Lecture 14
Muscles

Muscle Tissue Lets the Body Move

- The distinguishing characteristic of muscle cells is the abundance of contractible protein fibers
  - These microfilaments (myofilaments) are made up of actin and myosin
  - Muscle contraction occurs when actin and myosin slide past each other
- The vertebrate body possesses three different kinds of muscle cells
  - Smooth
  - Skeletal
  - Cardiac

Smooth Muscle

- Cells are long and spindle-shaped
  - Each contains a single nucleus
  - Cellular microfilaments are loosely organized

Found in the walls of blood vessels, stomach and intestines

Power rhythmic involuntary contractions
Skeletal Muscle

- Each muscle is a discrete organ composed of muscle tissue, blood vessels, nerve fibers, and connective tissue.
- The three connective tissue sheaths are:
  - Endomysium – fine sheath of connective tissue composed of reticular fibers surrounding each muscle fiber.
  - Perimysium – fibrous connective tissue that surrounds groups of muscle fibers called fascicles.
  - Epimysium – an overcoat of dense regular connective tissue that surrounds the entire muscle.

Produced by fusion of several cells at their ends.
- This creates a very long muscle fiber that contains all the original nuclei.
Microfilaments are bunched together into myofibrils.

Found in voluntary muscles
- Power voluntary contractions.

Myofibrils: why striations are seen
- Myofibrils are densely packed, rod-like contractile elements.
- They make up most of the muscle volume.
- Myofibrils are perfectly aligned within a fiber creating a repeating series of dark A bands and light I bands.
Sarcomeres

- The smallest contractile unit of a muscle
- The region of a myofibril between two successive Z discs
- Composed of myofilaments made up of contractile proteins
  - Myofilaments are of two types – thick (myosin) and thin (actin)

![Sarcomere Diagram]

Myofilaments: Banding Pattern

- **Thick filaments** – extend the entire length of an A band
- **Thin filaments** – extend across the I band and partway into the A band
- **Z-disc** – coin-shaped sheet of proteins (connectins) that anchors the thin filaments and connects myofibrils to one another
- **Thin filaments** do not overlap thick filaments in the lighter H zone
- **M lines** appear darker due to the presence of the protein desmin

![Myofilament Diagram]

Cardiac Muscle

- Composed of chains of single cells, each with its own nucleus
- Chains are interconnected, forming a latticework
- Each heart cell is coupled to its neighbors by gap junctions
- Allow electrical signals between cells
- Cause orderly pulsation of heart
How Muscles Work

- Skeletal muscles are attached to bones by straps of connective tissue called tendons.
- Bones pivot about flexible joints pulled back and forth by attached muscles.
  - Muscles only pull (never push).
  - Antagonists allow for movement in opposite directions.
  - Whatever a muscle (or group of muscles) does, another muscle (or group) “undoes.”
- The origin of the muscle is the end attached by a tendon to a stationary bone.
- The insertion is the end attached to a bone that moves during muscle contraction.

Antagonists

- Muscles in movable joints are attached in opposing pairs (antagonists).
  - Flexors retract limbs.
  - Extensors extend limbs.

Additional Antagonistic & Other Motions
Two Types of Muscle Contraction

- **Isotonic**
  - Muscle shortens, thus moving the bones

- **Isometric**
  - Muscle does not shorten, but it exerts a force

Myofilaments are made up of actin and myosin

- **Actin filaments** consist of two chains of actin molecules wrapped around one another
- **Myosin filaments** also consist of two chains wound around each other
  - One end consists of a very long rod
  - The other consists of a double-headed globular region or “head”

Myofilament Contraction

An ATP-powered myosin head-flex mechanism allows the actin filament to slide past myosin
How actin and myosin filaments interact

1. Formation of the muscle sarcomere, which consists of actin and myosin filaments.
2. Interaction between actin and myosin filaments through cross-bridges.
3. Shortening of the sarcomere, which is the result of sliding filament theory.

Neuromuscular Junction

- The neuromuscular junction is formed from:
  - Axonal endings, which have small membranous sacs (synaptic vesicles) that contain the neurotransmitter acetylcholine (ACh).
  - The motor end plate of a muscle, which is a specific part of the sarcolemma that contains ACh receptors and helps form the neuromuscular junction.
- Though exceedingly close, axonal ends and muscle fibers are always separated by a space called the synaptic cleft.

When a nerve impulse reaches the end of an axon at the neuromuscular junction:
- Voltage-regulated calcium channels open and allow Ca\(^{2+}\) to enter the axon.
- Ca\(^{2+}\) inside the axon terminal causes axonal vesicles to fuse with the axonal membrane.
- This fusion releases ACh into the synaptic cleft via exocytosis.
- ACh diffuses across the synaptic cleft to ACh receptors on the sarcolemma.
- Binding of ACh to its receptors initiates an action potential in the muscle.
- ACh bound to ACh receptors is quickly destroyed by the enzyme acetylcholinesterase.
- This destruction prevents continued muscle fiber contraction in the absence of additional stimuli.
How calcium controls muscle contraction

- When a muscle is relaxed, attachment sites for myosin heads are blocked by tropomyosin.
- For the muscle to contract, tropomyosin must be moved by another protein called troponin.
- The troponin-tropomyosin complex is regulated by calcium ion concentrations in the muscle cell.

Role of Calcium Ions in Contraction

- Muscle fibers store Ca²⁺ in the sarcoplasmic reticulum.
- Nerve activity causes the release of Ca²⁺ and ultimately muscle contraction.

Muscle Metabolism: Energy for Contraction

- ATP is the only source used directly for contractile activity.
- As soon as available stores of ATP are hydrolyzed (4-6 seconds), they are regenerated by:
  - The interaction of ADP with creatine phosphate (CP)
  - Anaerobic glycolysis
  - Aerobic respiration
Muscle Metabolism: Anaerobic Glycolysis

- When muscle contractile activity reaches 70% of maximum:
  - Bulging muscles compress blood vessels
  - Oxygen delivery is impaired
  - Pyruvic acid is converted into lactic acid
- The lactic acid:
  - Diffuses into the bloodstream
  - Is picked up and used as fuel by the liver, kidneys, and heart
  - Is converted back into pyruvic acid by the liver

Naming Skeletal Muscles

- **Location of muscle** – bone or body region associated with the muscle
- **Shape of muscle** – e.g., the deltoid muscle (deltoid = triangle)
- **Relative size** – e.g., *maximus* (largest), *minimus* (smallest), *longus* (long)
- **Direction of fibers** – e.g., *rectus* (fibers run straight), *transversus*, and *oblique* (fibers run at angles to an imaginary defined axis)
- **Number of origins** – e.g., *biceps* (two origins) and *triceps* (three origins)
- **Location of attachments** – named according to point of origin or insertion
- **Action** – e.g., *flexor* or *extensor*, as in the names of muscles that flex or extend, respectively

Major Skeletal Muscles: Anterior View

- The 40 superficial muscles here are divided into 10 regional areas of the body
The 27 superficial muscles here are divided into 7 regional areas of the body.