Chapter 12
Muscles!

Office hours:
Mon: 2:30 - 3:30
Wed: 2:30 - 5:30
Fri: 9:30 - 11:00
and
By appointment.

http://www.geneseo.edu/~lewis/phys/human%20phys.asp

Clinical Investigation

• Facts
  – Active, 40 yr. old female patient
  – Fatigue and muscle pain
  – Tight muscles
  – High maximal O₂ uptake with exercise.
  – Normal blood levels of creatine phosphokinase
  – Elevated blood calcium concentration
  – Takes calcium channel-blocking drug to control hypertension.

The three types of muscle fibers

- Skeletal-muscle fiber
- Cardiac-muscle fiber
- Smooth-muscle fiber

Fig not in book
Muscle cell
- Fusion of many individual cells = multinucleated
- Composed of many subunits = myofibrils
- Myofibrils composed of myofilaments
  - Actin and myosin
- Sarcoplasmic reticulum surrounds myofibrils
  - Specialized endoplasmic reticulum
- Sarcolemma - plasma membrane of cell
  - Contains transverse (t) tubules

Muscle cells grouped into muscle fiber bundles (fasciculus).
Muscle fiber columns grouped into muscles surrounded by fascia.
Connected to bone by tendons
The Neuromuscular Junction = motor end plate + axon.

- Motor neurons
  - Activate skeletal muscles (somatic efferents).
  - Cell bodies in brainstem or spinal cord.
- Motor unit
  - Motor neuron + muscle fibers it innervates.
- Motor end plate
  - Region of muscle fiber plasma membrane that lies just beneath terminal portion of axon.

Motor Unit

- Each somatic neuron together with all the muscle fibers it innervates.
- Each muscle fiber receives a single axon terminal from a somatic neuron.
- Each axon can have collateral branches to innervate an equal # of fibers.
Motors Unit

When somatic neuron activated, all the muscle fibers it innervates contract with all or none contractions.

- Innervation ratio:
  - Ratio of motor neuron: muscle fibers.
  - Fine neural control over the strength occurs when many small motor units are involved.

- Recruitment:
  - Larger and larger motor units are activated to produce greater strength.
Mechanisms of Contraction

- AP travels down the motor neuron to bouton.
- VG Ca$$^+$$ channels open, Ca$$^+$$ diffuses into the bouton.
- Ca$$^+$$ binds to vesicles of NT.
- ACh released into neuromuscular junction.
- ACh binds onto receptor.
- Chemical gated channel for Na$$^+$$ and K$$^+$$ open.

Events at the neuromuscular junction:
- Na$$^+$$ diffuses into and K$$^+$$ out of the membrane.
- End-plate potential occurs (depolarization).
- Positive ions are attracted to negative membrane.
- If depolarization sufficient, threshold occurs, producing AP.

Mechanisms of Contraction

- AP travels down sarclemma and T tubules.
- Terminal cisternae release Ca$$^{++}$$. 

Fig. 12.15
Fig. 12.16

Fig. 12.6 and 12.7

Fig. not in book
Sliding Filament Theory

- Sliding of filaments is produced by the actions of **cross bridges**.
- Cross bridges are part of the myosin proteins that form arms that terminate in heads.
- Each myosin head contains an ATP-binding site.
- The myosin head functions as a myosin ATPase.

Refer to Fig. 12.9
Molecular mechanisms of contraction.

- **Contraction** - turning on of force-generating sites (cross-bridges) in a muscle fiber. DOES NOT NECESSARY MEAN "SHORTENING".
- **Relaxation** - following contraction whereby mechanisms that initiate force generation are turned off and tension declines.

Cross bridges in the thick filaments

![Diagram of cross bridges in thick filaments]

Thin filament

![Diagram of thin filament components]

(part of a) Thick filament

Fig not in book
Contraction

- Myosin binding site splits ATP to ADP and Pi.
- ADP and Pi remain bound to myosin until myosin heads attach to actin.
- Pi is released, causing the power stroke to occur.

Contraction

- Power stroke pulls actin toward the center of the A band.
- ADP is released, when myosin binds to a fresh ATP at the end of the power stroke.
- Release of ADP upon binding to another ATP, causes the cross bridge bond to break.
- Cross bridges detach, ready to bind again.
Contraction

- **A bands:**
  - Move closer together.
  - Do not shorten.

- **I band:**
  - Distance between A bands of successive sarcomeres.
  - Decrease in length.

- Occurs because of sliding of thin filaments over and between thick filaments.

- **H band shortens.**
  - Contains only thick filaments.

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**Regulation of Contraction:**
the importance of calcium

- **Recall:**
  - AP travels down sarclemma and T tubules.
  - Terminal cisternae release Ca++.
Mechanisms of Contraction

- Ca\(^{++}\) binds to troponin.
- Troponin-tropomyosin complex moves.
- Active binding site on actin disclosed.

Regulation of Contraction

- Regulation of cross-bridge attachment to actin due to:
  - Tropomyosin.
  - Troponin.

Role of Ca\(^{++}\)

- Relaxation:
  - [Ca\(^{++}\)] in sarcoplasm low when tropomyosin block attachment.
  - Ca\(^{++}\) is pumped back into the SR in the terminal cisternae.
  - Muscle relaxes.
Role of \( \text{Ca}^{++} \) in Muscle Contraction

- Stimulated:
- \( \text{Ca}^{++} \) is released from SR.
- \( \text{Ca}^{++} \) attaches to troponin
- Tropomyosin-troponin configuration change

Refer to Fig. 12.14

Contraction

- ACh-esterase degrades ACh.
- \( \text{Ca}^{++} \) pumped back into SR.
- Choline recycled to make more ACh.
- Only about 50% of cross bridges are attached at any given time.
  - Asynchronous action.

Excitation-Contraction Coupling

- Refers to sequence of events by which action potential in plasma membrane of muscle fiber leads to cross-bridge activity mechanisms.
Poisoning the Neuromuscular Junction.

- **Curare**
  - Snake poison.
  - Binds to acetylcholine receptors (Ach receptors).
  - Is not destroyed by acetylcholinesterase nor does it open ion channels.

- **Nerve Gas**
  - Inhibits acetylcholinesterase.

- **Clostridium botulinum** toxin
  - Blocks release of Ach from axon terminus.
Individual Homework for Thursday.

- Homework question - draw a graph of the effect of curare, nerve gas and botulinum toxin, on muscle contraction versus that of acetylcholine. Y-axis equals contraction from point of action potential; X-axis equals time. (model after figure shown a few slides back).

Mechanisms of Single Fiber Contraction.

- Tension - force exerted on an object by a contracting muscle.
- Load - force exerted on muscle by an object.
- Relative magnitudes of tension and load determine whether force generation leads to fiber shortening.

Mechanisms of Single Fiber Contraction.

- Isometric contraction (constant length) - when a muscle develops tension but does not shorten or lengthen.
- Isotonic contraction (constant tension) - contraction in which a muscle shortens while load on the muscle remains constant.
Fig. 12.17

Isometric and Isotonic Contractions

Fig. 12.18

An isometric twitch of a skeletal-muscle fiber

Twitch - mechanical response of single muscle fiber to a single action potential.

Recording Muscle Contractions

Summation

Twitch

Tetanus

Fatigue

Fig. 12.18
Tension produced by a muscle fiber depends on:

- Number of cross bridges bound to actin and undergoing step 2 of cross-bridge cycle in each sarcomere.
- Force produced by each cross-bridge.
- Amount of time the cross-bridge remains active.
• Strength during contraction can be altered by changing the length of fiber before contraction.
• Length at which the fiber develops the greatest isometric active tension is the optimal length, \( I_0 \).

Length-Tension

- Ideal resting length: generate maximum force.
- Overlap too small: few cross-bridges can attach.
- No overlap: no cross-bridges can attach to actin.

Fig. 12.20