**Structure and Function of Exercising Muscle**

**Key Terms**

**Muscle**: a tissue composed of cells or fibers, the contraction of which produces movement in the body

**Fascicle**: a bundle of structures, such as nerve or muscle fibers

**Perimysium**: connective tissue that covers fasciculus (bundle of muscle fibers)

**Epimysium**: outer connective tissue covering of the muscle, fuses into tendon

**Endomysium**: connective tissue that covers each muscle fiber

**Tendon**: fibrous cords of connective tissue that transmit force generated by muscle fibers to the bones

**Muscle Fiber**: inside fascicle, muscle cell

**Myofibril**: bundles of proteins consisting of actin and myosin, make up muscle fibers

**Myosin**: thick filaments; has cross bridges that extend toward nearby actin filaments

**Actin**: thin filaments composed of actin molecules, troponin, tropomyosin

**Myosin Cross-bridge**: binds actin molecules to myosin heads and pulls the actin filament for contraction

**Titin**: fiber protein which attaches to M line; within but not a part of the thick filament. It pulls the muscle fiber/myofibrils back to its original position after contraction is over – it helps lengthen the sarcomere back out.

**Troponin**: protein component of the actin filament that when bound to Ca\(^{2+}\) Actin binding sites are uncovered

**Type II (fast-twitch fiber)**: 50 microseconds to reach peak tension when stimulated; type IIa and IIx

**Action potential**: moving impulse through an axon

**Adenosine Triphosphate (ATP)**: a compound consisting of an adenosine molecule bonded to three phosphate groups, present in all living tissue. The breakage of one phosphate linkage (to form adenosine diphosphate, ADP ) provides energy for physiological processes such as muscular contraction

**Adenosine Triphosphatase (ATPase)**: found in the myosin head and hydrolyzes ATP into ADP and P for contraction

**Alpha Motor Neuron**: terminal axons on different myofibrils (muscles) exciting a particular muscle

**Excitation – contraction coupling**: muscle contraction stimulated by an action potential through the neuron
**Concentric Contraction**: muscle shortening during contraction
  - Muscle generates force by shortening and decreasing the joint angle

**Eccentric Contraction**: muscle lengthening during contraction
  - Muscle generates force by lengthening and increasing the joint angle. More weight can be moved in this phase than in the concentric phase

**Isometric Contraction**: load is greater than the force of contraction of the muscle, so tension is created but the muscle does not shorten. The force is transferred to the tendon, which lengthens
  - Static (Isometric) Contraction: a muscle generates force while the joint angle remains the same; he muscles contract but the joint remains unmoved

**Isotonic Contractions**: force of contraction of muscle is greater than load, so tension is created and the muscle shortens
  - Dynamic (Isotonic) Contraction: force generated by the muscle causes movement in the joint. Two phases are concentric and eccentric

**Motor Unit**: motor neuron and all the muscle fibers it controls

**Nebulin**: an actin-binding protein found in the thin filaments in skeletal muscle

**Single-Fiber Contractile Velocity** ($V_0$):
  - In shortening (concentric) muscle actions, where contraction velocity is high, muscle force must be low. Where muscle force is high, contraction velocity must be low
  - In lengthening (eccentric) muscle actions, where contraction velocity is high, muscle force can be high. Where muscle force is low, contraction velocity must be low

**Transverse Tubules** (**T-tubules**): place where depolarization spreads, as T-tubule is depolarized, Ca2+ is released from the Sarcoplasmic reticulum

**Twitch**: the muscle fiber stimulation from one action potential; always looks the same regardless of action potential strength, made up of 5 stages
  1) Activation (due to Action Potential)  
  2) Latent period (delay between action potential and initial force)  
  3) Rate of tension rise (time to peak tension) (contraction phase)  
  4) Peak tension  
  5) Rate of force decline (relaxation phase)

**Plasmalemma**: the plasma membrane that surrounds each muscle fiber, part of sarcolemma, fuses with tendon
Power Stroke: movement of the cross-bridge (myosin head bound to actin molecule) pulling the actin filament; movement of myosin head towards M line

Principle of Orderly Recruitment: larger muscles require more stimulation to fire and lower motor neurons become active in order of increased size. Force of contraction increases with larger motor units [more fibers recruited]

Rate Coding: process by which the tension of a given motor unit can vary from that of a twitch to that of tetanus by increasing the frequency of stimulation of that motor unit.

Sarcolemma: covers muscle fiber, part of Endomysium

Sarcoplasm: cytoplasm of a muscle cell; holds the energy source Glycogen and Glucose

Sarcoplasmic Reticulum: smooth endoplasmic reticulum in muscle cells, stores calcium

Sarcomere: functional (contractile) unit of skeletal muscle; region of myofibril btwn two Z discs
  - A Band: composed of the whole length of the thick filament and some overlapping thin filaments and the M line
  - I Band: composed of the whole length of the thin filaments and Z disc
  - H Zone: composed of thick filaments excluding the area overlapping thin filaments; M line; the H Zone limits the amount of shortening so the thin filaments don’t collide
  - Z Disc: defines the area of the sarcomere, one sarcomere is btwn 2 Z discs
  - M line: crosses through thick filaments

Satellite Cells: involved in growth and development of skeletal muscles and their adaptation to injury, immobilization, and training; located between plasmalemma and basement membrane; provide response to microtears of muscle

Size Principle: the size of the motor units stimulated are directly correlated to the size of the force needed to be generated. Small force → small motor units stimulated; larger forces → larger motor units stimulated.

Summation: the increase in tension that results when a muscle fiber is unable to relax between twitches as calcium remains in the synaptic cleft and subsequent stimuli release additional Ca$^{2+}$ from the SR, which in turn increases the number of actin-myosin-cross bridges that form. Requires increasing stimulus frequency

Tetanus: loss of relaxation between stimulus impulses

Tropomyosin: protein component of the actin filament that covers the actin molecules’ binding sites

Type I (slow twitch) Fiber: 110 milliseconds to reach peak tension when stimulated
Study Questions

1. List and define the anatomical components that make up a muscle fiber

- Muscle → Fascicles → Muscle Fiber → Myofibril → Myosin and Actin
- Muscle Fibers are multinucleated due to their length and size
- A muscle fiber consists of: sarcolemma, sarcoplasmic reticulum, nuclei, myofibrils, thick and thin filaments, plasmalemma, satellite cells, sarcoplasm, Transverse Tubules

2. List the components of a motor unit

- A motor unit is composed of the motor neuron and all the muscle fibers it controls
- Signal from CNS → motor neuron → action potential and release of acetylcholine → spreads the electric impulse throughout the entire volume of the muscle cell via openings in the plasma membrane called T-tubules → action potential releases Ca$^{2+}$ from sarcoplasmic reticulum which binds to troponin, moving the tropomyosin out of the way and allowing the myosin heads to bind to the actin molecules for muscle contraction

3. What are the steps in excitation-contraction coupling (nerve → contraction):

   1) Action potential (AP) starts in brain
   2) AP arrives at axon terminal, releases acetylcholine (ACh)
   3) ACh crosses synapse, binds to ACh receptors on plasmalemma
   4) AP travels down plasmalemma, T-tubules
   5) Triggers Ca$^{2+}$ release from sarcoplasmic reticulum (SR)
   6) Ca$^{2+}$ enables actin-myosin contraction

4. What is the role of calcium in muscle contraction?

- Calcium is found in the sarcoplasmic reticulum and moves into the cytoplasm when the action potential diffuses through the muscle cell
- The Ca binds to troponin, which moves tropomyosin away from the actin molecules’ binding sites, unblocking it and allowing the myosin heads to bind thus initiating muscle contraction

5. Describe the sliding filament theory. How do muscle fibers shorten?

- A Sarcomere shortens when its thin filaments slide along its thick filaments
- During contraction, the Z lines and thin filaments move closer together
- Contraction only shortens the sarcomere, it does not change the length of the thick and thin filaments
• The myosin head attaches to an actin molecule, drags it, then releases that actin molecule and returns to its starting position to attach to and drag another actin molecule, thereby moving the entire thin filament
  o 1)Ca2+ binds to troponin
  o 2)Troponin-Ca2+ moves tropomyosin out of the way
  o 3)Myosin binds to actin
  o 4)Myosin head pulls actin toward sarcomere center (power stroke)
  o 5)Filaments slide past each other (sarcomeres, myofibrils, muscle fiber all shorten)

6. What are the basic characteristics that differ between Type I and Type II muscle fibers?

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type IIa</th>
<th>Type IIx</th>
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</thead>
<tbody>
<tr>
<td><strong>Name 1</strong></td>
<td>Slow twitch</td>
<td>Fast twitch a</td>
<td>Fast twitch x</td>
</tr>
<tr>
<td><strong>Name 2</strong></td>
<td>Slow, oxidative (SO)</td>
<td>Fast oxidative/glycolytic (FOG)</td>
<td>Fast glycolytic (FG)</td>
</tr>
<tr>
<td><strong>Oxidative Capacity</strong></td>
<td>High</td>
<td>Moderately high</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Glycolytic Capacity</strong></td>
<td>Low</td>
<td>High</td>
<td>Highest</td>
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<tr>
<td><strong>Contractile Speed</strong></td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
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<tr>
<td><strong>Fatigue Resistance</strong></td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
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<tr>
<td><strong>Motor Unit Strength</strong></td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Myosin ATPase Type</strong></td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td><strong>Sarcoplasmic Reticulum Development</strong></td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Motor Unit (muscle + nerve)</strong></td>
<td>Small / recruited 1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>Intermediate / recruited 2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>Large / recruited last</td>
</tr>
<tr>
<td><strong>Blood Supply [O2]</strong></td>
<td>High</td>
<td>Moderately high</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Fiber Size/ # Capillaries</strong></td>
<td>Small / many</td>
<td>Intermediate / intermediate</td>
<td>Large fibers / few capillaries</td>
</tr>
</tbody>
</table>

7. What is the role of genetics in determining the proportions of muscle fiber types and the potential for success in selected activities? Give an example.

• Force generation in a muscle fiber is due to: the frequency of stimulation (Ca2+ release > Ca2+ uptake and frequency of stimulation “warms up” the muscle → increases enzymatic activity); fiber diameter (due partly to genetics); change in fiber length.
• Fast Twitch muscle fibers are used in bursts of intense activity, such as sprints or dashes, while Slow Twitch fibers are worked during endurance training. Thus some athletes can be predispositioned to their sport based on how many muscle fibers they have.
• Muscle fiber characteristics determined early in life; Alpha-motor neuron determines the muscle fiber type by innervating that muscle fiber
• Type I fibers are more suited for prolonged endurance activities
• Type II are better suited for high-intensity, short, explosive activities
  o Muscles lose type II motor units as we age
• Intermediate fibers are have the ability to shift to Type I/II based on training

8. Describe the relationship between muscle force development and the recruitment of Type I and Type II motor units.

   • Size Principle: size of motor units stimulated are directly correlated to the size of the force needed to be generated
     o Less force=fewer/smaller motor units
     o More force=more/larger motor units
   • Recruitment → type I → type IIa → type IIx
   • Principle of Orderly Recruitment: larger muscles require more stimulation to fire; lower motor units become active in order of increased size; force of contraction increases with larger motor units (more fibers recruited)

9. Differentiate among, and give examples of concentric, static, and eccentric contractions

   • Concentric: Muscle shortens (sarcomere shortens, filaments slide toward center), joint movement is produced (dynamic contractions)
     o Ex) when an elbow is bent to bring a weight towards the shoulder
   • Eccentric: Muscle lengthens (cross-bridges form, but sarcomere lengths), joint movement (weight lifting->ex: lowering heavy weight)
   • Isometric/Static: Muscle generates force, but length stays the same, joint angle doesn’t change, myosin cross-bridges form and recycle-no sliding
     o Ex) when a person pushes against a wall

10. What two mechanisms are used by the body to increase force production in a single muscle?

   • Force Generation in a muscle fiber dependent on
     o Frequency of stimulation – muscle is “warmed up” → increase in enzymatic activity
     o Fiber Diameter – bigger fiber = more sarcomeres = can form more cross bridges
     o Changes in fiber length – see below
   • Length-tension relationship
     o 1)Optimal sarcomere length=optimal overlap
2) Too short (thin filaments at opposite ends of sarcomere begin to overlap and thick filaments come into contact with Z lines) or too stretched (sarcomeres are too spread out to form cross bridges) → little or no force develops

- Speed-force relationship
  - 1) Concentric = max. force development decreases at higher speeds
  - 2) Eccentric = max. force development increases at higher speeds

11. What is the optimal length of a muscle for maximum force development?

- Optimal length is where the number of cross-bridges is the greatest

12. What is the relation between maximal force development and the speed of shortening (concentric) and lengthening (eccentric) contractions?

- During concentric contractions, max. force development decreases progressively at high speeds. Eccentric contractions allow max. force development to increase progressively at low speeds
**Group thought:** How does the sarcomere change during contraction?
Figure 1: Muscle belly split into various component parts (from Essentials of Strength Training & Conditioning, National Strength & Conditioning Association)
Sources

- Merriam Webster Dictionary
- Class notes
- [http://www.cabrillo.edu/~mhalter/Biology5/6_FingerTwitch.pdf](http://www.cabrillo.edu/~mhalter/Biology5/6_FingerTwitch.pdf)