

## I. Muscle tissue

### A. Locations

1. Attached to the skeletal muscle framework.
2. Within the walls of hollow organs, blood vessels and ducts.

### B. Functions

1. Movement of the whole body and materials within the body.
2. Maintains posture.
3. Generates heat.

### C. Types of muscle

#### 1. Skeletal muscle

- a. Usually attached to the bones of the skeleton.
- b. Under voluntary control (Somatic Motor System).
- c. Appears **striated** under a microscope.
- d. Skeletal muscle **cells (fibers)** are very long and cylindrical in shape.
- e. Multinucleate
- f. Fibers contain **myoglobin** for storing oxygen in the muscle.
- g. Can only be controlled by the nervous system.

#### 2. Cardiac muscle

- a. Forms the wall of the heart.
- b. Is involuntary.
- c. Striated
- d. Usually have a single nucleus.
- e. Cardiac muscle cells (fibers) are short and branching.
- f. Have **intercalated disks** between the cells to help spread impulses from cell to cell.
- g. Contain large amounts of mitochondria and myoglobin.
- h. Can be controlled by either the nervous or endocrine system.

#### 3. Smooth muscle

- a. Located in the walls of hollow organs, eyes and blood vessels.
- b. Is involuntary.
- c. No striations.
- d. Smooth muscle cells (fibers) have a single nucleus.
- e. Are thin and elongate (fusiform) in shape.
- f. No myoglobin
- g. Can be controlled by either the nervous or endocrine system.

## II. Muscular System (skeletal muscle)

### A. Structure of **muscle fibers (cells)**.

1. The plasma membrane of muscle fibers is called **sarcolemma**.
  - a. Generates an action potential in response to stimulation by a neurotransmitter.
  - b. Invaginates into the muscle fiber to form the **transverse tubules (T tubules)**.
    - i. Transverse tubules carry the impulse into the muscle fibers.
2. Have multiple nuclei that lie at the periphery of the cell.
3. Contains **sarcoplasmic reticulum** (synonymous with smooth endoplasmic reticulum).
  - a. Stores and releases calcium ions for muscle contraction.
4. Throughout the muscle fiber are **myofibrils**.

- a. Long rod-like structures that fill the cytoplasm of skeletal and cardiac muscle cells.
  - b. Consists of **thick** and **thin myofilaments** that are organized into **sarcomeres** (the basic functional unit of striated muscle).
    - i. **Thick myofilaments** are composed of the protein **myosin**.
      - (a) A single myosin molecule is shaped like two golf clubs twisted together.
      - (b) A thick myofilament is composed of about 200 myosin molecules.
      - (c) The myosin heads can bind to the thin myofilaments forming **crossbridges**.
      - (d) At rest, a myosin head has split apart an ATP molecule using the enzyme **ATPase** and stores the energy for future work.
    - ii. **Thin myofilaments** are composed of three proteins.
      - (a) **Actin** molecules twist together to form a double helix.
        - (i) Has binding sites for the myosin heads to grab ahold of it.
      - (b) **Tropomyosin** winds around the actin molecules.
        - (i) Covers the binding sites on the actin molecules, preventing the myosin heads from attaching.
      - (c) **Troponin** binds at regular intervals to tropomyosin and actin molecules.
        - (i) Prior to contraction, calcium ions react with troponin to modify the position of tropomyosin, exposing the binding sites on actin.
- B. The muscle as a whole
1. Connective tissue associated with muscle.
    - a. **Endomysium** is connective tissue that surrounds each individual skeletal muscle fiber.
    - b. The individual muscle fibers are grouped together into structures called **fascicles**.
    - c. The fascicles are wrapped in connective tissue called **perimysium**.
    - d. The entire muscle is wrapped in more connective tissue forming the **epimysium**.
  2. Muscle attachments
    - a. All of the connective tissue layers of the muscle join together at the end of the muscle to form the **tendons** that attach the muscle to the periosteum of the bone.
      - i. Tendons are composed of dense regular connective tissue.
    - b. The **origin** of a muscle is the muscle's attachment to a stationary bone.
    - c. The **insertion** of a muscle is the muscle's attachment to a moveable bone.
  3. Categorizing muscles by action
    - a. A **prime mover (agonist)** is a muscle that is responsible for most of a given movement.
    - b. A **synergist** is a muscle that assists the action of the prime mover.
    - c. An **antagonist** is a muscle that resists the action of a prime mover.
- C. Motor unit
1. A **motor unit** is a single lower motor neuron and all of the muscle fibers it stimulates.
  2. Motor units can vary in the number of muscle fibers stimulated.
    - a. A single lower motor neuron may stimulate as few as 10 muscle cells or as many as 2000.

- b. The use of smaller motor units results in finer muscle control (eyes).
  - c. The large motor units are responsible for large, powerful movements such as those of the biceps brachii and gluteus muscles.
- D. The neuromuscular junction
1. The **neuromuscular junction** is between the terminal knobs of a lower motor neuron and the muscle fiber.
  2. Consists of
    - a. The **terminal knob** (synaptic end bulb) of a lower motor neuron.
      - i. Contain **synaptic vesicles** filled with **neurotransmitter**.
    - b. The **motor end plate** is the region of the **sarcolemma** near the terminal knob of the neuron.
      - i. One per cell.
      - ii. Will have receptors within the sarcolemma for the neurotransmitter to bind to in order to generate a muscular action potential
    - c. The **synaptic cleft** is the space between the terminal knob and the motor end plate of the muscle fiber.
      - i. The neurotransmitter is released into this space.
- E. Physiology of contraction
1. The arrival of a nerve impulse at the **terminal knob** stimulates the release of the neurotransmitter **acetylcholine** into the synaptic cleft.
  2. The acetylcholine diffuses across the synaptic cleft and binds to the receptors (nicotinic receptors) on the motor end plate.
  3. This binding stimulates the opening of sodium ion channels allowing the movement of sodium ions into the muscle cell and the generation of an action potential.
  4. The action potential spreads over the surface of the muscle fiber along the **sarcolemma**, traveling into the muscle cell at the **T tubules**.
    - a. Immediately after the action potential is generated sodium ions are being pumped back out of the muscle fiber in order to repolarize the muscle cell.
  5. The action potential traveling down the T tubules triggers the release of calcium ions from the **sarcoplasmic reticulum** into the muscle fiber.
  6. The calcium ions react with the **tropoin molecules** of the **thin filaments** causing it to change shape.
  7. This change in shape allows the **tropomyosin** molecules to uncover the binding sites on the **actin molecules**.
  8. Once the binding sites on the actin molecules are exposed, the **myosin heads** interact with the actin forming a **crossbridge**.
  9. Once a crossbridge is formed the myosin head uses the stored energy from the breakdown of ATP to do a **power stroke**.
  10. The power stroke is a swiveling action that pulls the actin toward the center of the **sarcomere**, shortening the sarcomere.
  11. In order to break the crossbridge a new molecule of ATP attaches to the myosin head.
  12. The myosin molecule uses this ATP to power the next binding cycle to actin.
 

**Note:** during a contraction only a portion of the myosin heads are attached and producing force while others are detached and preparing to bind again.
  13. This cycle is repeated until the actin meets in the middle of the sarcomere.
  14. The contraction cycle continues as long as ATP and calcium ions are available.

15. During the contraction cycle the calcium ions are actively being pumped back into the sarcoplasmic reticulum.
  - a. As the level of calcium ions fall, the calcium ions begin to dissociate from the troponin.
  - b. This allows the troponin to go back to its original shape causing the tropomyosin molecule to cover the active sites on the actin molecule preventing the myosin heads from binding..
  - c. The thin filaments then slide back to their original position.
  - d.

**16. Rigor mortis**

- a. Occurs due to calcium ions leaking out of the sarcoplasmic reticulum after death.
- b. Calcium ions bind to the troponin exposing the active sites.
- c. The myosin heads form a crossbridge with the actin and do a power stroke, shortening the muscle.
- d. Since there is no new ATP production to release the crossbridges the muscle remains contracted.
- e. Crossbridges release as the muscle proteins begin to breakdown.

F. Types of muscle contractions

**1. Isotonic contractions**

- a. Occurs anytime parts move.
- b. There is a change in the length of a muscle, but the tension remains constant through most of the movement.

**2. Isometric contractions**

- a. There is no change in the length of a muscle, but the tension continues to increase.
- b. Used primarily to maintain posture or hold joints in stationary positions.

**3. Note:** most body actions involve both isometric and isotonic contractions.

G. A muscle twitch

1. A **muscle twitch** is one brief contraction of a muscle in response to a single action potential.
2. Not common, i.e. blinking, but understanding twitches gives us insight into how muscles work.
3. Phases of a twitch
  - a. Latent phase**
    - i. Occurs between the instant a stimulus is applied and the beginning of the contraction.
    - ii. Includes depolarization, spreading the impulse down the T tubule, the release of calcium and the calcium binding to troponin to expose the binding sites, and ultimately the forming of a crossbridge.
  - b. Contraction phase**
    - i. Powerstrokes are occurring and the muscle is contracting.
  - c. Relaxation phase**
    - i. Calcium is returning to resting levels and powerstrokes are ceasing.
    - ii. Muscle returns to its original length.
    - iii. Related to the repolarization of the muscle fiber.

H. Muscle response to an increased frequency of stimulation

1. Summation
    - a. Occurs when a second stimulus is applied to a muscle before it has had the chance to completely relax from a previous stimulus.
    - b. Results in the second contraction being stronger than the first.
    - c. Because the application of the stimuli are close together the calcium ions released during the first twitch have not been completely removed before the second twitch occurs.
      - i. Results in a greater concentration of calcium ions within the muscle fiber allowing for a greater number of crossbridges to form, producing a stronger subsequent contraction.
    - d. Partial relaxation of the muscle is observed.
  2. Unfused tetanus
    - a. Occurs when a skeletal muscle is repeatedly stimulated at the same point as that seen during summation.
    - b. Results in a sustained but wavering contraction (like a tremor).
    - c. Due to the higher calcium levels explained with the summation.
  3. Fused tetanus
    - a. Occurs when the frequency of stimulus is so high that contractions completely fuse together, lacking even partial relaxation.
    - b. Can only occur in skeletal muscle.
    - c. Results in a smooth, sustained contraction.
    - d. In order to avoid fatigue during a sustained contraction the motor units that are contracting rotate. So as some motor units begin to fatigue other motor units begin to contract in order to maintain the contraction.
      - i. This is why you do not normally contract more than half of the motor units in a muscle at one time. If more than half are contracting, there is no opportunity to rotate.
  4. Muscle tone
    - a. Even when a muscle is not contracting a small number of motor units are still activated keeping the muscle in a continuous state of partial contraction.
    - b. Keeps muscle firm, but does not result in movement.
    - c. Maintains the muscle in a state of readiness.
- I. Recruitment in skeletal muscle
1. As the strength of a stimulus to a muscle is increased it calls more and more motor units into action, increasing the strength of the muscle contraction.
  2. A single skeletal muscle consists of many motor units differing in size.
    - a. At low levels of stimulation only a few motor units, usually the smaller ones, are stimulated resulting in a weak muscle contraction.
    - b. With strong stimuli more motor units are stimulated, recruiting the larger motor units, resulting in a stronger muscle contraction.
- J. Types of skeletal muscle fibers
1. Red fibers
    - a. Smaller in diameter.
    - b. Contain large amounts of myoglobin.
    - c. Have many mitochondria.
    - d. Good vascular supply.

- e. Are well suited for aerobic exercise and endurance activities.
  - f. Do not increase in size.
2. White fibers
- a. Larger in diameter.
  - b. Low myoglobin content and few mitochondria.
  - c. Generate powerful and rapid contractions.
  - d. Are well suited for intense activities of short duration, i.e. weightlifting, sprinting.
  - e. Fatigue quickly.
  - f. Are associated with increases in the size and strength of a muscle.
    - i. The number of muscle cells stays the same, hypertrophy (muscle enlargement) of fibers occurs due to an increase in the number of myofilaments.
3. Most skeletal muscle is a mix of red and white fibers, although any given motor unit will have all the same type of fiber.