Unit 6: Musculoskeletal System

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Essential Questions:

- How do the skeletal and muscular systems work together to provide structure to the body?

Unit Objectives:

- List and describe the functions of bones
- Describe the classes of bones
- Discuss the process of bone formation and development
- Explain how bone repairs itself after a fracture
- Discuss both functional and structural classifications for body joints
- Describe the characteristic features for fibrous, cartilaginous, and synovial joints and give examples of each
- Discuss the structure of specific body joints and the movements allowed by each
- Explain the organization of muscle tissue
- Describe the function and structure of skeletal muscle
- Explain how muscles work with tendons to move the body
- Describe how muscles contract and relax

Unit Vocabulary:

Axial skeleton
appendicular skeleton
osteocyte,
ossification
osteoclasts
fracture
hematoma
articulation
Muscle fiber
motor unit
neurotransmitter
tetanus
muscle tone
origin
insertion
prime mover
antagonist
synergist
fixator

<u>Lesson 1: What are bones?</u>

Objective:

- List and describe the functions of the skeletal system
- Classify bones according to their shapes
- Describe the function of each category of bones

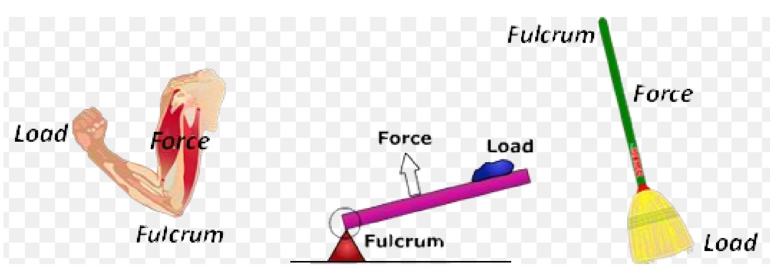
Bone, or osseous tissue, is a hard, dense **connective tissue** that forms most of the adult skeleton, the support structure of the body. In the areas of the skeleton where bones move (for example, the ribcage and joints), **cartilage,** a semi-rigid form of connective tissue, provides flexibility and smooth surfaces for movement. The skeletal system includes all the bones, cartilages, and ligaments of the body that support and give shape to the body and body structures. The **skeleton** consists of the bones of the body. The skeleton is subdivided into two major divisions—the axial and appendicular. The **axial skeleton** forms the vertical, central axis of the body and includes all bones of the head, neck, chest, and back. It serves to protect the brain, spinal cord, heart, and lungs. It also serves as the attachment site for muscles that move the head, neck, and back, and for muscles that act across the shoulder and hip joints to move their corresponding limbs. The **appendicular skeleton** includes all bones of the upper and lower limbs, plus the bones that attach each limb to the axial skeleton.

The **skeletal system** is the body system composed of bones and cartilage and performs the following critical functions for the human body:

- supports the body
- facilitates movement
- protects internal organs
- produces blood cells
- stores and releases minerals and fat

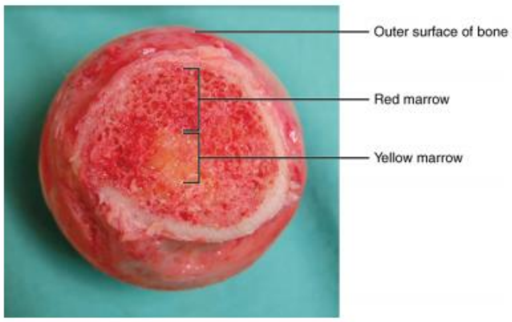
Support, Movement, and Protection

The most apparent functions of the skeletal system are the gross functions—those visible by observation. Simply by looking at a person, you can see how the bones support, facilitate movement, and protect the human body. Just as the steel beams of a building provide a scaffold to support its weight, the bones and cartilage of your skeletal system compose the scaffold that supports the rest of your body. Without the skeletal system, you would be a limp mass of organs, muscle, and skin. Bones also facilitate movement by serving as points of attachment for your muscles. While some bones only serve as a support for the muscles, others also transmit the forces produced when your muscles contract. From a mechanical point of view, bones act as **levers** and joints serve as **fulcrums**. Unless a muscle spans a joint and contracts, a bone is not going to move.

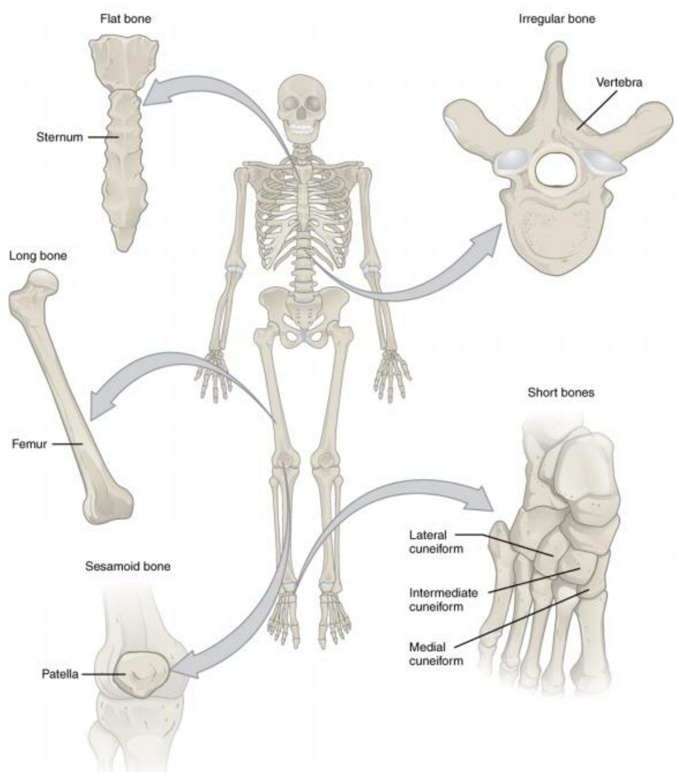


Mineral Storage, Energy Storage, and Hematopoiesis

On a metabolic level, bone tissue performs several critical functions. For one, the bone matrix acts as a reservoir for a number of minerals important to the functioning of the body, especially **calcium,** and **phosphorus**. These minerals, incorporated into bone tissue, can be released back into the bloodstream to maintain levels needed to support physiological processes**. Calcium ions** (Ca^{++}), for example, are essential for **muscle contractions** and controlling the flow of other ions involved in the transmission of **nerve impulses.** Bone also serves as a site for fat storage and blood cell production. The softer connective tissue that fills the interior of most bone is referred to as **bone marrow**. There are two types of bone marrow: yellow marrow and red marrow. **Yellow marrow** contains adipose tissue; the triglycerides(fats) stored in the adipocytes of the tissue can serve as a source of energy. **Red marrow** is where **hematopoiesis**—the production of blood cells—takes place. Red blood cells, white blood cells, and platelets are all produced in the red marrow.



The **206 bones** that compose the adult skeleton are divided into five categories based on their shapes. Their shapes and their functions are related such that each categorical shape of bone has a distinct function.



Long Bones

A long bone is one that is cylindrical in shape, being longer than it is wide. Long bones are found in the arms (humerus, ulna, radius) and legs (femur, tibia, fibula), as well as in the fingers (metacarpals, phalanges) and toes (metatarsals, phalanges). Long bones function as levers; they move when muscles contract.

Short Bones

A short bone is one that is cube-like in shape, being approximately equal in length, width, and thickness. The only short bones in the human skeleton are in the carpals of the wrists and the tarsals of the ankles. Short bones provide stability and support as well as some limited motion

Flat Bones

The term "flat bone" is somewhat of a misnomer because, although a flat bone is typically thin, it is also often curved. Examples include the cranial (skull) bones, the scapulae (shoulder blades), the sternum (breastbone), and the ribs. Flat bones serve as points of attachment for muscles and often protect internal organs.

Irregular Bones

An irregular bone is one that does not have any easily characterized shape and therefore does not fit any other classification. These bones tend to have more complex shapes, like the vertebrae that support the spinal cord and protect it from compressive forces. Many facial bones, particularly the ones containing sinuses, are classified as irregular bones.

Sesamoid Bones

A sesamoid bone is a small, round bone that, as the name suggests, is shaped like a sesame seed. These bones form in tendons (the sheaths of tissue that connect bones to muscles) where a great deal of pressure is generated in a joint. The sesamoid bones protect tendons by helping them overcome compressive forces. Sesamoid bones vary in number and placement from person to person but are typically found in tendons associated with the feet, hands, and knees. The patellae are the only sesamoid bones found in common with every person. The table below reviews bone classifications with their associated features, functions, and examples.

Bone Classifications

Bone classification	Features	Function(s)	Examples
Long	Cylinder-like shape, longer than it is wide	Leverage	Femur, tibia, fibula, metatarsals, humerus, ulna, radius, metacarpals, phalanges
Short	Cube-like shape, approximately equal in length, width, and thickness	Provide stability, support, while allowing for some motion	Carpals, tarsals
Flat	Thin and curved	Points of attachment for muscles; protectors of internal organs	Sternum, ribs, scapulae, cranial bones
Irregular	Complex shape	Protect internal organs	Vertebrae, facial bones
Sesamoid	Small and round; embedded in tendons	Protect tendons from compressive forces	Patellae

<u>Lesson 2: How are bones structured?</u>

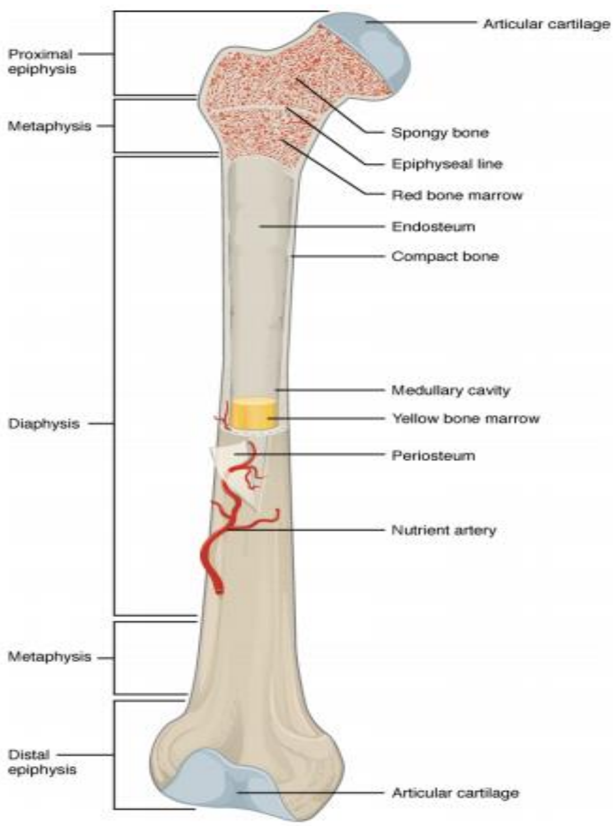
Objective:

- Identify the anatomical features of a bone
- Define and list examples of bone markings
- Compare and contrast compact and spongy bone
- Identify the structures that compose compact and spongy bone
- Describe how bones are nourished and innervated

Bone tissue (**osseous tissue**) differs greatly from other tissues in the body. Bone is hard and many of its functions depend on that characteristic hardness

Gross Anatomy of Bone

The structure of a long bone allows for the best visualization of all the parts of a bone. A long bone has two parts: the **diaphysis** and the **epiphysis**. The **diaphysis** is the tubular shaft that runs between the proximal and distal ends of the bone. The hollow region in the diaphysis is called the **medullary cavity**, which is filled with yellow marrow. The walls of the diaphysis are composed of dense and hard compact bone.



The wider section at each end of the bone is called the **epiphysis,** which is filled with **spongy bone**. Red marrow fills the spaces in the spongy bone. Each epiphysis meets the diaphysis at the **metaphysis**, the narrow area that contains the **epiphyseal plate** (growth plate), a layer of **hyaline** (transparent) cartilage in a growing bone. When the bone stops growing in early adulthood (approximately 18–21 years), the cartilage is replaced by osseous tissue and the epiphyseal plate becomes an **epiphyseal line**. The medullary cavity has a delicate membranous lining called the **endosteum**, where bone growth, repair, and remodeling occur. The outer surface of the bone is covered with a fibrous membrane called the **periosteum**. The periosteum contains blood vessels, nerves, and lymphatic vessels that nourish compact bone. **Tendons and ligaments** also attach to bones at the periosteum. The periosteum covers the entire outer surface except where the epiphyses meet other bones to form joints. In this region, the epiphyses are covered with **articular cartilage**, a thin layer of cartilage that reduces friction and acts as a shock absorber.

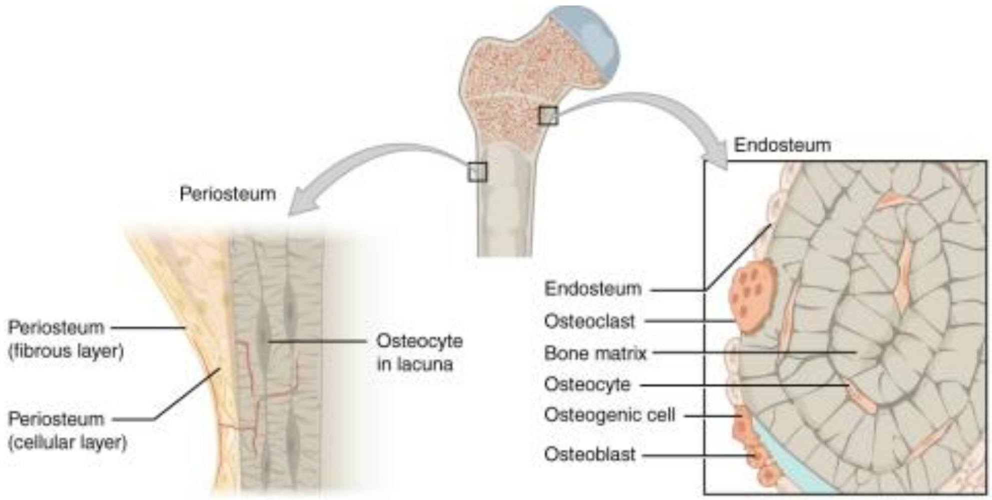
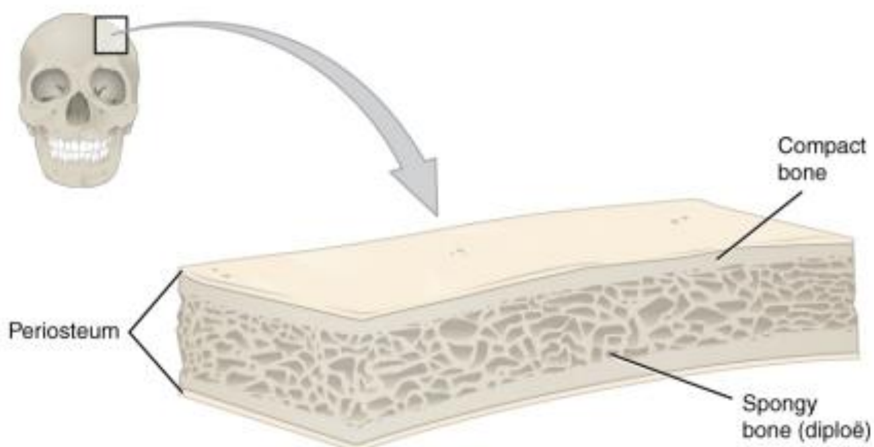


Figure 6.8 Periosteum and Endosteum The periosteum forms the outer surface of bone, and the endosteum lines the medullary cavity.

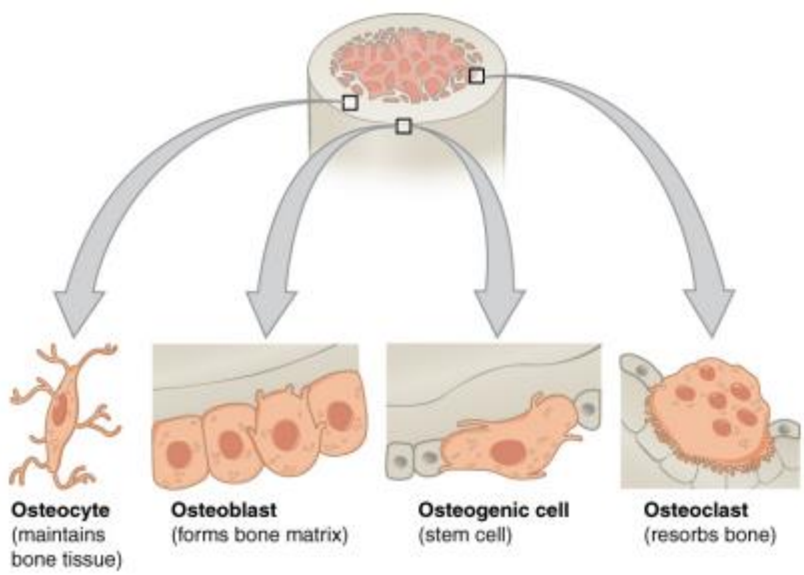
Flat bones, like those of the cranium, consist of a layer of **diploë** (spongy bone), lined on either side by a layer of compact bone (Figure 6.9). The two layers of compact bone and the interior spongy bone work together to protect the internal organs. If the outer layer of a cranial bone fractures, the brain is still protected by the intact inner layer.



Osseous (bone) Tissue

Bone contains a relatively small number of cells entrenched in a matrix of collagen fibers that provide a surface for inorganic salt crystals to adhere. These salt crystals form when **calcium phosphate** and **calcium carbonate** combine to create **hydroxyapatite**, which incorporates other inorganic salts like magnesium hydroxide, fluoride, and sulfate as it crystallizes, or calcifies, on the collagen fibers. The **hydroxyapatite crystals** give bones their hardness and strength, while the **collagen fibers** give them flexibility so that they are not brittle. Although bone cells compose a small amount of the bone volume, they are crucial to the function of bones. Four types of cells are found within bone tissue: **osteoblasts, osteocytes, osteogenic cells, and osteoclasts**

The **osteoblast** is the bone cell responsible for forming new bone and is found in the growing portions of bone, including the periosteum and endosteum. Osteoblasts, which do not divide, synthesize and secrete the collagen matrix and calcium salts. As the secreted matrix surrounding the osteoblast calcifies, the osteoblast become trapped within it; as a result, it changes in structure and becomes an **osteocyte**, the primary cell of mature bone and the most common type of bone cell. Each osteocyte is located in a space called a **lacuna** and is surrounded by bone tissue. Osteocytes maintain the mineral concentration of the matrix via the secretion of enzymes. Like osteoblasts, osteocytes lack mitotic activity. They can communicate with each other and receive nutrients via long cytoplasmic processes that extend through **canaliculi**, channels within the bone matrix. If osteoblasts and osteocytes are incapable of mitosis, then how are they replenished when old ones die? The answer lies in the properties of a third category of bone cells—the **osteogenic cell**. These osteogenic cells are undifferentiated, and they are the only bone cells that divide. Immature osteogenic cells are found in the deep layers of the periosteum and the marrow. They differentiate and develop into osteoblasts. The dynamic nature of bone means that new tissue is constantly formed, and old, injured, or unnecessary bone is dissolved for repair or for calcium release. The cell responsible for bone resorption, or breakdown, is the **osteoclast**. They are found on bone surfaces, are multinucleated, and originate from monocytes and macrophages, two types of white blood cells, not from osteogenic cells. **Osteoclasts are continually breaking down old bone while osteoblasts are continually forming new bone**. The ongoing balance between osteoblasts and osteoclasts is responsible for the constant but subtle reshaping of bone.



Compact and Spongy Bone

Most bones contain **compact** and **spongy osseous tissue**, but their distribution and concentration vary based on the bone's overall function. **Compact bone** is dense so that it can withstand compressive forces, while **spongy (cancellous) bone** has open spaces and supports shifts in weight distribution.

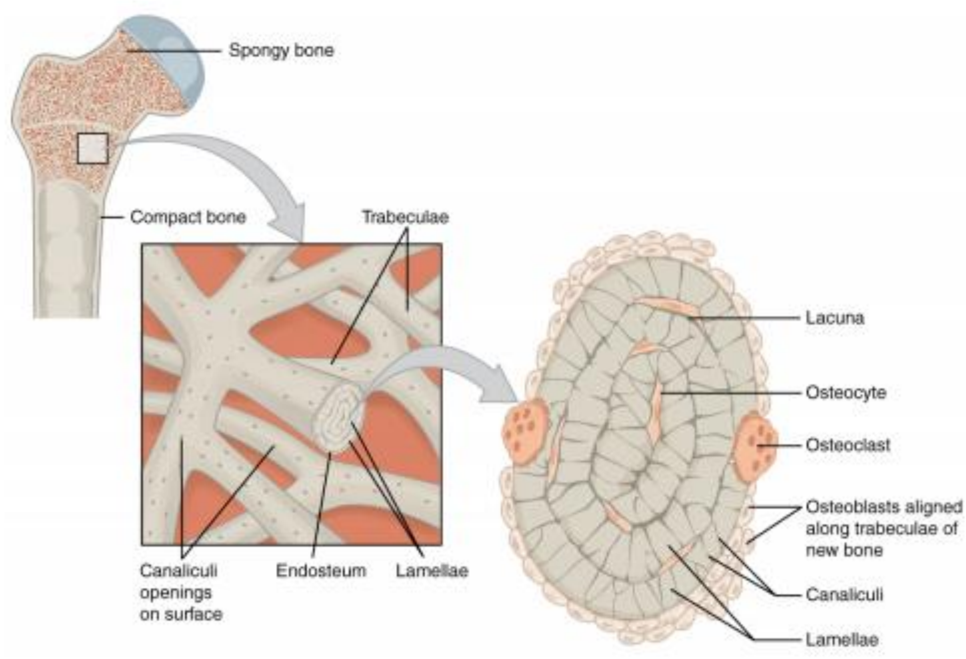
Compact Bone

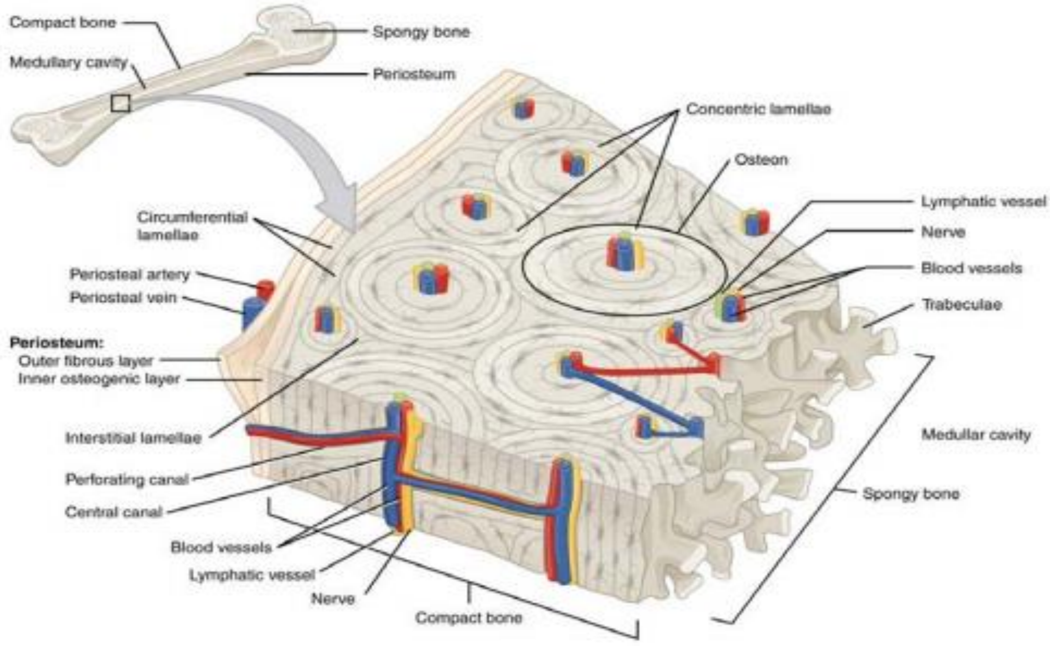
Compact bone is the denser, stronger of the two types of bone tissue. It can be found under the periosteum and in the diaphysis of long bones, where it provides support and protection.

The microscopic structural unit of compact bone is called an osteon, or **Haversian system**. Each osteon is composed of concentric rings of calcified matrix called **lamellae.** Running down the center of each osteon is the central canal, or **Haversian canal**, which contains blood vessels, nerves, and lymphatic vessels. These vessels and nerves branch off at right angles through a perforating canal, also known as **Volkmann's canals**, to extend to the periosteum and endosteum. The osteocytes are located inside spaces called **lacunae,** found at the borders of adjacent lamellae. As described earlier, canaliculi connect with other lacunae and eventually with the central canal. This system allows nutrients to be transported to the osteocytes and wastes to be removed from them.

Spongy (Cancellous) Bone

Like compact bone, spongy bone, also known as **cancellous bone**, contains osteocytes housed in lacunae, but they are not arranged in concentric circles. Instead, the lacunae and osteocytes are found in a lattice-like network of matrix spikes called **trabeculae**. The trabeculae may appear to be a random network, but each trabecula forms along lines of stress to provide strength to the bone. The spaces of the trabeculated network provide balance to the dense and heavy compact bone by making bones lighter so that muscles can move them more easily. In addition, the spaces in some spongy bones contain red marrow, protected by the trabeculae, where **hematopoiesis** (production of blood cells) occurs.





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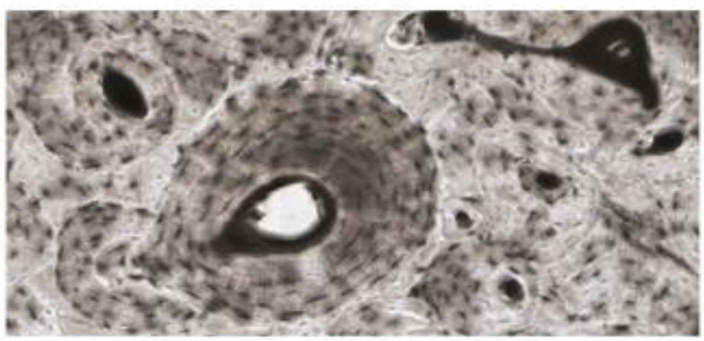


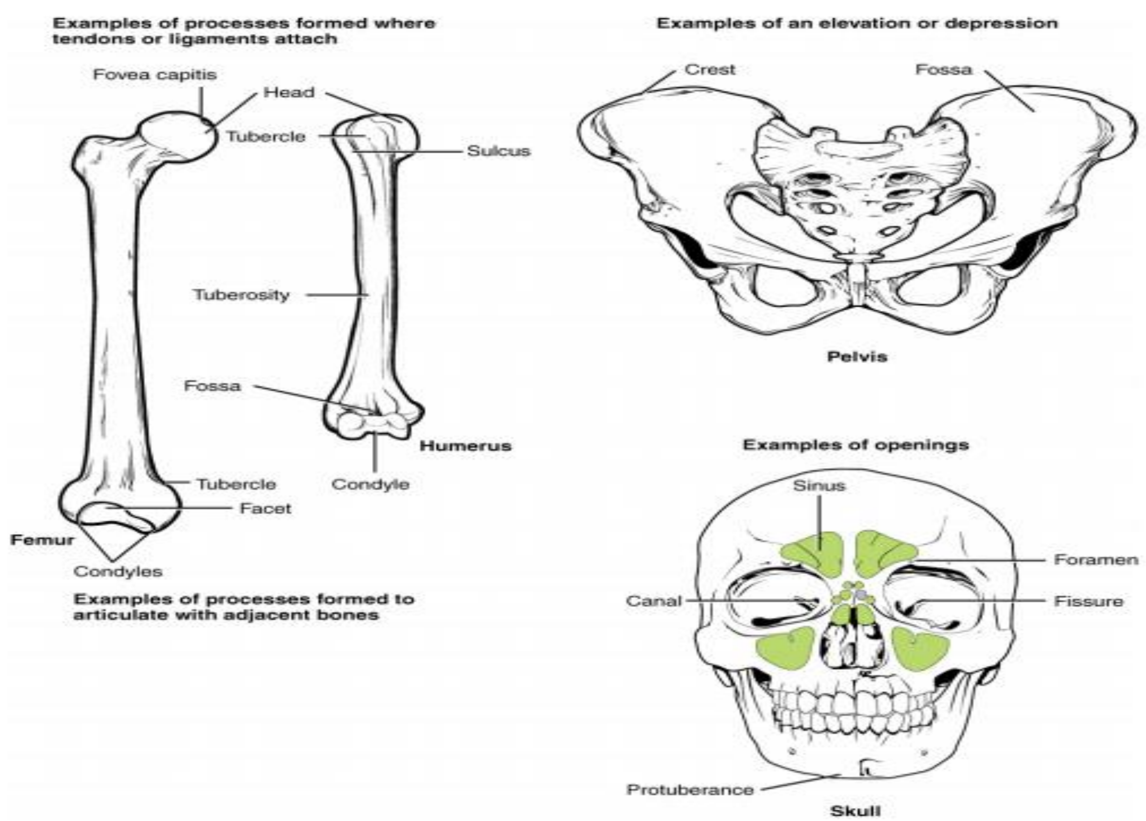
(b)

Bone Markings

The surface features of bones vary considerably, depending on the function and location in the body. There are three general classes of bone markings: (1) articulations, (2) projections, and (3) holes. As the name implies, an **articulation** is where two bone surfaces come together. These surfaces tend to conform to one another, such as one being rounded and the other cupped, to facilitate the function of the articulation. A **projection** is an area of a bone that projects above the surface of the bone. These are the attachment points for tendons and ligaments. In general, their size and shape is an indication of the forces exerted through the attachment to the bone. A **hole** is an opening or groove in the bone that allows blood vessels and nerves to enter the bone. As with the other markings, their size and shape reflect the size of the vessels and nerves that penetrate the bone at these points.

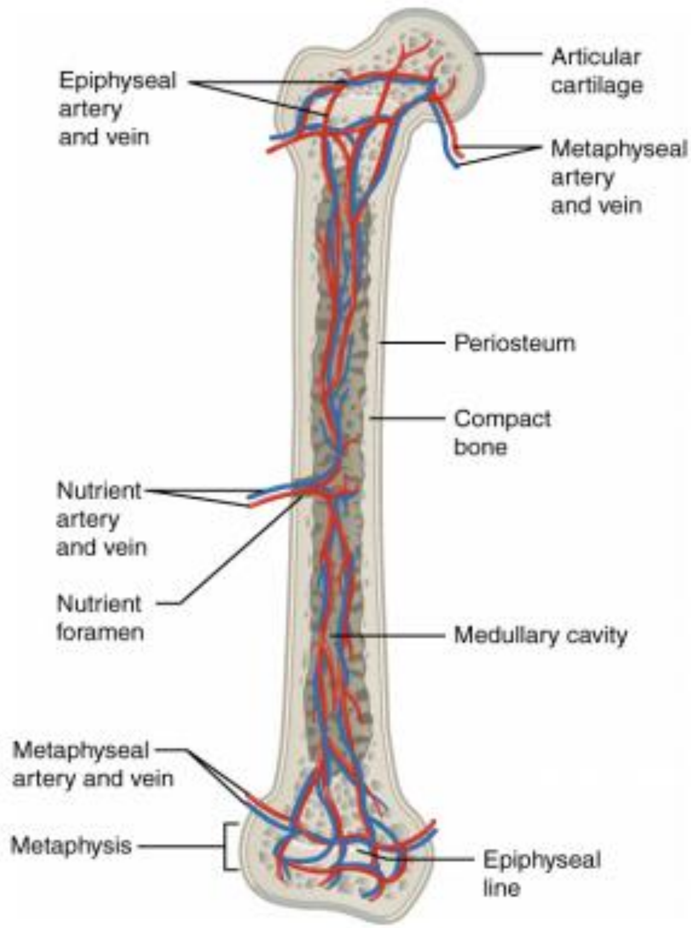
Bone Markings

Marking	Description	Example
Articulations	Where two bones meet	Knee joint
Head	Prominent rounded surface	Head of femur
Facet	Flat surface	Vertebrae
Condyle	Rounded surface	Occipital condyles
Projections	Raised markings	Spinous process of the vertebrae
Protuberance	Protruding	Chin
Process	Prominence feature	Transverse process of vertebra
Spine	Sharp process	Ischial spine
Tubercle	Small, rounded process	Tubercle of humerus
Tuberosity	Rough surface	Deltoid tuberosity
Line	Slight, elongated ridge	Temporal lines of the parietal bones
Crest	Ridge	Iliac crest
Holes	Holes and depressions	Foramen (holes through which blood vessels can pass through)
Fossa	Elongated basin	Mandibular fossa
Fovea	Small pit	Fovea capitis on the head of the femur
Sulcus	Groove	Sigmoid sulcus of the temporal bones
Canal	Passage in bone	Auditory canal
Fissure	Slit through bone	Auricular fissure
Foramen	Hole through bone	Foramen magnum in the occipital bone
Meatus	Opening into canal	External auditory meatus
Sinus	Air-filled space in bone	Nasal sinus



Blood and Nerve Supply

The spongy bone and medullary cavity receive nourishment from arteries that pass through the compact bone. The arteries enter through the nutrient **foramen**, small openings in the diaphysis. The osteocytes in spongy bone are nourished by blood vessels of the periosteum that penetrate spongy bone and blood that circulates in the marrow cavities. As the blood passes through the marrow cavities, it is collected by veins, which then pass out of the bone through the foramina. In addition to the blood vessels, nerves follow the same paths into the bone where they tend to concentrate in the more metabolically active regions of the bone. The nerves sense pain, and it appears the nerves also play roles in regulating blood supplies and in bone growth, hence their concentrations in metabolically active sites of the bone



<u>Lesson 3: How are bones formed and repaired?</u>

Objective:

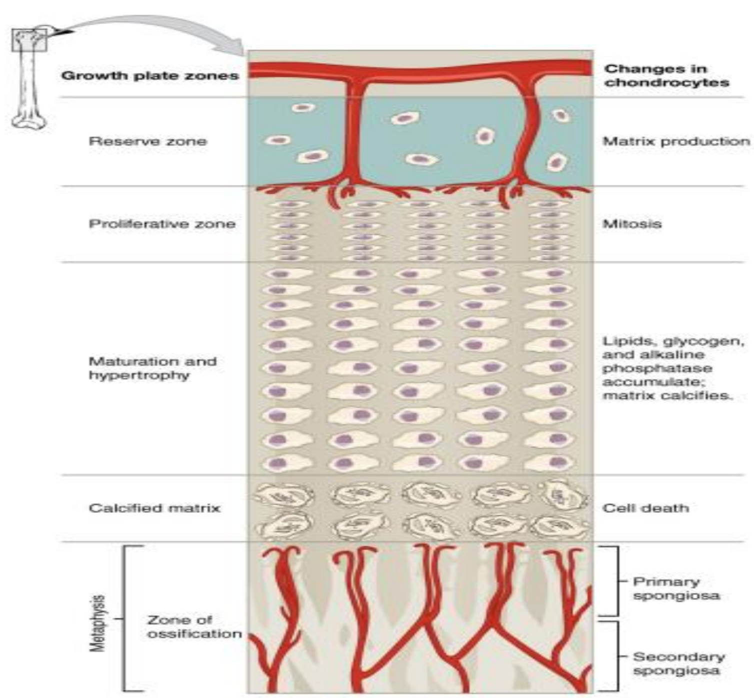
- List the steps of intramembranous ossification
- Compare and contrast the processes of modeling and remodeling
- Explain the process of calcium homeostasis

In the early stages of embryonic development, the embryo's skeleton consists of fibrous membranes and **hyaline cartilage**. All bone formation is a replacement process. Embryos develop a cartilaginous skeleton and various membranes. During development, these are replaced by bone during the **ossification process.** Ossification is the gradual transition from a fibrous or cartilaginous template to bone. This process takes place at different rates and is completed at different ages depending on the site of ossification. There are two distinct types of ossification, intramembranous and endochondral.

Intramembranous Ossification: This is the less common form of bone formation, being limited primarily to the flat bones of the skull such as the parietal, parts of the temporal, and parts of the maxilla. In this form, bone is deposited between two fibrous membranes. The bone formed in this way is normally quite porous and does **not** display the **Haversian System** of other bones.

Endochondral Ossification: In this type of bone formation a cartilage template, surrounded by the perichondrium, is entered by blood vessels to begin the process. As the template grows, ossification begins in the central portion of the template, which will become the **diaphysis**. This area is termed the **primary ossification center**. Later, the extremities of the template each develop ossification centers called **secondary ossification centers**, which are located in the **epiphyses** (proximal and distal ends of the bone). Once the template has begun to grow the perichondrium is referred to as the periosteum.

During endochondral ossification, the area between the primary and secondary ossification centers that remains cartilage is called the **epiphyseal plate** and is an example of a **synchondrosis,** a cartilaginous joint. The final ossification of these plates takes place gradually and is completed at different chronological ages.



How Bones Grow in Diameter

While bones are increasing in length, they are also increasing in diameter; growth in diameter can continue even after longitudinal growth ceases**. Osteoclasts** resorb old bone that lines the medullary cavity, while **osteoblasts**, via intramembranous ossification, produce new bone tissue beneath the periosteum. The erosion of old bone along the medullary cavity and the deposition of new bone beneath the periosteum not only increase the diameter of the diaphysis but also increase the diameter of the medullary cavity. This process is called **modeling**.

Bone Remodeling

The process in which matrix is resorbed on one surface of a bone and deposited on another is known as **bone modeling**. Modeling primarily takes place during a bone's growth. However, in adult life, bone undergoes remodeling, in which resorption of old or damaged bone takes place on the same surface where osteoblasts lay new bone to replace that which is resorbed. Injury, exercise, and other activities lead to remodeling. Even without injury or exercise, about 5 to 10 percent of the skeleton is remodeled annually just by destroying old bone and renewing it with fresh bone.

A **fracture** is a broken bone. It will heal whether or not a physician resets it in its anatomical position. If the bone is not reset correctly, the healing process will keep the bone in its deformed position. When a broken bone is manipulated and set into its natural position without surgery, the procedure is called a **closed reduction**. **Open reduction** requires surgery to expose the fracture and reset the bone. While some fractures can be minor, others are quite severe and result in grave complications. For example, a fractured diaphysis of the femur has the potential to release fat globules into the bloodstream. These can become lodged in the capillary beds of the lungs, leading to respiratory distress and if not treated quickly, death.

Types of Fractures

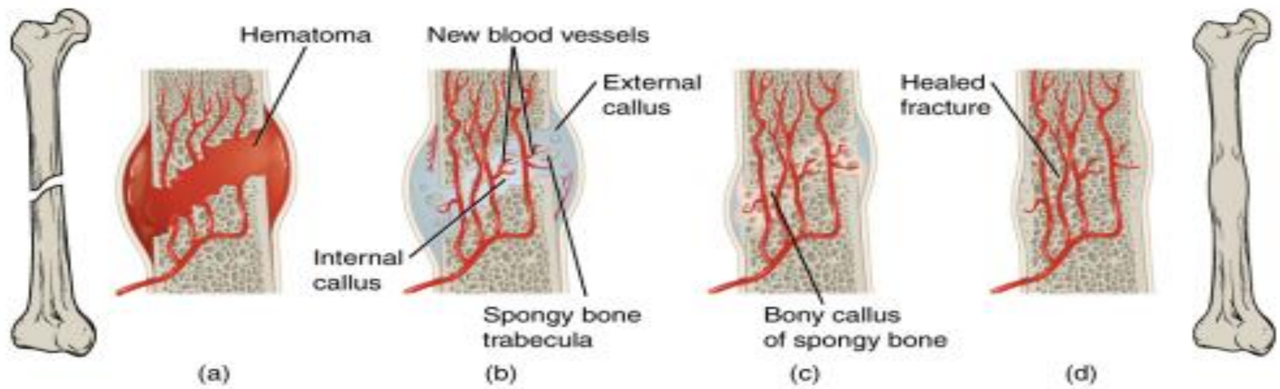
Fractures are classified by their complexity, location, and other features. The table below outlines common types of fractures. Some fractures may be described using more than one term because it may have the features of more than one type (e.g., an open transverse fracture).

Types of Fractures

Type of fracture	Description
Transverse	Occurs straight across the long axis of the bone
Oblique	Occurs at an angle that is not 90 degrees
Spiral	Bone segments are pulled apart as a result of a twisting motion
Comminuted	Several breaks result in many small pieces between two large segments
Impacted	One fragment is driven into the other, usually as a result of compression
Greenstick	A partial fracture in which only one side of the bone is broken
Open (or compound)	A fracture in which at least one end of the broken bone tears through the skin; carries a high risk of infection
Closed (or simple)	A fracture in which the skin remains intact

Bone Repair

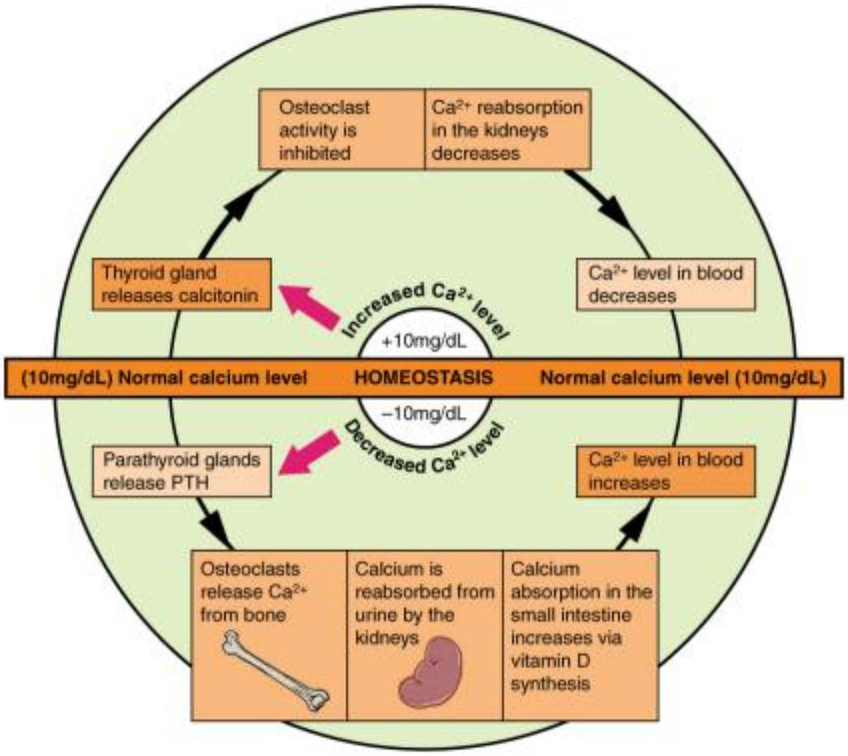
When a bone breaks, blood flows from any vessel torn by the fracture. These vessels could be in the periosteum, osteons, and/or medullary cavity. The blood begins to clot, and about six to eight hours after the fracture, the clotting blood has formed a **fracture hematoma**. The disruption of blood flow to the bone results in the death of bone cells around the fracture.



Within about 48 hours after the fracture, **chondrocytes (cartilage forming cells)** from the endosteum have created an internal callus by secreting a **fibrocartilaginous matrix** between the two ends of the broken bone, while the periosteal chondrocytes and osteoblasts create an external callus of hyaline cartilage and bone, respectively, around the outside of the break. This stabilizes the fracture. Over the next several weeks, osteoclasts resorb the dead bone; osteogenic cells become active, divide, and differentiate into osteoblasts. The cartilage in the calli is replaced by trabecular bone via endochondral ossification. Eventually, the internal and external calli unite, compact bone replaces spongy bone at the outer margins of the fracture, and healing is complete. A slight swelling may remain on the outer surface of the bone, but quite often, that region undergoes remodeling, and no external evidence of the fracture remains.

Calcium Homeostasis: Interactions of the Skeletal System and Other Organ Systems

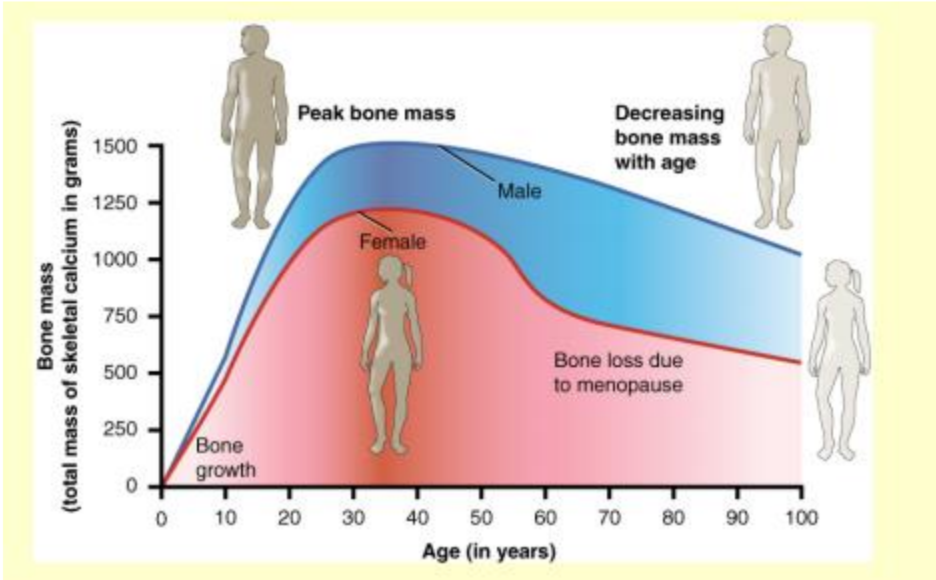
Calcium is not only the most abundant mineral in bone, it is also the most abundant mineral in the human body. **Calcium ions(Ca^{++})** are needed not only for bone mineralization but for tooth health, regulation of the heart rate and strength of contraction, blood coagulation, contraction of smooth and skeletal muscle cells, and regulation of nerve impulse conduction. The normal level of calcium in the blood is about 10 mg/dL. When the body cannot maintain this level, a person will experience hypo or hypercalcemia. **Hypocalcemia,** a condition characterized by abnormally low levels of calcium, can have an adverse effect on a number of different body systems including circulation, muscles, nerves, and bone. Without adequate calcium, blood has difficulty coagulating (forming blood clots), the heart may skip beats or stop beating altogether, muscles may have difficulty contracting, nerves may have difficulty functioning, and bones may become brittle. The causes of hypocalcemia can range from hormonal imbalances to an improper diet. Treatments vary according to the cause, but prognoses are generally good. Conversely, in **hypercalcemia,** a condition characterized by abnormally high levels of calcium, the nervous system is underactive, which results in lethargy, sluggish reflexes, constipation and loss of appetite, confusion, and in severe cases, coma. Obviously, calcium homeostasis is critical. The skeletal, endocrine, and digestive systems play a role in this, but the kidneys do, too. These body systems work together to maintain a normal calcium level in the blood



Calcium is a chemical element that cannot be produced by any biological processes. The only way it can enter the body is through the diet. The bones act as a storage site for calcium: The body deposits calcium in the bones when blood levels get too high, and it releases calcium when blood levels drop too low. This process is regulated by **PTH (parathyroid hormone), vitamin D, and calcitonin**. Cells of the **parathyroid gland** have plasma membrane receptors for calcium. When calcium is not binding to these receptors, the cells release PTH, which stimulates osteoclast proliferation and resorption of bone by osteoclasts. This demineralization process releases calcium into the blood. PTH promotes reabsorption of calcium from the urine by the kidneys, so that the calcium returns to the blood. Finally, PTH stimulates the synthesis of vitamin D, which in turn, stimulates calcium absorption from any digested food in the small intestine. When all these processes return blood calcium levels to normal, there is enough calcium to bind with the receptors on the surface of the cells of the parathyroid glands, and this cycle of events is turned off. When blood levels of calcium get too high, the **thyroid gland** is stimulated to release **calcitonin**, which inhibits osteoclast activity and stimulates calcium uptake by the bones, but also decreases reabsorption of calcium by the kidneys. All of these actions lower blood levels of calcium. When blood calcium levels return to normal, the thyroid gland stops secreting calcitonin.

Osteoporosis

Osteoporosis is a disease characterized by a decrease in bone mass that occurs when the rate of bone resorption exceeds the rate of bone formation, a common occurrence as the body ages. In contrary, **Paget's disease** occurs when new bone is formed in an attempt to keep up with the resorption by the overactive osteoclasts, but that new bone is produced haphazardly. In fact, when a physician is evaluating a patient with thinning bone, he or she will test for osteoporosis and Paget's disease (as well as other diseases). Osteoporosis does not have the elevated blood levels of alkaline phosphatase found in Paget's disease



While osteoporosis can involve any bone, it most commonly affects the proximal ends of the femur, vertebrae, and wrist. As a result of the loss of bone density, the osseous tissue may not provide adequate support for everyday functions, and something as simple as a sneeze can cause a vertebral fracture. When an elderly person falls and breaks a hip (really, the femur), it is very likely the femur that broke first, which resulted in the fall. Histologically, osteoporosis is characterized by a reduction in the thickness of compact bone and the number and size of trabeculae in cancellous bone. The figure above shows that women lose bone mass more quickly than men starting at about 50 years of age. This occurs because 50 is the approximate age at which women go through menopause. Not only do their menstrual periods lessen and eventually cease, but their ovaries reduce in size and then cease the production of estrogen, a hormone that promotes osteoblastic activity and production of bone matrix. Thus, osteoporosis is more common in women than in men, but men can develop it, too. Anyone with a family history of osteoporosis has a greater risk of developing the disease, so the best treatment is prevention, which should start with a childhood diet that includes adequate intake of calcium and vitamin D and a lifestyle that includes weight-bearing exercise. These actions are important in building bone mass. Promoting proper nutrition and weight-bearing exercise early in life can maximize bone mass before the age of 30, thus reducing the risk of osteoporosis. For many elderly people, a hip fracture can be life threatening. The fracture itself may not be serious, but the immobility that comes during the healing process can lead to the formation of blood clots that can lodge in the capillaries of the lungs, resulting in respiratory failure; pneumonia due to the lack of poor air exchange that accompanies immobility; pressure sores (bed sores) that allow pathogens to enter the body and cause infections; and urinary tract infections from catheterization. Current treatments for managing osteoporosis include bisphosphonates (the same medications often used in Paget's disease), calcitonin, and estrogen (for women only). Minimizing the risk of falls, for example, by removing tripping hazards, is also an important step in managing the potential outcomes from the disease.

Lesson 4 : Classification of Joints

Objective:

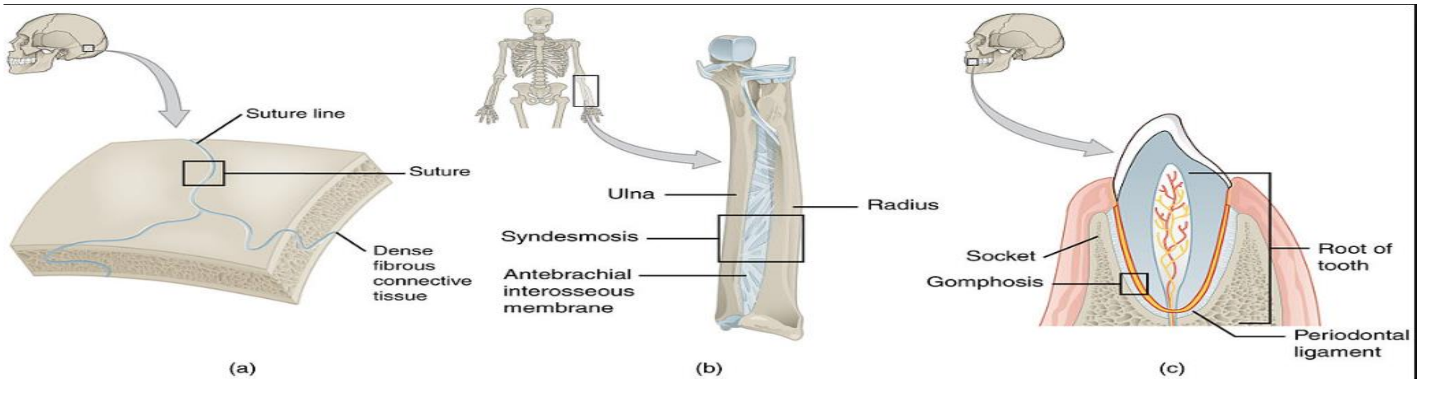
- Discuss both functional and structural classifications for body joints.
- Describe the characteristic features for fibrous, cartilaginous, and synovial joints and give examples of each.

Structural classifications of the body joints are based on how the bones are held together and **articulate** with each other. At **fibrous joints**, the adjacent bones are directly united to each other by fibrous connective tissue. Similarly, at a **cartilaginous joint**, the adjacent bones are united by cartilage. In contrast, at a **synovial joint**, the articulating bone surfaces are not directly united to each other but come together within a fluid-filled joint cavity.

The **functional classification** of body joints is based on the degree of movement found at each joint. A **synarthrosis** is a joint that is essentially immobile. This type of joint provides for a strong connection between the adjacent bones, which serves to protect internal structures such as the brain or heart. Examples include the fibrous joints of the skull sutures and the cartilaginous manubriosternal joint. A joint that allows for limited movement is an **amphiarthrosis**. An example is the pubic symphysis of the pelvis, the cartilaginous joint that strongly unites the right and left hip bones of the pelvis. The cartilaginous joints in which vertebrae are united by intervertebral discs provide for small movements between the adjacent vertebrae and are also an amphiarthrosis type of joint. Thus, based on their movement ability, both fibrous and cartilaginous joints are functionally classified as a synarthrosis or amphiarthrosis. The most common type of joint is the **diarthrosis**, which is a freely moveable joint. All **synovial joints** are functionally classified as diarthroses. A **uniaxial diarthrosis**, such as the elbow, is a joint that only allows for movement within a single anatomical plane. Joints that allow for movements in two planes are **biaxial joints**, such as the metacarpophalangeal joints of the fingers. A **multiaxial joint**, such as the shoulder or hip joint, allows for three planes of motions.

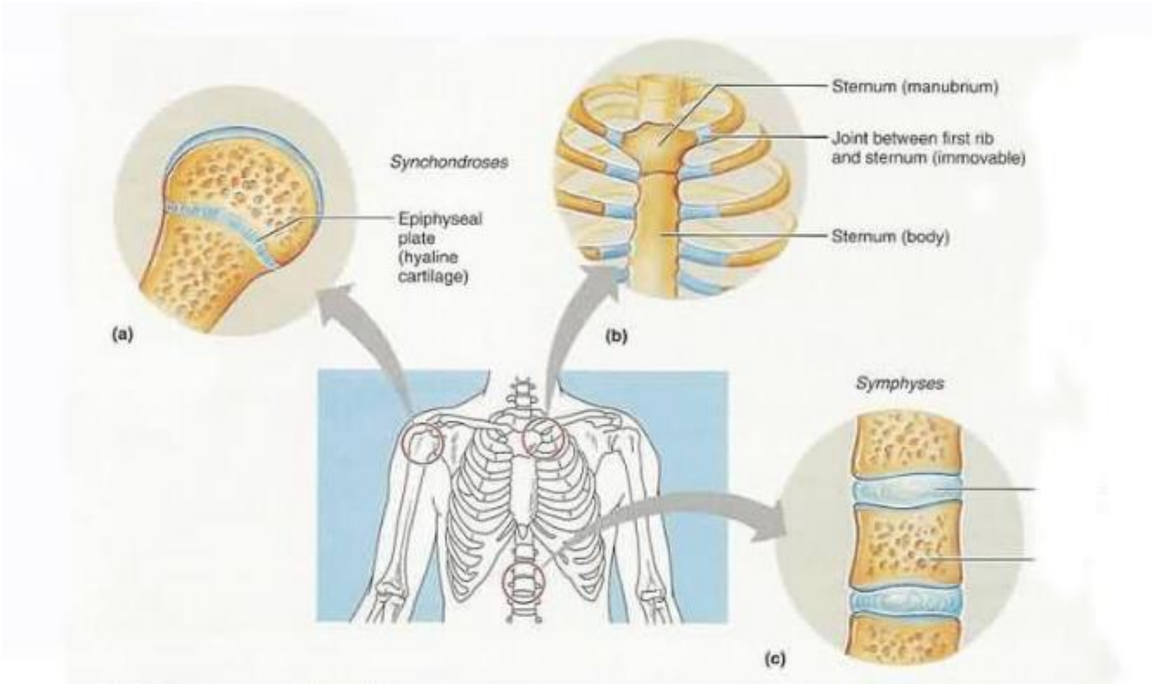
Fibrous Joints

Fibrous joints are where adjacent bones are strongly united by fibrous connective tissue. The gap filled by connective tissue may be narrow or wide. The three types of fibrous joints are sutures, gomphoses, and syndesmoses. A **suture** is the narrow fibrous joint that unites most bones of the skull. At a **gomphosis**, the root of a tooth is anchored across a narrow gap by periodontal ligaments to the walls of its socket in the bony jaw. A **syndesmosis** is the type of fibrous joint found between parallel bones. The gap between the bones may be wide and filled with a fibrous **interosseous** membrane, or it may narrow with ligaments spanning between the bones. Syndesmoses are found between the bones of the forearm (radius and ulna) and the leg (tibia and fibula). Fibrous joints strongly unite adjacent bones and thus serve to provide protection for internal organs, strength to body regions, or weight-bearing stability.



Cartilaginous Joints

There are two types of cartilaginous joints. A **synchondrosis** is formed when the adjacent bones are united by hyaline cartilage. A temporary synchondrosis is formed by the epiphyseal plate of a growing long bone, which is lost when the epiphyseal plate ossifies as the bone reaches maturity. Permanent synchondroses that do not ossify are found at the first sternocostal joint and between the anterior ends of the bony ribs and the junction with their costal cartilage. A **symphysis** is where the bones are joined by fibrocartilage and the gap between the bones may be narrow or wide. A narrow symphysis is found at the manubriosternal joint and at the pubic symphysis. A wide symphysis is the intervertebral symphysis in which the bodies of adjacent vertebrae are united by an intervertebral disc.



Synovial Joints

Synovial joints are the most common type of joints in the body. They are characterized by the presence of a joint cavity, inside of which the bones of the joint articulate with each other. The articulating surfaces of the bones at a synovial joint are not directly connected to each other by connective tissue or cartilage, which allows the bones to move freely against each other. The walls of the joint cavity are formed by the **articular capsule.** Friction between the bones is reduced by a thin layer of articular cartilage covering the surfaces of the bones, and by a lubricating **synovial fluid**, which is secreted by the synovial membrane. Synovial joints are strengthened by the presence of **ligaments**, which hold the bones together and resist excessive or abnormal movements of the joint. Some synovial joints also have an **articular disc** (meniscus), which can provide padding between the bones, smooth their movements, or strongly join the bones together to strengthen the joint. Muscles and their **tendons** acting across a joint can also increase their contractile strength when needed, thus providing indirect support for the joint. **Bursae** contain a lubricating fluid that serves to reduce friction between structures.

Based on the shape of the articulating bone surfaces and the types of movement allowed, synovial joints are classified into six types.

- At a **pivot joint,** one bone is held within a ring by a ligament and its articulation with a second bone. Pivot joints only allow for rotation around a single axis. These are found at the articulation between the C1 (atlas) and the dens of the C2 (axis) vertebrae, which provides the side-to-side rotation of the head, or at the proximal radioulnar joint between the head of the radius and the radial notch of the ulna, which allows for rotation of the radius during forearm movements.

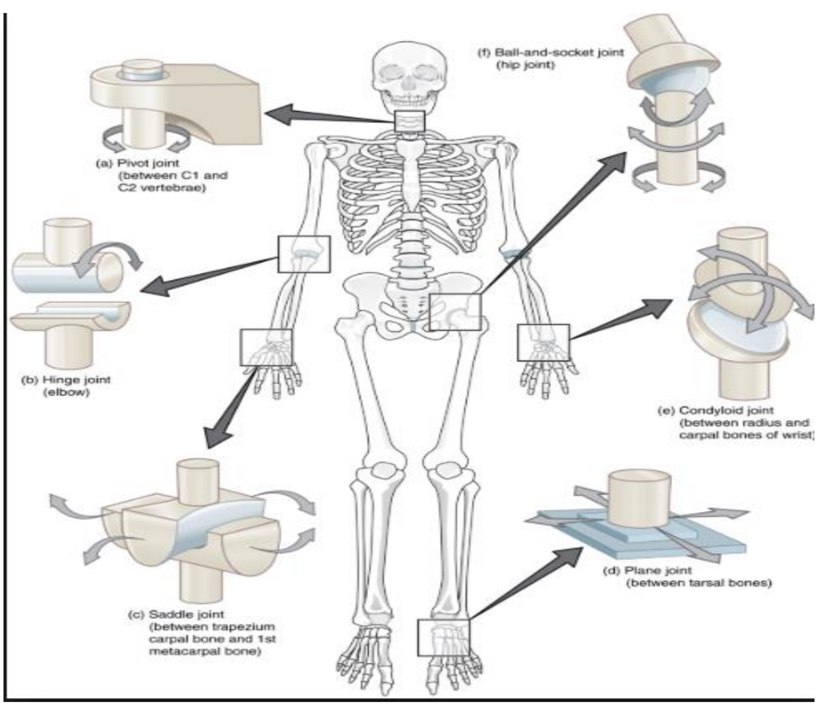
- **Hinge joints**, such as at the elbow, knee, ankle, or interphalangeal joints between phalanx bones of the fingers and toes, allow only for bending and straightening of the joint. Pivot and hinge joints are functionally classified as uniaxial joints.

- **Condyloid joints** are found where the shallow depression of one bone receives a rounded bony area formed by one or two bones. Condyloid joints are found at the base of the fingers (metacarpophalangeal joints) and at the wrist (radiocarpal joint).

- At a **saddle joint,** the articulating bones fit together like a rider and a saddle. An example is the first carpometacarpal joint located at the base of the thumb. Both condyloid and saddle joints are functionally classified as biaxial joints.

- **Plane joints** are formed between the small, flattened surfaces of adjacent bones. These joints allow the bones to slide or rotate against each other, but the range of motion is usually slight and tightly limited by ligaments or surrounding bones. This type of joint is found between the articular processes of adjacent vertebrae, at the acromioclavicular joint, or at the intercarpal joints of the hand and intertarsal joints of the foot.

- **Ball-and-socket joints**, in which the rounded head of a bone fits into a large depression or socket, are found at the shoulder and hip joints. Both plane and ball-and-sockets joints are classified functionally as multiaxial joints. However, ball-and-socket joints allow for large movements, while the motions between bones at a plane joint are small.

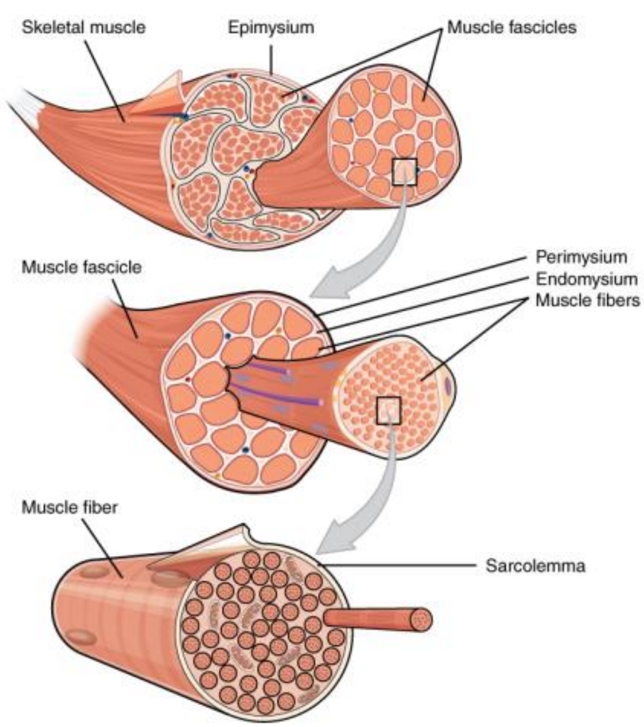


Lesson 5: Skeletal Muscle

Objective:

- Describe the function of skeletal muscles
- Describe the layers of connective tissues packaging skeletal muscle
- Explain how muscles work with tendons to move the body
- Identify areas of the skeletal muscle fibers

The best-known feature of skeletal muscle is its ability to contract and cause movement. **Skeletal muscles** act not only to produce movement but also to stop movement, such as resisting gravity to maintain posture. Small, constant adjustments of the skeletal muscles are needed to hold a body upright or balanced in any position. Muscles also prevent excess movement of the bones and joints, maintaining skeletal stability and preventing skeletal structure damage or deformation. Joints can become misaligned or dislocated entirely by pulling on the associated bones; muscles work to keep joints stable. Skeletal muscles are located throughout the body at the openings of internal tracts to control the movement of various substances. These muscles allow functions, such as swallowing, urination, and defecation, to be under voluntary control. Skeletal muscles also protect internal organs (particularly abdominal and pelvic organs) by acting as an external barrier or shield to external trauma and by supporting the weight of the organs. Skeletal muscles contribute to the maintenance of homeostasis in the body by generating heat. Muscle contraction requires energy, and when **ATP** is broken down, heat is produced. This heat is very noticeable during exercise, when sustained muscle movement causes body temperature to rise, and in cases of extreme cold, when shivering produces random skeletal muscle contractions to generate heat. Each skeletal muscle is an organ that consists of various integrated tissues. These tissues include the skeletal muscle fibers, blood vessels, nerve fibers, and connective tissue. Each skeletal muscle has three layers of connective tissue called **mysia** that enclose it and provide structure to the muscle as a whole, and also compartmentalize the muscle fibers within the muscle. Each muscle is wrapped in a sheath of dense, irregular connective tissue called the **epimysium**, which allows a muscle to contract and move powerfully while maintaining its structural integrity. The epimysium also separates muscle from other tissues and organs in the area, allowing the muscle to move independently.



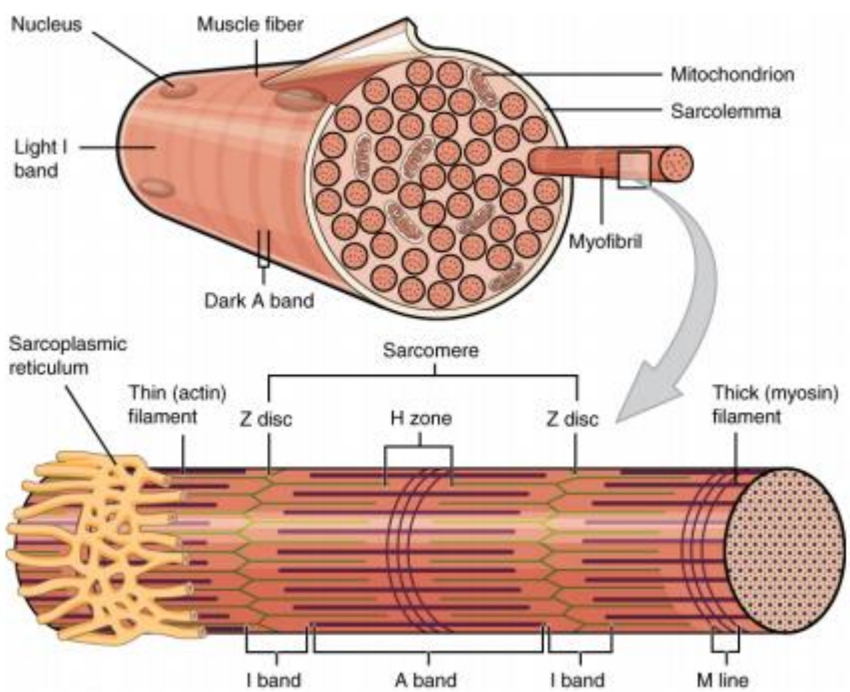
Inside each skeletal muscle, muscle fibers are organized into individual bundles, each called a **fascicle**, by a middle layer of connective tissue called the **perimysium**. This fascicular organization is common in muscles of the limbs; it allows the nervous system to trigger a specific movement of a muscle by activating a subset of muscle fibers within a bundle, or fascicle of the muscle. Inside each fascicle, each muscle fiber is encased in a thin connective tissue layer of collagen and reticular fibers called the **endomysium**. The endomysium contains the extracellular fluid and nutrients to support the muscle fiber. These nutrients are supplied via blood to the muscle tissue.

In skeletal muscles that work with **tendons** to pull on bones, the collagen in the three tissue layers (the mysia) intertwines with the collagen of a tendon. At the other end of the tendon, it fuses with the periosteum coating the bone. The tension created by contraction of the muscle fibers is then transferred though the mysia, to the tendon, and then to the periosteum to pull on the bone for movement of the skeleton. In other places, the mysia may fuse with a broad, tendon-like sheet called an **aponeurosis**, or to **fascia**, the connective tissue between skin and bones.

Every skeletal muscle is also richly supplied by blood vessels for nourishment, oxygen delivery, and waste removal. In addition, every muscle fiber in a skeletal muscle is supplied by the axon branch of a **somatic motor neuron**, which signals the fiber to contract.

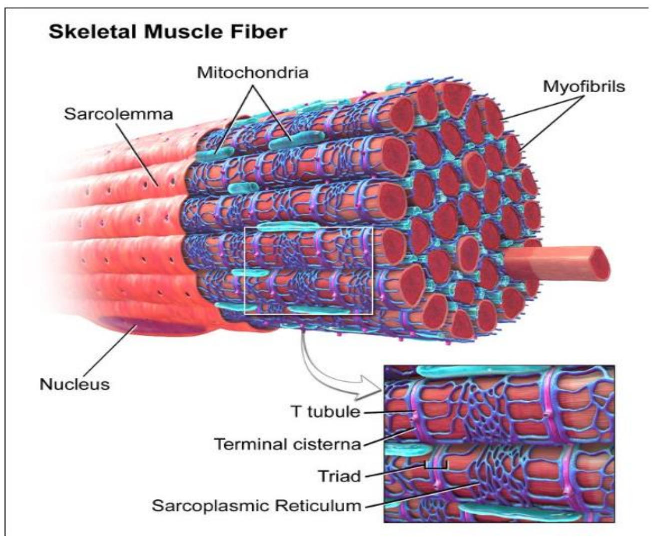
Skeletal Muscle Fibers

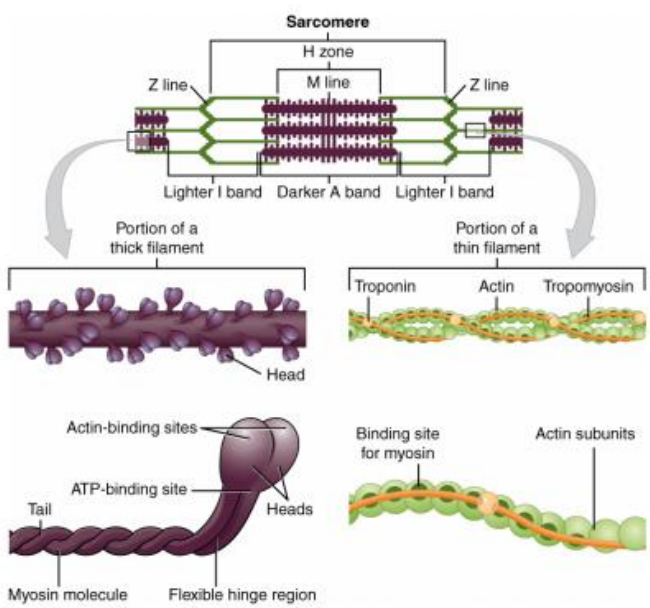
Because skeletal muscle cells are long and cylindrical, they are commonly referred to as **muscle fibers**. Skeletal muscle fibers can be quite large for human cells, with diameters up to 100 μm and lengths up to 30 cm (11.8 in) in the Sartorius of the upper leg.



The Sarcomere

The **striated** appearance of skeletal muscle fibers is due to the arrangement of the myofilaments of **actin** and **myosin** in sequential order from one end of the muscle fiber to the other. Each packet of these **microfilaments** and their regulatory proteins, **troponin and tropomyosin** (along with other proteins) is called a **sarcomere**. The **sarcomere** is the functional unit of the muscle fiber. The sarcomere itself is bundled within the **myofibril** that runs the entire length of the muscle fiber and attaches to the **sarcolemma** at its end. As **myofibrils contract, the entire muscle cell contracts**. Because myofibrils are only approximately 1.2 μm in diameter, hundreds to thousands (each with thousands of sarcomeres) can be found inside one muscle fiber. Each sarcomere is approximately 2 μm in length with a three-dimensional cylinder-like arrangement and is bordered by structures called Z-discs (also called Z-lines, because pictures are two-dimensional), to which the actin myofilaments are anchored. Because the actin and its troponin/tropomyosin complex (projecting from the Z-discs toward the center of the sarcomere) form strands that are thinner than the myosin, it is called the **thin filament** of the sarcomere. Likewise, because the myosin strands and their multiple heads (projecting from the center of the sarcomere, toward but not all to way to, the Z-discs) have more mass and are thicker, they are called the M line of the sarcomere.





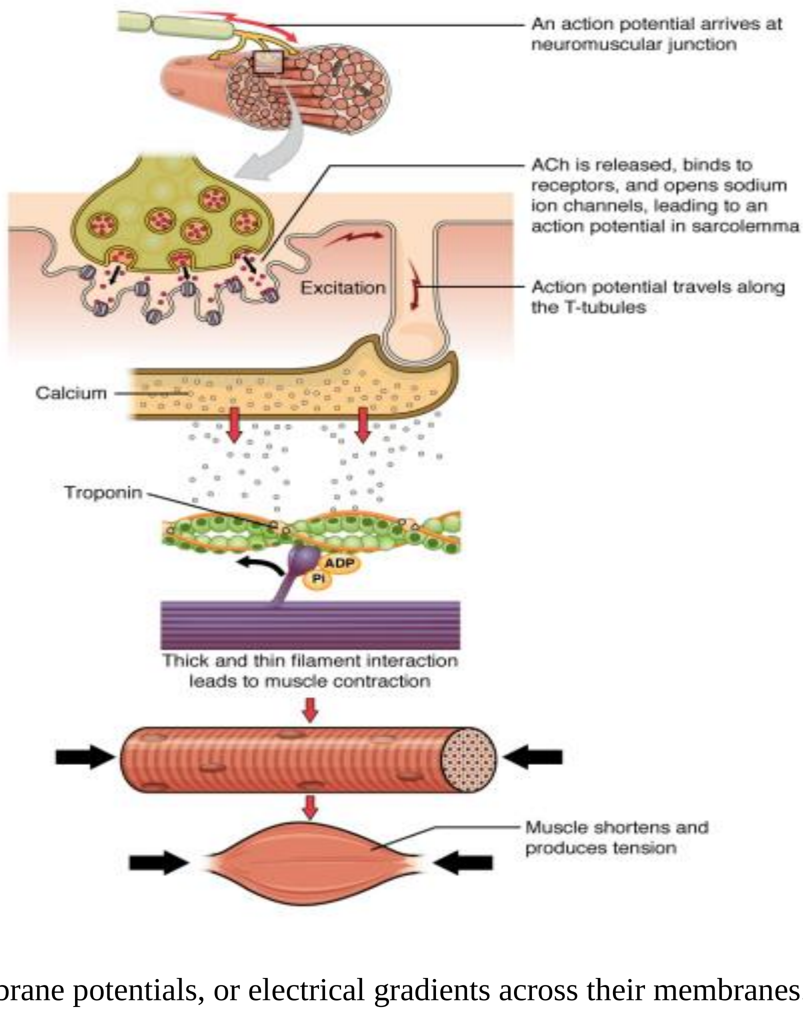
<u>Lesson 6: How Does a Muscle Contract?</u>

Objective:

- Describe the components involved in a muscle contraction
- Explain how muscles contract and relax
- Describe the sliding filament model of muscle contraction

In order for a skeletal muscle contraction to occur;

1. There must be a neural stimulus
2. There must be calcium in the muscle cells
3. ATP must be available for energy



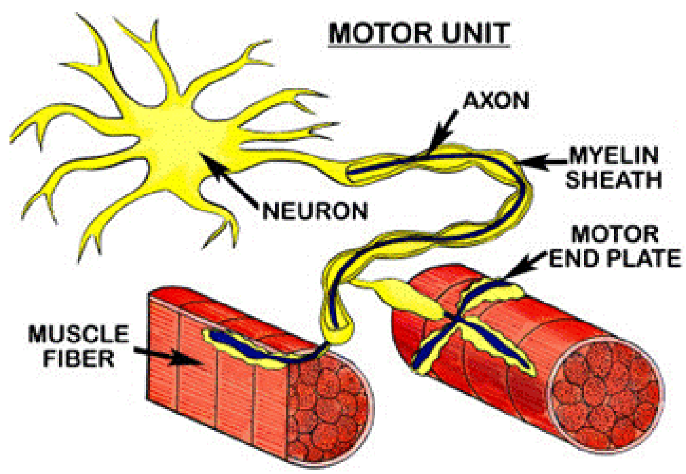
All living cells have membrane potentials, or electrical gradients across their membranes. The inside of the membrane is usually around -60 to -90 mV, relative to the outside. This is referred to as a cell's **membrane potential**. Neurons and muscle cells can use their membrane potentials to generate electrical signals. They do this by controlling the movement of charged particles, called **ions**, across their membranes to create electrical currents. This is achieved by opening and closing specialized proteins in the membrane called **ion channels.** Although the currents generated by ions moving through these channel proteins are very small, they form the basis of both neural signaling and muscle contraction. Both neurons and skeletal muscle cells are electrically

excitable, meaning that they are able to generate **action potentials.** An action potential is a special type of electrical signal that can travel along a cell membrane as a wave. This allows a signal to be transmitted quickly and faithfully over long distances.

The Sliding Filament Theory

The sliding filament theory is the explanation for how muscles contract to produce force. The **actin and myosin** filaments within the **sarcomeres** of muscle fibers bind to create cross-bridges and slide past one another, creating a contraction. The sliding filament theory explains how these cross-bridges are formed and the subsequent contraction of muscle.

For a contraction to occur there must first be a stimulation of the muscle in the form of an **impulse** (action potential) from a **motor neuron** (nerve that connects to muscle).



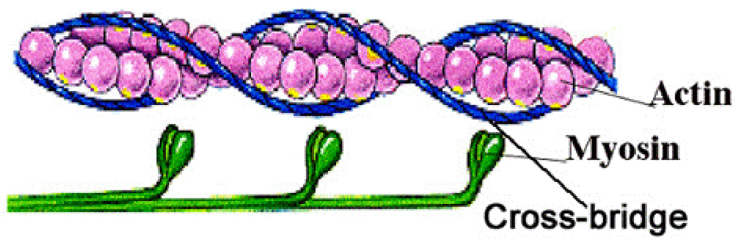
Note that one motor neuron does not stimulate the entire muscle but only a number of muscle fibers within a muscle. The individual motor neuron plus the muscle fibers it stimulates, is called a **motor unit**. The motor end plate (also known as the **neuromuscular junction**) is the junction of the motor neurons axon and the muscle fibers it stimulates.

When an impulse reaches the muscle fibers of a motor unit, it stimulates a reaction in each **sarcomere** between the actin and myosin filaments. This reaction results in the start of a **contraction** and the sliding filament theory.

The reaction, created from the arrival of an impulse stimulates the 'heads' on the myosin filament to reach forward, attach to the actin filament and pull actin towards the center of the sarcomere. This process occurs simultaneously in all sarcomeres, the end process of which is the shortening of all sarcomeres.

Troponin is a complex of three proteins that are integral to muscle contraction. Troponin is attached to the protein **tropomyosin** within the actin filaments. When the muscle is relaxed tropomyosin blocks the attachment sites for the myosin cross bridges (heads), thus preventing contraction.

When the muscle is stimulated to contract by the nerve impulse, calcium ion (Ca^{++}) channels open in the **sarcoplasmic reticulum** (which is effectively a storage house for calcium within the muscle) and release calcium into the **sarcoplasm** (fluid within the muscle cell). Some of this calcium attaches to troponin which causes a change in the muscle cell that moves tropomyosin out of the way so the cross bridges can attach and produce muscle contraction.



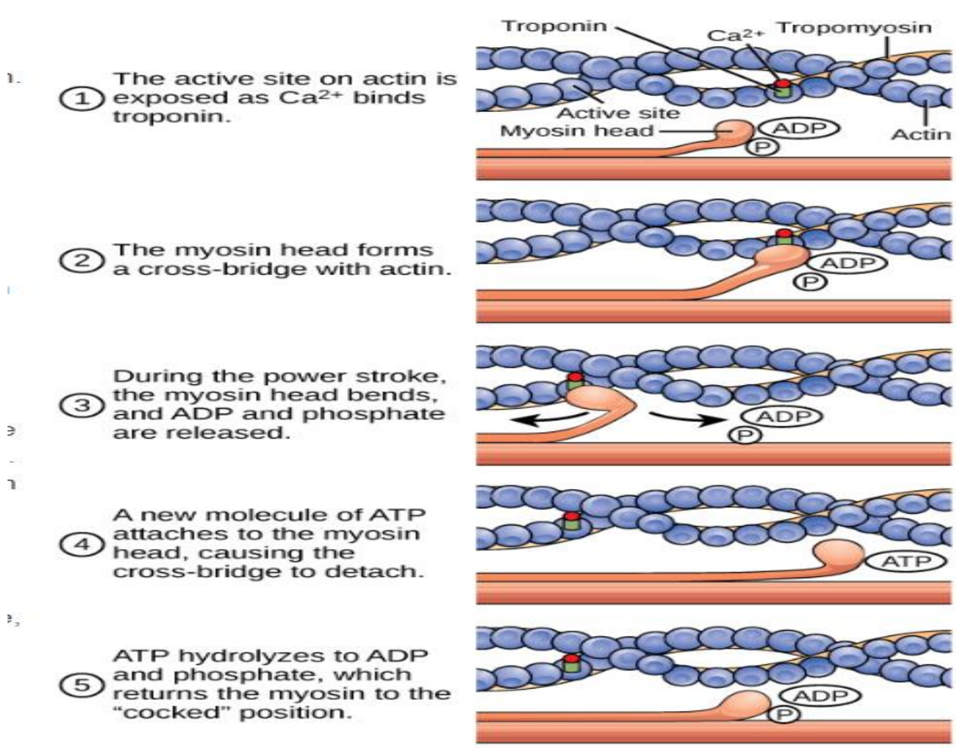
The sliding filament theory of muscle contraction can be broken down into four distinct stages, these are;

1. **Muscle activation:** The motor nerve stimulates an action potential (impulse) to pass down a neuron to the neuromuscular junction. This stimulates the sarcoplasmic reticulum to release calcium into the muscle cell.

2. **Muscle contraction:** Calcium floods into the muscle cell binding with troponin allowing actin and myosin to bind. The actin and myosin cross bridges bind and contract using ATP as energy.

3. **Recharging:** ATP is re-synthesized allowing actin and myosin to maintain their strong binding state

4. **Relaxation:** Relaxation occurs when stimulation of the nerve stops. Calcium is then pumped back into the sarcoplasmic reticulum breaking the link between actin and myosin. Actin and myosin return to their unbound state causing the muscle to relax. Alternatively, relaxation (failure) will also occur when ATP is no longer available.



Cross-bridge muscle contraction cycle: The cross-bridge muscle contraction cycle, which is triggered by Ca2+ binding to the actin active site, is shown. With each contraction cycle, actin moves relative to myosin.

A few things can stop a contraction;

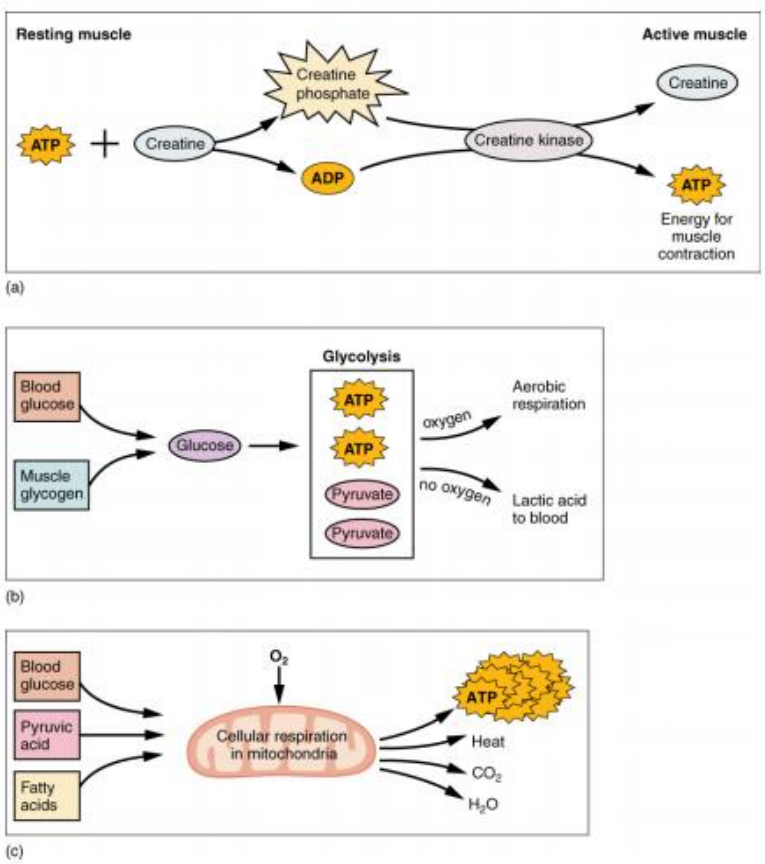
1. **Energy system fatigue:** There is no more ATP left in the muscle cell so it can't keep contracting.

2. **Nervous system fatigue:** The nervous system is not able to create impulses sufficiently or quickly enough to maintain the stimulus and cause calcium to release.

3. **Voluntary nervous system control:** The nerve that tells the muscle to contract stops sending that signal because the brain tells it to, so no more calcium ions will enter the muscle cell and the contraction stops.

4. **Sensory nervous system information**: For example, a sensory neuron (nerves that detect stimuli like pain or how heavy something is) provides feedback to the brain indicating that a muscle is injured while you are trying to lift a heavy weight and consequently the impulse to that muscle telling it to contract is stopped.

In the gym or during exercise virtually all muscular fatigue occurring is energy system fatigue. That is, the rate of work within the muscle cannot be maintained because ATP (energy) can no longer be provided. Strength and hypertrophy (training to make muscles stronger or bigger) training are prime examples of the types of training that can cause muscle failure due to energy system fatigue.



<u>Lesson 7: Interactions of Skeletal Muscles and body movement</u>

Objective:

- Compare and contrast agonist and antagonist muscles
- Explain the major events of a skeletal muscle contraction within a muscle in generating force
- Differentiate among the types of movements possible at synovial joints

Think about the things that you do each day—talking, walking, sitting, standing, and running—all of these activities require movement of particular skeletal muscles. Skeletal muscles are even used during sleep. The diaphragm is a sheet of skeletal muscle that has to contract and relax for you to breathe day and night. If you recall from your study of the skeletal system and joints, body movement occurs around the joints in the body.

The skeleton and muscles act together to move the body. Have you ever used the back of a hammer to remove a nail from wood? The handle acts as a **lever** and the head of the hammer acts as a **fulcrum**, the fixed point that the force is applied to when you pull back or push down on the handle. The effort applied to this system is the pulling or pushing on the handle to remove the nail, which is the load, or "resistance" to the movement of the handle in the system. Our musculoskeletal system works in a similar manner, with bones being stiff levers and the articular endings of the bones—encased in synovial joints—acting as fulcrums. The load would be an object being lifted or any resistance to a movement (your head is a load when you are lifting it), and the effort, or applied force, comes from contracting skeletal muscle.

To move the skeleton, the tension created by the contraction of the fibers in most skeletal muscles is transferred to the tendons. The **tendons** are strong bands of dense, regular connective tissue that connect muscles to bones. The bone connection is why this muscle tissue is called skeletal muscle.

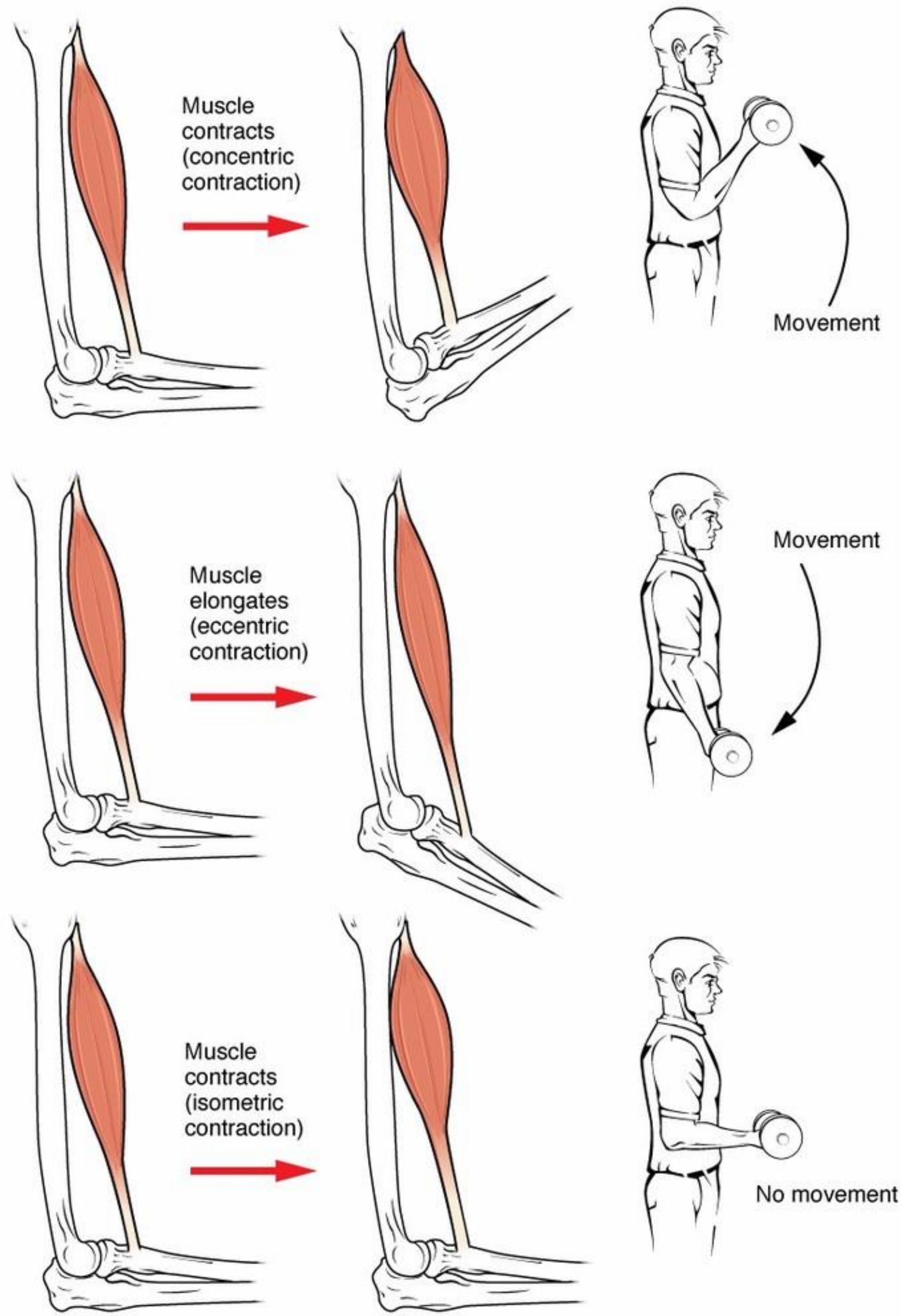
A muscle fiber generates tension through actin and myosin cross-bridge cycling. While under tension, the muscle may lengthen, shorten, or remain the same. Although the term contraction implies shortening, when referring to the muscular system, it means the generation of tension within a muscle fiber. Several types of muscle contractions occur and are defined by the changes in the length of the muscle during contraction.

Isotonic Contractions

Isotonic contractions maintain constant tension in the muscle as the muscle changes length. Isotonic muscle contractions can be either concentric or eccentric.

A **concentric** contraction is a type of muscle contraction in which the muscles shorten while generating force, overcoming resistance. For example, when lifting a heavy weight, a concentric contraction of the biceps would cause the arm to bend at the elbow, lifting the weight towards the shoulder. Cross-bridge cycling occurs, shortening the sarcomere, muscle fiber, and muscle.

An **eccentric** contraction results in the elongation of a muscle while the muscle is still generating force; in effect, resistance is greater than force generated. Eccentric contractions can be both voluntary and involuntary. For example, a voluntary eccentric contraction would be the controlled lowering of the heavy weight raised during the above concentric contraction. An involuntary eccentric contraction may occur when a weight is too great for a muscle to bear and so it is slowly lowered while under tension. Cross-bridge cycling occurs even though the sarcomere, muscle fiber, and muscle are lengthening, controlling the extension of the muscle.

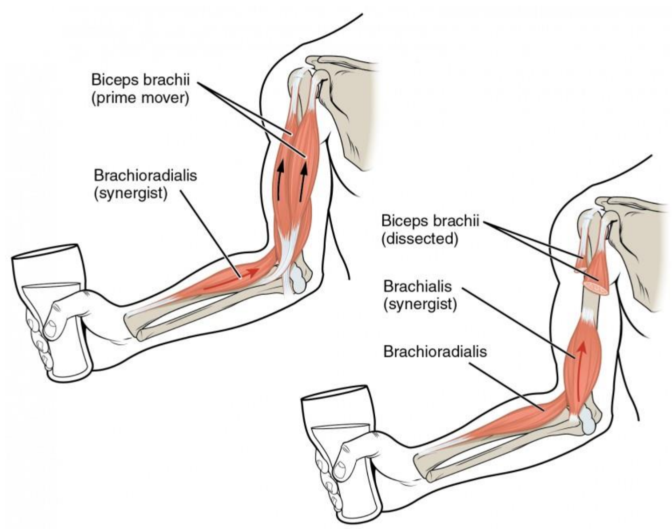

Muscle
contracts
(concentric
contraction)
Movement
Muscle
elongates
(eccentric
contraction)
Movement
Muscle
contracts
(isometric
contraction)
No movement

Isometric Contractions

In contrast to isotonic contractions, **isometric** contractions generate force without changing the length of the muscle, common in the muscles of the hand and forearm responsible for grip. Using the above example, the muscle contraction required to grip but not move a heavy object prior to lifting would be isometric. Isometric contractions are frequently used to maintain posture. Cross-bridge cycling is maintaining tension in the muscle; the sarcomere, muscle fibers, and muscle are not changing length.

Interactions of Skeletal Muscles in the Body

To pull on a bone, that is, to change the angle at its synovial joint, which essentially moves the skeleton, a skeletal muscle must also be attached to a fixed part of the skeleton. The moveable end of the muscle that attaches to the bone being pulled is called the muscle's **insertion**, and the end of the muscle attached to a fixed (stabilized) bone is called the **origin**. During forearm flexion—bending the elbow—the brachioradialis assists the brachialis.



Although a number of muscles may be involved in an action, the principal muscle involved is called the **prime mover,** or **agonist**. To lift a cup, a muscle called the biceps brachii is actually the prime mover; however, because it can be assisted by the brachialis, the brachialis is called a **synergist** in this action. A synergist can also be a **fixato**r that stabilizes the bone that is the attachment for the prime mover's origin.

A muscle with the opposite action of the prime mover is called an **antagonist.** Antagonists play two important roles in muscle function:

1. They maintain body or limb position, such as holding the arm out or standing erect
2. They control rapid movement, as in shadow boxing without landing a punch or the ability to check the motion of a limb

For example, to extend the knee, a group of four muscles called the quadriceps femoris in the anterior compartment of the thigh are activated (and would be called the agonists of knee extension). However, to flex the knee joint, an opposite or antagonistic set of muscles called the hamstrings is activated.

Agonist and Antagonist Skeletal Muscle Pairs

Agonist	Antagonist	Movement
Biceps brachii: in the anterior compartment of the arm	Triceps brachii: in the posterior compartment of the arm	The biceps brachii flexes the forearm, whereas the triceps brachii extends it.
Hamstrings: group of three muscles in the posterior compartment of the thigh	Quadriceps femoris: group of four muscles in the anterior compartment of the thigh	The hamstrings flex the leg, whereas the quadriceps femoris extend it.
Flexor digitorum superficialis and flexor digitorum profundus: in the anterior compartment of the forearm	Extensor digitorum: in the posterior compartment of the forearm	The flexor digitorum superficialis and flexor digitorum profundus flex the fingers and the hand at the wrist, whereas the extensor digitorum extends the fingers and the hand at the wrist.

Movement at Synovial Joints

The range of movement allowed by synovial joints is fairly wide. These movements can be classified as: gliding, angular, rotational, or special movement.

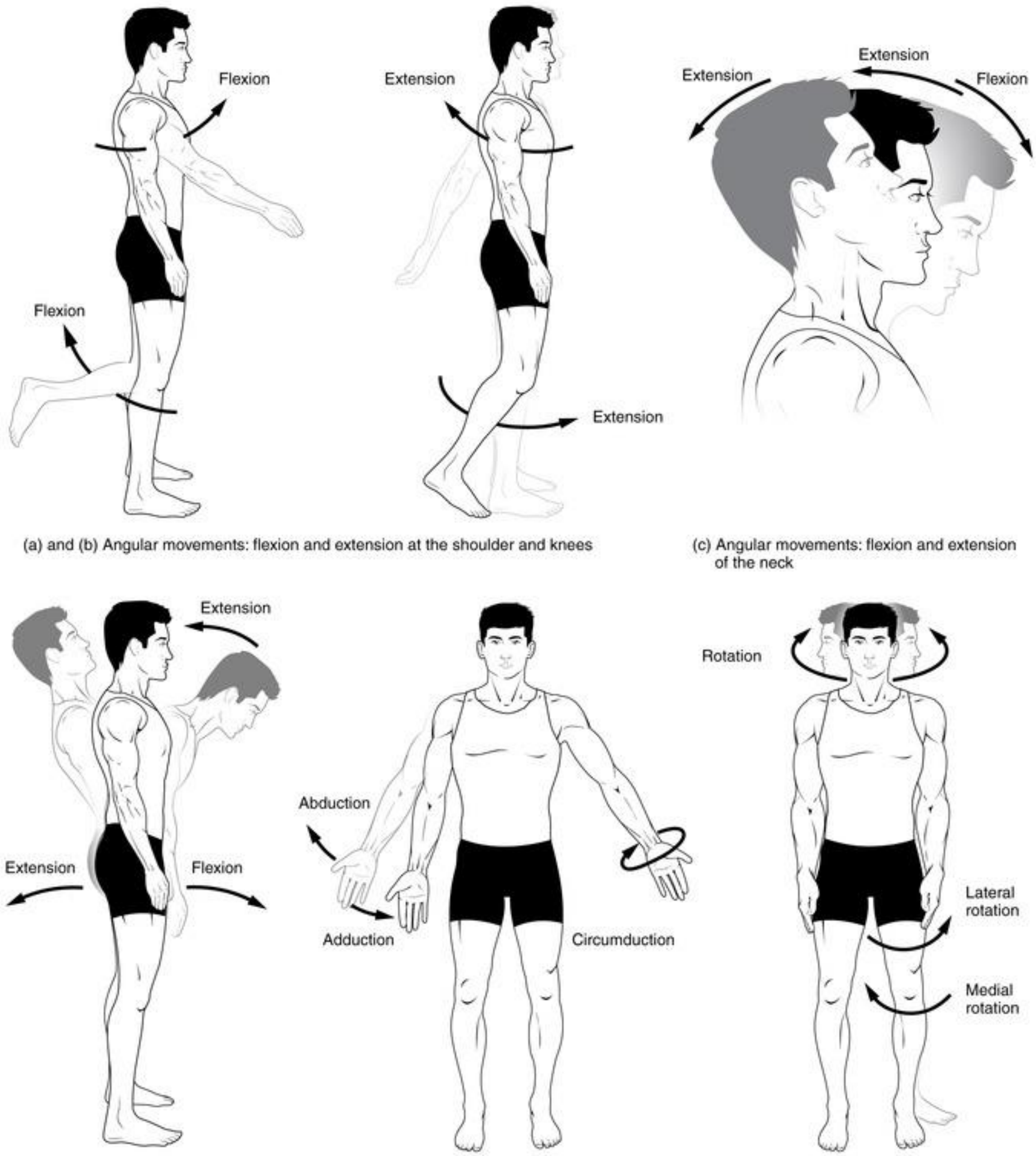
Gliding Movement

Gliding movements occur as relatively flat bone surfaces move past each other. They produce very little rotation or angular movement of the bones. The joints of the carpal and tarsal bones are examples of joints that produce gliding movements.

Angular Movement

Angular movements are produced by changing the angle between the bones of a joint. There are several different types of angular movements, including **flexion, extension, hyperextension, abduction, adduction,** and **circumduction**. **Flexion,** or bending, occurs when the angle between the bones decreases. Moving the forearm upward at the elbow or moving the wrist to move the hand toward the forearm are examples of flexion. In **extension**, the opposite of flexion, the angle between the bones of a joint increases. Straightening a limb after flexion is an example of extension. Extension past the normal anatomical position is referred to as hyperextension. This includes moving the neck back to look upward or bending the wrist so that the hand moves away from the forearm.

Abduction occurs when a bone moves away from the midline of the body. Examples of abduction include moving the arms or legs laterally to lift them straight out to the side. **Adduction** is the movement of a bone toward the midline of the body. Movement of the limbs inward after abduction is an example of adduction. **Circumduction** is the movement of a limb in a circular motion, as in swinging an arm around.



(a) and (b) Angular movements: flexion and extension at the shoulder and knees

(c) Angular movements: flexion and extension of the neck

(d) Angular movements: flexion and extension of the vertebral column

(e) Angular movements: abduction, adduction, and circumduction of the upper limb at the shoulder

(f) Rotation of the head, neck, and lower limb

Rotational Movement

Rotational movement is the movement of a bone as it rotates around its longitudinal axis. Rotation can be toward the midline of the body, which is referred to as medial rotation, or away from the midline of the body, which is referred to as lateral rotation. Movement of the head from side to side is an example of rotation.

Special Movements

Some movements that cannot be classified as gliding, angular, or rotational are called special movements. **Inversion** involves moving the soles of the feet inward, toward the midline of the body. **Eversion**, the opposite of inversion, involves moving of the sole of the foot outward, away from the midline of the body. **Protraction** is the anterior movement of a bone in the horizontal plane. **Retraction** occurs as a joint moves back into position after protraction. Protraction and retraction can be seen in the movement of the mandible as the jaw is thrust outwards and then back inwards. **Elevation** is the movement of a bone upward, such as shrugging the shoulders, lifting the scapulae. **Depression** is the opposite of elevation and involves moving the bone downward, such as after the shoulders are shrugged and the scapulae return to their normal position from an elevated position. **Dorsiflexion** is a bending at the ankle such that the toes are lifted toward the knee. **Plantarflexion** is a bending at the ankle when the heel is lifted, such as when standing on the toes. **Supination** is the movement of the radius and ulna bones of the forearm so that the palm faces forward or up. **Pronation** is the opposite movement, in which the palm faces backward or down. **Opposition** is the movement of the thumb toward the fingers of the same hand, making it possible to grasp and hold objects.