CHAPTER IX

The Skeletal & Muscular Systems: Supporting Movements

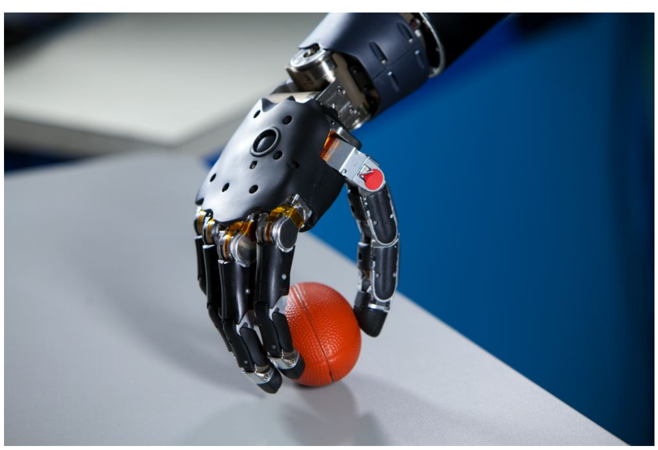
LEARNING OBJECTIVES

By the end of this class you should be able to:

- Identify the components of the skeletal system and list its functions.
- Describe the different types of joints.
- Describe the structure, growth, maintenance and repair of bones and the different types of bones.
- Explain osteoporosis and ways to prevent it.
- Describe the different types of muscles and functions of the muscular system.
- Understand how muscles are named.
- Explain muscular hypertrophy, atrophy and fibrosis.
- Describe the structures allowing the contraction of muscles.

Introduction

The muscular and skeletal systems provide support to the body and allow for movement. The bones of the skeleton protect the body's internal organs and support the weight of the body. The muscles of the muscular system contract and pull on the bones, allowing for movements as diverse as standing, walking, running, and grasping items. Injury or disease affecting the musculoskeletal system can be very debilitating. The most common musculoskeletal diseases worldwide are caused by malnutrition, which can negatively affect development and maintenance of bones and muscles. Other diseases affect the joints, such as arthritis, which can make movement difficult and, in advanced cases, completely impair mobility. Progress in the science of prosthesis design has resulted in the development of artificial joints, with joint replacement surgery in the hips and knees being the most common. Replacement joints for shoulders, elbows, and fingers are also available. In cases of severe accidents and amputations, prosthetics able to mimic the musculoskeletal functions of entire limbs. Even with this progress, there is still room for improvement in the design of prostheses. The state-of-the-art prostheses have limited durability and therefore wear out quickly, particularly in young or active individuals. Current research is focused on the use of new materials, such as carbon fiber, that may make prostheses more durable.



Prosthetic Arm. A brain-controlled, prosthetic arm funded by the Defense Advanced Research Projects Agency. RPA. Food and Drugs Administration (credit: FDA, photo courtesy of The Johns Hopkins University Applied Physics Laboratory (JHU/APL), Public Domain).

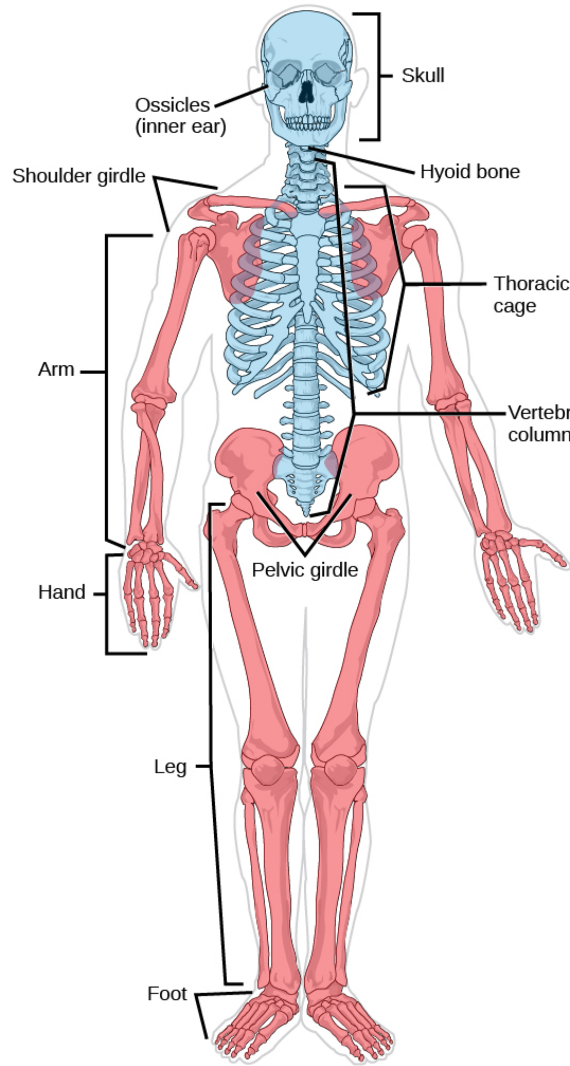
The Skeletal System

The human skeleton is an **endoskeleton** that consists of 206 bones in the adult. An endoskeleton develops within the body rather than outside like the exoskeleton of insects. The skeleton has five main functions: providing support to the body, storing minerals and lipids, producing blood cells, protecting internal organs, and allowing for movement. The skeletal system in vertebrates is divided into the **axial skeleton** (which consists of the skull, vertebral column, and rib cage), and the **appendicular skeleton** (which consists of limb bones, the pectoral or shoulder girdle, and the pelvic girdle).

(1) The Axial Skeleton

The axial skeleton forms the central axis of the body and includes the bones of the skull, ossicles of the middle ear, hyoid bone of the throat, vertebral column, and the thoracic cage (rib cage).

- The bones of the **skull** support the structures of the face and protect the brain. The skull consists of cranial bones and facial bones. The cranial bones form the cranial cavity, which encloses the brain and serves as an attachment site for muscles of the head and neck. In the adult they are tightly jointed with connective tissue and adjoining bones do not move.
- The **auditory ossicles** of the middle ear transmit sounds from the air as vibrations to the fluid-filled cochlea. The auditory ossicles consist of two malleus (hammer) bones, two incus (anvil) bones, and two stapes (stirrups), one on each side. Facial bones provide cavities for the sense organs (eyes, mouth, and nose), and serve as attachment points for facial muscles.
- The **hyoid bone** lies below the mandible in the front of the neck. It acts as a movable base for the tongue and is connected to muscles of the jaw, larynx, and tongue. The mandible forms a joint with the base of the skull. The mandible controls the opening to the mouth and hence, the airway and gut.
- The **vertebral column**, or spinal column, surrounds and protects the spinal cord, supports the head, and acts as an attachment point for ribs and muscles of the back and neck. It consists of 26 bones: the 24 vertebrae, the sacrum, and the coccyx. Each vertebral body has a large hole in the center through which the spinal cord passes down to the level of the first lumbar vertebra. Below this level, the hole contains spinal nerves which exit between the vertebrae. There is a notch on each side of the hole through which the spinal nerves, can exit from the spinal cord to serve different regions of the body. The vertebral column is approximately 70 cm (28 in) in adults and is curved, which can be seen from a side view. Intervertebral discs composed of fibrous cartilage lie between adjacent vertebrae from the second cervical vertebra to the sacrum. Each disc helps form a slightly moveable joint and acts as a cushion to absorb shocks from movements such as walking and running.
- **The thoracic cage**, also known as the rib cage consists of the ribs, sternum, thoracic vertebrae, and costal cartilages. The thoracic cage encloses and protects the organs of the thoracic cavity including the heart and lungs. It also provides support for the shoulder girdles and upper limbs and serves as the attachment point for the diaphragm, muscles of the back, chest, neck, and shoulders. Changes in the volume of the thorax enable breathing. The sternum, or breastbone, is a long flat bone located at the anterior of the chest. Like the skull, it is formed from many bones in the embryo, which fuse in the adult. The ribs are 12 pairs of long curved bones that attach to the thoracic vertebrae and curve toward the front of the body, forming the ribcage. Costal cartilages connect the anterior ends of most ribs to the sternum.



The Skeleton. The axial skeleton, shown in blue, consists of the bones of the skull, ossicles of the middle ear, hyoid bone, vertebral column, and thoracic cage. The appendicular skeleton, shown in red, consists of the bones of the pectoral limbs, pectoral girdle, pelvic limb, and pelvic girdle. (credit: CNX OpenStax, CC BY 4.0)

(2) The Appendicular Skeleton

The appendicular skeleton is composed of the bones of the upper and lower limbs. It also includes the pectoral, or shoulder girdle, which attaches the upper limbs to the body, and the pelvic girdle, which attaches the lower limbs to the body.

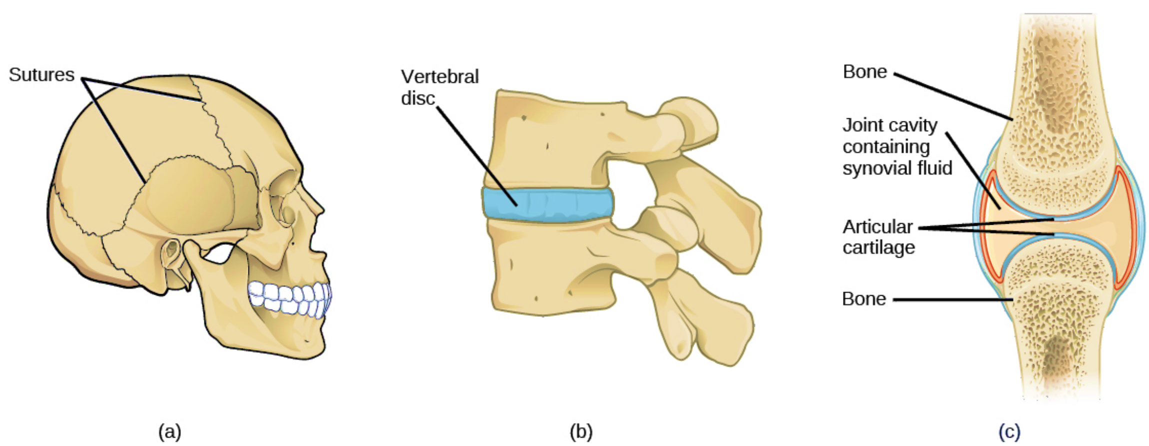
- **The pectoral girdle** bones transfer force generated by muscles acting on the upper limb to the thorax. It consists of the clavicles (or collarbones) in the anterior, and the scapulae (or shoulder blades) in the posterior.
- The **upper limb** contains bones of the arm (shoulder to elbow), the forearm, and the hand. The humerus is the largest and longest bone of the upper limb. It forms a joint with the shoulder and with the forearm at the elbow. The forearm extends from the elbow to the wrist and consists of two bones. The hand includes the bones of the wrist, the palm, and the bones of the fingers.
- The **pelvic girdle** attaches to the lower limbs of the axial skeleton. Since it is responsible for bearing the weight of the body and for locomotion, the pelvic girdle is securely attached to the axial skeleton by strong ligaments. It also has deep sockets with robust ligaments that securely attach to the femur. The pelvic girdle is mainly composed of two large hip bones. The hip bones join together in the anterior of the body at a joint called the pubic symphysis and with the bones of the sacrum at the posterior of the body.
- The **lower limb** consists of the thigh, the leg, and the foot. The bones of the lower limbs are thicker and stronger than the bones of the upper limbs to support the entire weight of the body and the forces from locomotion. The femur, or thighbone, is the longest, heaviest, and strongest bone in the body. The femur and pelvis form the hip joint. At its other end, the femur, along with the shinbone and kneecap, form the knee joint.

(3) Joints and Skeletal Movement

The point at which two or more bones meet is called a **joint or articulation**. Joints are responsible for movement, such as the movement of limbs, and stability, such as the stability found in the bones of the skull.

There are two ways to classify joints: based on their structure or based on their function. The structural classification divides joints into **fibrous**, **cartilaginous**, and **synovial** joints depending on the material composing the joint and the presence or absence of a cavity in the joint.

- The bones of fibrous joints are held together by fibrous connective tissue. There is no cavity, or space, present between the bones, so most fibrous joints do not move at all, or are only capable of minor movements. The joints between the bones in the skull and between the teeth and the bone of their sockets are examples of fibrous joints
- Cartilaginous joints are joints in which the bones are connected by cartilage. An example is found at the joints between vertebrae, the so-called "disks" of the backbone. Cartilaginous joints allow for very little movement.
- Synovial joints are the only joints that have a space between the adjoining bones. This space is referred to as the joint cavity and is filled with fluid. The fluid lubricates the joint, reducing friction between the bones and allowing for greater movement. The ends of the bones are covered with cartilage and the entire joint is surrounded by a capsule. Synovial joints are capable of the greatest movement of the joint types. Knees, elbows, and shoulders are examples of synovial joints.

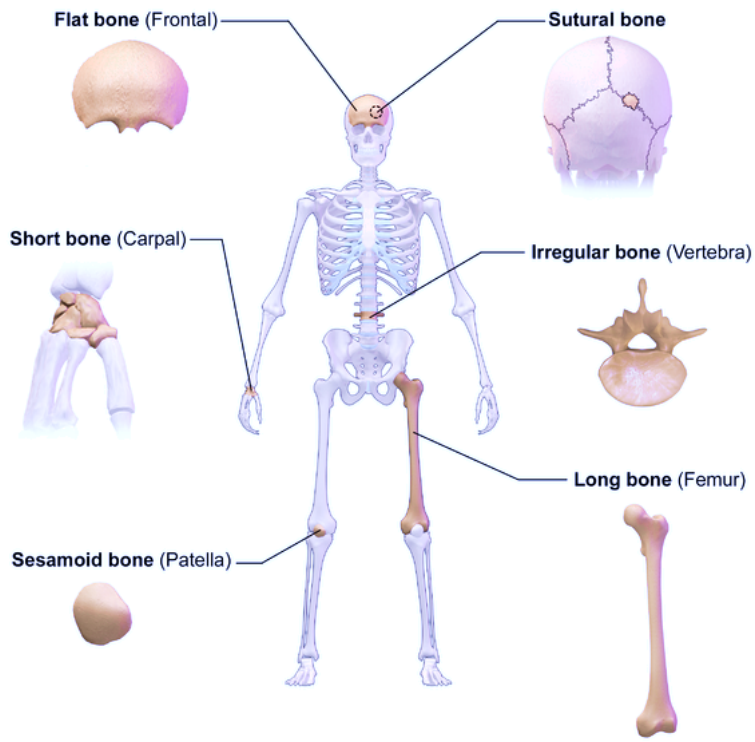


Joints. Sutures are fibrous joints found only in the skull. (b) Cartilaginous joints are bones connected by cartilage, such as between vertebrae. (c) Synovial joints are the only joints that have a space or "synovial cavity" in the joint (credit: CNX OpenStax CC BY 4.0).

(4) Bones Are Organs That Are Constantly Renewed

Bone, or osseous tissue, is a connective tissue that constitutes the endoskeleton. It contains specialized cells and a matrix of mineral salts and collagen fibers. The mineral salts primarily include hydroxyapatite, a mineral formed from calcium phosphate. **Calcification** is the process of deposition of mineral salts on the collagen fiber matrix that crystallizes and hardens the tissue. The process of calcification only occurs in the presence of collagen fibers. Bones of the human skeleton are classified by their shape:

- **Short bones**, or cuboidal bones, are bones that are the same width and length, giving them a cube-like shape. For example, the bones of the wrist (carpals) and ankle (tarsals) are short bones.
- **Flat bones** are thin and relatively broad bones that are found where extensive protection of organs is required or where broad surfaces of muscle attachment are required. Examples of flat bones are the sternum (breast bone), ribs, scapulae (shoulder blades), and the roof of the skull.
- **Irregular bones** are bones with complex shapes. These bones may have short, flat, notched, or ridged surfaces. Examples of irregular bones are the vertebrae, hip bones, and several skull bones.
- **Sesamoid bones** are small, flat bones and are shaped similarly to a sesame seed. The patellae are sesamoid bones. Sesamoid bones develop inside tendons and may be found near joints at the knees, hands, and feet.
- **Sutural bones** are small, flat, irregularly shaped bones. They may be found between the flat bones of the skull. They vary in number, shape, size, and position.

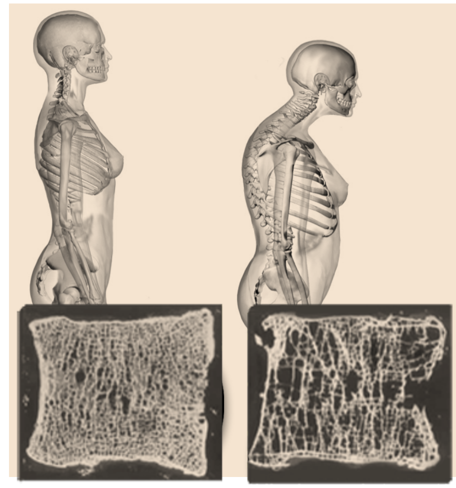


Types of Bones by Shape. Shown are different types of bones: flat, sutural, irregular, long, sesamoid and short (credit: BruceBlaus, CC BY 3.0).

Bones are considered organs because they contain various types of tissue, such as blood, connective tissue, nerves, and bone tissue. Osteocytes, the living cells of bone tissue, form the mineral matrix of bones. There are two types of bone tissue: compact and spongy. **Compact bone** (or cortical bone) forms the hard external layer of all bones and surrounds the medullary cavity, or bone marrow. It provides protection and strength to bones. It helps the bone resist bending or fracturing and is prominent in areas of bone at which stresses are applied in only a few directions. Whereas compact bone tissue forms the outer layer of all bones, **spongy bone** or cancellous bone forms the inner layer of all bones. Spongy bone is prominent in areas of bones that are not heavily stressed or where stresses arrive from many directions.

Ossification, or osteogenesis, is the process of bone formation by cells called **osteoblasts**. Ossification is distinct from the process of calcification; whereas calcification takes place during the ossification of bones, it can also occur in other skeleton consists entirely of fibrous membranes and hyaline cartilage. Bone growth continues until approximately age 25. Bones can grow in thickness throughout life, but after age 25, ossification functions primarily in bone remodeling and repair. Bone renewal continues after birth into adulthood. Bone remodeling is the replacement of old bone tissue by new bone tissue. It involves the processes of bone deposition and bone resorption by different types of cells, osteoblasts and **osteoclasts** respectively. Normal bone growth requires vitamins D, C, tissues. Ossification begins approximately six weeks after fertilization in an embryo. Before this time, the embryonic and A, plus minerals such as calcium, phosphorous, and magnesium. Hormones such as parathyroid hormone, growth hormone, and calcitonin are also required for proper bone growth and maintenance.

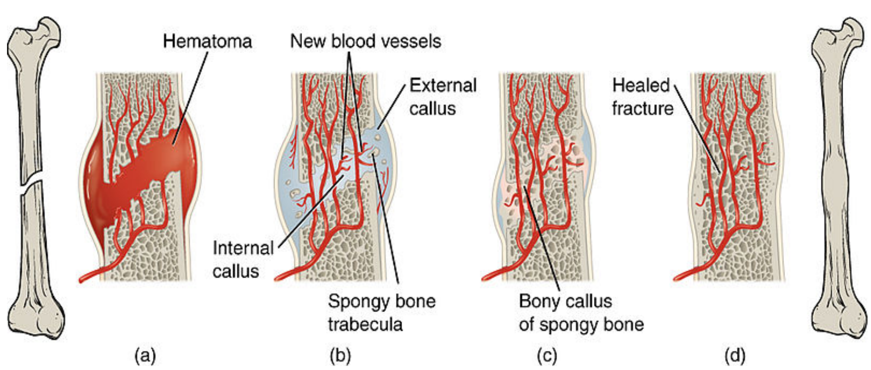
During long space missions, astronauts can lose approximately 1 to 2 percent of their bone mass per month. This loss of bone mass is thought to be caused by the lack of mechanical stress on astronauts' bones due to the low gravitational forces in space. Lack of mechanical stress causes bones to lose mineral salts and collagen fibers, and thus strength. Similarly, mechanical stress stimulates the deposition of mineral salts and collagen fibers. Numerous, controlled studies have demonstrated that people who exercise regularly have greater bone density than those who are more sedentary. Any type of exercise will stimulate the deposition of more bone tissue, but resistance training has a greater effect than cardiovascular activities. Resistance training is especially important to slow down the eventual bone loss due to aging and for preventing **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.



Osteoporosis. The effects of osteoporosis a the whole-body (top; credit: modified from BruceBlaus, CC BY 3.0) and bone levels (bottom; modified from Turner Biomechanics Laboratory, Public Domain). On the left is a healthy patient/bone and on the right a patient/bone with osteoporosis.

Bone turnover rates are quite high, with five to seven percent of bone mass being recycled every week. Differences in turnover rate exist in different areas of the skeleton and in different areas of a bone. For example, the bone in the head of the femur may be fully replaced every six months, whereas the bone along the shaft is altered much more slowly. Bone remodeling allows bones to adapt to stresses by becoming thicker and stronger when subjected to stress. Bones that are not subject to normal stress, for example when a limb is in a cast, will begin to lose mass. A fractured or broken bone undergoes repair through four stages:

1. Blood vessels in the broken bone tear and hemorrhage, resulting in the formation of clotted blood, or a hematoma, at the site of the break. The severed blood vessels at the broken ends of the bone are sealed by the clotting process, and bone cells that are deprived of nutrients begin to die.
2. Within days of the fracture, capillaries grow into the hematoma, and phagocytic cells begin to clear away the dead cells. Though fragments of the blood clot may remain, fibroblasts and osteoblasts enter the area and begin to reform bone. Fibroblasts produce collagen fibers that connect the broken bone ends, and osteoblasts start to form spongy bone. The repair tissue between the broken bone ends is called the fibrocartilaginous callus, as it is composed of both hyaline and fibrocartilage. Some bone spicules may also appear at this point.
3. The fibrocartilaginous callus is converted into a bony callus of spongy bone. It takes about two months for the broken bone ends to be firmly joined together after the fracture. This is similar to the endochondral formation of bone, as cartilage becomes ossified; osteoblasts, osteoclasts, and bone matrix are present.
4. The bony callus is then remodeled by osteoclasts and osteoblasts, with excess material on the exterior of the bone and within the medullary cavity being removed. Compact bone is added to create bone tissue that is similar to the original, unbroken bone. This remodeling can take many months, and the bone may remain uneven for years.



Bone Fracture. Left: Stages in Fracture Repair The healing of a bone fracture follows a series of progressive steps: (a) A fracture hematoma forms. (b) Internal and external calli form. (c) Cartilage of the calli is replaced by trabecular bone. (d) Remodeling occurs. (credit: OpenStax College, CC BY 3.0); Right: X-Ray of a fracture of the humerus with callus formation (credit: Bill Rhodes, CC BY 2.0).

Activity 1. The Skeletal System

1.1 - Obtain bones displayed in the room and determine if they belong to the axial or appendicular skeleton, the type of joint they are associated with. Make sure you observe all types of bones and joints.

1.2 - For each bone on the list below:

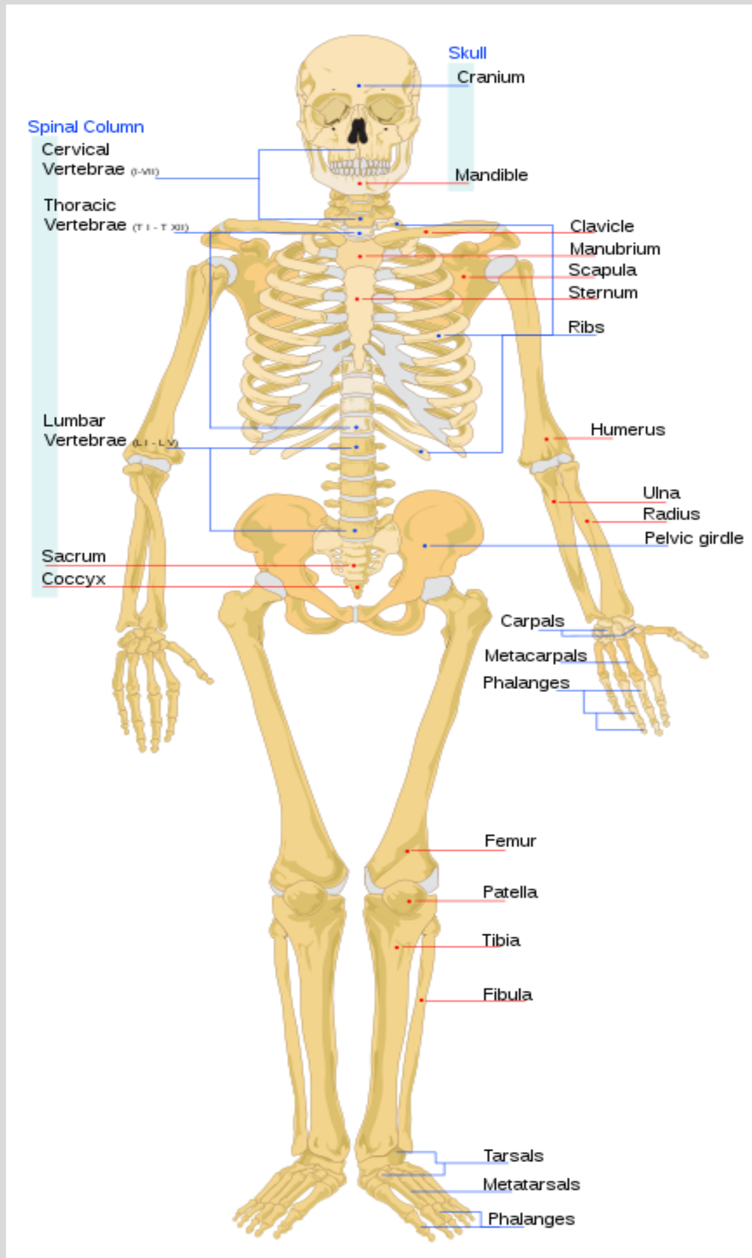
i. find it on the skeleton figure

ii. determine its shape

iii. note whether it belongs to the axial or appendicular skeleton

iv. identify the type of joint it is associated to

a. Sternum
b. Fibula
c. Coccyx
d. Rib
e. Ulna
f. Lumbar vertebrae
g. Scapula
h. Femur
i. Metacarpal
j. Patella
k. Humerus
l. Tibia



The Muscular System

(1) Our Different Muscles

Muscles allow for movement such as walking, and they also facilitate bodily processes such as respiration and digestion. The body contains three types of muscle tissue: skeletal muscle, cardiac muscle, and smooth muscle.

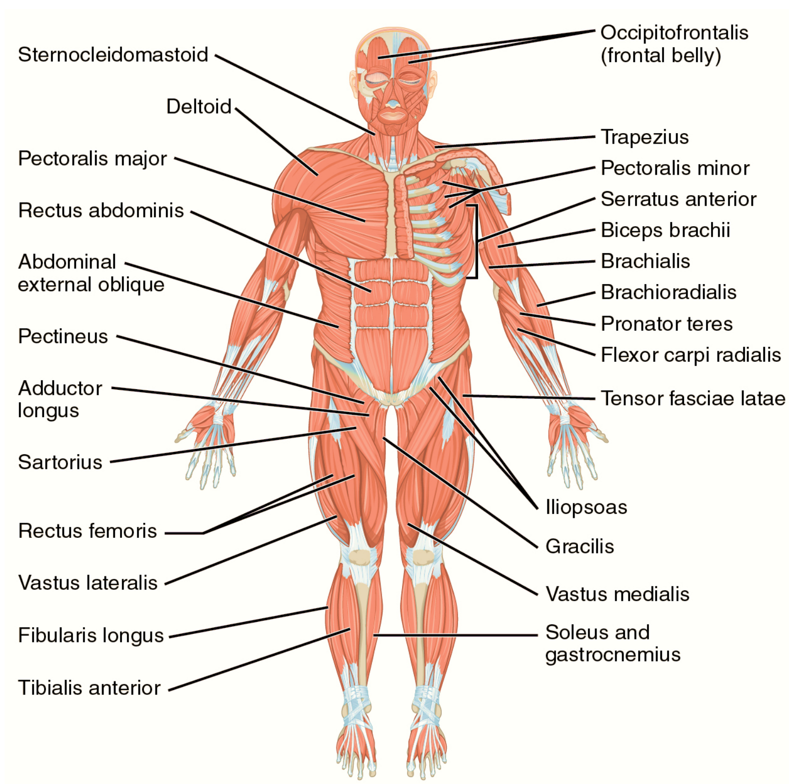
- Skeletal muscle tissue forms skeletal muscles, which attach to bones and sometimes the skin and control locomotion and any other movement that can be consciously controlled. Because it can be controlled intentionally, skeletal muscle is also called voluntary muscle. When viewed under a microscope, skeletal muscle tissue has a striped or striated appearance. This appearance results from the arrangement of the proteins inside the cell that are responsible for contraction. The cells of skeletal muscle are long and tapered and have multiple nuclei on the periphery of each cell.
- Smooth muscle tissue occurs in the walls of hollow organs such as the intestines, stomach, and urinary bladder, and around passages such as in the respiratory tract and blood vessels. Smooth muscle has no striations, is not under voluntary control, and is called involuntary muscle. Smooth muscle cells have a single nucleus.
- Cardiac muscle tissue is only found in the heart. The contractions of cardiac muscle tissue pump blood throughout the body and maintain blood pressure. Like skeletal muscle, cardiac muscle is striated, but unlike skeletal muscle, cardiac muscle cannot be consciously controlled and is called involuntary muscle. The cells of cardiac muscle tissue are connected to each other through intercalated disks and usually have just one nucleus per cell.

Palmaris Longus Muscle. This muscle visible as a small tendon in the wrist is absent in about 14 percent of the population; absence of the palmaris longus does not have an effect on grip strength (credit: Hwilms, Public Domain).

The muscular system consists of all the muscles present in a single body. There are approximately 650 skeletal muscles in the human body, but an exact number is difficult to define. The difficulty lies partly in the fact that different sources group the muscles differently and partly in that some muscles, such as palmaris longus, are not always present. The muscles of the body can be difficult to remember, as their names are often long and confusing. Knowing the basics of muscle naming conventions makes it easier to remember and locate them. The Greeks and Romans conducted the first studies done on the human body in Western culture. The educated class of subsequent societies studied Latin and Greek, and therefore the early pioneers of anatomy continued to apply Latin and Greek terminology or roots when they named the skeletal muscles. Anatomists name the skeletal muscles according to a number of criteria, each of which describes the muscle in some way:

- Deltoid - shaped like a triangle
  Orbicularis - orbit, circular muscle
- Major/Minor - large/small or sometimes upper and lower
- Vastus – large
- Dorsi or Dorsal – backside
- Infra / Supra - lower and upper
- Longus / Brevis - long/ short (brief)
- Medialis / Lateralis - medial (toward the inside), lateral (toward the outside).

Some muscles are named for the region or the bone they are attached to, for example: biceps femoris - two headed muscle attached to the femur; extensor carpi radialis longus - long muscle that runs the length of the radius (bone) to the carpals (wrist bones) that extends the fingers.



Major Muscles of The Body. Right side; superficial; left side deep (anterior view) (credit: OpenStax, CC BY 4.0).

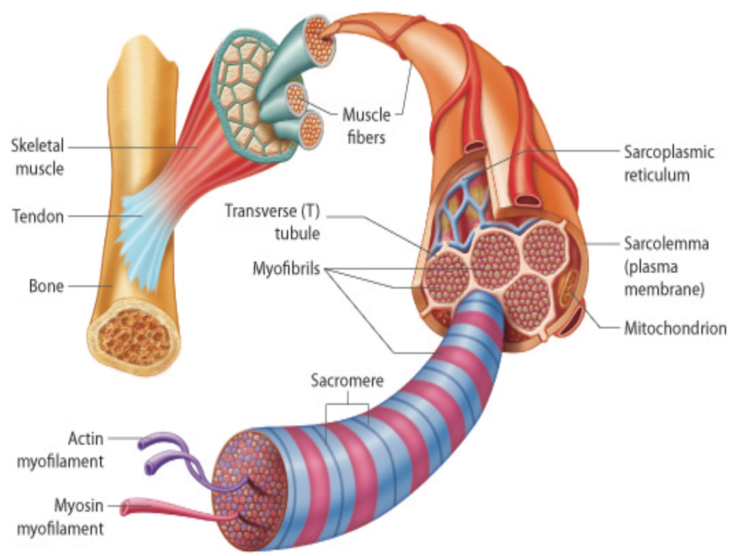
(2) We Keep the Same Muscles Cells Our Entire Life

Muscle cells can change in size but new cells are not formed when muscles grow. Instead, structural proteins are added to muscle fibers in a process called **hypertrophy**, so cell diameter increases as exemplified by the large skeletal muscles seen in body builders and other athletes. When muscle cells die, they are not regenerated but instead are replaced by connective tissue and adipose tissue, which do not possess the contractile abilities of muscle tissue. Muscles **atrophy** when they are not used, and over time if atrophy is prolonged, muscle cells die. There are various causes of atrophy, including mechanical injury, disease, and age. Although the number of muscle cells is set during development, **satellite cells**, a type of stem cells, help to repair skeletal muscle cells. Satellite cells are incorporated into muscle cells and facilitate the protein synthesis required for repair and growth. These cells are stimulated to grow and fuse with muscle cells by growth factors that are released by muscle fibers under certain forms of stress. Satellite cells can regenerate muscle fibers to a very limited extent, but they primarily help to repair damage in living cells. If a cell is damaged to a greater extent than can be repaired by satellite cells, the muscle fibers are replaced by scar tissue in a process called **fibrosis**. Because scar tissue cannot contract, muscle that has sustained significant damage loses strength and cannot produce the same amount of power or endurance as it could before being damaged. Smooth muscle tissue can regenerate from a type of stem cell called a **pericyte**, which is found in some small blood vessels. Pericytes allow smooth muscle cells to regenerate and repair much more readily than skeletal and cardiac muscle tissue. Similar to skeletal muscle tissue, cardiac muscle does not regenerate to a great extent. Dead cardiac muscle tissue is replaced by scar tissue, which cannot contract. As scar tissue accumulates, the heart loses its ability to pump because of the loss of contractile power. However, some minor regeneration may occur due to stem cells found in the blood that occasionally enter cardiac tissue.

Muscle Hypertrophy. Resistance exercise affects muscles by increasing the thickness of muscle fibers. This added structure causes hypertrophy, or the enlargement of muscles as seen in this female body builder (credit: Sabre Blade, Public Domain).

(3) Our Do Muscles Do It?

Each skeletal muscle fiber is a skeletal muscle cell. Within each muscle fiber are **myofibrils**, long cylindrical structures that lie parallel to the muscle fiber. Myofibrils run the entire length of the muscle fiber. They attach to the plasma membrane, called the **sarcolemma**, at their ends, so that as myofibrils shorten, the entire muscle cell contracts. The striated appearance of skeletal muscle tissue is a result of repeating bands of the proteins **actin** and **myosin** that occur along the length of myofibrils. Myofibrils are composed of smaller structures called **myofilaments**. There are two main types of myofilaments: thick filaments and thin filaments. Thick filaments are composed of the protein myosin. The primary component of thin filaments is the protein actin. The thick and thin filaments alternate with each other in a structure called a **sarcomere.** The sarcomere is the unit of contraction in a muscle cell. Contraction is stimulated by an electrochemical signal from a nerve cell associated with the muscle fiber. For a muscle cell to contract, the sarcomere must shorten. However, thick and thin filaments do not shorten. Instead, they slide by one another, causing the sarcomere to shorten while the filaments remain the same length. The combined activity of many binding sites and repeated movements within the sarcomere causes it to contract. The coordinated contractions of many sarcomeres in a myofibril leads to contraction of the entire muscle cell and ultimately the muscle itself. The movement of the myosin head requires ATP, made by the mitochondria, which provides the energy for the contraction.

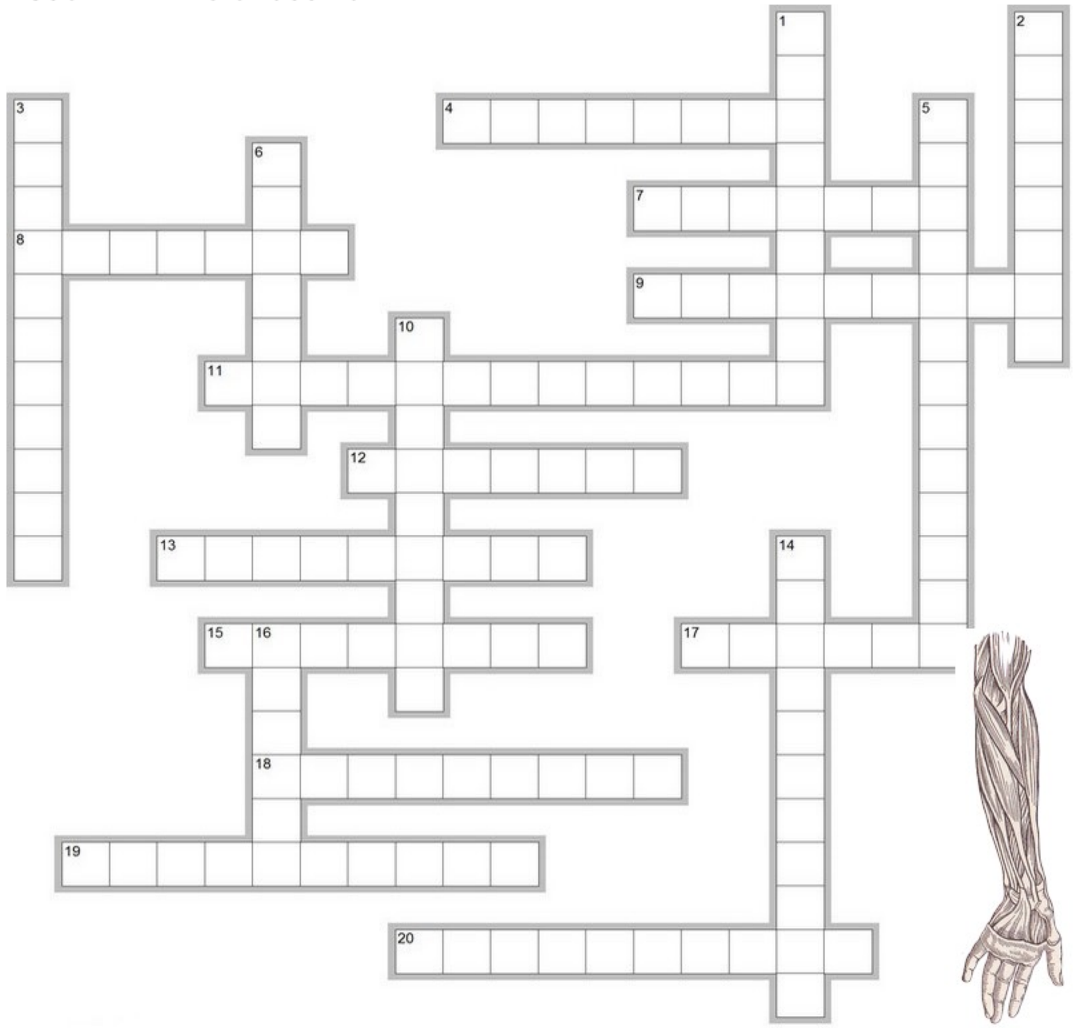


Muscle Fiber Structure. A skeletal muscle fiber is surrounded by a plasma membrane called the sarcolemma, with a cytoplasm called the sarcoplasm. A muscle fiber is composed of many fibrils packaged into orderly units. The orderly arrangement of the proteins in each unit, gives the cell its striated appearance (credit: Socratic.org, CC BY-NV-SA 4.0).

Activity 2. The Muscular System

Using the models displayed in the classroom and the illustration of the muscular system above, complete the crosswords game below:

MUSCLE NAMING CROSSWORD



ACROSS

4. Jaw, chewing
7. Front middle thigh, rectus __
8. Side muscles of the torso; external __
9. Extends fingers; extensor ___
11. located above the spine of the scapula
12. Shoulder muscle
13. forehead (epicranius)
15. Groin and inner thigh
17. flexor of the arm, two heads
18. Large upper back and neck muscle
19. Large middle back muscle
20. Chest muscles, major and minor

DOWN

1. Hip to inner knee
2. Front of the neck and chin
3. Cheek
5. Calf muscle
6. Rump muscle; ___ maximus
10. Outer thigh, one of the quadriceps; vastus ___
14. back of the head (epicranius)
16. Up and down on the abdomen (abdominus)

Credit: Biology Corner, CC BY-NC-SA 3.0).

Review Questions
1. What are the different parts of the skeletal system and their functions? 2. Provide an example for each: long bones, short bones, flat bones, and irregular bones, sutural bones and sesamoid bones. 3. What are the different types of joints? What type of movement do they allow? Provide examples for each. 4. Explain how bones are maintained and can change when under stress. 5. How are bones repaired? 6. How can osteoporosis be prevented? 7. What are the different types of muscles and their functions? 8. How are skeletal muscles named? 9. Provide a definition for muscle atrophy and hypertrophy. What do they result from? 10. What happens to dead muscle cells? 11. Describe the fine structure of muscle fibers and how it allows them to contract. 12. Explain why it is important to undergo some physical therapy exercises after a fractured bone, treated with immobilization in a cast, has healed