Muscle Physiology

Lecture Outline

- Muscle Function
- Muscle Characteristics
- Muscle Tissue Types
- Skeletal Muscle
  - General Functions of Skeletal Muscle
  - Functional Anatomy
  - Physiology
  - Skeletal Muscle Types
  - Energetics
  - Adaptive Responses
- Cardiac Muscle Physiology
- Smooth Muscle Physiology

Muscle Function

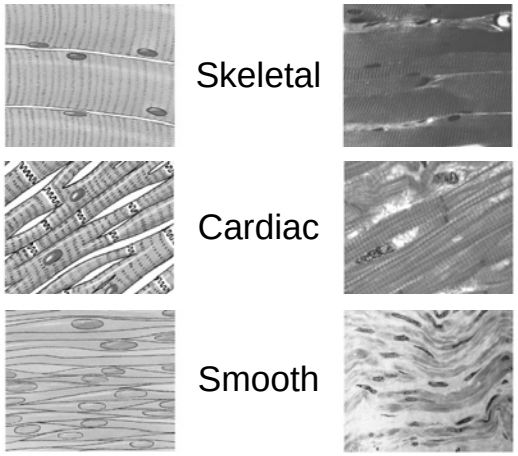
- Movement
  - Depends on type of muscle tissue
  - Depends on location of muscle tissue
- Thermogenesis
- Protection
- Posture Maintenance
- Joint Stabilization

Muscle Tissue Characteristics

All muscle tissues share basic characteristics

1. Excitability
2. Contractility
3. Elasticity
4. Extensibility

Muscle Tissue Types



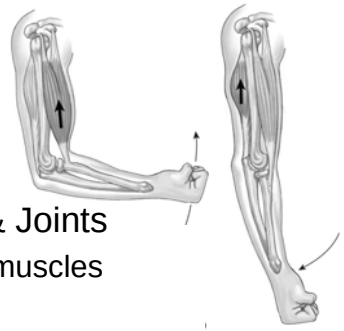
Muscle Comparison Chart

Muscle Tissue	Cell Shape	Striae	Nucleus	Control	Special structures
Skeletal	Cylindrical	Yes	Multi-nucleate & peripheral	Voluntary	none
Cardiac	Cylindrical & branched	Yes	Uninucleate & central	Involuntary	Intercalated discs
Smooth	Fusiform	No	Uninucleate & central	Involuntary	May be single-unit or multi-unit

Skeletal Muscle

General Functions - Voluntary

- Movement
  - Only have contractility in one direction
    - Requires multiple muscles to create movements from the simple
      - flexion and extension
    - To the complex
      - Circumduction
- Stabilizing Movements & Joints
  - The result of synergistic muscles



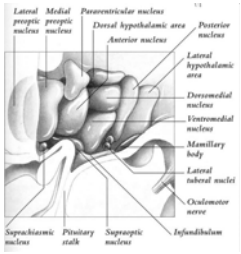
Skeletal Muscle

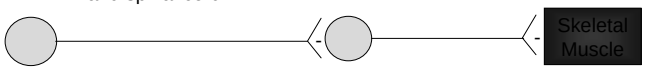
General Functions

- Protection
  - of underlying structures
    - abdominal viscera
  - Stronger muscles = greater protection, increased joint stability

Skeletal Muscle
General Functions - Involuntary

- Shivering Thermogenesis (shivering reflex)
  - asynchronous & involuntary
  - Initiated by hypothalamic nuclei in the primary motor center for shivering (posterior nuclei)
    - Normally inhibited by the heat center in the hypothalamus (preoptic nuclei) when body temp is in range (96.8-99.5)
      - Receives cold signals from skin and spinal cord





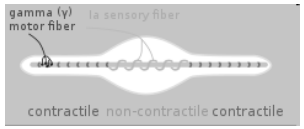
preoptic nucleus

posterior nucleus

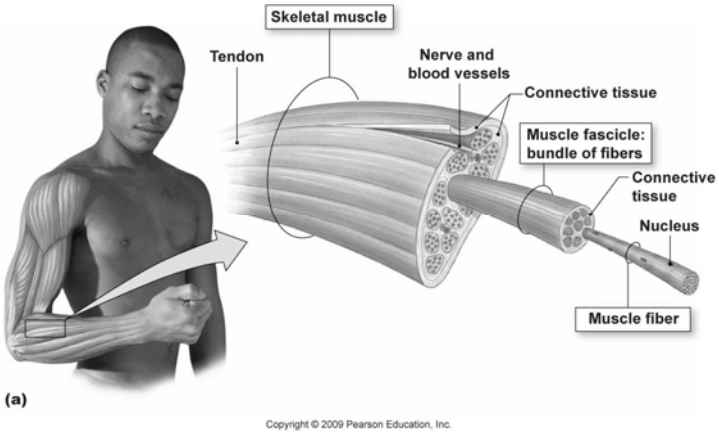
Damage to the posterior nuclei would cause?

Skeletal Muscle
General Functions - Involuntary

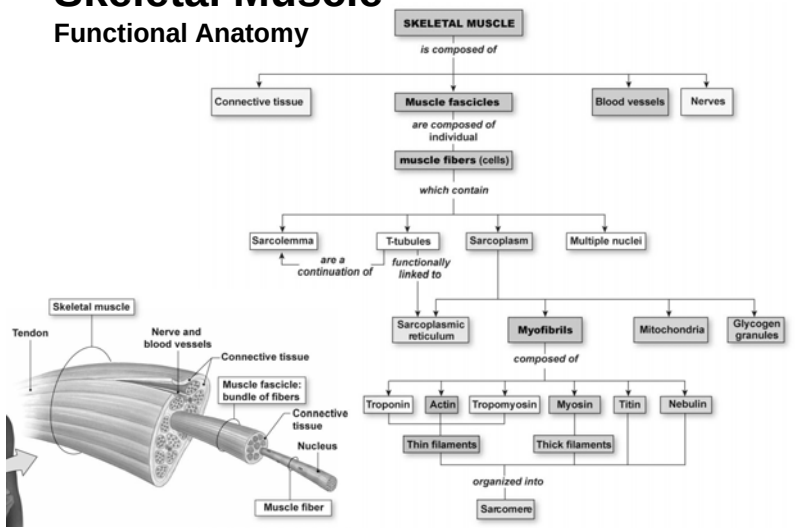
- Maintenance of Posture
  - Involves stretch reflexes
    - Static reflexes
      - Long term sustained contractile events
    - Phasic reflexes
      - Dynamic and short term corrective responses
    - Regulated by gamma neurons which adjust tension in the muscle spindles



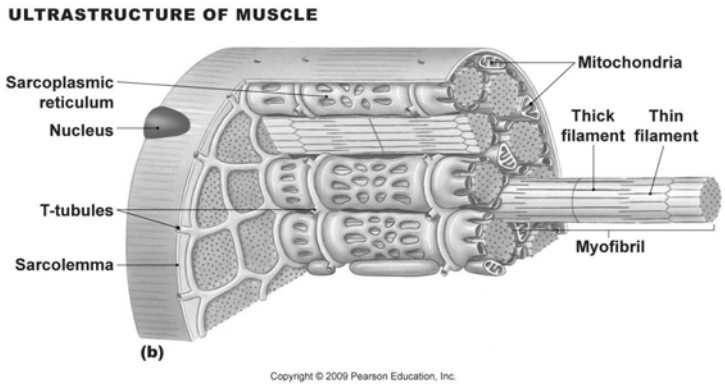
Skeletal Muscle
Functional Anatomy



Skeletal Muscle
Functional Anatomy

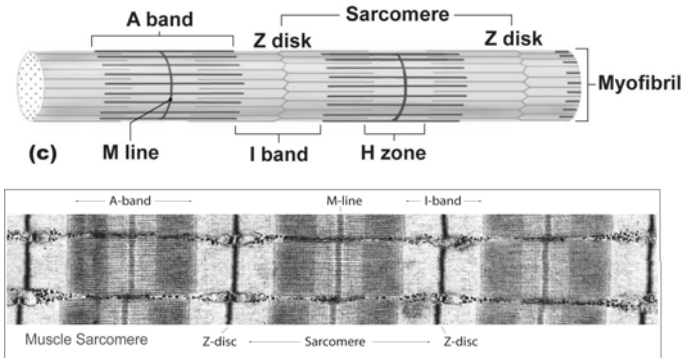


Skeletal Muscle
Functional Anatomy



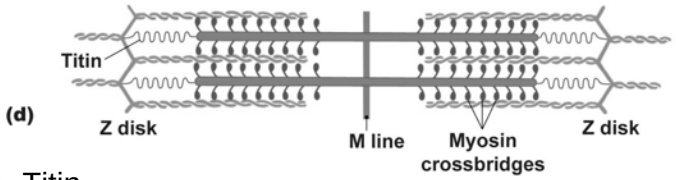
Skeletal Muscle
Functional Anatomy

- The smallest functional unit of skeletal muscle is the sarcomere



Skeletal Muscle
Functional Anatomy

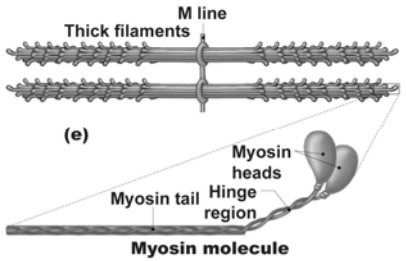
- Sarcomere is composed of various microfilaments and supporting structures



- Titin
  - largest known elastomeric protein
  - Connects myosin to z-disc
  - thought to be critical in the development of sarcomeres

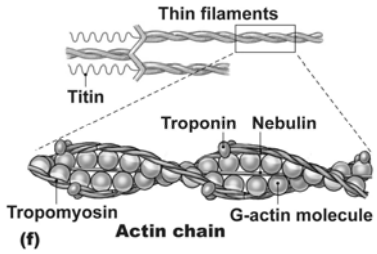
Skeletal Muscle
Functional Anatomy

- Myosin molecule consists of tail, hinge and heads
  - Heads contain active sites for
    - Actin
    - ATP
- M-line consists of myomesin and skelemin proteins
  - stabilize the myosin filaments
  - theorized to aid in transmission of force from sarcomere to cytoskeletal intermediate filaments



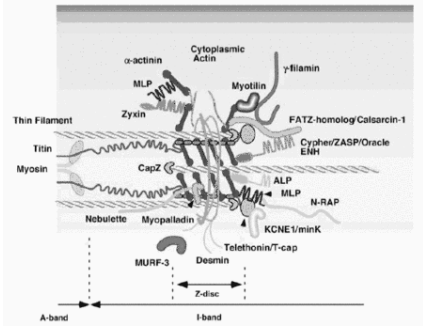
Skeletal Muscle
Functional Anatomy

- Thin filaments are composed of
  - g-actin molecules in a helical arrangement
    - Contain myosin binding sites
  - nebulin
    - Filament that forms internal support and attachment for actin
  - tropomyosin filaments
  - troponin molecules attached to tropomyosin
    - Has binding sites for Ca^{2+}



Skeletal Muscle
Functional Anatomy

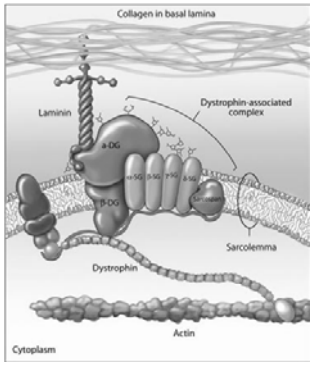
- The Z-disc
  - Anchors the filaments and interacts with cytoskeletal framework



Skeletal Muscle
Functional Anatomy

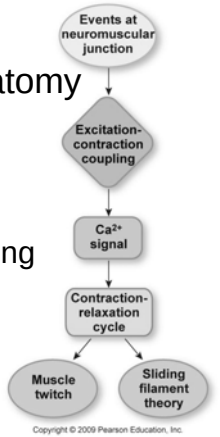
- Transmission of force from the sarcomere to the tissue at large
  - Sarcomeres linked by distrophin to sarcolemma, then via membrane proteins interacting with cytoskeletal framework

Muscular Dystrophy?



Skeletal Muscle
Physiology of Contraction

- How does all this functional anatomy work?
  - 1st – synaptic transmission at the neuromuscular junction
  - 2nd – excitation-contraction coupling
  - 3rd – contraction-relaxation cycle



Skeletal Muscle

Physiology of Contraction - NMJ

1. Events at the neuromuscular junction (NMJ)
   a. action potential arrives at the pre-synaptic membrane
   b. depolarization of membrane opens voltage gated Ca^{2+} channels
   c. calcium influxes into synaptic bulb
   d. calmodulin is activated by Ca^{2+} which
   e. activates protein kinase II (PK II)
   f. PKII phosphorylates synapsin (motor protein)
   g. vessicle binds to membrane proteins (SNAREs)
   h. exocytosis of ACh
   i. ACh binds to nicotinic receptors
   j. Na^{+} influx creates an End Plate Potential (EPP)
   k. EPP spreads to edge of the motor end plate and initiates an action potential in the sarcolemma

Skeletal Muscle

Physiology of Contraction – Excitation-Contraction Coupling

2. Excitation-Contraction Coupling Process
   a. Action potential spreads along sarcolemma and down t-tubules
   b. Depolarization of membrane alters membrane protein dihydropyridine L (DHP) configuration
   c. Altered DHP configuration signals ryanodine Ca^{2+} receptors (RyR Ca^{2+}) in the terminal cisternae of the sarcoplasmic reticulum
      - Neatly, these are near the I and A bands of the sarcomere!
   d. Ca^{2+} is released into the sarcoplasm and
   e. binds to troponin
   f. initiates a conformational change in the troponin-tropomyosin complex exposing the binding sites for myosin on actin
   g. Myosin binds to actin (electrostatic attraction)

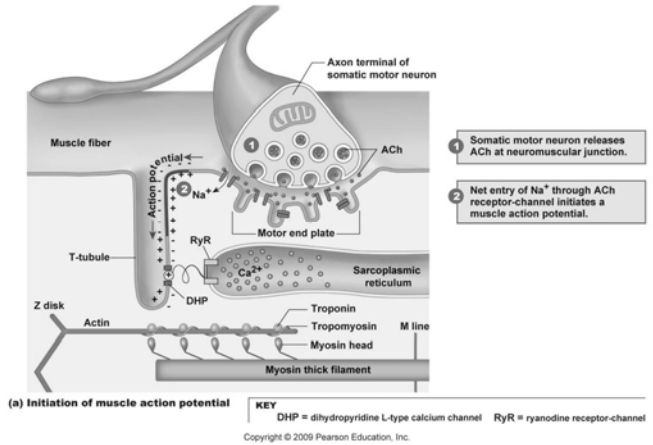
Skeletal Muscle

Physiology of Contraction – Contraction-Relaxation Cycle

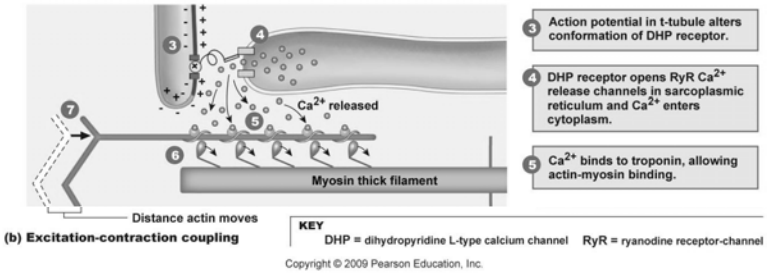
3. Contraction-Relaxation Cycle
   a. Myosin upon attaching to actin is hydrolized (phosphate coming from the splitting of ATP by Myosin ATPase)
   b. This changes the conformation of myosin causing it to bend at the neck towards the m-line
   c. ADP is released by the conformational change during the “power stroke”
   d. ATP binding site is now available for another ATP (along with magnesium Mg^{2+})
   e. Splitting of ATP to ADP + P by myosin detaches and returns myosin to its active state
   f. This single event creates a twitch

Skeletal Muscle

Physiology of Contraction

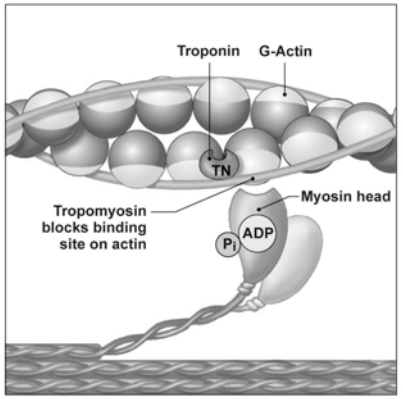


Skeletal Muscle
Physiology of Contraction



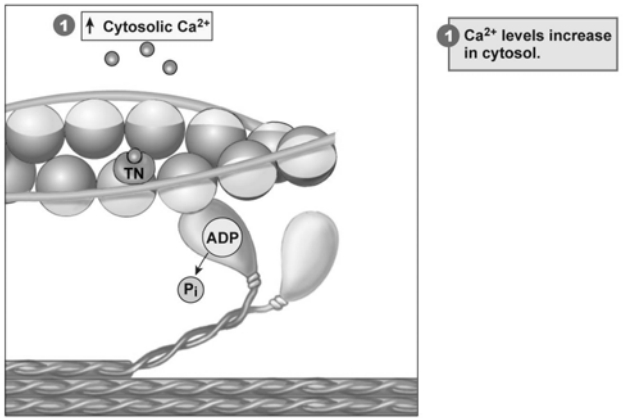
(b) Excitation-contraction coupling

Skeletal Muscle
Physiology of Contraction



(a) Relaxed state. Myosin head cocked.

Skeletal Muscle
Physiology of Contraction



(b) Initiation of contraction

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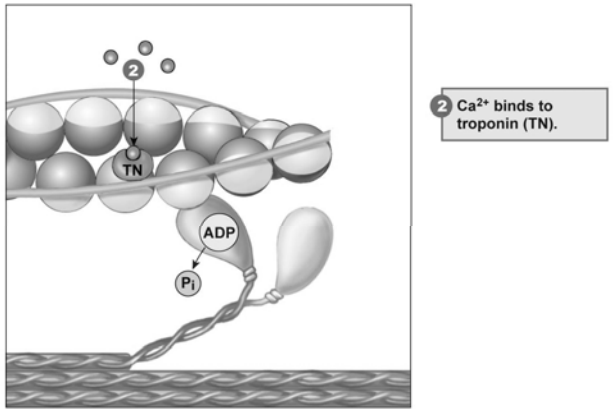
Physiology of Contraction



(b) Initiation of contraction

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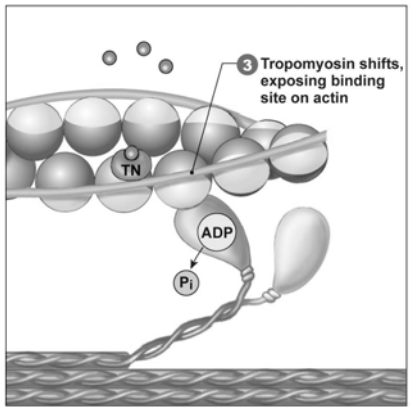
Physiology of Contraction



(b) Initiation of contraction

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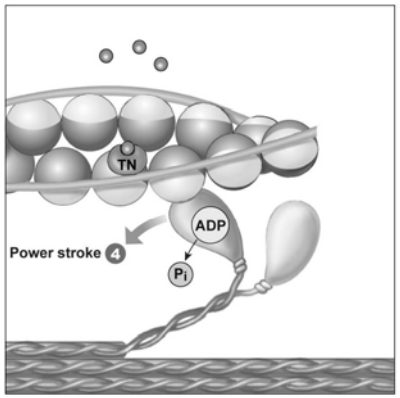
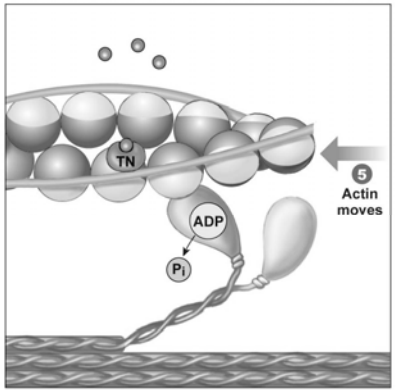
Physiology of Contraction



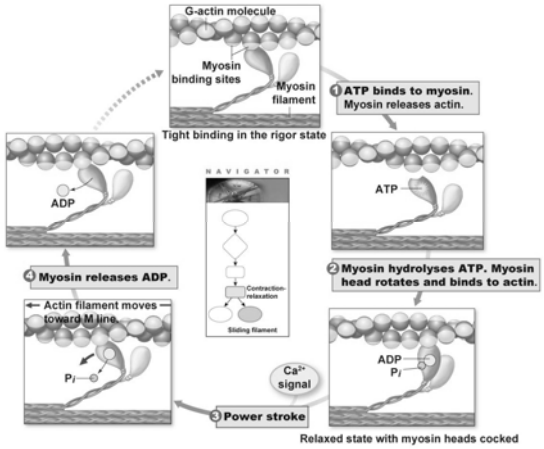
(b) Initiation of contraction

Skeletal Muscle
Physiology of Contraction



(b) Initiation of contraction

Skeletal Muscle
Physiology of Contraction



Skeletal Muscle

Physiology of Contraction

- Animation of Skeletal Muscle Contraction-Relaxation Events

Next Time…

- Muscle Energetics
- Muscle types