Chapter 9a: Part II: Muscle Contraction, Neuromuscular Junction & Muscle Tissue cont... (Interactive pgs.297-304)
Neuromuscular Junction (NMJ):

- A type of synapse.
- Also called a myoneural junction.
- Site where an axon of motor neuron and skeletal muscle fiber interact.
- Skeletal muscle fibers contract only when stimulated by a motor neuron.

Parts of a NMJ:

- Motor neuron.
- Motor end plate.
- Synaptic cleft.
- Synaptic vesicles.
- Neurotransmitters.
Stimulus for Contraction

**Acetylcholine** (ACh) is the neurotransmitter

Nerve impulse causes release of ACh from synaptic vesicles

ACh binds to ACh receptors on motor end plate

ACh causes changes in membrane permeability to Na\(^+\) and K\(^+\)
Which generates a muscle impulse (action potential)

Impulse causes release of Ca\(^{2+}\) from SR, which leads to muscle contraction
Clinical Application 9.1

Myasthenia Gravis (MG)

MG is an autoimmune disorder

Antibodies attack Acetylcholine receptors on skeletal muscle fibers (motor end plates) in neuromuscular junctions

Person may have only one-third normal number of ACh receptors

Leads to widespread muscle weakness and muscle fatigue

Treatments:
• Drugs that inhibit acetylcholinesterase.
• Immunosuppressant drugs.
• Administering antibodies that inactivate harmful antibodies.
• Plasma exchange.
Excitation-Contraction Coupling

**Excitation-Contraction Coupling:** Connection between muscle fiber stimulation and muscle contraction

**During muscle relaxation:**

- $Ca^{2+}$ ions are stored in SR.
- Troponin-tropomyosin complexes cover binding sites on actin filaments.

**Upon muscle stimulation:**

- Muscle impulses cause SR to release $Ca^{2+}$ ions into cytosol.
- $Ca^{2+}$ ions into cytosol.
- $Ca^{2+}$ on binds to troponin to change its shape.
- Each tropomyosin is held in place by a troponin molecule. The change in shape of troponin alters the position of tropomyosin.
- Binding sites on actin are now exposed.
- Myosin heads bind to actin, forming cross-bridges.
Figure 9.9 Excitation-Contraction Coupling

1. Relaxed muscle
2. Exposed binding sites on actin allow the muscle contraction cycle to occur
3. Myosin heads bind to actin, forming cross-bridges, connecting myosin to actin
4. ADP and P release from myosin and cross-bridge pulls thin filament (power stroke)
5. New ATP binds to myosin, breaking the connection to actin
6. ATP splits, which provides power to "cock" the myosin heads and store energy for the next power stroke

Muscle contraction: Release of Ca²⁺ from sarcoplasmic reticulum exposes binding sites on thin filament.

Muscle relaxation: Active transport of Ca²⁺ into sarcoplasmic reticulum, which requires ATP, makes myosin binding sites unavailable.
Figure 9.10 The Sliding Filament Model

**Sliding Filament Model of Muscle Contraction:**

- When sarcomeres shorten, thick and thin filaments slide past one another.
- H zones and I bands narrow.
- Z lines move closer together.
- Thin and thick filaments do not change length.
- Overlap between filaments increases.
Cross-Bridge Cycling

Myosin head attaches to actin binding site, forming cross-bridge

Myosin cross-bridge pulls thin filament toward center of sarcomere

ADP and phosphate are released from myosin

New ATP binds to myosin

Linkage between actin and myosin cross-bridge break

ATP splits

Myosin cross-bridge goes back to original position
Relaxation

When neural stimulation of muscle fiber stops:

• **Acetylcholinesterase** (enzyme) rapidly decomposes ACh remaining in the synapse.
• Muscle impulse stops when ACh is decomposed.
• Stimulus to sarcolemma and muscle fiber membrane ceases.
• **Calcium pump** moves $Ca^{+2}$ back into sarcoplasmic reticulum (SR).
• **Troponin-tropomyosin complex** again covers binding sites on actin.
• Myosin and actin binding are now prevented.
• Muscle fiber relaxes.
Figure 9.11 Energy Sources for Contraction

1. ATP reserves: small amount.
2. Creatine phosphate: initial source of energy to regenerate ATP from ADP and P.
3. Cellular respiration.
Cellular respiration:

Anaerobic Phase:
• Glycolysis.
• Occurs in cytoplasm.
• Produces little ATP.

Aerobic Phase:
• Citric acid cycle and electron transport system.
• Occurs in the mitochondria.
• Produces the most ATP.
• Myoglobin stores extra oxygen in muscles.
Oxygen Debt

During rest or moderate exercise, respiratory & cardiovascular systems supply enough $O_2$ to support aerobic respiration.

**Anaerobic (Lactic Acid) Threshold:**

Shift in metabolism from aerobic to anaerobic, during strenuous muscle activity, when the above systems cannot supply the necessary $O_2$. Lactic acid is produced.

**Oxygen Debt:**

Amount of oxygen needed by liver cells to convert the accumulated lactic acid to glucose, and to restore muscle ATP and creatine phosphate concentrations.
Figure 9.13 Oxygen Debt

Glycogen

<table>
<thead>
<tr>
<th>Glycolysis and lactic acid formation (in muscle)</th>
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| Synthesis of glucose from lactic acid (in liver) |

Glucose

Pyruvic acid

Lactic acid

Energy to synthesize

ATP

Energy from

ATP
Muscle Fatigue

Muscle Fatigue:
Inability to contract muscle

Common causes of muscle fatigue:
• Decreased blood flow.
• Ion imbalances across the sarcolemma.
• Loss of desire to continue exercise.
• Accumulation of lactic acid (controversial).

Muscle Cramp:
• Sustained, involuntary muscle contraction.
• May be caused by changes in electrolyte concentration in extracellular fluids in the area.
Heat Production

Heat is a by-product of cellular respiration in active cells.

Muscle cells are major source of body heat.

More than half the energy released in cellular respiration becomes heat; less than half is transferred to ATP.

Blood transports heat throughout body core.
Chapter 9: Part III:
Muscle Response
(Interactive pgs.302-308)
Muscular Responses

Muscle contraction can be observed by removing a single skeletal muscle fiber and connecting it to a device that senses and records changes in the overall length of the muscle fiber.

Electrical stimulator promotes the contractions
Threshold Stimulus

**Threshold Stimulus**: Minimum strength of stimulation of a muscle fiber required to cause contraction

When strength of stimulus reaches threshold, an action potential is generated

Impulse spreads through muscle fiber, releasing $\text{Ca}^{+2}$ from SR and activating crossbridge formation

One action potential from a motor neuron releases enough ACh to produce threshold stimulus in muscle fiber, causing a muscle impulse
Figure 9.14 Recording of a Muscle Contraction

**Twitch**: Contractile response of a single muscle fiber to a single impulse

- Latent period.
- Period of contraction.
- Period of relaxation.
Figure 9.15 Length-Tension Relationship

Length of muscle fiber before stimulation determines amount of force it can develop

Optimum starting length is resting length of the muscle fiber; this allows the greatest force to develop

Stretched muscle fibers develop less force, since some myosin heads cannot reach binding sites on actin

Shortened muscle fibers also develop less force, since compressed sarcomeres cannot shorten further
**Figure 9.16 Summation**

**Summation:**

- Process by which the force of individual muscle fiber twitches combine.
- Produces sustained contractions.
- Can lead to partial or complete tetanic contractions.
Figure 9.17 Recruitment of Motor Units

**Motor Unit:**

A motor neuron plus all of the muscle fibers it controls

A whole muscle consists of many motor units

Coarse movements are produced with large numbers of fibers in a motor unit

Precise movements are produced with fewer muscle fibers in a motor unit
Recruitment of Motor Units

**Recruitment:**

Increase in the number of motor units activated, to produce more force.

Certain motor units are activated first, and others are activated only when the intensity of stimulus increases.

As intensity of stimulation increases, recruitment of motor units continues until all motor units are activated.
Sustained Contractions

Smaller motor units (smaller diameter axons) - recruited first

Larger motor units (larger diameter axons) - recruited later

Summation and recruitment can produce sustained contractions of increasing strength

Whole muscle contractions are smooth movements

**Muscle tone (tonus):** Continuous state of partial contraction in resting muscles
Figure 9.18 Types of Contractions

**Isotonic**: muscle contracts and changes length; equal force

- **Concentric**: shortening contraction.
- **Eccentric**: lengthening contraction.

**Isometric**: muscle contracts but does not change length; change in force

(a) Muscle contracts with force greater than resistance and shortens (concentric contraction)

(b) Muscle contracts with force less than resistance and lengthen (eccentric contraction)

(c) Muscle contracts but does not change length (isometric contraction)
# Fast- and Slow-Twitch Muscle Fibers

## Slow-twitch fibers (Type I):
- Always oxidative.
- Resistant to fatigue.
- Red fibers.
- Abundant myoglobin.
- Good blood supply.
- Many mitochondria.
- Slow ATPase activity; slow to contract.

## Fast-twitch fatigue-resistant fibers (Type IIa):
- Intermediate twitch fibers.
- Intermediate oxidative capacity.
- Intermediate amount of myoglobin.
- White fibers.
- Resistant to fatigue.
- Rapid ATPase activity.

## Fast-twitch glycolytic fibers (Type IIb):
- Anaerobic respiration (glycolysis).
- White fibers (less myoglobin).
- Poorer blood supply.
- Fewer mitochondria than fast-twitch.
- More SR than fast-twitch.
- Susceptible to fatigue.
- Fast ATPase activity; contract rapidly.
Clinical Application

Use and Disuse of Skeletal Muscles

**Hypertrophy:** Enlargement of skeletal muscle that is exercised

**Atrophy:** Decrease in size and strength of skeletal muscle that is unused

Aerobic exercise stimulates slow-twitch fibers. In response, fibers increase their capillaries and mitochondria.

Forceful exercise stimulates mainly fast-twitch fibers. In response, fibers produce new actin & myosin filaments, and the muscle enlarges.