Summary: Locomotion

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1 Overview: Locomotion

When an animal isn't moving, it is kept in place through two forces: gravity and friction. When an organism overcomes these forces and moves, an organism engages in **locomotion**, or active travel from one place to another. Regardless of implementation details that differ between organisms, all types of locomotion require the movement of protein strands against each other. This behavior is demonstrated in avrious organisms and environments, such as:

- **Acquatic** animals: due the density of the water encompassing their natural environment, these organisms need not hastily concern themselves with overcoming the force of gravity, but, rather, friction.
- **Terrestrial** animals: due to the lack of support provided by air, terrestrial organisms must expend energy to counter the force of gravity, and, additionally, friction with respect to the ground.
  - Walking animals
    - Bipedal animals: utilize just two limbs (legs) in maintaining balance, maintaining contact with the ground on at least one foot, but lack the stability of their quadrapedal or tripedal equivalents
    - Quadrapedal animals: constantly utilize at least three feet in maintaining balance
    - In both quadrapedal and bipedal animals, momentum plays an important part in the persistence of balance while running
  - Hopping animals
    - Kangaroos: travel by generating power in hind leg muscles, and by storing energy in connected tendons
  - Crawling animals
    - Energy expenditure is focused towards friction
    - Snakes: entire body is undulated from side to side
    - Earthworms: perform a sequence of muscle contractions from head to tail (**peristalsis**)
  - Flying animals (i.e., birds, bats, and various invertebrates)
    - Energy expenditure is focused towards combating gravity and developing "lift."
    - Capability is reliant on airfoil-like wing structures that create lift, inducing an air pressure different conducive to flight

2 Role of the Skeletal system in locomotion

2.1 Hydrostatic Skeletons

The **hydrostatic skeleton** is one of the three commonly cited types of skeletons (i.e., hydrostatic skeletons, exoskeletons, and endoskeletons), and it consists of the pressurized enclosure of fluid in a compartment. This structure can be differentiated widely from its external and internal counterparts, but is commonplace in both terrestrial and aquatic animals, who each share various similarities:

- Flexibility and a soft texture
- Burrowing or crawling behaviors via peristalsis

Though they share similiar behaviors and generalized structures, the various organisms that utilize this form of skeleton build upon the functional base of a hydrostatic skeleton in unique ways. Earthworms, for example, are capable of persitalsis by forcing circular and longitudal muscles to work "against" their skeletons. Hydras and jellies, on the other hand, are capable of modifying their body shape through the exertion of pressure.

Hydrostatic skeletons are ill-suited for terrestrial animals whose modes of locomotion mimic that of humans (i.e., above-ground movement akin to walking).

2.2 Differences between Exoskeletons and Endoskeletons

The term "invertebrate" or "vertebrate" is often used to describe various organisms. These terms are used to describe organisms with **exoskeletons** and **endoskeletons**, respectively. The central difference with respect to these two types of skeletons lies in the location of the skeleton: in exoskeleton systems, the entire system lies outside of the body, while in endoskeleton systems, the system lies inside the body. Furthermore, in contrast to vertebrates, invertebrates are not capable of growing alongside their skeletons, and, thus, "shed" or **molt** their exoskeletons at regular intervals. By comparison, in vertebrates, skeletal systems are typically composed of cartilage or bone, rather than *strictly* inorganic, static material, thus mitigating a need for "shedding" behaviors.

Figure 1: The skeletal system of a frog

2.3 Common Components of Vertebrate Skeletons

In all vertebrates, there exist several components in a skeletal system:

- An **axial skeleton**: the "trunk" of the body, consisting of the:
  - Skull: protects the brain
  - Backbone: consists of disc-conjoined vertebrae (i.e., 24 cartilage pade-conjoined vertebrae in humans, and 400 in pythons), comprising various regions of the vertebral column:
    - Cervical / neck: supports the head
    - Thoracic / chest: forms joints with the ribs
    - Lumbar / lower back

    * Sacral / between the hips
    * Cocygeal / tail
  - Commonly, rib cage
- An **appendicular skeleton**: anchors appendages (e.g., legs and arms) to the axial skeleton

2.4 The structure of a bone

In endoskeletal systems, bones are living—that is, they are comprised by various living tissues:

- Coating fibrous connective tissue: allows for the formation of a newpagebone in a fracture
- Cushioning cartialage: protects bones as they glide past each other
- Various **matrix**-secreting constituent living cells
- **Bone matrix**: protein collagens that keep the bone flexible and a collection of compression-resistent minerals
- **Yellow bone marrow**: stored fat delivered by way of blood
- **Red bone marrow**: produces blood cells

3 Functional actors in locomotion

3.1 Joints

A **join** is defined as "a point at which parts of an artificial structure are joined." In endoskeletal systems, **ligaments**, fibrous connective tissue, are utilized in various bone-connected movable joints:

- **Ball-and-socket joints**: enable the rotation of arms and legs, and are found where the humerus joins the pectoral girdle
- **Hinge joints**: permit movement about a plane (e.g., elbows and knees)
- **Pivot joints**: permits side-to-side movement

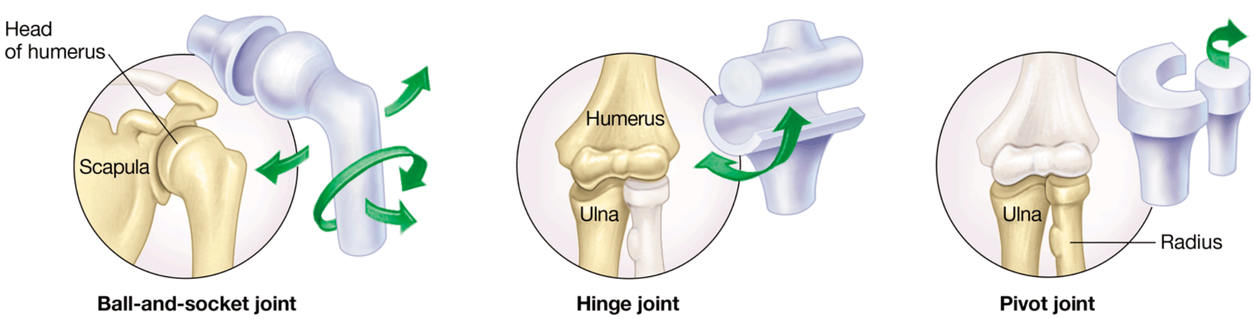

Figure 2: The three kinds of joints

3.2 Muscles

Muscles aid in locomotion through their innate tendencies to contract and normalize with respect to **tendon** connections. At these connections, muscles are attached to bones, introducing a fixed tendency to perform these actions, respectively.

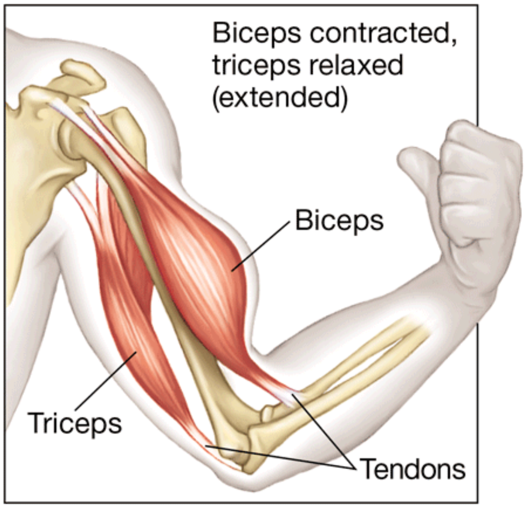

Figure 3: Antagonistic action of muscles in the human arm

The aformentioned function of muscles is achieved through the utilization of various **muscle fibers**, which are, in turn, comprised by myofibril protein bundles containing **actin** and **myosin**.

These filaments are composable, and can be arranged in various ways. Among others, **thin filaments**, or actin molecule-comprised banding is one such example often found in the sacromere—a single unit of the aforementioned "protein bundles." **Thick filaments**, by contrast, are composed of myosin molecules. Each of these filaments serve distinct functions in locomotion. More specifically, the contraction of the sarcomere—the structural unit of a muscle fiber comprised by each of these filaments—is dependent on the sliding of the aformentioned thin filaments against thick filaments.

In other words, as a muscle contracts, the following events occur:

1. Myosin, the "engine of movement" in contraction, remains in its low-energy position
2. Energy is released as the aforementioned myosin molecule hydrolyzes ATP
3. The excited myosin molecule binds to actin, causing the filament to move in the desired direction
4. The myosin molecule returns to its initial state once an ATP molecule binds to the myosin molecule's head

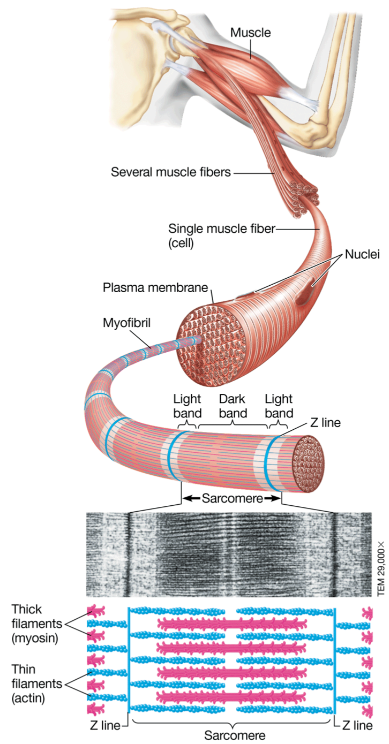

Figure 4: The contractile apparatus of skeletal muscle

The aforementioned process is both reliant on both myosin's various bindings sites and its ability to hydrolyze ATP, and will repeat until it is signaled to terminate, or it has fulfilled its purpose (i.e., to fully contract the targeted muscle).

3.2.1 Activation of Muscles

As are many other effector cells, muscles are "activated" through the generation of an action potential. More specifically, the secretion of acetylcholine, a neurotransmitter, prompts the triggering of such a potential as it crosses the plasma membrane. However, in contrast to many other effector cells and neurons, tropomyosin and troponin molecules prevent myosing molecules from binding to actin molecules, such that they are prevented from entering the active state whereby the muscle is contracted. Once Ca^{2+} binds to the aformentioned troponin molecule, contraction is permitted. This process is restarted once an action potential is terminated.

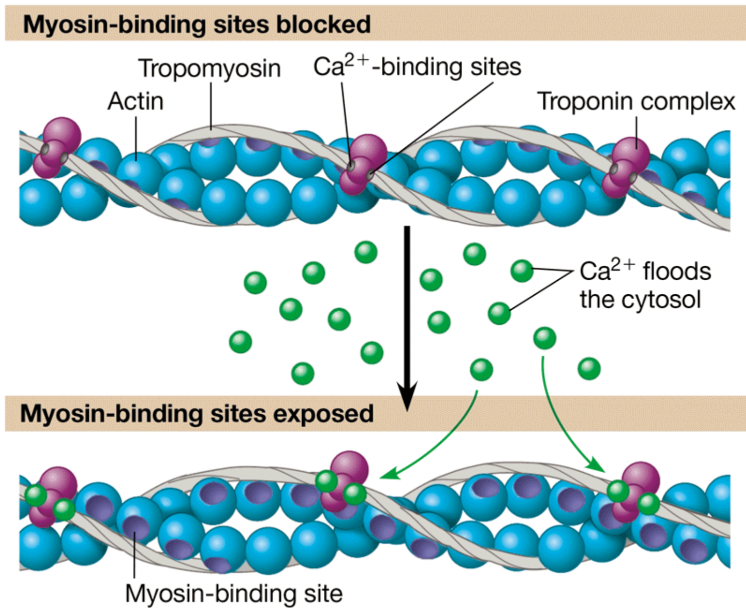

Figure 5: Thin filament, showing the interactions among actin, regulatory proteins, and Ca^{2+}