Announcements: Optional notebook + Lab 6

Pulmonary Function Testing today. Q?

Pulmonary Function Lab Overview

Muscle Structure & Function: LS ch 8, DC Module 12

A. How is skeletal muscle organized? LS fig 8-2, DC fig 12-2
B. What do thick filaments look like? LS fig 8-4, DC fig 12-4
C. How about thin filaments? LS fig 8-5
D. Banding pattern? LS fig 8-3, fig 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
H. Exercise adaptation variables: mode, intensity, duration, frequency, distribution, individual & environmental char...?
I. Endurance vs. strength training continuum? fiber types...
NB: Should be able to blow out $\geq 75 - 85\%$ of VC/FVC in 1 second! That's $\text{FEV}_{1.0}/\text{FVC} \geq 0.75 - 0.85$. If less, may indicate asthma or other lung disease.

*Respirometer* $\rightarrow$ measures complete *Pulmonary Function Test* or *PFT*!
PFT measures all lung volumes & capacities (sum of ≥ 2 volumes). Subject relaxes & breathes normally into and out of tank.
 Spirogram graphing complete PFT from computer simulation.

**Normal Spirogram of Healthy Young Adult Male**

- **TV** = Tidal volume (500 ml)
- **IRV** = Inspiratory reserve volume (3,000 ml)
- **IC** = Inspiratory capacity (3,500 ml)
- **ERV** = Expiratory reserve volume (1,000 ml)
- **RV** = Residual volume (1,200 ml)
- **FRC** = Functional residual capacity (2,200 ml)
- **VC** = Vital capacity (4,500 ml)
- **TLC** = Total lung capacity (5,700 ml)
**Vitalometer** → Can only measure **Vital Capacity** (VC). No graph paper, so no time component.
Inhale air in room maximally!

NB: noseclip & mouthpiece!
Exhale into tube maximally!
More modern-day computerized Pulmonary Function Testing

Complete with HH!
Happy Helpers!
How to put together?
Sample subject setup
Thoughtful, identical twin, group partner with incredible quickness, speed & agility!
Q about lab?

Sample data!
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

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

(a)

(b)

Actin binding site
Myosin ATPase site

Heads

Tail

100 nm

Cross bridges

Myosin molecules

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

Myosin Heads

Myosin Tails

Bare Zone

Myosin Heads
Actin molecules

Actin helix

Tropomyosin

Troponin

Thin filament

Binding site for attachment with myosin cross bridge

LS 2006, cf:
LS 2012 fig 8-5
Triad ≡ T tubule abutting cisternae

Mitochondria

Sarcomere

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

I Band = Light Band
Isotropic = Light Can Shine Through
Discussion + Time for Questions!
What do we guess happens at the molecular level?
Cross-Bridge Cycle

1. **Energized**
   - Energy
   - ADP
   - P_i

2. **Resting**
   - Energy
   - ADP
   - P_i

3. **Binding**
   - Ca^{++} present (excitation)

4. **Detachment**
   - ATP (Mg^{++})

5. **Bending (power stroke)**
   - Energy
   - ADP
   - P_i

6. **Rigor complex**
   - Fresh ATP available
   - No ATP (after death)

LS 2006, cf: LS 2012 fig 8-11
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!
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.
Muscle Contraction Resources

https://ed.ted.com/lessons/how-your-muscular-system-works-emma-bryce

https://ed.ted.com/on/s3Zzdm8u


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

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?
Muscle Adaptations to Exercise
As muscles tug on bones, bones get stronger, too!...many systems adapt!!
Echocardiography documents hypertrophy...
Cardiac Adaptations to Exercise: 
① Endurance vs. ② Strength Training

NB: ① > ↑ LBM
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 Ila)</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!