Part 1

General Principles

Chapter 1

Musculoskeletal structures and function

The skeletal structures

Modern orthopaedics is concerned with the diagnosis and management of disorders of the musculoskeletal system, that is the skeleton and the soft tissues associated with it. Worldwide, orthopaedic surgeons deal with both injuries of the musculoskeletal system, particularly fractures, as well as non-traumatic conditions. Subspecialization within orthopaedics is increasingly common and can be organized by patient age (e.g. paediatric orthopaedics), by region (e.g. hip surgery) or by condition (e.g. rheumatoid surgery). Alternatively, orthopaedics can be considered in terms of the structures with which it is primarily concerned. A knowledge of the anatomy, physiology and pathology of these structures and tissues forms a logical starting point for studying the clinical aspects of the subject.

The connective tissues

The connective tissues of the body are composed of cells embodied in a matrix which varies in its quantity and composition. The cells can be categorized by the nature of the intercellular material, of which there are three types:

- **Bony**—osteoid (produced by osteoblasts)
- **Cartilaginous**—chondroid (produced by chondroblasts)
- **Fibrous**—collagenous tissue (produced by fibroblasts).

Structure

In each case the matrix is mainly composed of a complex mixture of proteoglycans and glycoproteins, forming a ground substance in which is embedded a meshwork of fibrils, mostly of collagen, a protein. At least four genetically different types of collagen are now recognized—bone contains Type I and hyaline cartilage Type II. Skin contains Types I and III and, being a convenient tissue for biopsy, is used for the study of certain collagen-related bone diseases. Elastin, a different protein, is found within skin and to a lesser extent in tendon.

Matrix disorders cause a wide variety of clinical manifestations. For example, in the so-called 'mucopolysaccharoidoses' (see p. 68), an enzyme deficiency interferes with the breakdown of large mucopolysaccharide molecules, which accumulate in the tissues causing widespread abnormalities.

Connective tissues grow by cell proliferation and deposition of intercellular material.

Physiology

The connective tissues are by no means inert and they play an important role in biochemical processes in the body.

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Ground substance is an important water-binding agent and acts as an ion-exchange resin in controlling the passage of electrolytes. Its deposition is influenced by many factors, such as hormones and vitamins, and its composition reflects abnormalities in the supply of these factors.

Cartilage 'turnover' is the subject of much research. It is controlled by a complex interaction of different enzymes, some of which promote and others suppress chondrocyte function. Thus, balanced synthesis and degradation of the ground substance has been shown to continue throughout life.

Bone is known to play a vital role in metabolism, mainly because of its calcium and phosphate content. These minerals enter into the formation of crystals of hydroxyapatite and their deposition is sensitive to many influences. Diseases such as rickets, osteomalacia and hyperparathyroidism are associated with dramatic changes in bone development.

Demineralization of bone results in loss of bone strength and may be caused by diminished matrix formation, inadequate calcification or bone resorption. The latter occurs as a result of the activity of special cells—*osteoclasts*—which remove both the organic and inorganic components. The radiographic appearances of loss of density are similar whatever the cause of the demineralization, and these appearances give rise to the term 'osteoporosis', although specific scans (dual energy X-ray absorption [DEXA] scan) are required to make a definitive diagnosis of osteoporosis.

Bone

Macroscopic structure

A long bone is characteristically tubular with expanded ends and is remarkably strong for its weight. The shaft is called the *diaphysis* and the zone adjacent to the epiphyseal line is the *metaphysis* (Fig. 1.1). This is the part of the developing bone that is most likely to be the seat of disease, probably because it is the most metabolically active area and has the greatest blood supply. Damage to, or abnormal development of, the epiphyseal plate itself is likely to result in growth disturbance.

The short bones consist of a cancellous core surrounded by a layer of cortical bone, partly covered by articular cartilage. They contain red marrow in their trabecular spaces and the vertebral bodies are important sites of blood formation throughout life.

A normal bone can resist large compressive forces and considerable bending stresses, and only breaks when subjected to considerable violence. It may, however, be weakened by disease and can then fracture as a result of minimal trauma. Such *pathological fractures* are often orientated transversely across the bone.

The bones form fixed points for muscle attachments and their periosteal sheaths blend with the collagen of the tendons and ligaments.

Microscopic structure

Bone consists of osteoid, which is resilient and is heavily infiltrated with calcium salts, giving it hardness and strength. The mechanism of mineralization is not well understood. The mineral is mainly deposited in crystalline form as hydroxyapatite, but there is also an amorphous phase which is found particularly in newly formed bone. It is worth noting that various ions, such as strontium, fluoride and lead, can enter the crystal lattice of bone mineral.

A normal bone is composed of concentric cylinders of matrix with cells lying in lacunae between the layers, the whole forming a 'Haversian system'. In the hard cortex, the Haversian systems are packed tightly together; in the spongy or cancellous bone, they are more loosely arranged (Fig. 1.2). The bony trabeculae are structured and orientated to withstand the stresses of weight-bearing and muscle activity, obeying Wolff's Law. The interstices of the cancellous bone and the hollow centres of the shafts of long bones are filled with marrow. Haemopoiesis occurs in the marrow throughout the bones in the child, but in the adult is confined to the short bones, particularly the vertebral bodies, and to the ends of the long bones.

Each bone is ensheathed by fibrous periosteum with an underlying layer of osteoblasts, and is

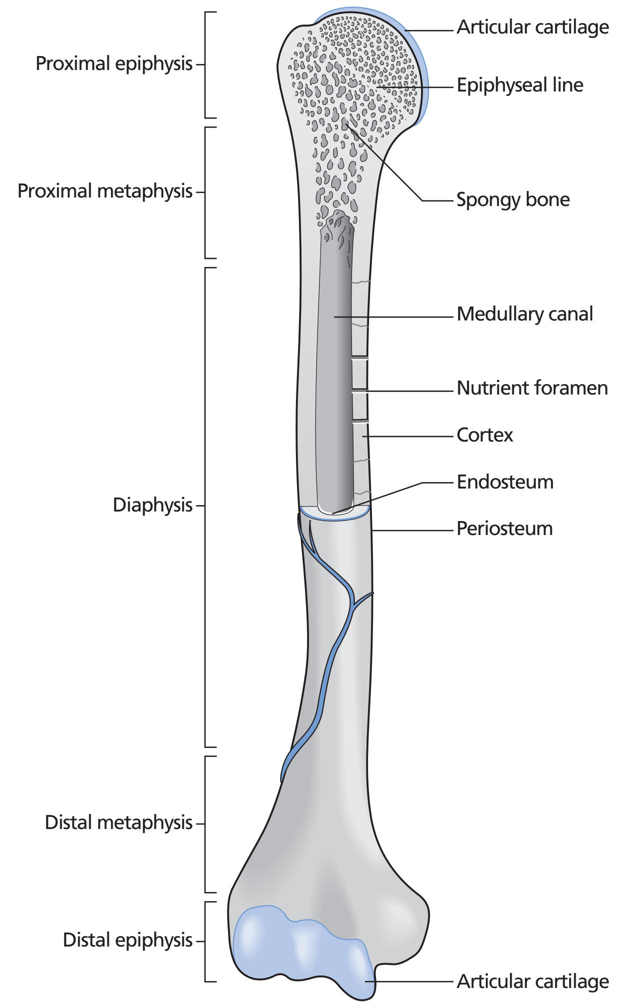

Figure 1.1 Macroscopic structure of bone.

vascularized from the periosteum and by one or more nutrient arteries penetrating the cortex.

Bone formation

The bones develop initially in early intrauterine life as condensations of mesenchymal tissue in the axis of the limb (Fig. 1.3a), and by the sixth week the connective tissue cells have started to lay down cartilage to form the shape of the future bone (Fig. 1.3b). At the centre of the cartilage mass, the cells hypertrophy and apparently die, and with the ingrowth of vascular connective tissue, the matrix calcifies and eventually ossifies (Fig. 1.3c). This process spreads along the bone (Fig. 1.3d), so that it eventually consists of a bony shaft with cartilaginous ends (Fig. 1.3e) which become the sites of secondary ossification centres (Fig. 1.3f). The intervening or epiphyseal cartilage remains until maturity as the growth point for bone length, the proliferating cartilage cells on the diaphyseal side forming into columns and undergoing a series of

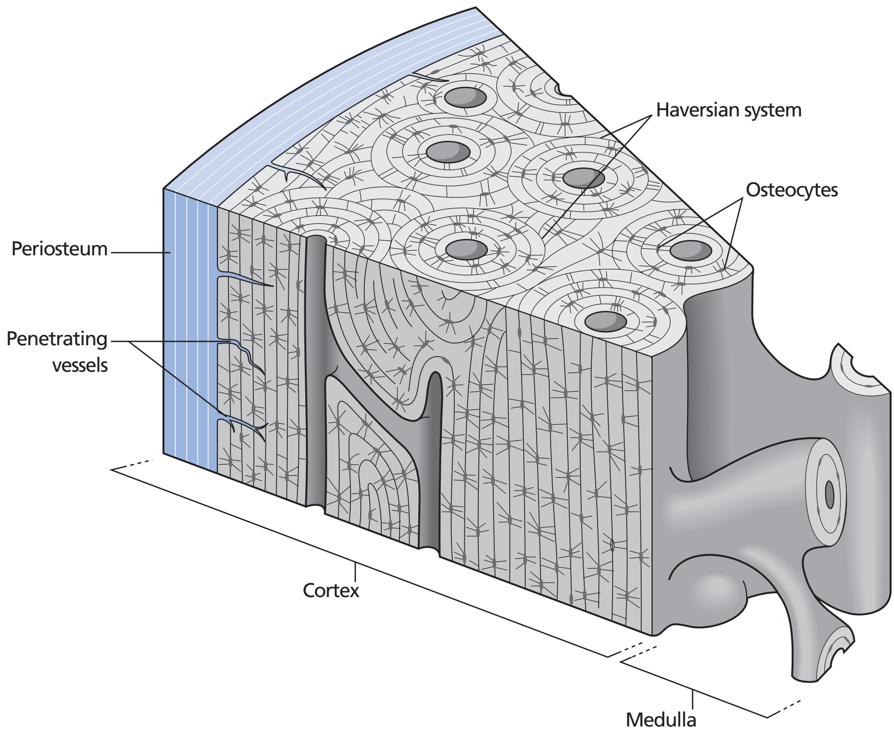

Figure 1.2 Microscopic bone structure.

changes, eventually 'ballooning' as the zone of vascularization reaches them and ossification of the matrix begins. This results in gradual growth of the epiphysis away from the centre of the shaft. Growth in width occurs by deposition of non-cartilaginous subperiosteal bone and the whole bone is constantly remodelled as the child grows.

The earliest bone to be laid down is often called 'woven bone' because its histological structure shows the fibrils to be randomly distributed, unlike the regular lamellar structure of mature bone. Some bones develop entirely by intramembranous ossification, with no intermediate cartilage stage, the clavicle and the skull being examples.

Growth does not occur equally at the two ends of a long bone. It is more active, for example, at the ends farthest from the elbow and nearest to the knee (growth is often described by 'to the elbow I grow, from the knee I flee'). Diseases such as osteomyelitis and tumours are noticeably more common at these sites. The spongy ends of the bone have a complex architecture and it is here that the trabeculae can be seen to follow the lines of greatest stress (Fig. 1.4).

Remodelling of bone continues throughout life, but particularly during growth and after fracture healing. In children, even severe residual deformities can be corrected fully, with the possible exception of rotational deformities; this capacity for remodelling is less in the adult and, although the bone smoothes itself out, it is usually possible to spot the site of a fracture many years later (Fig. 1.5).

Cartilage

This varies in appearance and physical characteristics, depending on the predominant type of fibril and the density of the matrix. Two types of fibril,

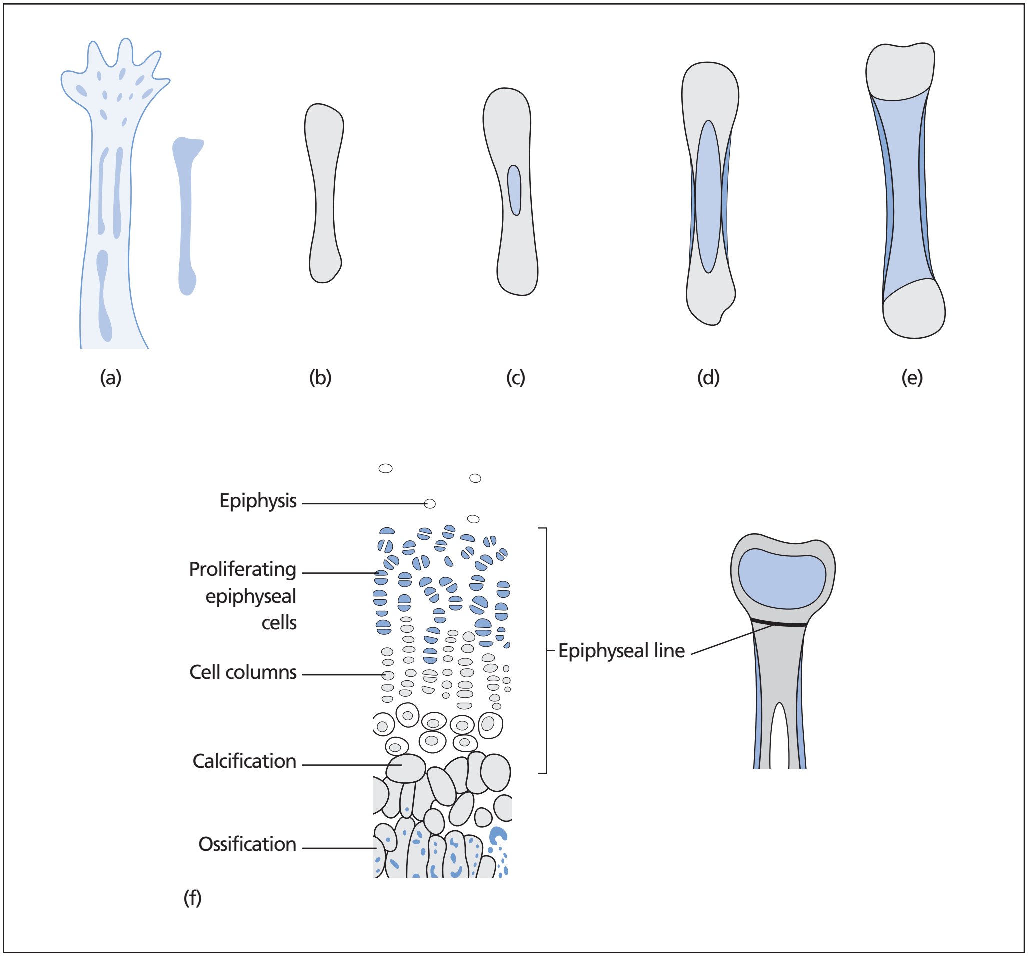

Figure 1.3 Bone growth and development.

collagen and elastin, are found in varying proportions. Three types of cartilage are normally recognized.

1 Hyaline cartilage The pre-ossified epiphyses and the articular surfaces both consist of hyaline cartilage, which is indistinguishable in the two by ordinary histological techniques, but has different properties and, of course, different functions in the two tissues.

2 White fibro-cartilage is found mainly in midline structures such as intervertebral discs and symphyses. The collagen content is much greater than in hyaline cartilage and the fibres are much more obvious. This type of cartilage has the ability to withstand strong tension and bear heavy compressive loads.

3 Yellow or elastic fibro-cartilage is found in the nasal and aural cartilages, and contains the highest proportion of elastin.

Cartilage grows by direct proliferation of the cells with pericellular deposition of matrix, but even during rapid active growth relatively few cells can be seen to be dividing. The capacity of hyaline cartilage to regenerate and repair itself is strictly limited, which means that damage to an articular surface can have long-lasting consequences. There is some evidence that intrinsic mechanisms of repair can be supplemented by ingrowth and metaplasia of periarticular collagenous tissue, but repair of any but the smallest defect is seldom complete.

Figure 1.4 Upper end of femur to show trabeculae.

Fibrous tissue

Fibrous tissue is widespread throughout the body and consists mainly of collagen fibres with relatively little matrix.

Disorders of collagen metabolism are being extensively studied because of their dramatic effects on body structure and development. These conditions are sometimes called 'true collagen diseases', as opposed to the non-developmental diseases of collagen, such as rheumatoid arthritis. Osteogenesis imperfecta (see p. 66), is an example of an inherited disorder of collagen metabolism, mainly affecting the structure and strength of bone.

Collagen growth is an important aspect of general body development and fibroblasts are frequently to be seen proliferating and laying down collagen fibres. This is particularly the case in any situation where repair of tissues is required. The usual end-result of repair, the scar, consists almost entirely of collagenous material. In situations where there is continuing damage to the tissues, with concomitant repair, the scar tissue formed can be extremely dense. As it matures, collagenous scar tissue tends to contract, sometimes producing distortion and obstruction of internal structures or contractures of skin and joints. Occasionally, the healing of a skin wound may be complicated

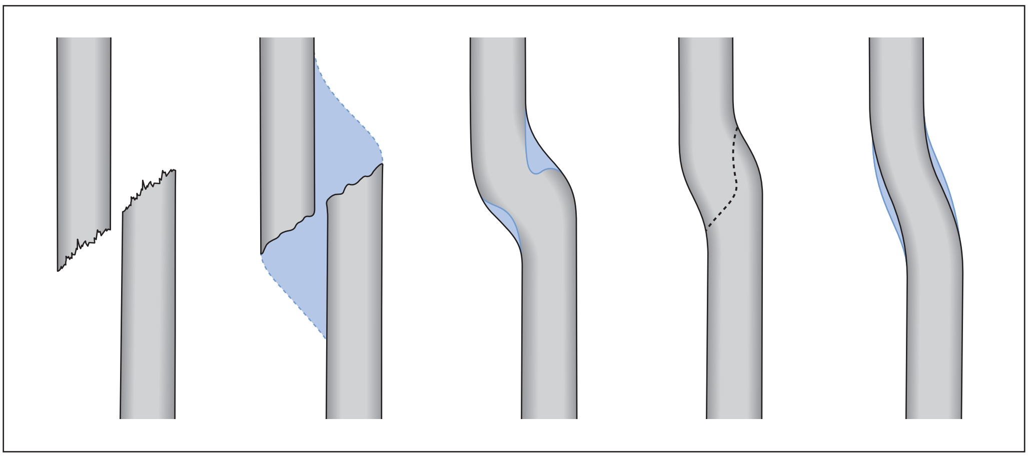

Figure 1.5 Remodelling after a fracture.

by the formation of over-exuberant scar tissue, producing a wide and thickened scar known as 'keloid'. This is more common in races with black skin.

Ligaments

These may be either discrete structures or thickenings of the joint capsule. Being necessary for joint stability, they are strong and are orientated to resist specific stresses. They are, however, occasionally ruptured, either completely or partially, and are difficult to restore when damaged. A partial rupture is known as a *sprain* or *strain*, and usually heals completely.

Joints

The function of a limb is heavily dependent on the smooth working of the joints, and joint diseases are common and troublesome.

Three types of joint are usually recognized.

1 Fibrous joints or syndesmoses. As the name suggests, in this type of joint the bones are connected by a continuous band of fibrous tissue, as is the case with the sutures of the skull. These joints are strong and not readily disrupted, but they allow little movement.

2 Cartilaginous joints or synchondroses. These consist of a cartilaginous band joining the bones. This may be hyaline, as between some of the skull bones, in which case ossification usually occurs at maturity. Secondary cartilaginous joints consist of a mass of fibro-cartilage lying between two thin plates of hyaline cartilage.

3 Synovial joints. This type of joint allows the greatest mobility. The joint surfaces are covered with hyaline cartilage and the joint is enclosed by a fibrous capsule which is usually attached close to the edge of the articular surface. It is lined by a vascular synovial membrane which secretes synovial fluid. This fluid is a remarkable substance which performs a nutritive function and has important lubricating properties. Articular cartilage, apart from its deepest layer, derives most of its nutrition from the synovial fluid which must, therefore, have access to the whole articular surface. There is some evidence that degenerative joint disease may be, at least partly, due to an interruption in the free flow of this fluid.

Some joints contain fibro-cartilaginous discs partly separating the joint surfaces. The menisci of the knee are examples of this and they have been shown to have an important stress-distributing function.

Articular cartilage, normally smooth and elastic, may be pitted or eroded by disease or completely worn away to reveal the underlying bony cortex. The earliest stages of this process are known as 'fibrillation'. The articular cartilage becomes irregular and tends to fray and split. To some extent, this phenomenon is age-related, but it does not occur uniformly throughout the joints and varies in its extent from individual to individual. It is essentially a focal change, and there are certain sites where it is common, particularly those areas which rarely contact the opposing articular surface and/or where loads are high, such as the patella. In certain circumstances, this condition progresses to fully developed osteoarthritis (see Chapter 11).

Blood supply and innervation of joints

All joints have a free blood supply with many anastomozing arteries. An operation on a major joint without a tourniquet provides a good demonstration of joint vascularity. There is a fine plexus of lymphatics within the synovial membranes.

The nerve supply of a joint is the same as that of the overlying muscles moving the joint and the skin over their insertions (Hilton's Law). Most of the nerve end-organs lie in the joint capsule, but muscle and tendon end-organs are equally important for proprioception. Autonomic nerves also reach the joint, mainly with the blood vessels, and control the blood supply and perhaps the formation of synovial fluid.

The protective and proprioceptive functions of nerves supplying joints are vital to the normal functioning of a joint, which rapidly disintegrates if this protection is lost (Charcot's joint).

Muscles

The functions of joints and muscles are closely interrelated. Not only are muscles important for moving the joints, but their co-ordinated action is essential for joint stability. This is very evident in paralytic conditions where the lack of stability may have to be compensated by the use of external splints.

Skeletal muscle is composed of fibres whose length varies from a few millimetres to about 30 cm. Each fibre contains many nuclei embedded in its syncytium and the fibre itself is built up of many myofibrils, each of which consists of units of the proteins actin and myosin. These are arranged in interlocking bands. They give the fibre its characteristic cross-sections, and are the contractile elements of the muscle.

The form of a muscle determines its power and contractility. If the fibres are arranged parallel to the line of pull, the contractility is greatest: where there are many fibres arranged obliquely to the line of pull, the power is greater but the ability to shorten is less.

Nerve supply to muscles

The nerve enters the muscle at the motor point, which is usually constant and is the point at which electrical stimulation is most effective. The smaller branches of each nerve fibre supply a variable number of muscle fibres, each junction being called a *motor end-plate*. Where fine control is needed, as with the small muscles of the hand, the number of muscle fibres supplied by each nerve fibre is small, whereas more coarsely innervated muscles may have one nerve fibre dividing to supply over a hundred motor end-plates. Afferent fibres derive from muscle spindles and are essential for the feedback mechanisms controlling contraction.

Muscles have many actions, sometimes functioning as prime movers, at other times as co-ordinating antagonists, synergists and co-operating muscles. Many of their so-called ‘voluntary’ activities are concerned with posture and are essentially unconscious.

Tendons and bursae

Most muscles are attached to the bone ends by a tendon, which may be a few millimetres or many centimetres long. Many of the larger tendons move within a fibrous sheath, which has a synovial lining (Fig. 1.6a).

Tendons do not resist pressure very well and are frequently separated or protected from their underlying bones by thin-walled cavities containing synovial fluid. Some of the larger tendons contain a bone within their substance at the place where they cross a joint and have to bear considerable stresses. These are known as *sesamoid bones*. Examples are the patella and the sesamoids under the first metatarsal head. They have articular cartilage on their deep surfaces (Fig. 1.6b).

Small sacs or *bursae* are often found overlying bony prominences. They may be fairly constant anatomical structures, like those overlying the

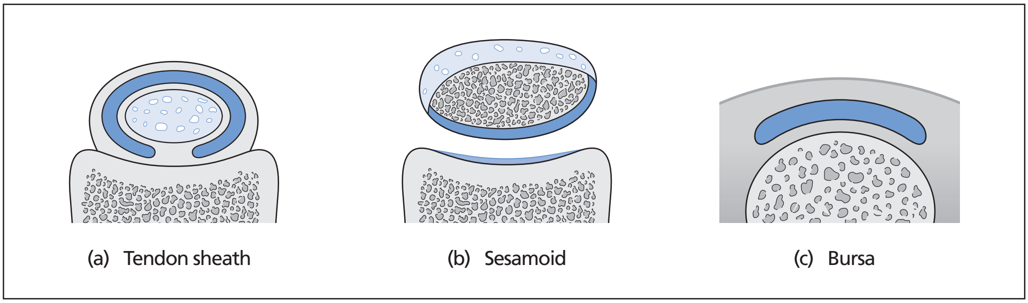

Figure 1.6 Tendons and bursae. The darker blue areas indicate: (a) synovial sheath, (b) hyaline cartilage and (c) a fluid-filled bursa.

ischial tuberosity or olecranon, or they may be produced as a response to external pressure, when they are called ‘adventitious’ bursae, e.g. the one which develops over the patellar tendon in occupations involving continuous kneeling, or the first metatarsal head from pressure on the shoe (Fig. 1.6c). Certain anatomical bursae communicate with the nearby joint and may become distended or diseased if pathology develops in the underlying joint (such as a Baker’s cyst).