Lab 9
The Musculoskeletal System

Learning Objectives

- Compare and contrast hydrostatic skeletons, exoskeletons, and endoskeletons.
- Examine slides of compact bone and spongy bone found in a human long bone.
- Identify bones from the human axial and appendicular skeleton.
- Identify skeletal muscles from the human body.
- Discuss how muscles work as antagonistic pairs.
- Understand the structure of a sarcomere
- Discuss the role of ions and ATP in the contraction of sarcomeres.

Introduction

The musculoskeletal system in animals is necessary to provide support for the body, protect delicate internal organs, and allow the organism to move. There are three different types of skeletons that perform these functions. Soft-bodied invertebrates, particularly those which live in aquatic environments, have **hydrostatic skeletons**. Terrestrial invertebrates are more likely to have **exoskeletons**, with muscles attached to an external skeleton to create movement at joints. Vertebrate **endoskeletons** are composed of bones, cartilage, and ligaments; muscles are attached to the endoskeleton via tendons, and they contract to produce movement.

I. Animal Skeletons

The hydrostatic skeleton, formed by a fluid-filled cavity, is found in soft-bodied annelids, cniderians, and other invertebrates. Aqueous fluid in the hydrostatic skeleton provides a framework for the body, supporting the organs within the coelom and resisting external pressure. Pressure from muscle contractions around the coelom changes the shape of the coelom and produces movement.

An exoskeleton is a type of body frame found in corals, some mollusks, and arthropods. It is made of a hard encasement on the outer surface of the organism. This type of skeleton provides some defense against predation, supports the body, and allows movement via contractions from attached muscles. Arthropod exoskeletons are approximately 30-50% chitin, a polysaccharide derived from glucose, which is a strong yet flexible material. Chitin is secreted by the animal’s epidermal cells, and may be further reinforced by calcium carbonate (e.g., lobsters). Since the exoskeleton of an arthropod is acellular, it does not grow with the organism and must periodically be shed as the animal increases in size.

An endoskeleton is an internal body frame consisting of hard, mineralized structures within the soft tissue of animals. Endoskeletons support the body, protect internal organs, and allow movement via the contractions of attached skeletal muscles. The spicules of poriferans are one example of a primitive endoskeleton. Vertebrates have skeletons composed of true tissues, including living cells. Unlike arthropod exoskeletons, vertebrate endoskeletons grow with the organism and provide sites for blood cell production and mineral storage. The skeleton of many vertebrates is composed of two types of connective tissue: bone and cartilage.

Bone, also called osseous tissue, is a type of connective tissue that forms most of the endoskeleton in many vertebrates. It consists of specialized cells and an extracellular matrix of collagen fibers and mineral salts. Calcification is the process of depositing mineral salts formed from calcium phosphate on the collagen fibers, hardening the tissue. Calcification does not occur in the absence of collagen fibers.

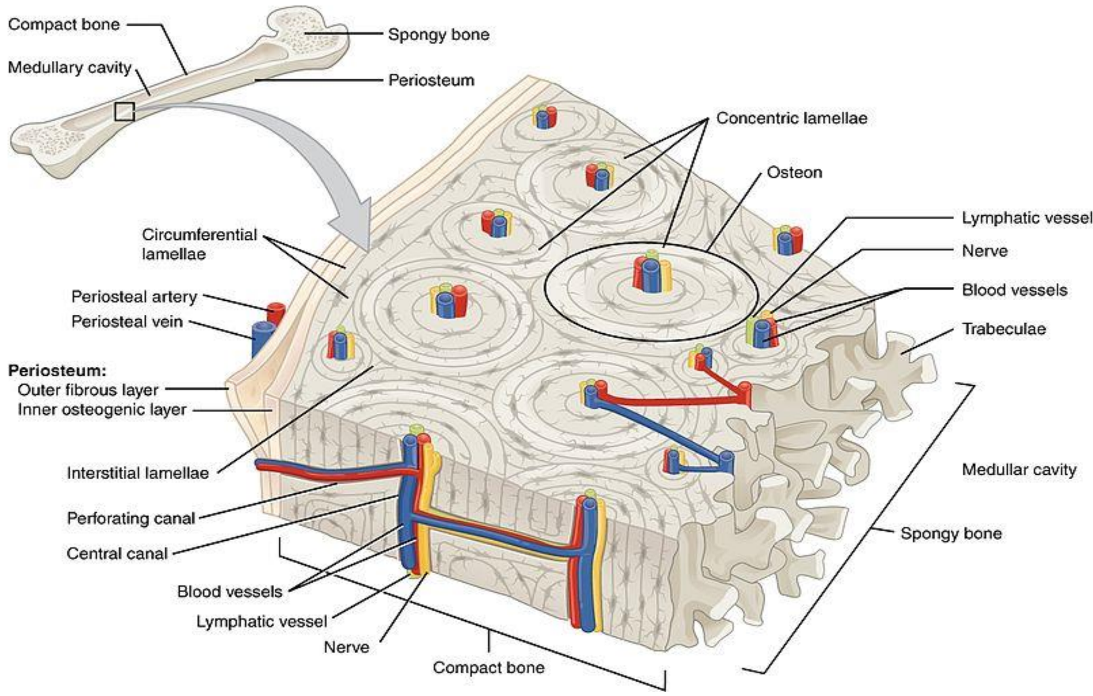


Figure 1. Compact bone vs. spongy bone. *(https://commons.wikimedia.org/wiki/File:605_Compact_Bone.jpg)*

Compact bone forms the hard, external layer of all bones and surrounds the bone marrow. Compact bone tissue is made of units called **osteons**, also known as Haversian systems. Osteons are cylindrical in shape and contain a calcified matrix and living cells called **osteocytes**. The osteocytes are fixed in their location within the matrix, in pockets called **lacunae**, and are connected to each other by canals called **canaliculi**. The canaliculi also connect the lacunae to the **central canal** in each osteon, which allows blood vessels and nerve fibers to run through the middle of each osteon.

Spongy bone, also known as cancellous bone, forms the inner layer of long bones. There are no osteons in spongy bone tissue; instead, spongy bone is made of **trabeculae** that are arranged to form bars or plates. Irregular spaces in spongy bone allow the ends of long bones to be compressed as a result of external stress. **Red bone marrow** is located between the trabeculae. Red blood cells, platelets, and most white blood cells are produced in red bone marrow. **Yellow bone marrow**, consisting mostly of fat, is found in the central cavities of long bones. Yellow bone marrow produces adipose tissue, cartilage, and bone.

Hyaline cartilage, the most prevalent of the three types of cartilage, forms the temporary embryonic skeleton of vertebrates, which is replaced by bone except in cyclostomes and cartilaginous fish. Hyaline cartilage is composed of specialized cells called **chondrocytes** in lacunae within a gel-like matrix. The matrix is primarily composed of collagen and chondroitin sulfate. In adults, hyaline cartilage is found on the ends of ribs, in the respiratory tract, nose, ears, and on the surfaces of bones at joints.

<u>Activity 1: Compact vs. Spongy Bone</u>

Materials:

Compact bone slides

Spongy bone slides

Procedure:

1. Examine the slides on 40X and sketch them in the table below.

Name of Specimen	Sketch (40X Objective)

II. The Human Skeleton

Bones in the human skeleton are classified by their shape. They may be **long bones**, **short bones**, **irregular bones**, **flat bones**, **sutural bones**, or **sesamoid bones**.

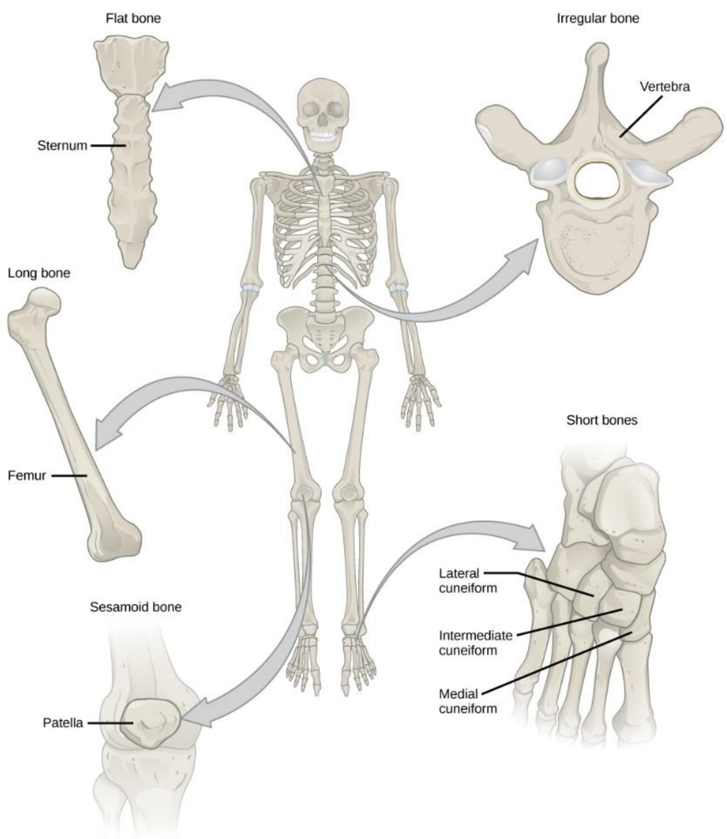


Figure 2. Types of bones found in the human skeleton.

(https://cnx.org/contents/GFy_h8cu@11.1:qmrJu64i@4/Bone)

Long bones, like the humerus and femur, are longer than they are wide and consist of a shaft and two ends. The central shaft contains bone marrow inside of a central cavity. The rounded ends are covered in hyaline cartilage and are filled with red bone marrow. Many bones in the arms and legs are long bones. **Short bones**, such as the carpals of the wrist or the tarsals of the ankle, may also be called cuboidal bones. These bones are approximately equal in width and length, giving them a boxy appearance. **Flat bones**, like the sternum and scapulae, are thin and somewhat broad in appearance. These bones are found in areas where extensive protection is required for underlying organs, or where broad surfaces are needed for muscle attachment. **Irregular bones**, such as the vertebrae, are bones with complex shapes. They may have surfaces that are short, flat, notched, or ridged. These bones are specialized for a particular function. **Sesamoid bones**, like the patella of the knee, are small and flat, similar in shape to a sesame seed. Sesamoid bones develop inside tendons and may be found near joints at the hands and feet as well as in the knee.

The vertebrate skeleton is divided into the **axial** and **appendicular skeletons**. The axial skeleton consists of the skull, vertebral column, and rib cage, whereas the appendicular skeleton is formed by the limbs, pectoral girdle, and pelvic girdle. The adult human endoskeleton is made of approximately 206 bones.

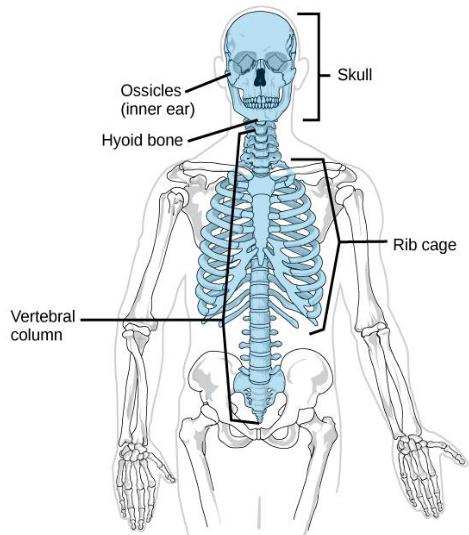


Figure 3. The bones of the axial skeleton. *(https://cnx.org/contents/GFy_h8cu@11.1:sw1Ot2vk@4/Types-of-Skeletal-Systems)*

The axial skeleton in humans is made up of 80 bones in six areas: the skull, the auditory ossicles, the hyoid, the rib cage, the sternum, and the vertebrae. The human skull can be divided into two regions. The **cranium** is the part of the skull that encases the brain. The **facial bones** form the features of the human face, surrounding the sensory organs and the entrances to the digestive and respiratory systems. The jaw bone that holds the lower row of teeth is known as the **mandibl**e. Inside the tympanic cavity of the middle ear are the three tiny auditory ossicles, bones that transfer mechanical sound waves from the tympanic membrane to the inner ear. The **hyoid** is located underneath the chin in the neck. It provides support for the tongue and is an attachment site for many muscles.

The **vertebral column** protects the spinal cord and can be divided into five regions: the **cervical vertebrae**, the **thoracic vertebrae**, the **lumbar vertebrae**, the **sacrum**, and the **coccyx**. Seven cervical vertebrae are located in the neck region, just below the skull. These vertebrae tend to be smaller than other types and are flexible to allow a wide range of head movement. Twelve thoracic vertebrae are each attached to one of the twelve pairs of ribs that form the rib cage. Thoracic vertebrae are more rigid than other types of vertebrae so they can provide a framework for the rib cage and protect underlying organs. The thoracic vertebrae are slightly larger than cervical vertebrae, but smaller than lumbar vertebrae. The five lumbar vertebrae are larger than thoracic or cervical vertebrae, because they must support more of the body's weight and allow for bending, twisting, and hip flexion. The sacrum, which forms part of the pelvis, is made up of five sacral vertebrae that fuse together. On the lower end of the sacrum is the coccyx, also known as the tailbone.

The ribcage protects the heart and lungs. It is composed of the **sternum**, a flat bone that runs down the front of the thoracic cavity, and twelve pairs of ribs. The first seven pairs of ribs attach directly through their individual costal cartilages to the sternum. Rib pairs 8 - 10 attach to the sternum indirectly through shared cartilage, whereas rib pairs 11 and 12 are floating ribs that are not attached to the sternum at all.

The appendicular skeleton consists of the bones of the upper and lower limbs, as well as the **pectoral** (shoulder) **girdle**, and the **coxal bones** of the pelvis. The pectoral girdle attaches the upper limbs to the axial skeleton. This region is composed of the **clavicles** and **scapulae**. Clavicles are S-shaped bones on the front of the thorax that position the arms. Scapulae, are flat, triangular bones that support the muscles of the shoulder. In the upper limbs, the **humerus** is the bone of the upper arm, whereas the framework of the forearm is provided by the **radius** and **ulna**. The short bones of the wrist are known collectively as **carpal bones**; long **metacarpal bones** extend from the carpals to form the frame of the hands. **Phalanges**, the bones of the fingers, are attached to the metacarpals at the knuckle joints.

In the **pelvic girdle**, the coxal bones attach directly to the sacrum of the axial skeleton, and provide a point of attachment for the **femurs** of the thigh. A sesamoid patella is found at each knee joint. Below the knee, the **tibia** and the **fibula** run parallel to each other through the leg. The short bones of the ankle joint are known as **tarsals**; long **metatarsal bones** extend from the tarsals to form the frame for most of the foot, and **phalanges** support the toes.

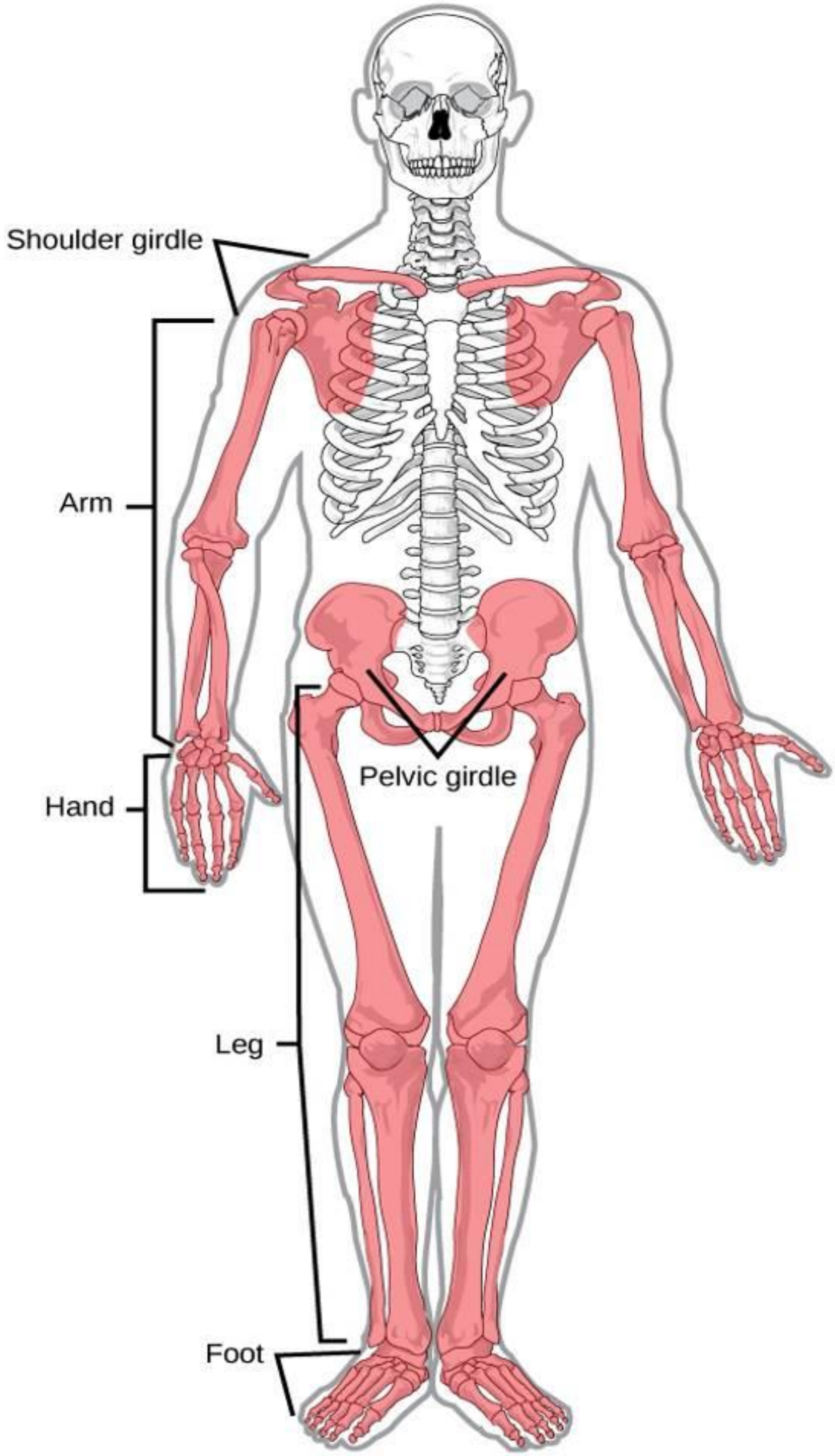


Figure 4. The bones of the appendicular skeleton.
(https://cnx.org/contents/GFy_h8cu@11.1:sw1Ot2vk@4/Types-of-Skeletal-Systems)

Activity 2: The Human Skeleton

Materials:

Individual bone models

Mini skeleton models

Procedure:

1. Locate the bones on the model and classify each as long, short, irregular, flat, or sesamoid.

Human Bones	Type of Bone
Skull	
Cranial bones	____________
Facial bones	____________
Hyoid	____________
Vertebral column	
Cervical vertebrae	____________
Thoracic Vertebrae	____________
Lumbar vertebrae	____________
Sacrum	____________
Coccyx	____________
Rib cage	
Ribs	____________
Sternum	____________
Pectoral girdle	
Clavicle	____________
Scapula	____________
Upper limbs	
Humerus	____________
Radius	____________
Ulna	____________
Carpals	____________
Metacarpals	____________
Phalanges	____________
Pelvic girdle	
Coxal bones	____________
Lower limb	
Femur	____________
Patella	____________
Tibia	____________
Fibula	____________
Tarsals	____________
Metatarsals	____________
Phalanges	____________

III. Vertebrate Muscles

Approximately 40% of human body mass is skeletal muscle. Skeletal muscle contracts voluntarily to allow body movement, stabilize posture, and produce facial expressions. By generating heat during contractions, skeletal muscle also plays a role in thermal homeostasis.

Motor neurons regulate the contractions of skeletal muscle, controlled by voluntary signals from the brain. Excitatory motor neurons release neurotransmitters that induce muscle contractions, whereas inhibitory motor neurons signal muscles to relax.

A muscle is composed of a group of cells called **muscle fibers** whose contraction causes movement. Because all of the muscle fibers in a muscle are parallel, a muscle contraction only generate force in one direction. Each muscle is composed of several **fascicles**, skeletal muscle fibers arranged in bundles surrounded by connective tissue.

Each muscle fiber is composed of **myofibrils**, which contain many **myofilaments**. The myofilaments are fibrous proteins, which can be divided into two types. **Thick filaments** are myofilaments composed of myosin, while **thin filaments** are myofilaments that are composed of actin. Each myofibril can be divided into a series of repeating units called **sarcomeres,** which are the functional units of skeletal muscle. One sarcomere is the space between two **Z-discs**, which anchor the actin filaments. The myosin filaments are attached to the **M-line** in the center of the sarcomere.

For a muscle cell to contract, the sarcomeres must shorten as actin and myosin filaments slide past each other. **Myosin heads** bind to actin in an ATP-dependent process, which pulls the actin inwards. The binding of ATP to myosin causes myosin to release actin. Myosin then hydrolyzes the ATP and remains in a high-energy state until excitatory motor neurons prompt another muscle contraction.

Skeletal muscle tissue has striations, which are visible due to the alternation of actin and myosin, along with other supporting proteins in the sarcomeres. Each sarcomere contains one dark **A-band** and two halves of an **I-band** on either side of the Z-disc. The A-band contains the entire length of myosin filaments, while the I-bands are the regions where actin filaments attached to the Z-discs. Most of the A-band appears as a dark region on a micrograph, because this region contains both actin and myosin filaments. In the middle of the A-band is a lighter region called the **H-zone,** which contains only the myosin filaments. The I-bands appear to be lighter than the A-band on a micrograph because they only contain actin filaments. The repetition of dark A-bands and light I-bands along the length of myofibrils and the alignment of myofibrils in the muscle fiber causes these cells to appear striated.

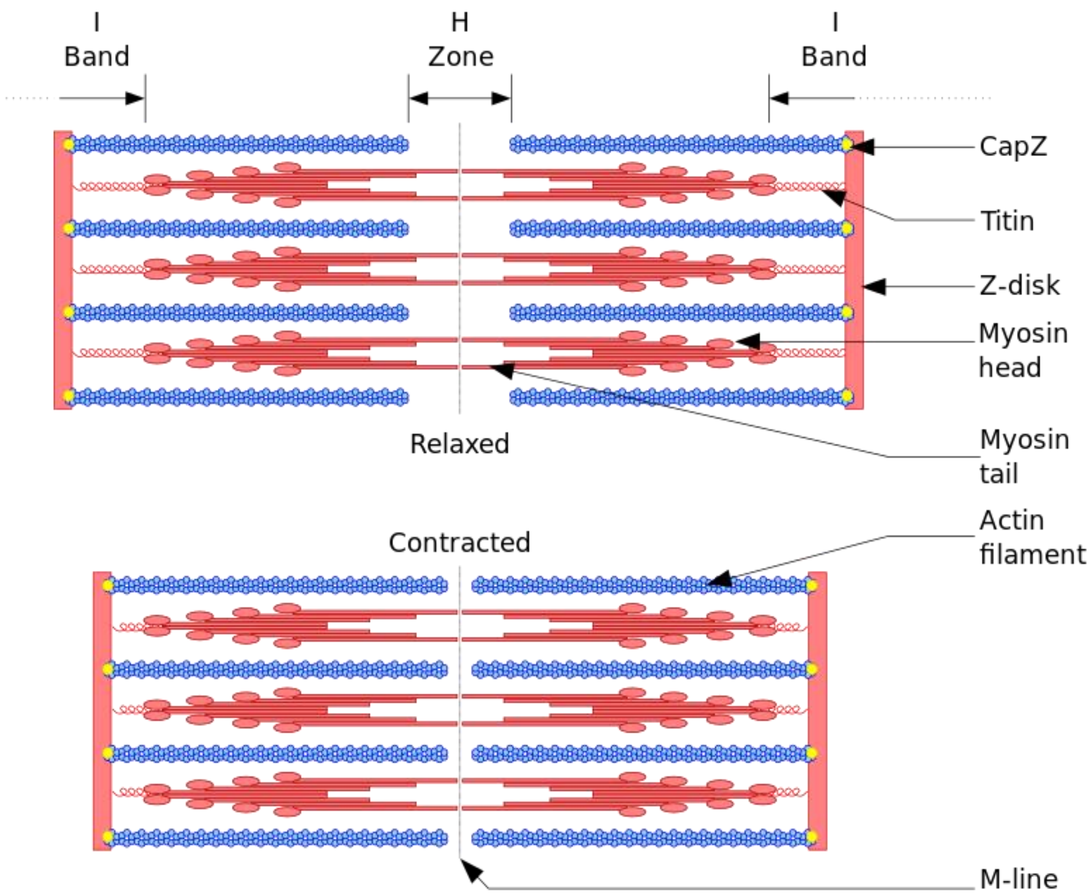


Figure 5. Relaxed sarcomere vs. contracted sarcomere.
(https://commons.wikimedia.org/wiki/File:Sarcomere.svg)

Skeletal muscles are attached to bones via tendons. Therefore, most muscles have at least two points of attachment, called the **origin** and **insertion**. The origin of a muscle is the point of attachment that does not move when the muscle contracts. The insertion is the attachment point that does move when the muscle contracts.

Muscles cause movement by contraction, which generates force in only one direction. **Antagonistic pairs** are pairs of muscles whose contractions create opposing movements. In order for one muscle in an antagonistic pair to contract, the other must elongate, and vice versa.

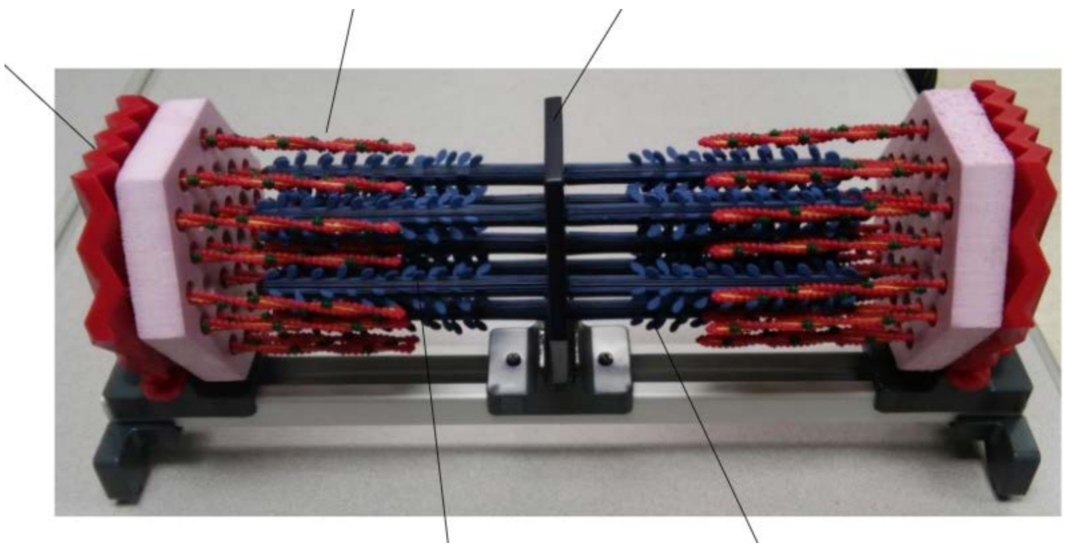
There are numerous types of movements which can be produced from muscle contractions. When muscle contractions move a limb further from the midline of the body, this type of movement is called **abduction**. **Adduction** occurs when muscle contractions move the limb closer to the midline of the body. **Extension** is a type of movement that increases the angle between the bones at a joint, whereas **flexion** decreases the angle between the bones.

Muscle contractions can be categorized into two types based on how the contraction affects the muscle: **isometric** and **isogenic** (isotonic). Isometric contractions generate force without changing the length of the muscle or producing movement at a joint. Holding a weight in a stationary position for a period of time is an example of an isometric contraction. Isogenic contractions generate force by changing the length of the muscle, which results in movement at a joint, and can be concentric or eccentric. Concentric contractions shorten muscles, because the force generated by the muscle contraction exceeds the external force. For example, lifting weights rely on a series of concentric contractions. However eccentric contractions elongate a muscle in response to a greater opposing force. This type of contraction would occur when lifting a weight that is too heavy.

Activity 3: The Sarcomere

Materials:
Sarcomere model

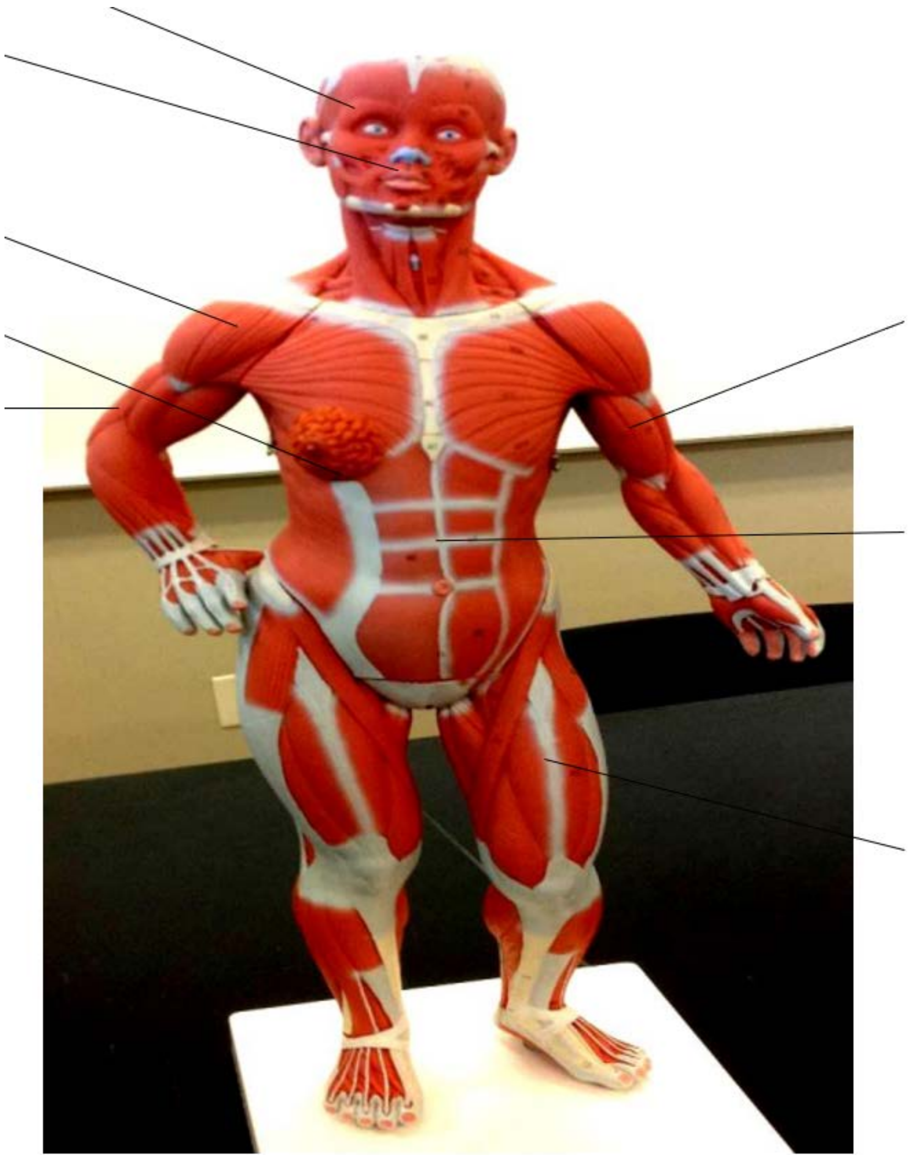
Procedure:
1. Identify the following structures on the model and label them on the picture below: sarcomere, Z-discs, M-line, actin filaments, myosin filaments, and myosin heads.



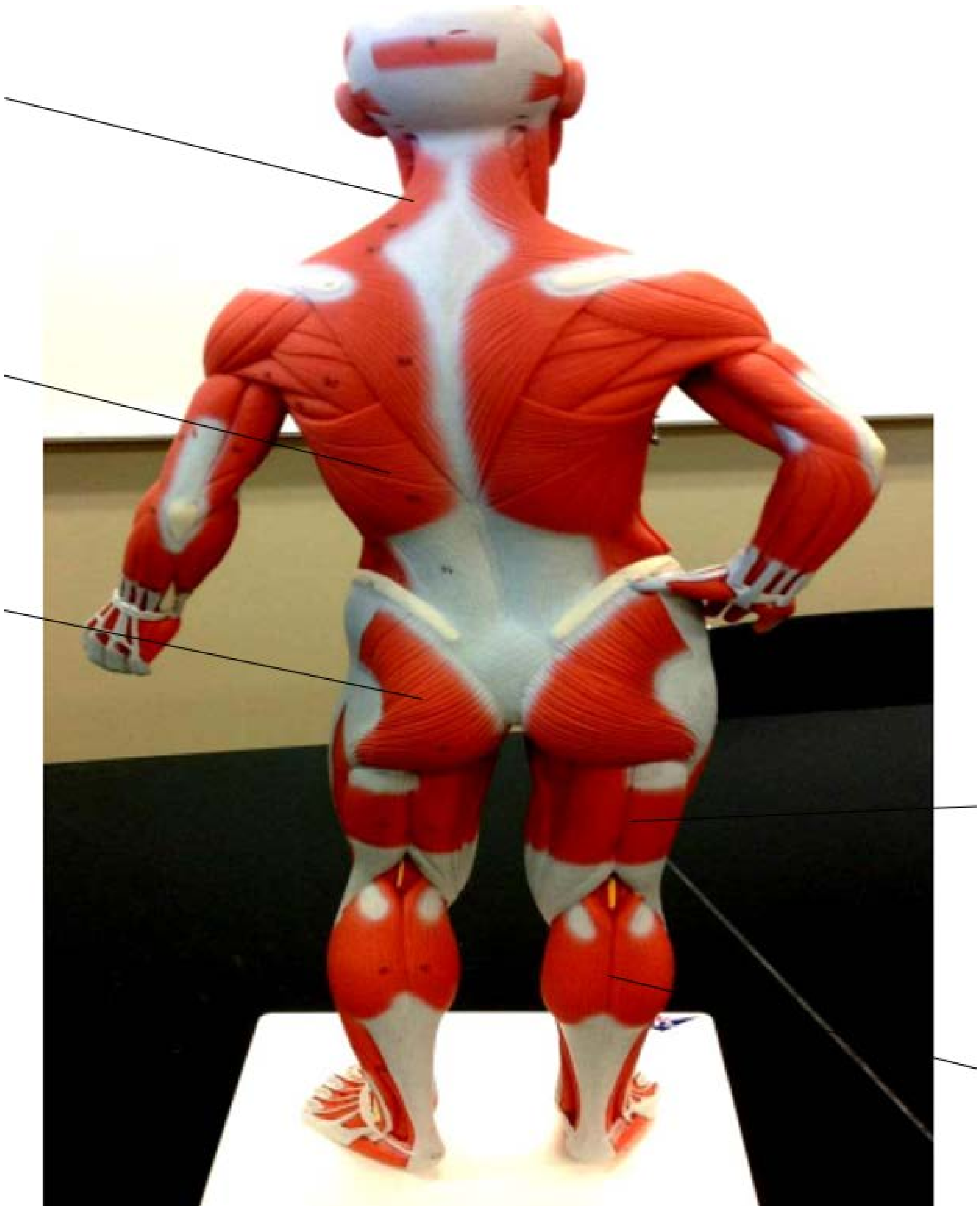
Activity 4: Human Muscles

Materials:
Mini muscle man models

Procedure:
1. Identify the following muscles on the model and label them on the picture below: orbicularis oculi, orbicularis oris, deltoid, pectoralis major, biceps brachii, triceps brachii, rectus abdominis, and quadriceps femoris.



2. Identify the following muscles on the model and label them on the picture below: trapezius, latissimus dorsi, gluteus maximus, hamstring, and gastrocnemius.



3. List the type of movement caused by each muscle in the action column below: abduction, adduction, flexion, or extension.

Human Muscles	Action
Deltoid	____________
Latissimus dorsi	____________
Biceps brachii	____________
Triceps brachii	____________
Quadriceps femoris	____________
Hamstring	____________

Activity 5: Isometric vs. Isogenic Contractions

Materials:
A textbook or other heavy object

Procedure:
1. Cover the right bicep brachii with the left hand.
2. Hold a textbook or other heavy object in a stationary position in front of your body. Notice that the shape of the biceps brachii remains constant. This is an example of an isometric contraction.
3. Now flex the biceps brachii muscle to bring the object closer to our body. Notice that the biceps brachii shortens during flexion. This is an example of a concentric muscle contraction.

Review Questions

1. What type of skeleton is found in cniderians?

2. Vertebrate endoskeletons are composed of __________________________, ________________________, and ______________________________.

3. Why do arthropods have to shed their exoskeleton periodically?

4. Approximately how many bones are in the adult human endoskeleton?

5. What category to these bones belong to, based on their shapes?
   a. Radius __________________________
   b. Lumbar vertebra _________________
   c. Scapula _________________________
   d. Patella __________________________
   e. Carpal bones _____________________

6. What are the two regions of the skull?

7. Are skeletal muscle contractions voluntary or involuntary?

8. What causes skeletal muscle to appear striated?

9. ________________________ are the functional units of skeletal muscle.

10. What is the difference between the origin and the insertion of a skeletal muscle?