The Anatomy and Physiology of the Musculoskeletal System

CHAPTER 1

INTRODUCTION

The musculoskeletal system forms the structural framework of the human body, enabling movement, posture and protection of vital organs. It is composed of bones, joints, muscles, tendons, ligaments and associated connective tissues, all working in close coordination with the nervous and vascular systems (Manfred 2022). An understanding of musculoskeletal anatomy and physiology is not limited to theory; it underpins almost every aspect of patient care, from safe patient handling to recognising signs of injury or disease.

In clinical practice, musculoskeletal knowledge is essential for skills such as performing physical assessments, interpreting mobility limitations, recognising abnormalities and supporting patients through rehabilitation. For example, knowing the major muscle groups and joint mechanics assists in assessing range of movement, while awareness of bone structure and common fracture sites supports safe and effective care delivery. Likewise, understanding how muscles contract and coordinate movement is critical when observing gait, posture or recovery from trauma.

This chapter introduces the anatomy and physiology of the musculoskeletal system. It highlights not only the structural components but also the functional principles that enable those who offer care and support to people to apply their knowledge directly in practice.

THE MUSCULOSKELETAL SYSTEM

The musculoskeletal system (also known as the locomotor system) is the body's framework for movement, posture and protection of vital organs. It works in close partnership with the nervous system to allow both voluntary and involuntary movements. Every time a person walks, sits, lifts an object or simply maintains an upright position, the musculoskeletal system is at work.

Movement of the body, whether involving the whole body or just specific parts, is essential for many everyday activities, including breathing, eating, drinking, avoiding harm and reproduction. Most body movements occur under conscious (voluntary) control, meaning we choose and direct them. However, some movements happen automatically, before we are even aware of them. These are known as reflex actions and serve as protective mechanisms. For example, a person may instantly withdraw a hand from a hot surface or blink rapidly when an irritant approaches the eye.

Kinesiology, also known as body mechanics, is the study of the movement of body parts. In practice, body mechanics focuses on how the body is used to perform tasks safely and efficiently. Both patients and healthcare providers benefit when correct body mechanics are used.

For patients, safe movement and correct positioning reduce the risk of complications such as falls, joint stiffness or pressure injuries. For healthcare workers, correct posture and alignment during tasks such as lifting or repositioning patients prevents musculoskeletal strain and long-term injury.

When the body is in correct anatomical alignment, that is, when its parts are arranged in a straight line and balanced, it functions at its best. Correct alignment allows for even distribution of weight and the efficient use of muscles and joints. For example, standing tall with the head, shoulders, hips and feet aligned can help to maintain balance, decrease strain on supporting structures and promote optimal breathing and circulation. Conversely, poor posture can place stress on muscles and joints, leading to fatigue, discomfort and increased risk of injury.

In clinical care, awareness of body mechanics is a vital skill. Healthcare staff must constantly consider posture and alignment – not only the patient's comfort and safety, but also how they themselves are standing, bending or moving. Using body mechanics in the correct way protects both the patient and the caregiver. Posture and body alignment are outlined in Table 1.1.

Good posture promotes balance, efficiency and safety (Peate 2019). Poor posture increases the risk of strain and injury. Curr and Fordham-Clarke (2022) describe postural malalignment (see Figure 1.1).

Understanding the musculoskeletal system and the principles of kinesiology, you will be better equipped to:

- Safely move and position patients.
- Protect yourself from injury during clinical tasks.
- Recognise abnormal posture or movement in patients.
- Encourage mobility and independence as part of recovery and rehabilitation.

This chapter discusses the anatomy and physiology of the musculoskeletal system, showing how bones, joints and muscles work together to produce movement. It will also emphasise the importance of applying this knowledge to everyday clinical practice, ensuring safety and promoting health for both patients and healthcare providers.

Table 1.1 Posture and body alignment

Body part	Good posture/correct alignment	Poor posture/common errors
Head	Upright, chin level, eyes forward	Head tilted forward or downward; chin jutting out
Shoulders	Relaxed, level, aligned with hips	Rounded forward; one shoulder higher than the other
Spine	Natural curves maintained	Slouched, exaggerated curve (kyphosis or lordosis)
Abdomen	Slightly pulled in to support spine	Protruding abdomen, increasing spinal strain
Hips	Level, weight evenly distributed	Tilted to one side; uneven weight on one leg
Knees	Straight but not locked	Knees locked back or bent forward
Feet	Flat on floor, shoulder-width apart, toes forward	Feet too close or wide apart; toes turned in/out
Arms/hands	Hanging naturally, elbows close to body	Arms held stiffly or away from body

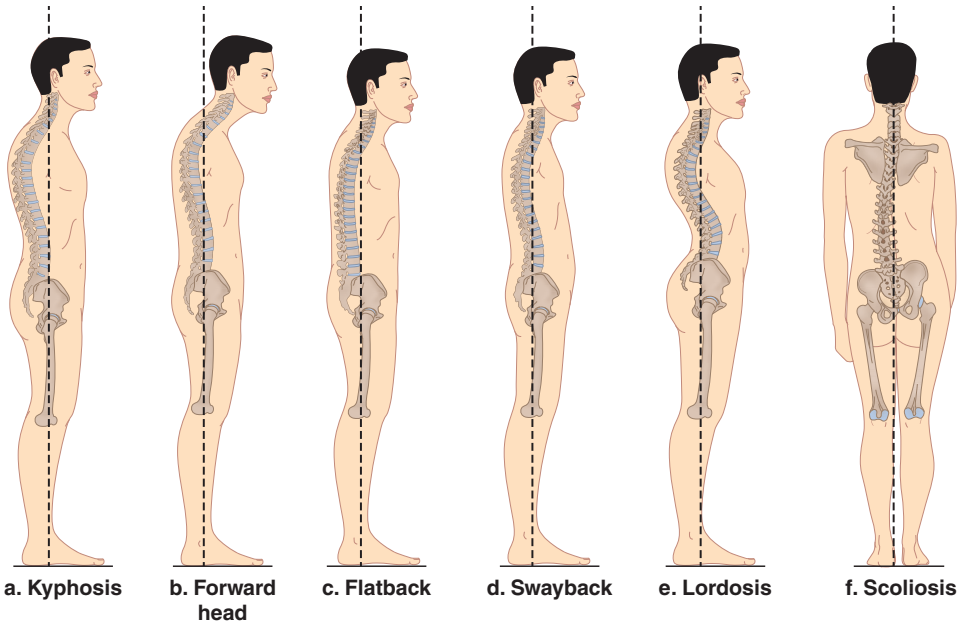


FIGURE 1.1 Postural malalignment. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

BONES

The adult skeleton is made up of 206 bones of different shapes and sizes. At birth, however, a baby has around 300 bones. As the child grows, some of these bones gradually fuse together, forming the larger bones found in adults. In infancy, bones consist largely of cartilage, a flexible connective tissue, which is slowly replaced by bone through the process of ossification. Notably, about half of the bones in the adult body are located in the hands and feet.

Joints, such as those located at the elbow and knee, are essential for movement. Without joints, the skeleton would be rigid and immobile. Cartilage plays a key role in joint function by acting as a firm yet flexible cushion, protecting joint surfaces from the forces generated during movement. Ligaments, which connect bone to bone, provide stability and strength to joints. These may form part of the joint capsule or exist independently around the joint. Actual movement occurs when muscles contract across the joint, pulling on the bones to create motion. Table 1.2 summarises the roles of bones, cartilage, ligaments and muscles in movement.

AXIAL AND APPENDICULAR SKELETON

The skeleton provides the body with structure, shape and physical support for the organs and systems that it contains. It also forms an essential part of the musculoskeletal system, which enables movement.

The skeleton is divided into two main parts: the axial skeleton and the appendicular skeleton. Figure 1.2 shows the human skeleton, highlighting the axial skeleton in blue and the appendicular skeleton in white.

Tables 1.3 and 1.4 outline the bones of the axial and appendicular skeleton, respectively.

Table 1.2 Bones, cartilage, ligaments and muscles

Structure	Description	Role in movement
Bones	Rigid framework of 206 bones in the adult body	Provide structure, protection and act as levers for movement
Cartilage	Firm but flexible connective tissue covering joint surfaces	Cushions joints, reduces friction and absorbs shock during movement
Ligaments	Strong bands of connective tissue connecting bone to bone	Stabilise joints, prevent excessive movement and maintain alignment
Muscles	Contractile tissues attached to bones by tendons	Generate movement by contracting and pulling on bones across joints

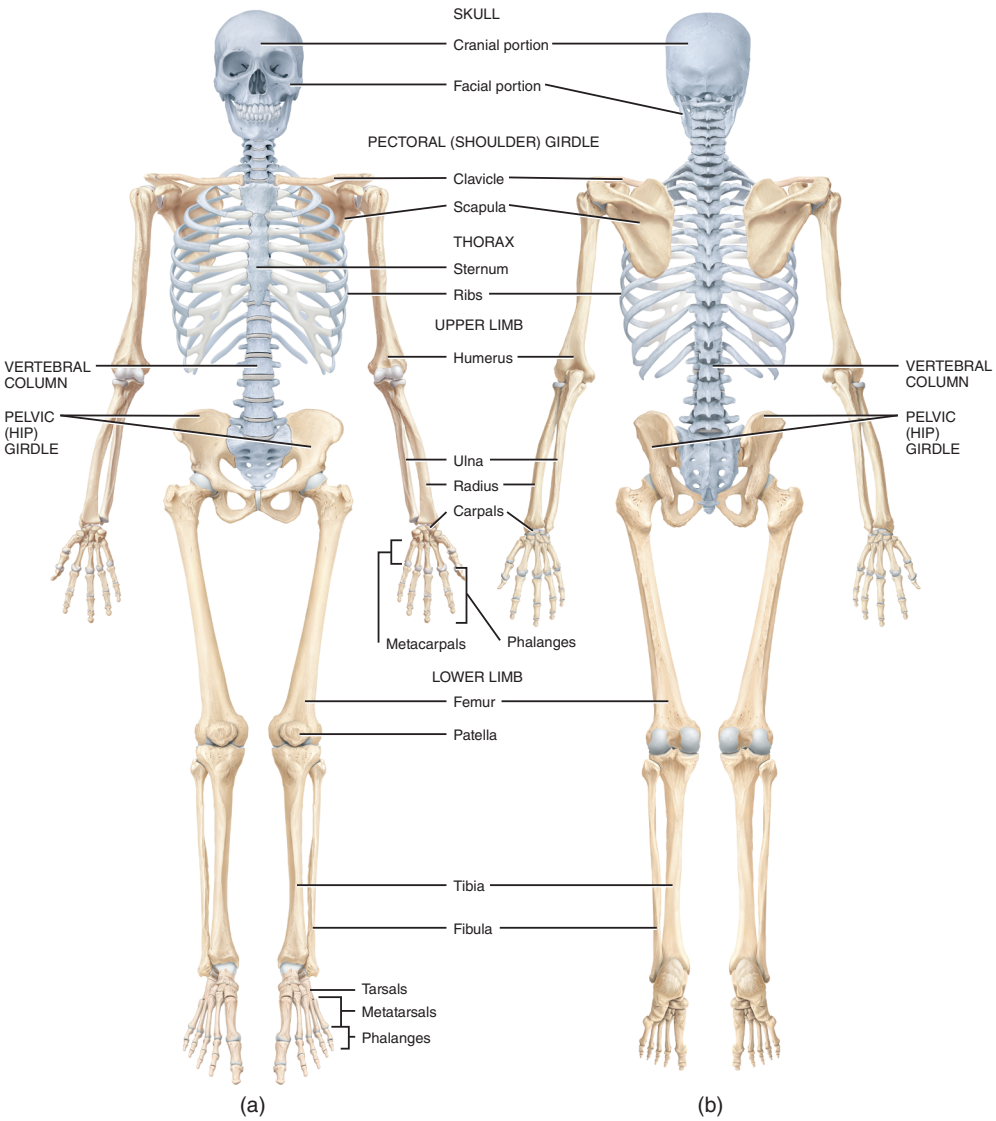


FIGURE 1.2 The human skeleton (a) anterior view, (b) posterior view. Axial skeleton in blue, appendicular skeleton in white. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

Table 1.3 Bones of the axial skeleton

Structure	Number of bones
Skull	
Cranium	8
Face	14
Hyoid	1
Auditory ossicles	6
Vertebral column	26
Thorax	
Sternum	1
Ribs	24
Total bones in axial skeleton	80

Note: This counts the sacrum and coccyx as single vertebrae; they are actually formed from five sacral and four coccygeal fused vertebrae. Some sources list 33 vertebrae for this reason.

Table 1.4 Bones of the appendicular skeleton

Structure	Number of bones
Pectoral girdle	
Clavicle	2
Scapula	2
Upper limbs	
Humerus	2
Ulna	2
Radius	2
Carpals	16
Metacarpals	10
Phalanges	28
Pelvic girdle	
Pelvic bone	2
Lower limbs	
Femur	2
Patella	2
Fibula	2
Tibia	2
Tarsals	14
Metatarsals	10
Phalanges	28
Total bones in appendicular skeleton	126
Total number of bones in the adult human skeleton	206

COMPOSITION OF BONE AND FUNCTION

Although bones are strong enough to protect underlying tissues and organs as well as supporting the body's weight, they are not completely solid. The outer layer of bones is dense, compact bone, which provides strength and rigidity. In contrast, the interior of bones consists of spongy (or trabecular) bone, a lighter, mesh-like structure that reduces skeletal weight while still contributing to internal strength. The struts of spongy bone act like internal supports, reinforcing the bone from within.

At the centre of many bones lies the medullary cavity, which houses blood vessels supplying the bone and the bone marrow, the site of blood cell production. Figure 1.3 illustrates compact and spongy bone along with their blood supply.

In addition to structural support, bones act as a reservoir for minerals, particularly calcium and phosphate, helping to maintain mineral balance in the blood.

PHYSIOLOGICAL ROLES OF BONE

Support and protection

Bones provide structural support and define the shape of the body. Soft tissues adhere to and envelop the skeleton, which is essentially non-compressible, giving the body its overall contour. Bones also protect delicate organs:

- The skull safeguards the brain.
- The sternum and ribs protect the heart and lungs.

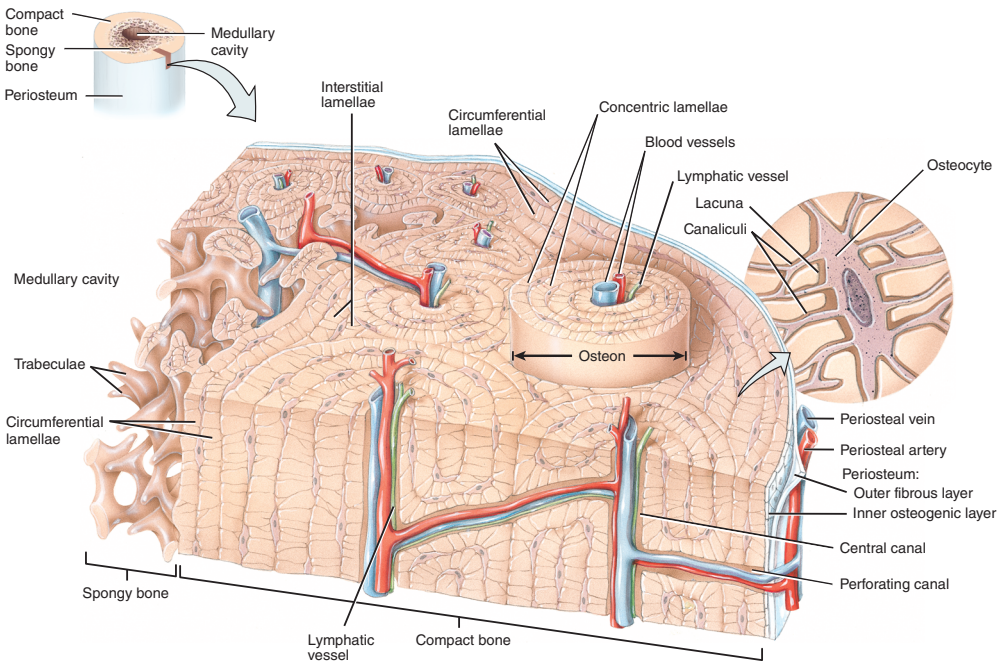


FIGURE 1.3 Compact and spongy bone with blood supply. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

- The vertebrae shield the spinal cord.
- The pelvis protects abdominal and female reproductive organs.

Protection is balanced with mobility. For example, the ribs form a 'cage' that allows the chest to expand during breathing, and the vertebral column consists of 26 vertebrae with mobile joints, permitting bending and stretching while still offering protection to the spinal cord.

Enabling movement

Bones act as rigid levers for muscles to pull on, enabling purposeful movement of the whole body or its parts. They also provide supportive platforms for maintaining posture and body position. Standing and walking on two legs (bipedal posture) puts extra pressure or load on the bones and muscles of the back and spine. These bones and muscles have to work harder than if we were walking on all fours, because they must support the weight of the entire upper body while keeping us upright and stable.

Movement is achieved at joints, where bones articulate and is powered by the contraction of skeletal muscles. This arrangement allows a wide range of motion, from fine finger movements to whole-body locomotion.

Haematopoiesis (blood cell production)

Bones are the site of blood cell formation, occurring in red bone marrow (myeloid tissue). In adults, red marrow is found in vertebrae, pelvis, ribs, skull and the ends of long bones. It produces:

- Red blood cells for oxygen transport.
- White blood cells for immune defence.
- Platelets for blood clotting.

Red bone marrow contains multipotent stem cells, capable of developing into various blood cells. Regular production of blood cells is essential, as they have a limited lifespan. Inadequate bone marrow function can lead to anaemia (red cell deficiency) or immune deficiencies (white cell deficiency).

Some bones, such as the shafts of long bones, contain yellow marrow, which primarily stores fat and does not produce blood cells.

Mineral storage and calcium homeostasis

Bones store essential minerals, especially calcium and phosphate and can release them into the bloodstream to maintain homeostasis. This process is regulated by parathyroid hormone. Calcium is vital for:

- Muscle contraction
- Nerve impulse transmission
- Blood clotting
- Maintaining bone health

Maintaining stable blood calcium levels is therefore critical for overall physiological function.

A healthy skeleton is essential for overall health and well-being. It provides structural support, protects vital organs, enables movement, regulates mineral metabolism and contributes to blood cell production. Maintaining bone health through adequate nutrition, regular exercise and healthy lifestyle habits is crucial for optimal physical function throughout life.

BONE: A DYNAMIC CONNECTIVE TISSUE

Bone is a specialised type of connective tissue, it is not just a static, hard structure. Instead, it is a living tissue that constantly changes, adapts and remodels itself in response to the body's needs. As is the case with other connective tissues, it consists of specialised cells that are embedded within an extracellular matrix. The three main bone cell types, osteoblasts, osteoclasts and osteocytes, perform distinct functions to maintain, remodel and repair bone.

The extracellular matrix of bone has an organic framework that is primarily collagen, onto which layers of inorganic calcium salts are deposited. This combination provides bones with strength and rigidity from calcium salts, while collagen contributes flexibility. Together, these properties give bone:

- Tensile strength: The ability to resist being pulled or stretched without breaking. Collagen primarily provides this.
- Compressive strength: The ability to withstand being squeezed or compressed without collapsing. Calcium salts mainly provide this.
- Resilience: The ability to absorb energy and return to its original shape after being bent, twisted or stressed.

Healthy bone maintains the right balance of collagen and calcium to function optimally. Disorders affecting these components can compromise bone strength:

- Osteogenesis imperfecta (brittle bone disease) results from defective collagen, producing fragile bones prone to fractures.
- Rickets occurs when bones lack sufficient calcium salts, often due to vitamin D deficiency, leading to soft, easily bent bones.
- Osteoporosis, the most common disorder, involves reduced bone density despite normal collagen-to-calcium ratios, increasing fracture risk.

Bone is dynamic and adaptive, constantly undergoing renewal. Bone has a special property known as piezoelectricity, which means it can produce a small electrical charge when it is compressed or stressed. For example, when undertaking weight-bearing exercise such as walking, running or lifting, the bones experience pressure or stress. This stress causes tiny electrical charges in the bone, which stimulate bone cells to deposit more bone tissue, making the bone stronger along the lines of stress. Conversely, lack of weight-bearing activity (e.g. prolonged bed rest) can rapidly reduce bone density.

FUNCTIONS OF BONE CELLS

Bone is a living tissue; continual growth, maintenance and repair depend on the coordinated activity of three specialised types of cells. Each cell type performs a unique role in maintaining bone strength, structure and adaptability: some build bone, some break it down and others

monitor and regulate the process. Understanding these cells is essential for appreciating how bones grow, remodel and heal after injury.

OSTEOBLASTS

Osteoblasts produce the organic bone matrix (this is collagen) and regulate calcium deposition, forming solid bone. They are essential for bone formation and for fracture healing.

OSTEOCLASTS

Osteoclasts are large cells that break down bone by secreting enzymes and acids, releasing minerals into the blood. This process initiates bone renewal, and prepares the bone surface for osteoblasts to deposit new bone. Bone density depends on the balance between osteoblast and osteoclast activity.

OSTEOCYTES

Osteocytes develop from osteoblasts and become embedded in the bone matrix, extending cellular projections to communicate with neighbouring cells. They form a network that detects mechanical stress and helps regulate bone remodelling. Osteocytes are crucial for bone's piezoelectric properties.

CARTILAGE

Cartilage is a specialised type of connective tissue that provides cushioning, support and protection for bones and other structures. It plays a critical role in joint function, allowing smooth movement while absorbing shock and reducing friction between bones. Cartilage also maintains the shape of certain structures, such as the outer ear and nasal tip.

Unlike bone, cartilage is avascular, meaning it does not contain blood vessels. Instead, nutrients diffuse through the matrix to reach the cells, which is one reason cartilage heals more slowly than bone. Over time, age, mechanical stress or injury can lead to cartilage degeneration, contributing to joint conditions such as osteoarthritis, characterised by pain, stiffness and loss of joint mobility.

Types of cartilage:

1. Hyaline cartilage
   - Appears smooth and glassy, minimising friction at joint surfaces.
   - Found on the ends of bones within movable joints, rib tips, the nasal tip and comprises much of the fetal skeleton, providing a template for bone formation.
   - Its smooth surface is essential for fluid, pain-free movement and for reducing wear on bones.
2. Elastic cartilage
   - Contains elastin fibres in addition to collagen, giving it flexibility and resilience.
   - Allows structures to return to their original shape after bending or stretching.
   - Key locations include the epiglottis, which covers the airway during swallowing and the external ear, maintaining its shape.

3. Fibrocartilage
    - Contains abundant collagen, making it strong, moderately elastic and resistant to compression.
    - Serves as a shock absorber and stabiliser in areas that experience heavy loads or stress.
    - Found in the intervertebral discs, menisci of the knee and pubic symphysis, where it cushions joints and distributes pressure efficiently.

Understanding the different types of cartilage is important in clinical practice, as degeneration or injury to specific cartilage types can lead to joint dysfunction, reduced mobility and chronic pain. Preservation of cartilage through exercise, nutrition and injury prevention is crucial for maintaining healthy joints throughout life.

LIGAMENTS AND TENDONS

Ligaments are strong bands connecting bone to bone, providing joint stability. Joint mobility depends on ligament number and tension. Highly flexible ligaments can allow hyperextension ('double-jointed').

Tendons attach muscles to bones, transmitting force to produce movement. They are slightly elastic to absorb sudden forces yet strong enough to move bones efficiently.

BONE FORMATION AND GROWTH

Most bone formation begins in utero with hyaline cartilage models (endochondral ossification), although some bones form directly from mesenchyme via intramembranous ossification. By the third month of pregnancy, the skeletal framework is formed mainly of cartilage. Through endochondral ossification, cartilage is gradually replaced by bone as osteoblasts deposit calcium onto the collagen matrix (see Figure 1.4).

In long bones, cartilage remains at the ends as articular cartilage (reducing friction at joints) and as the epiphyseal (growth) plate, allowing longitudinal growth (see Figure 1.5). Bone width increases circumferentially through osteoblast deposition on the outer surface and osteoclast resorption inside the bone cavity, maintaining proportional thickness (see Figure 1.6).

Bone remodelling continues throughout life, balancing bone formation and resorption based on mechanical stress, hormones and nutrition (see Figure 1.7).

BONE HEALING

A remarkable feature of bone is its ability to fully regenerate after a fracture. Unlike ligaments, cartilage or tendons, which often heal with scar tissue, bone can restore its original structure and function. The healing process is carefully orchestrated and occurs in several overlapping stages (Evans 2026):

1. Formation of a cartilaginous callus
    - Immediately after a fracture, the body stabilises the broken bone ends.
    - A soft callus composed of cartilage and connective tissue forms around the fracture site, bridging the gap and providing temporary structural support.
    - This stage protects the injured area and begins the framework for new bone formation.

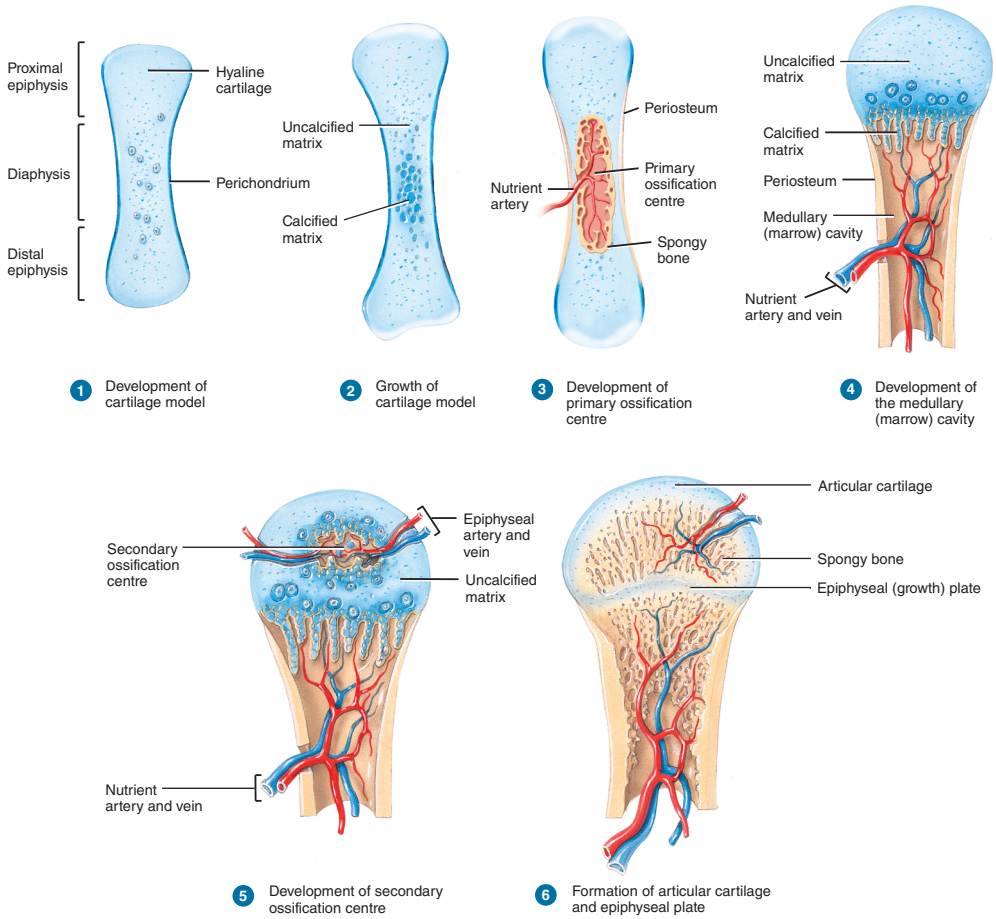


FIGURE 1.4 Endochondral ossification of the tibia. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

2. Replacement by a bony callus
   - Osteoblasts gradually replace the cartilaginous callus with hard, mineralised bone, forming a bony callus.
   - At this stage, the bone regains sufficient strength to bear weight and withstand mechanical stress, although it is not yet fully remodelled.
3. Bone remodelling
   - Over weeks to months, the bony callus undergoes remodelling, where osteoclasts and osteoblasts reshape the bone into its original compact and spongy architecture.
   - The repaired bone restores its original strength and structural alignment, leaving no scar tissue and can function as it did before the fracture.

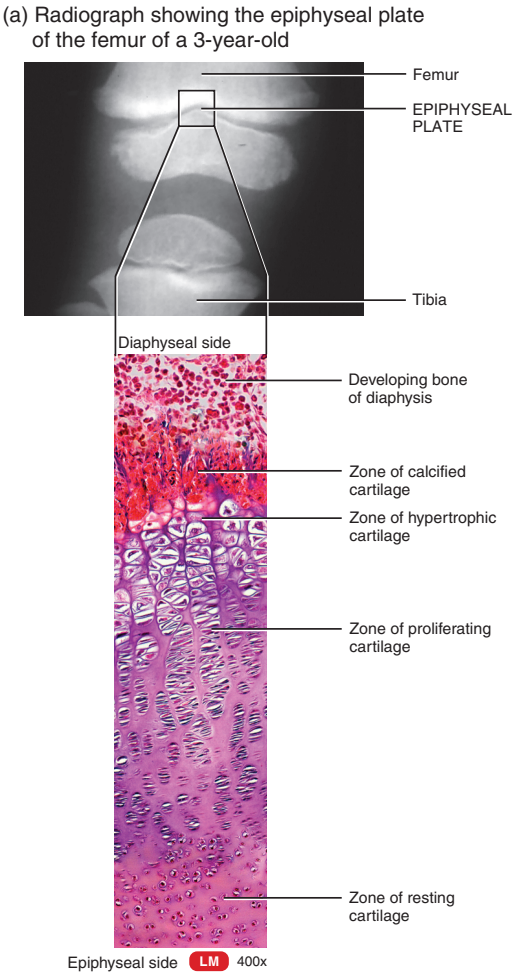
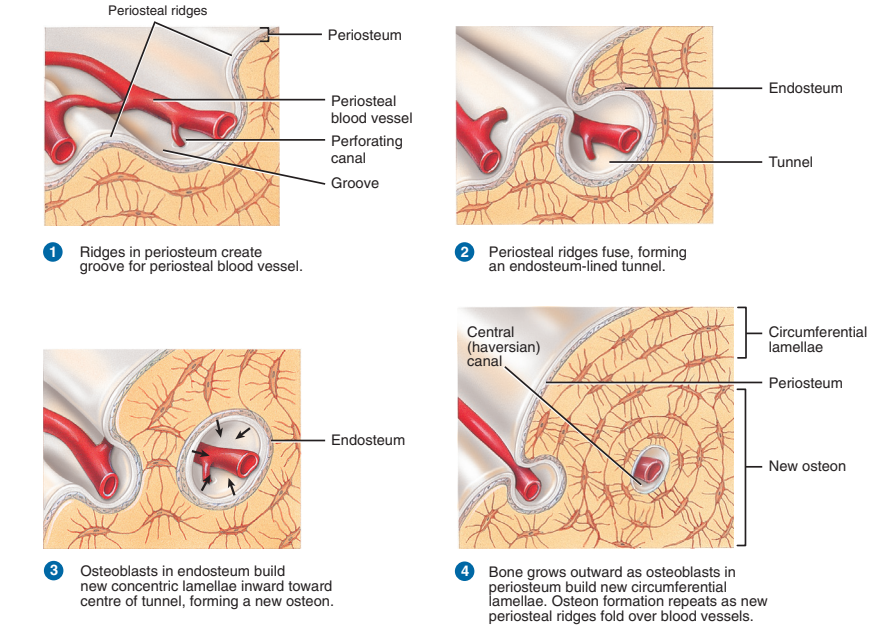
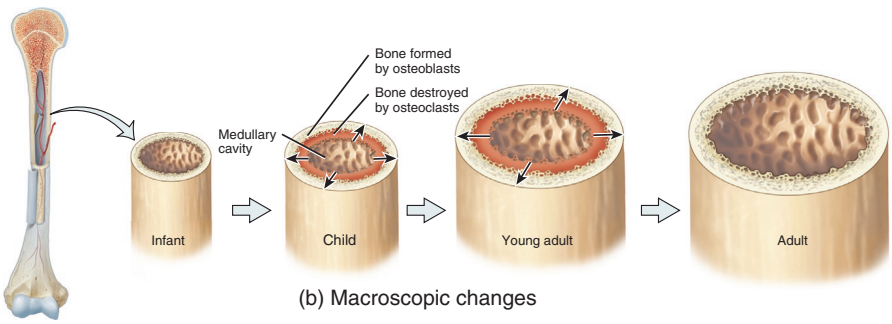


FIGURE 1.5 Long bones grow in length from the cartilaginous epiphyseal plates. *Source*: Tortora and Derrickson (2014). With permission of John Wiley & Sons.



(a) Microscopic details



(b) Macroscopic changes

FIGURE 1.6 Bones increase in width but maintain the same proportion of compact bone to medullary cavity. *Source*: Tortora and Derrickson (2014). With permission of John Wiley & Sons.

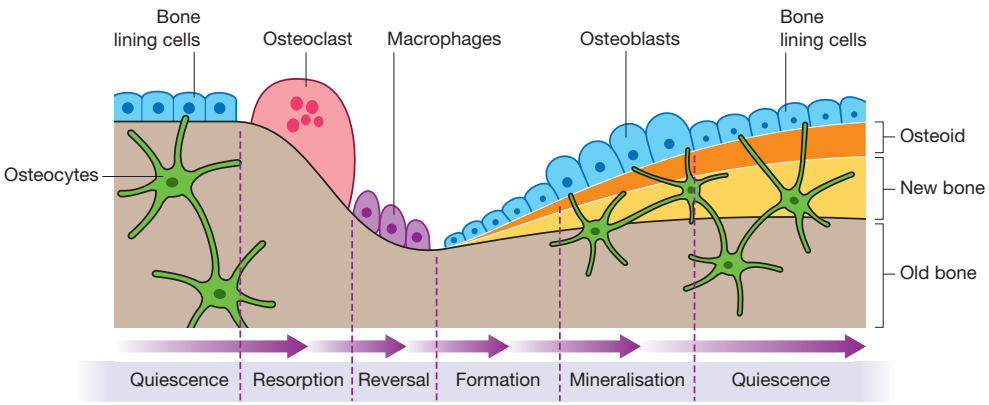


FIGURE 1.7 Bone remodelling. *Source*: Peate et al. (2014). With permission of John Wiley & Sons.

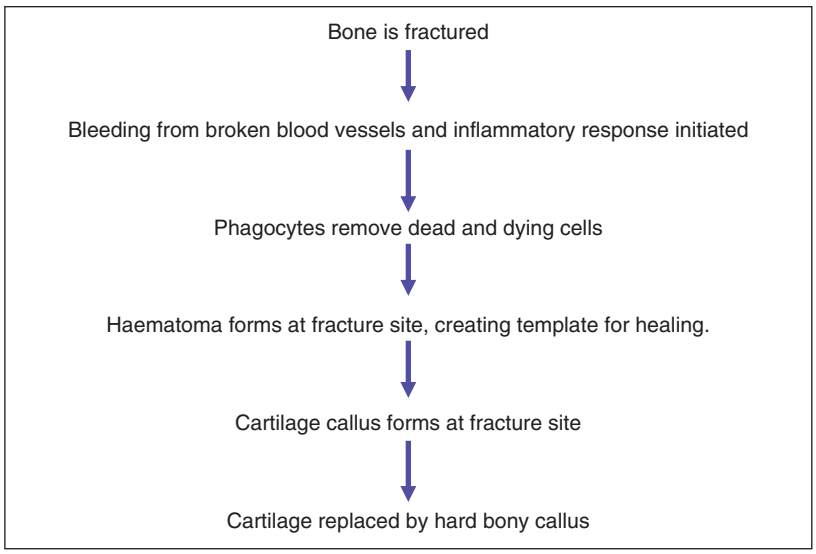


FIGURE 1.8 Stages of fracture healing in bone. *Source*: Curr and Fordham-Clarke (2022). With permission of John Wiley & Sons.

A rich blood supply is critical at every stage of fracture healing. Blood vessels:

- Deliver oxygen and nutrients necessary for cell survival and bone formation.
- Bring osteoblasts, osteoclasts and stem cells to the fracture site.
- Carry phagocytic white blood cells to remove debris and prevent infection.

See Figure 1.8.

CLINICAL CONSIDERATIONS

Healing can be delayed or impaired by poor circulation, infection, malnutrition, smoking or certain medications. Weight-bearing and mechanical stress applied gradually during rehabilitation help stimulate bone remodelling, strengthening the repaired bone along the lines of stress.

Bone healing is an example of the skeleton's dynamic and regenerative nature, demonstrating how structural support, cellular activity and vascular supply work together to restore function after injury.

BONE SHAPES

Bones are classified by shape and function:

- Long bones: Longer than wide; e.g. humerus, femur, metacarpals. Shaft (diaphysis) is compact bone; ends (epiphyses) are spongy bone (see Figure 1.9).
- Short bones: Approximately equal in width and length; e.g. carpals, tarsals. Thin compact layer covers spongy bone (see Figure 1.10).
- Flat bones: Thin, protect organs or provide broad muscle attachment; e.g. skull, scapula, sternum, ribs (see Figure 1.11).

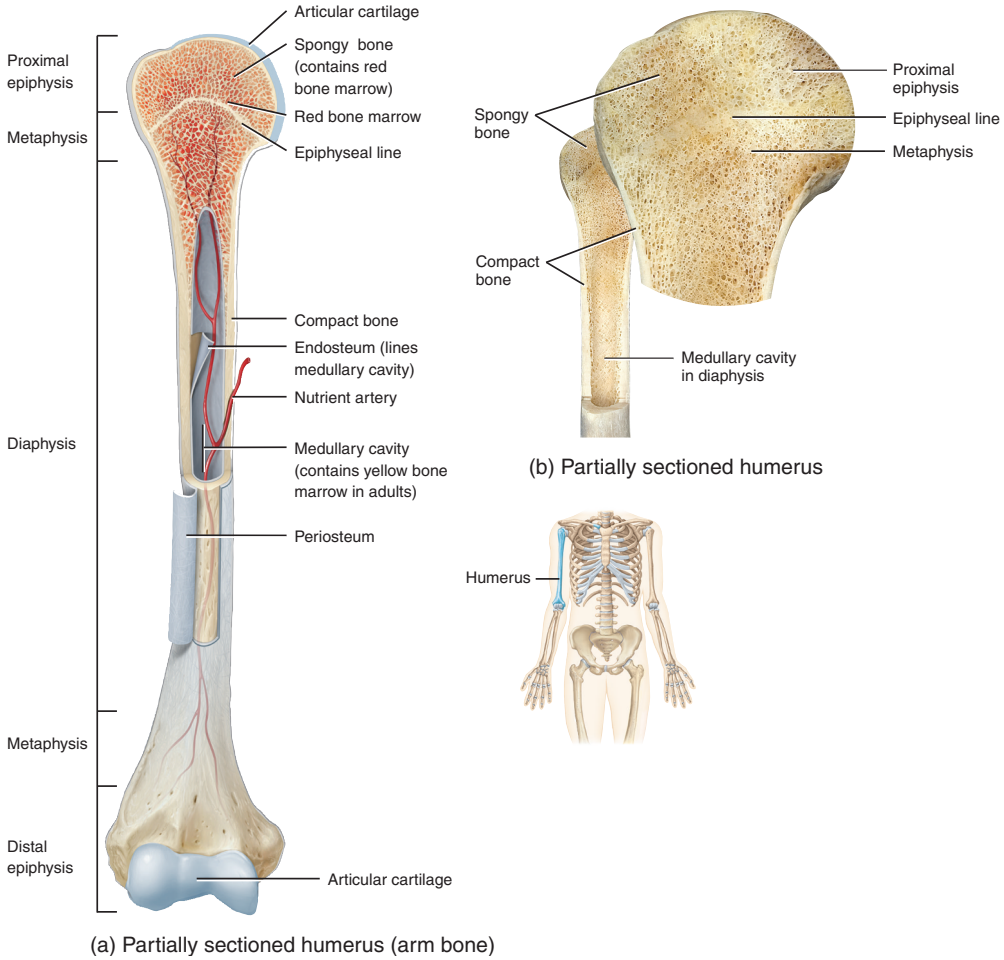


FIGURE 1.9 Parts of long bone. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

- Irregular bones: Complex shapes; e.g. vertebrae, sphenoid, ossicles (see Figure 1.12).
- Sesamoid bones: Develop in tendons to reduce friction; e.g. patella (see Figure 1.13).

JOINTS

Joints are points where two bones meet. With the exception of the hyoid bone in the neck, every bone in the body connects to at least one other bone at a joint. Joints are also called articulations, not only join bones but also allow movement and provide stability.

MOVEMENTS

Bones act as levers, transmitting the forces generated by skeletal muscles. By pulling and contracting, muscles can move bones in different directions and with varying degrees of force.

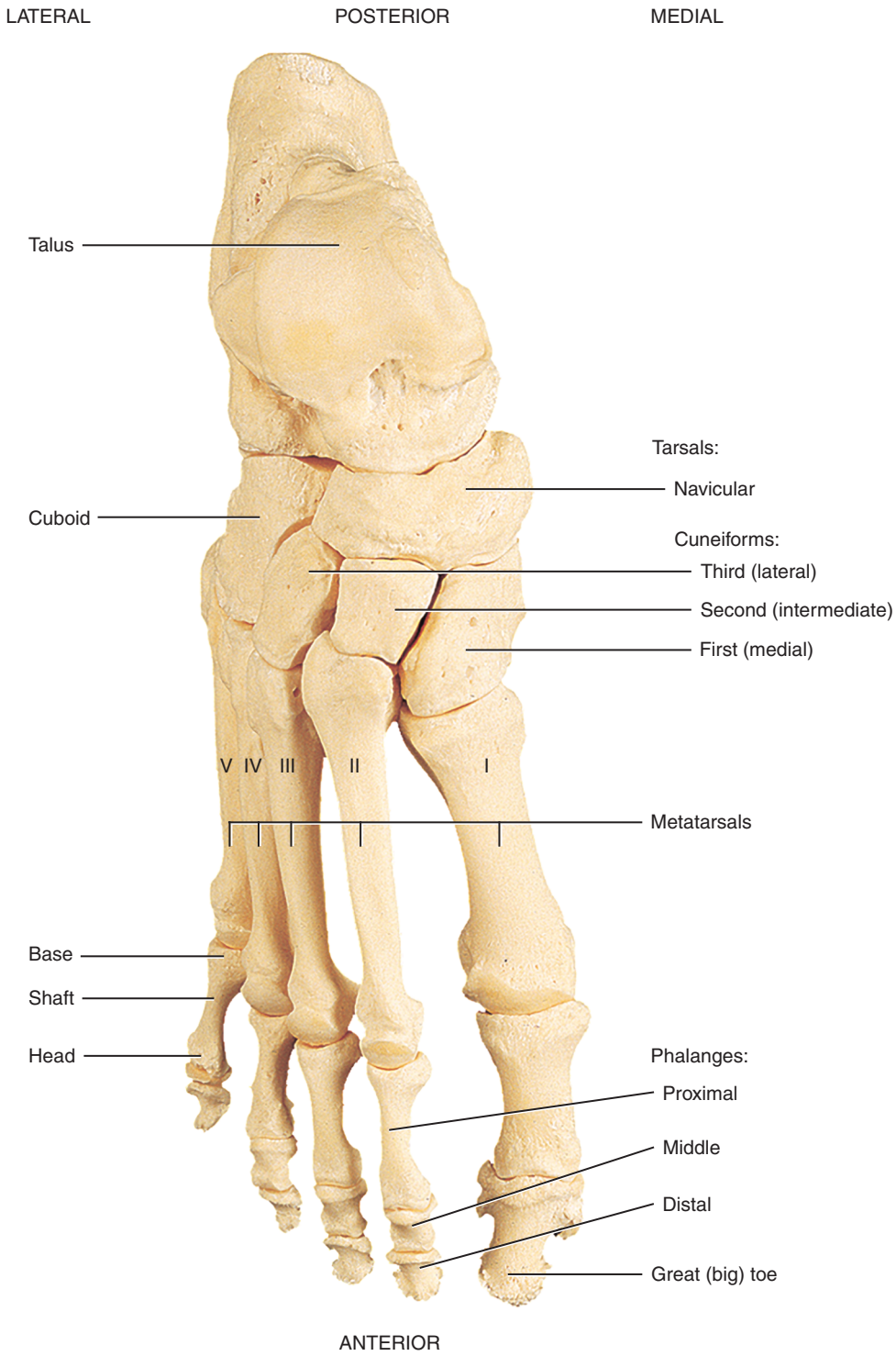


FIGURE 1.10 Parts of short bone. *Source*: Tortora (2008). With permission of John Wiley & Sons.

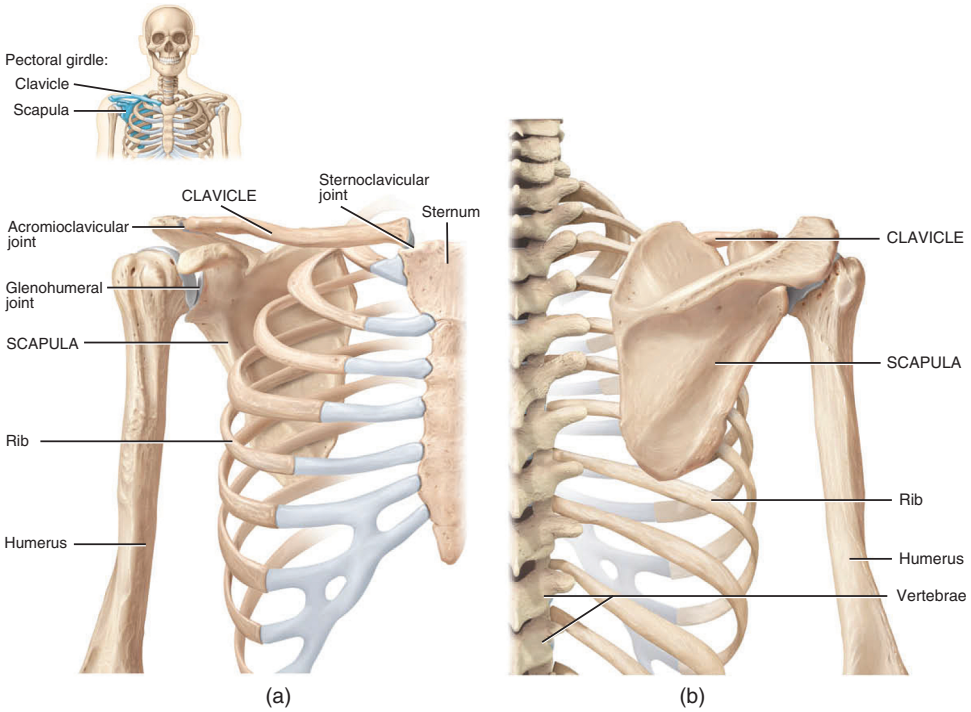


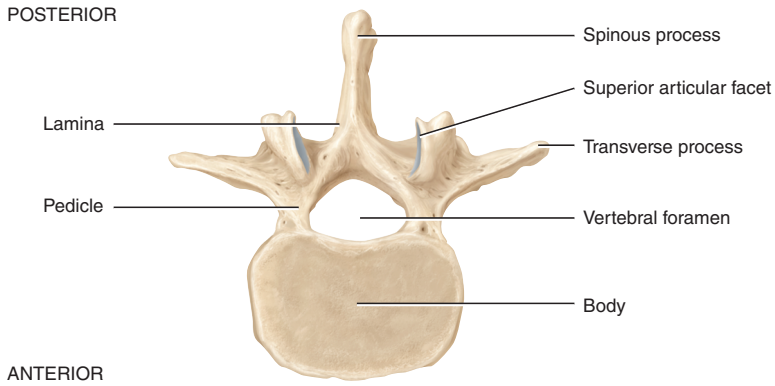
FIGURE 1.11 Flat bones: (a) the sternum and (b) the scapula and ribs. *Source*: Tortora and Derrickson (2014). With permission of John Wiley & Sons.

These movements range from fine, precise actions such as writing or threading a needle, to gross, large-scale movements, for example, changing body position. The coordinated action of muscles and bones is also essential for functions such as breathing.

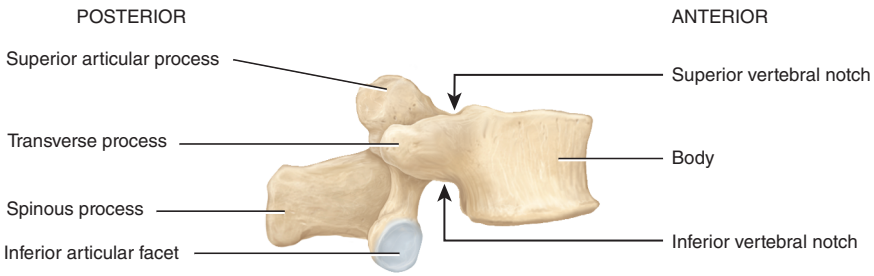
- Tendons are fibrous connective tissues that attach muscles to bones and in some cases, to structures such as the eyeball, enabling movement.
- Ligaments attach bone to bone, providing stability and preventing excessive motion at the joint.

Different joints allow varying ranges and types of movement. For example, the shoulder joint is more versatile than the knee joint. Common joint movements include:

- Flexion: Decreasing the angle at a joint (e.g. bending the knee or elbow).
- Extension: Increasing the angle at a joint (e.g. straightening the knee or elbow).
- Adduction: Moving a body part toward the midline (e.g. bringing one leg toward the other).
- Abduction: Moving a body part away from the midline (e.g. taking one leg away from the other).
- Rotation: Turning a body part around its axis, either external/lateral or internal/medial (e.g. turning the foot outward or inward).



(a) Superior view



(b) Right lateral view

FIGURE 1.12 The vertebrae – irregular bones (a, b). *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

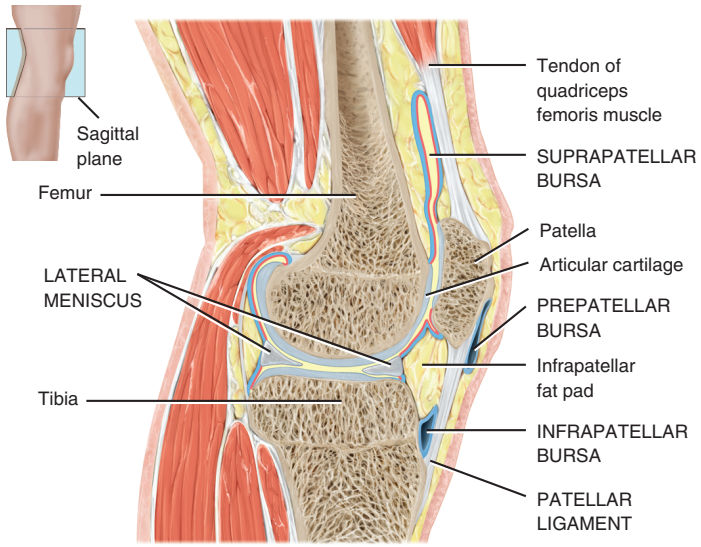


FIGURE 1.13 A sesamoid bone, the patella, shown in lateral view, in the tendon of the quadriceps muscle, positioned to protect the tendon from friction when the knee joint bends. *Source*: Tortora and Derrickson (2014). With permission of John Wiley & Sons.

TYPES OF JOINTS

Fibrous joints

- Also called synarthroses, fibrous joints are connected only by ligaments, which are dense connective tissues rich in collagen fibres.
- These joints lack a synovial cavity, making them generally immobile or very limited in movement.

Cartilaginous joints

- These joints, including synchondroses and symphyses, connect bones with cartilage and do not have a synovial cavity.
- Examples include intervertebral joints in the spine.
- Symphysis joints are permanent cartilaginous joints with a fibrocartilage pad, such as the pubic symphysis.

Synovial joints

- Also called diarthroses, synovial joints are the most common and highly mobile type of joint.
- They are enclosed in an articular capsule, lined by a synovial membrane that produces synovial fluid.
- Hyaline cartilage covers the ends of the bones, cushioning and reducing friction.
- Synovial fluid is clear or slightly yellow, viscous and lubricates the joint while supplying nutrients and removing waste.

There are six types of freely moveable synovial joints (see Figure 1.14), each allowing specific patterns and ranges of motion.

Most joints in the body are synovial joints, which allow considerably more movement than cartilaginous joints. They are predominantly found in the limbs, where mobility is essential. Ligaments provide stability, while muscles contract to produce movement.

TYPES OF SYNOVIAL JOINTS

HINGE JOINTS

- A convex surface of one bone fits into a concave surface of another, similar to a household hinge.
- Movement is uniaxial, restricted to flexion and extension, producing an open-and-close motion, such as at the elbow or knee.

PIVOT JOINTS

- A rounded portion of one bone fits into a groove of another bone, allowing rotation around a single axis.
- These are uniaxial joints, for example, the proximal radioulnar joint in the forearm.

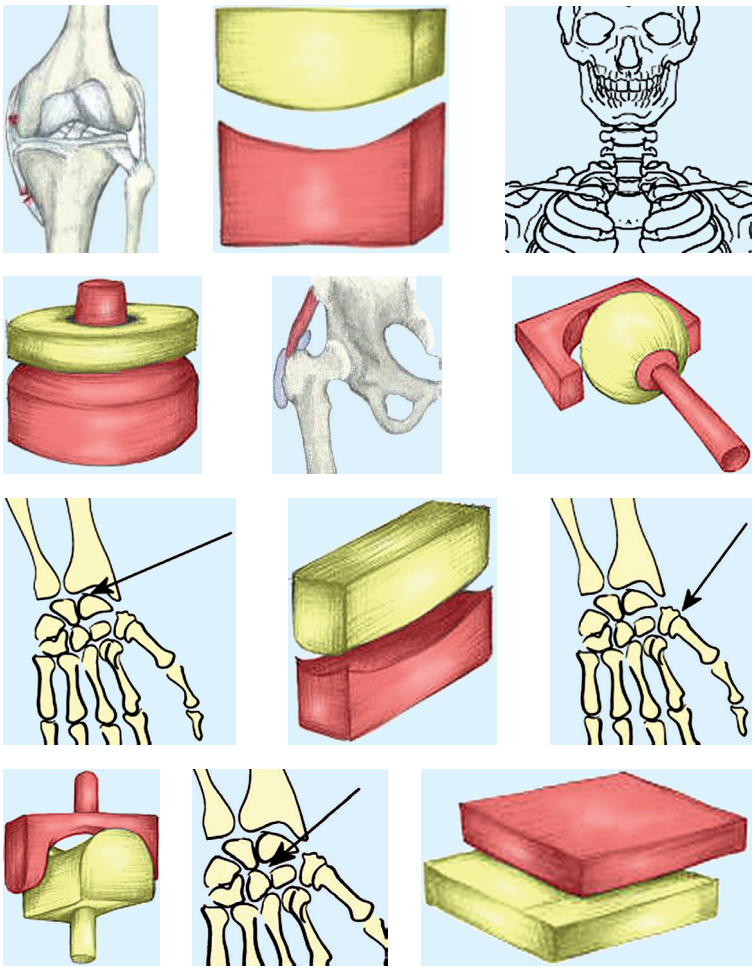


FIGURE 1.14 Joint types. *Source*: Tortora and Derrickson (2014). With permission of John Wiley & Sons.

BALL-AND-SOCKET JOINTS

- A spherical end of one bone fits into a concave socket of another, allowing movement in multiple planes.
- These triaxial joints permit flexion, extension, abduction, adduction and rotation, as seen in the shoulder and hip.

CONDYLOID JOINTS

- An oval surface of one bone fits into a complementary concave surface of another.
- These biaxial joints allow flexion, extension, abduction and adduction, such as the wrist joint.

SADDLE JOINTS

- Similar to condyloid joints but with a greater range of movement.
- They allow flexion, extension, abduction and adduction and are considered triaxial, as seen in the thumb (carpometacarpal joint).

GLIDING (PLANE) JOINTS

- These joints have flat or slightly curved surfaces, permitting sliding or gliding movements.
- Movement is limited, typically back-and-forth or side-to-side, and the joints are stabilised by ligaments, such as in the intercarpal joints of the wrist.

FIXED (IMMOVABLE) JOINTS

- Some joints do not allow any movement.
- Examples include sutures in the skull and joints in the pelvis, where bones are held together by fibrous tissue.

Table 1.5 summarises joint types.

MUSCLES

The muscular system generates and controls movement. By contracting and relaxing, muscles pull on bones to create motion at joints. Movement is therefore the result of a close interplay between bones, muscles, tendons and ligaments. A fundamental principle of muscle

Table 1.5 Joint types, movement axes and examples

Joint type	Movement axis	Description/movement	Example
Hinge	Uniaxial	Allows flexion and extension; open-and-close motion	Elbow, knee
Pivot	Uniaxial	Allows rotation of one bone around another	Proximal radioulnar joint
Ball-and-socket	Triaxial	Allows flexion, extension, abduction, adduction, rotation	Shoulder, Hip
Condyloid	Biaxial	Allows flexion, extension, abduction, adduction	Wrist (radiocarpal joint)
Saddle	Triaxial	Greater range than condyloid; flexion, extension, abduction, adduction	Thumb (carpometacarpal joint)
Gliding (plane)	Limited (multidirectional)	Sliding or gliding; back-and-forth and side-to-side motion	Intercarpal joints (wrist)
Fixed (fibrous)	None	No movement; bones held together by fibrous tissue	Skull sutures, Pelvic joints

physiology is that muscles can only pull, not push. When one muscle contracts, it shortens and exerts a pulling force on the bone it is attached to, while other muscles relax or lengthen to permit the movement. Without muscles, the skeleton would remain immobile and function only as a passive structure.

FUNCTIONS OF MUSCLES

Muscles are not only responsible for external, visible movements such as walking, running or lifting objects but also play vital roles in sustaining internal physiological activities:

- Locomotion and voluntary movement: Skeletal muscles enable deliberate and coordinated actions, from gross movements such as standing, jumping or reaching, to fine motor tasks including writing, sewing or manipulating instruments.
- Postural control: Even when the body is at rest, muscles maintain a low level of tension (muscle tone) that stabilises the skeleton and preserves posture. Without this constant activity, upright stance and balance could not be maintained.
- Internal organ function: Smooth and cardiac muscles operate involuntarily, ensuring vital processes such as respiration, digestion, circulation and urinary function. Smooth muscles in the digestive tract, for example, regulate peristalsis, while cardiac muscle powers the continuous pumping of the heart.
- Facial expression and communication: There are over 40 small muscles in the face that allow humans to smile, frown, speak and display subtle emotional cues, which are central to interpersonal communication.
- Heat production (known as thermogenesis): Because muscle contraction requires energy, heat is generated as a natural by-product of metabolism. This heat contributes significantly to maintaining body temperature, particularly during cold conditions or shivering responses.
- Protection and support: Muscles form protective layers around internal organs, such as the abdominal wall and help stabilise joints by reinforcing the skeletal framework.

MUSCLE ACTIONS

Most skeletal muscles work in opposing pairs across the joints:

- The agonist (prime mover) contracts to produce a specific movement.
- The antagonist relaxes and lengthens to permit that movement but also provides resistance to prevent excessive or uncontrolled action.
- Synergists assist the agonist by adding strength or stabilising nearby joints.
- Fixator muscles act to hold a bone steady, giving the prime mover a firm base from which to act.

When bending the elbow, for example, the biceps brachii (one of the major muscles of the upper arm) acts as the agonist, contracting to pull the forearm upward, while the triceps brachii acts as the antagonist by lengthening. This coordinated balance allows smooth, precise movement.

MUSCLES AND BODY MECHANICS

The muscular system also plays a central role in safe and efficient movement, particularly in healthcare practice and daily activities:

- Body mechanics involves using muscles in ways that maximise efficiency and minimise injury risk. This includes lifting with the legs rather than the back, keeping loads close to the body and avoiding twisting while carrying weight.
- Balance is achieved through integration of muscular activity, sensory input from the vestibular system in the inner ear and proprioceptive feedback from muscles and joints. Together, these mechanisms allow the body to respond rapidly to changes in terrain or external forces.
- Posture and alignment depend on continuous muscular control, particularly from the core, spinal and neck muscles. Correct posture distributes forces evenly across joints, reduces strain on muscles and ligaments and helps prevent musculoskeletal pain or long-term damage.

MUSCLE TYPES

There are three main types of muscle, each adapted to a different function:

1. Skeletal muscle. Voluntary, striated muscle attached to bones, responsible for posture, locomotion and voluntary movements.
2. Cardiac muscle. Involuntary, striated muscle found only in the heart, designed for rhythmic contraction and endurance.
3. Smooth muscle. Involuntary, non-striated muscle located in the walls of hollow organs such as blood vessels, the bladder and the intestines, controlling movement of substances within the body.

See Figure 1.15 for muscle tissue.

Together, these three tissue types ensure that the muscular system not only allows humans to interact with their environment but also sustains life itself by supporting vital organ function, circulation and energy balance.

See Table 1.6 for a summary of muscles.

SKELETAL MUSCLE

Skeletal muscles form the main component of the muscular system, comprising over 600 individual muscles and accounting for approximately 40–50% of an adult's body weight (Migliozzi 2026). These muscles are made up of elongated, striated fibres that can range in length from just a few centimetres to as much as 40 cm. Each fibre contains multiple nuclei. Unlike cardiac and smooth muscle, skeletal muscle is under voluntary control, meaning its contraction and relaxation occur through conscious effort. For this reason, skeletal muscle is often referred to as voluntary muscle. Under the microscope, the fibres display a banded appearance, giving rise to the alternative name striated or striped muscle.

Each muscle cell is surrounded by a membrane called the sarcolemma, which encloses the sarcoplasm (the cytoplasm of the muscle cell). From the sarcolemma, tubular

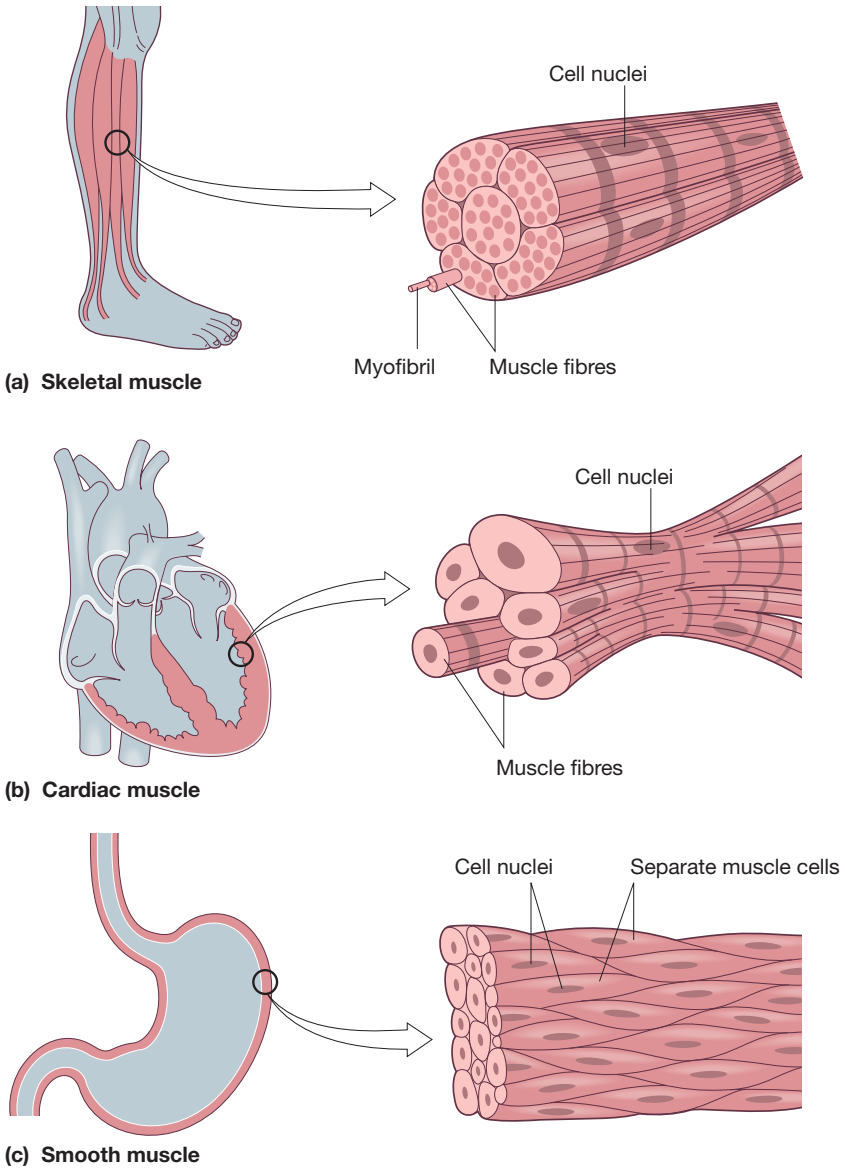


FIGURE 1.15 Muscle tissue. *Source*: Peate (2022). With permission of John Wiley & Sons.

extensions penetrate into the sarcoplasm, enabling rapid transmission of contraction signals throughout the fibre. Within each fibre are myofibrils, the contractile elements of muscle, composed of thin actin filaments and thick myosin filaments. These are organised into repeating structural units known as sarcomeres. Figure 1.16 shows a skeletal muscle fibre.

Table 1.6 Muscles

Category	Description	Notes
Primary role	Generate movement by contracting and pulling on bones	Muscles can only pull, not push
External functions	• Locomotion and voluntary movement • Postural control • Facial expression and communication • Protection and support of organs	Walking, writing, smiling, stabilising joints
Internal functions	• Cardiac muscle: powers the heart • Smooth muscle: controls digestion, respiration, circulation, urinary function • Heat production (thermogenesis)	Heartbeat, peristalsis, shivering to maintain temperature
Muscle actions	• Agonist – Prime mover • Antagonist – Opposes agonist • Synergist – Assists agonist • Fixator – Stabilises base bone	Example: Biceps (agonist) and triceps (antagonist) during elbow flexion
Body mechanics	Efficient use of muscles to minimise strain and injury	Lifting with legs, avoiding twisting with loads
Balance and posture	Balance: muscles along with vestibular system and proprioception Posture: alignment of spine, core and limbs	Core stability, neutral spine, weight distribution
Types of muscle tissue	• Skeletal muscle – Voluntary, striated, movement and posture • Cardiac muscle – Involuntary, striated, heart pumping • Smooth muscle – Involuntary, non-striated, organ function	Skeletal: Biceps, quadriceps Cardiac: Myocardium Smooth: Intestines, bladder

The sarcomere is the fundamental functional unit of skeletal muscle. It is bordered by Z lines, with the M line positioned centrally. Actin filaments are anchored at the Z lines and extend toward the centre, while myosin filaments are located between actin filaments. Contraction occurs when actin and myosin interact via cross-bridges, which repeatedly attach and release, causing the sarcomere to shorten. This process is triggered by the release of calcium ions, which initiate the sliding filament mechanism.

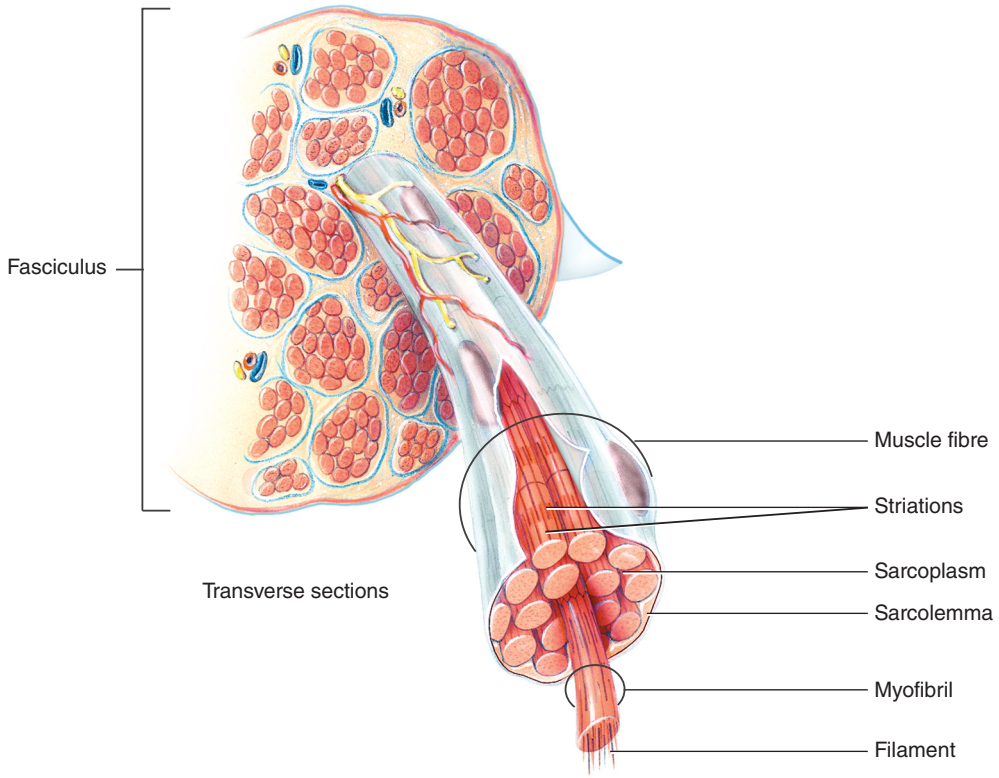


FIGURE 1.16 Skeletal muscle fibre. *Source*: Curr and Fordham-Clarke (2022). With permission of John Wiley & Sons.

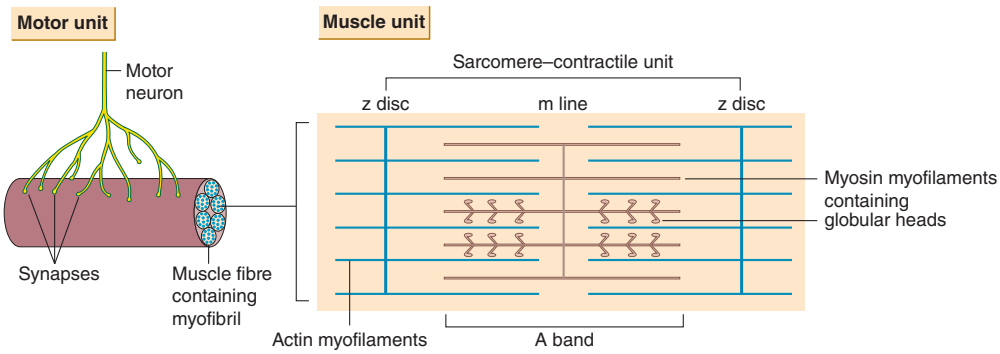


FIGURE 1.17 Motor and muscle units. *Source*: Peate (2021). With permission of John Wiley & Sons.

Each muscle fibre is surrounded by a delicate connective tissue layer called the endomysium. Groups of fibres are bundled together into fascicles, each encased in the perimysium. Multiple fascicles are then collectively surrounded by the epimysium, forming the entire muscle.

See Figure 1.17. Motor and muscle units.

THE NEUROMUSCULAR JUNCTION

The neuromuscular junction is the specialised site where a nerve impulse initiates muscle contraction. Each muscle fibre contains a single neuromuscular junction, the point at which the axon of a motor neuron communicates with the muscle cell. At the terminal end of the axon, adjacent to the motor endplate, lies a small gap called the synaptic cleft, which separates the nerve ending from the muscle fibre. Importantly, the two structures never come into direct physical contact.

Muscle activation at the neuromuscular junction occurs through chemical transmission. The axon terminal releases the neurotransmitter acetylcholine (ACh), which diffuses across the synaptic cleft and binds to specialised receptors on the motor endplate. See Figure 1.18, the neuromuscular junction.

This binding triggers a cascade of events:

- An action potential is generated in the muscle fibre.
- The action potential rapidly spreads along the sarcolemma and penetrates into the fibre's interior via the transverse (T) tubules.
- This electrical signal stimulates the release of calcium ions from the sarcoplasmic reticulum.
- The increase in calcium concentration initiates the sliding filament mechanism, ultimately leading to muscle contraction.

CARDIAC MUSCLE

Cardiac muscle is a specialised type of striated muscle that is found exclusively in the walls of the heart. The fibres are striated like skeletal muscle, giving them a banded appearance under a microscope, but they are branched, which distinguishes them from the long, cylindrical

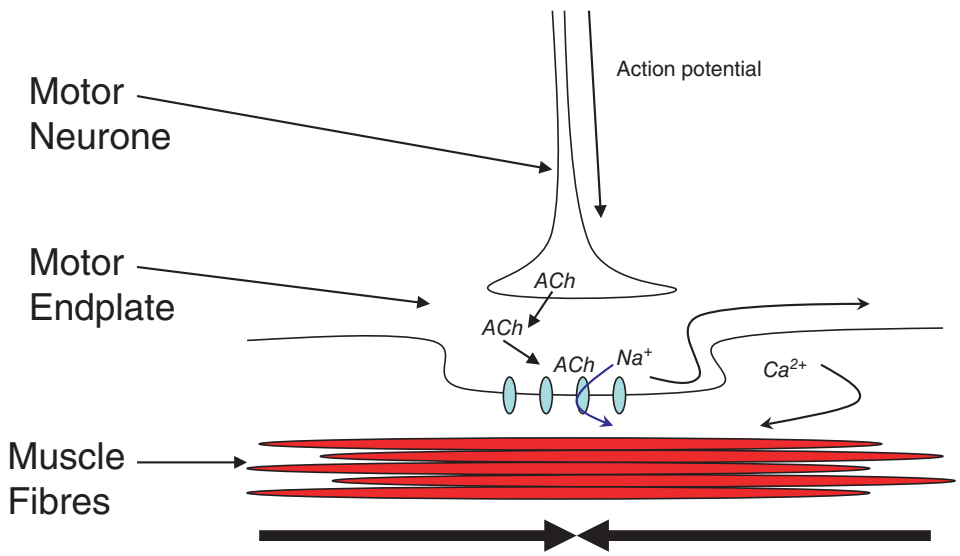


FIGURE 1.18 The neuromuscular junction. *Source*: Bench (2024). With permission of John Wiley & Sons.

fibres of skeletal muscle. Typically, each fibre contains a single, centrally located nucleus, although occasional fibres may contain two nuclei.

At the ends of cardiac muscle fibres are intercalated discs, specialised structures that connect adjacent fibres. These discs contain desmosomes and gap junctions, which perform distinct and essential functions:

- Desmosomes act as mechanical anchors; they provide structural cohesion and prevent fibres from separating during the strong contractions required to pump blood.
- Gap junctions allow rapid transmission of electrical impulses between the adjacent fibres, this usually ensures that the heart contracts in a coordinated, rhythmic manner. This electrical coupling is critical for maintaining the synchronised heartbeat necessary for efficient blood circulation.

Unlike skeletal muscle, cardiac muscle is involuntary, meaning its activity is not under conscious control. Its contraction is automatic and rhythmic, regulated by the heart's intrinsic conduction system, including the sinoatrial node and atrioventricular node. The coordinated contractions of cardiac muscle fibres generate the force required to propel blood through the heart chambers and into the systemic and pulmonary circulations, sustaining life.

Additionally, cardiac muscle demonstrates high endurance and resistance to fatigue due to its rich supply of mitochondria and reliance on aerobic metabolism. This enables the heart to contract continuously throughout a person's life without exhaustion.

SMOOTH MUSCLE

Smooth muscle is composed of non-striated, involuntary fibres, each containing a single centrally located nucleus. Unlike skeletal muscle, smooth muscle fibres are spindle-shaped and lack the banded appearance of striated muscle. Individual fibres are interconnected by numerous gap junctions, which allow electrical impulses to pass rapidly from one cell to another, facilitating coordinated contractions across multiple fibres. These contractions are generally slower and more sustained than those of skeletal muscle, enabling smooth muscle to maintain prolonged tension without fatigue.

Smooth muscle is found in a variety of anatomical structures, including the walls of hollow organs (such as the stomach, intestines, urinary bladder and uterus), blood vessels and the iris of the eye. Its ability to contract independently or in coordinated waves allows for a range of vital physiological functions.

One of the most important roles of smooth muscle is peristalsis; this is the coordinated, wave-like contractions and relaxations that propel substances through hollow organs. For example:

- In the digestive tract, peristaltic movements push food along the oesophagus, stomach and intestines. These contractions not only move food forward but also mix it with digestive enzymes, promoting efficient digestion and facilitating nutrient absorption.
- In the stomach, smooth muscle contractions churn food and mix it with gastric juices, breaking it down into smaller, digestible particles essential for nutrient extraction in the intestines.
- In the urinary bladder, smooth muscle forms the detrusor muscle, which stretches as the bladder fills with urine. Coordinated contractions of the detrusor muscle generate the sensation of urgency and enable controlled emptying of the bladder via the urethra.

Table 1.7 Muscle types, a comparative overview

Feature	Skeletal muscle	Cardiac muscle	Smooth muscle
Appearance	Striated, banded	Striated, branched	Non-striated, spindle-shaped
Control	Voluntary (conscious)	Involuntary (automatic)	Involuntary (automatic)
Location	Attached to bones	Heart walls	Walls of hollow organs (stomach, intestines, bladder, blood vessels, uterus), iris
Nuclei	Multiple, peripherally located	Usually one, centrally located	Single, centrally located
Fibre structure	Long, cylindrical	Branched, interconnected	Spindle-shaped, tapering at ends
Special structures	Sarcomeres for contraction	Intercalated discs with desmosomes and gap junctions	Gap junctions in some organs for coordinated contraction
Contraction	Rapid, forceful, short duration	Rhythmic, coordinated, continuous	Slow, sustained, wave-like (peristalsis)
Function	Voluntary movement, posture, heat production	Propels blood, maintains heartbeat	Moves substances through hollow organs, regulates vessel diameter, controls pupil size
Regeneration	Limited	Very limited	Moderate; can undergo hyperplasia in some tissues
Examples	Biceps brachii, quadriceps, gluteus maximus	Myocardium of the heart	Stomach wall, intestines, bladder, uterus, iris

Smooth muscle is also crucial in blood vessels, where it regulates vascular tone and blood pressure by contracting or relaxing in response to neural and chemical signals. Similarly, in the iris, smooth muscle adjusts pupil diameter to control the amount of light entering the eye, demonstrating the versatility of this muscle type.

Overall, smooth muscle is essential for internal bodily functions, including digestion, excretion, circulation and vision, operating largely outside conscious control while responding dynamically to the body's physiological needs.

Table 1.7 provides a comparative overview of muscle types.

MUSCLE TISSUE PROPERTIES

The unique properties of muscle tissues allow muscles to respond to stimuli, generate force, stretch without damage and return to their original shape. Understanding these properties is essential as they underpin both normal muscle function and the mechanisms behind muscle injuries, disorders and rehabilitation strategies (see Table 1.8).

Muscle tissue is essential for movement, posture and the function of vital organs. Its distinctive properties, responsiveness to stimuli, ability to contract, capacity to stretch safely and return to its original shape, are fundamental to understanding normal muscle function.

Table 1.8 Muscle properties

Property	Description	Example	Clinical relevance
Excitability (irritability)	Ability to detect and respond to stimuli by generating electrical impulses that trigger contraction.	Skeletal muscle contracts in response to a nerve impulse.	Essential for reflexes and voluntary movements; impaired excitability occurs in neuropathies.
Contractility	Capacity of muscle fibres to actively shorten, producing force and movement.	Biceps brachii shortening to bend the elbow.	Critical for movement and lifting; reduced contractility can result from muscle atrophy.
Extensibility	Ability to be stretched or lengthened without damage.	Stretching hamstrings during exercise.	Important in flexibility, joint range of motion and injury prevention.
Elasticity	Capacity of muscle fibres to return to their original resting length after being stretched or contracted.	Returning calf muscle to resting length after tiptoe standing.	Maintains muscle tone and prevents permanent deformation; loss occurs in scarred or fibrotic muscles.

For those who offer people care and support, a thorough knowledge of these properties is crucial, as it underpins assessment of musculoskeletal health, the prevention and management of injuries, rehabilitation strategies and safe patient handling. Recognising how muscles respond and adapt to stress or injury enables clinicians to plan interventions, exercise programmes and therapeutic approaches that maintain or restore optimal muscle function.

CONCLUSION

The musculoskeletal system is the foundation of human movement, providing structural support, protecting vital organs and enabling a wide range of voluntary and involuntary actions. Insight and understanding of its anatomy and physiology, including the bones, joints, muscles, tendons, ligaments and connective tissues, is essential for those who provide care and support to people. Knowledge of how bones provide leverage, how muscles generate force and how joints allow mobility is fundamental for assessing movement, preventing injury and delivering safe, effective care.

Furthermore, recognising the dynamic nature of bone and muscle tissue, the roles of cartilage in cushioning joints and the properties that enable muscles to contract, stretch and maintain posture can help to identify abnormalities, interpret clinical findings and design interventions for rehabilitation and functional recovery.

GLOSSARY OF TERMS

Actin: A protein filament in muscle fibres that interacts with myosin to produce contraction.

Adduction: Movement of a body part toward the midline of the body.

Agonist: The muscle responsible for initiating and carrying out a specific movement; also called the prime mover.

Antagonist: A muscle that opposes the action of the agonist and helps control movement.

Cartilage: A flexible connective tissue that cushions bones, supports structures and reduces friction in joints.

Compact bone: Dense, solid bone forming the outer layer of most bones, providing strength and protection.

Contractility: The ability of muscle fibres to shorten and generate force.

Desmosome: A cell structure that provides strong adhesion between cardiac muscle cells during contraction.

Endomysium: Connective tissue that surrounds individual muscle fibres.

Epiphyseal plate (growth plate): Cartilage at the ends of long bones that enables longitudinal growth during development.

Epiphysis: The rounded end of a long bone, typically covered with articular cartilage.

Excitability (irritability): The ability of muscle to respond to stimuli by generating electrical impulses.

Fibrocartilage: Strong, compression-resistant cartilage in intervertebral discs, menisci and pubic symphysis.

Fibrous joint (synarthrosis): A joint connected by dense connective tissue with little or no movement, such as in the skull.

Flexion: Decreasing the angle between two bones at a joint.

Hinge joint: A uniaxial synovial joint allowing movement in one plane, e.g. elbow or knee.

Homeostasis: The maintenance of a stable internal environment, including mineral balance in bones.

Hyaline cartilage: Smooth cartilage covering joint surfaces and forming part of the fetal skeleton.

Insertion: The attachment point of a muscle that moves during contraction.

Joint (articulation): The site where two or more bones meet, allowing movement and providing stability.

Ligament: A strong connective tissue that connects bone to bone and stabilises joints.

Long bone: Bones longer than they are wide, such as femur, humerus, radius and ulna.

Medullary cavity: Central cavity within long bones that contains bone marrow.

Muscle tone: Continuous, partial contraction of skeletal muscles that maintains posture.

Myofibril: Contractile thread within a muscle fibre composed of actin and myosin filaments.

Neuromuscular junction: The synapse where a motor neuron stimulates a muscle fibre to contract.

Osteoblast: A bone cell responsible for producing new bone and regulating calcium deposition.

Osteoclast: A bone cell that breaks down bone tissue, releasing minerals and initiating bone remodelling.

Osteocyte: A mature bone cell embedded in the bone matrix that helps regulate bone maintenance.

Pivot joint: A uniaxial synovial joint that allows rotation, e.g. atlas and axis in the neck.

Posture: The alignment of the body in space that allows efficient movement and minimises strain.

Proprioception: The body's ability to sense position, movement and balance.

Sarcolemma: The cell membrane of a muscle fibre.

Sarcomere: The functional contractile unit of a muscle fibre composed of actin and myosin.

Skeletal muscle: Voluntary, striated muscle attached to bones, responsible for locomotion and posture.

Smooth muscle: Involuntary, non-striated muscle found in the walls of hollow organs.

Synovial fluid: Lubricating fluid within synovial joints that reduces friction and nourishes cartilage.

Synovial joint: A freely movable joint with a synovial cavity, articular cartilage and joint capsule.

Tendon: A strong connective tissue that attaches muscle to bone and transmits force.

Trabecular (spongy) bone: Light, porous bone found inside bones, providing strength without excessive weight.

MULTIPLE CHOICE QUESTIONS

1. Which of the following is the primary structural component of the skeleton?
   a) Muscle
   b) Bone
   c) Cartilage
   d) Ligament

2. How many bones are present in the adult human skeleton?
   a) 206
   b) 300
   c) 212
   d) 196

3. Which type of bone is primarily responsible for absorbing shock and reducing skeletal weight?
   a) Compact bone
   b) Spongy (trabecular) bone
   c) Cortical bone
   d) Sesamoid bone

4. Which of the following is NOT a function of bone?
   a) Protection of organs
   b) Blood cell production
   c) Conduction of nerve impulses
   d) Mineral storage

5. The hyoid bone is unique because:
   a) It does not articulate with any other bone
   b) It contains red bone marrow
   c) It is a sesamoid bone
   d) It is located in the wrist

6. Which joint type allows the greatest range of motion?
   a) Hinge
   b) Fibrous
   c) Pivot
   d) Ball-and-socket

7. What is the primary role of ligaments?
   a) Connect bone to bone
   b) Connect muscle to bone
   c) Produce synovial fluid
   d) Generate muscle contraction

8. Osteoblasts are primarily responsible for:
   a) Breaking down bone tissue
   b) Maintaining bone matrix
   c) Forming new bone
   d) Producing red blood cells

9. The neuromuscular junction is the site where:
   a) A muscle fibre connects to a tendon
   b) Synovial fluid is produced
   c) Two bones articulate
   d) A motor neuron stimulates a muscle fibre

10. Which type of muscle is involuntary and found in hollow organs?
    a) Skeletal muscle
    b) Cardiac muscle
    c) Smooth muscle
    d) Striated muscle

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