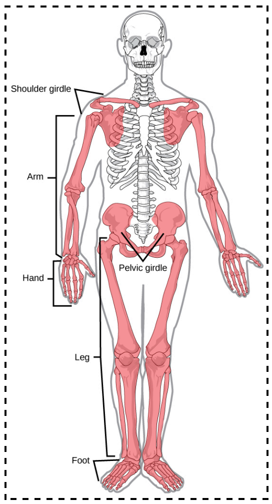
Chapter 2: The Musculoskeletal System

Objectives

1. Name and describe the 3 types of skeletons found in invertebrates
2. Define vertebrate, vertebral column
3. Name the 2 divisions of the vertebrate skeleton
4. List the bones associated with each of the 2 divisions of the vertebrate skeleton
5. Locate the major structures and bones on a diagram of a human skeleton
6. Name and describe the cells and components of the ECM in bone tissue
7. Define spongy bone, compact bone, osteon, red bone marrow, yellow bone marrow
8. Locate the structures in #7 above on a diagram of a bone
9. Explain the process of bone formation
10. Explain how bones are used to regulate blood calcium levels
11. Define osteoporosis and describe how to prevent it
12. Define joint, fibrous joint, cartilaginous joint, synovial joint, ligament, sprain, torn meniscus, dislocation, arthritis, tendon
13. Name and describe the 2 types of arthritis
14. Define muscle fiber, myofibril, sarcomere, thick filament, thin filament, myosin, actin
15. Order the structures of a muscle (listed above in #14) from largest to smallest or smallest to largest)
16. Explain broadly how muscle contraction happens
17. Explain in detail the steps of the sliding filament model, using the terms in #14, as well as how ATP and calcium are involved.

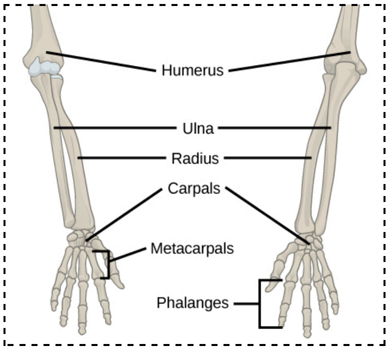
Types of Skeletal Systems

- 2.1a: Hydrostatic Skeleton - a skeleton formed by a fluid-filled compartment within the body (coelom); soft
  - Coelom organs are supported by aqueous fluid that also resists external compression
  - This compartment is under hydrostatic pressure because of the fluid and supports the other organs of the organism
  - Found in soft-bodied animals
  - Movement
    - Provided by muscles around the coelom
    - Muscles of the hydrostatic skeleton contract to change coelom's shape
      - Fluid pressure in the coelom produces movement
- 2.1b: Exoskeleton - an external skeleton that consists of a hard encasement on the surface of an organism; crunchy
  - Provides defense, supports the body, allows for movement through contraction of attached muscles
  - As with vertebrates, muscles must cross a joint inside the exoskeleton
    - Shortening of the muscle changes the relationship of the 2 segments of the exoskeleton
  - Arthropods' exoskeletons are made of chitin—a polysaccharide derivative of glucose that is a strong but flexible material, secreted by the epidermal cells
    - Further strengthened by calcium carbonate
  - Exoskeletons are acellular, so the organism must shed as it grows
- 2.1c: Endoskeleton - a skeleton that consists of hard, mineralized structures located within the soft tissue of organisms; the ones humans have
  - Ex.: spicules of sponges
    - The bones of vertebrates are made of tissue whereas sponges have no tissue
  - Endoskeletons provide support, protect internal organs, , allow movement through contraction of muscles attached to the skeleton
  - Divided into axial and appendicular skeletons
    - Axial → the skull, vertebral column, and rib cage
    - Appendicular → the shoulders, limb bones, the pectoral girdle, and the pelvic girdle
  - Chordate - animal with a notochord, including humans (briefly)
    - Notochord - cylinder of support of dense tissue; part of the endoskeleton
    - Replaced by vertebral column but persists as pads between vertebrae

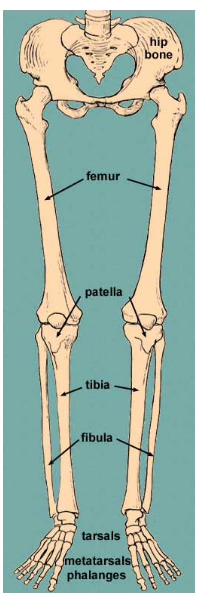


- 2.1d: Human Axial Skeleton - forms the central axis of the body and includes the bones of the skull, ossicles of the middle ear, hyoid bone of the throat, vertebral column, and the thoracic cage (ribcage); provides support and protection for the brain, spinal cord, and the organs in the ventral body cavity
  - Rib - one of 12 pairs of long, curved bones that attach to the thoracic vertebrae and curve toward the front of the body to form the ribcage
  - Provides a surface for the attachment of muscles that move the head, neck, and trunk
  - Performs respiratory movements
  - Stabilizes parts of the appendicular skeleton

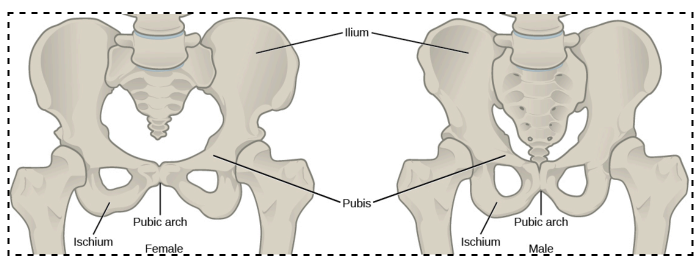
- <u>Pectoral Girdle</u> - provide the points of attachment of the upper limbs to the axial skeleton
    - In humans, it's made of clavicle/collarbone in the anterior and the scapula/shoulder blades in the posterior
        - <u>Clavicle</u> - S-shaped bones that position the arms on the body; lie horizontally across the front of the thorax/chest above the first rib
            - Fairly fragile and susceptible to fractures
            - Articulates with the sternum and the scapula
        - <u>Scapulae</u> - flat, triangular bones that are located at the back of the pectoral girdle; support the muscles crossing the shoulder joint
            - A ridge—called a <u>spine</u>—runs across the back of the scapula; can be felt under the skin
                - Good example of a bony protrusion that facilitates a broad area of attachment for muscles to bone



- <u>Upper Limb</u> - contains 30 bones in 3 regions: the arm (shoulder to elbow), the forearm (ulna and radius), and the wrist and hand
    - <u>Articulation</u> - any place at which two bones are joined
    - <u>Humerus</u> - largest and longest bone of the upper limb and the only bone of the arm; articulates with the scapula at the shoulder and with the forearm at the elbow
    - <u>Forearm</u> - extends from the elbow to the wrist and consists of two bones: the ulna and the radius
    - <u>Radius</u> - located along the lateral (thumb) side of the forearm and articulates with the humerus at the elbow
    - <u>Ulna</u> - located on the medial aspect (pinky-finger side) of the forearm; articulates with the humerus at the elbow
        - Longer than the radius
        - The radius and ulna also articulate with the carpal bones and with each other, which in vertebrates enables a variable degree of rotation of the carpus with respect to the long axis of the limb
    - <u>Hand</u> - includes the carpus, metacarpus, and phalanges
        - <u>Carpus</u> - wrist
        - <u>Metacarpus</u> - palm
        - <u>Phalanges</u> - digits
            - Each digit has 3 phalanges; thumb only has 2

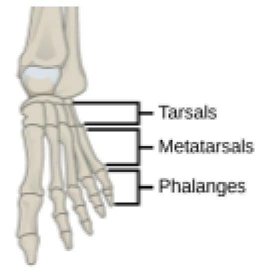


- <u>Pelvic Girdle</u> - attaches to the lower limbs of the axial skeleton; responsible for bearing the weight of the body and for locomotion, attached by strong ligaments
    - Has deep sockets with robust ligaments to attach the femur to the body
    - Strengthened by 2 large hip bones: coxal bones (in adults)
        - <u>Coxal Bones</u> - formed by the fusion of three pairs of bones: the ilium, ischium, and pubis
    - The pelvis joins 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
    - Female vs. Male Pelvises
        - Females with a wider pubic angle and larger diameter pelvic canal reproduced more successfully



- <u>Lower Limb</u> - made of the thigh, leg, and foot; the femur (thigh bone), patella (kneecap), tibia and fibula (bones of the leg), tarsals (bones of the ankle), and metatarsals and phalanges (bones of the foot)
    - Thicker and stronger than that of the upper limb to support body weight
    - <u>Femur</u> - AKA thighbone; longest, heaviest, and strongest bone in the body
        - The femur and pelvis form the hip joint at the proximal end
        - At the distal end, the femur, tibia, and patella form the knee joint

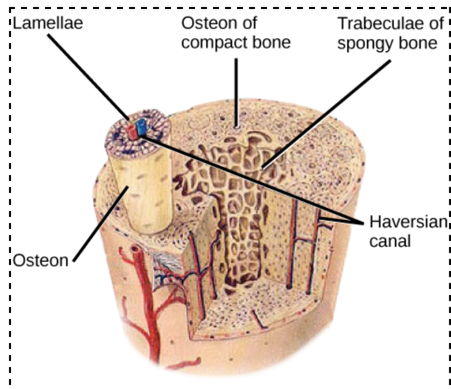
- Patella - AKA kneecap; a triangular bone that lies anterior to the knee joint embedded in the tendon of the femoral extensors (quadriceps) and improves knee extension by reducing friction
- Tibia - AKA shinbone; a large bone of the leg that is located directly below the knee; articulates with the femur at its proximal end, with the fibula and the tarsal bones at its distal end
  - Second largest bone in the human body and is responsible for transmitting the weight of the body from the femur to the foot
- Fibula - AKA calf bone; parallels and articulates with the tibia; acts as a site for muscle attachment and forms the lateral part of the ankle joint
- Tarsals - the 7 bones that make up the ankle; transmits the weight of the body from the tibia and the fibula to the foot
- Metatarsals - the 5 bones that make up the foot
- Phalanges - the 14 bones of the toes
  - Each toe consists of three phalanges, except for the big toe that has only 2

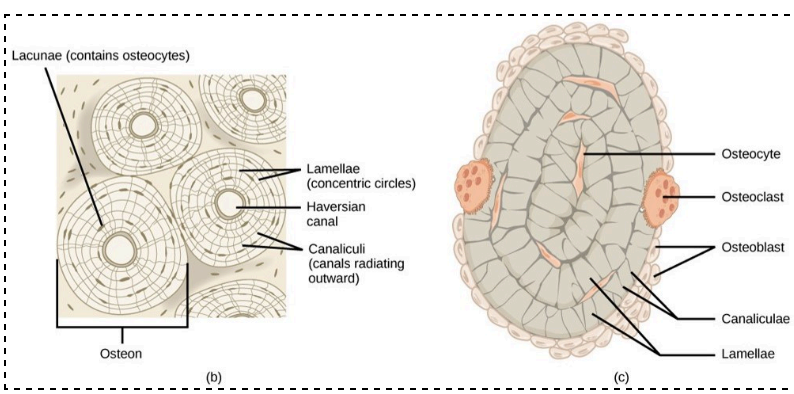


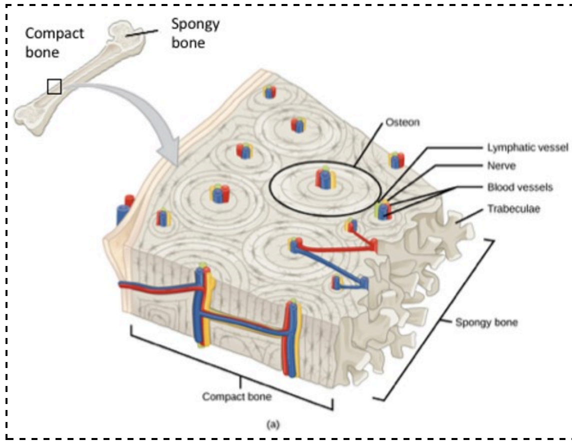
Bone

➢ 2.2 Introduction
  - Bone/Osseous Tissue - connective tissue that constitutes the endoskeleton, containing specialized cells and a matrix of mineral salts and collagen fibers; covered in a layer of dense irregular connective tissue that allows bones to change shape
    - Mineral salts primarily include hydroxyapatite, a mineral formed from calcium phosphate
  - Calcification - the process of deposition of mineral salts on the collagen fiber matrix that crystallizes and hardens the tissue; only occurs in the presence of collagen fibers

➢ 2.2a: Bone Tissue
  - Bones are considered organs because they contain various types of tissue, such as blood, connective tissue, nerves, and bone tissue
  - Osteocytes—living cells of bone tissue—form the mineral matrix of the bones
  - 2 types of bone tissue: compact and spongy
    - Compact Bone (A) - forms the hard external layer of all bones and surrounds the medullary cavity, or bone marrow; provides protection and strength to bones
      - Made of osteons/Haversian systems, cylindrical structures that contain a mineral matrix and living bone cells connected by *canaliculi*
      - Canaliculi - transport nutrients between cells; aligned parallel to the long axis of the bone and made of *lamellae*
      - Lamellae - layers of compact matrix that surround a *central canal*
      - Central Canal - contains the bone's blood vessels and nerve fibers







- Spongy Bone (B) - forms the inner layer of all bones; doesn't have osteons
  - Made of trabeculae, which are lamellae, arranged as rods or plates
    - Red bone marrow is found between the trabeculae
    - Blood vessels within this tissue deliver nutrients to osteocytes and remove waste
    - The red bone marrow of the femur and the interior of other large bones, such as the ileum, forms blood cells

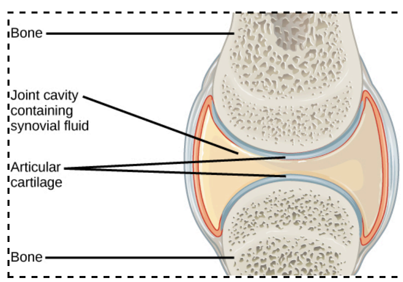
➢ 2.2b: Cell Types in Bones (C)
- Osteoclasts - large bone cells with up to 50 nuclei; remove bone structure by releasing lysosomal enzymes and acids that dissolve the bony matrix
  - Minerals released from bones into the blood help regulate calcium concentrations in body fluids
  - Bone may also be resorbed for remodeling, if the applied stresses have changed
- Osteoblasts - on surface of bones bone cells that are responsible for bone formation. Osteoblasts synthesize and secrete the organic and inorganic part of the extracellular matrix of bone tissue, and collagen fibers; become trapped in these secretions and differentiate into less active *osteocytes*
  - After an osteoblast surrounds itself, it becomes an osteocyte
- Osteocytes - inside bone; mature bone cells and are the main cells in bony connective tissue; these cells cannot divide; maintain normal bone structure by recycling the mineral salts in the bony matrix
- Osteogenic - on surface of bones; STEM cells that replace tissue

➢ 2.2c: Development of Bone
- Ossification/Osteogenesis - process of bone formation by osteoblasts
  - Differs from calcification in that ossification begins approximately six weeks after fertilization in an embryo; calcification can take place in other organs
    - Before this time, the embryonic skeleton consists entirely of fibrous membranes and hyaline cartilage
- Intramembranous Ossification - development of bone from fibrous membranes
- Endochondral ossification - development from 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

Joints and Skeletal Movement

➢ 2.3a Introduction
- Joint/Articulation - point at which two or more bones meet
  - Responsible for movement, such as the movement of limbs, and stability, such as the stability found in the bones of the skull

➢ 2.3a: Classification of Joints on the Basis of Structure

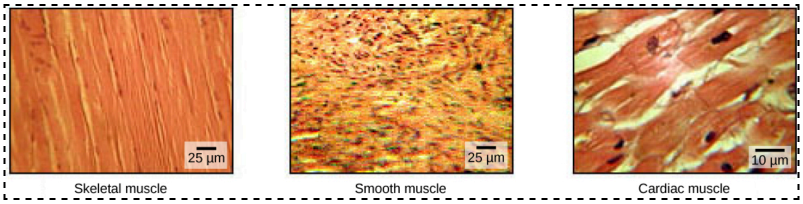


- Classified on the basis of their structure or on the basis of their function
- Fibrous Joints - held together by fibrous connective tissue
  - No cavity, or space, present between the bones and so most fibrous joints do not move at all, or are only capable of minor movements
- Cartilaginous Joints - the bones are connected by cartilage
- Synovial Joints - have a space between adjoining bones (only kind of joints like this)
  - Synovial/Joint Cavity - the space between the bones

- Full of synovial fluid that lubricates the joint, reducing friction between the bones and allowing for greater movement
  - The ends of bones are covered with articular cartilage, a hyaline cartilage which allows movement of the joint while resisting dislocation
  - Articular capsules may also possess ligaments that hold the bones together
  - The more mobile a joint, the weaker

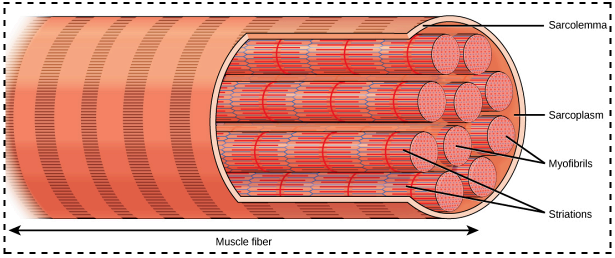
Muscle Contraction and Locomotion

- ➢ 2.4 Introduction
  - When 2 muscles are on opposite sides, they move in opposition
    - Agonist - contract
    - Antagonist - stretch

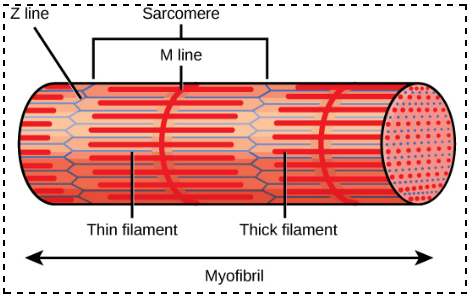


Skeletal muscle Smooth muscle Cardiac muscle

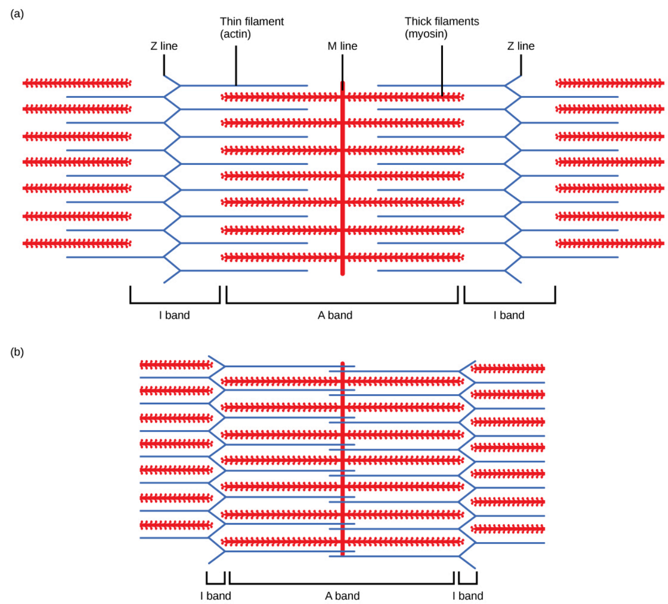
  - Skeletal Muscle Tissue - attached to bones or skin and control locomotion and any movement that can be consciously controlled
    - Voluntary muscles
    - Long and cylindrical in appearance
    - When viewed under a microscope, skeletal muscle tissue has a striped or striated appearance
      - Caused by actin—a globular contractile protein that interacts with myosin for muscle contraction
  - Smooth Muscle Tissue - occurs in the walls of hollow organs such as the intestines, stomach, and urinary bladder, and around passages such as the respiratory tract and blood vessels
    - Involuntary
    - No striations
    - 1 nucleus per cell
    - Tapered at both ends
  - Cardiac Muscle Tissue - only found in the heart
    - Cardiac contractions pump blood throughout the body and maintain blood pressure
      - Involuntary
      - Striated
      - 1 nucleus per cell
      - Has intercalated disks
- ➢ 2.4a: Skeletal Muscle Fiber Structure
  - Each skeletal muscle fiber is a skeletal muscle cell which are very large



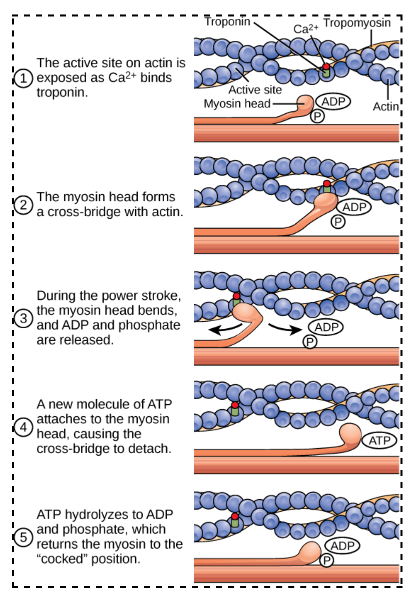
    - Sarcolemma - plasma membrane of skeletal muscle fiber
      - The site of action potential conduction, which triggers muscle contraction
    - Myofibrils - long cylindrical structures that lie parallel to the muscle fiber
      - Runs the entire length of the muscle fiber, and because they are only approximately 1.2 µm in diameter, hundreds to thousands can be found inside one muscle fiber
      - Attaches to the sarcolemma at their ends, so that as myofibrils shorten, the entire muscle cell contracts
      - Made of many *sarcomeres*, thick filaments, and thin filaments
        - As the sarcomeres individually contract, the myofibrils and muscle cells shorten
        - Thick Filaments - composed of the protein myosin
          - The tail of a myosin molecule connects with other myosin molecules to form the central region of a thick filament near the M line, whereas the heads aligned on either side of the thick filament where the thin filaments overlap
        - Thin Filaments - composed of the protein actin



                - Strands of tropomyosin block the binding sites and prevent actin–myosin interactions when the muscles are at rest
                    - Troponin - made of 3 globular subunits: one that binds to tropomyosin, actin, and Ca^{2+} ions
            - Striations come from repeating bands of actin and myosin that are present in the myofibrils



- ➢ 2.4b: Sliding Filament Model of Contraction
    - Sarcomeres must shorten to contract a muscle
    - However, thick and thin filaments do not shorten; they slide by one another
    - The sliding filament theory of muscle contraction was developed to fit the differences observed in the named bands on the sarcomere at different degrees of muscle contraction and relaxation
            - The mechanism of contraction is the binding of myosin to actin, forming cross-bridges that generate filament movement
        - When a sarcomere shortens, some regions shorten whereas others stay the same length
            - Sarcomere - makes up microfibrils; defines as the distance between 2 consecutive Z disks/lines
- ➢ 2.4c: ATP and Muscle Contraction (video)
    - The motion of muscle shortening occurs as myosin heads bind to actin and pull the actin inwards which requires energy provided by ATP
    - Myosin is the key as it has a binding site for the globular actin protein and ATP
        - ATP binding causes myosin to release actin, allowing actin and myosin to detach from each other
        - The newly bound ATP is converted to ADP and inorganic phosphate (P_i)
            - The enzyme at the binding site on myosin is called ATPase
        - Energy released during ATP hydrolysis changes the angle of the myosin head to a "cocked" position
            - Positioned for further movement and potential energy in a high-energy configuration
                - Energy is expended as the myosin head moves through a power stroke
                - By the end of the power stroke, the myosin head is in a lower-energy position again
            - ADP and P_i are still attached
        - If the Actin Sites Are Left Uncovered…
            - A cross-bridge—the myosin head spans the distance between the actin and myosin molecules—forms
            - P_i is released, allowing myosin to expend the stored energy as a conformational change
            - The myosin head moves toward the M line, pulling the actin along with it
            - A power stroke—as the actin is pulled, filaments move 10 nm toward the M line—occurs
            - After the power stroke, ADP is released; however, the cross-bridge formed is still in place, and actin and myosin are bound together



            - ATP can then attach to myosin, which allows the cross-bridge cycle to start again and further muscle contraction can occur

- 2.4d: Regulatory Proteins
    - A muscle in a resting state separates actin and myosin
    - To keep actin from binding to the active site on myosin, regulatory proteins block the molecular binding sites
        - Tropomyosin - blocks myosin binding sites on actin molecules, preventing cross-bridge formation and preventing contraction in a muscle without nervous input
        - Troponin - binds to tropomyosin and helps to position it on the actin molecule; it also binds Ca^{2+} ions
    - Enabling Muscle Contraction
        - Involves conformation of tropomyosin which uncovers the myosin-binding site on an actin molecule, enabling a cross-bridge to form
        - Can only happen in the presence of Ca which is kept in low concentrations in the sarcoplasm
        - Ca^{2+} ions are released when a signal from a neuron reaches the muscle fiber
        - Ca^{2+} ions bind to troponin, causing conformational changes in troponin that allow tropomyosin to move away from the myosin binding sites on actin
        - Once the tropomyosin is removed, a cross-bridge can form between actin and myosin, triggering contraction
        - Continues until ions and ATP aren't available, and tropomyosin covers the binding site on actin