Tyldesley & Grieve's

Muscles, Nerves and Movement in Human Occupation

Fourth Edition





Ian R McMillan | Gail Carin-Levy

WILEY-BLACKWELL

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Preface to the fourth edition

The first edition of this book was published by Barbara Tyldesley and June Grieve in 1989 with the intention of studying anatomy combined with undertanding movement in daily living. Since then, subsequent editions have added chapters and further detail in numerous ways to promote and meet the original aim.

This new fourth edition enhances that original aim by revising the text, revising the practice note-pads which highlight some of the common conditions seen in clients/patients that students and therapists will encounter, adding key terms and a conceptual overview at the beginning of each chapter and providing a summary at the end of each chapter. There has also been a comprehensive revision of the figures and overall addition of colour throughout.

Section I introduces you to the idea of movement by looking at the basic units of structure and function, movement terminology and the structure and function of the central and peripheral nervous system that are involved in the control of movement.

Section II continues with the anatomy of movement in everyday living by examining the positioning movements of the shoulder and elbow, the manipulative movements produced by the forearm, wrist and hand, the nerve supply to the upper limb, the role of the lower limb in support and propulsion, the nerve supply to the lower limb and the role of the trunk in posture and breathing.

Section III looks at the sensorimotor control of movement that includes the sensory background to movement and motor control.

Section IV turns your attention to Human Occupation by firstly looking at occupational performance skills and capacities. The remaining part of this section examines different case scenarios where understanding anatomy, movement, the effects of conditions and how this influences human occupations are considered.

We trust this book will be useful not only to you as a student embarking on your career as an allied health professional, but also to practitioners in a variety of settings.

Ian R. McMillan, Gail Carin-Levy

Acknowledgements

We would like to extend our sincere thanks to all of the team associated with the production of this book at various stages: Cathryn Gates, Ruth Swan, Sarah Crawley-Vigneau and Joanna Brocklesby. We would also like to extend our thanks to Jane Fallows who completely revised and redrew all the figures for this new edition.

We very much appreciate the time and energy given by Linda Gnanasekaran who originally produced Chapter 13 in this edition.

We are also grateful to occupational therapists Ronnie Bentley, Linda Gwilliam and Louise Hogan who originally contributed to the case scenario exercises in Chapter 14 of this edition.

Finally and most importantly, we would like to take this opportunity to recognise the immense achivements of Barbara Tyldesley and June Grieve. They both pioneered the idea for this book to facilitate the education of health care students, with the first edition being published in 1989. Since then, countless numbers of students and qualified staff have utillised Tyldesley and Grieve's seminal textbook to deepen their understanding of the human body, the integration required for movement and its use in daily occupations.

> 'If we have seen further it is by standing on the shoulders of giants'
> Isaac Newton 1676

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Section I

Introduction to movement

Components of the musculoskeletal and nervous system, movement terminology

- Basic units, structure and function: supporting tissues, muscle and nerves
- Movement terminology
- The central nervous system: the brain and spinal cord
- The peripheral nervous system: cranial and spinal nerves

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Basic units, structure and function: supporting tissues, muscle and nerve

Key terms

connective tissues, articulations, skeletal muscle, neurone, muscle tone

Conceptual overview

This chapter addresses the basic components of structure that are organised to allow movement at joint level. Nerves, muscles and connective tissues work together to produce movement: connective tissues which provide stability and support; skeletal muscle which changes in length and pulls on bones to produce movements at joints; and neurones and nerves which conduct information between the environmental sensors, the control centres for movement and the muscles.

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Framework and support: the connective tissues

The overall function of connective tissue is to unite or connect structures in the body, and to give support. Bone is a connective tissue which provides the rigid framework for support. Where bones articulate with each other dense fibrous connective tissue, rich in collagen fibres, surrounds the ends of the bones, allowing movement to occur while maintaining stability. Cartilage, another connective tissue, is also found associated with joints, where it forms a compressible link between two bones, or provides a low-friction surface for smooth movement of one bone on another. Connective tissue attaches muscles to bone, in the form of either a cord (tendon) or a flat sheet (fascia). The connective tissues may be divided into:

- **dense fibrous tissue**;
- **cartilage**;
- **bone**.

Dense fibrous tissue

Dense fibrous connective tissue unites structures in the body while still allowing movement to occur. It has high tensile strength to resist stretching forces. This connective tissue has few cells and is largely made up of fibres of collagen and elastin that give the tissue great strength. The fibres are produced by fibroblast cells that lie in between the fibres (Figure 1.1). The toughness

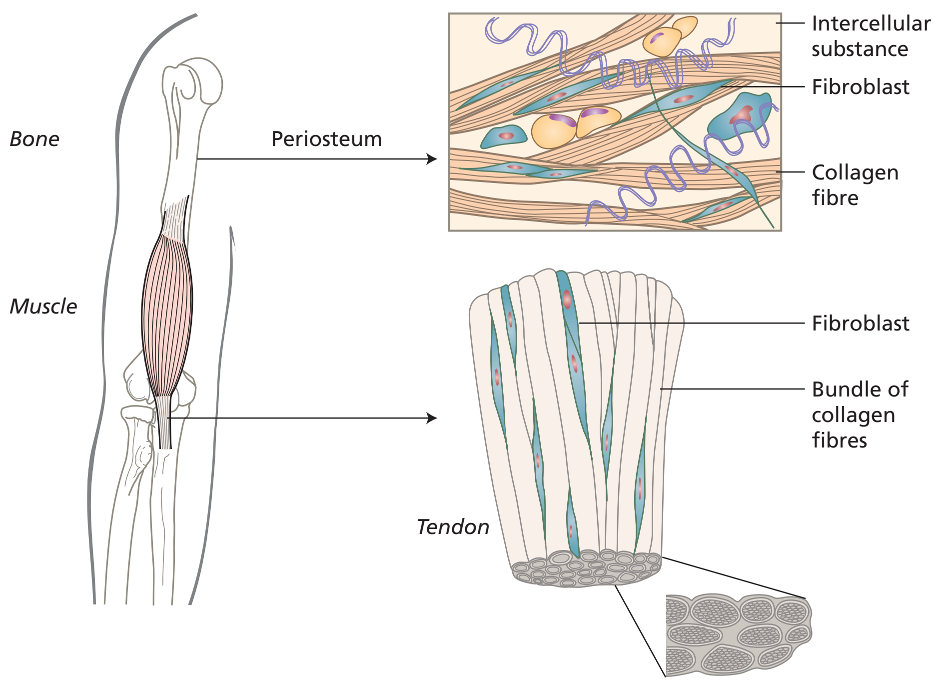

Figure 1.1 Dense fibrous connective tissue seen covering bone as periosteum, and forming the tendon of a skeletal muscle.

of this tissue can be felt when cutting through stewing steak with a blunt knife. The muscle fibres are easily sliced, but the covering of white connective tissue is very tough. Examples of this tissue are as follows:

- The **capsule** surrounding the movable (synovial) joints which binds the bones together (see Figure 1.7).
- **Ligaments** form strong bands that join bone to bone. Ligaments strengthen the joint capsules in particular directions and limit movement.
- **Tendons** unite the contractile fibres of muscle to bone.

In tendons and ligaments, the collagenous fibres lie in parallel in the direction of greatest stress.

- An **aponeurosis** is a strong flat membrane, with collagen fibres that lie in different directions to form sheets of connective tissue. An aponeurosis can form the attachment of a muscle, such as the oblique abdominal muscles, which meet in the midline of the abdomen (see Chapter 10, Figure 10.6). In the palm of the hand and the sole of the foot an aponeurosis lies deep to the skin and forms a protective layer for the tendons underneath (see Chapter 8, Figure 8.21).
- A **retinaculum** is a band of dense fibrous tissue that binds tendons of muscles and prevents bowstring during movement. An example is the flexor retinaculum of the wrist, which holds the tendons of muscles passing into the hand in position (see Chapter 6, Figure 6.15).
- **Fascia** is a term used for the large areas of dense fibrous tissue that surround the musculature of all the body segments. Fascia is particularly developed in the limbs, where it dips down between the large groups of muscles and attaches to the bone. In some areas, fascia provides a base for the attachment of muscles, for example the thoracolumbar fascia gives attachment to the long muscles of the back (see Chapter 10, Figure 10.6).
- **Periosteum** is the protective covering of bones. Tendons and ligaments blend with the periosteum around bone (see Figure 1.3).
- **Dura** is thick fibrous connective tissue protecting the brain and spinal cord (see Chapter 3, Figure 3.21).

Cartilage

Cartilage is a tissue that can be compressed and has resilience. The cells (chondrocytes) are oval and lie in a ground substance that is not rigid like bone. There is no blood supply to cartilage, so there is a limit to its thickness. The tissue has great resistance to wear, but cannot be repaired when damaged.

Hyaline cartilage is commonly called gristle. It is smooth and glass-like, forming a low-friction covering to the articular surfaces of joints. In the elderly, the articular cartilage tends to become eroded or calcifies, so that joints become stiff. Hyaline cartilage forms the costal cartilages which join the anterior ends of the ribs to the sternum (Figure 1.2). In the developing foetus, most of the bones are formed in hyaline cartilage. When the cartilaginous model of each bone reaches a critical size for the survival of the cartilage cells, ossification begins.

Reflective task

Look at some large animal bones from the butcher to see the cartilage covering the joint surfaces at the end. Note that it is bluish and looks like glass.

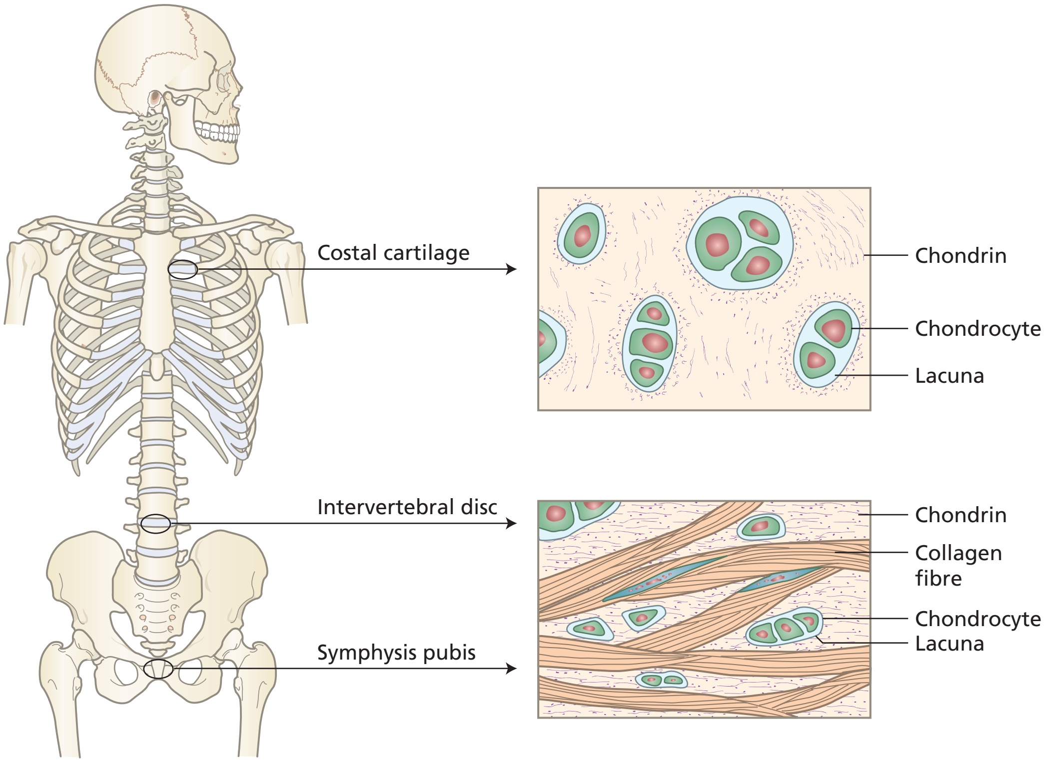

Figure 1.2 Microscopic structure of hyaline and fibrocartilage, location in the skeleton of the trunk.

Fibrocartilage consists of cartilage cells lying in between densely packed collagen fibres (Figure 1.2). The fibres give extra strength to the tissue while retaining its resilience. Examples of where fibrocartilage is found are the discs between the bones of the vertebral column, the pubic symphysis joining the two halves of the pelvis anteriorly, and the menisci in the knee joint.

Bone

Bone is the tissue that forms the rigid supports for the body by containing a large proportion of calcium salts (calcium phosphate and carbonate). It must be remembered that bone is a living tissue composed of cells and an abundant blood supply. It has a greater capacity for repair after damage than any other tissue in the body, except for blood. The strength of bone lies in the thin plates (lamellae), composed of collagen fibres with calcium salts deposited in between. The lamellae lie in parallel, held together by fibres, and the bone cells or **osteocytes** are found in between. Each bone cell lies in a small space or lacuna, and connects with other cells and to blood capillaries by fine channels called canaliculi (Figure 1.3).

In **compact bone**, the lamellae are laid down in concentric rings around a central canal containing blood vessels. Each system of concentric lamellae (known as a Haversian system or an osteon)

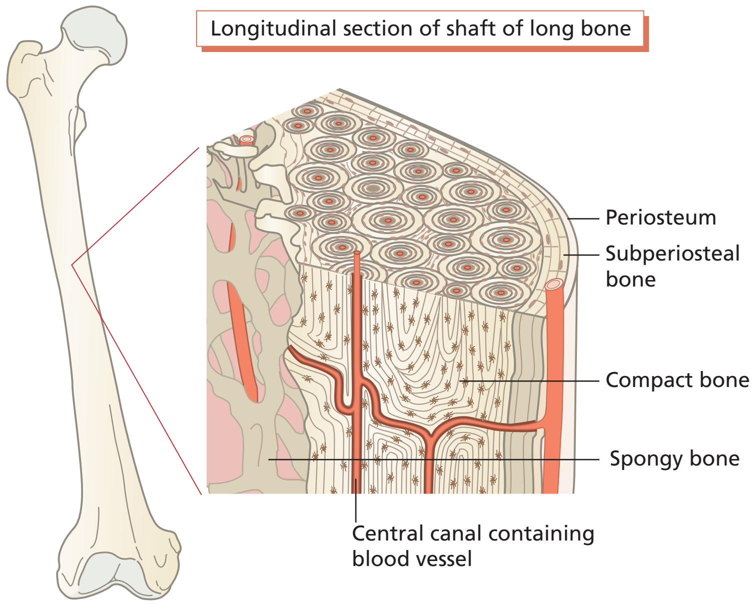

Figure 1.3 A section of the shaft of a long bone.

lies in a longitudinal direction. Many of these systems are closely packed to form the dense compact bone found in the shaft of long bones (Figure 1.3).

> **Practice note-pad 1A: osteoporosis**
>
> Osteoporosis is literally a condition of porous bones, largely due to a depletion of calcium from the body. For a number of reasons, calcium loss exceeds calcium absorption from the diet, causing bone mass to decrease excessively. This leads to fractures occurring as a result of normal mechanical stresses upon the skeleton which it would normally withstand. Spontaneous fractures may also occur.

In **cancellous** or trabeculate bone, the lamellae form plates arranged in different directions to form a mesh. The plates are known as trabeculae and the spaces in between contain blood capillaries. The bone cells lying in the trabeculae communicate with each other and with the spaces by canaliculi. The expanded ends of long bones are filled with cancellous bone covered with a thin layer of compact bone. The central cavity of the shaft of long bones contains bone marrow. This organisation of the two types of bone produces a structure with great rigidity without excessive weight (Figure 1.4). Bone has the capacity to remodel in shape in response to the stresses on it, so that the structure lines of the trabeculae at the ends of the bone follow the lines of force on the bone. For example, the lines of trabeculae at the ends of weight-bearing bones, such as

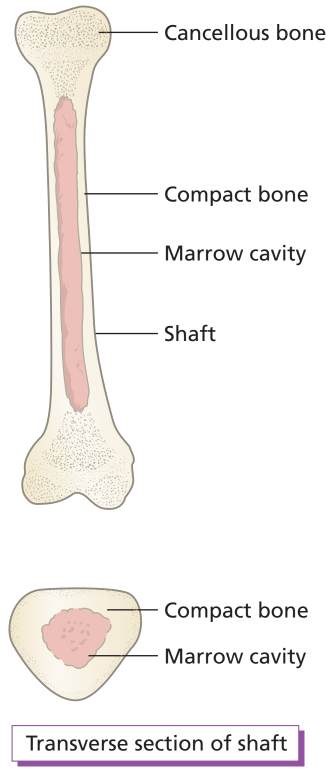

Figure 1.4 Gross structure of long bone: longitudinal and transverse sections.

the femur, provide maximum strength to support the body weight against gravity. Remodelling of bone is achieved by the activity of bone-forming cells known as osteoblasts, and bone-destroying cells known as osteoclasts; both types of cell are found in bone tissue. The calcium salts of bone are constantly interchanging with calcium ions in the blood, under the influence of hormones (parathormone and thyrocalcitonin). Bone is a living, constantly changing connective tissue that provides a rigid framework on which muscles can exert forces to produce movement.

Reflective task

Look at any of the following examples of connective tissue that are available to you:

(1) Microscopic slides of dense fibrous tissue, cartilage and bone, noting the arrangement of the cellular and fibre content.
(2) Dissected material of joints and muscles which include tendons, ligaments, aponeurosis and retinaculum.
(3) Fresh butcher's bone: note the pink colour (blood supply), and the central cavity in the shaft of long bones.
(4) Fresh red meat to see fibrous connective tissue around muscle.

Articulations

Where the rigid bones of the skeleton meet, connective tissues are organised to bind the bones together and to form joints. It is the joints that allow movement of the segments of the body relative to each other. The joints or articulations between bones can be divided into three types based on the particular connective tissues involved. The three main classes of joint are **fibrous**, **cartilaginous** and **synovial**.

Fibrous joints

Here, the bones are united by dense fibrous connective tissue.

The **sutures** of the skull are fibrous joints that allow no movement between the bones. The edge of each bone is irregular and interlocks with the adjacent bone, a layer of fibrous tissue linking them (Figure 1.5a).

A **syndesmosis** is a joint where the bones are joined by a ligament that allows some movement between the bones. A syndesmosis is found between the radius and the ulna (Figure 1.5b). The interosseous membrane allows movement of the forearm.

A **gomphosis** is a specialised fibrous joint that fixes the teeth in the sockets of the jaw (Figure 1.5c).

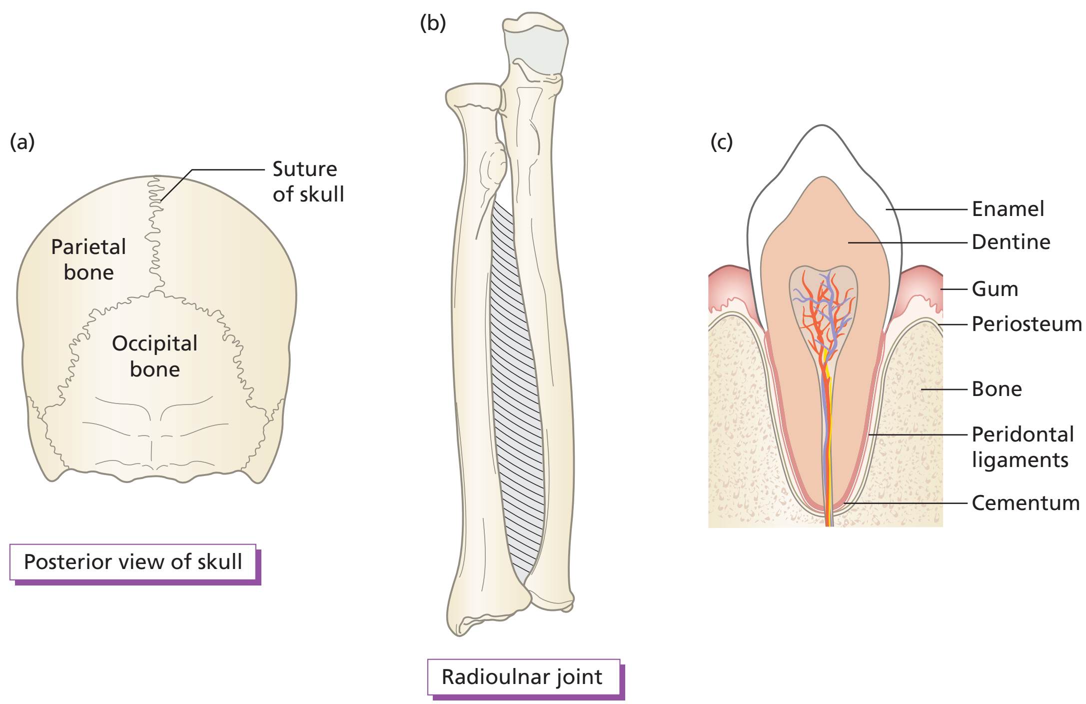

Figure 1.5 Fibrous joints: (a) suture between bones of the skull; (b) syndesmosis between the radius and ulna; (c) gomphosis: tooth in socket.

Cartilaginous joints

In these joints the bones are united by cartilage.

A **synchondrosis** or primary cartilaginous joint is a joint where the union is composed of hyaline cartilage. This type of joint is also called primary cartilaginous. The articulation of the first rib with the sternum is by a synchondrosis. During growth of the long bones of the skeleton, there is a synchondrosis between the ends and the shaft of the bone, where temporary cartilage forms the epiphyseal plate. These plates disappear when growth stops and the bone becomes ossified (Figure 1.6a).

A **symphysis** or secondary cartilaginous joint is a joint where the joint surfaces are covered by a thin layer of hyaline cartilage and united by a disc of fibrocartilage. This type of joint (sometimes called secondary cartilaginous) allows a limited amount of movement between the bones by compression of the cartilage. The bodies of the vertebrae articulate by a disc of fibrocartilage (Figure 1.6b). Movement between two vertebrae is small, but when all of the intervertebral discs are compressed in a particular direction, considerable movement of the vertebral column occurs. Little movement occurs at the pubic symphysis, the joint where the right and left halves of the pelvis meet. Movement is probably increased at the pubic symphysis in the late stage of pregnancy and during childbirth, to increase the size of the birth canal.

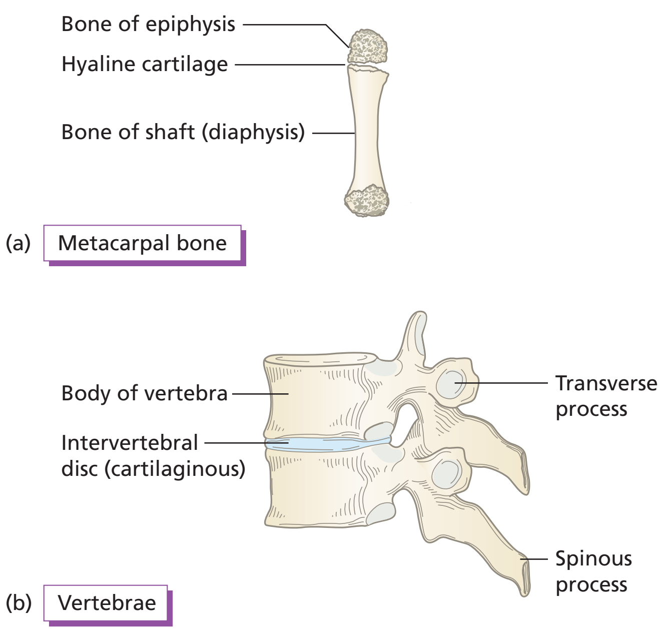

Figure 1.6 Cartilaginous joints: (a) synchondrosis in a child's metacarpal bone, as seen on X-ray; (b) symphysis between the bodies of two vertebrae.

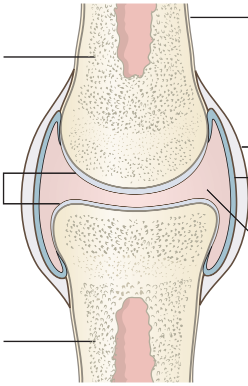

Figure 1.7 Typical synovial joint.

Synovial joints

Synovial joints are the mobile joints of the body. There is a large number of these joints, which show a variety of form and range of movement. The common features of all of them are shown in the section of a typical synovial joint (Figure 1.7) and listed as follows:

- **Hyaline cartilage** covers the ends of the two articulating bones, providing a low-friction surface for movement between them.
- A **capsule** of dense fibrous tissue is attached to the articular margins, or some distance away, on each bone. The capsule surrounds the joint like a sleeve.
- There is a **joint cavity** inside the capsule which allows free movement between the bones.
- **Ligaments**, bands or cords of dense fibrous tissue, join the bones. The ligaments may blend with the capsule or they are attached to the bones close to the joint.
- A **synovial membrane** lines the joint capsule and all non-articular surfaces inside the joint, i.e. any structure within the joint not covered by hyaline cartilage.

One or more bursae are found associated with some of the synovial joints at a point of friction where a muscle, a tendon or the skin rubs against any bony structures. A bursa is a closed sac of fibrous tissue lined by a synovial membrane and containing synovial fluid. The cavity of the bursa sometimes communicates with the joint cavity. Pads of fat, liquid at body temperature, are also present in some joints. Both structures have a protective function.

Practice note-pad 1B: osteoarthritis

Osteoarthritis is a degenerative disease occurring in middle-aged and older people. There is a progressive loss of the articular cartilage in the weight-bearing joints, usually the hip and the knees. Bony outgrowths occur at the margins of the joint and the capsule may become fibrosed. The joints become stiff and painful.

Practice note-pad 1C: rheumatoid arthritis

Rheumatoid arthritis is a systemic disease that can occur at any age (average 40 years) and it is more common in women. The peripheral joints (hands and feet) are affected first, followed by the involvement of other joints. Inflammation of the synovial membrane, bursae and tendon sheaths leads to swelling and pain which may be relieved by drugs. Deformity is the result of erosion of articular cartilage, stretching of the capsule and the rupture of tendons.

All of the large movable joints of the body, for example the shoulder, elbow, wrist, hip, knee and ankle, are synovial joints. The direction and the range of their movements depend on the shape of the articular surfaces and the presence of ligaments and muscles close to the joint. The different types of synovial joint are described in Chapter 2 where the directions of movement at joints are considered.

Skeletal muscle

Skeletal muscle is attached to the bones of the skeleton and produces movement at joints. The basic unit of skeletal muscles is the **muscle fibre**. Muscle fibres are bound together in bundles to form a whole muscle, which is attached to bones by fibrous connective tissue. When **tension** develops in the muscle, the ends are drawn towards the centre of the muscle. In this case, the muscle is contracting in length and a body part moves. Alternatively, a body part may be moved by gravity and/or by an added weight, for example an object held in the hand. Now the tension developed in the muscle may be used to resist movement and hold the object in one position.

In summary, the tension developed allows a muscle:

- to shorten to produce movement;
- to resist movement in response to the force of gravity or an added load.

Furthermore, muscles may develop tension when they are increasing in length. This will be considered in Chapter 2, in the section on types of muscle work.

Both muscle and fibrous connective tissue have elasticity. They can be stretched and return to the original length. The unique function of muscle is the capacity to shorten actively.

Reflective task

- Hold a glass of water in the hand. Feel the activity in the muscles above the elbow by palpating them with the other hand. The tension in the muscles is resisting the weight of the forearm and the water.
- Lift the glass to the mouth. Feel the muscle activity in the same muscles as they shorten to lift the glass.

Structure and form

The structure of a whole muscle is the combination of muscle and connective tissues, which both contribute to the function of the active muscle. In a whole muscle, groups of contractile muscle fibres are bound together by fibrous connective tissue. Each bundle is called a fasciculus. Further coverings of connective tissue bind the fasciculi together and an outer layer surrounds the whole muscle (Figure 1.8).

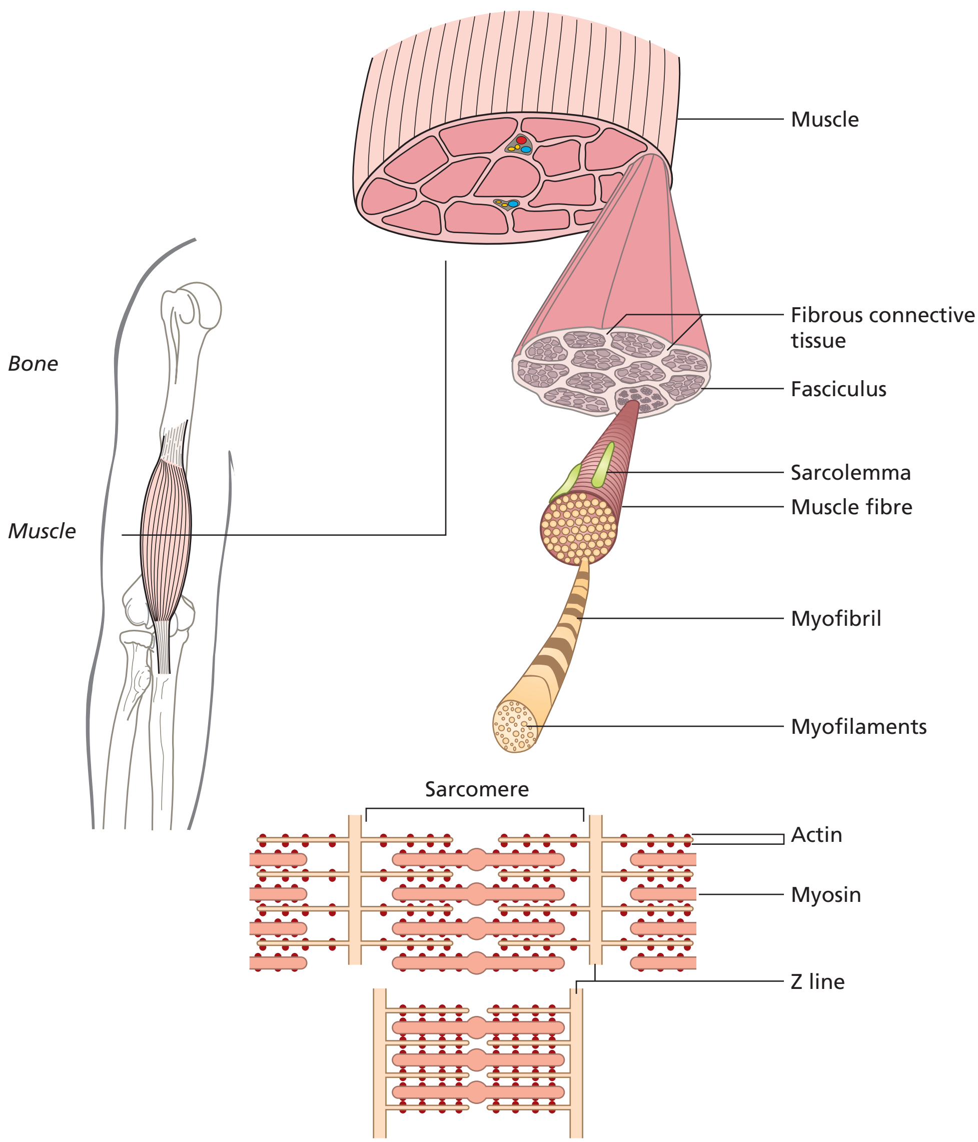

Figure 1.8 Skeletal muscle: the organisation of muscle fibres into a whole muscle, and a sarcomere in the relaxed and the shortened state (as seen by an electron microscope).

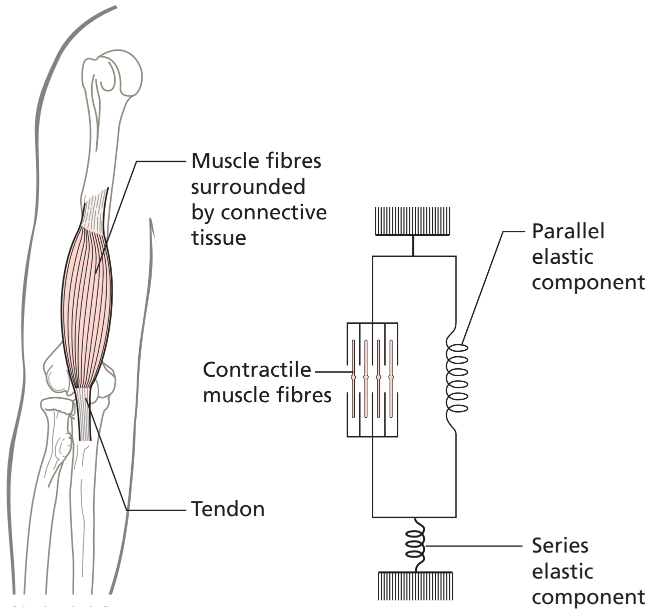

Figure 1.9 Elastic components of muscle.

The total connective tissue element lying in between the contractile muscle fibres is known as the parallel elastic component. The tension that is built up in muscle when it is activated depends on the tension in the muscle fibres and in the parallel elastic component. The fibrous connective tissue, for example a tendon, which links a whole muscle to bone is known as the series elastic component. The initial tension that builds up in an active muscle tightens the series elastic component and then the muscle can shorten. A model of the elastic and contractile parts of a muscle is shown in Figure 1.9. If the connective tissue components lose their elasticity, through lack of use in injury or disease, a muscle may go into contracture. Lively splints are used to maintain elasticity and prevent contracture while the muscle recovers.

The individual muscle fibres lie within a muscle in one of the following two ways:

- Parallel fibres are seen in strap and fusiform muscles (Figure 1.10a, b). These muscles have long fibres which are capable of shortening over the entire length of the muscle, but the result is a less powerful muscle.
- Oblique fibres are seen in pennate muscles. The muscle fibres in these muscles cannot shorten to the same extent as parallel fibres. The advantage of this arrangement, however, is that more muscle fibres can be packed into the whole muscle, so that greater power can be achieved.

The muscles with oblique fibres are known as unipennate, bipennate or multipennate, depending on the particular way in which the muscle fibres are arranged (Figure 1.10c, d). Some of the large muscles of the body combine parallel and oblique arrangements. The deltoid muscle of the shoulder (see Chapter 5, Figure 5.9) has one group of fibres that are multipennate and two groups

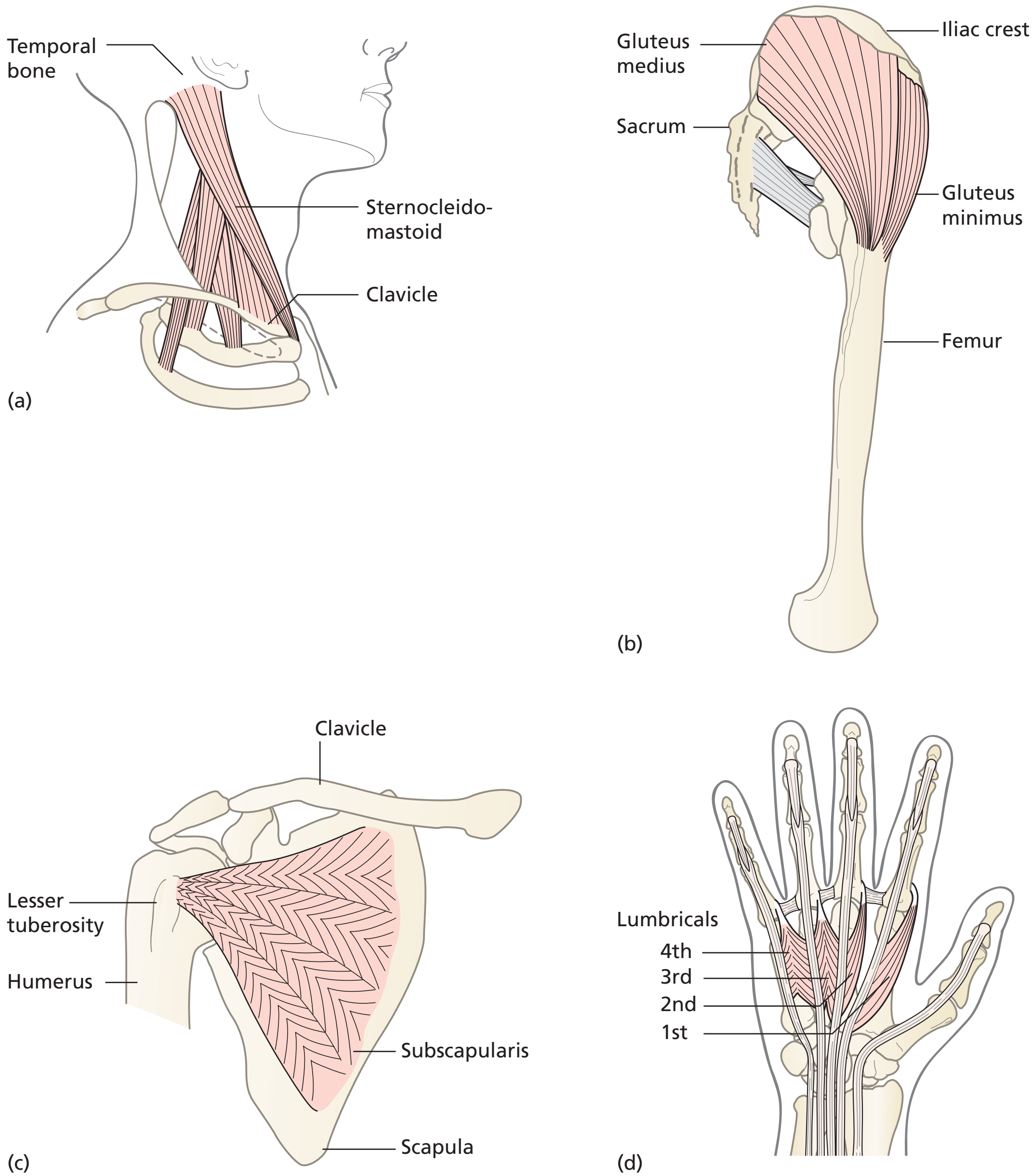

Figure 1.10 Form of whole muscle: parallel fibres (a) strap and (b) fusiform; oblique fibres (c) multipennate and (d) unipennate and bipennate.

that are fusiform, which combines strength to lift the weight of the arm with a wide range of movement. The form of a particular muscle reflects the space available and the demands of range and strength of movement.

Muscles have a limited capacity for repair, although a small area of damage to muscle fibres may regenerate. In more extensive damage, the connective tissue responds by producing more collagen fibres and a scar is formed. An intact nerve and adequate blood supply are essential for muscle function. If these are interrupted the muscle may never recover. Movement can then only be restored by other muscles taking over the functions of the damaged muscles.

Microscopic structure

A muscle fibre can just be seen with the naked eye. Each muscle fibre is an elongated cell with many nuclei surrounded by a strong outer membrane, the sarcolemma. If one fibre is viewed under a light microscope, the nuclei can be seen close to the membrane around the fibre. The chief constituent of the fibre is several hundreds of myofibrils, strands of protein extending from one end of the fibre to the other (Figure 1.8). The arrangement of the two main proteins, actin and myosin, that form each myofibril presents a banded appearance. The light and dark bands in adjacent myofibrils coincide, so that the whole muscle fibre is striated.

The electron microscope reveals the detail of the cross-striations in each myofibril. A repeating unit, known as the sarcomere, is revealed along the length of the myofibril. Each sarcomere links to the next one at a disc called the Z-line. The thin filaments of actin are attached to the Z-line and project towards the centre of the sarcomere. The thicker myosin filaments lie in between the actin strands. The darkest bands of the myofibril are where the actin and myosin overlap in the sarcomere.

The arrangement of the myosin molecules in the thick myosin filaments forms cross-bridges that link with special sites on the active filaments when the muscle fibre is activated. The result of this linking is to allow the filaments to slide past one another, so that each sarcomere becomes shorter. This, in turn, means that the myofibril is shorter, and since all the myofibrils respond together, the muscle fibre shortens.

Reflective task

Look at Figure 1.8, starting at the bottom, to identify the details of the structure of a muscle: (1) sarcomeres lie end to end to form a myofibril; (2) myofibrils are packed tightly together inside a muscle fibre; (3) muscle fibres are bound together in a fasciculus; and (4) fasciculi are bound to form a whole muscle.

In active muscles, the energy required to develop tension is released by chemical reactions. Most of these reactions occur in structures called **mitochondria** (Figure 1.11). All cells have mitochondria, but they are more abundant in muscle fibres where they lie adjacent to the myofibrils. The breakdown of adenosine triphosphate (ATP) and a 'back-up' phosphocreatine provide a high level of energy output in the muscle. The store of ATP is replenished in the mitochondria using oxygen and glucose brought by the blood in the network of capillaries surrounding muscle fibres (Figure 1.11). In this way, the muscle fibres have a continuous supply of energy, as long as the supply of oxygen is maintained (aerobic metabolism). Glycogen is another source of energy that

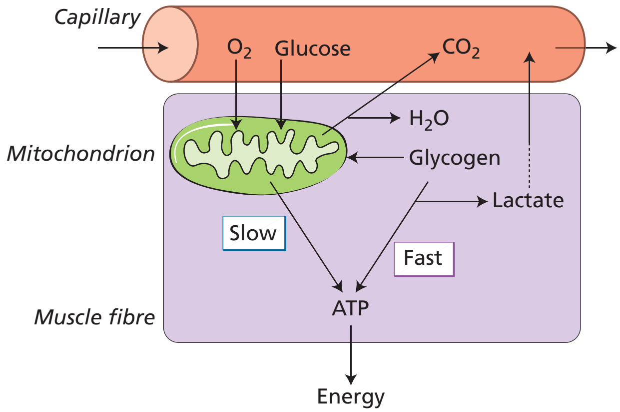

Figure 1.11 Energy for muscle contraction (simplified). The 'slow' pathway predominates in type I fibres, where ATP is replenished by aerobic reactions to provide the energy for long periods of low-level activity. The 'fast' pathway predominates in type II fibres, where glycogen provides energy without oxygen for short bursts of high-level activity.

is stored in muscle fibres. When there is insufficient oxygen to replenish ATP by oxidative reactions, energy is released from breakdown of glycogen to maintain the ATP levels. This occurs during a short burst of high-level muscle activity.

Adaptation of muscles to functional use

Not all muscle fibres in one muscle are the same. Two main types have been distinguished:

- **Slow** fibres, known as type I fibres, are red because they contain myoglobin which stores oxygen, like the haemoglobin in the blood, and they are surrounded by many capillaries. Energy supply for the slow fibres (called SO) is mainly from oxidative reactions. The slow fibres respond to stimulation with a slow twitch and they are resistant to fatigue.
- **Fast** fibres, known as type II fibres, are white with no myoglobin and have fewer capillaries per fibre. Energy is derived mainly from the breakdown of glucose and stored glycogen without oxygen. The fast fibres (called FG) respond with a fast twitch, but they are easily fatigued when the glycogen stores are used up.

Slow fibres are adapted for sustained postural activity, while the fast fibres are recruited for rapid intense bursts of activity, for example running, cycling and kitchen tasks such as cutting bread and chopping vegetables.

Skeletal muscle shows a remarkable capacity to adapt its structure to functional use. Both the relative proportion of slow and fast fibres and the number of sarcomeres in the myofibrils can change over time.

Muscle strength and bulk is increased by progressive resistance training programmes using weights or strength-training machines. The added strength is due to an increase in the number and size of the myofibrils, particularly in the fast muscle fibres which hypertrophy most readily.

Less increase occurs in the slow fibre type. There is little evidence that similar training programmes can strengthen the muscles of patients with chronic degenerative disorders of the neuromuscular system. Any change may depend on the number of remaining intact fibres. For these patients, improvement in stamina rather than strength will be more useful for daily living in any case. Training for endurance in healthy young adults has the effect of changes in some fast fibres, which become more like slow fibres. The presence of these type IIA or FGO fibres increases the length of time that the muscle can perform movement without fatigue.

Studies of the effects of ageing have shown a progressive decrease in the size of fast fibres with fewer changes in slow fibres. These changes are most likely to be the response to a less active life. Fast fibres can increase in size in elderly people, so that exercise programmes are beneficial when there are no pathological changes present.

Muscles also change the number of sarcomeres in the myofibrils if a muscle is held in a shortened or lengthened position, for example by a plaster cast. Sarcomeres are lost in the shortened position and added in the lengthened position. This is an adaptation to changes in the functional length of the muscle. Any benefit, however, may be overridden by the changes in the muscle which lead to muscle contracture.

Practice note-pad 1D: myopathies

Neuromuscular disorders that are myopathic originate in the muscle, and may be inherited or acquired. There is muscle weakness in the proximal muscles, which is slowly progressive with muscle wasting.

Duchenne muscular dystrophy is an inherited myopathy that affects boys only. There is a rapid progression of muscle weakness that begins in childhood.

Acquired myopathy can result from infections, or endocrine disorders, or as a complication of steroid drug treatment.

Basic units of the nervous system

The functions of the nervous system in movement are: to conduct motor commands from the brain to the muscles; to regulate the activity in the cardiovascular and respiratory systems which supply the muscles with essential nutrients and oxygen; and to monitor changes in the environment that affect movement.

The properties of **neurones** are:

- excitation: neurones generate impulses in response to stimulation;
- conduction of impulses between neurones (in one direction only).

Neurones are organised in networks or centres in the brain and the spinal cord. Activity in one centre is directed to a particular end, for example the location of a specific sensation. The output from one processing centre is then conducted to one or many other centres in a series of operations, for example from motor centres in the brain to the spinal cord. Information can also be conducted in parallel between processing centres.

The properties of neural networks are: