Skeletal Muscle Physiology

Objectives
1. Structure & function of skeletal muscle
2. Training for power
   • Anaerobic
   • Aerobic
3. Strength training

Gross Structure
- Long multi-nucleated fibers
- Levels of organization:
  1. Endomysium: wraps each fiber
  2. Perimysium: surrounds several fibers (up to 150) and forms bundles called a fasciculus
  3. Epimysium: surrounds all the bundles to form the entire muscle
- Tendons:
  • Connective tissue (periosteum of bone to muscle)
    ✓ Origin – more stable bone; Insertion – moving bone

Gross Structure (cont.)
- Sarcolemma:
  • Muscle cell membrane
- Satellite cells:
  • myogenic stem cells located within the sarcolemma
    ✓ Help regenerative cell growth
    ✓ Play a role in hypertrophy
- Sarcoplasmic Reticulum:
  • Extensive lattice-like network of tubules and vesicles
    ✓ Provides structural integrity
    ✓ Stores, releases, and reabsorbs Ca^{2+}

Figure 18.1
Chemical Composition

- 75% water
- 20% protein
  - Myosin
  - Actin
  - Tropomyosin & Troponin
  - Myoglobin
- 5% salts, phosphates, ions, and macronutrients

Blood Supply

- Skeletal muscle has a rich vascular network
  - Enhanced capillarization with training
    - Increased capillary-to-muscle-fiber ratio
- Flow is rhythmic during aerobic activity
  - Vessels compressed during contraction phase
  - Vessels open during relaxation phase
- During sustained contractions > 60% capacity
  - Occludes localized blood flow (elevated intramuscular pressure)
  - Anaerobic processes supply ATP

Skeletal Muscle Ultrastructure

Muscle Fiber Alignment

- Long Axis of a Muscle
  - From origin to insertion
  - Determines fiber arrangement
    1. Fusiform
    2. Pennate
    3. Bipennate
- Fiber arrangement influences:
  - Force generating capacity
  - Physiological cross sections (PCSA)
    - Sum of cross-sectional areas of all the fibers within the particular muscle
The degree of pennation directly affects the number of sarcomeres per cross-sectional area:
- Allows for packing a large number of fibers into a small cross-sectional area
- Able to generate considerable power

**Greater force & power**

- **Rapid muscle shortening**
- **Effect on force**
- **Effect on fiber packing**

**Figure 18.4**

**Fiber Length:Muscle Length Ratio**

- Fusiform muscles (long fibers) show a longer working range and lower maximum force output
- Pennate muscles (short fibers) show a shorter working range & approximately double the force output

**Actin-Myosin Orientation**

- Actin filaments lie in a hexagonal pattern around myosin
- Cross-bridges spiral around the myosin where actin and myosin overlap

**Figure 18.6**
Actin-Myosin Orientation (cont.)
- Tropomyosin: lies along actin in the groove formed by the double helix
  - Covers cross-bridge binding site
- Troponin is embedded at regular intervals along actin
  - Interacts with Ca\(^{2+}\)
  - Moves tropomyosin, revealing binding sites

Intracellular Tubule Systems
- The sarcoplasmic reticulum is distributed around the myofibrils such that each sarcomere has 2 triads
- Each triad contains:
  - 2 vesicles
  - 1 T-tubule

Sliding Filament Model
- Contraction occurs as myosin and actin slide past one another
- Myosin cross-bridges cyclically attach, rotate, and detach from actin filaments
- Energy is provided by ATP hydrolysis
**Mechanical Action of Cross-bridges**
- Myosin Cross-bridge contain actin-activated ATPase
- Provides ability for mechanical movement
- Cross-bridging performs repeated, nonsynchronous pulling or ratcheting

**Sarcomere Length-Isometric Tension Curves**

**Link Between Actin, Myosin, & ATP**
1. Myosin head bends around ATP molecule and becomes ready for movement
2. Myosin interacts with actin
3. ATP is hydrolyzed
4. Energy release forces the bound sight to move
Excitation-Contraction Coupling

- The electrical discharge at the muscle that initiates the chemical events at the muscle cell surface
  - Release of Ca\(^{2+}\)

Neuromuscular Junction (REVIEW)

- Action potential propagation in motor neuron
- Acetylcholine release
- Voltage-gated Na\(^{+}\) channel
- Voltage-gated calcium channel
- Acetylcholine receptor site
- Muscle fiber

Relaxation

- Ca\(^{2+}\) is actively pumped back into SR
- Troponin allows tropomyosin to interfere with actin-myosin interaction

Muscle Fiber Type

- Two distinct fiber types identified by characteristics:
  1. Contractile
  2. Metabolic

Slow-Twitch Fibers: TYPE I

- Low myosin ATPase activity
- Slower Ca\(^{2+}\) release and reuptake by SR
- Low glycolytic capacity
- Large number of mitochondria
Fast-Twitch Fibers: TYPE II
- High capacity to transmit AP
- High myosin-ATPase activity
- Rapid release and reuptake of Ca\(^{2+}\) by SR
- High rate of cross-bridge turnover
- Capable of high force generation
- Rely on anaerobic metabolism
  - ATP-PCr
  - Glycolysis

Fast-Twitch Subdivisions
- IIa Fibers
  - Fast shortening speed
  - Moderately well-developed capacity for both anaerobic and aerobic energy production
- IIb Fibers
  - Most rapid shortening velocity
  - Rely on anaerobic energy production

Fiber Type Differences Among Athletic Groups
- Large individual difference in fiber type distribution
- Endurance athletes:
  - > TYPE I fibers
  - Some as high as 90–95% in gastrocnemius
- Speed and power athletes:
  - > TYPE II fibers
- Middle distance athletes:
  - More even fiber distribution

Fiber Type vs. VO\(_{2}\)max

Measurement of Muscle Strength
- Cable tensiometry:
Measurement of Muscle Strength (cont.)

- Dynamometry
  - One-repetition maximum (1-RM)
  - Estimations of 1-RM

Measurement of Muscle Strength (cont.)

- Computer-assisted, electromechanical, and isokinetic methods
  - Isokinetic dynamometer

Strength-testing considerations

- Standardize pre-testing instructions
- Uniformity of warm-up
- Adequate practice
- Standardize testing protocol
  - Body position, size & composition
  - Joint angles
  - Reps (pre-determined minimum number of trials)
  - Scoring criteria (select tests with high reproducibility)

Gender Differences

- Several applied approaches to determine whether or not a gender difference exists:
  - Based on evaluation of:
    1. Muscle’s cross-sectional area
    2. Absolute basis of total force exerted
    3. Architectural characteristics
    4. Relative to body mass or FFM

Greater CSA = greater strength
Training for Strength Improvement

- Muscles need to be trained close to its current force-generating capacity
  - Overload Principle

- Systematic approach to the Overload Principle:
  - Progressive resistance training
  - Isokinetic training
  - Isometric training

Types of Muscle Contractions

- Progressive resistance, isokinetic & isometric training relies on 3 different muscle actions:
  1. Concentric action
     - Muscle shortening
  2. Eccentric action
     - Muscle lengthening
  3. Isometric action
     - No net change in muscle length

Equal strength per CSA

Absolute muscle strength greater in men

*muscle mass distribution

Little difference in strength when expressed in relative terms

Types of Muscle Contractions
**Resistance Training for Children?**

**Progressive Resistance Training**
- Progressive resistance exercise general recommendations (ACSM Guidelines):
  1. Between 3-RM to 12-RM to improve strength
  2. Additional 1-RM lifts once per week may significantly increase strength
  3. One set is effective if 10-RM is used
    - Produce most of the health benefits
    - Increase compliance
    - 2–3 days/week is most effective
  4. Faster rate of movement improves strength over a slower rate (generally)

**Periodization**
- Incorporates 4 distinct phases:
  1. Preparation phase
    - Modest strength development
    - Focus on high volume, low intensity
  2. First transition phase
    - Emphasis on strength development
    - Focus on moderate volume, moderate intensity
  3. Competition phase
    - Selective strength development
    - Focus on low volume, high intensity
  4. Second transition phase (active recovery)
    - Recreational activities & low intensity workouts

**Practical Recommendations (Program Initiation)**
- Avoid maximal lifts initially
- Use 12-RM to 15-RM initially
- Increase weight after 2 weeks
  - Use 6–8 RM
  - Progress gradually
- Work larger muscle groups first & progress to smaller muscle groups
Other Principles of Strength Training

➢ Combination of strength & endurance training
  • Inhibition of strength improvements

➢ Isometric strength training
  • Limited in ROM & practical application
  • Beneficial for isolating weakness angles during rehabilitation

➢ Static vs. dynamic methods
  • Specificity of the training response (sport performance)
  • Combination of neural & fiber recruitment

Other Principles of Strength Training (cont.)

➢ Isokinetic resistance training
  • Provides muscle overload at a preset constant speed while the muscle mobilizes its force-generating capacity throughout the full ROM
  • Theoretically stimulates the largest number of motor units

➢ Isokinetic exercise allows for determination of force-velocity patterns associated with various movements
  • Also allows for fiber type comparison for a given movement

Other Principles of Strength Training (cont.)

➢ Plyometric training
  • Incorporates various explosive jumping activities to mobilize the inherent stretch-recoil characteristics of the muscle
  • Avoid the disadvantage of having to decelerate in the latter part of the joint ROM

Figure 22.15
Structural & Functional Adaptations

Factors Modifying the Expression of Strength

Psychologic-Neural adaptations:
- More efficient neural recruitment patterns
- Increased CNS activation
- Improved motor unit coordination
- Lowered neural inhibitory reflexes
- Inhibition of GTO (Golgi Tendon Organs)

Psychologic-neural factors account for most initial strength gains

Factors Modifying the Expression of Strength (cont.)

Muscular adaptations:
- Muscle fiber size (hypertrophy) & strength
- Decreased twitch contraction time
- Enzymes CK, PFK & myokinase (MK)
- Resting levels of ATP, glycogen & PCr
- Strength of tendons & ligaments
- Bone mineral content

Muscular adaptations include ↓ in:
- Body fat & associated changes in BMR
- Mitochondria volume & density

Hyperplasia (↑ cells) vs. Hypertrophy

General adaptation involves cellular proliferation (increased fiber # or hypertrophy)
Changes in Fiber-Type Composition

Only changes in recruitment patterns

Training Adaptations & Gender

- Amount of absolute muscle hypertrophy represents primary difference
  - Probably resulting from gender-specific differences in hormonal levels
    - Higher testosterone levels
  - Substantial hypertrophy (relative) regardless of gender after/during training

Muscle Strength & Bone Density

Circuit Resistance Training

- Benefit of increasing caloric output
  - Vary according to circuit
- Aerobic improvement:
  - ~ 50% less than improvement observed in cycling or running
    - Due to predominance of CRT including upper body exercise
- Hypertrophic response:
  - Lower than traditional resistance training

Muscle Soreness & Stiffness

- Delayed-onset muscle soreness (DOMS) caused by:
  - Minute tears in muscle tissue
  - Osmotic pressure changes causing fluid retention
  - Muscle spasms
  - Overstretching (eccentric exercises)
  - Acute inflammation
  - Alteration of Ca^{2+} regulation (depressed rate of uptake into SR)

Current DOMS Model
Soreness Ratings & Subsequent Light Exercise

Figure 22.30