# Skeletal Muscle Characteristics

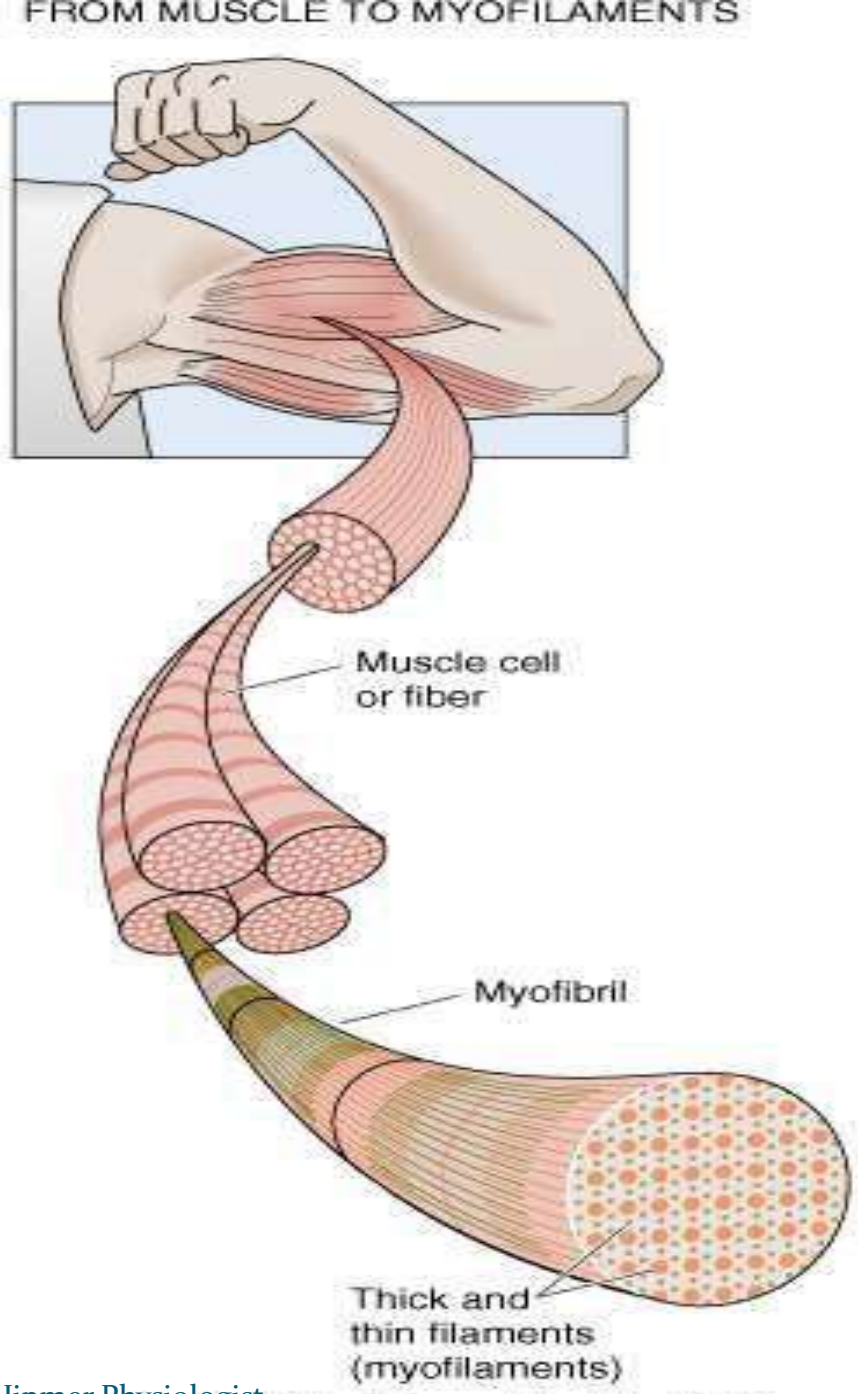
- Most are attached by tendons to bones
- Cells are multinucleate
- Striated – have visible banding
- Voluntary – subject to conscious control
- Cells are surrounded and bundled by connective tissue = great force, but tires easily

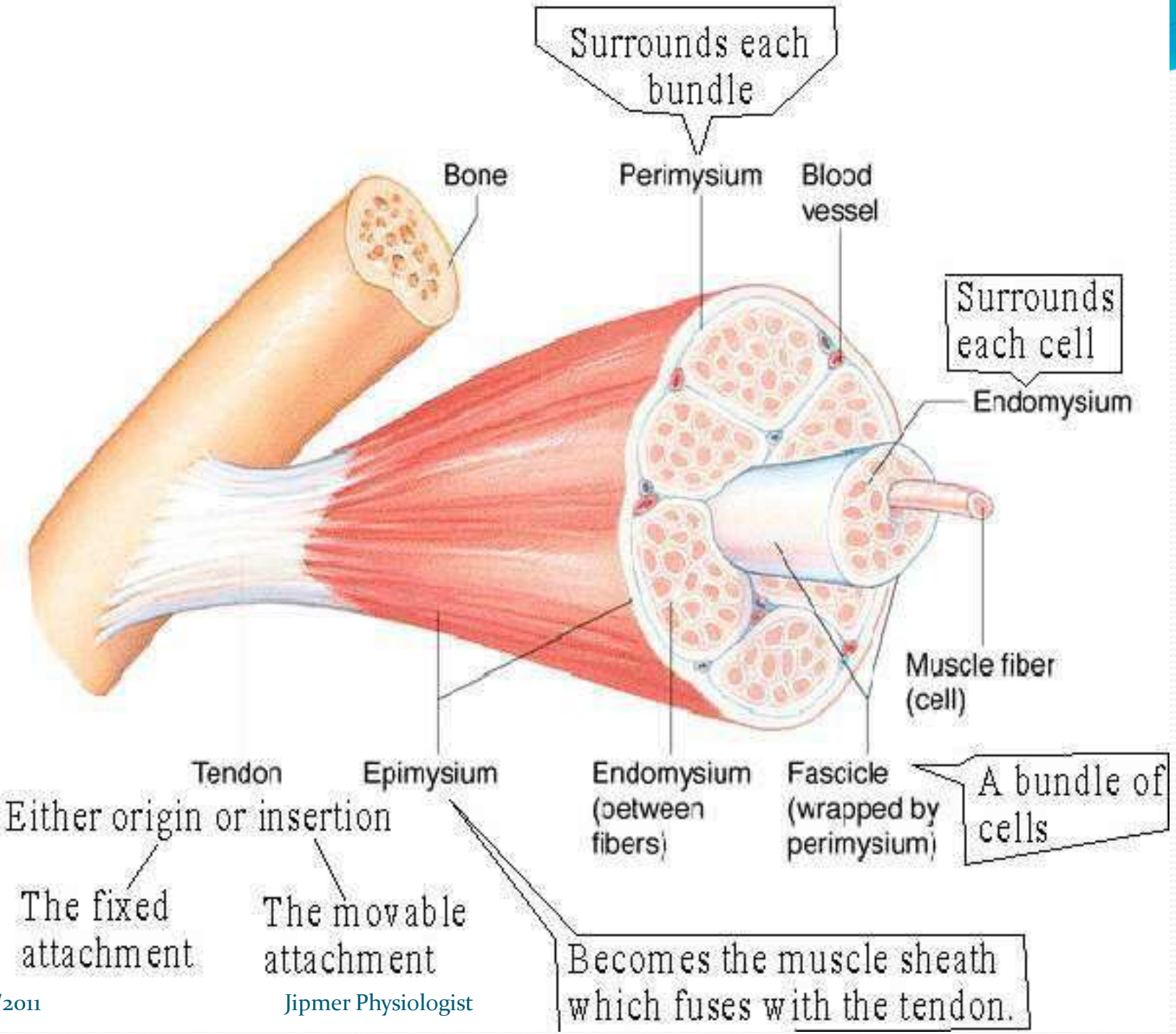
# Terms

- Sarcolemma = Cell membrane
- Sarcoplasm = Cytoplasm
- Sarcoplasmic Reticulum = Endoplasmic Reticulum
- Sarcosomes = Mitochontria

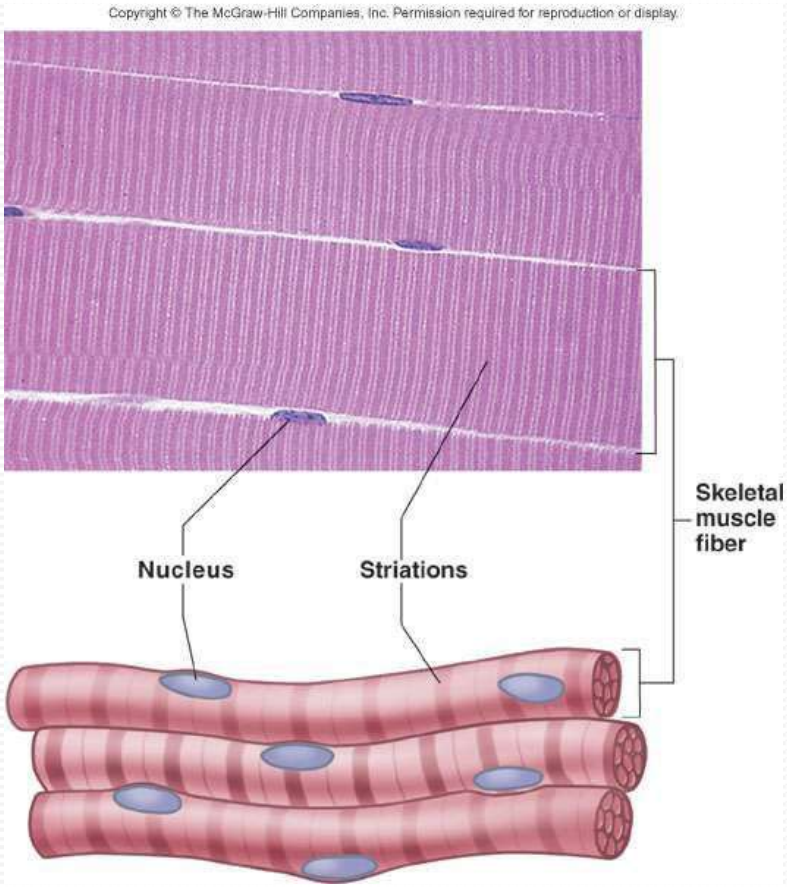
# Structure of skeletal muscle: *connective tissue covering*

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

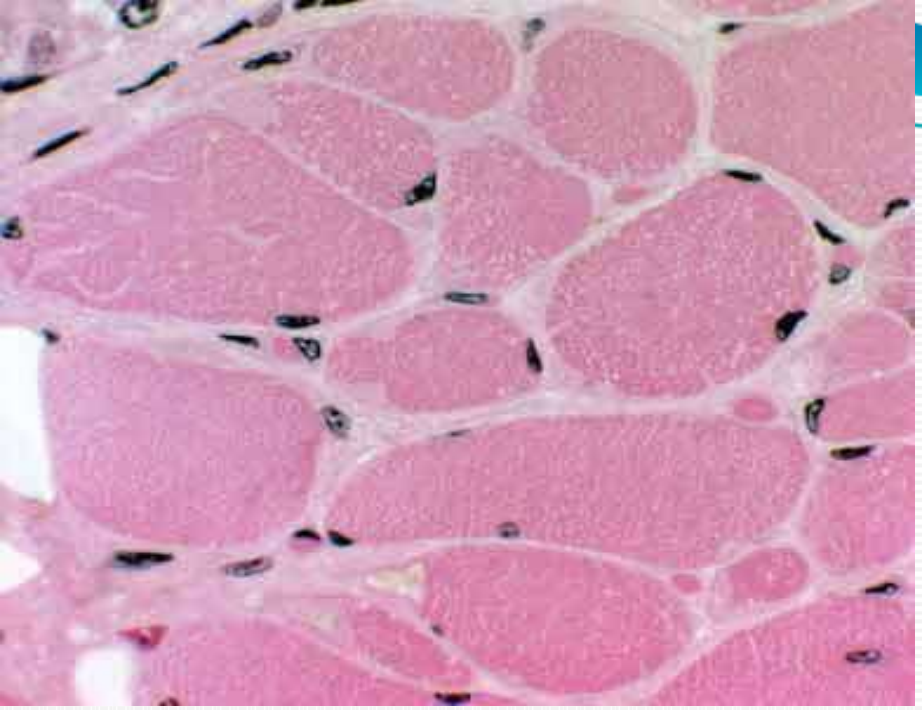


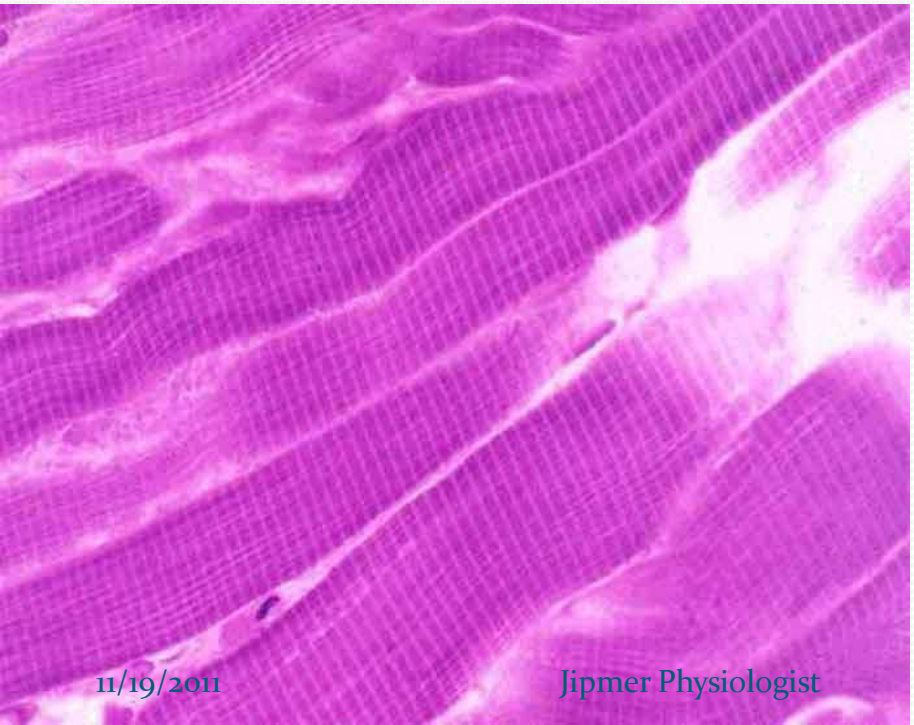

Surrounds each bundle
Bone
Perimysium
Blood vessel
Surrounds each cell
Endomysium
Muscle fiber (cell)
Tendon
Epimysium
Endomysium (between fibers)
Fascicle (wrapped by perimysium)
A bundle of cells
Either origin or insertion
The fixed attachment
The movable attachment
Becomes the muscle sheath which fuses with the tendon.

# Skeletal muscle structure

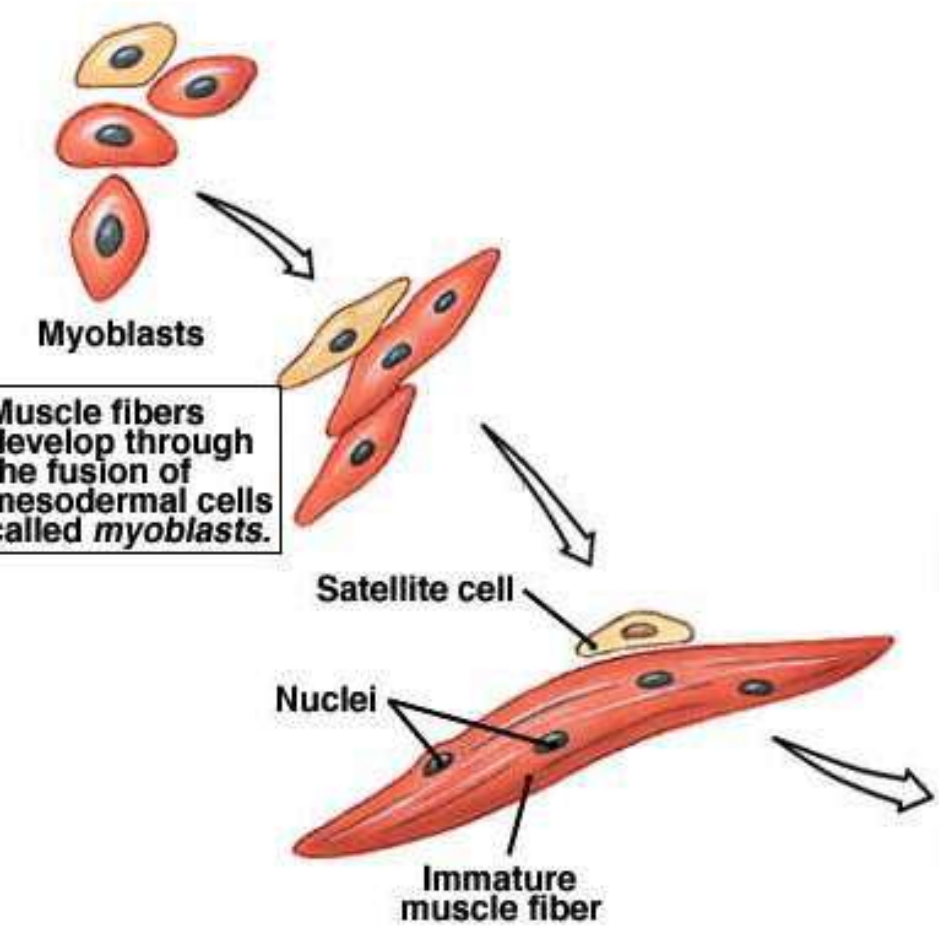


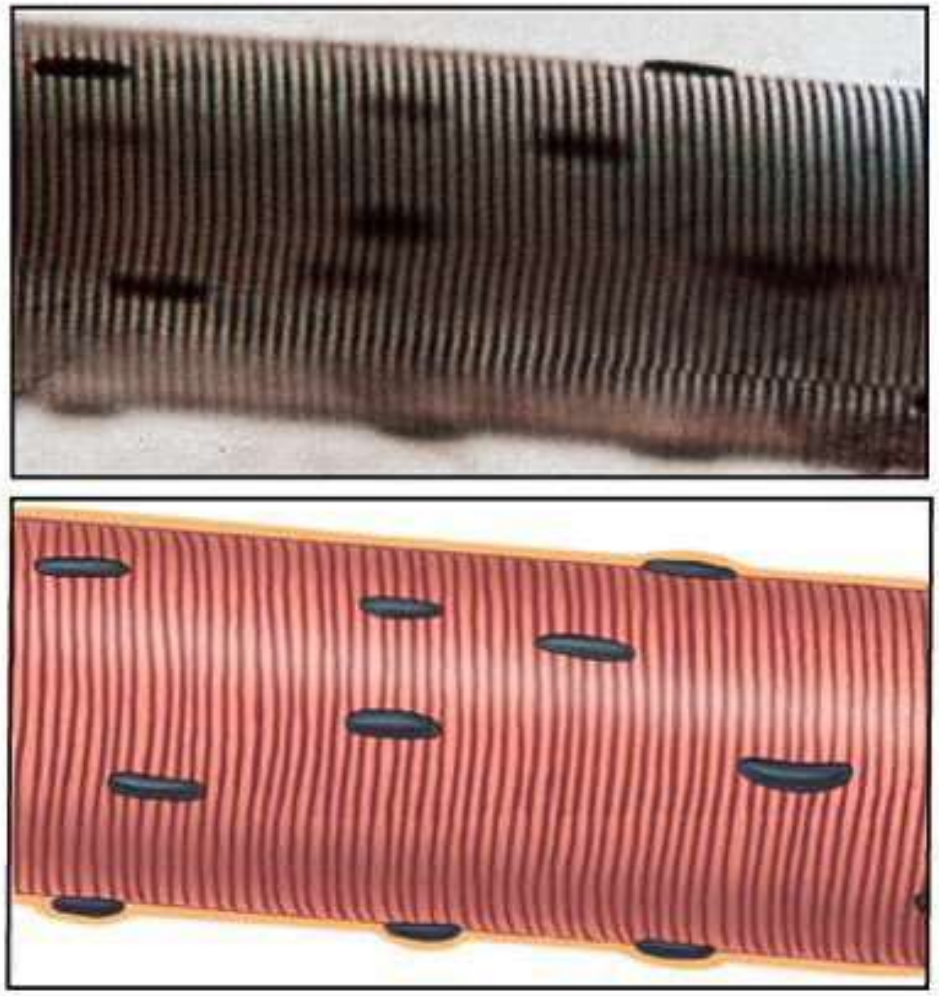

- Composed of muscle cells (fibers), connective tissue, blood vessels, nerves
- Fibers are long, cylindrical, and multinucleated
- Tend to be smaller diameter in small muscles and larger in large muscles. 1 mm- 4 cm in length





- Develop from myoblasts; numbers remain constant
- Striated appearance
- Nuclei are peripherally located


Myoblasts
Muscle fibers develop through the fusion of mesodermal cells called *myoblasts*.
Satellite cell
Nuclei
Immature muscle fiber

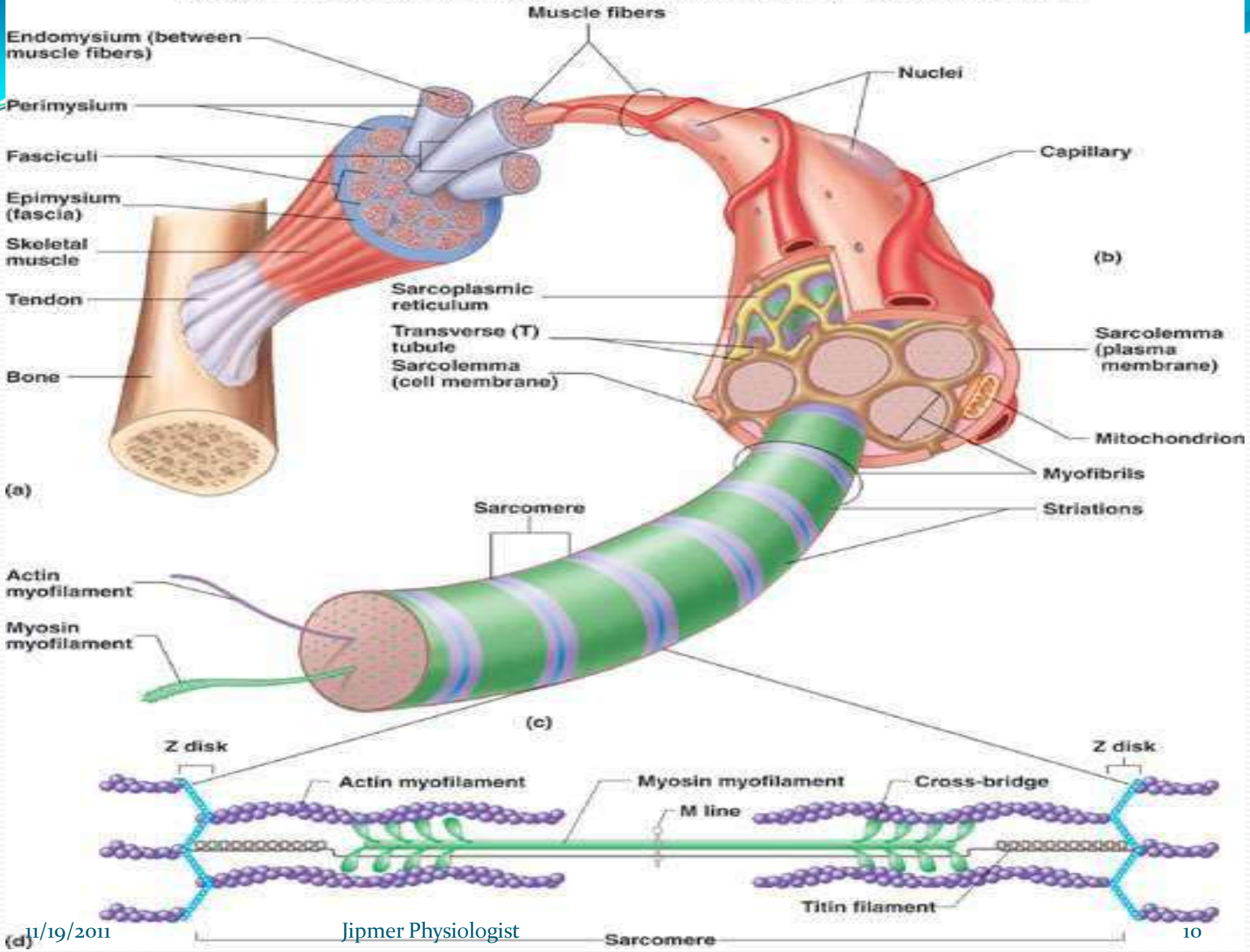


# Muscle fiber anatomy

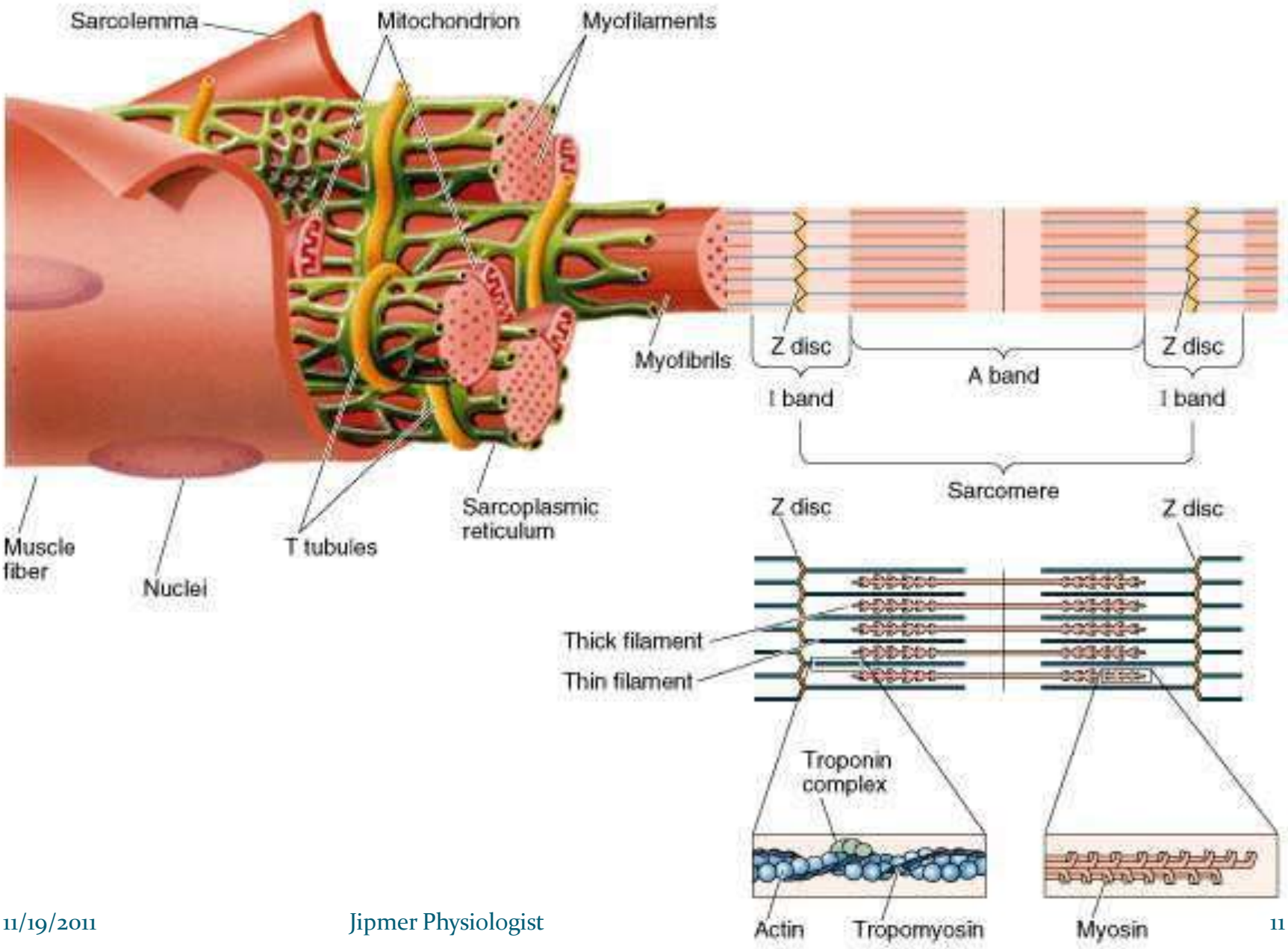
- **Sarcolemma** - cell membrane
  - Surrounds the ***sarcoplasm*** (cytoplasm of fiber)
    - Contains many of the same organelles seen in other cells
    - An abundance of the oxygen-binding protein ***myoglobin***
  - Punctuated by openings called the ***transverse tubules (T-tubules)***
    - Narrow tubes that extend into the sarcoplasm at right angles to the surface
    - Filled with extracellular fluid
- **Myofibrils** -cylindrical structures within muscle fiber
  - Are bundles of protein filaments (=**myofilaments**)
    - Two types of myofilaments
      1. Actin filaments (thin filaments)
      2. Myosin filaments (thick filaments)

– At each end of the fiber, myofibrils are anchored to the inner surface of the sarcolemma

– When myofibril shortens, muscle shortens (contracts)



## ► Organization of a Muscle Fiber

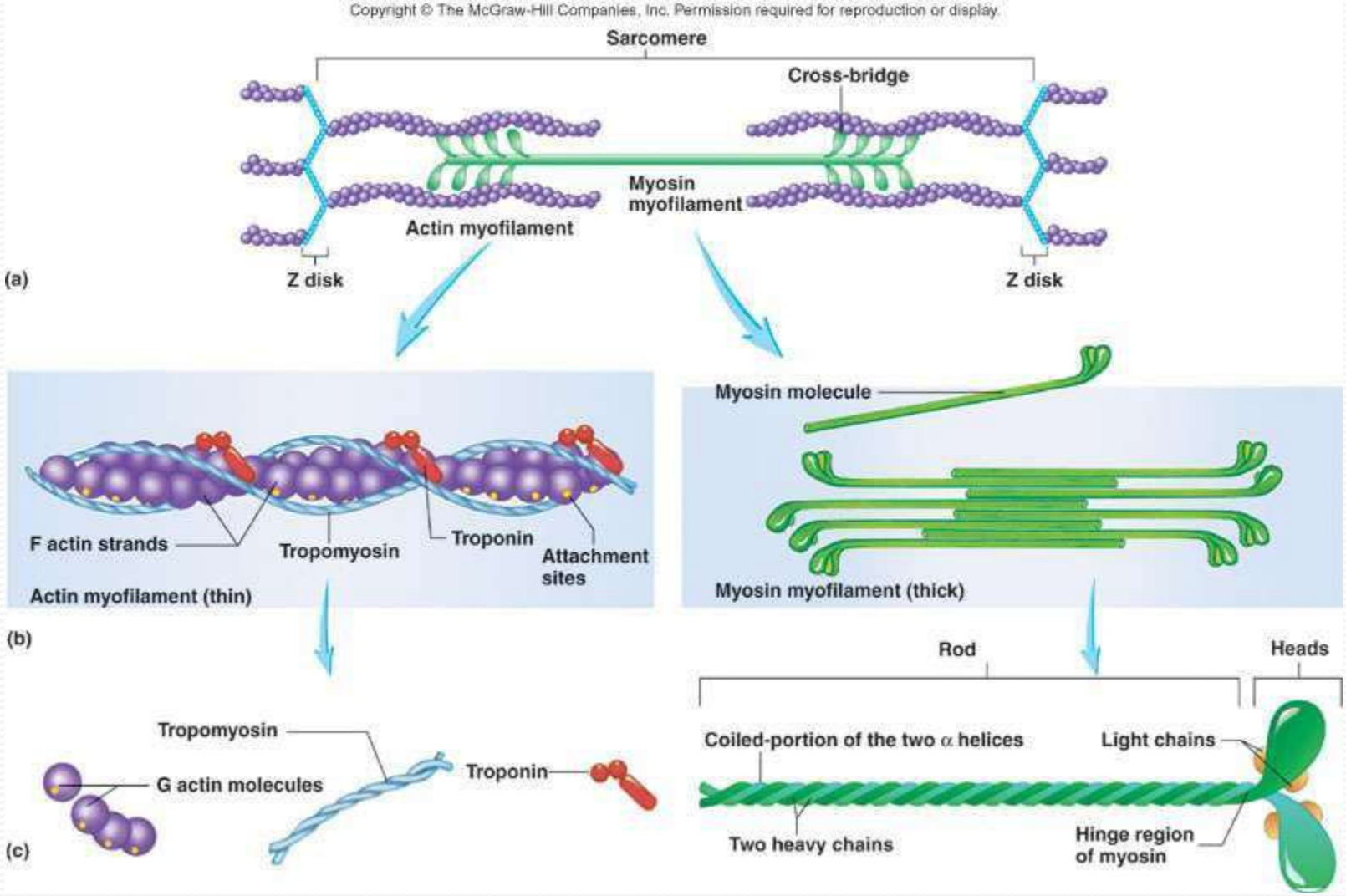


# Muscle proteins

Contractile proteins

- Actin- thin myofilament
- Myosin- thick filament Regulatory proteins
- Tropomyosin
- Troponin Attachment proteins
- Titin, nebulin, alpha actinin, dystrophin

# Structure of Actin and Myosin



# Actin (Thin) Myofilaments

Thin Filament: composed of 3 major proteins

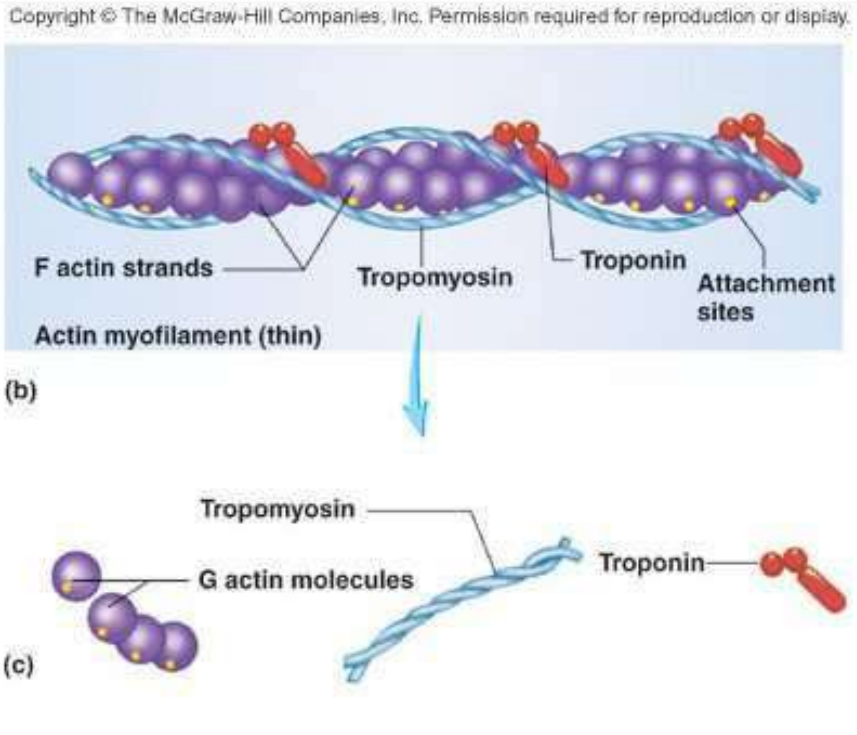
1. F (fibrous) actin
2. Tropomyosin
3. Troponin

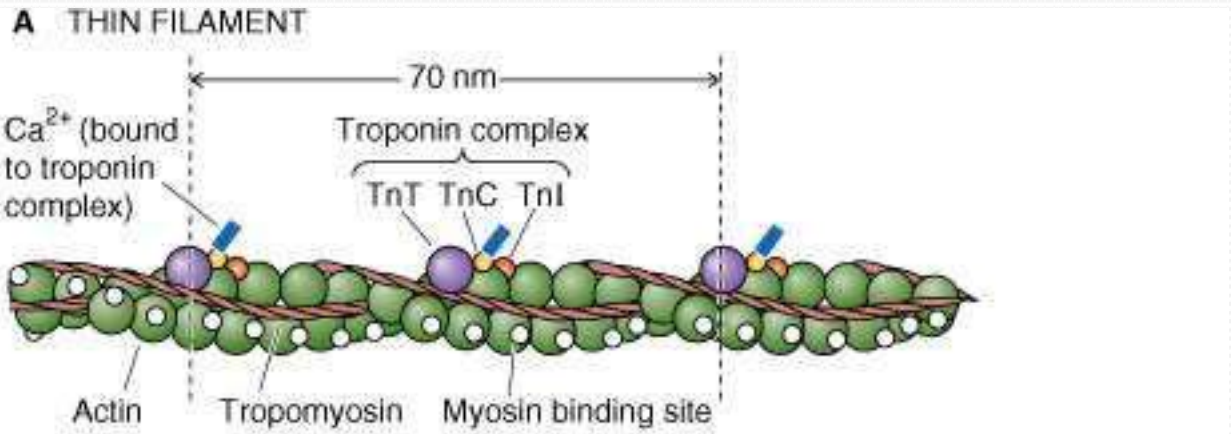
- Two strands of fibrous (F) actin form a double helix extending the length of the myofilament; attached at either end at sarcomere.
  - Composed of G actin monomers each of which has a *myosin-binding site*

Tropomyosin: an elongated protein winds along the groove of the F actin double helix.

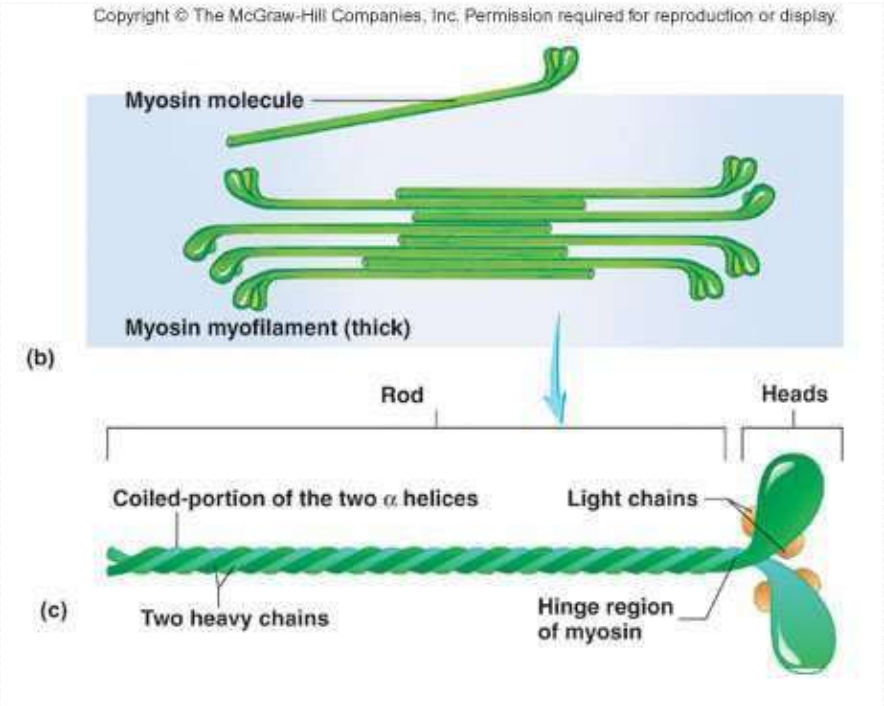
Troponin is composed of three subunits:

- Tn-A : binds to actin
- Tn-T :binds to tropomyosin,
- Tn-C :binds to calcium ions.





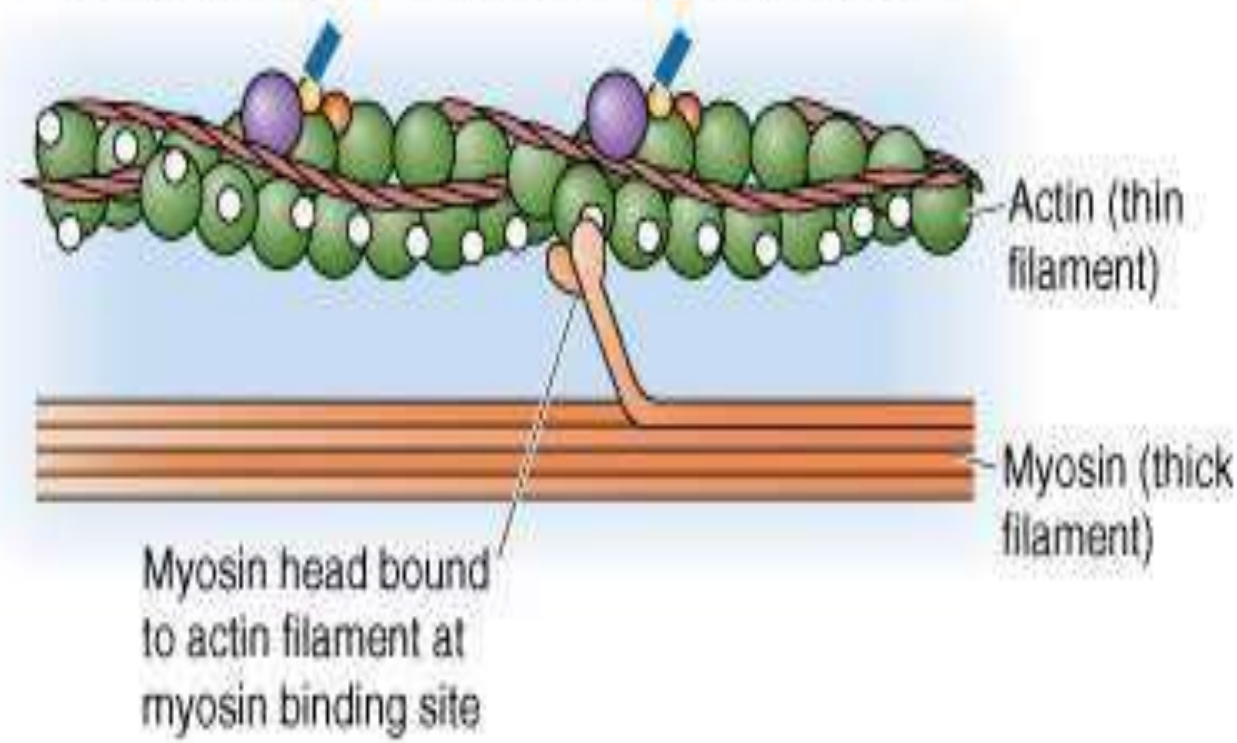
# Myosin (Thick) Myofilament

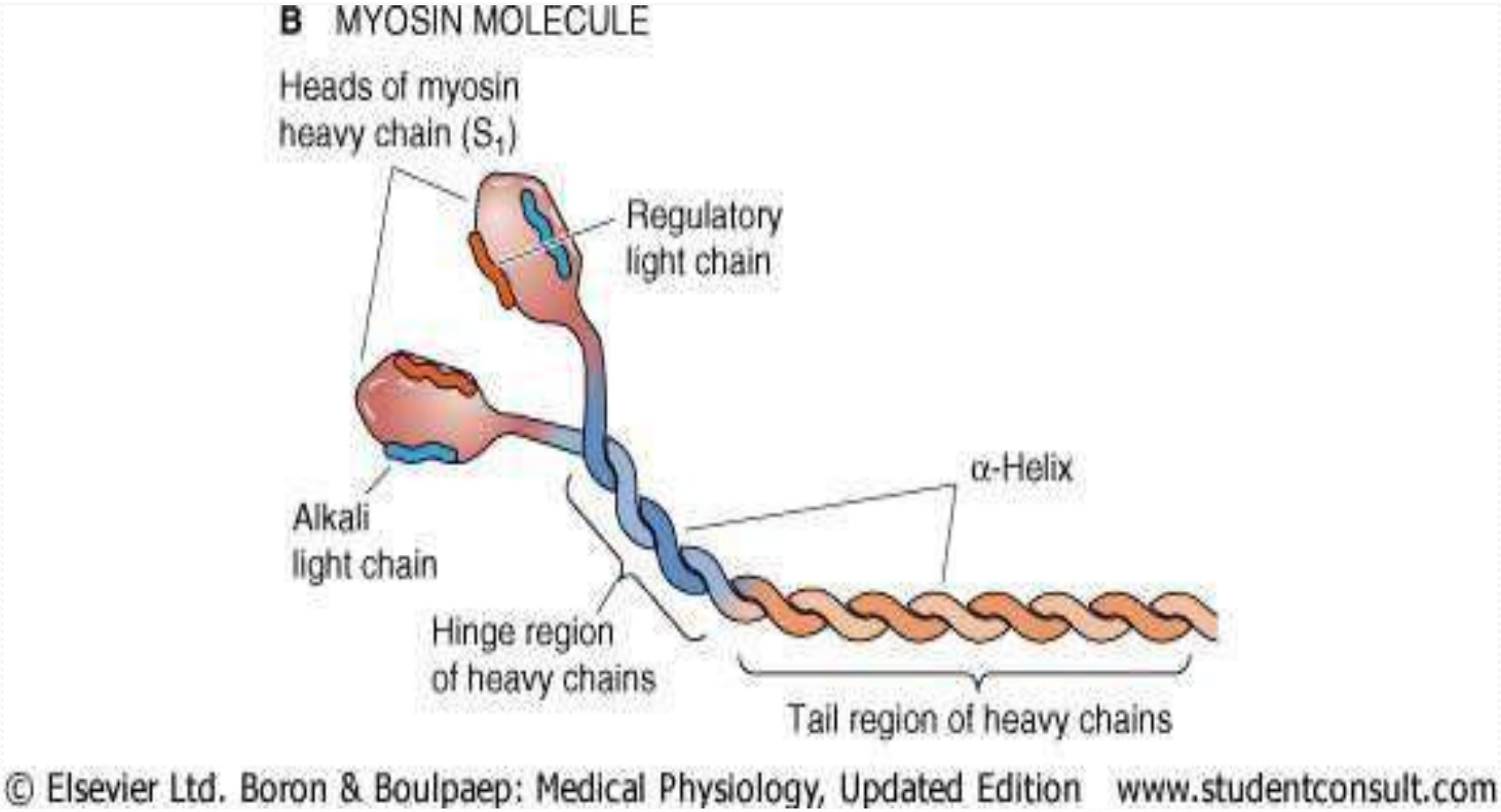



- Many elongated myosin molecules shaped like golf clubs.
- Single filament contains roughly 300 myosin molecules
- Molecule consists of two heavy myosin molecules wound together to form a rod portion lying parallel to the myosin myofilament and two heads that extend laterally.
- Myosin heads

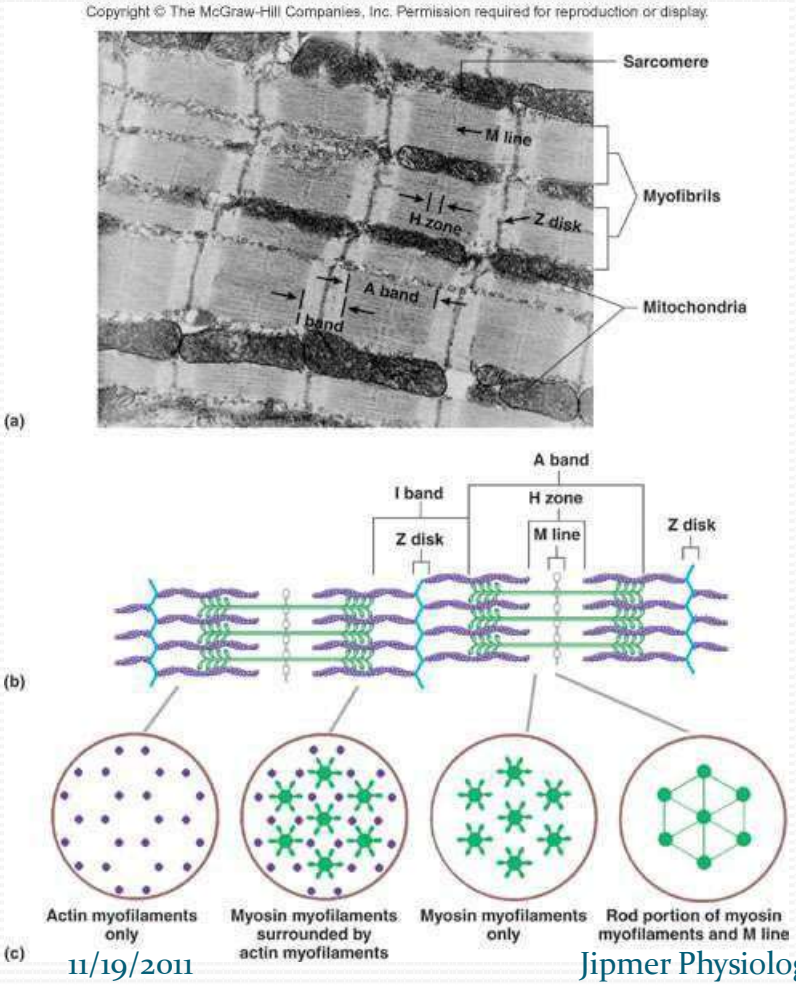
1. Can bind to active sites on the actin molecules to form cross-bridges. (Actin binding site)
2. Attached to the rod portion by a hinge region that can bend and straighten during contraction.
3. Have ATPase activity: activity that breaks down adenosine triphosphate (ATP), releasing energy. Part of the energy is used to bend the hinge region of the myosin molecule during contraction

C INTERACTION OF THIN AND THICK FILAMENTS

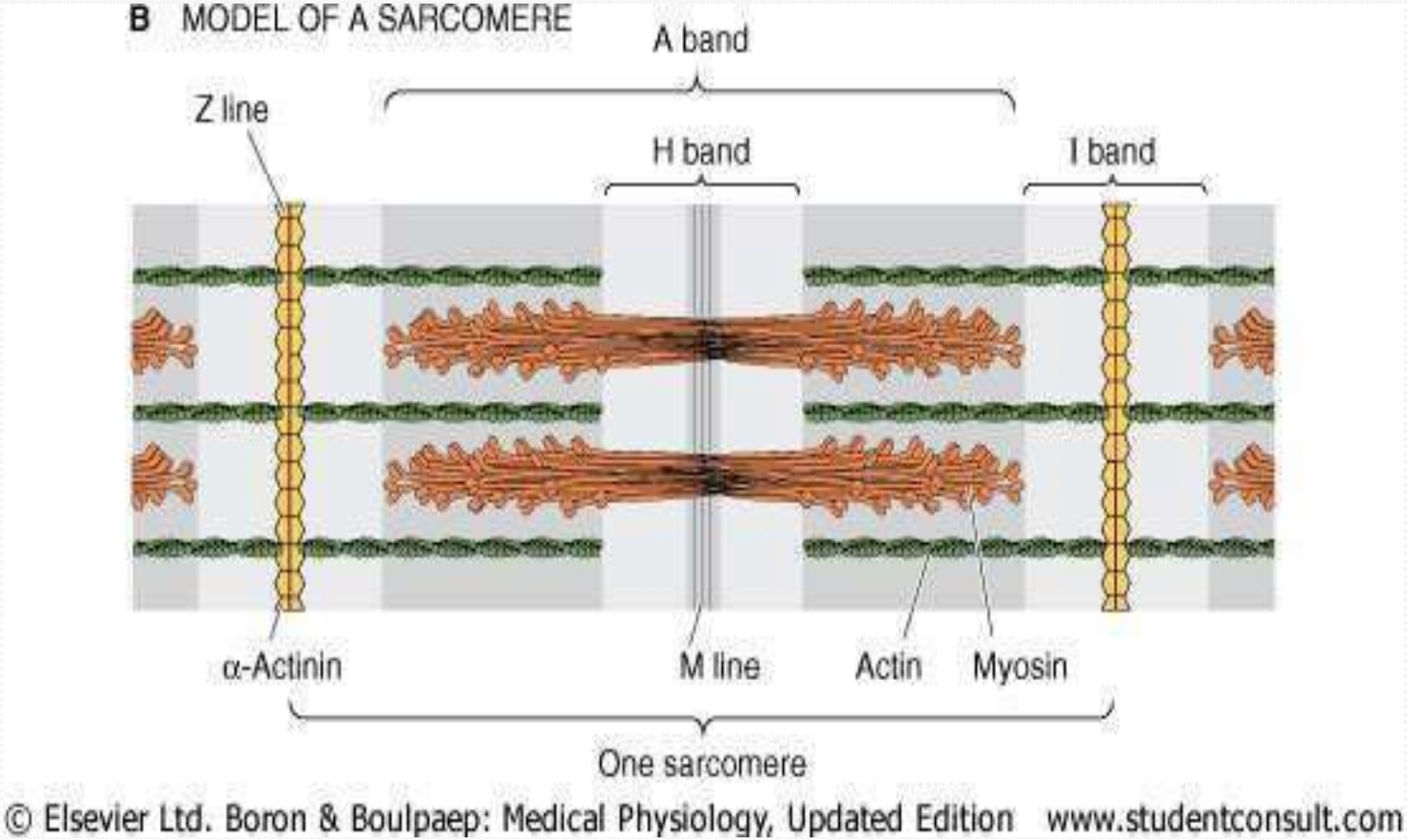




# Sarcomeres: Z Disk to Z Disk




- **Sarcomere** - repeating *functional units* of a myofibril
  - **About 10,000 sarcomeres per myofibril, end to end**
  - **Each is about 2 µm long**
  - Differences in size, density, and distribution of thick and thin filaments gives the muscle fiber a banded or striated appearance.
    - A bands: a dark band; full length of thick (myosin) filament
    - M line - protein to which myosins attach
    - H zone - thick but NO thin filaments
    - I bands: a light band; from Z disks to ends of thick filaments
      - Thin but NO thick filaments
      - Extends from A band of one sarcomere to A band of the next sarcomere
    - Z disk: filamentous network of protein. Serves as attachment for actin myofilaments
    - Titin filaments: elastic chains of amino acids; keep thick and thin filaments in proper alignment


B MODEL OF A SARCOMERE
A band
Z line
H band
I band
α-Actinin
M line
Actin
Myosin
One sarcomere
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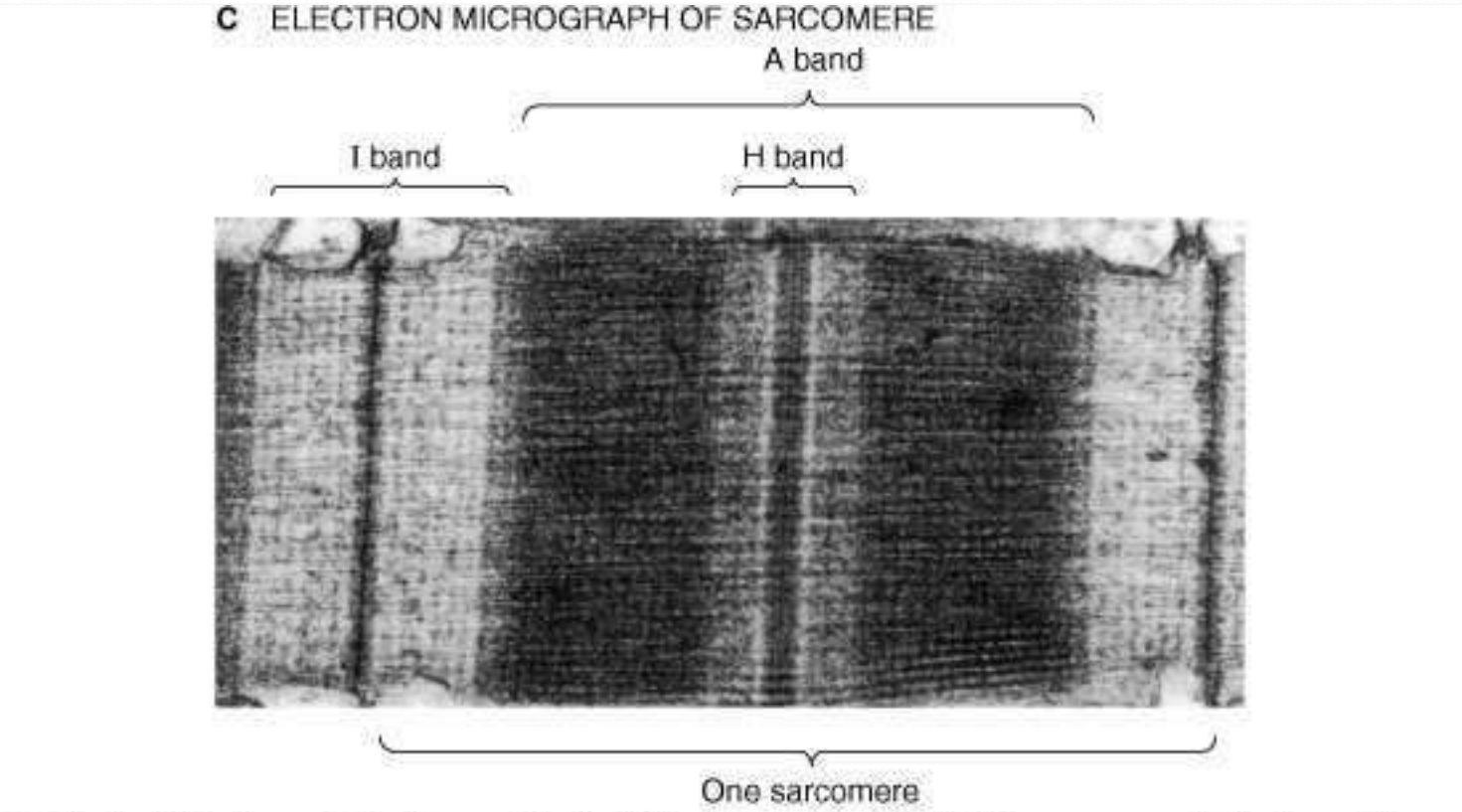


# Sarcoplasmic Reticulum (SR)

- SR is an elaborate, smooth endoplasmic reticulum
  - runs longitudinally and surrounds each myofibril
  - Form chambers called *terminal cisternae* on either side of the T-tubules
- A single T-tubule and the 2 terminal cisternae form a *triad*
- SR stores $Ca^{++}$ when muscle not contracting
  - When stimulated, calcium released into sarcoplasm
  - SR membrane has $Ca^{++}$ pumps that function to pump $Ca^{++}$ out of the sarcoplasm back into the SR after contraction

# Sarcoplasmic Reticulum (SR)

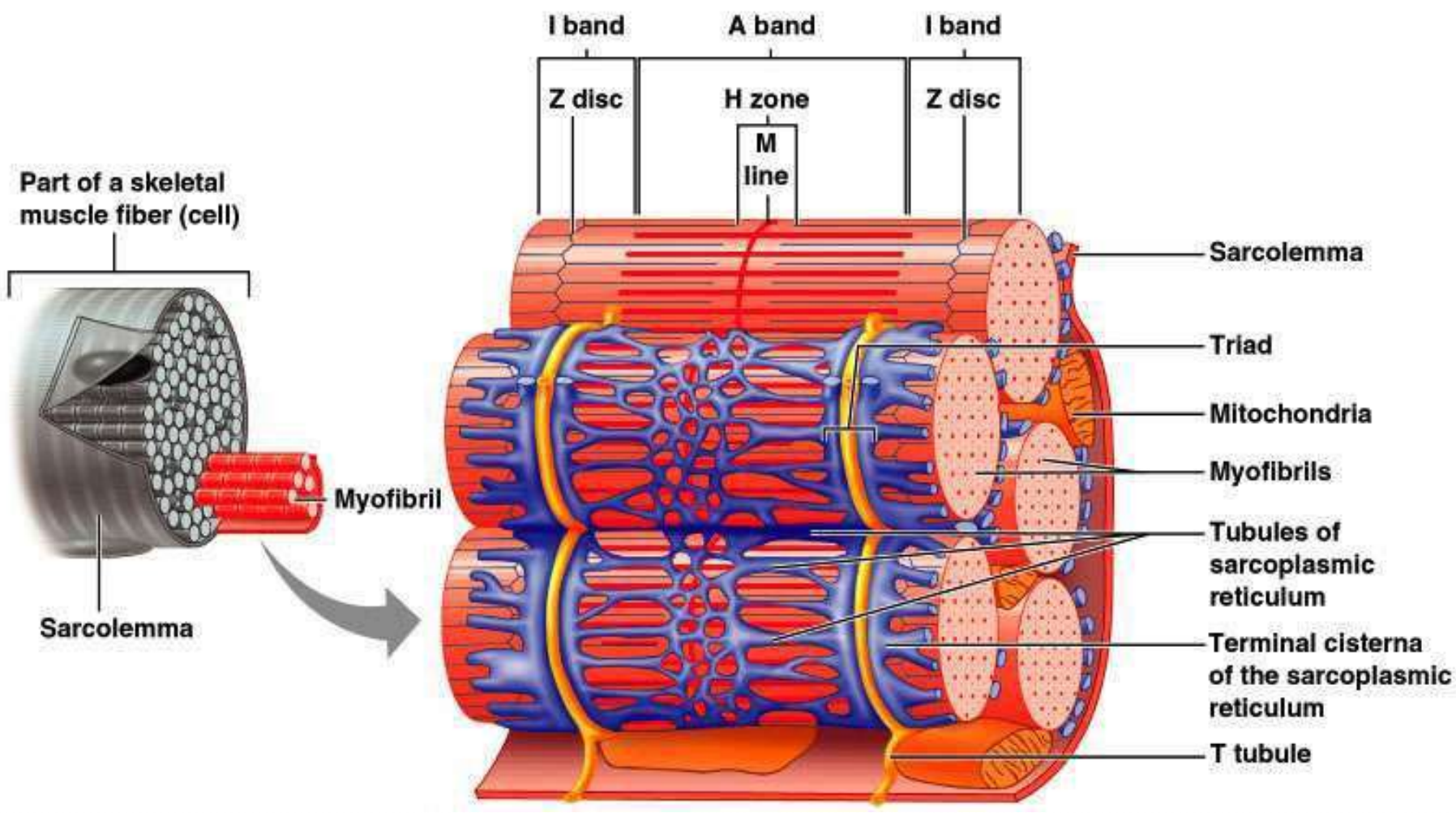
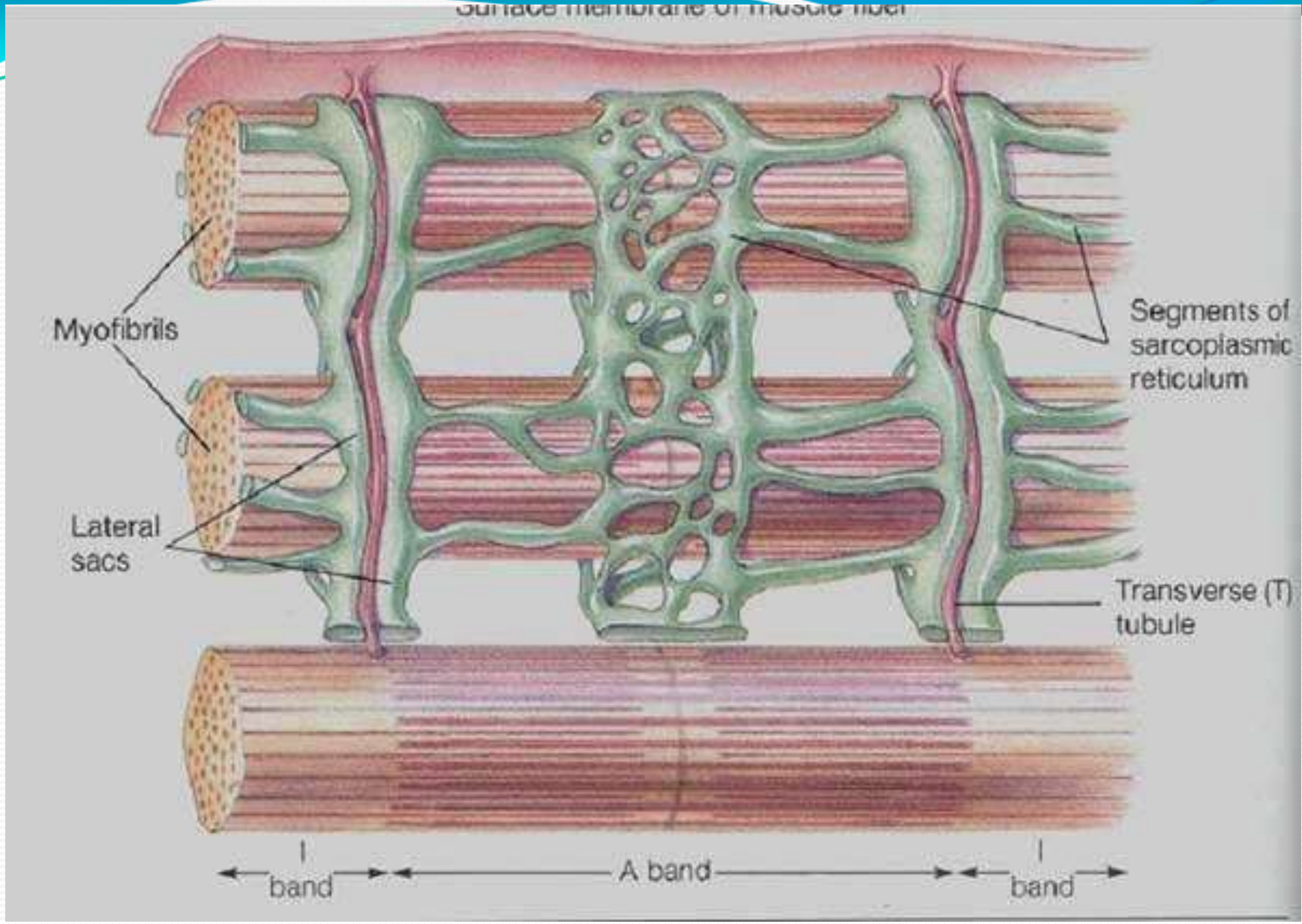



Figure 9.5


Myofibrils
Lateral sacs
Segments of sarcoplasmic reticulum
Transverse (T) tubule
I band
A band
I band

# 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
  - Reduction in the distance between Z-lines of the sarcomere

# Sliding Filament Theory

- Rest – uncharged ATP cross-bridge complex
- Excitation-coupling – charged ATP cross-bridge

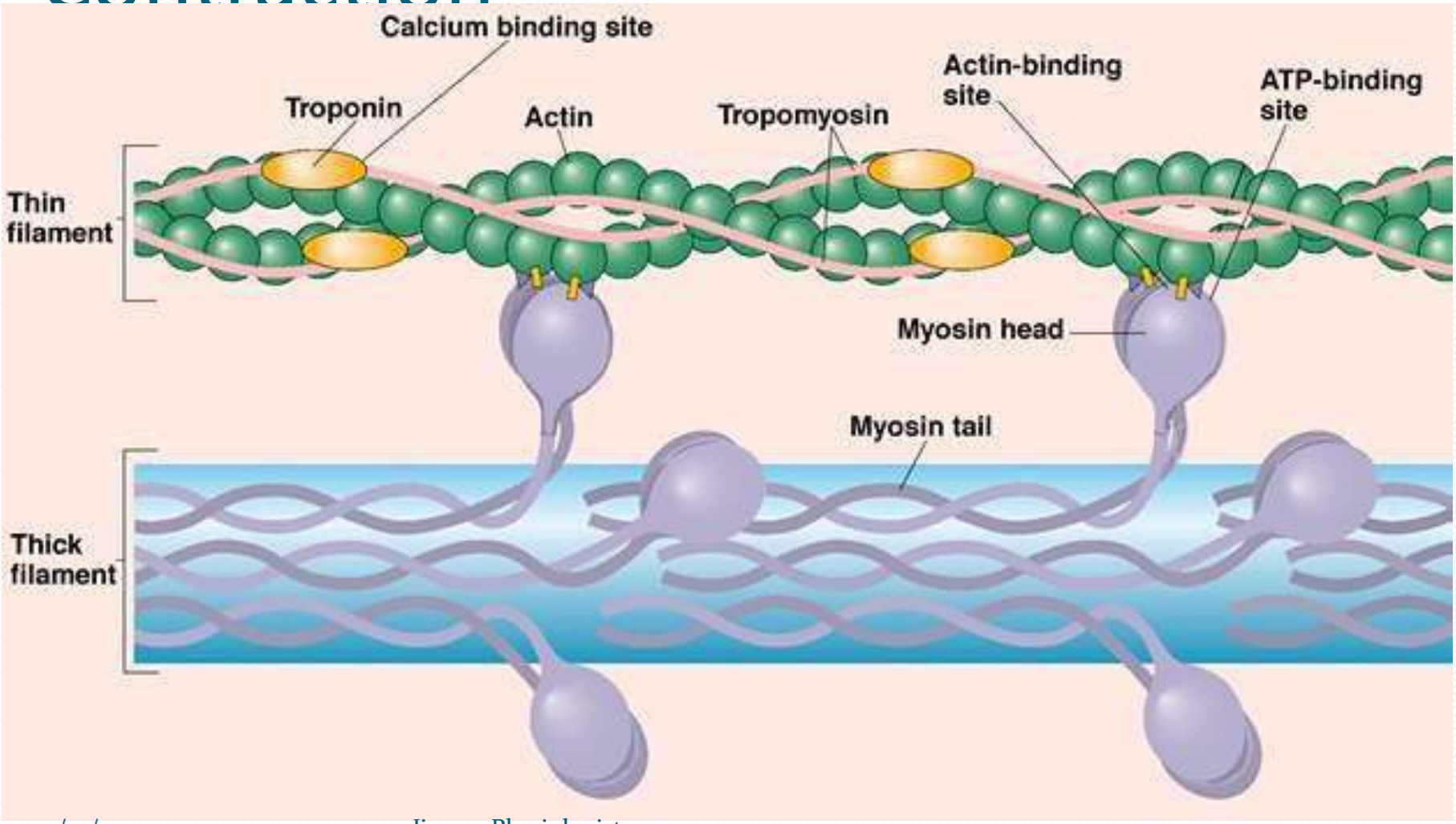
complex, “turned on”

- Contraction – actomyosin – ATP > ADP & Pi + energy
- Recharging – reload cross-bridge with ATP
- Relaxation – cross-bridges “turned off”

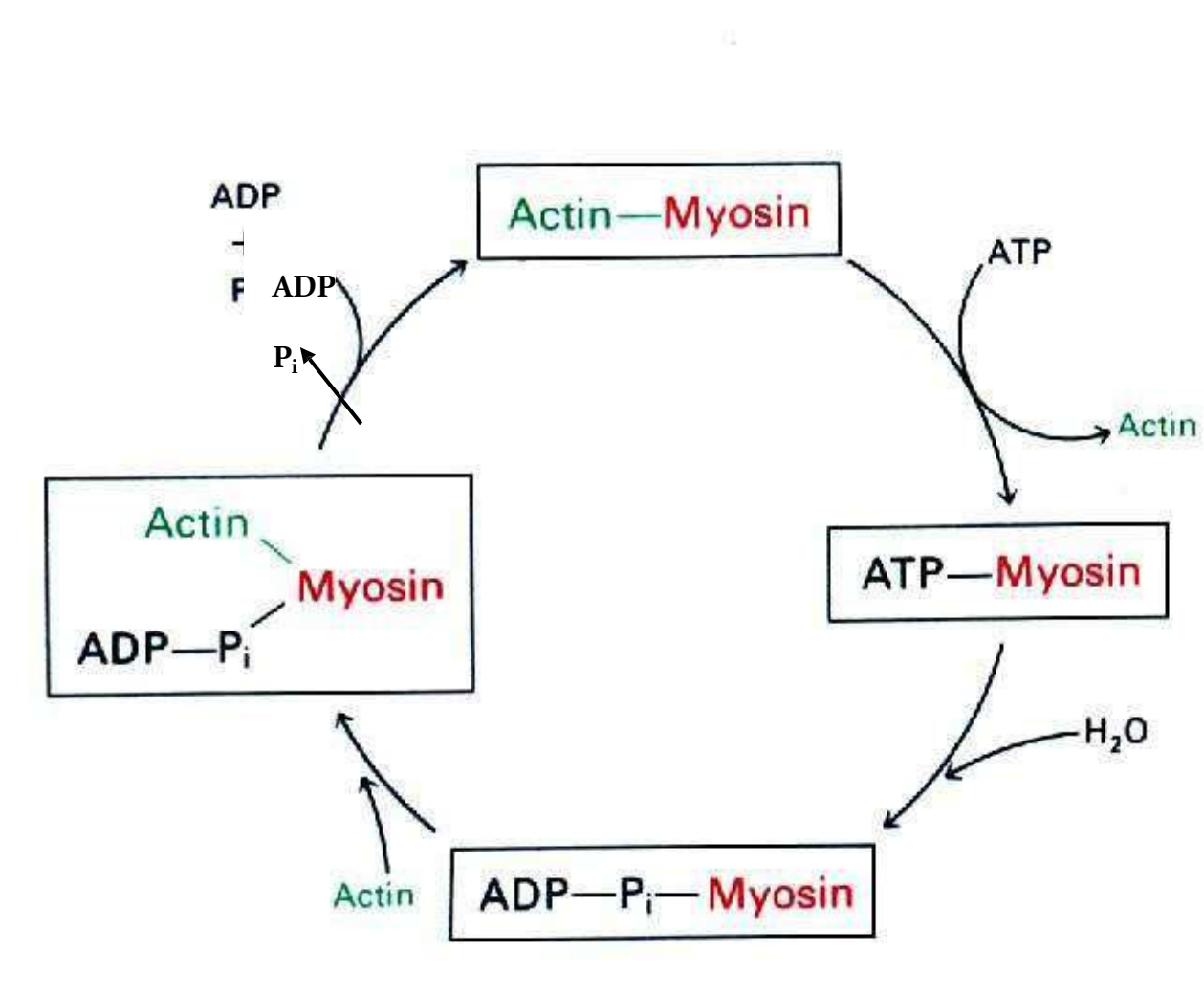
# Sliding Filament Model of Contraction

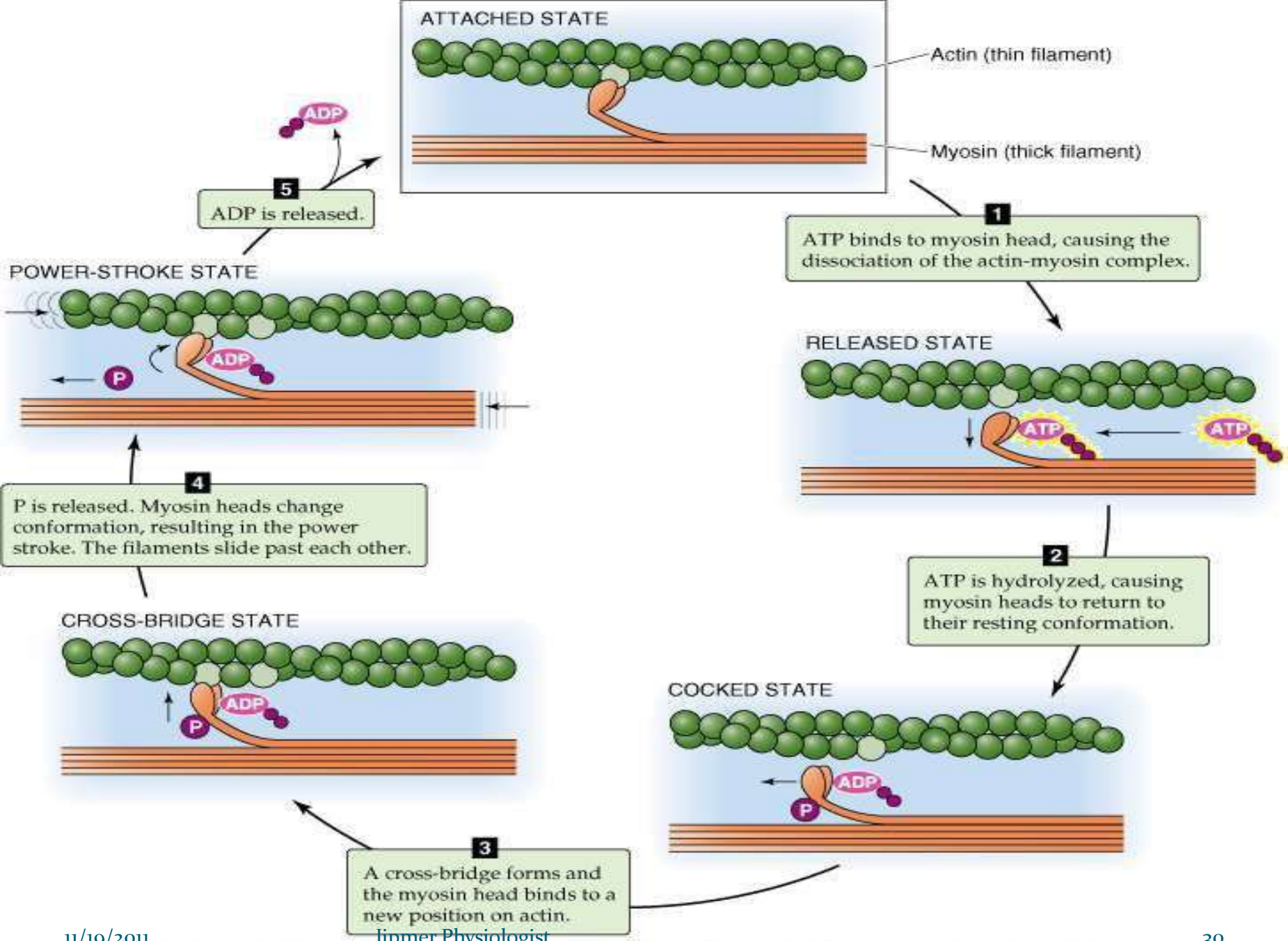
- Thin filaments slide past the thick ones so that the actin and myosin filaments overlap to a greater degree
- In the relaxed state, thin and thick filaments overlap only slightly
- Upon stimulation, myosin heads bind to actin and sliding begins

# Cross-Bridge Formation in Muscle Contraction

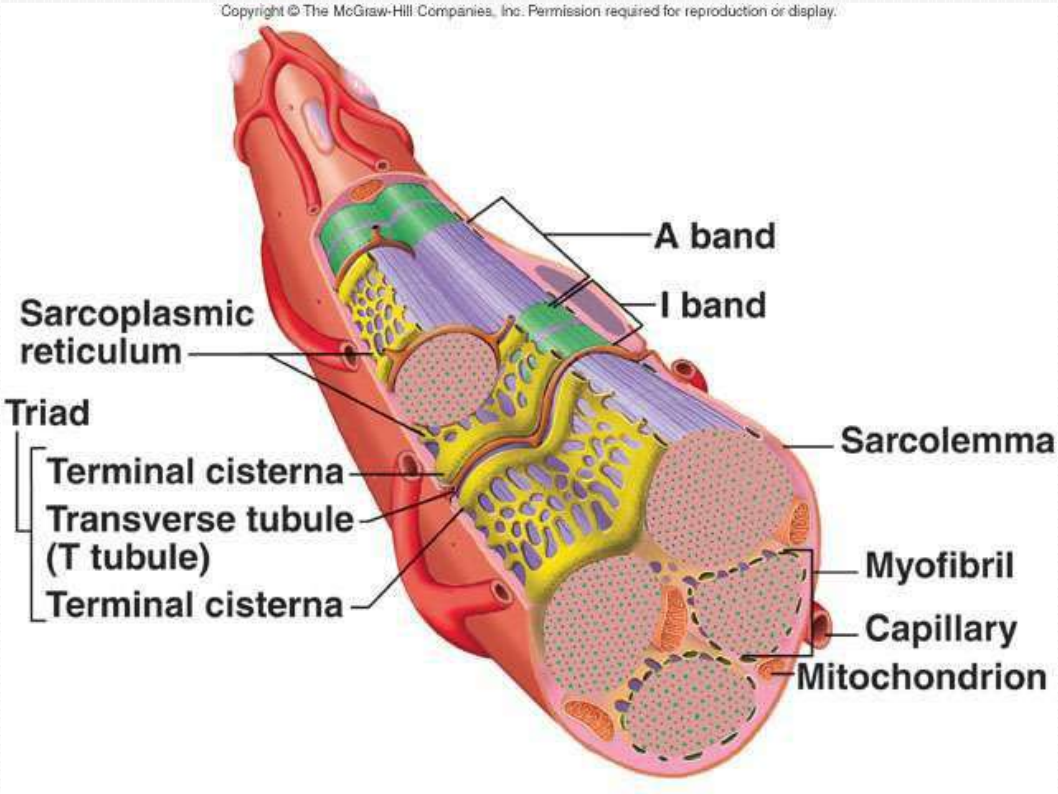


# Myosin ATPase Cycle





# Excitation-Contraction Coupling




- Mechanism where an action potential causes muscle fiber contraction
- Involves
  - Sarcolemma
  - Transverse or T tubules
  - Terminal cisternae
  - Sarcoplasmic reticulum
  - $Ca^{2+}$
  - Troponin

# Energy Sources

- ATP provides immediate energy for muscle contractions from 3 sources
  - Creatine phosphate
    - During resting conditions stores energy to synthesize ATP
  - Anaerobic respiration
    - Occurs in absence of oxygen and results in breakdown of glucose to yield ATP and lactic acid
  - Aerobic respiration
    - Requires oxygen and breaks down glucose to produce ATP, carbon dioxide and water
    - More efficient than anaerobic

# Energy for Muscle Contraction

- Direct phosphorylation
  - Muscle cells contain creatine phosphate (CP)
  - CP is a high-energy molecule
  - After ATP is depleted, ADP is left
  - CP transfers energy to ADP, to regenerate ATP
  - CP supplies are exhausted in about 20 seconds

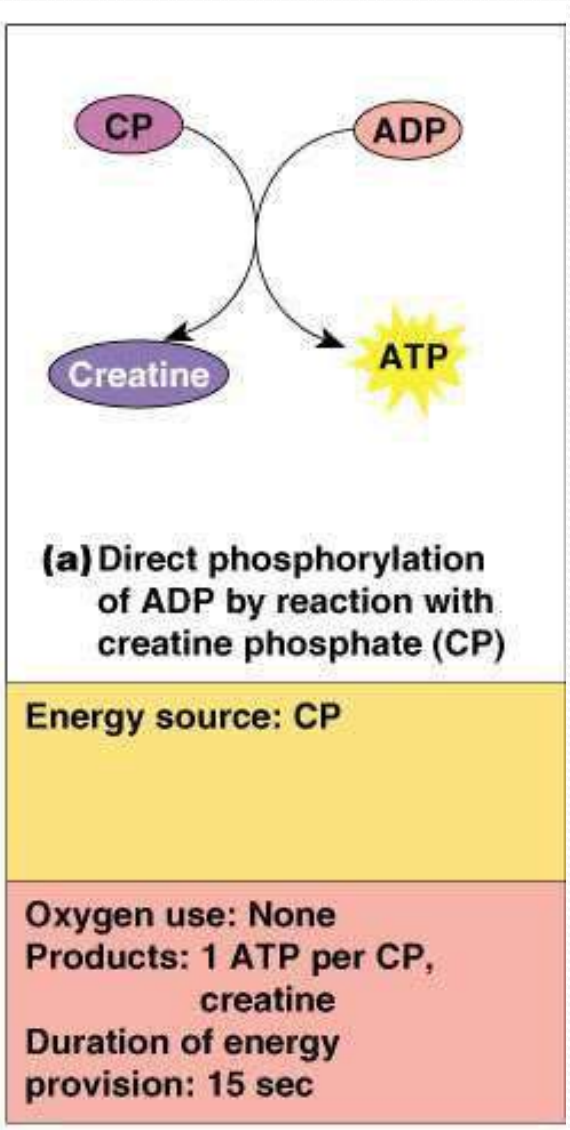



Figure 6.10a

# Energy for Muscle Contraction

- Anaerobic glycolysis
  - Reaction that breaks down glucose without oxygen
  - Glucose is broken down to pyruvic acid to produce some ATP
  - Pyruvic acid is converted to lactic acid

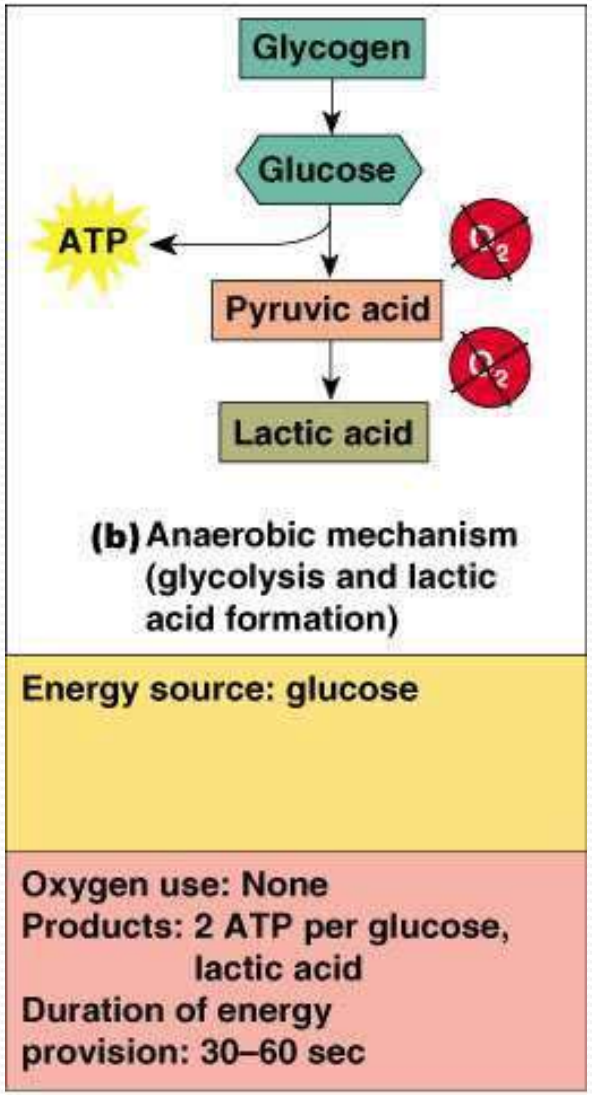



Figure 6.10b

# Energy for Muscle Contraction

- Aerobic Respiration
  - Series of metabolic pathways that occur in the mitochondria
  - Glucose is broken down to carbon dioxide and water, releasing energy
  - This is a slower reaction that requires continuous oxygen

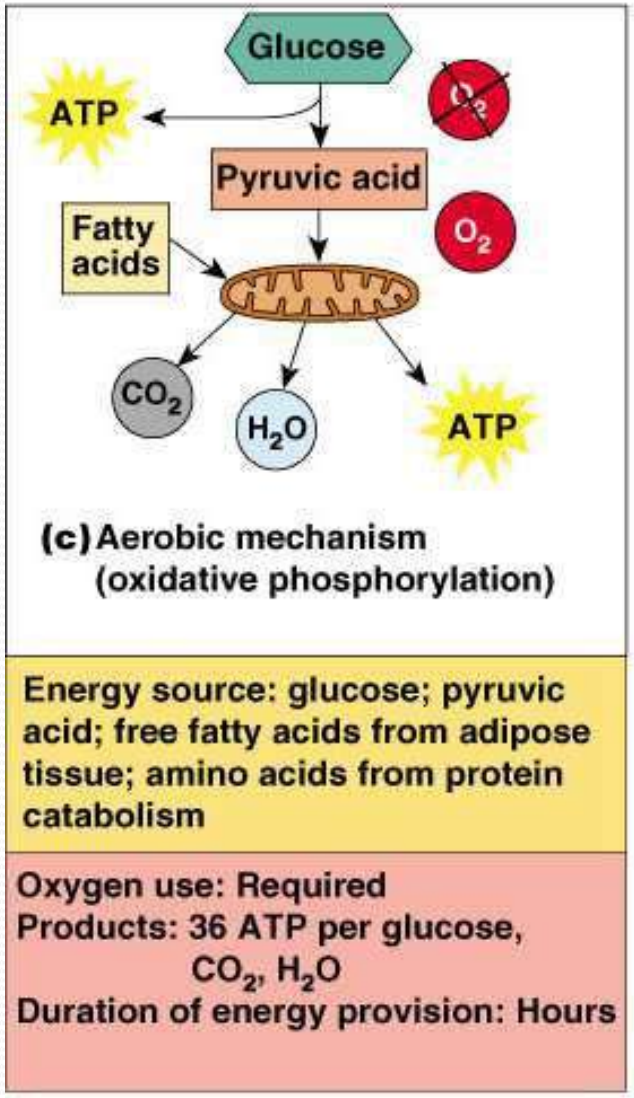



Figure 6.10c