BL 121 Lecture 14

I. **Announcements** Last Lab 6, Pulmonary Function Testing + Optional notebook ✓ this Thurs. Exam II, Dec 7, 8 am Q?

II. **Nervous System Connections** LS 7
   A. How does the signal cross the nerve-muscle gap? ch 7 p 185-92 fig 7-5 p 190
   B. What do black widow spider venom, botulism/Botox, curare & nerve gas have in common? LS fig 7-5 p 190

III. **Muscle Structure-Function & Adaptation** LS ch 8 + DC Mod 12
   A. Muscle types: cardiac, smooth, skeletal LS fig 8-1 pp194-6
   B. How is skeletal muscle organized? LS fig 8-2, DC fig 12-2
   C. What do thick filaments look like? LS fig 8-4, DC fig 12-4
   D. Thin filaments? Banding pattern LS fig 8-5, 8-3, 8-7
   E. How do muscles contract? LS fig 8-6, 8-10
   F. What's a cross-bridge cycle? LS fig 8-11 +...
   G. Summary of skeletal muscle contraction, videos courtesy David Bolinsky, XVIVO & Malcolm Campbell, Davidson C.
   H. Exercise adaptation variables, strength vs. endurance tr.
Synaptic Transmission

1. Voltage-gated Ca\(^{2+}\) channel
2. Neurotransmitter molecule
3. Synaptic cleft
4. Chemically-gated ion channel for Na\(^{+}\), K\(^{+}\), or Cl\(^{-}\)
5. Receptor for neurotransmitter

NT Balance!

Uptake

Release

LS 2012 fig 4-14
Links That May Be Helpful!

https://www.youtube.com/watch?v=6RbPIOq0O3w
https://www.youtube.com/watch?v=mItV4rC57kM
https://www.youtube.com/watch?v=WhowH0kb7n0
http://sites.sinauer.com/psychopharm2e/animation03.01.html
https://www.youtube.com/watch?v=VitFvNvRIIY
Skeletal Muscles

Homeostasis
Skeletal muscles contribute to homeostasis by playing a major role in the procurement of food, breathing, heat generation for maintenance of body temperature, and movement away from harm.

Homeostasis is essential for survival of cells

Cells make up body systems

Cells

Body systems maintain homeostasis
Striated muscle

Skeletal muscle

Cardiac muscle

Unstriated muscle

Smooth muscle

Voluntary muscle

Involuntary muscle
Skeletal Muscle Histology: Microscopic Anatomy

Muscle fiber or cylindrical cell

“Threads” ≡ Myofibrils

Nuclei

Dark-Light...bands ≡ Overlapping thick & thin filaments

x1000

H Howard 1980.
Organ = Muscle

Cell = Myocyte = Fiber

Subcellular = Cytoskeleton

Molecules = Actin & Myosin
Golf Club Analogy?

Actin binding site
Myosin ATPase site
Heads

Tail

100 nm

Cross bridges

Myosin molecules

(a)

(b)

LS 2006, cf:
LS 2012 fig 8-4
Broccoli Analogy?

Myosin Heads

Myosin Tails

Bare Zone

Myosin Heads
LS 2006, cf:
LS 2012 fig 8-5

Actin molecules

Binding site for attachment with myosin cross bridge

Actin helix

Tropomyosin

Troponin

Thin filament
Triad $\equiv$ T tubule abutting cisternae
A Band = Dark Band
Anisotropic = Light Can’t Shine Through

I Band = Light Band
Isotropic = Light Can Shine Through
A diagram illustrating the changes in sarcomere structure between a relaxed and a contracted state. In the relaxed state, the H zone, I band, and A band are distinct. As the sarcomere contracts, the H zone becomes shorter, the I band shortens, and the A band maintains the same width. The thick filaments and thin filaments interact differently in the contracted state compared to the relaxed state, with the sarcomere overall becoming shorter.
Discussion + Time for Questions!
What do we guess happens at the molecular level?
Relaxed: No Cross-Bridge Binding

(a) Relaxed

1. No excitation.

2. No cross-bridge binding because cross-bridge binding site on actin is physically covered by troponin–tropomyosin complex.

3. Muscle fiber is relaxed.
**Excited: Calcium Triggers Cross-Bridge Binding**

(b) Excited

1. Muscle fiber is excited and $\text{Ca}^{2+}$ is released.

2. Released $\text{Ca}^{2+}$ binds with troponin, pulling troponin–tropomyosin complex aside to expose cross-bridge binding site.

3. Cross-bridge binding occurs.

4. Binding of actin and myosin cross bridge triggers power stroke that pulls thin filament inward during contraction.

LS 2012 fig 8-6b
Rope Climb or Tug of War
Grasp, then Regrasp!
Summary
We are almost there!
1. Acetylcholine released by axon of motor neuron crosses cleft and binds to receptors/channels on motor end plate.

2. Action potential generated in response to binding of acetylcholine and subsequent end plate potential is propagated across surface membrane and down T tubules of muscle cell.

3. Action potential in T tubule triggers Ca^{2+} release from sarcoplasmic reticulum.

4. Calcium ions released from lateral sacs bind to troponin on actin filaments; leads to tropomyosin being physically moved aside to uncover cross-bridge binding sites on actin.

5. Myosin cross bridges attach to actin and bend, pulling actin filaments toward center of sarcomere; powered by energy provided by ATP.

6. Ca^{2+} actively taken up by sarcoplasmic reticulum when there is no longer local action potential.

7. With Ca^{2+} no longer bound to troponin, tropomyosin slips back to its blocking position over binding sites on actin; contraction ends; actin passively slides back to original resting position.

LS 2006 cf: LS 2012 fig 8-10
Relaxation Phase

1. Excitation by nerve fiber
2. Conduction by T-tubules
3. Ca$^{2+}$ release by SR

Contractile Phase

D Liang & VP
Lombardi 1989
Muscle Contraction Resources

https://www.ncbi.nlm.nih.gov/books/NBK9961/

https://www.youtube.com/watch?v=jUBBW2Yb5KI

https://www.youtube.com/watch?v=sJZm2YsBwMY

A. Malcolm Campbell
Davidson College, Davidson, NC
www.bio.davidson.edu/courses/movies.html

David Bolinsky, XVIVO
Rocky Hill, CT
http://www.xvivo.net/
Adaptations to Exercise?
Mode, Intensity, Duration, Frequency, Distribution of Training Sessions?
Conditions of Environment? Individual?
Adaptations to Exercise?

Body Levels of Organization?
Which Body System?

Molecular
Cell/Tissue
Organ
Body System
Echocardiography documents hypertrophy...
Cardiac Adaptations to Exercise:

1. Endurance vs. 2. Strength Training

\[ NB: 1 \geq \uparrow LBM \]

1 + 2
As muscles tug on bones, bones get stronger, too!...many systems adapt!!
Muscle Adaptations to Exercise
Atrophy

decrease in size & strength

Hypertrophy

increase in size & strength
Skeletal Muscle

Atrophy

Hypertrophy

Hyperplasia
Women & Hypertrophy?
What happens in muscles at cellular & subcellular levels?
Hypertrophy: *Increased Number of Myofibrils, Thick & Thin Filaments, Myosin & Actin Molecules*
## Characteristics of Skeletal Muscle Fibers

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Slow Oxidative (Type I)</th>
<th>Fast Oxidative (Type IIa)</th>
<th>Fast Glycolytic (Type IIb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myosin-ATPase Activity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Speed of Contraction</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Resistance to Fatigue</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Aerobic Capacity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Anaerobic Capacity</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
<tr>
<td>Mitochondria</td>
<td>Many</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Capillaries</td>
<td>Many</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Myoglobin Content</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Color of Fibers</td>
<td>Red</td>
<td>Red</td>
<td>White</td>
</tr>
<tr>
<td>Glycogen Content</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
</tbody>
</table>
Changes in Muscle Due to Strength Training

↑ Size of larger fast vs smaller slow fibers
↑ CP as well as creatine phosphokinase (CPK) which enhances short-term power output
↑ Key enzymes which help store and dissolve sugar including glycogen phosphorylase (GPP) & phosphofructokinase (PFK)
↓ Mitochondrial # relative to muscle tissue
↓ Vascularization relative to muscle tissue
↑ Splitting of fast fibers? Hyperplasia?
With growth hormone (GH), androgenic-anabolic steroids (AAS)?
Changes in Muscle Due to Endurance Training

↑ Mitochondria, # & size
↑ Mitochondrial (aerobic) enzymes including those specific for fat burning
↑ Vascularization of muscles (better blood flow)
↑ Stores of fat in muscles accompanied by
↓ Triglycerides/fats in bloodstream
↑ Enzymes: activation, transport, breakdown (β-oxidation) of fatty acids
↑ Myoglobin (enhances O₂ transport)
↑ Resting energy levels which inhibit sugar breakdown
↑ Aerobic capacity of all three fiber types.
Which end of continuum?

+ 

Which energy nutrient/s?
Which specific muscles?
Dancing can be super aerobic exercise, too, & you don’t have to be a star!
Extremes of the energy continuum!