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 (*periosteium* 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+}

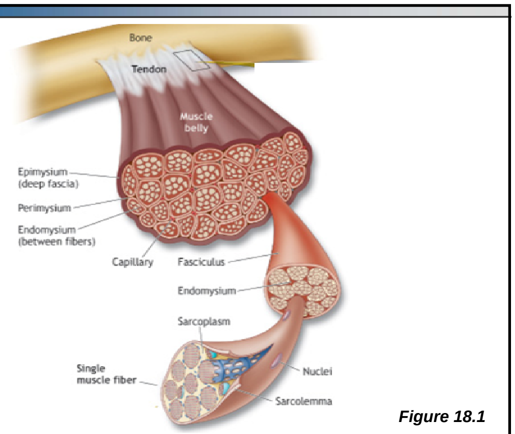
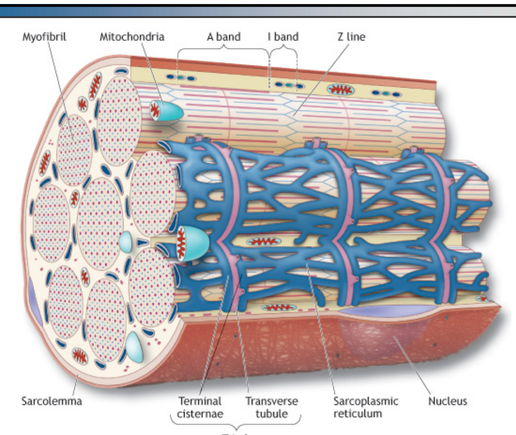


Figure 18.1



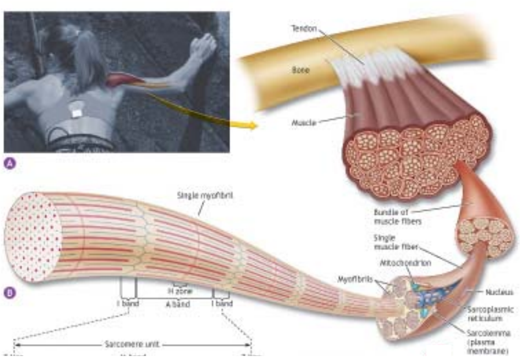
Chemical Composition

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

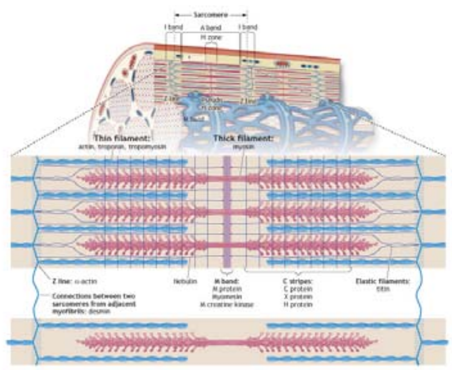
Blood Supply

- 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



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

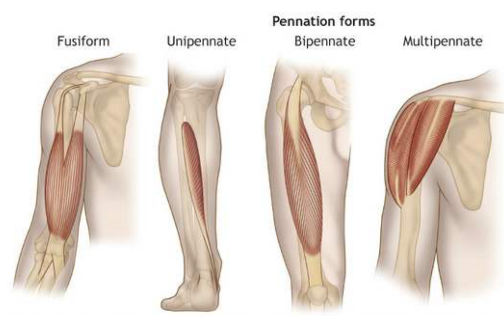


Figure 18.5

- 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

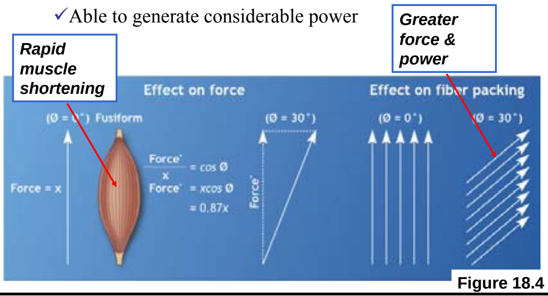
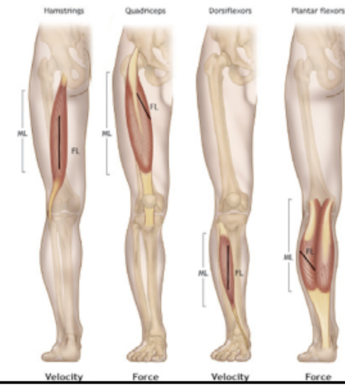
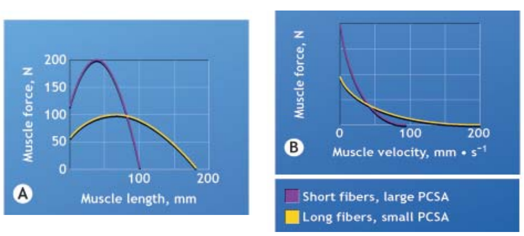


Figure 18.4

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

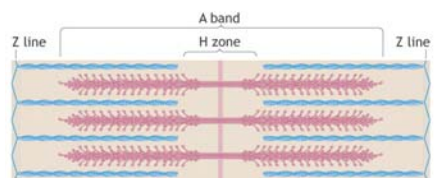
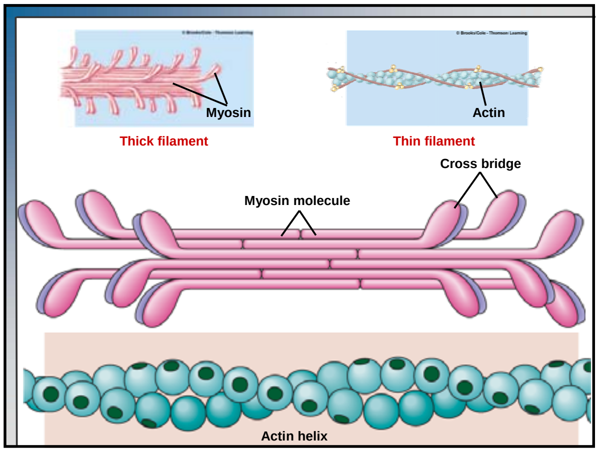
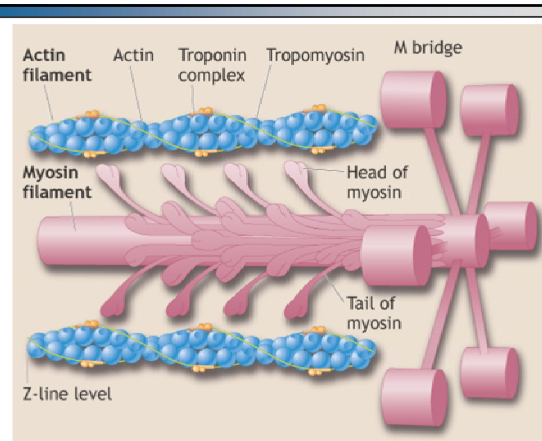


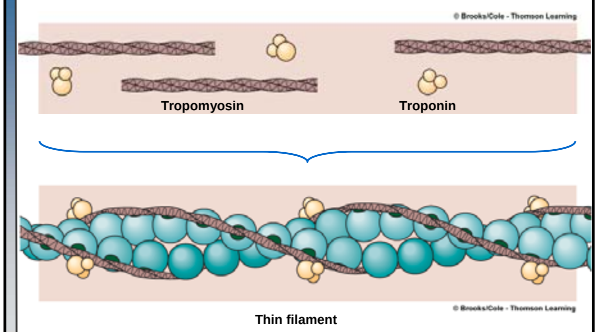
Figure 18.6





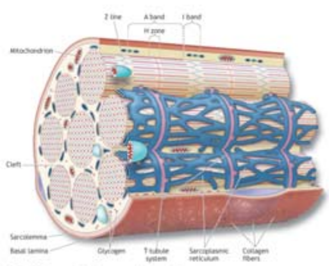
Actin-Myosin Orientation (cont.)

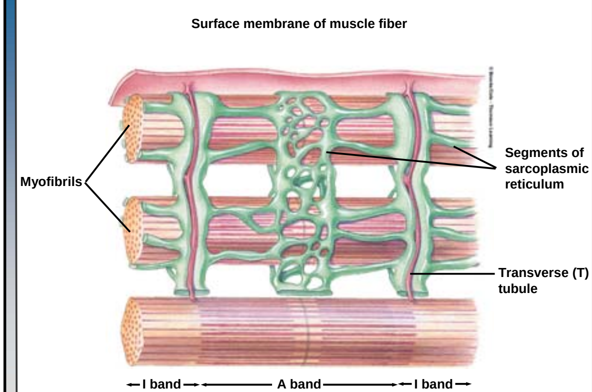
- Tropomyosin: lies along actin in the groove formed by the double helix
  - Covers cross-bridge binding site
- Troponin is embedded at regular intervals along actin
  - Interacts with Ca^{2+}
  - Moves tropomyosin, revealing binding sites



Intracellular Tubule Systems

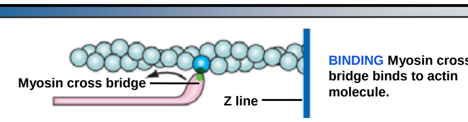
- The sarcoplasmic reticulum is distributed around the myofibrils such that each sarcomere has 2 triads
- Each triad contains:
  - 2 vesicles
  - 1 T-tubule





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



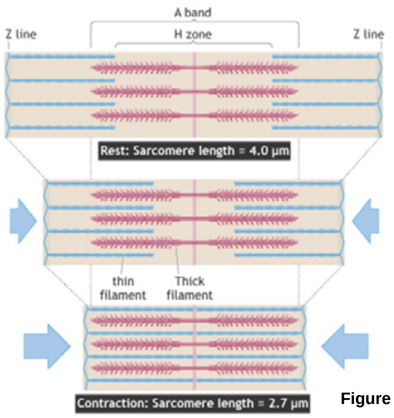


Figure 18.9

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

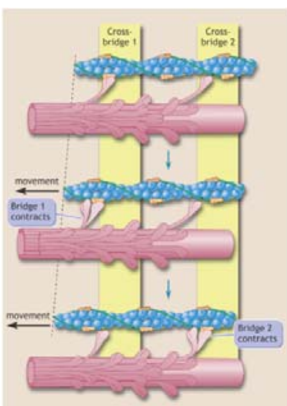
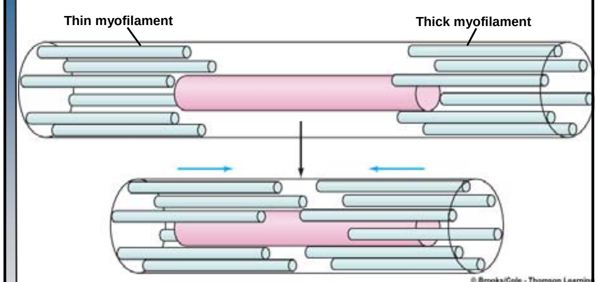


Figure 18.10



Sarcomere Length-Isometric Tension Curves

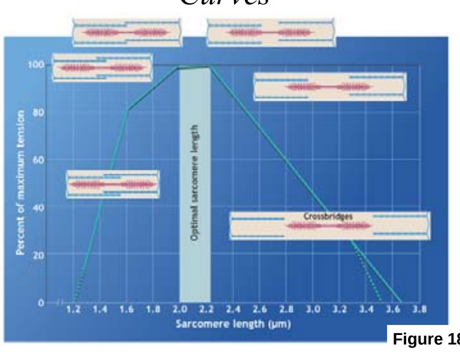


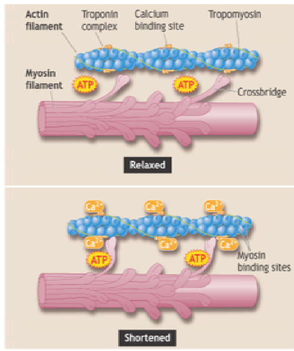
Figure 18.11

Link Between Actin, Myosin, & ATP

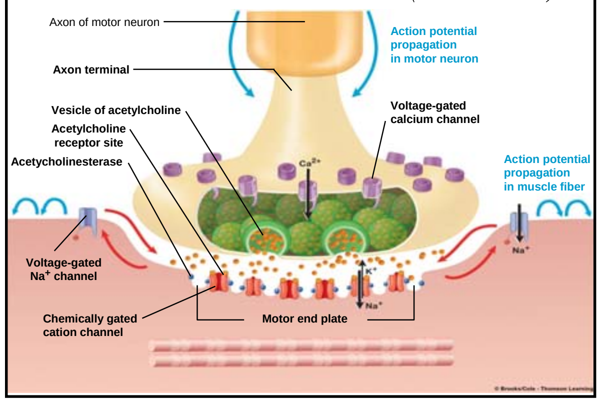
1. Myosin head bends around ATP molecule and becomes ready for movement
2. Myosin interacts with actin
3. ATP is hydrolyzed
4. Energy release forces the bound sight to move

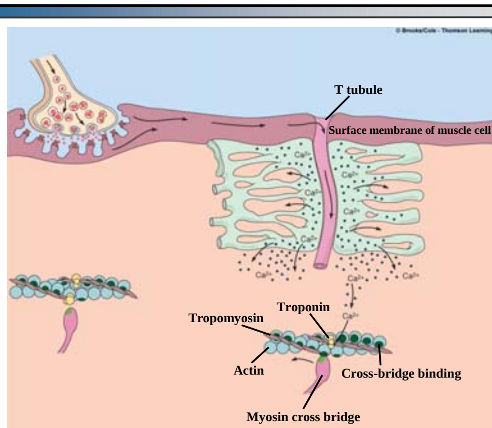
Excitation-Contraction Coupling

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



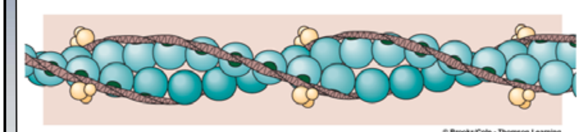
Neuromuscular Junction (REVIEW)





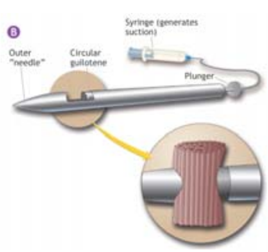
Relaxation

- 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_2max

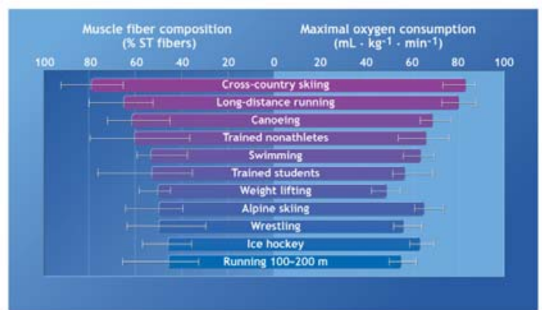
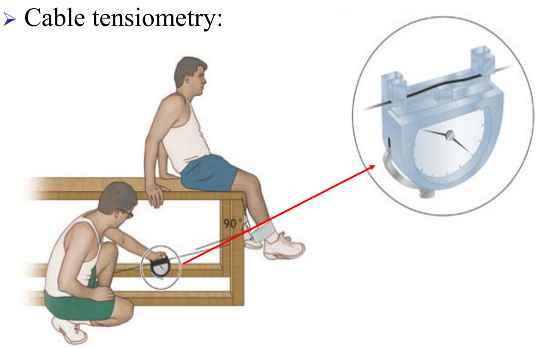


Figure 18.17

Muscular Strength Training

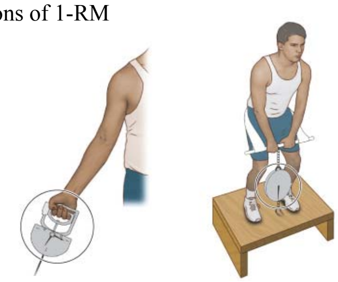
Measurement of Muscle Strength

- Cable tensiometry:



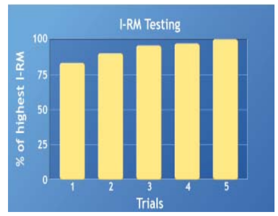
Measurement of Muscle Strength (cont.)

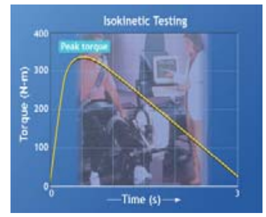
- Dynamometry
  - One-repetition maximum (1-RM)
  - Estimations of 1-RM



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)

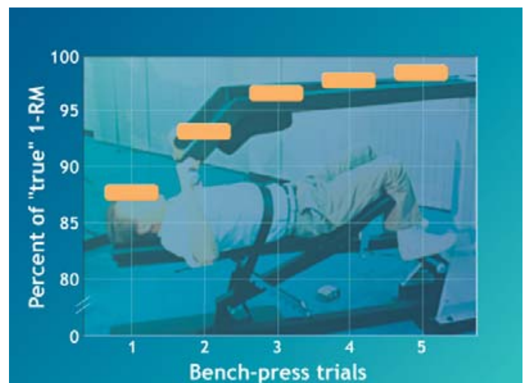


Figure 22.3

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

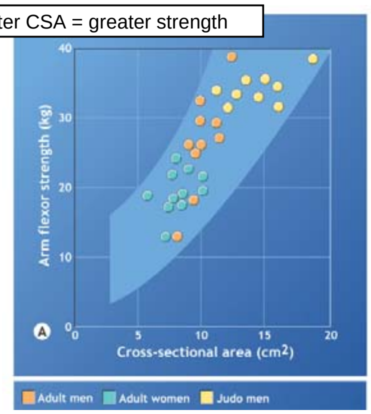
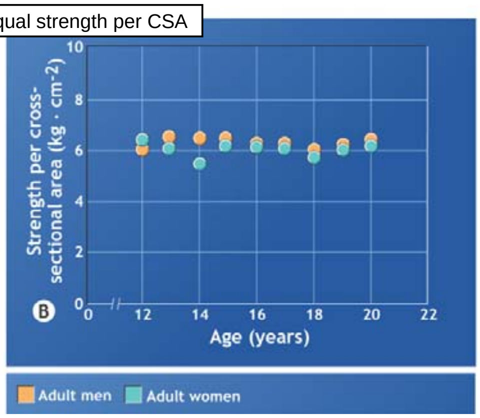


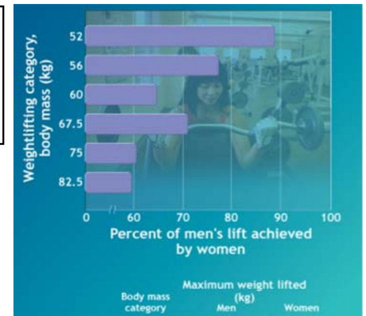
Figure 22.4

Equal strength per CSA

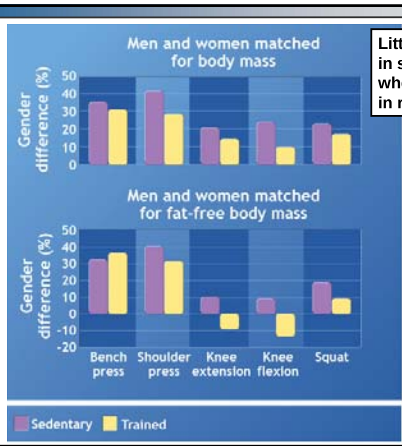


Absolute muscle strength greater in men

**muscle mass distribution*



Body mass category	Men	Women
52 kg	185.5	165.0
56 kg	202.5	160.0
60 kg	260.0	170.0
67.5 kg	275.0	197.5
75 kg	290.0	177.5
82.5 kg	325.0	195.0



Little difference in strength when expressed in relative terms

Figure 22.6

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

Types of Muscle Contractions

Concentric **Eccentric** **Isometric**

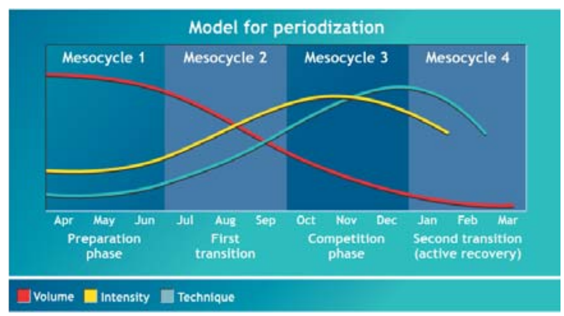
Resistance Training for Children?

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



Macrocycles, Mesocycles & Microcycles

4 Phases of Periodization

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

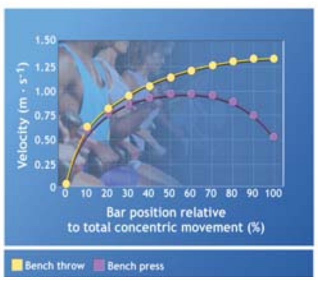
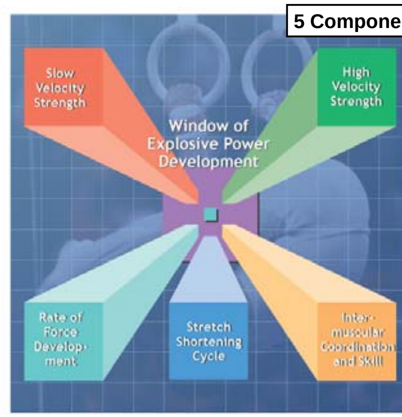


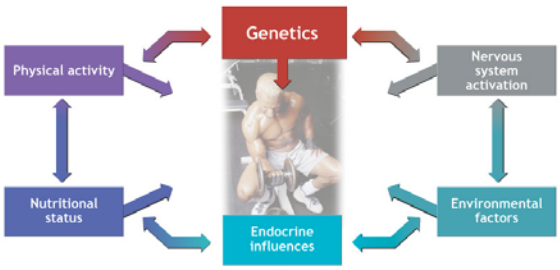
Figure 22.15




5 Component Model



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

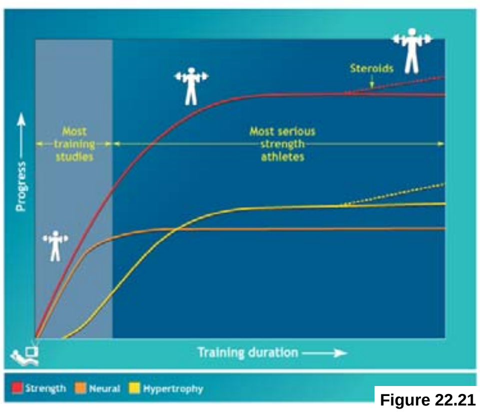


Figure 22.21

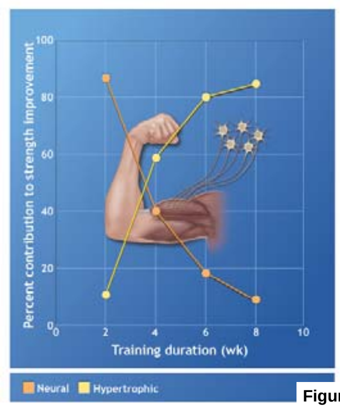
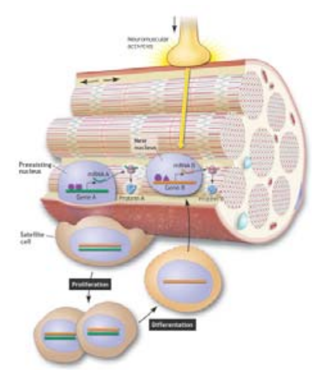


Figure 22.22

Factors Modifying the Expression of Strength (cont.)

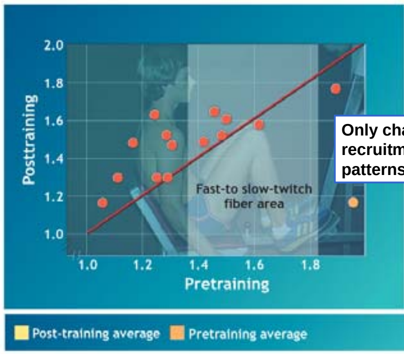
- Muscular adaptations:
  - Muscle fiber size (hypertrophy) & strength
  - Decreased twitch contraction time
  - Enzymes CK, PFK & myokinase (MK)
  - Resting levels of ATP, glycogen & PCr
  - Strength of tendons & ligaments
  - Bone mineral content
- Muscular adaptations include ↓ in:
  - Body fat &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

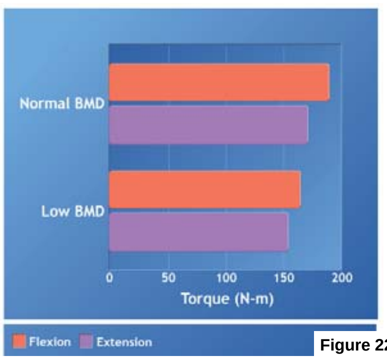


Figure 22.29

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 inflamation
  - Alteration of Ca^{2+} regulation (depressed rate of uptake into SR)

Current DOMS Model

Soreness Ratings & Subsequent Light Exercise

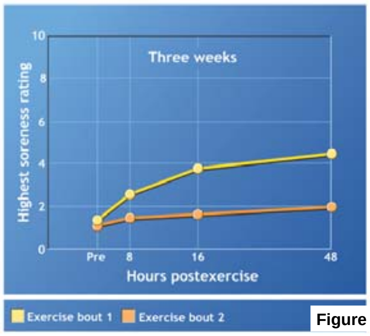


Figure 22.30