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

II. **Action Potential + Neuromuscular Junction Connections** LS 7
What’s an AP? What do black widow spider venom, botulism, curare & nerve gas have in common? LS fig 7-5 p190 Botox?

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? LS fig 8-5
E. Banding pattern? LS fig 8-3, fig 8-7
F. How do muscles contract? LS fig 8-6, 8-10
G. What's a cross-bridge cycle? LS fig 8-11 +…
H. Summary of skeletal muscle contraction
I. Exercise adaptation variables: *mode, intensity, duration, frequency, distribution, individual & environment?*
J. Endurance vs. strength training continuum? fiber types...
- Action potential
- After hyperpolarization

Membrane potential (mV)

- Na⁺ equilibrium
- Threshold
- Resting potential
- K⁺ equilibrium

Time (msec)

1 msec
Falling phase
Caused by K⁺ exiting

Rising phase
Caused by Na⁺ entry

Threshold
**Synapse** = Generic term = connection between excitable cells!

- Presynaptic neuron
- Direction of conduction of nerve impulse
- Vesicles containing neurotransmitters
- Mitochondrion
- Synaptic cleft
- Postsynaptic neuron
- Receptors on postsynaptic membrane bound to neurotransmitter

DC 2003
Neuromuscular junction
= Nerve-muscle connection
3

Axon of motor neuron
Myelin sheath
Action potential propagation in motor neuron

Terminal button
Vesicle of acetylcholine
Calcium channel
Action potential propagation in muscle fiber

Plasma membrane of muscle fiber
Acetylcholine receptor site
Cation channel
Acetylcholinesterase
Local current flow between depolarized end plate and adjacent membrane

Motor end plate
Contractile elements within muscle fiber
Skeletal Muscles

Body systems maintain homeostasis

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

LS 2012 ch 8 vignette
Muscle fiber or cylindrical cell

“Threads” ≡ Myofibrils

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

x1000

H Howard 1980.
Organ = Muscle

Cell = Myocyte = Fiber

Subcellular = Cytoskeleton

Molecules = Actin & Myosin

LS 2006, cf:
LS 2012 fig 8-2
DC 2013 fig 12-3
Golf Club Analogy?

(a) Actin binding site
   Myosin ATPase site
   Heads
   Tail
   100 nm

(b) Myosin molecules
   Cross bridges

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

Myosin Heads

Myosin Tails

Myosin Heads

Bare Zone
Actin molecules

Binding site for attachment with myosin cross bridge

Actin helix

+ 

Tropomyosin

Troponin

Thin filament

LS 2006, cf:
LS 2012 fig 8-5
Sarcomere

Triad $\equiv$ T tubule abutting cisternae

Mitochondria

Myofibril

Sarcomere
A Band = Dark Band
Anisotropic = Light Can’t Shine Through

I Band = Light Band
Isotropic = Light Can Shine Through
Sarcomere

Z line  H zone  I band  A band  Z line

Relaxed

H zone shorter
I band shorter
A band same width

Contracted

Sarcomere shorter

Thick filament
Thin filament

LS 2012 fig 8-7
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 Ca\(^{2+}\) is released.

2. Released 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.
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
David Bolinsky, XVIVO
Rocky Hill, CT
http://www.xvivo.net/
muscleanimation.mov
A. Malcolm Campbell
Davidson College, Davidson, NC
http://www.bio.davidson.edu/misc/movies/musclcp.mov
Adaptations to Exercise?

Mode, Intensity, Duration, Frequency, Distribution of Training Sessions? Conditions of Environment? Individual?
Adaptations to Skeletal Voluntary Muscle
Atrophy
*decrease in size & strength*

Hypertrophy
*increase in size & strength*
Skeletal Muscle

Hyperplasia

Hypertrophy

Atrophy
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?