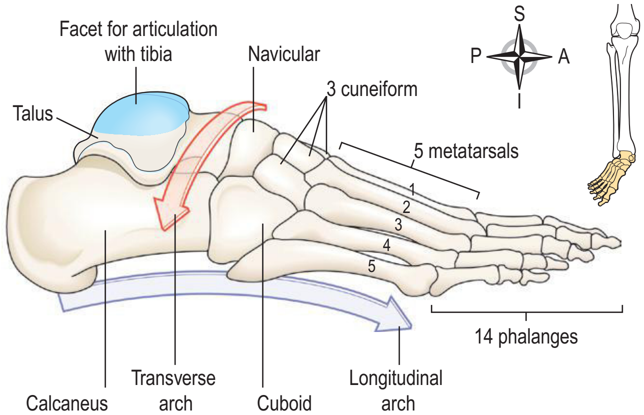

Figure 16.41 The bones of the left foot. Lateral view.

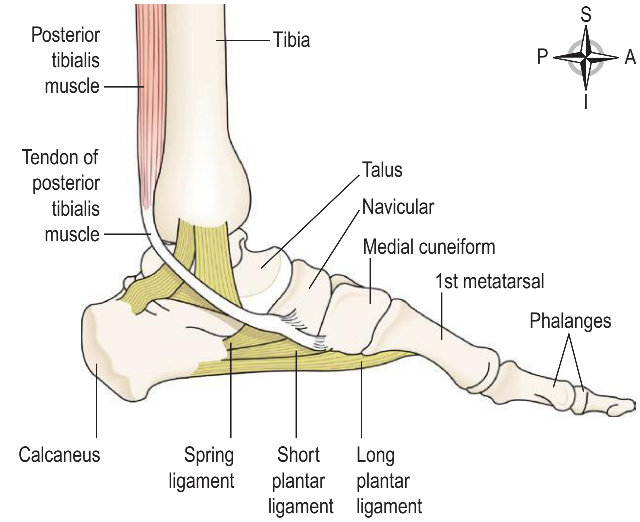

Figure 16.42 The tendons and ligaments supporting the arches of the left foot. Medial view.

condyle of the tibia, forming the proximal tibiofibular joint, and the lower extremity articulates with the tibia, and projects beyond it to form the *lateral malleolus*. This helps to stabilise the ankle joint.

Patella (knee cap)

This is a roughly triangular-shaped sesamoid bone associated with the knee joint. Its posterior surface articulates with the patellar surface of the femur in the knee joint and its anterior surface is in the *patellar tendon*, i.e. the tendon of the quadriceps femoris muscle.

Tarsal (ankle) bones (Fig. 16.41)

The seven tarsal bones forming the posterior part of the foot (ankle) are the talus, calcaneus, navicular, cuboid and three cuneiform bones. The talus articulates with the tibia and fibula at the ankle joint. The calcaneus forms the heel of the foot. The other bones articulate with each other and with the metatarsal bones.

Metatarsals (bones of the foot, Fig. 16.41)

These are five bones, numbered from inside out, which form the greater part of the dorsum (sole) of the foot. At their proximal ends they articulate with the tarsal bones and at their distal ends, with the phalanges. The enlarged distal head of the 1st metatarsal bone forms the 'ball' of the foot.

Phalanges (toe bones, Fig. 16.41)

There are 14 phalanges arranged in a similar manner to those in the fingers, i.e. two in the great toe (the *hallux*) and three in each of the other toes.

Arches of the foot. The arrangement of bones in the foot, supported by associated ligaments and action of associated muscles, gives the sole of the foot an arched or curved shape (Figs 16.41 and 16.42). The curve running from heel to toe is called the *longitudinal* arch, and the curve running across the foot is called the *transverse* arch.

In the normal longitudinal arch, only the calcaneus and the distal ends of the metatarsals should touch the ground, the bones in between being lifted clear. This gives the conventional footprint shape. If, however, the concavity of the sole is lost because of sagging ligaments or tendons, the arch sinks and much more of the sole of the foot is in contact with the ground: this is called *flat foot*. Because the arches of the foot are important in distributing the weight of the body evenly whilst upright, whether stationary or moving, the flat foot loses the springiness of normal foot structure and leads to sore feet when standing, walking or running for long periods. As there are movable joints between all the bones of the foot, very strong muscles and ligaments are necessary to maintain the strength, resilience and stability of the foot during walking, running and jumping.

Posterior tibialis muscle This is the most important muscular support of the longitudinal arch. It lies on the posterior aspect of the lower leg, originates from the middle third of the tibia and fibula and its tendon passes behind the medial malleolus to be inserted into the navicular, cuneiform, cuboid and metatarsal bones. It acts as a sling or 'suspension apparatus' for the arch.

Short muscles of the foot This group of muscles is mainly concerned with the maintenance of the longitudinal and transverse arches. They make up the fleshy part of the sole of the foot.

Plantar calcaneonavicular ligament ('spring' ligament) This is a very strong thick ligament stretching from the calcaneus to the navicular bone. It plays an important part in supporting the medial longitudinal arch.

Plantar ligaments and interosseous membranes These structures support the lateral and transverse arches.

Joints

Learning outcomes

After studying this section, you should be able to:

- state the characteristics of fibrous and cartilaginous joints
- list the different types of synovial joint
- outline the movements possible at five types of synovial joint
- describe the structure and functions of a typical synovial joint.
- describe the structure and movements of the following synovial joints: shoulder, elbow, wrist, hip, knee and ankle.

A joint is the site at which any two or more bones articulate or come together. Joints allow flexibility and movement of the skeleton and allow attachment between bones.

Fibrous joints

The bones forming these joints are linked with tough, fibrous material. Such an arrangement often permits no movement. For example, the joints between the skull bones, the *sutures*, are completely immovable (Fig. 16.43), and the healthy tooth is cemented into the mandible by the periodontal ligament. The tibia and fibula in the leg are held together along their shafts by a sheet of fibrous tissue called the interosseous membrane (Fig. 16.40). This fibrous joint allows a limited amount of movement and stabilises the alignment of the bones.

Cartilaginous joints

These joints are formed by a pad of tough fibrocartilage that acts as a shock absorber. The joint may be immovable, as in the cartilaginous epiphyseal plates, which in the growing child links the diaphysis of a long bone to the epiphysis. Some cartilaginous joints permit limited movement, as between the vertebrae, which are separated by the intervertebral discs (Fig. 16.44), or at the symphysis pubis (Fig. 16.37), which is softened by circulating hormones during pregnancy to allow for expansion during childbirth.

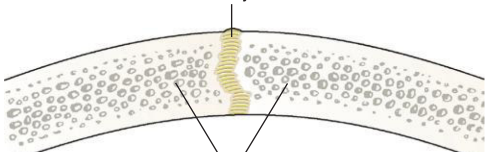

Figure 16.43 Suture (fibrous joint) of the skull.

Synovial joints

Synovial joints are characterised by the presence of a space or capsule between the articulating bones (Fig. 16.45). The ends of the bones are held close together by a sleeve of fibrous tissue, and lubricated with a small amount of fluid. Synovial joints are the most moveable of the body.

Characteristics of a synovial joint

All synovial joints have certain characteristics in common (Fig. 16.45).

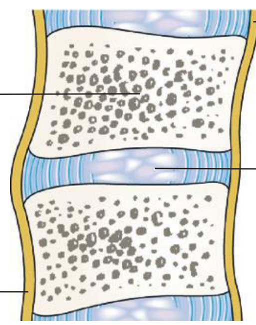

Figure 16.44 The cartilaginous joint between adjacent vertebral bodies.

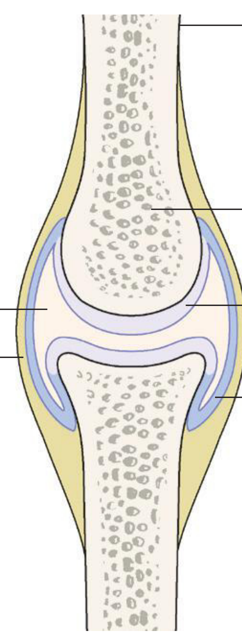

Figure 16.45 The basic structure of a synovial joint.

Articular or hyaline cartilage

The parts of the bones in contact with each other are coated with hyaline cartilage (see Fig. 3.22A). This provides a smooth articular surface, reduces friction and is strong enough to absorb compression forces and bear the weight of the body. The cartilage lining, which is up to 7 mm thick in young people, becomes thinner and less compressible with age. This leads to increasing stress on other structures in the joint. Cartilage has no blood supply and receives its nourishment from synovial fluid.

Capsule or capsular ligament

The joint is surrounded and enclosed by a sleeve of fibrous tissue which holds the bones together. It is sufficiently loose to allow freedom of movement but strong enough to protect it from injury.

Synovial membrane

This epithelial layer lines the capsule and covers all non-weight-bearing surfaces inside the joint. It secretes synovial fluid.

Synovial fluid. This is a thick sticky fluid, of egg-white consistency, which fills the synovial cavity. It:

- nourishes the structures within the joint cavity
- contains phagocytes, which remove microbes and cellular debris
- acts as a lubricant
- maintains joint stability
- prevents the ends of the bones from being separated, as does a little water between two glass surfaces.

Little sacs of synovial fluid or *bursae* are present in some joints, e.g. the knee. They act as cushions to prevent friction between a bone and a ligament or tendon, or skin where a bone in a joint is near the surface.

Other intracapsular structures

Some joints have structures within the capsule to pad and stabilise the joint, e.g. fat pads and menisci in the knee joint. If these structures do not bear weight they are covered by synovial membrane.

Extracapsular structures

- *Ligaments* that blend with the capsule stabilise the joint.
- *Muscles* or their *tendons* also provide stability and stretch across the joints they move. When the muscle contracts it shortens, pulling one bone towards the other.

Nerve and blood supply

Nerves and blood vessels crossing a joint usually supply the capsule and the muscles that move it.

Table 16.2 Movements possible at synovial joints

Movement	Definition
Flexion	Bending, usually forward but occasionally backward, e.g. knee joint
Extension	Straightening or bending backward
Abduction	Movement away from the midline of the body
Adduction	Movement towards the midline of the body
Circumduction	Movement of a limb or digit so that it describes the shape of a cone
Rotation	Movement round the long axis of a bone
Pronation	Turning the palm of the hand down
Supination	Turning the palm of the hand up
Inversion	Turning the sole of the foot inwards
Eversion	Turning the sole of the foot outwards

Movements at synovial joints

Movement at any given joint depends on various factors, such as the tightness of the ligaments holding the joint together, how well the bones fit and the presence or absence of intracapsular structures. Generally, the more stable the joint, the less mobile it is. The main movements possible are summarised in Table 16.2 and Figure 16.46.

Types of synovial joint

Synovial joints are classified according to the range of movement possible (Table 16.2) or to the shape of the articulating parts of the bones involved.

Ball and socket joints

The head of one bone is ball-shaped and articulates with a cup-shaped socket of another. The joint allows for a wide range of movement, including flexion, extension, adduction, abduction, rotation and circumduction. Examples include the shoulder and hip.

Hinge joints

The articulating ends of the bones fit together like a hinge on a door, and movement is therefore restricted to flexion and extension. The elbow joint is one example, permitting only flexion and extension of the forearm. Other hinge joints include the knee, ankle and the joints between the phalanges of the fingers and toes (interphalangeal joints).

Gliding joints

The articular surfaces are flat or very slightly curved and glide over one another, but the amount of movement

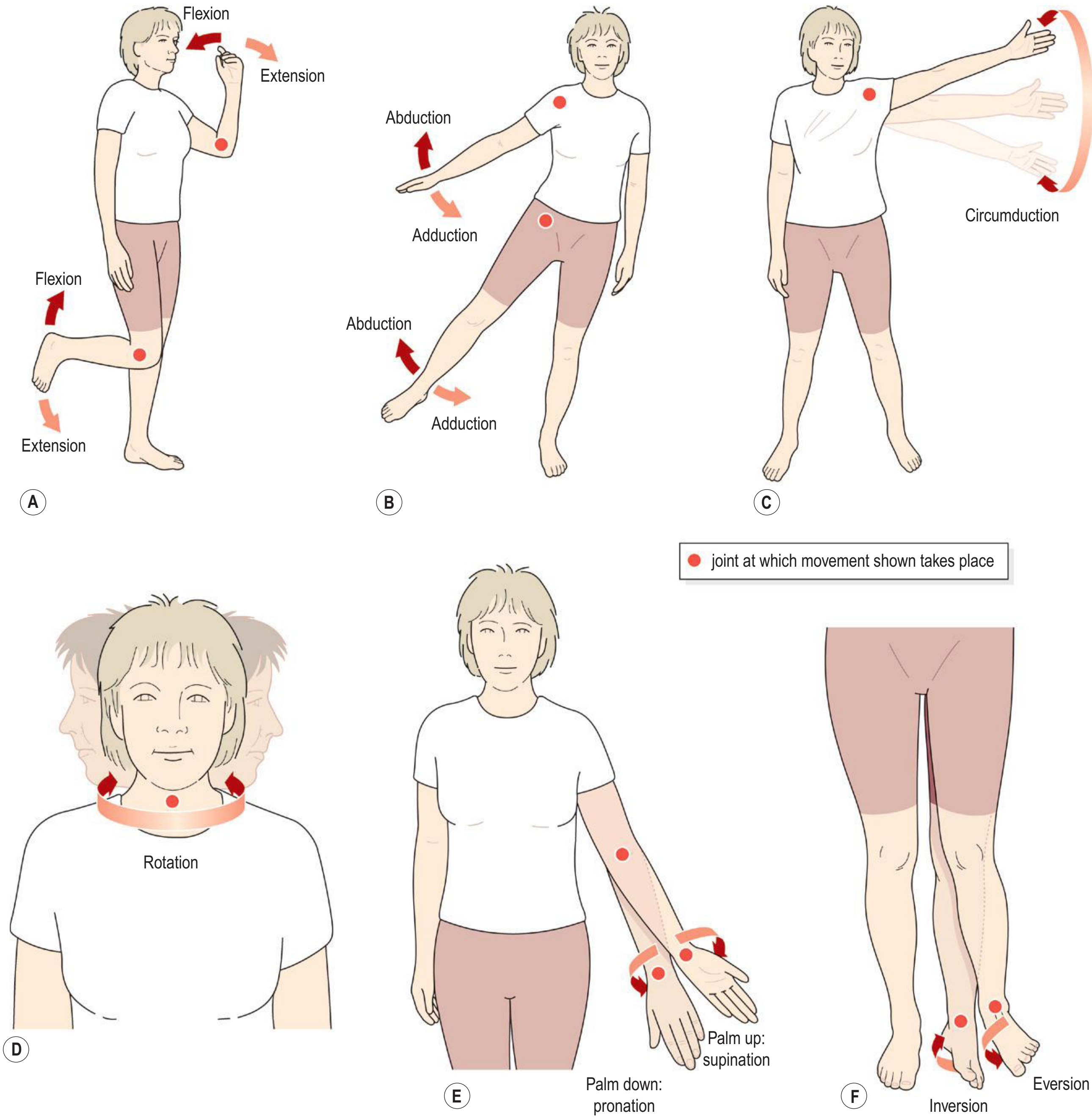

Figure 16.46 The main movements possible at synovial joints.

possible is very restricted; this group of joints is the least movable of all the synovial joints. Examples include the joints between the carpal bones in the wrist, the tarsal bones in the foot, and between the processes of the spinal vertebrae (note that the joints between the vertebral bodies are the cartilaginous discs; Fig. 16.44).

Pivot joints

These joints allow a bone or a limb to rotate. One bone fits into a hoop-shaped ligament that holds it close to another bone and allows it to rotate in the ring thus formed. For example, the head rotates on the pivot joint formed by the dens of the axis held within the ring formed by the transverse ligament and the odontoid process of the atlas (Fig. 16.22).

Condyloid joints

A condyle is a smooth, rounded projection on a bone and in a condyloid joint it sits within a cup-shaped depression on the other bone. Examples include the joint between the condylar process of the mandible and the temporal bone, and the joints between the metacarpal and phalangeal bones of the hand, and between the metatarsal and phalangeal bones of the foot. These joints permit flexion, extension, abduction, adduction and circumduction.

Saddle joints

The articulating bones fit together like a man sitting on a saddle. The most important saddle joint is at the base of the thumb, between the trapezium of the wrist and the first metacarpal bone (Fig. 16.35). The range of movement is similar to that at a condyloid joint but with additional flexibility; *opposition* of the thumb, the ability to touch each of the fingertips on the same hand, is due to the nature of the thumb joint.

Main synovial joints of the limbs 16.4

All synovial joints have the characteristics described above, so only their distinctive features are included in this section.

Shoulder joint (Fig. 16.47)

This ball and socket joint is the most mobile in the body, and consequently is the least stable and prone to dislocation, especially in children. It is formed by the glenoid cavity of the scapula and the head of the humerus, and is well padded with protective bursae. The capsular ligament is very loose inferiorly to allow for the free movement normally possible at this joint. The glenoid cavity is deepened by a rim of fibrocartilage, the *glenoidal labrum*, which provides additional stability without limiting movement. The tendon of the long head of the *biceps muscle* is held in the intertubercular (bicipital) groove of the humerus by the transverse humeral ligament. It extends through the joint cavity and attaches to the upper rim of the glenoid cavity.

Synovial membrane forms a sleeve round the part of the tendon of the long head of the biceps muscles within the capsular ligament and covers the glenoidal labrum.

The joint is stabilised partly by a number of ligaments (the glenohumoral, coracohumeral and transverse humeral) but mainly by the muscles (and their tendons) present in the shoulder. Some of these muscles collectively are called the *rotator cuff*, and rotator cuff injury is a common cause of shoulder pain (p. 435). The stability of the joint may be reduced if these structures, together with the tendon of the biceps muscle, are stretched by repeated dislocations of the joint.

Muscles and movements (see Fig. 16.65)

The muscles that move the arm are described in more detail on page 427, and Table 16.3 summarises the muscles and movements possible at the shoulder joint.

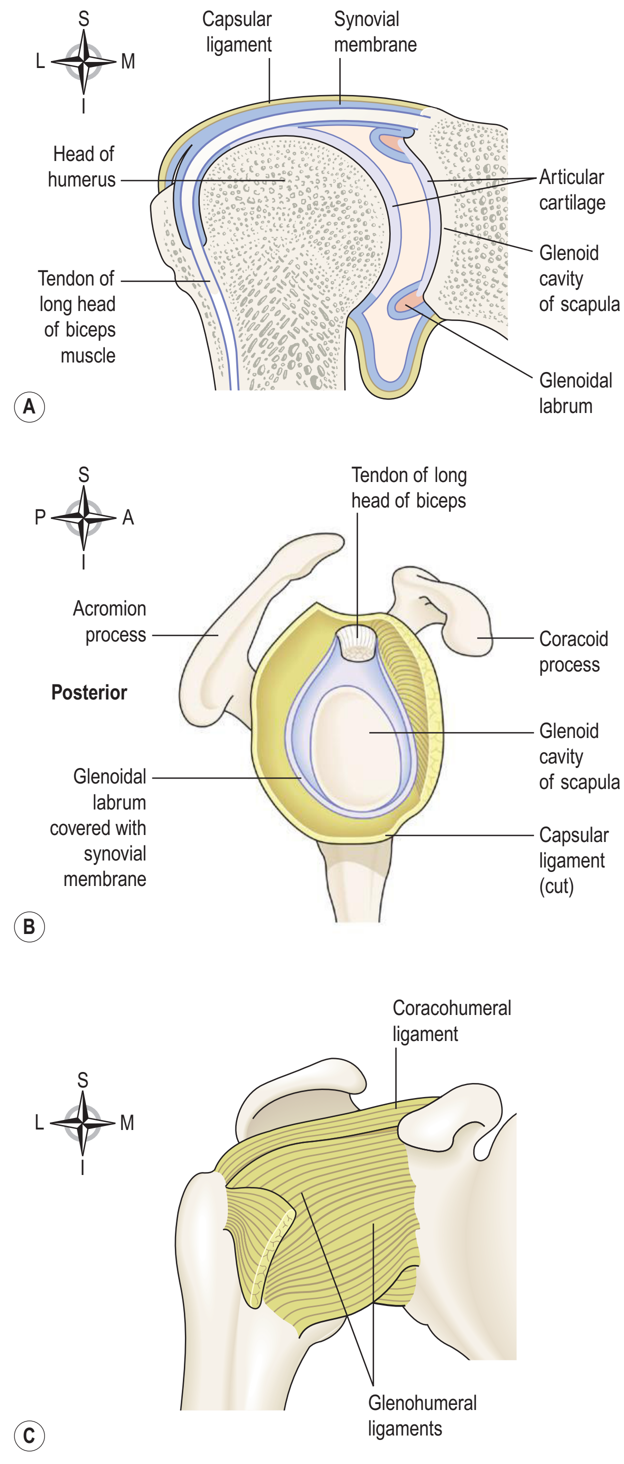

Figure 16.47 The right shoulder joint. A. Section viewed from the front. **B.** The position of glenoidal labrum with the humerus removed, viewed from the side. **C.** The supporting ligaments viewed from the front.

Elbow joint (Fig. 16.48)

This hinge joint is formed by the trochlea and the capitulum of the humerus, and the trochlear notch of the ulna and the head of the radius. It is an extremely stable joint

Table 16.3 Muscles and movements at the shoulder joint	
Extension	Latissimus dorsi, teres major
Flexion	Coracobrachialis, pectoralis major
Abduction	Deltoid
Adduction	Latissimus dorsi, pectoralis major
Lateral rotation	Teres minor, posterior part of deltoid
Medial rotation	Latissimus dorsi, pectoralis major, teres major and anterior part of deltoid
Circumduction	Combination of actions of above muscles

because the humeral and ulnar surfaces interlock, and the capsule is very strong.

Extracapsular structures consist of anterior, posterior, medial and lateral strengthening ligaments, which contribute to joint stability.

Muscles and movements (see Fig. 16.65)

Because of the structure of the elbow joint, the only two movements it allows are flexion and extension. The biceps is the main flexor of the forearm, aided by the brachialis; the triceps extends it.

Proximal and distal radioulnar joints

The *proximal radioulnar joint* is a pivot joint formed by the rim of the head of the radius rotating in the radial notch of the ulna, and is in the same capsule as the elbow joint. The *annular ligament* is a strong extracapsular ligament that encircles the head of the radius and keeps it in contact with the radial notch of the ulna (Fig. 16.48B).

The distal *radioulnar joint* is a pivot joint between the distal end of the radius and the head of the ulna (Fig. 16.49).

Note, in addition, the presence of a fibrous membrane linking the bones along their shafts; this interosseous membrane (Fig. 16.34) is a type of fibrous joint and prevents separation of the bones when force is applied at either end, i.e. at the wrist or elbow.

Muscles and movements (see Fig. 16.65)

The forearm may be pronated (turned palm down) or supinated (turned palm up). Pronation is caused by the pronator teres (p. 428) and supination by the supinator and biceps muscles (p. 427-8).

Wrist joint (Fig. 16.49)

This is a condyloid joint between the distal end of the radius and the proximal ends of the scaphoid, lunate and triquetrum. A disc of white fibrocartilage separates the

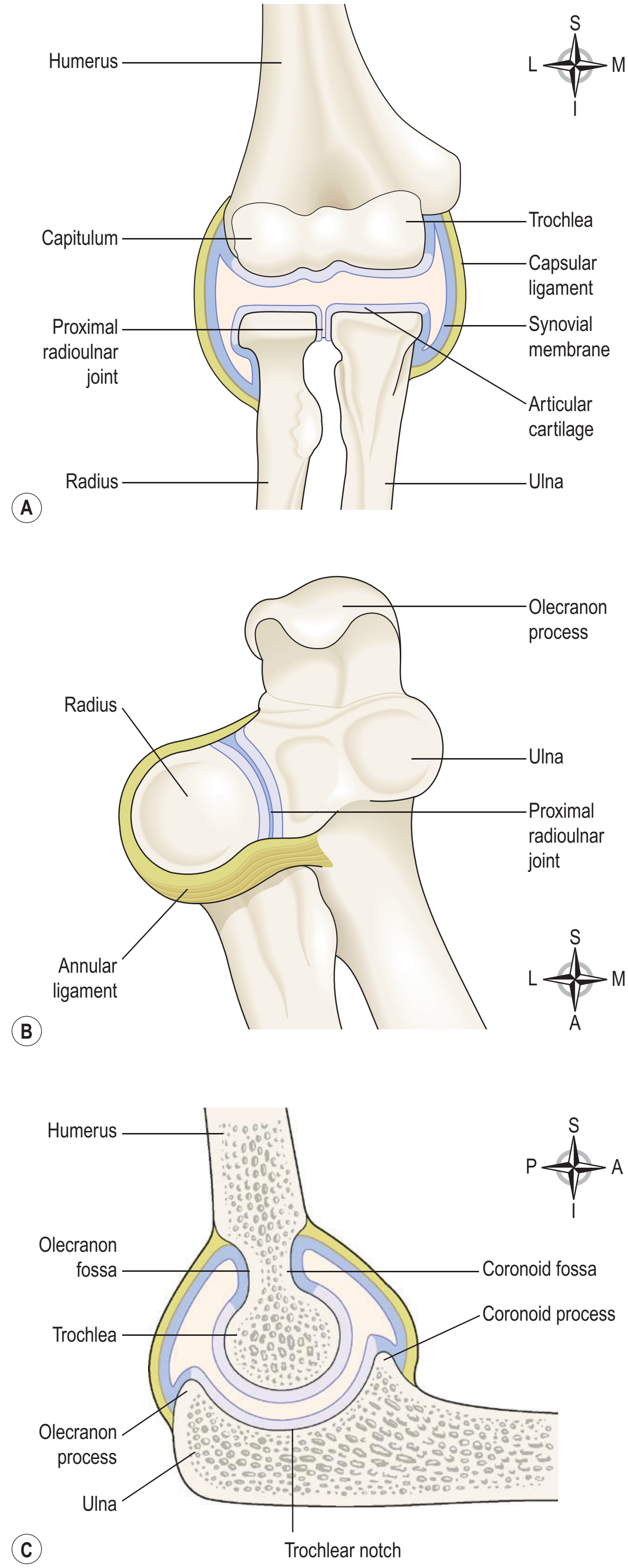

Figure 16.48 The right elbow and proximal radioulnar joints. **A.** Section viewed from the front. **B.** The proximal radioulnar joint, viewed from above. **C.** Section of the elbow joint, partly flexed, viewed from the right side.

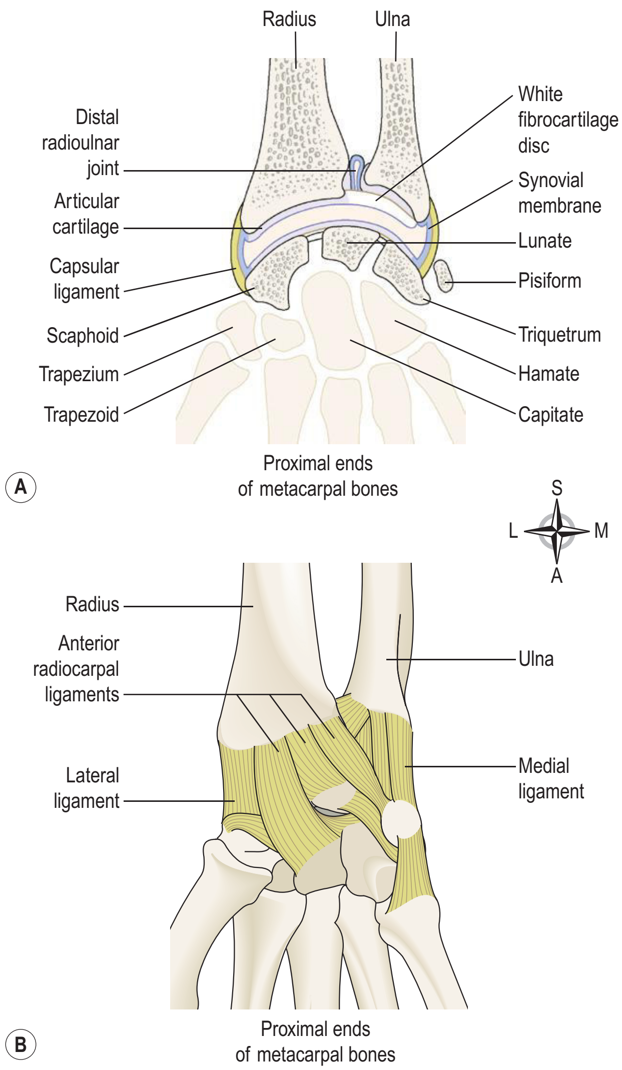

Figure 16.49 The right wrist and distal radioulnar joints. Anterior view. **A.** Section. **B.** Supporting ligaments.

ulna from the joint cavity and articulates with the carpal bones. It also separates the inferior radioulnar joint from the wrist joint.

Extracapsular structures consist of medial and lateral ligaments and anterior and posterior radiocarpal ligaments.

Muscles and movements (see Fig. 16.65)

The wrist can be flexed, extended, abducted and adducted. The muscles that perform these movements are described in more detail on page 428. Table 16.4 summarises the main muscles that move the wrist.

Joints of the hands and fingers

There are synovial joints between the carpal bones, between the carpal and metacarpal bones, between the metacarpal bones and proximal phalanges and between the phalanges. Movement at the hand and finger joints is controlled by muscles in the forearm and smaller muscles within the hand. There are no muscles in the fingers; finger movements are produced by tendons extending from muscles in the forearm and the hand.

The joint at the base of the thumb is a saddle joint, unlike the corresponding joints of the other fingers, which are condyloid. This means that the thumb is more mobile than the fingers and the thumb can be flexed, extended, circumducted, abducted and adducted. In addition, the thumb can be moved across the palm to touch the tips of each of the fingers on the same hand (opposition), giving great manual dexterity and allowing, for example, the holding of a pen and the fine manipulation of objects held in the hand.

The joints between the metacarpals and finger bones allow movement of the fingers. The fingers may be flexed, extended, adducted, abducted and circumducted, with the first finger more flexible than the others. The finger joints are hinge joints, and allow only flexion and extension.

The *flexor retinaculum* is a strong fibrous band that stretches across the front of the carpal bones, forming the *carpal tunnel*. The tendons of flexor muscles of the wrist joint and the fingers and the median nerve pass through the carpal tunnel, the retinaculum holding them close to the bones. Synovial membrane forms sleeves around these tendons in the carpal tunnel and extends some way into the palm of the hand. Synovial sheaths also enclose the tendons on the flexor surfaces of the fingers. Their synovial fluid prevents friction that might damage the tendons as they move over the bones (Fig. 16.50).

The *extensor retinaculum* is a strong fibrous band that extends across the back of the wrist. Tendons of muscles that extend the wrist and finger joints are encased in synovial membrane under the retinaculum. The synovial fluid secreted prevents friction.

Table 16.4 Muscles and movements at the wrist joint

Flexion	Flexor carpi radialis, flexor carpi ulnaris
Extension	Extensors carpi radialis (longus and brevis), extensor carpi ulnaris
Adduction	Flexor carpi radialis, extensor carpi radialis
Abduction	Flexor carpi ulnaris, extensor carpi ulnaris

Hip joint (Fig. 16.51)

This ball and socket joint is formed by the cup-shaped acetabulum of the innominate (hip) bone and the almost spherical head of the femur. The capsular ligament encloses the head and most of the neck of the femur. The

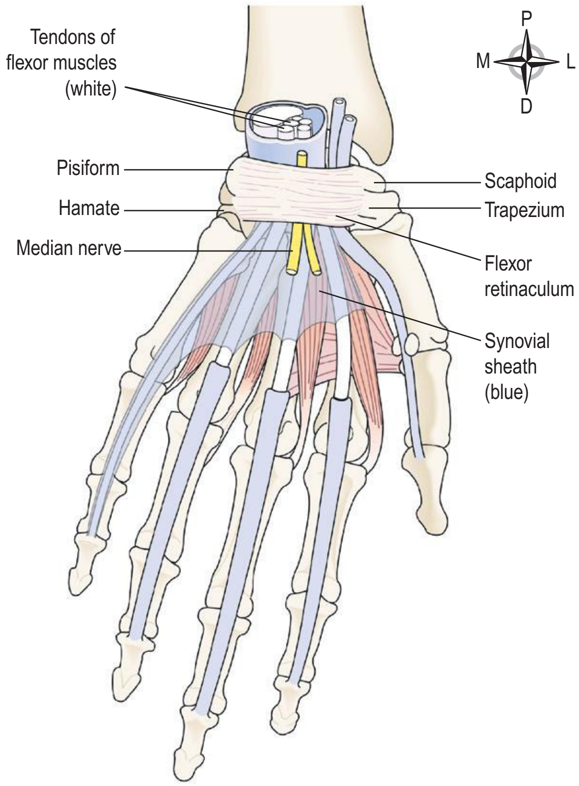

Figure 16.50 The carpal tunnel and synovial sheaths in the wrist and hand in blue; tendons in white. Palmar view, left hand.

cavity is deepened by the *acetabular labrum*, a ring of fibrocartilage attached to the rim of the acetabulum, which stabilises the joint without limiting its range of movement. The hip joint is necessarily a sturdy and powerful joint, since it bears all body weight when standing. It is stabilised by its surrounding musculature, but its ligaments are also important. The three main external ligaments are the *iliofemoral*, *pubofemoral* and *ischiofemoral* ligaments (Fig. 16.51B). Within the joint, the ligament of the head of the femur (*ligamentum teres*) attaches the femoral head to the acetabulum (Fig. 16.51A and C).

Muscles and movements (see Fig. 16.66)

The lower limb can be extended, flexed, abducted, adducted, rotated and circumducted at the hip joint (Table 16.5).

Knee joint (Fig. 16.52)

This is the body's largest and most complex joint. It is a hinge joint formed by the condyles of the femur, the condyles of the tibia and the posterior surface of the patella. The anterior part of the capsule is formed by the tendon of the quadriceps femoris muscle, which also supports the patella. Intracapsular structures include two *cruciate ligaments* that cross each other, extending from the

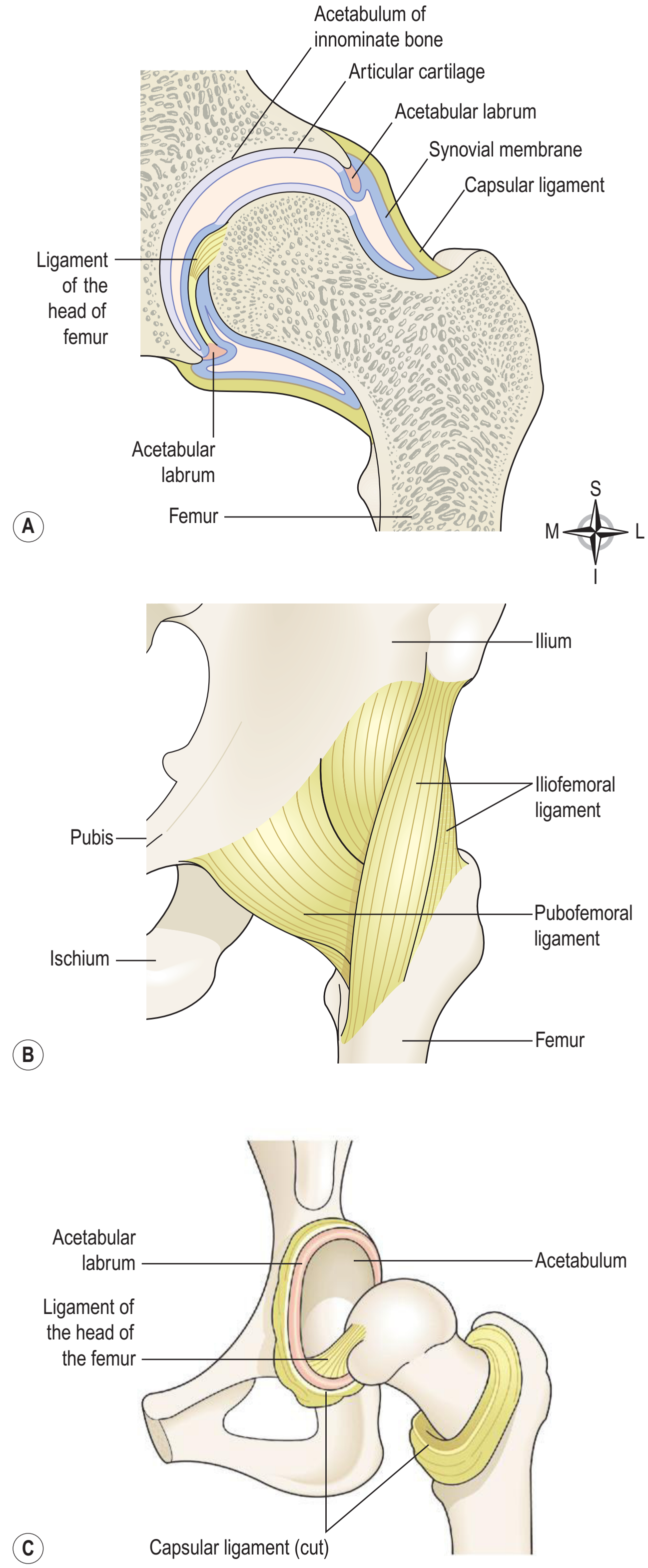

Figure 16.51 The left hip joint. Anterior view. **A.** Section. **B.** Supporting ligaments. **C.** Head of femur and acetabulum separated to show acetabular labrum and ligament of head of femur.

Table 16.5 Muscles and movements at the hip joint

Flexion	Psoas, iliacus, sartorius
Extension	Gluteus maximus, hamstrings
Abduction	Gluteus medius and minimus, sartorius
Adduction	Adductor group (longus, brevis and magnus)
Medial rotation	Gluteus medius and minimus, adductor group
Lateral rotation	Gluteus maximus, quadratus femoris, obturators

intercondylar notch of the femur to the *intercondylar eminence* of the tibia. They help to stabilise the joint.

Semilunar cartilages or *menisci* are incomplete discs of white fibrocartilage lying on top of the articular condyles of the tibia. They are wedge shaped, being thicker at their outer edges, and provide stability. They prevent lateral displacement of the bones, and cushion the moving joint by shifting within the joint space according to the relative positions of the articulating bones.

Bursae and pads of fat are numerous. They prevent friction between a bone and a ligament or tendon and between the skin and the patella. Synovial membrane covers the cruciate ligaments and the pads of fat. The menisci are not covered with synovial membrane because they are weight bearing. External ligaments provide further support, making it a hard joint to dislocate. The main ligaments are the patellar ligament, an extension of the quadriceps tendon, the popliteal ligaments at the back of the knee and the collateral ligaments to each side.

Muscles and movements (see Fig. 16.66)

Possible movements at this joint are flexion, extension and a rotatory movement that 'locks' the joint when it is fully extended. When the joint is locked, it is possible to stand upright for long periods of time without tiring the knee extensors. The main muscles extending the knee are the quadriceps femoris, and the principal flexors are the gastrocnemius and hamstrings.

Ankle joint (Fig. 16.53)

This hinge joint is formed by the distal end of the tibia and its malleolus (medial malleolus), the distal end of the fibula (lateral malleolus) and the talus. Four important ligaments strengthen this joint: the deltoid and the anterior, posterior, medial and lateral ligaments.

Muscles and movements (see Fig. 16.66)

The movements of *inversion* and *eversion* occur between the tarsal bones and not at the ankle joint. Ankle joint

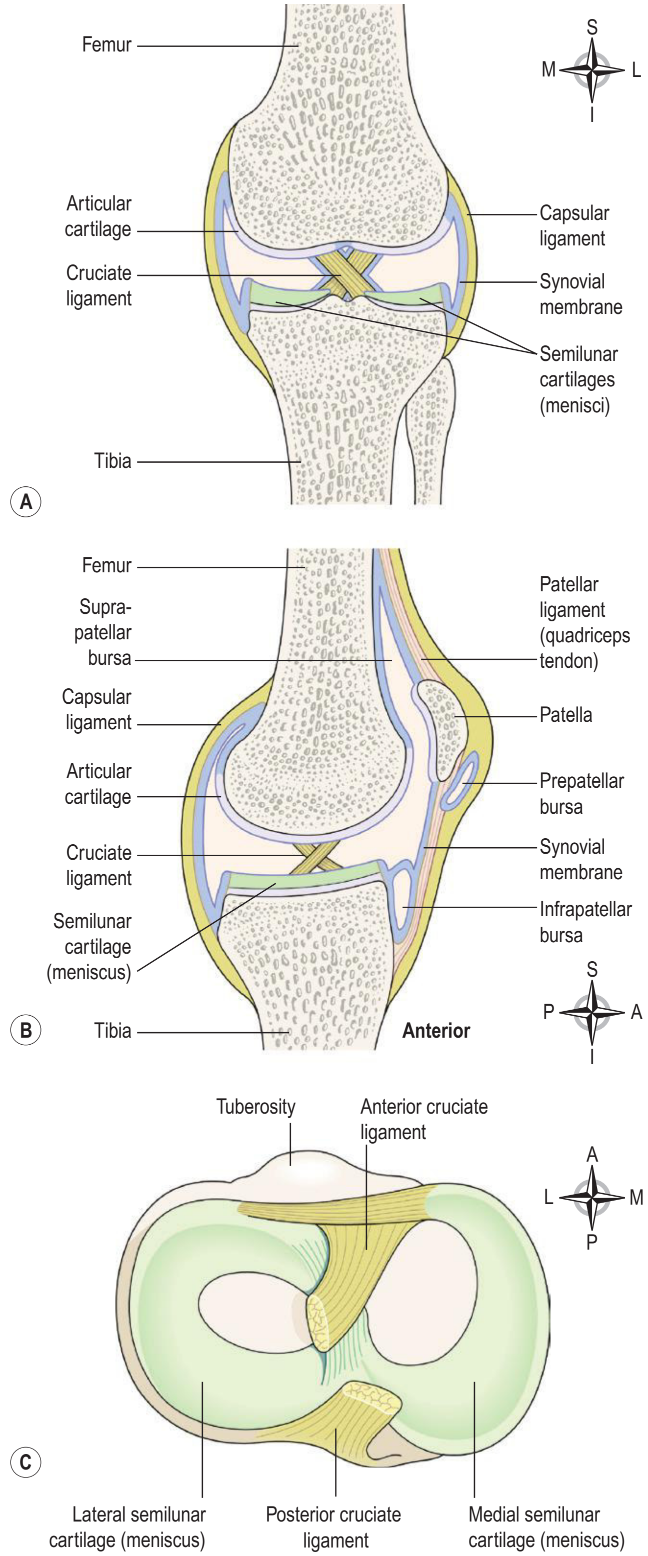

Figure 16.52 The left knee joint. A. Section viewed from the front. **B.** Section viewed from the side. **C.** The superior surface of the tibia, showing the semilunar cartilages and the cruciate ligaments.

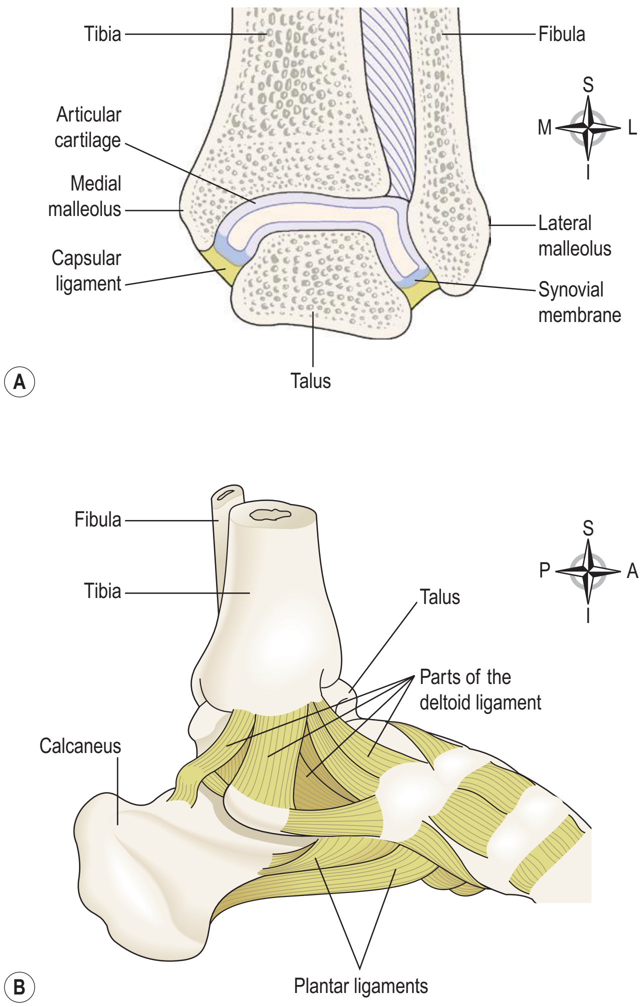

Figure 16.53 The left ankle joint. A. Section viewed from the front. **B.** Supporting ligaments, medial view.

Table 16.6 Muscles and movements at the ankle joint	
Dorsiflexion (lifting toes towards calf)	Anterior tibialis and toe extensors
Plantar flexion (rising on tiptoe)	Gastrocnemius, soleus and toe flexors

movements and the related muscles are shown in Table 16.6.

Joints of the feet and toes

There are a number of synovial joints between the tarsal bones, between the tarsal and metatarsal bones, between the metatarsals and proximal phalanges and between the phalanges. Movements are produced by muscles in the leg with long tendons that cross the ankle joint, and by muscles of the foot. The tendons crossing the ankle joint are wrapped in synovial sheaths and held close to the bones by strong transverse ligaments. They move smoothly within their sheaths as the joints move. In addition to moving the joints of the foot, these muscles support the arches of the foot and help to maintain balance.

Skeletal muscle

Learning outcomes

After studying this section, you should be able to:

- identify the main characteristics of skeletal muscle
- relate the structure of skeletal muscle fibres to their contractile activity
- describe the nature of muscle tone and fatigue
- discuss the factors that affect the performance of skeletal muscle
- name the main muscles of the body regions described in this section
- outline the functions of the main muscles described in this section.

Muscle cells are specialised contractile cells, also called *fibres*. The three types of muscle tissue, *smooth*, *cardiac* and *skeletal*, each differ in structure, location and physiological function. Smooth muscle and cardiac muscle are not under voluntary control and are discussed elsewhere (smooth muscle and cardiac muscle p. 43-4). Skeletal muscles, which are under voluntary control, are attached to bones via their tendons (Fig. 16.54A) and move the skeleton. Like cardiac (but not smooth) muscle, skeletal muscle is *striated* (striped), and the stripes are seen in a characteristic banded pattern when the cells are viewed under the microscope (Fig. 16.54B, Fig. 16.55).

Organisation of skeletal muscle (Fig. 16.54)

A skeletal muscle may sometimes contain hundreds of thousands of muscle fibres as well as blood vessels and nerves. Throughout the muscle, providing internal structure and scaffolding, is an extensive network of connective tissue. The entire muscle is covered in a connective tissue sheath called the *epimysium*. Within the muscle, the cells are collected into separate bundles called fascicles, and each *fascicle* is covered in its own connective tissue sheath called the *perimysium*. Within the fascicles, the individual muscle cells are each wrapped in a fine connective tissue layer called the *endomysium*. Each of these connective tissue layers runs the length of the muscle. They bind the fibres into a highly organised structure,

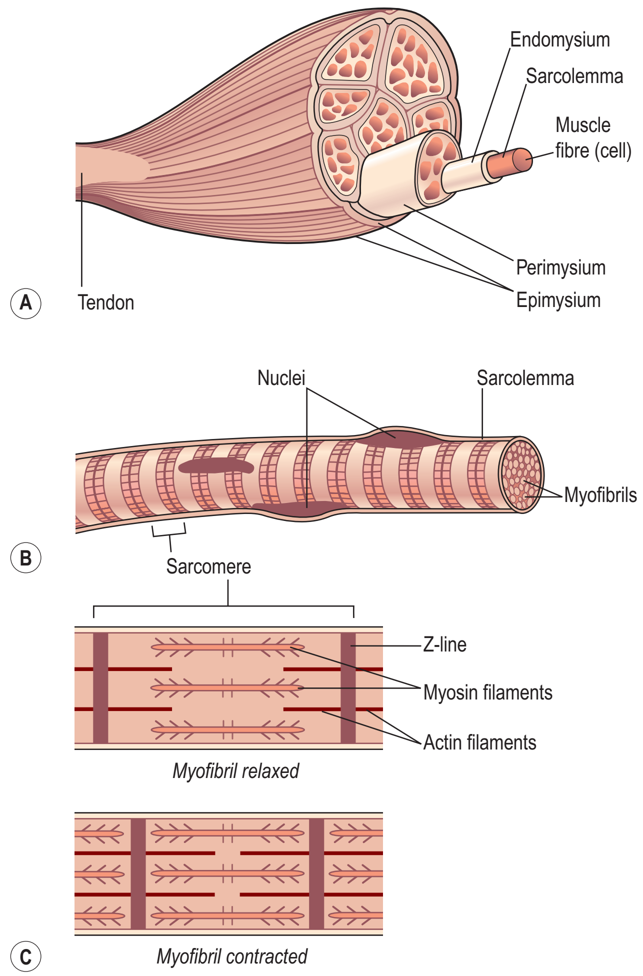

Figure 16.54 Organisation within a skeletal muscle. **A.** A skeletal muscle and its connective tissue. **B.** A muscle fibre (cell). **C.** A myofibril, relaxed and contracted.

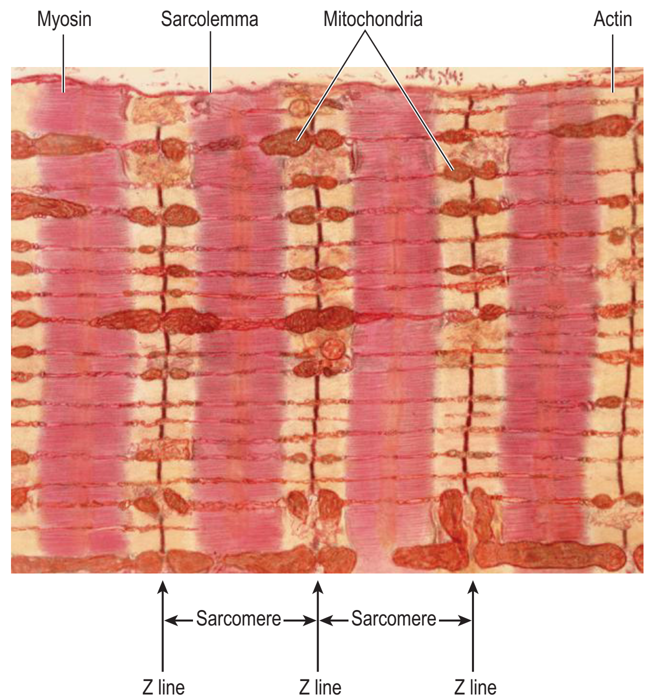

Figure 16.55 Coloured transmission electron micrograph of part of a skeletal muscle cell, showing the characteristic banding pattern and multiple mitochondria.

and blend together at each end of the muscle to form the *tendon*, which secures the muscle to bone. Often the tendon is rope-like, but sometimes it forms a broad sheet called an *aponeurosis*, e.g. the occipitofrontalis muscle (see Fig. 16.58). The multiple connective tissue layers throughout the muscle are important for transmitting the force of contraction from each individual muscle cell to its points of attachment to the skeleton.

The fleshy part of the muscle is called the *belly*.

Skeletal muscle cells (fibres)

Contraction of a whole skeletal muscle occurs because of coordinated contraction of its individual fibres.

Structure

Under the microscope, skeletal muscle cells are seen to be roughly cylindrical in shape, lying parallel to one another, with a distinctive banded appearance consisting of alternate dark and light stripes (Figs 16.54B and 16.55). Individual fibres may be very long, up to 35 cm in the longest muscles. Each cell has several nuclei (because the cells are so large), found just under the cell membrane (the *sarcolemma*). The cytoplasm of muscle cells, also called *sarcoplasm*, is packed with tiny filaments running longitudinally along the length of the muscle; these are the contractile filaments. There are also many mitochondria (Fig. 16.55), essential for producing adenosine triphosphate (ATP) from glucose and oxygen to power the contractile mechanism. Also present is a specialised oxygen-binding substance called *myoglobin*, which is similar to the haemoglobin of red blood cells and stores oxygen within the muscle. In addition, there are extensive intracellular stores of calcium, which is released into the sarcoplasm by nervous stimulation of muscle and is essential for the contractile activity of the myofilaments.

Actin, myosin and sarcomeres. There are two types of contractile myofilament within the muscle fibre, called thick and thin, arranged in repeating units called sarcomeres (Figs 16.54C and 16.55). The thick filaments, which are made of the protein *myosin*, correspond to the dark bands seen under the microscope. The thin filaments are made of the protein *actin*. Where only these are present, the bands are lighter in appearance.

Each sarcomere is bounded at each end by a dense stripe, the *Z line*, to which the actin fibres are attached, and lying in the middle of the sarcomere are the myosin filaments, overlapping with the actin.

Contraction

The skeletal muscle cell contracts in response to stimulation from a nerve fibre, which supplies the muscle cell usually about halfway along its length. The name given to a synapse between a motor nerve and a skeletal muscle fibre is the *neuromuscular junction*. When the action potential spreads from the nerve along the sarcolemma, it is conducted deep into the muscle cell through a special network of channels that run through the sarcoplasm, and releases calcium from the intracellular stores. Calcium triggers the binding of myosin to the actin filament next to it, forming so-called cross-bridges. ATP then provides the energy for the two filaments to slide over each other, pulling the Z lines at each end of the sarcomere closer to one another, shortening the sarcomere (Fig. 16.54C). This is called the *sliding filament theory*. If enough fibres are stimulated to do this at the same time, the whole muscle will shorten (contract). **16.5**

The muscle relaxes when nerve stimulation stops. Calcium is pumped back into its intracellular storage areas, which breaks the cross-bridges between the actin and myosin filaments. They then slide back into their starting positions, lengthening the sarcomeres and returning the muscle to its original length.

The neuromuscular junction **16.6**

The axons of motor neurones, carrying impulses to skeletal muscle to produce contraction, divide into a number of fine filaments terminating in minute pads called synaptic knobs. The space between the synaptic knob and the muscle cell is called the synaptic cleft. Stimulation of the motor neurone releases the neurotransmitter acetylcholine (ACh), which diffuses across the synaptic cleft and binds to acetylcholine receptors on the postsynaptic membrane on the *motor end plate* (the area of the muscle membrane directly across the synaptic cleft, Fig. 16.56). Acetylcholine causes contraction of the muscle cell.

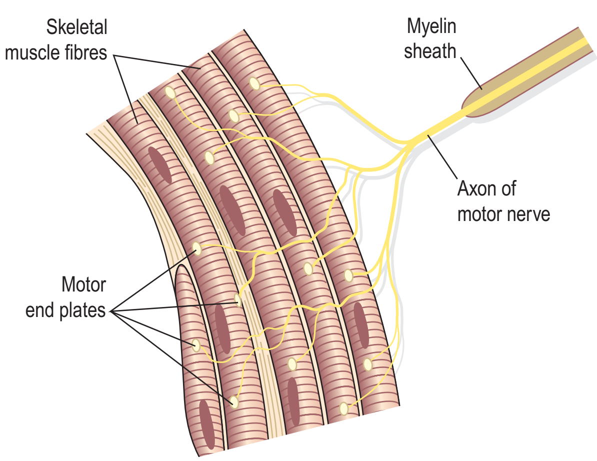

Figure 16.56 The neuromuscular junction.

Motor units

Each muscle fibre is stimulated by only one synaptic knob, but since each motor nerve has many synaptic knobs, it stimulates a number of muscle fibres. Figure 16.57 shows an electron micrograph of a motor nerve and two of its motor end plates.

One nerve fibre and the muscle fibres it supplies constitute a *motor unit*. Nerve impulses cause serial contraction of motor units in a muscle, and each unit contracts to its full capacity. The *strength* of the contraction depends on the *number* of motor units in action at a particular time.

Some motor units contain large numbers of muscle fibres, i.e. one nerve serves many muscle cells. This arrangement is associated with large-scale, powerful movements, such as in the legs or upper arms. Fine, delicate control of muscle movement is achieved when one motor unit contains very few muscle fibres, as in the muscles controlling eye movement.

Action of skeletal muscle

When individual muscle cells in a muscle shorten, they pull on the connective tissue framework running through the whole muscle, and the muscle develops a degree of tension (tone).

Muscle tone

When a muscle fibre contracts, it obeys the *all-or-none law*, i.e. the whole fibre either contracts completely or not at all. The degree of contraction achieved by a whole muscle depends therefore on the number of fibres within it that are contracting at any one time, as well as how often they

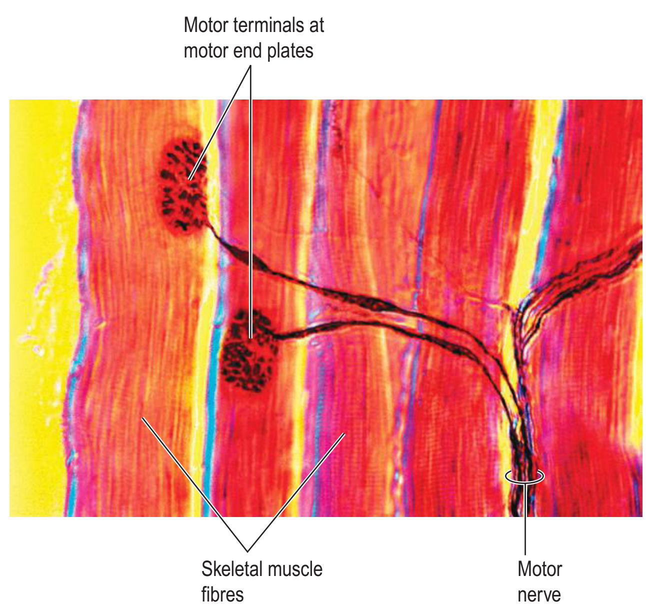

Figure 16.57 The neuromuscular junction. Colour transmission electron micrograph of a motor neurone and two of its motor end plates.

are stimulated. Powerful contractions involve a larger proportion of available fibres than weaker ones; to lift a heavy weight, more active muscle fibres are required than to lift a lighter one. *Muscle tone* is a sustained, partial muscle contraction that allows posture to be maintained without fatiguing the muscles involved. For instance, keeping the head upright requires constant activity of the muscles of the neck and shoulders. Groups of muscle fibres within these muscles take it in turns to contract, so that at any one time, some fibres are contracted and others are resting. This allows the effort required to hold the head upright to be distributed throughout the muscles involved. Good muscle tone protects joints and gives a muscle firmness and shape, even when relaxed.

Muscle fatigue

To work at sustained levels, muscles need an adequate supply of oxygen and fuel such as glucose. Fatigue occurs when a muscle works at a level that exceeds these supplies. The muscle response decreases with fatigue.

The chemical energy (ATP) that muscles require is usually derived from the breakdown of carbohydrate and fat; protein may be used if supplies of fat and carbohydrate are exhausted. An adequate oxygen supply is needed to fully release all the energy stored within these fuel molecules; without it, the body uses anaerobic metabolic pathways (p. 316) that are less efficient and lead to lactic acid production. Fatigue (and muscle pain) resulting from inadequate oxygen supply, as in strenuous exercise, occurs when lactic acid accumulates in working muscles. Fatigue may also occur because energy stores are exhausted, or due to physical injury to muscle, which may occur after prolonged episodes of strenuous activity, e.g. marathon running.

Muscle recovery

After exercise, muscle needs a period of time to recover, to replenish its ATP and glycogen stores and to repair any damaged fibres. For some time following exercise, depending on the degree of exertion, the *oxygen debt* remains (an extended period of increased oxygen demand), as the body converts lactic acid to pyruvic acid and replaces its energy stores.

Factors affecting skeletal muscle performance

Skeletal muscle performs better when it is regularly exercised. Training improves endurance and power. Anaerobic training, such as weightlifting, increases muscle bulk because it increases the size of individual fibres within the muscle (hypertrophy).

The action of skeletal muscles

In order to move a body part, the muscle or its tendon must stretch across at least one joint. When it contracts, the muscle then pulls one bone towards another. For example, when the elbow is bent during flexion of the forearm, the main mover is the biceps brachii, which is anchored on the scapula at one end and on the radius at the other. When it contracts, its shortening pulls on the radius, moving the forearm up toward the upper arm and bending the elbow.

This example also illustrates another feature of muscle arrangement: that of *antagonistic pairs*. Many muscles/muscle groups of the body are arranged so that their actions oppose one another. Using the example of bending the elbow, when the main flexors on the front of the upper arm contract, the muscles at the back of the upper arm must simultaneously relax to prevent injury.

Isometric and isotonic contraction 16.7

Contraction of a muscle usually results in its shortening, as happens for instance to the biceps muscle if the forearm is used to pick up a cup. The power generated by the muscle is used to lift the manageable weight, and tension in the muscle remains constant. In this situation, the contraction is said to be isotonic (iso = same; tonic = tension). However, imagine trying to lift an 80 kg man with one hand. Most people would be unable to perform this task, but the muscles of the arm and shoulder would still be working hard as they attempted it. In this situation, because the resistance from the man's weight is too great for him to be moved by the efforts of the lifter, the muscles would be unable to shorten, and the power generated increases the muscle tension instead. This is *isometric* contraction (iso = same; metric = length).

Muscle terminology

Muscles are named according to various characteristics (Table 16.7), and becoming familiar with the principal ones makes it much easier to identify unfamiliar muscles.

The *origin* of a muscle is (usually) its proximal attachment; this is generally the bone that remains still when the muscle contracts, giving it an anchor to pull against. The *insertion* is (usually) the distal attachment site, generally on the bone that is moved when the muscle contracts.

Principal skeletal muscles

This section considers the main muscles that move the limbs, as well as the major muscles of the face and neck, back, chest, pelvic floor and abdominal wall.

Muscles of the face and neck (Fig. 16.58)

Muscles of the face

Many muscles are involved in changing facial expression and with movement of the lower jaw during chewing and speaking. Only the main muscles are described here. Except where indicated the muscles are present in pairs, one on each side.

Occipitofrontalis (unpaired). This consists of a posterior muscular part over the occipital bone (*occipitalis*), an anterior part over the frontal bone (*frontalis*) and an extensive flat tendon or aponeurosis that stretches over the dome of the skull and joins the two muscular parts. It raises the eyebrows.

Table 16.7 Muscle terminology

Characteristic	Example	Comment
Shape	Trapezius	Trapezium shaped
Fibre direction	Oblique muscles of abdomen	Fibres run obliquely
Muscle position	Tibialis	Found close to tibia in the leg
Movement produced	Extensor carpi ulnaris	Attached to the carpal bones of the wrist and the ulna, and extends the wrist
Number of points of attachment	Biceps brachii	Bi = 2; this muscle has two points of attachment at the shoulder
Bones to which muscle is attached	Carpi radialis muscles	Attached to the carpal bones of the wrist and the radius of the forearm

Levator palpebrae superioris. This muscle extends from the posterior part of the orbital cavity to the upper eyelid. It raises the eyelid.

Orbicularis oculi. This muscle surrounds the eye, eyelid and orbital cavity. It closes the eye and when strongly contracted 'screws up' the eyes.

Buccinator. This flat muscle of the cheek draws the cheeks in towards the teeth in chewing and in forcible expulsion of air from the mouth ('the trumpeter's muscle').

Orbicularis oris (unpaired). This muscle surrounds the mouth and blends with the muscles of the cheeks. It closes the lips and, when strongly contracted, shapes the mouth for whistling.

Masseter. This broad muscle extends from the zygomatic arch to the angle of the jaw. In chewing it draws the mandible up to the maxilla, closing the jaw, exerting considerable pressure on the food.

Temporalis. This muscle covers the squamous part of the temporal bone. It passes behind the zygomatic arch to be inserted into the coronoid process of the mandible. It closes the mouth and assists with chewing.

Pterygoid. This muscle extends from the sphenoid bone to the mandible. It closes the mouth and pulls the lower jaw forward.

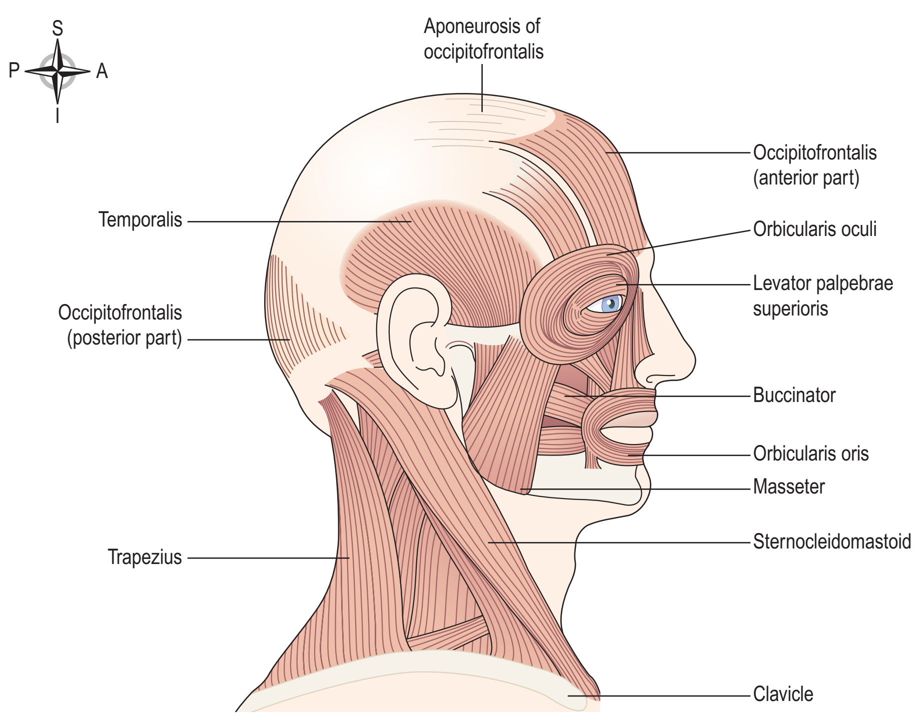

Figure 16.58 The main muscles on the right side of the face, head and neck.

Muscles of the neck

There are many muscles in the neck, but only the two largest are considered here.

Sternocleidomastoid. This muscle arises from the manubrium of the sternum and the clavicle and extends upwards to the mastoid process of the temporal bone. It assists in turning the head from side to side and is also an accessory muscle in respiration. When the muscle on one side contracts it draws the head towards the shoulder. When both contract at the same time they flex the cervical vertebrae or draw the sternum and clavicles upwards when the head is maintained in a fixed position, e.g. in forced respiration.

Trapezius. This muscle covers the shoulder and the back of the neck. The upper attachment is to the occipital protuberance, the medial attachment is to the transverse processes of the cervical and thoracic vertebrae and the lateral attachment is to the clavicle and to the spinous and acromion processes of the scapula. It pulls the head backwards, squares the shoulders and controls the movements of the scapula when the shoulder joint is in use.

Muscles of the trunk

These muscles stabilise the association between the appendicular and axial skeletons at the pectoral girdle, and stabilise and allow movement of the shoulders and upper arms.

Muscles of the back

There are six pairs of large muscles in the back, in addition to those forming the posterior abdominal wall (Figs 16.59–16.61). The arrangement of these muscles is the same on each side of the vertebral column. They are:

- trapezius (see above)
- latissimus dorsi
- teres major
- psoas (p. 429)
- quadratus lumborum
- sacrospinalis.

Latissimus dorsi. This arises from the posterior part of the iliac crest and the spinous processes of the lumbar and lower thoracic vertebrae. It passes upwards across the back then under the arm to be inserted into the bicipital groove of the humerus. It adducts, medially rotates and extends the arm.

Teres major. This originates from the inferior angle of the scapula and is inserted into the humerus just below the shoulder joint. It extends, adducts and medially rotates the arm.

Quadratus lumborum. This muscle originates from the iliac crest, then it passes upwards, parallel and close to the vertebral column and it is inserted into the 12th rib

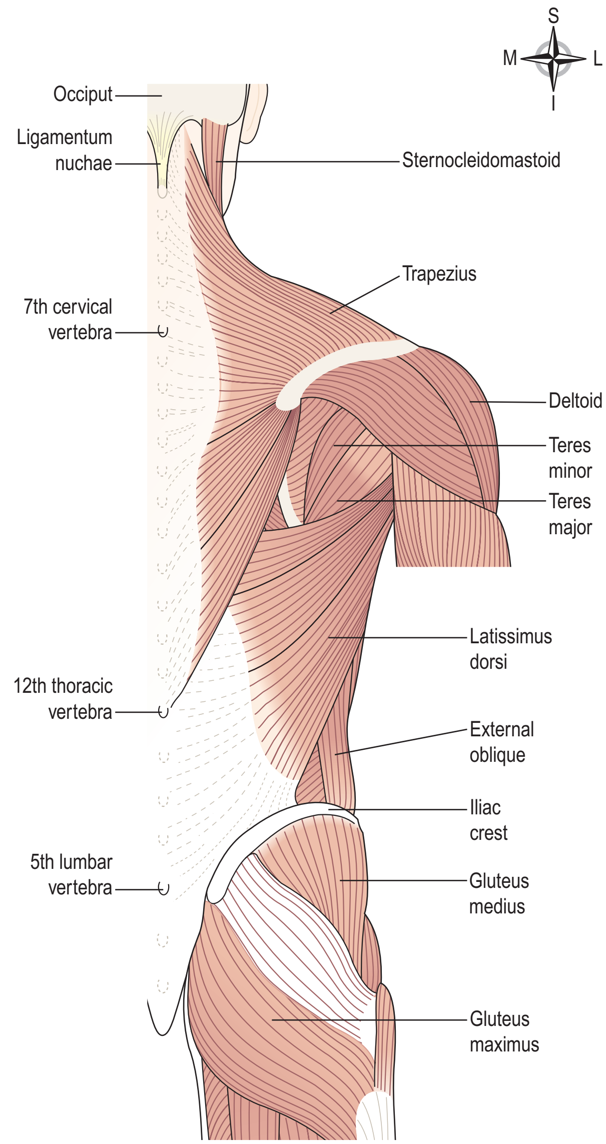

Figure 16.59 The main muscles of the back. Right side.

(Fig. 16.60). Together the two muscles fix the lower rib during respiration and cause extension of the vertebral column (bending backwards). If one muscle contracts it causes lateral flexion of the lumbar region of the vertebral column.

Sacrospinalis (erector spinae). This is a group of muscles lying between the spinous and transverse processes of the vertebrae (Fig. 16.61). They originate from the sacrum and are finally inserted into the occipital bone. Their contraction causes extension of the vertebral column.

Muscles of the abdominal wall

Five pairs of muscles form the abdominal wall (Figs 16.62 and 16.63). From the surface inwards they are:

- rectus abdominis
- external oblique

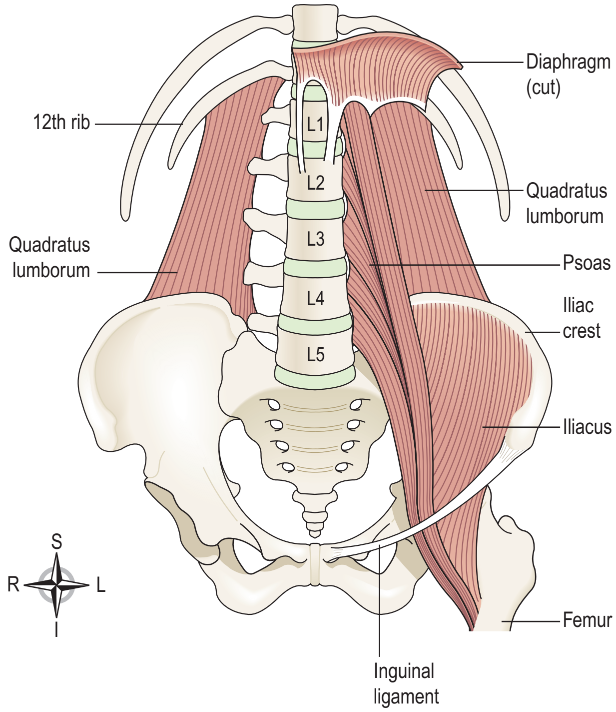

Figure 16.60 The deep muscles of the posterior abdominal wall. Anterior view.

- internal oblique
- transversus abdominis
- quadratus lumborum (see above).

The main function of these paired muscles is to form the strong muscular anterior wall of the abdominal cavity. When the muscles contract together they:

- compress the abdominal organs
- flex the vertebral column in the lumbar region (Fig. 16.61).

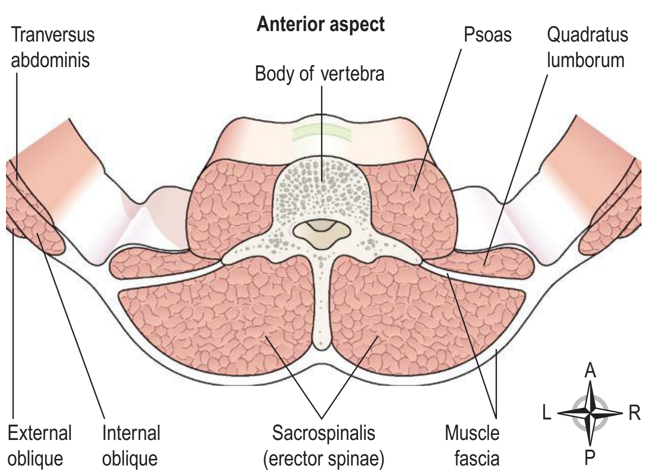

Figure 16.61 Transverse section of the posterior abdominal wall: a lumbar vertebra and its associated muscles.

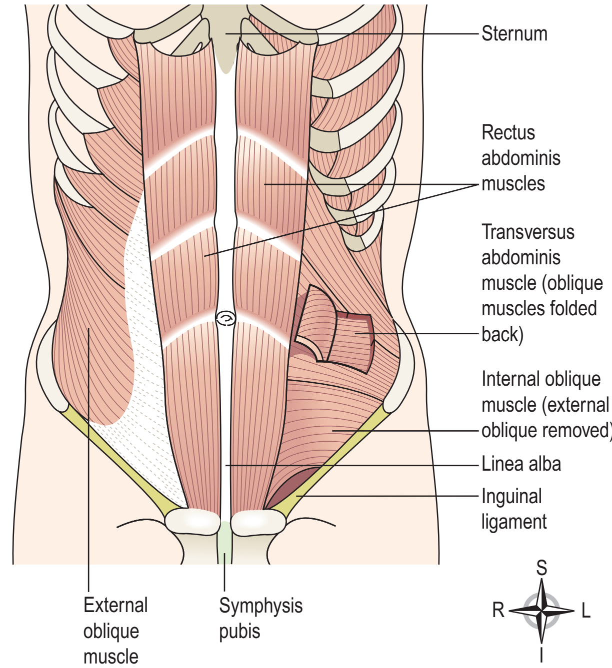

Figure 16.62 The muscles of the anterior abdominal wall.

Contraction of the muscles on one side only bends the trunk towards that side. Contraction of the oblique muscles on one side rotates the trunk.

The anterior abdominal wall is divided longitudinally by a very strong midline tendinous cord, the *linea alba* (meaning 'white cord') which extends from the xiphoid process of the sternum to the symphysis pubis.

Rectus abdominis. This is the most superficial muscle. It is broad and flat, originating from the transverse part of the pubic bone then passing upwards to be inserted into the lower ribs and the xiphoid process of the sternum. Medially the two muscles are attached to the linea alba.

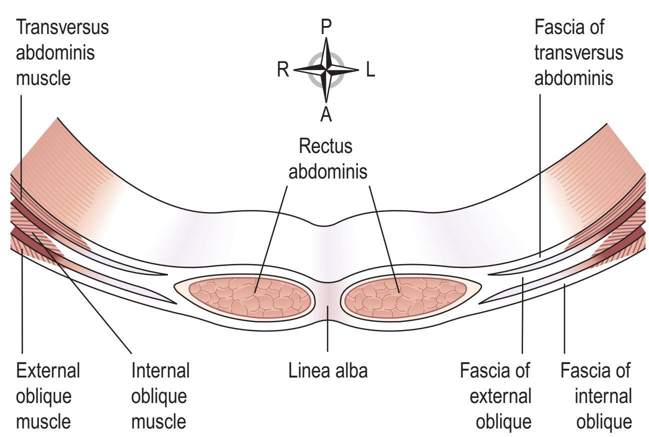

Figure 16.63 Transverse section of the muscles and fasciae of the anterior abdominal wall.

External oblique. This muscle extends from the lower ribs downwards and forward to be inserted into the iliac crest and, by an aponeurosis, to the linea alba.

Internal oblique. This muscle lies deep to the external oblique. Its fibres arise from the iliac crest and by a broad band of fascia from the spinous processes of the lumbar vertebrae. The fibres pass upwards towards the midline to be inserted into the lower ribs and, by an aponeurosis, into the linea alba. The fibres are at right angles to those of the external oblique.

Transversus abdominis. This is the deepest muscle of the abdominal wall. The fibres arise from the iliac crest and the lumbar vertebrae and pass across the abdominal wall to be inserted into the linea alba by an aponeurosis. The fibres are at right angles to those of the rectus abdominis.

Inguinal canal

This canal is 2.5–4 cm long and passes obliquely through the abdominal wall. It runs parallel to and immediately in front of the transversalis fascia and part of the inguinal ligament (Fig. 16.60). In the male it contains the *spermatic cord* and in the female, the *round ligament*. It constitutes a weak point in the otherwise strong abdominal wall through which herniation may occur.

Muscles of the thorax

These muscles are concerned with respiration, and are discussed in Chapter 10.

Muscles of the pelvic floor (Fig. 16.64)

The pelvic floor is divided into two identical halves that unite along the midline. Each half consists of fascia and muscle. The muscles are the levator ani and the coccygeus.

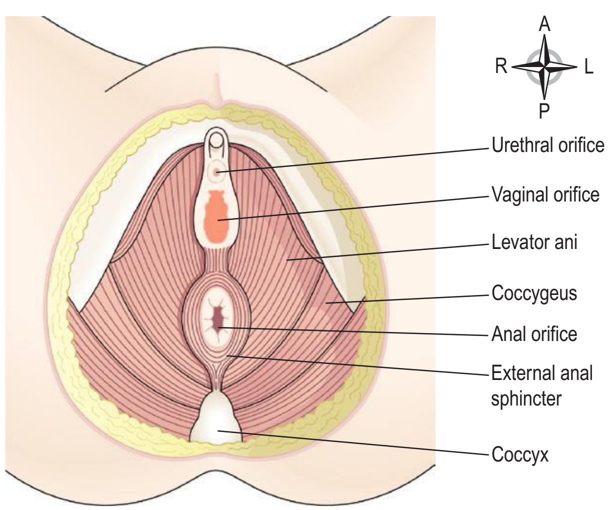

Figure 16.64 The muscles of the female pelvic floor.

The pelvic floor supports the organs of the pelvis and maintains continence, i.e. it resists raised intrapelvic pressure during micturition and defaecation.

Levator ani. This is a pair of broad flat muscles, forming the anterior part of the pelvic floor. They originate from the inner surface of the true pelvis and unite in the midline. Together they form a sling that supports the pelvic organs.

Coccygeus. This is a paired triangular sheet of muscle and tendinous fibres situated behind the levator ani. They originate from the medial surface of the ischium and are inserted into the sacrum and coccyx. They complete the formation of the pelvic floor, which is perforated in the male by the urethra and anus, and in the female by the urethra, vagina and anus.

Muscles of the shoulder and upper limb (Fig. 16.65)

These muscles stabilise the association between the appendicular and axial skeletons at the pectoral girdle, and stabilise and allow movement of the shoulders and upper arms.

Deltoid. These muscle fibres originate from the clavicle, acromion process and spine of scapula and radiate over the shoulder joint to be inserted into the deltoid tuberosity of the humerus. It forms the fleshy and rounded contour of the shoulder and its main function is movement of the arm. The anterior part causes flexion, the middle or main part abduction and the posterior part extends and laterally rotates the shoulder joint.

Pectoralis major. This lies on the anterior thoracic wall. The fibres originate from the middle third of the clavicle and from the sternum and are inserted into the lip of the intertubercular groove of the humerus. It draws the arm forward and towards the body, i.e. flexes and adducts.

Coracobrachialis. This lies on the upper medial aspect of the arm. It arises from the coracoid process of the scapula, stretches across in front of the shoulder joint and is inserted into the middle third of the humerus. It flexes the shoulder joint.

Biceps. This lies on the anterior aspect of the upper arm. At its proximal end it is divided into two parts (heads), each of which has its own tendon. The short head rises from the coracoid process of the scapula and passes in front of the shoulder joint to the arm. The long head originates from the rim of the glenoid cavity and its tendon passes through the joint cavity and the bicipital groove of the humerus to the arm. It is retained in the bicipital groove by a transverse humeral ligament that stretches across the groove. The distal tendon crosses the elbow joint and is inserted into the radial tuberosity. It helps to stabilise and flex the shoulder joint and at the elbow joint it assists with flexion and supination.

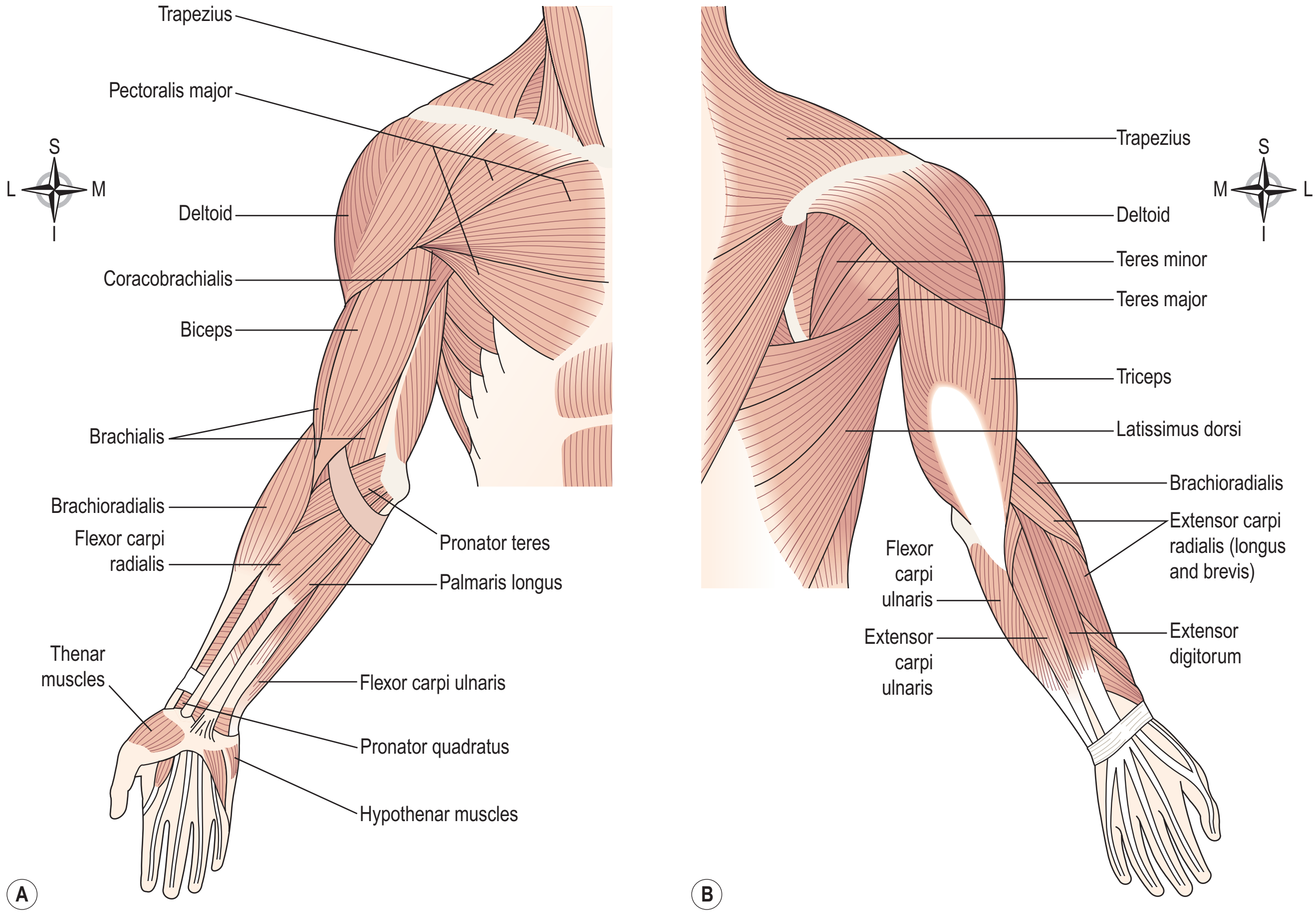

Figure 16.65 The main muscles of the right shoulder and upper limb. A. Anterior view. **B.** Posterior view.

Brachialis. This lies on the anterior aspect of the upper arm deep to the biceps. It originates from the shaft of the humerus, extends across the elbow joint and is inserted into the ulna just distal to the joint capsule. It is the main flexor of the elbow joint.

Triceps. This lies on the posterior aspect of the humerus. It arises from three heads, one from the scapula and two from the posterior surface of the humerus. The insertion is by a common tendon to the olecranon process of the ulna. It helps to stabilise the shoulder joint, assists in adduction of the arm and extends the elbow joint.

Brachioradialis. The brachioradialis spans the elbow joint, originating on the distal end of the humerus and inserts on the lateral epicondyle of the radius. Contraction flexes the elbow joint.

Pronator quadratus. This square-shaped muscle is the main muscle causing pronation of the hand and has attachments on the lower sections of both the radius and the ulna.

Pronator teres. This lies obliquely across the upper third of the front of the forearm. It arises from the medial epicondyle of the humerus and the coronoid process of the ulna and passes obliquely across the forearm to be inserted into the lateral surface of the shaft of the radius. It rotates the radioulnar joints, changing the hand from the anatomical to the writing position, i.e. pronation.

Supinator. This lies obliquely across the posterior and lateral aspects of the forearm. Its fibres arise from the lateral epicondyle of the humerus and the upper part of the ulna and are inserted into the lateral surface of the upper third of the radius. It rotates the radioulnar joints, often with help from the biceps, changing the hand from the writing to the anatomical position, i.e. supination. It lies deep to the muscles shown in Figure 16.65.

Flexor carpi radialis. This lies on the anterior surface of the forearm. It originates from the medial epicondyle of the humerus and is inserted into the second and third metacarpal bones. It flexes the wrist joint, and when acting with the extensor carpi radialis, abducts the joint.

Flexor carpi ulnaris. This lies on the medial aspect of the forearm. It originates from the medial epicondyle of the humerus and the upper parts of the ulna and is inserted into the pisiform, the hamate and the fifth metacarpal bones. It flexes the wrist, and when acting with the extensor carpi ulnaris, adducts the joint.

Extensor carpi radialis longus and brevis. These lie on the posterior aspect of the forearm. The fibres originate from the lateral epicondyle of the humerus and are inserted by a long tendon into the second and third metacarpal bones. They extend and abduct the wrist.

Extensor carpi ulnaris. This lies on the posterior surface of the forearm. It originates from the lateral epicondyle of the humerus and is inserted into the fifth metacarpal bone. It extends and adducts the wrist.

Palmaris longus. This muscle resists shearing forces that might pull the skin and fascia of the palm away from the underlying structures, and flexes the wrist. Its origin is on the medial epicondyle of the humerus, and it inserts on tendons on the palm of the hand.

Extensor digitorum. This muscle originates on the lateral epicondyle of the humerus and spans both the elbow and wrist joints; in the wrist, it divides into four tendons, one for each finger. Action of this muscle can extend any of the joints across which it passes, i.e. the elbow, wrist or finger joints.

Muscles that control finger movements. Large muscles in the forearm that extend to the hand give power to the hand and fingers, but not the delicacy of movement needed for fine and dexterous finger control. Smaller muscles, which originate on the carpal and metacarpal bones, control tiny and precise finger movements via tendinous attachments on the phalanges; muscle fibres do not extend into the fingers.

Muscles of the hip and lower limb (Fig. 16.66)

The biggest muscles of the body are found here, since their function is largely in weight bearing. The lower parts of the body are designed to transmit the force of body weight in walking, running, etc., evenly throughout weight-bearing structures, and act as shock absorbers.

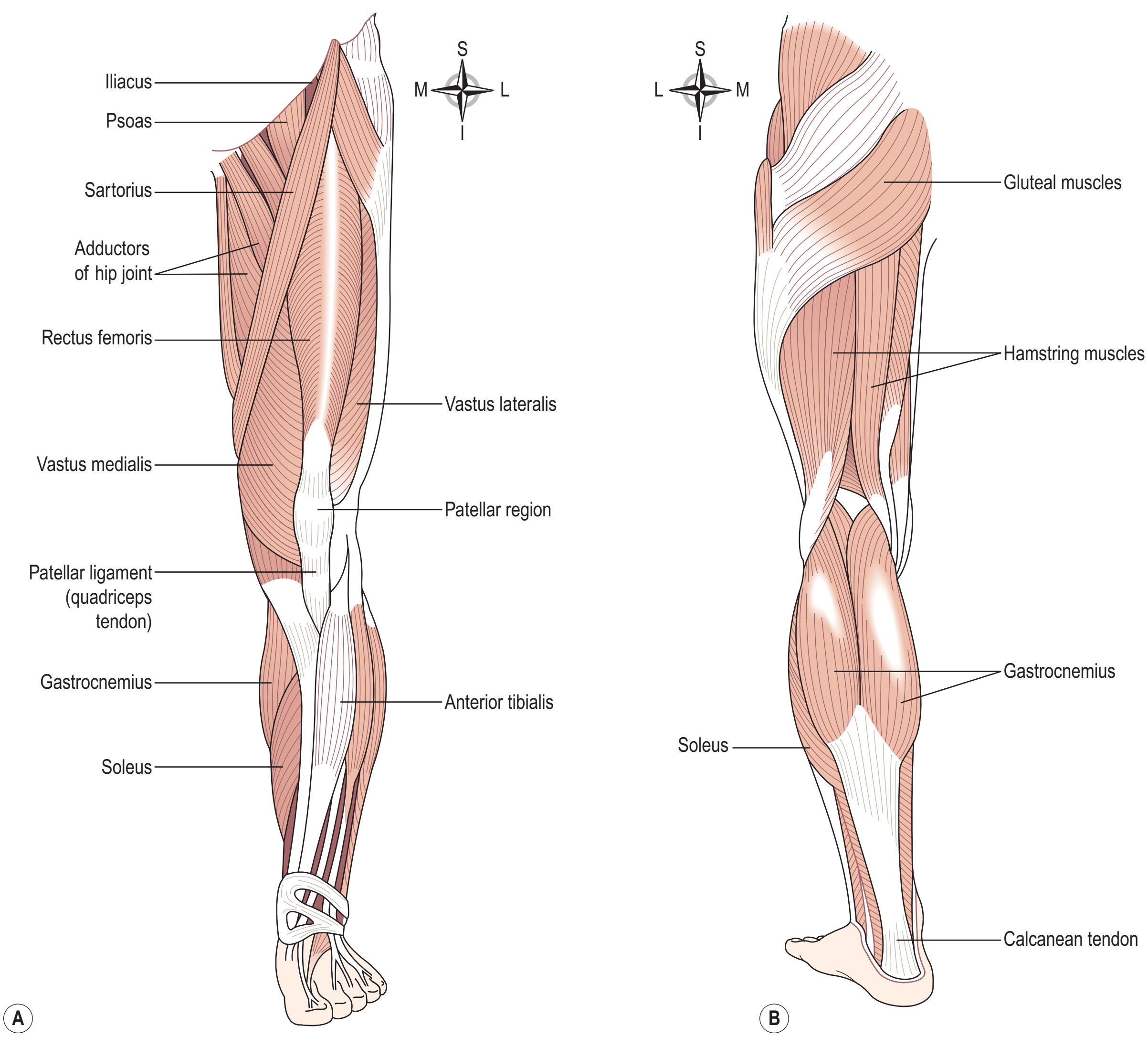

Figure 16.66 The main muscles of the left lower limb. A. Anterior view. **B.** Posterior view.

Psoas. This arises from the transverse processes and bodies of the lumbar vertebrae. It passes across the flat part of the ilium and behind the inguinal ligament to be inserted into the femur. Together with the iliacus it flexes the hip joint (see Fig. 16.60).

Iliacus. This lies in the iliac fossa of the innominate bone. It originates from the iliac crest, passes over the iliac fossa and joins the tendon of the psoas muscle to be inserted into the lesser trochanter of the femur. The combined action of the iliacus and psoas flexes the hip joint.

Quadriceps femoris. This is a group of four muscles lying on the front and sides of the thigh. They are the *rectus femoris* and three *vasti*: lateralis, medialis and intermedius (this last muscle is not shown in Figure 16.66 because it lies deep to the other two). The rectus femoris originates from the ilium and the three vasti from the upper end of the femur. Together they pass over the front of the knee joint to be inserted into the tibia by the patellar tendon. Only the rectus femoris flexes the hip joint. Together, the group acts as a very strong extensor of the knee joint.

Obturators. The obturators, deep muscles of the buttock, have their origins in the rim of the obturator foramen of the pelvis and insert into the proximal femur. Their main function lies in lateral rotation at the hip joint.

Gluteals. These consist of the *gluteus maximus*, *medius* and *minimus*, which together form the fleshy part of the buttock. They originate from the ilium and sacrum and are inserted into the femur. They cause extension, abduction and medial rotation at the hip joint.

Sartorius. This is the longest muscle in the body and crosses both the hip and knee joints. It originates from the anterior superior iliac spine and passes obliquely across the hip joint, thigh and knee joint to be inserted into the medial surface of the upper part of the tibia. It is associated with flexion and abduction at the hip joint and flexion at the knee.

Adductor group. This lies on the medial aspect of the thigh. They originate from the pubic bone and are inserted into the linea aspera of the femur. They adduct and medially rotate the thigh.

Hamstrings. These lie on the posterior aspect of the thigh. They originate from the ischium and are inserted into the upper end of the tibia. They are the *biceps femoris*, *semimembranosus* and *semitendinosus muscles*. They flex the knee joint.

Gastrocnemius. This forms the bulk of the calf of the leg. It arises by two heads, one from each condyle of the femur, and passes down behind the tibia to be inserted into the calcaneus by the *calcanean tendon* (*Achilles tendon*). It crosses both knee and ankle joints, causing flexion at the knee and plantarflexion (rising onto the ball of the foot) at the ankle.

Anterior tibialis. This originates from the upper end of the tibia, lies on the anterior surface of the leg and is inserted into the middle cuneiform bone by a long tendon. It is associated with dorsiflexion of the foot.

Soleus. This is one of the main muscles of the calf of the leg, lying immediately deep to the gastrocnemius. It originates from the heads and upper parts of the fibula and the tibia. Its tendon joins that of the gastrocnemius so that they have a common insertion into the calcaneus by the calcanean (Achilles) tendon. It causes plantarflexion at the ankle and helps to stabilise the joint when standing.

Ageing and the musculoskeletal system

Learning outcome

After reading this section, you should be able to:

- describe the effects of ageing on the structure and function of the musculoskeletal system.

Bone tissue in old age becomes lighter and less dense, so fractures are more likely. This natural process is called *osteopenia* and begins between the ages of 30 and 40. Oestrogen protects against the loss of bone mass, and there is a significant acceleration in the process in post-menopausal women, predisposing to osteoporosis (p. 431). Compaction of the intervertebral discs reduces the length of the spinal column and leads to a shortening in stature.

Cartilage and other connective tissues stiffen and may degenerate with age, leading to reduced flexibility and mobility of joints and predisposing to osteoarthritis (p. 434). Skeletal muscle fibres become smaller, less elastic and take longer to repair following injury. Damaged muscle may be replaced with fibrous tissue, which is inelastic and reduces the strength of contraction. Exercise tolerance reduces because each cell stores less glucose and myoglobin, and as cardiovascular function declines, regulation of blood supply to muscle becomes less efficient. In addition, older adults cannot lose the heat generated by working muscle as effectively as younger people.

Regular exercise throughout life can significantly slow these age-related changes.

Diseases of bone

Learning outcomes

After studying this section, you should be able to:

- explain the pathological features of osteoporosis, Paget's disease, rickets and osteomalacia
- outline the causes and effects of osteomyelitis
- describe abnormalities of bone development
- explain the effects of bone tumours.

Osteoporosis

In this condition, bone density (the amount of bone tissue) is reduced because its deposition does not keep pace with resorption (Fig. 16.67). Although the bone is adequately mineralised, it is fragile and microscopically abnormal, with loss of internal structure. Peak bone mass occurs around 35 years and then gradually declines in both sexes. Lowered oestrogen levels after the menopause are associated with a period of accelerated bone loss in women. Thereafter bone density in women is less than in men for any given age. A range of environmental factors and diseases are also associated with decreased bone mass and are implicated in development of osteoporosis (Box 16.1). Some can be influenced by changes in lifestyle. Exercise and calcium intake during childhood and adolescence are thought to be important in determining eventual bone mass of an individual, and therefore the risk of osteoporosis in later life. As bone mass decreases, susceptibility to fractures increases. Immobility causes reversible osteoporosis, the extent of which corresponds to the length and degree of immobility. For instance, during prolonged periods of unconsciousness, osteoporotic changes are uniform throughout the skeleton, but immobilisation of a particular joint following fracture leads to local osteoporotic changes in involved bones only.

Common features of osteoporosis are:

- skeletal deformity – gradual loss of height with age, caused by compression of vertebrae
- bone pain
- fractures – especially of the hip (neck of femur), wrist (Colles' fracture) and vertebrae.

Figure 16.67 Osteoporosis. Scanning electron micrograph of spongy bone.

Paget's disease

Paget's disease is a disorder of bone remodelling, where the normal balance between bone building and bone breakdown becomes disorganised and both osteoblasts and osteoclasts become abnormally active. The bone deposited is soft and structurally abnormal. This predisposes to deformities (Fig. 16.68) and fractures, commonly of the pelvis, femur, tibia and skull. Most cases occur after 40 years of age and the incidence increases with age. The cause is unknown and it often goes undetected until complications arise. The disease increases the risk of osteoarthritis (p. 434) and osteosarcoma.

Rickets and osteomalacia

In both conditions, bone is inadequately mineralised, usually because of vitamin D deficiency, or sometimes because of defective vitamin D metabolism. Rickets occurs in children, whose bones are still growing, leading to characteristic bowing and deformity of the lower limbs. Adults still require vitamin D for normal turnover of bone, and deficiency leads to osteomalacia, which is associated with increased risk of fracture and bone pain.

Box 16.1 Causes of decreased bone mass

Risk factors	Drugs
Female gender	Corticosteroids
Increasing age	
White ethnic origin	**Diseases**
Family history	Cushing's syndrome
Lack of exercise/ immobility	Hyperparathyroidism
Diet (low calcium)	Type 1 diabetes mellitus
Smoking	Rheumatoid arthritis
Excess alcohol intake	Chronic renal failure
Early menopause/ oophorectomy	Chronic liver disease
Thin build (small bones)	Anorexia nervosa
	Certain cancers

Figure 16.68 Severe leg deformity in Paget's disease.

Deficiency may be caused by poor diet, malabsorption, or by limited exposure to sunlight (needed for normal vitamin D metabolism).

Osteomyelitis

This is bacterial infection of bone and may follow an open fracture or surgical procedures, which allow microbial entry through broken skin. It may also be a consequence of blood-borne infection from a focus elsewhere, such as the ear, throat or skin; this is most commonly seen in children. If promptly and adequately treated, the infection can resolve without permanent damage, but if not, it may become chronic, with sinus formation draining pus to the skin, fever and pain.

Developmental abnormalities of bone

Achondroplasia

This is caused by a genetic abnormality that prevents the proper ossification of bones that develop from cartilage models, such as the long bones of the limbs, leading to short limbs and characteristic dwarfism.

Osteogenesis imperfecta ('brittle bone syndrome')

This is a group of conditions in which there is a congenital defect of collagen synthesis, resulting in failure of ossification. The bones are brittle and fracture easily, either spontaneously or following very slight trauma.

Tumours of bone

Benign tumours

Single or multiple tumours may develop for unknown reasons in bone and cartilage. They may cause pathological fractures or pressure damage to soft tissues, e.g. a benign vertebral tumour may damage the spinal cord or a spinal nerve. Benign tumours of cartilage have a tendency to undergo malignant change.

Malignant tumours

Metastatic tumours

The most common malignancies of bone are metastases of primary carcinomas of the breast, lungs, thyroid, kidneys and prostate gland. The usual sites are those with the best blood supply, i.e. spongy bone, especially the bodies of the lumbar vertebrae and the epiphyses of the humerus and femur. Tumour fragments are spread in blood, and possibly along the walls of the veins from pelvic tumours to vertebrae. Tumour growth erodes and weakens normal bone tissue, leading to pain, pathological fractures and destruction of normal bone architecture.

Primary tumours

Primary malignant tumours of bone are relatively rare. *Osteosarcoma* is rapidly growing and often highly malignant. It is commonest in adolescence and usually develops in the medullary canal of long bones, especially the femur. It occasionally occurs in elderly people, generally in association with Paget's disease, and involving the vertebrae, skull and pelvis.

Disorders of joints

Learning outcomes

After studying this section, you should be able to:

- relate the features of the diseases in this section to abnormal anatomy and physiology
- compare and contrast the features of rheumatoid arthritis and osteoarthritis.

The tissues involved in diseases of the synovial joints are synovial membrane, hyaline cartilage and bone.

Inflammatory joint disease (arthritis)

Rheumatoid arthritis (RA, rheumatoid disease)

This is a chronic progressive inflammatory autoimmune disease mainly affecting peripheral synovial joints. It is a systemic disorder in which inflammatory changes affect not only joints but also many other sites including the heart, blood vessels and skin.

It is more common in females than males and can affect all ages, including children (Still's disease), although it usually develops between the ages of 35 and 55 years. The cause is not clearly understood but autoimmunity may be initiated by microbial infection, possibly by viruses, in genetically susceptible people. Risk factors include:

- age – risk increases with age
- gender – premenopausal women are affected three times as commonly as men
- genetic risk – there is a strong familial link in some cases, and some markers on the surface membranes of white blood cells have also been associated with higher risk of the disease.

Up to 90% of affected individuals have rheumatoid factor (RF-autoantibodies) in their body fluids. High levels of RF, especially early in the disease, are strongly associated with accelerated and more severe disease. Symptoms include joint pain and stiffness, particularly in the morning and after rest. Joints can be visibly swollen, hot and tender.

Acute exacerbations of rheumatoid arthritis are usually accompanied by fever, and are interspersed with periods of remission. The joints most commonly affected are those of the hands (Fig. 16.69) and feet, but in severe cases most synovial joints may be involved. With each exacerbation there is additional and cumulative damage to the joints, leading to increasing deformity, pain and loss of function. The early changes, which may be reversible, include hypertrophy and hyperplasia of synovial cells and fibrinous inflammatory effusion into the joint. Progression of the disease usually leads to permanent tissue damage. Growth of inflammatory granulation tissue, called *pannus*, distorts the joint and destroys articular cartilage, exposing the bone below and causing further damage. Fibrosis of the pannus reduces joint mobility. Pain, stiffness and deformity severely restrict the use of affected joints, and as a result the associated muscles start to waste. About a third of patients, usually those with the most aggressive form of the disease, develop nodules of connective tissue (rheumatoid nodules), usually in the forearm or elbow. Extra-articular symptoms can include anaemia, peripheral neuropathy, cardiac abnormalities, pleurisy and vasculitis.

In the later stages of the disease, the inflammation and fever are less marked. The extent of disability varies from slight to severe. Table 16.8 highlights differences between osteoarthritis and rheumatoid arthritis.

Figure 16.69 Severe deformity of the hands in rheumatoid arthritis.

Other types of polyarthritis

Polyarthritis means inflammation of more than one joint. This group of autoimmune inflammatory arthritic diseases has many characteristics similar to RA but the rheumatoid factor is absent. The causes are not known but genetic features may be involved.

Ankylosing spondylitis. This tends to occur in young adults, and affects the joints of the vertebral column. Calcification of the intervertebral joints and laying down of new bone leads to reduced spinal flexibility and permanent deformity.

Psoriatic arthritis. This occurs in a proportion of people who suffer from psoriasis (p. 371), especially if the nails are involved. The joints most commonly affected are those of the fingers and toes.

Reiter's syndrome (polyarthritis with urethritis and conjunctivitis). This syndrome may be precipitated by *Chlamydia trachomatis* infection; the affected joints are usually those of the lower limb.

Table 16.8 Features of the two main types of arthritis

	Osteoarthritis	Rheumatoid arthritis
Type of disease	Degenerative	Inflammatory and autoimmune
Tissue affected	Articular cartilage	Synovial membrane
Age of onset	Late middle age	Any age, mainly 30–55 years, occasionally children
Joints affected	Weight bearing, e.g. hip, knee; often only a single joint	Small, e.g. hands, feet; often many joints

Rheumatic fever. Rheumatic fever (p. 128) is a diffuse inflammatory condition that affects many connective tissues. Polyarthritis is a common presenting feature, often involving the wrists, elbows, knees and ankles. Unlike cardiac effects (p. 128), arthritis usually resolves spontaneously without complications.

Infective arthritis

Joint infection (septic arthritis) usually results from a blood-borne systemic infection (septicaemia, mainly staphylococcal), although it may also be caused by a penetrating joint injury. Often the joint has been damaged by pre-existing disease, making it more susceptible to infection. Normally, only one joint is involved, which becomes acutely inflamed, and the patient is likely to be ill from the associated septicaemia. Complete resolution is possible if treatment is prompt, but permanent joint damage occurs early in the disease.

Osteoarthritis (osteoarthrosis, OA)

This is a degenerative non-inflammatory disease that results in pain and restricted movement of affected joints. Osteoarthrosis is the more appropriate name but is less commonly used. In its early stages, OA is often asymptomatic. It is very common, with the majority of over-65s showing some degree of osteoarthritic changes. Articular cartilage gradually becomes thinner because its renewal does not keep pace with its breakdown. Eventually the bony articular surfaces come in contact and the bones begin to degenerate. Bone repair is abnormal and the articular surfaces become misshapen, reducing mobility of the joint. Chronic inflammation develops with effusion (collection of fluid) into the joint, possibly due to irritation caused by tissue debris not removed by phagocytes. Sometimes there is abnormal outgrowth of cartilage at the edges of bones that becomes ossified, forming *osteophytes*.

In most cases, the cause of OA is unknown (primary OA), but risk factors include excessive repetitive use of the affected joints, female gender, increasing age, obesity and heredity. Secondary OA occurs when the joint is already affected by disease or abnormality, e.g. trauma or gout. Osteoarthritis usually develops in late middle age and affects large weight-bearing joints, i.e. the hips, knees and joints of the cervical and lower lumbar spine. In many cases only one joint is involved.

Traumatic injury to joints

Sprains, strains and dislocations

These damage the soft tissues, tendons and ligaments round the joint without penetrating the joint capsule. In dislocations there may be additional damage to intracapsular structures by stretching, e.g. to the long head of biceps muscle in the shoulder joint, the cruciate ligaments in the knee joint, or the ligament of head of femur in the hip joint. If repair is incomplete there may be some loss of stability, which increases the risk of repeated injury.

Penetrating injuries

These may be caused by a compound fracture of one of the articulating bones, or trauma. Healing may be uneventful or delayed by the presence of fragments of damaged or torn joint tissue (bone, cartilage or ligaments), which cannot be removed or repaired by normal body mechanisms and prevent full joint recovery. Infection is another risk. Chronic inflammation can lead to permanent degenerative changes in the joint.

Gout

This condition is caused by the deposition of sodium urate crystals in joints and tendons, provoking an acute inflammatory response. Risk factors include male gender, obesity, heredity, hyperuricaemia and high alcohol intake. *Primary* gout, the commonest form, occurs almost always in men and is associated with reduced ability to excrete urate or increased urate production. *Secondary* gout occurs usually as a consequence of diuretic treatment or kidney failure, both of which reduce urate excretion.

In many cases only one joint is involved (monoarthritis) and it is typically red, hot and extremely painful. The sites most commonly affected are the metatarsophalangeal joint of the big toe and the ankle, knee, wrist and elbow joints. Episodes of arthritis lasting days or weeks are interspersed with periods of remission. After repeated acute attacks, permanent damage may occur with chronic deformity and loss of function of the affected joints. Gout is sometimes complicated by the development of renal calculi.

Connective tissue diseases

This group of chronic autoimmune disorders has common features. They:

- affect many systems of the body, especially the joints, skin and subcutaneous tissues
- tend to occur in early adult life
- usually affect more females than males.

They include the following:

- *Systemic lupus erythematosus* (SLE) – the affected joints are usually the hands, knees and ankles. A characteristic red 'butterfly' rash may occur on the face. Kidney involvement is common and can result in glomerulonephritis that may be complicated by chronic renal failure.
- *Systemic sclerosis* (*scleroderma*) – in this group of disorders there is progressive thickening of connective tissue. There is increased production of collagen that affects many organs. In the skin there is dermal

fibrosis and tightness that impairs the functioning of joints, especially of the hands. It also affects the walls of blood vessels, intestinal tract and other organs.
- Rheumatoid arthritis (p. 432).
- Ankylosing spondylitis (p. 433).
- Reiter's syndrome (p. 433).

Carpal tunnel syndrome

This occurs when the median nerve is compressed in the wrist as it passes through the carpal tunnel (see Fig. 16.50). It is common, especially in women, between the ages of 30 and 50 years. There is pain and numbness in the hand and wrist affecting the thumb, index and middle fingers, and half of the ring finger. Many cases are idiopathic or secondary to other conditions, e.g. rheumatoid arthritis, diabetes mellitus, acromegaly and hypothyroidism. Repetitive flexion and extension of the wrist joint also cause the condition, e.g. following prolonged keyboard use.

Diseases of muscle

Learning outcomes

After studying this section, you should be able to:

- list the causes of the diseases in this section
- compare and contrast the characteristics of different types of muscular dystrophy.

Myasthenia gravis

This autoimmune condition of unknown origin affects more women than men, usually aged between 20 and 40 years. Antibodies are produced that bind to and block the acetylcholine receptors of the neuromuscular junction. The transmission of nerve impulses to muscle fibres is therefore blocked. This causes progressive and extensive muscle weakness, although the muscles themselves are normal. Extrinsic and eyelid muscles are affected first, causing *ptosis* (drooping of the eyelid) or *diplopia* (double vision), followed by those of the neck (possibly affecting chewing, swallowing and speech) and limbs. There are periods of remission, relapses being precipitated by, for example, strenuous exercise, infections or pregnancy.

Muscular dystrophies

In this group of inherited diseases there is progressive degeneration of groups of muscles. The main differences in the types are age of onset, rate of progression and groups of muscles involved.

Duchenne muscular dystrophy

Inheritance of this condition is sex linked (p. 444).

Signs and symptoms may not appear until about 5 years of age. Wasting and weakness begin in muscles of the lower limbs then spread to the upper limbs, progressing rapidly without remission. Death usually occurs in adolescence, often from respiratory failure, cardiac arrhythmias or cardiomyopathy.

Facioscapulohumeral dystrophy

This disease affects both sexes. It usually begins in adolescence and the younger the age of onset the more rapidly it progresses. Muscles of the face and shoulders are affected first. This is a chronic condition that usually progresses slowly and may not cause complete disability. Life expectancy is normal.

Myotonic dystrophy

This disease usually begins in adult life and affects both genders. Muscles contract and relax slowly, often seen as difficulty in releasing an object held in the hand. Muscles of the tongue and the face are first affected, then muscles of the limbs. Systemic conditions associated with myotonic dystrophy include:

- cataracts (p. 211)
- atrophy of the gonads
- cardiomyopathy
- glucose intolerance.

The disease progresses without remission and with increasing disability. Death usually occurs in middle age from respiratory or cardiac failure.

Rotator cuff injury

The rotator cuff muscles (p. 415) stabilise and strengthen the shoulder joint. Injury here is common, leading to pain and restricted mobility of the shoulder. Healing can take months or even years.

For a range of self-assessment exercises on the topics in this chapter, visit Evolve online resources: https://evolve.elsevier.com/Waugh/anatomy/