Chapter 8:

Skeletal Muscle: Structure and Function

Objectives
- Draw & label the microstructure of skeletal muscle
- Outline the steps leading to muscle shortening
- Define the concentric and isometric
- Discuss: twitch, summation & tetanus

Objectives
- Discuss the major biochemical and mechanical properties of skeletal muscle fiber types
- Discuss the relationship between skeletal muscle fibers types and performance
- List & discuss those factors that regulate the amount of force exerted during muscular contraction

Skeletal Muscle
- Human body contains over 400 skeletal muscles
  - 40-50% of total body weight
- Functions of skeletal muscle
  - Force production for locomotion and breathing
  - Force production for postural support
  - Heat production during cold stress

Muscle
- 3 types in humans
  - Smooth, nonstriated (GI tract)
  - Striated, skeletal
  - Striated, cardiac

Muscle Structure
- Muscle fiber-single muscle cell
- Muscle is a number of muscle fibers bounded together by connective tissue
- Muscle-few hundred fibers bound together
- Muscle-several thousand fibers
Muscle Structure

- Length
  - Few mm to 40-50 mm
- Diameter
  - 10-100 microns (micrometer; μm)
  - Nearly invisible without magnification
  - One millionth of a meter
  - .000001 m

Muscle Structure

- Nerve and blood vessels weave throughout muscle
  - 3 to 4 capillaries around each muscle fiber in sedentary people
  - 5 to 7 capillaries around fibers in endurance trained
- 2 to 3 capillary/muscle fiber increase

Connective Tissue Covering Skeletal Muscle

- Epimysium
  - Surrounds entire muscle
- Perimysium
  - Surrounds bundles of muscle fibers
  - Fascicles
- Endomysium
  - Surrounds individual muscle fibers

Microstructure of Skeletal Muscle

- Within the sarcoplasm
  - Sarcoplasmic reticulum
  - Storage sites for calcium
  - Transverse tubules
  - Terminal cisternae
  - Mitochondria

Within the Sarcoplasm

Fig 8.3
The Neuromuscular Junction
- Where motor neuron meets the muscle fiber
- Motor end plate: pocket formed around motor neuron by sarcolemma
- Neuromuscular cleft: short gap
- Ach is released from the motor neuron
  - Causes an end-plate potential (EPP)
  - Depolarization of muscle fiber

Muscular Contraction
- The sliding filament model
  - Muscle shortening occurs due to the movement of the actin filament over the myosin filament
  - Formation of cross-bridges between actin and myosin filaments “Power stroke”
    - 1 power stroke only shorten muscle 1%
  - Reduction in the distance between Z-lines of the sarcomere

Sarcomere
- Basic functional unit of myofibril
- Joined end to end at Z disk-myofibril
- Between Z disks
  - Actin – thin filament
  - Myosin – thick filaments

Actin
- Thin filament
  - Double stranded
  - Binding site
    - With each myosin head
  - Troponin with calcium binding site
    - Tube-shaped protein
  - Tropomyosin
    - Attached at regular intervals to
      - Actin
      - Tropomyosin
Myosin

- Myosin head
  - Thick area sticking out from ends of filament
  - Crossbridges
- Myosin tails
  - Strands wrapped around each other

Actin & Myosin Relationship

![Fig 8.6](image_url)

Sarcomere-rest

- Two Z lines
- I band
  - Actin filaments
  - Anchored to Z lines
- A band
  - Myosin filaments
  - Some actin overlap
- H zone
  - No actin present

Sarcomere-contraction

- Actin filaments slide over myosin filaments
- I band shortens
- Z lines pulled towards center
- A band length doesn’t change
- Neither filament changes in length
- H zone disappears

Energy for Muscle Contraction

- ATP is required for muscle contraction
  - Myosin ATPase breaks down ATP as fiber contracts
- Sources of ATP
  - Phosphocreatine (PC)
  - Glycolysis
  - Oxidative phosphorylation

Phases of Contraction

- Rest
- Excitation-coupling
- Contraction
- Recharging
- Relaxation
Excitation-Contraction Coupling

- Depolarization of motor end plate (excitation) is coupled to muscular contraction
  - Nerve impulse travels down T-tubules and causes release of Ca++ from SR
  - Ca++ binds to troponin and causes position change in tropomyosin, exposing active sites on actin
  - Permits strong binding state between actin and myosin and contraction occurs

Rest

- Crossbridges (CB, myosin heads) extend
  - No interaction with actin
- ATP molecule is bound to CB
- ATP molecule is uncharged
- Calcium stored in SR
- Troponin inhibits actin/myosin binding with no free calcium

Excitation/Coupling

- Impulse from motor nerve reaches motor end plate
  - Ach released
- Ach stimulates impulse on sarcolemma
- Impulse goes down T-tubules to SR
- This releases calcium stored in terminal cisternae

Excitation/Coupling

- Ca is taken up by troponin-turns on active sites
- Uncharged ATP molecule becomes charged
- Charged Ca and ATP are attracted
- Physical/chemical coupling occurs
  - Actomyosin complex

Myosin heads attach to actin
Contraction
- Actomyosin complex activates enzyme
  - ATPase-catalyst to cause change
- ATP → ATPase → ADP + Pi (energy release)
- Energy for CB to RATCHET
- Actin filament slides over myosin
- Sliding develops tension and movement

Recharging
- Actin and myosin make and break hundreds of times/sec
- Continual recharging is necessary
- Old bond of actomyosin is broken by
  - Reloading ATP molecule on CB which then-
  - Breaks actomyosin complex
  - Rotates back to starting position (SWIVES) to attach to new
    active site

Relaxation
- Nerve impulses cease
  - No Ach released
  - No Ca released from SR
  - No Ca and ATP attraction
  - No actomyosin complex
  - No sliding

Relaxation
- Ca$^{2+}$ unbound from troponin
  - Pumped back into SR
  - This “turns off” actin
  - ATP on CB unable to form bond
  - Muscle is relaxed

Analysis of Skeletal Movement
- 1. Nerve impulse to motor end plate
- 2. Release of acetylcholine
- 3. Ach stimulates impulse to sarcolemma
- 4. Impulse goes down T-tubules to terminal cisternae
- 5. Impulse causes release of Ca$^{2+}$ from terminal cisternae
- 6. Ca$^{2+}$ is bound by troponin
  - “turns on” active sites on actin filament

OVERVIEW
Motor neuron releases Ach-receptors
AP triggers release of Ca from SR
Ca binds to troponin,
Myosin head attaches
Analysis of Movement

7. Uncharged ATP CB complex becomes charged
8. "Charged" ATP complex means actin and myosin are physically attracted to each other
   - Actomyosin complex is formed
9. Formation of actomyosin complex activates ATPase
10. ATP breaks down

11. 7-12 kcals released
12. Myosin CB RATCHETS
13. Actin slides
14. Z lines come closer together, sarcomere shortens
15. I bands shorten
16. Myofibrils shorten over fiber length
17. Reloading of ATP molecule on CB

Analysis of Movement

18. Breaks actomyosin complex
    (Myosin CB release from actin)
19. Myosin CB SWIVELS (return to starting position)
20. As myofibrils shorten
21. Endomysium moves
22. Perimysium moves
23. Muscle shortens

24. Epimysium moves
25. Tendon moves
26. Bone moves
27. Skeletal movement
28. Motor impulses cease
29. Ca²⁺ pumped back into terminal cisternae

Properties of Muscle Fiber Types

Biochemical properties
   - Oxidative capacity
   - Type of ATPase
Contractile properties
   - Maximal force production
   - Speed of contraction
   - Muscle fiber efficiency
Individual Fiber Types

**Fast fibers**
- Type IIx fibers
  - Fast-twitch fibers
  - Fast-glycolytic fibers
- Type IIa fibers
  - Intermediate fibers
  - Fast-oxidative glycolytic fibers

**Slow fibers**
- Type I fibers
  - Slow-twitch fibers
  - Slow-oxidative fibers

Muscle Fiber Types

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Fast Fibers</th>
<th>Slow fibers</th>
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<tbody>
<tr>
<td>Number of mitochondria</td>
<td>Type IIx</td>
<td>Type IIa</td>
</tr>
<tr>
<td>Resistance to fatigue</td>
<td>Low</td>
<td>High/mod</td>
</tr>
<tr>
<td>Predominant energy system</td>
<td>Anaerobic</td>
<td>Combination</td>
</tr>
<tr>
<td>ATPase</td>
<td>Highest</td>
<td>High</td>
</tr>
<tr>
<td>$V_{max}$ (speed of shortening)</td>
<td>Highest</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Specific tension</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Comparison of Maximal Shortening Velocities Between Fiber Types

Fiber Types and Performance

- **Power athletes**
  - Sprinters
  - Possess high percentage of fast fibers
- **Endurance athletes**
  - Distance runners
  - Have high percentage of slow fibers
- **Others**
  - Weight lifters and nonathletes
  - Have about 50% slow and 50% fast fibers

Alteration of Fiber Type by Training

- **Endurance and resistance training**
  - Early research
  - Cannot change fast fibers to slow fibers
  - More recent
  - Weight training
    - Can result in shift from Type IIx to IIa fibers (incomplete)
    - Toward more oxidative properties
  - **Endurance training**
    - Ten weeks, 90 min/day
    - Type IIx to Type I

Histochemical Staining of Fiber Type
Training-Induced Changes in Muscle Fiber Type

Age-Related Changes in Skeletal Muscle
- Aging is associated with a loss of muscle mass
  - Rate increases after 50 years of age
- Regular exercise training can improve strength and endurance
  - Cannot completely eliminate the age-related loss in muscle mass

Types of Muscle Contraction
- Isometric
  - Muscle exerts force without changing length
  - Pulling against immovable object
  - Postural muscles
- Isotonic (dynamic)
  - Concentric
    - Muscle shortens during force production
  - Eccentric
    - Muscle produces force but length increases

Speed of Muscle Contraction and Relaxation
- Muscle twitch
  - Contraction as the result of a single stimulus
  - Latent period
    - Lasting only ~5 ms
  - Contraction
    - Tension is developed
    - 40 ms
  - Relaxation
    - 50 ms

Isotonic and Isometric Contractions

Muscle Twitch
Force Regulation in Muscle

- Types and number of motor units recruited
  - More motor units = greater force
  - Fast motor units = greater force
  - Increasing stimulus strength recruits more & faster/stronger motor units

- Initial muscle length
  - “Ideal” length for force generation

- Nature of the motor units neural stimulation
  - Frequency of stimulation
    - Simple twitch, summation, and tetanus

Relationship Between Stimulus Frequency and Force Generation

- Maximal response

Initial muscle length

- "Ideal" length for force generation

Nature of the motor units neural stimulation

- Frequency of stimulation
  - Simple twitch, summation, and tetanus

Simple Twitch, Summation, and Tetanus

Length-Tension Relationship

- Optimal length
- Greater than optimal length
- Less than optimal length

Force-Velocity Relationship

- At any absolute force the speed of movement is greater in muscle with higher percent of fast-twitch fibers
- The maximum velocity of shortening is greatest at the lowest force
  - True for both slow and fast-twitch fibers

Force-Velocity Relationship

- < 40% PT
- > 90% PT

Fig 8.16

Fig 8.17

Fig 8.18

Fig 8.19
Force-Power Relationship

- At any given velocity of movement the power generated is greater in a muscle with a higher percent of fast-twitch fibers.
- The peak power increases with velocity up to movement speed of 200-300 degrees•second⁻¹.
  - Force decreases with increasing movement speed beyond this velocity.

Receptors in Muscle

- Muscle spindle
  - Changes in muscle length
  - Rate of change in muscle length
  - Intrafusal fiber contains actin & myosin, and therefore has the ability to shorten.
  - Gamma motor neuron stimulate muscle spindle to shorten.

- Stretch reflex
  - Stretch on muscle causes reflex contraction.

Receptors in Muscle

- Golgi tendon organ (GTO)
  - Monitor tension developed in muscle.
  - Prevents damage during excessive force generation.
  - Stimulation results in reflex relaxation of muscle.