Ch 12: Muscles

Review micro-anatomy of muscle tissue

*Terminology examples:* sarcolemma, t-tubules, sarcoplasmic reticulum, myofibrils, myofilaments, sarcomere...
SLOs

- Differentiate levels of muscle structure: muscle $\rightarrow$ muscle fascicle $\rightarrow$ muscle fiber $\rightarrow$ myofibril $\rightarrow$ sarcomere $\rightarrow$ thick and thin filaments $\rightarrow$ actin, myosin, troponin, tropomyosin, and titin.

- Describe motor units, and explain the significance of recruitment of motor units.

- Describe the banding pattern of a myofibril and how these bands change during muscle contraction.

- Outline the sliding filament theory of contraction.

- Diagram the molecular events of excitation-contraction coupling.

- Describe how muscles meet their constant energy requirements.

- Discuss the differences between slow-twitch fibers, fast-twitch oxidative-glycolytic fibers, and fast-twitch glycolytic fibers.

- Explain why each sarcomere contracts with optimal force if it is at optimal length.

- Explain how summation increases force of contraction and ends in tetanus.

- Describe what a motor unit is and how skeletal muscles can create graded contractions of varying force and duration.
Anatomy Review: Motor End Plates and Motor Units

- Motor end plate
- Motor unit: ____________________________
  ____________________________
  ____________________________
- Graded contractions: Contraction strength depends on how many different motor units are stimulated → motor unit recruitment
- Neuromuscular junction: Site where ..........

- NT used:
Neuromuscular Junctions and Motor End Plates

Figs 12.2 - 12.4
Fine Muscle Control

Finest muscle control with ________motor units (with ________muscle fibers).

• Eye muscles ~23 muscle fibers/motor units
• Calve muscles 1000s of muscle fibers
• Control and strength are trade-offs!

Motor units compare to Fig. 12.4
12.2 Mechanisms of Contraction: Sliding Filament Theory

Compare to Figs 12-7/8
Striations

• Sarcomere = unit of contraction

• Striations produced by thick and thin filaments

• Thick filament =

• Thin filament =
  I bands: contain.....
  A bands: contain.....
  H bands: contain.....
  Z discs (lines): ....

Fig 12-6
Myofibrils = Contractile Organelles of Myofiber

6 types of proteins make up myofibril:

- **Actin** • Contractile
- **Myosin** • Contractile
- **Tropomyosin** • Regulatory
- **Troponin** • Regulatory
- **Titin** • Accessory
- **Nebulin** • Accessory
Titin and Nebulin

• **Titin**: biggest protein known (25,000 aa); elastic!
  – *Function?*

• **Nebulin**: inelastic giant protein
  – *Function?*

*Compare to Fig 12-8*
Changes in a Sarcomere during Contraction

Myosin = motor protein: chemical energy (in form of _____) \(\rightarrow\) converted to mechanical energy of motion

Myosin “walks down” an actin fiber towards Z-line

?_____ - band shortens
?_____ - band does not shorten
Action of Sliding

1. Sliding produced by **cross bridge formation** when myosin head binds to actin

2. Myosin heads serve as a **ATPase enzyme**, splitting ATP into ______ + ____

   ⇒ Head binds to actin **when muscle is stimulated**

*Activation of myosin head Fig. 12.10*
3. Release of $P_i$ cocks myosin head ⇒ **power stroke** ⇒ pulls actin toward center of sarcomere

4. ADP released and a new ATP binds ⇒ myosin releases actin

5. ATP split ⇒ myosin head straightens out and rebinds to actin farther back

This cycle repeats until sarcomere shortened

**Fig. 12.11**
Contraction Cycle

1. ATP binds to myosin. Myosin releases actin.

2. Myosin hydrolyses ATP. Myosin head rotates and binds to actin.

3. Power stroke

4. Myosin releases ADP.

- Actin filament moves toward M line.

Tight binding in the rigor state

Relaxed state with myosin heads cocked

Compare to Fig 12-12
Crossbridges: The Molecular Basis of Contraction:

**Troponin & Tropomyosin = ___________ proteins**

Tropomyosin physically blocks cross bridges.

Troponin complex:
- *Troponin I* inhibits binding of myosin.
- *Troponin T* binds to tropomyosin.
- *Troponin C* binds to calcium.

*Fig 12-8*
Role of Calcium in Muscle Contraction

Muscle cell stimulated

→ Ca\(^{2+}\) release inside muscle fiber

→ Ca\(^{2+}\) attaches to troponin C

→ Conformational change

→ Myosin has access to form cross bridges with actin
Rigor mortis

Joint stiffness and muscular rigidity of dead body

Begins 2 – 4 h post mortem. Can last up to 4 days depending on temperature and other conditions

Ca$^{2+}$ ions not pumped out anymore and ATP depletion

Maximum stiffness ~ 12-24 h post mortem, then?

"Post-prandial Rigor Mortis, Miss Borgia, there's a lot of it about."

Lucrezia Borgia
Sarcoplasmic reticulum (SR) = _______________

Function?
Excitation-Contraction Coupling

Explains how you get from AP in axon to contraction in sarcomere

ACh released from somatic motor neuron

AP in muscle fiber

[Diagram showing the process of excitation-contraction coupling with labels for extracellular fluid, acetylcholine, ion channels, binding sites, and cytoplasm.]
E/C Coupling cont.

Net Na\(^+\) entry creates EPSP

AP to T-tubules

Voltage gated Ca\(^{2+}\) channels change shape

Ca\(^{2+}\) channels in SR open.

Intracellular [Ca\(^{2+}\)] ↑

Ca\(^{2+}\) binds to Troponin C
Electromechanical Release Mechanism of Ca\(^{2+}\)

1. Somatic motor neuron releases ACh at neuromuscular junction.
2. Net entry of Na\(^+\) through ACh receptor-channel initiates a muscle action potential.

**Compare to Fig 12-16**
Contraction

Ca\textsuperscript{2+} re-uptake into SR via Ca\textsuperscript{2+} ATPase also known as SERCA

Relaxation
12.3 **Contractions of Skeletal Muscles**

**Muscle twitch**: Contraction / relaxation cycle after a single electrical shock of sufficient voltage

**Latent period** – time between stimulus and contraction (EC coupling to attachment of myosin cross bridges to actin)
**Summation**: Graded contractions:
Stronger contractions result in recruitment of more fibers, until all fibers are contracting.
Force of Contraction

Increases with

- muscle-twitch summation
  (2\textsuperscript{nd} twitch may partially piggy-back on 1\textsuperscript{st})

and

- recruitment of motor units
Tetanus

Smooth, sustained contraction with no relaxation time between twitches.

Fig 12-19
**Length-Tension Relationship**

**Muscle strength is determined by:**

- Number of fibers recruited to contract
- Frequency of stimulation
- Thickness of each muscle fiber (thicker is stronger)
- Initial length of the fiber at rest

*Tension is maximal* when sarcomeres are at normal resting length.
Muscle Tension is Function of Fiber Length

- Sarcomere length reflects thick, thin filament overlap
- Short Sarcomere: Too much overlap
  \[\Rightarrow\] tension decreases rapidly
- Long Sarcomere: little overlap, few crossbridges
  \[\Rightarrow\] weak tension generation
12.4 Energy Requirements of Skeletal Muscles

Where / when is ATP needed?

1. 

2. 

3. 

Only enough ATP stored for 8 twitches
Twitch = single contraction relaxation cycle
Where does all the ATP come from?

**Phosphocreatine:** Backup energy source

Creatine produced by liver and kidneys or obtained in diet

Creatine supplements can increase muscle phosphocreatine and aid short-term high-energy exercise, but long-term use may damage liver.
Muscles Fuel Consumption during Exercise

- Rest & mild exercise: Aerobic respiration of fatty acids
- Moderate exercise: Glycogen stores
- Heavy exercise: Blood glucose

Insertion of GLUT4 into sarcolemma!

Fig 12-22
Muscle Adaptation to Exercise

**Endurance training:**
- More & bigger mitochondria
- More enzymes for aerobic respiration
- More myoglobin
  - no hypertrophy

**Resistance training:**
- More actin & myosin proteins & more sarcomeres
- More myofibrils
  - muscle hypertrophy
Muscle Fiber Classification: Slow- and Fast-Twitch Fibers

- **Slow-twitch Fibers** (Type I)
  - Oxydative
  - Muscle fiber characteristics:
    - Is aerobic
    - Has steady power
    - Has endurance

- **Fast-twitch Fibers** (Type II X)
  - Glycolytic
  - Muscle fiber characteristics:
    - Is anaerobic
    - Has explosive power
    - Fatigues easily
Type II A fibers or fast oxidative fibers

Also known as intermediate (type II A) fibers

Fast-twitch but with high oxidative capacity

% of fast- vs. slow-twitch fibers in a person’s muscles depends on
• genetics and
• Training

Endurance training leads to increase of type IIA and decrease of type IIX
Neural control of skeletal muscles and smooth muscles not covered

Cardiac muscles covered later

"To keep you moving we put bacon grease on your neck and light it on fire. That's why we call it our Fat Burning Workout."