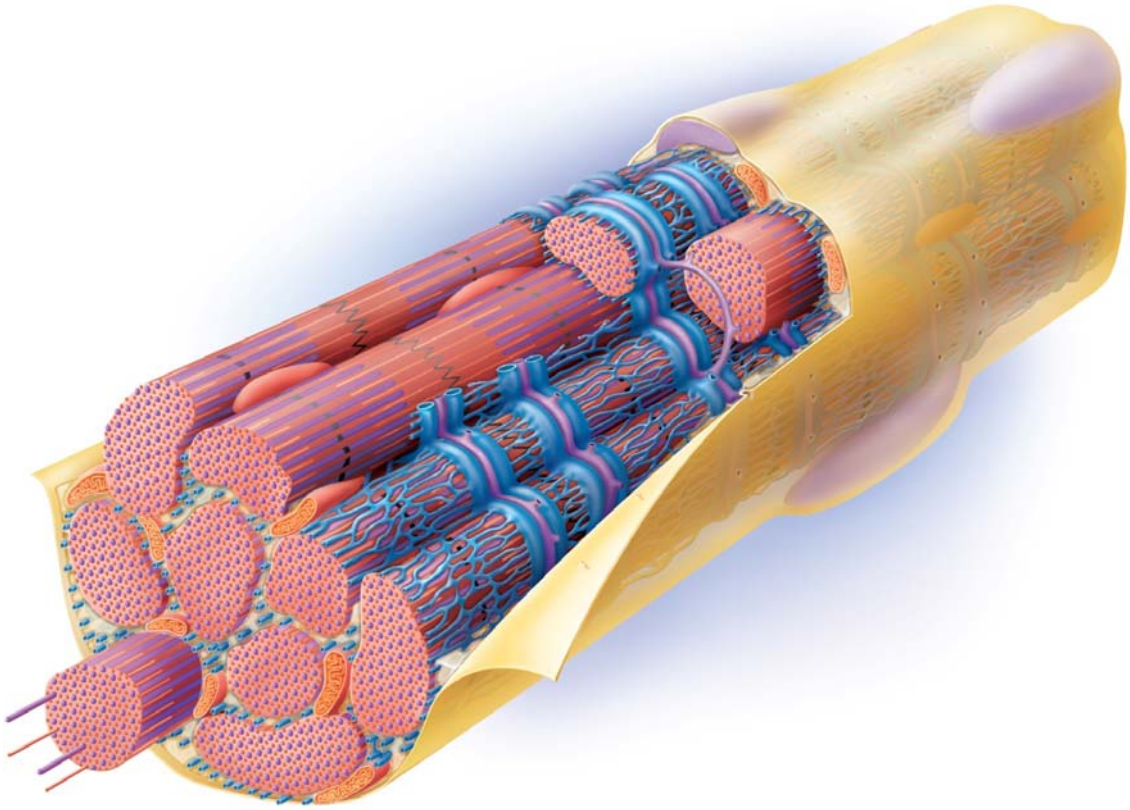
Chapter 10.2

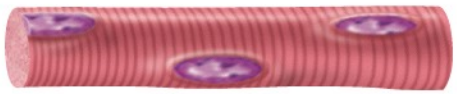
Skeletal Muscle



Introduction to Muscle

- Movement is a fundamental characteristic of all living things
- All muscle cells (skeletal, cardiac, smooth) are capable of changing chemical energy of ATP into mechanical energy of contraction
- Contraction occurs when a “muscle cell shortens”.
- Why do skeletal muscle cell shorten? How do we explain muscle contraction as a function of molecular action?
- *In this lecture we will focus on the structure and function of skeletal muscle cells also called muscle fibers // we will briefly define cardiac and smooth muscle function and cover the cardiac muscle in detail in Unit 3*

Skeletal muscle

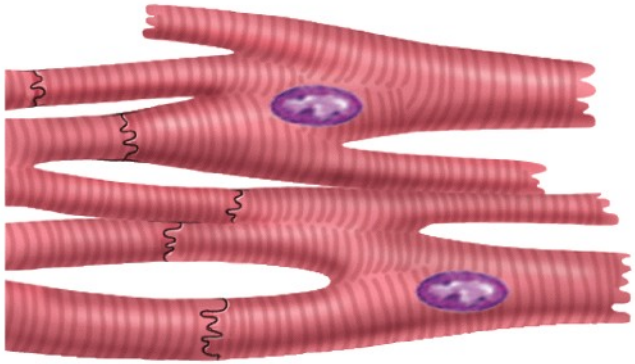


Striated

Voluntary

Somatic NS

Cardiac muscle



Striated

Involuntary

ANS

Smooth muscle

No striation

Involuntary

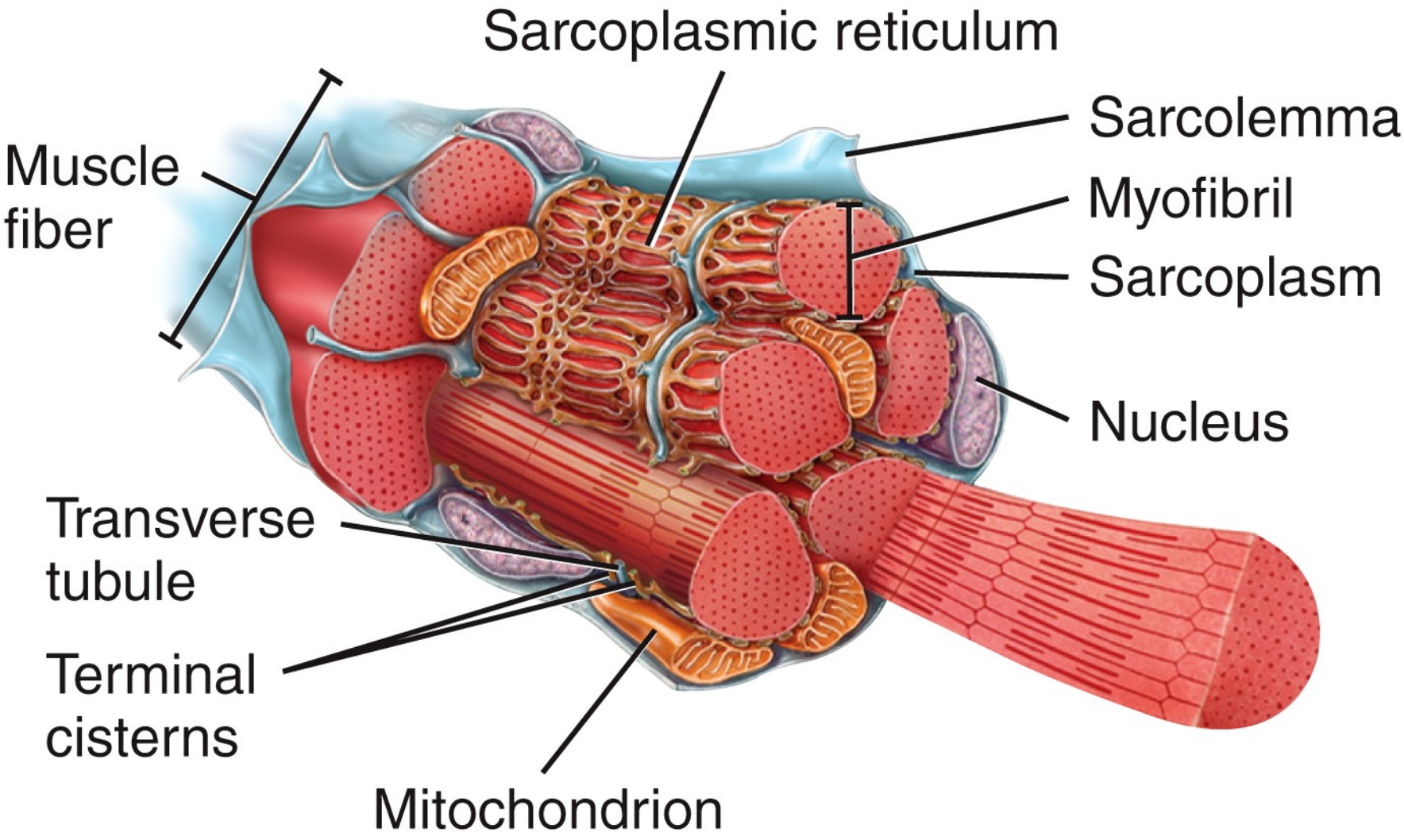
ANS

Skeletal Muscle Cell = Muscle Fiber (1 of 2)

- Sarcolemma
  - plasma membrane of a muscle fiber
- Sarcoplasm
  - cytoplasm of a muscle fiber
  - glycogen – stored in abundance to provide energy with heightened exercise
  - myoglobin – red pigment – stores oxygen needed for muscle activity
- Myofibrils
  - long protein bundles that occupies the main portion of the sarcoplasm
- Multiple nuclei
  - flattened nuclei pressed against the inside of the sarcolemma

Skeletal Muscle Cell = Muscle Fiber (2 of 2)

- Mitochondria // packed in spaces between myofibrils
- sarcoplasmic reticulum (SR) // smooth ER that forms a network around each myofibril – calcium reservoir
  - calcium activates the muscle contraction process
- terminal cisternae // dilated end-sacs of SR which cross muscle fiber from one side to the other
- T tubules // tubular infoldings of the sarcolemma which penetrate through the cell and emerge on the other side
- triad // a T tubule and two terminal cisterns


Sarcoplasmic reticulum
Sarcolemma
Muscle fiber
Myofibril
Sarcoplasm
Nucleus
Transverse tubule
Terminal cisterns
Mitochondrion

Skeletal Muscle Cell = Muscle Fiber (1 of 2)

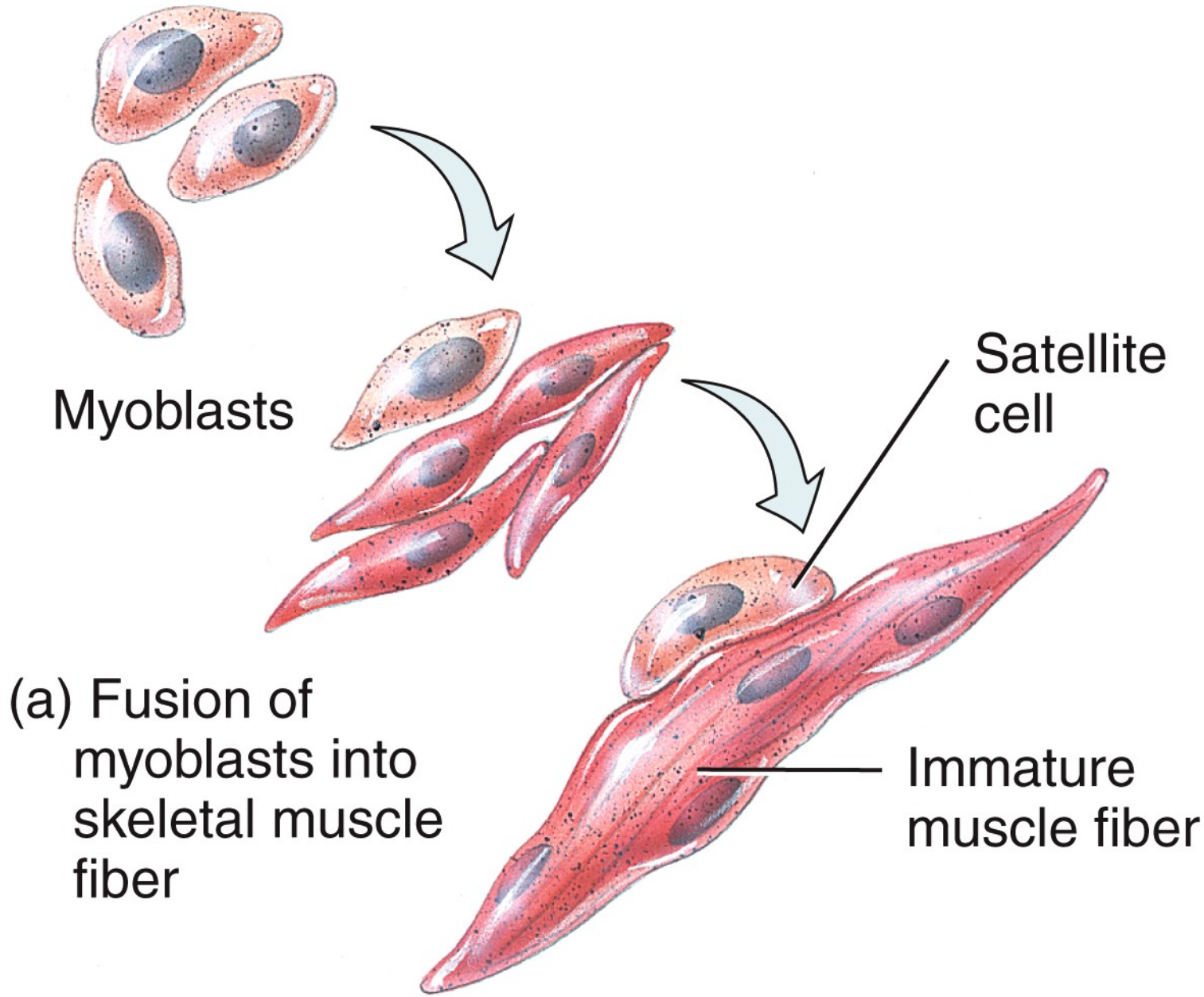
- Myoblasts // stem cells in embryonic development that fuse to form each muscle fiber

- Satellite cells – unspecialized myoblasts remaining between the muscle fiber and endomysium // may multiply and produce new muscle fibers to some degree

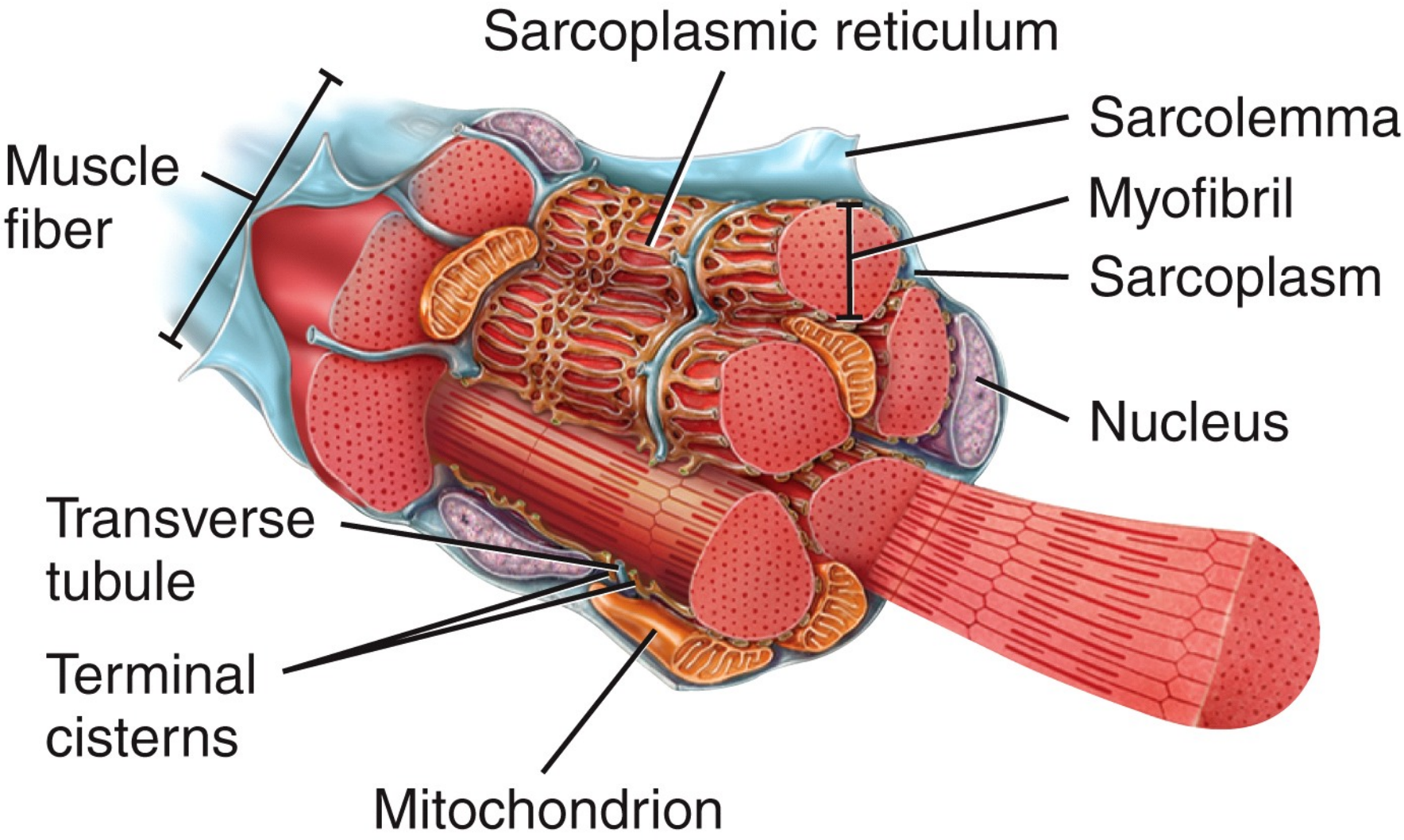
- Repair by fibrosis // Muscle fibers do not undergo mitosis

  – These cells are in G zero!

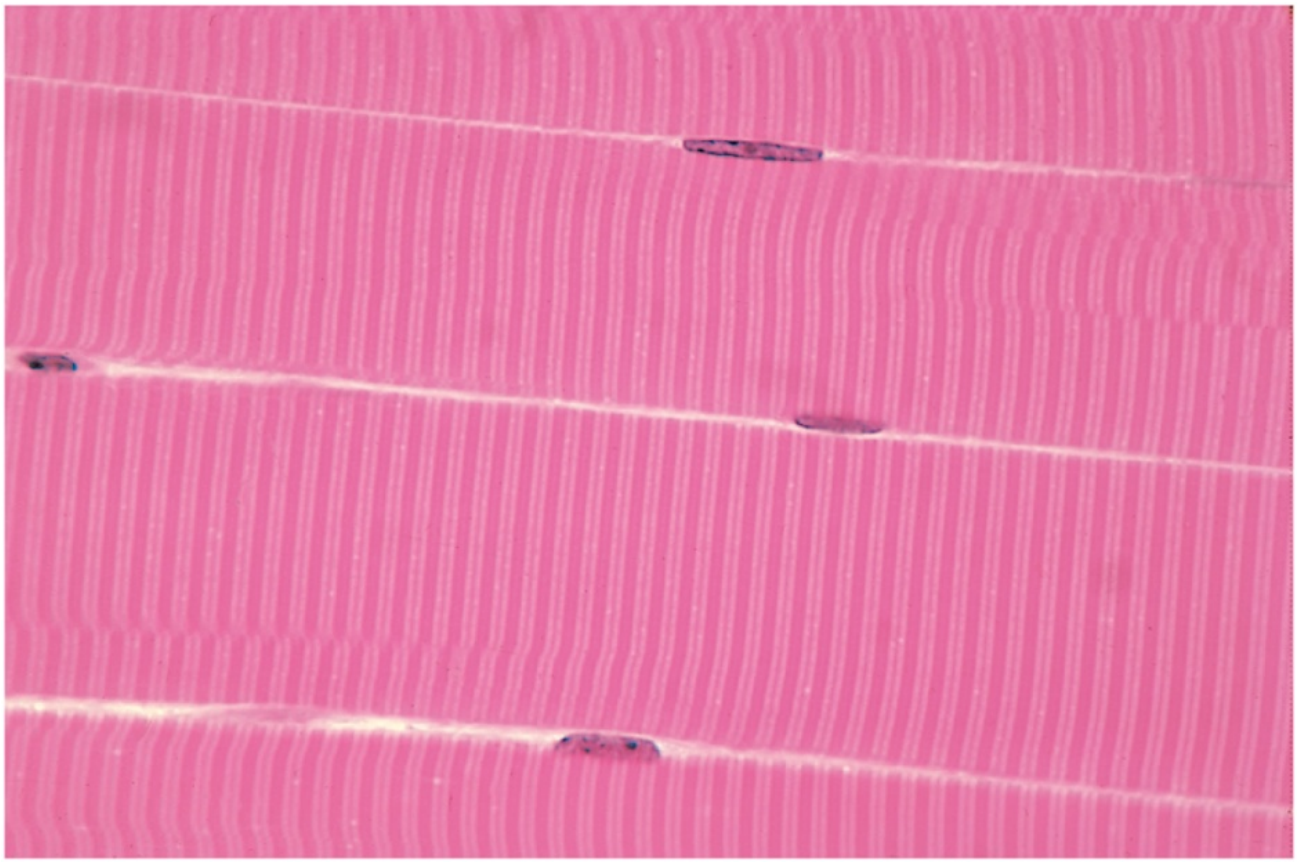
  – rather than regeneration of functional muscle, replaced with scar tissue (fibrosis)



(a) Fusion of myoblasts into skeletal muscle fiber

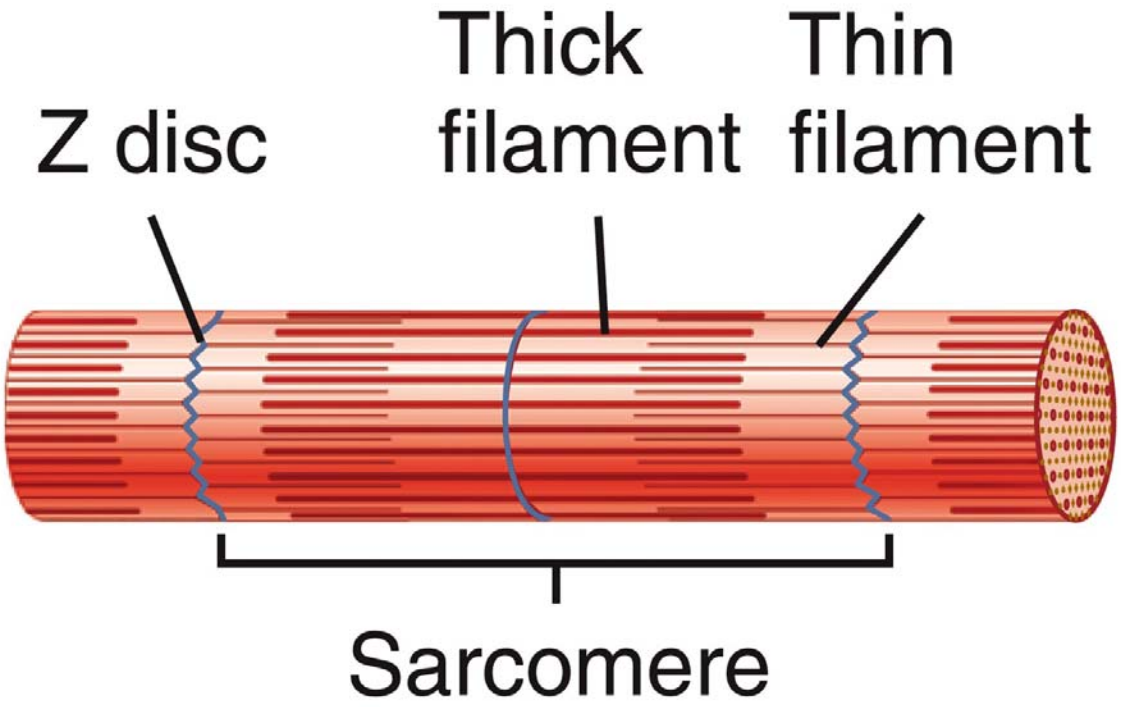

Sarcoplasmic reticulum
Sarcolemma
Muscle fiber
Myofibril
Sarcoplasm
Nucleus
Transverse tubule
Terminal cisterns
Mitochondrion

Striations of Skeletal Muscle



Alternating light and dark transverse bands // results from an overlapping of internal contractile proteins

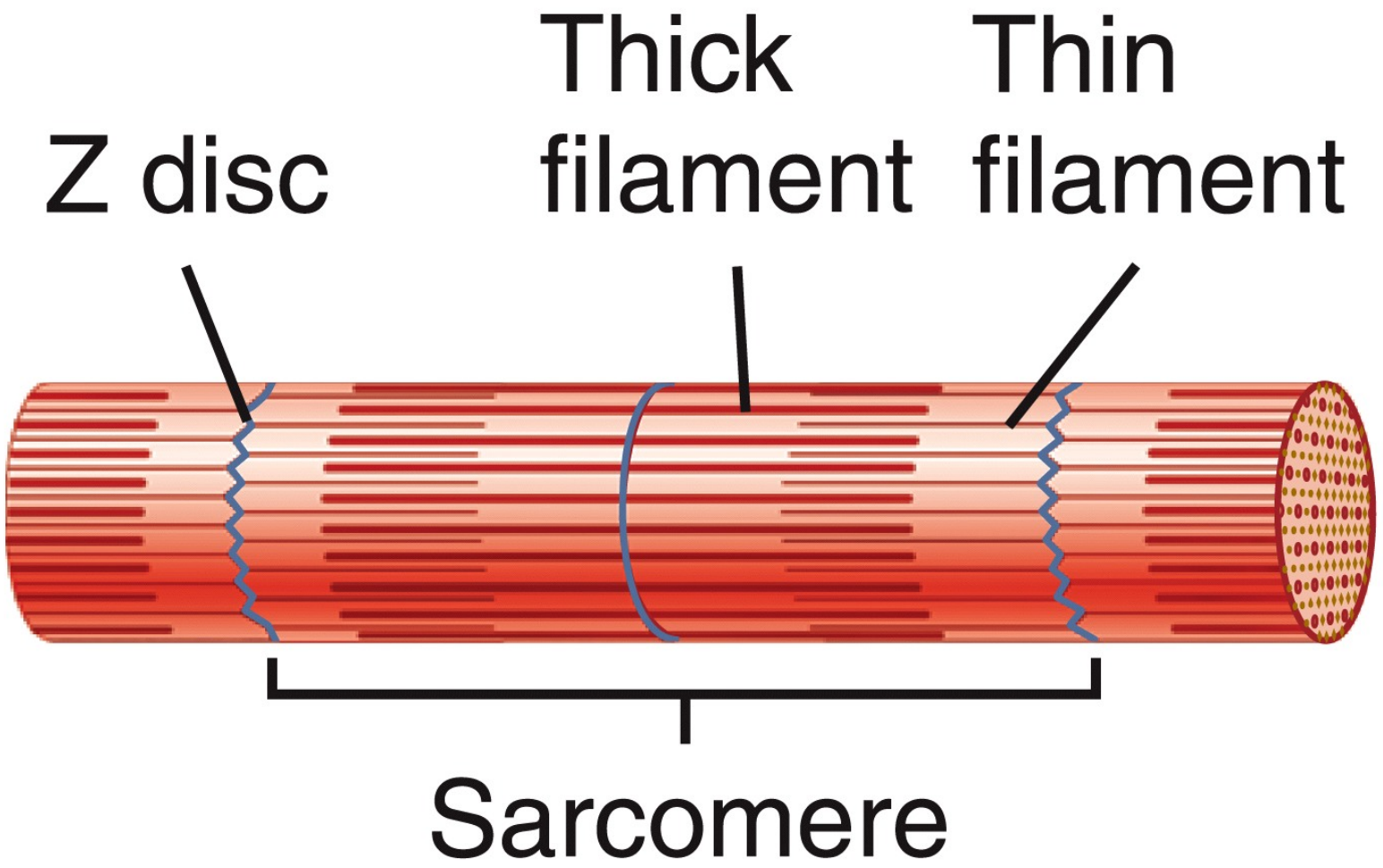
Striations, Sarcomeres, and the Sliding Filament Theory



- ***Functional contractile unit of a muscle fiber***
  - muscle shortens because protein fibers slide across each other
  - sarcomere shorten but length of individual proteins do not shorten
  - pulls z discs closer to each other

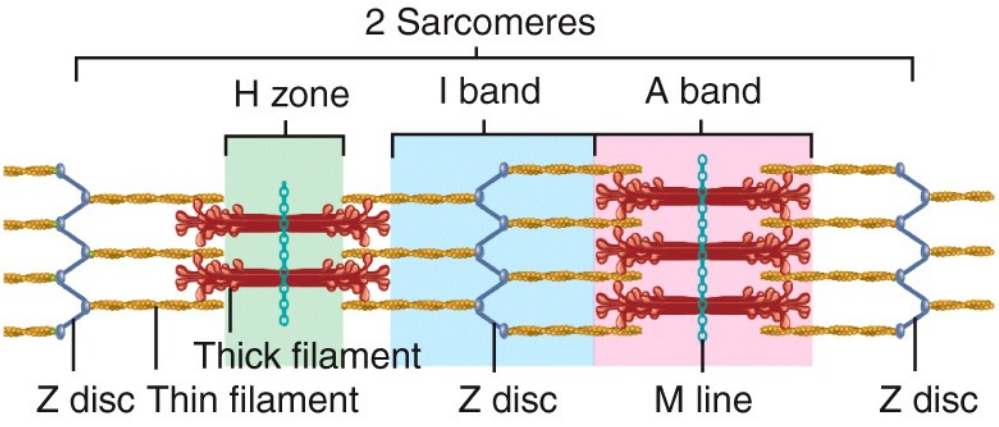
Sarcomeres

- **sarcomere** - segment from Z disc to Z disc
  - functional contractile unit of muscle fiber
- muscle cells shorten because their individual sarcomeres shorten
  - Z disc (Z lines) are pulled closer together as thick and thin filaments slide past each other

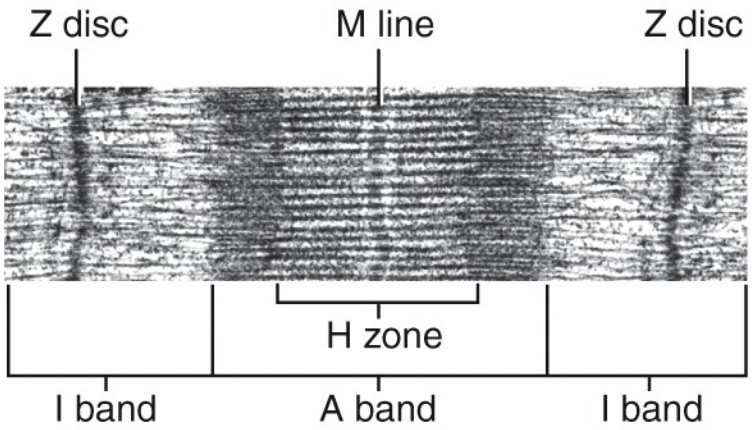


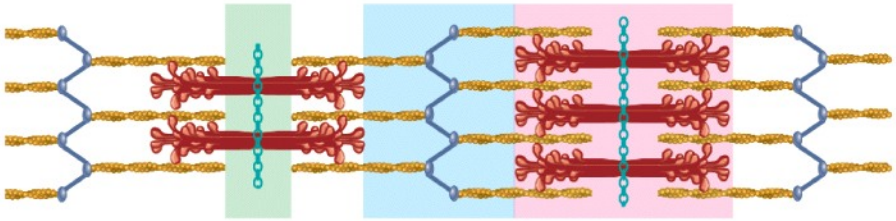
Thick fliaments = myosin

Thin filaments = actin

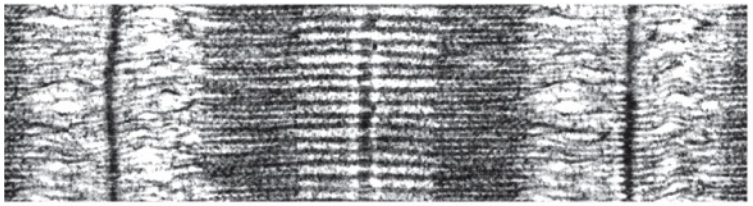


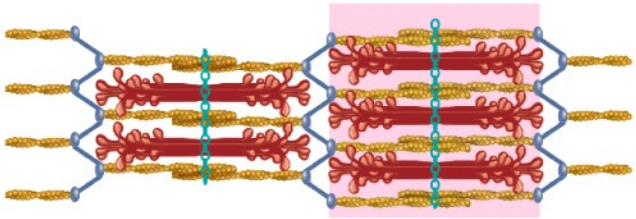
(a) Relaxed muscle



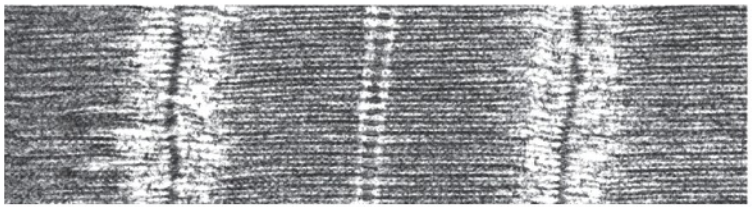


(b) Partially contracted muscle





(c) Maximally contracted muscle



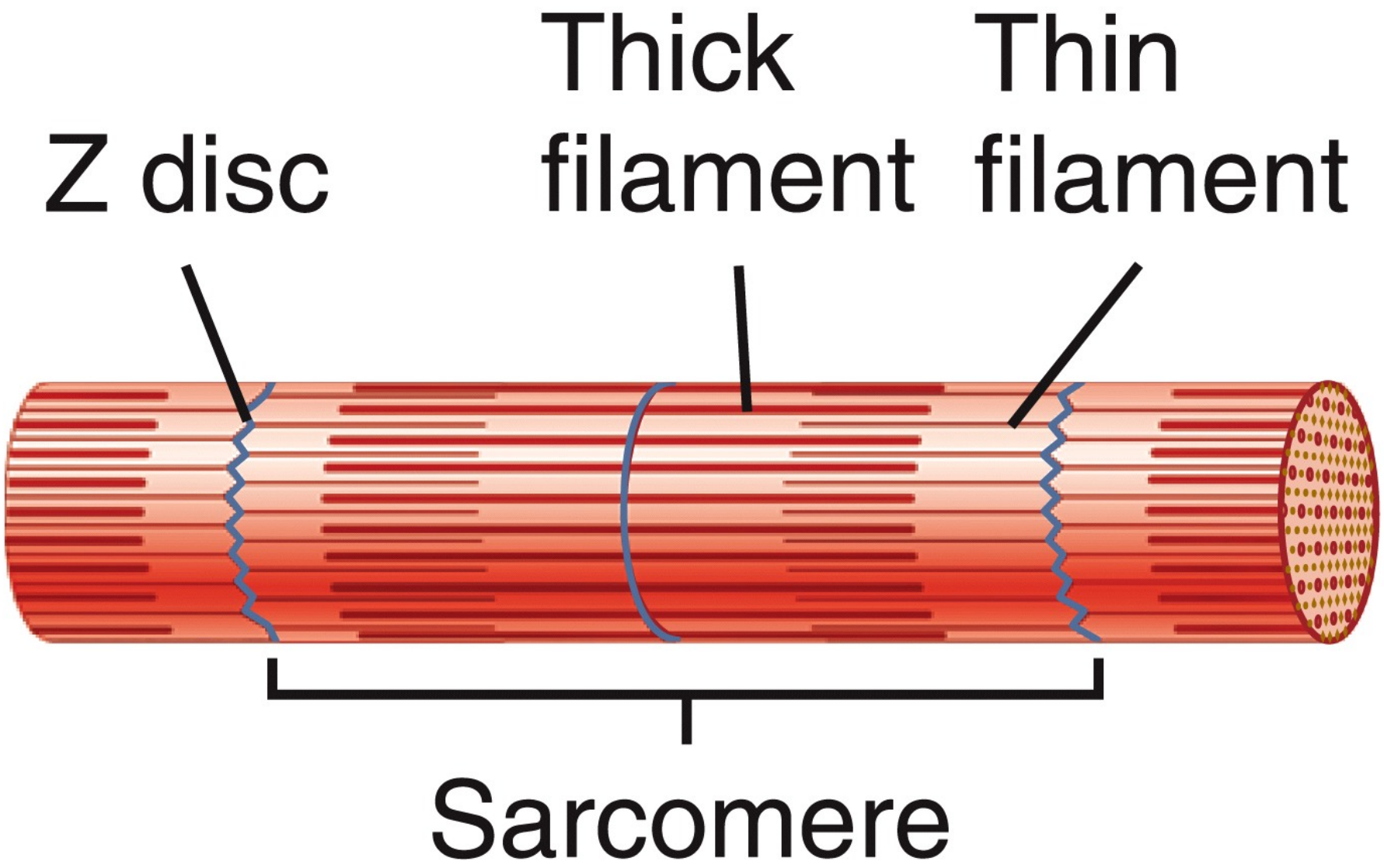
Courtesy Hiroyouki Sasaki, Yale E. Goldman and Clara Franzini-Armstrong

Skeletal Muscle Fiber Proteins

- **Contractile Proteins**
  - **Myosin (ATP binding site and ATPase // also the motor protein)**
  - **Actin (interacts with myosin to form “cross bridge” between contractile proteins**
- **Regulatory Proteins**
  - **Tropomyosin (blocks myosin binding site)**
  - **Troponin (binds calcium to expose myosin binding sites)**
- **Structural Proteins**
  - **Titin**
  - **Alpha-actinin**
  - **Myomesin**
  - **Nubulin**
  - **Dystrophin**

Sarcomeres

- neither thick nor thin filaments change length during shortening
  - only the amount of overlap changes
- during shortening dystrophin & other linking proteins pull on connective tissue's extracellular proteins
  - transfers force of contraction to connective tissue surrounding muslce (endomysium)
  - Continuous and direct transfer of force to CT surrounding muscle, tendons, perimysium, sharpe fibers, and collagen of the bone matrix
    - this force used to shape bone growth!
    - regulates osteoblast and osteoclast activity


Thick filament
Thin filament
Z disc
Sarcomere

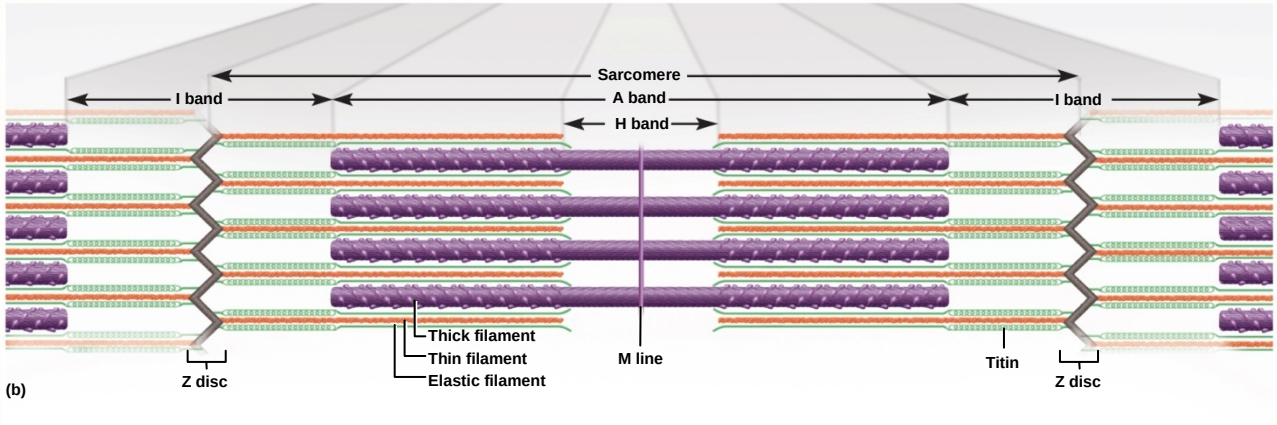
Functional Unit = Sarcomere

- **myosin** and **actin** are “contractile” proteins found in all cells (including non muscle cells) // e.g. actin in the peripheral protein of the cell’s cytoskeleton

  – function in cellular motility, mitosis, transport of intracellular material

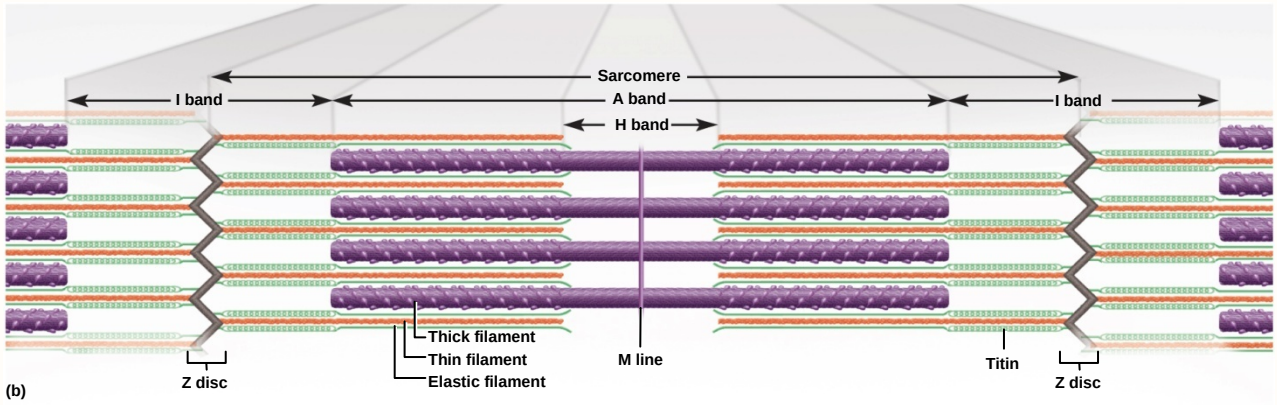
- organized in a precise way in **skeletal** and **cardiac** muscle

- results in striated appearance / overlap of proteins



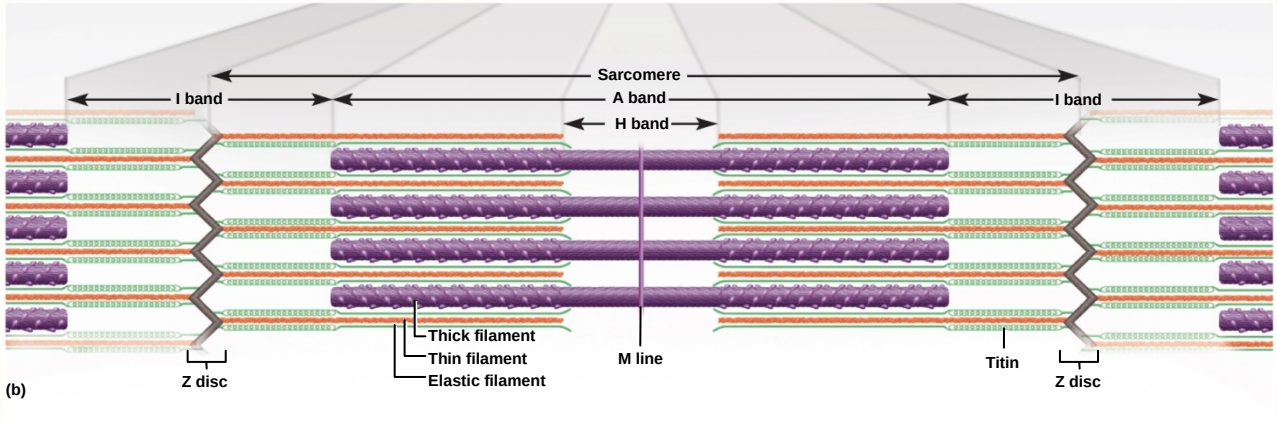
Functional Unit = Sarcomere

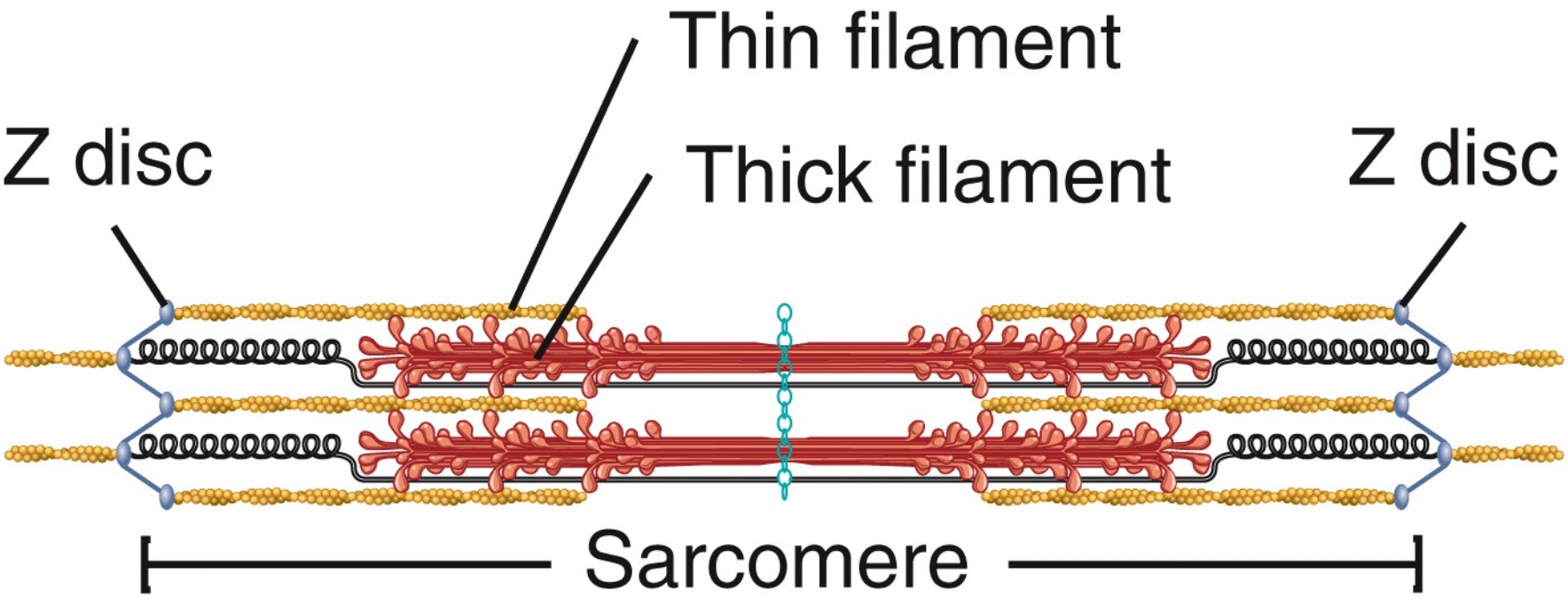
- A band – dark – A stands for anisotropic
  - part of A band where thick and thin filaments overlap is especially dark
  - H band in the middle of A band – just thick filaments
  - M line is in the middle of the H band
- I band – alternating lighter band – I stands for isotropic
  - the way the bands reflect polarized light

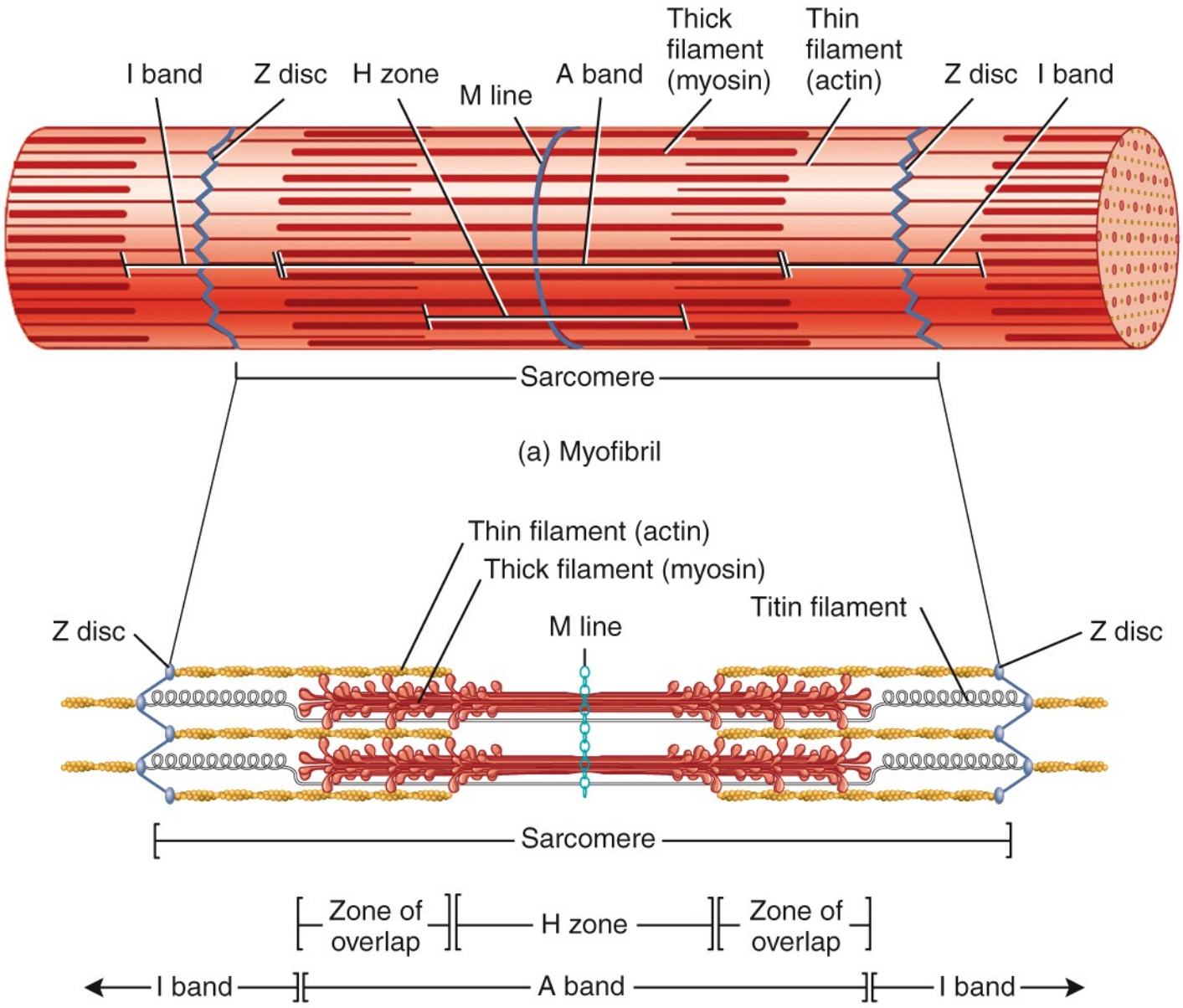


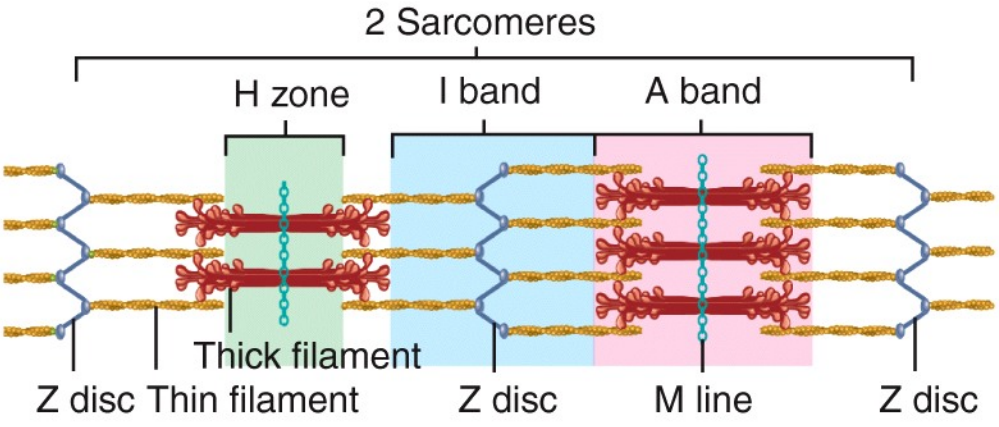
Functional Unit = Sarcomere

- z disc – provides anchorage for thin filaments and elastic filaments (titin)
  - bisects I band
- sarcomere – the segment of the myofibril from one z disc to the next
- <u>The actin and myosin polymers do not change length during a muscle contraction!</u>




Thin filament
Z disc
Thick filament
Z disc
Sarcomere


I band
Z disc
H zone
M line
A band
Thick filament (myosin)
Thin filament (actin)
Z disc
I band
Sarcomere
(a) Myofibril
Thin filament (actin)
Thick filament (myosin)
Titin filament
Z disc
M line
Z disc
Sarcomere
Zone of overlap
H zone
Zone of overlap
I band
A band
I band
(b) Details of filaments and Z discs



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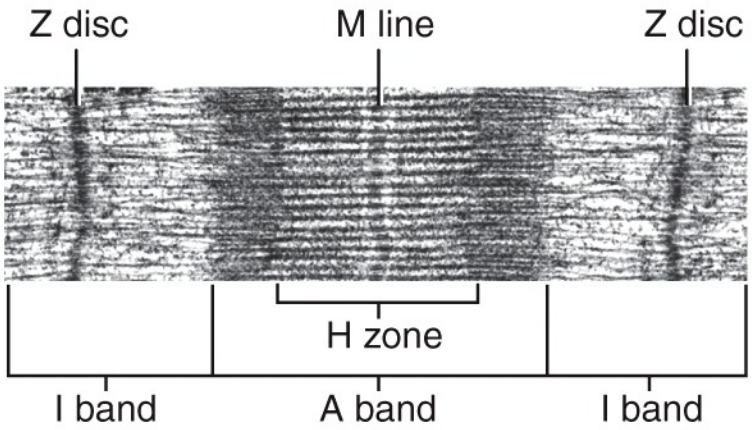
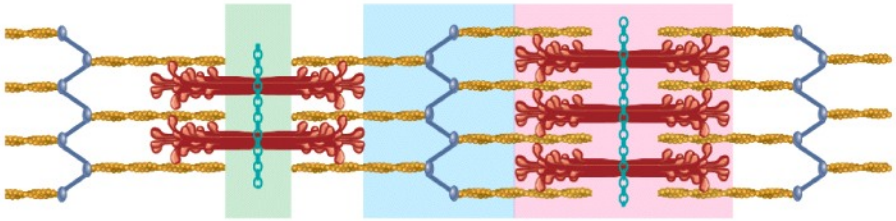
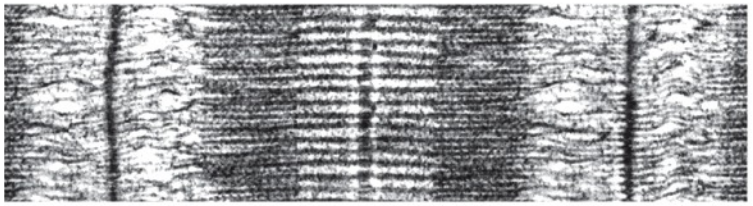
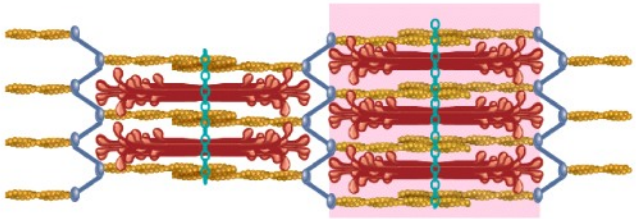


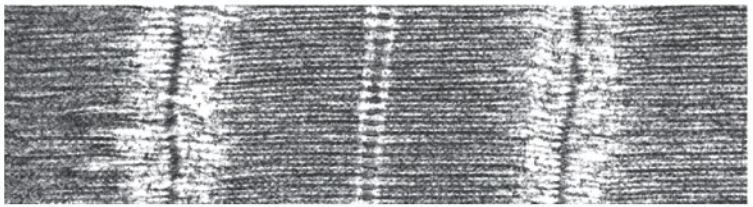


(b) Partially contracted muscle

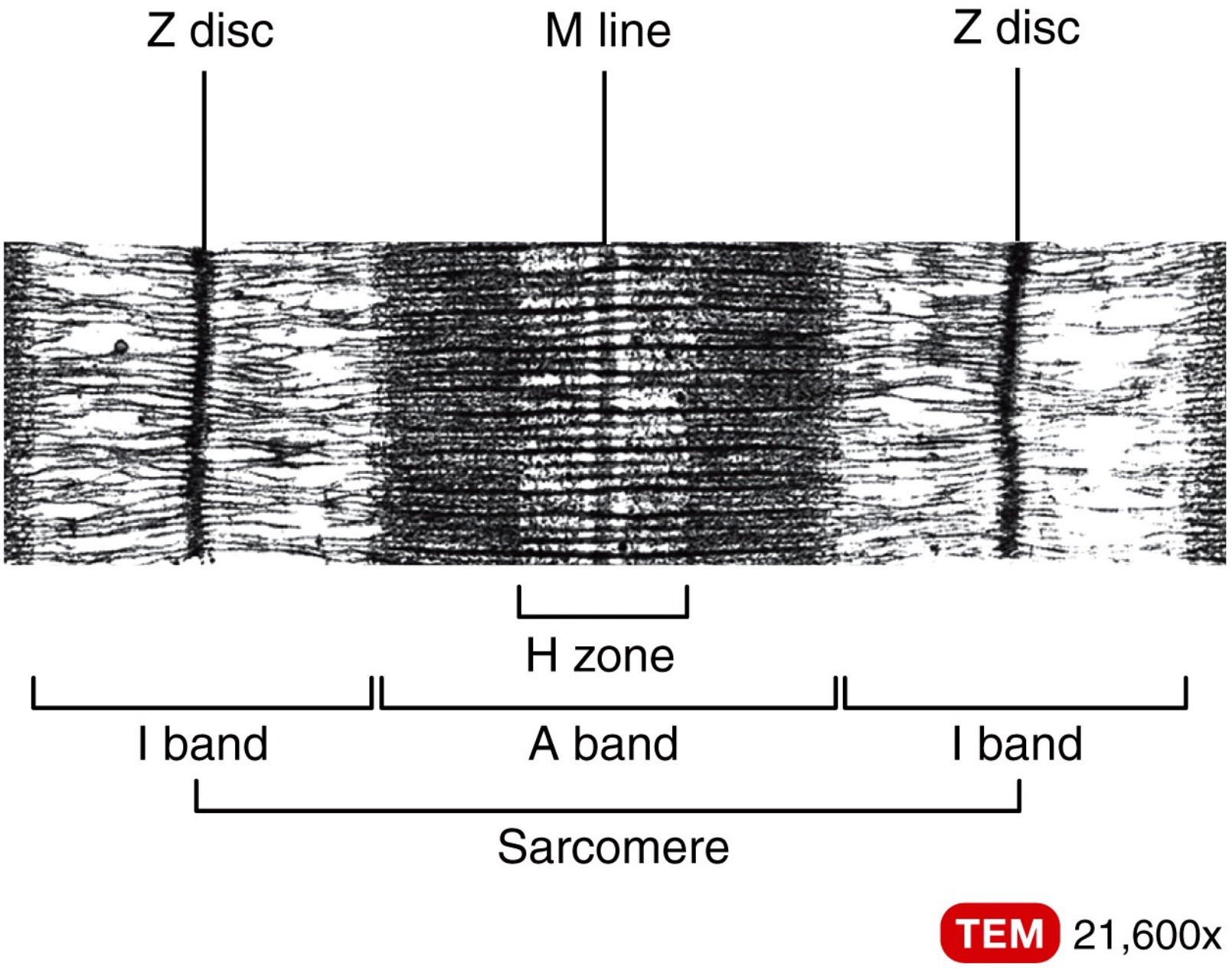




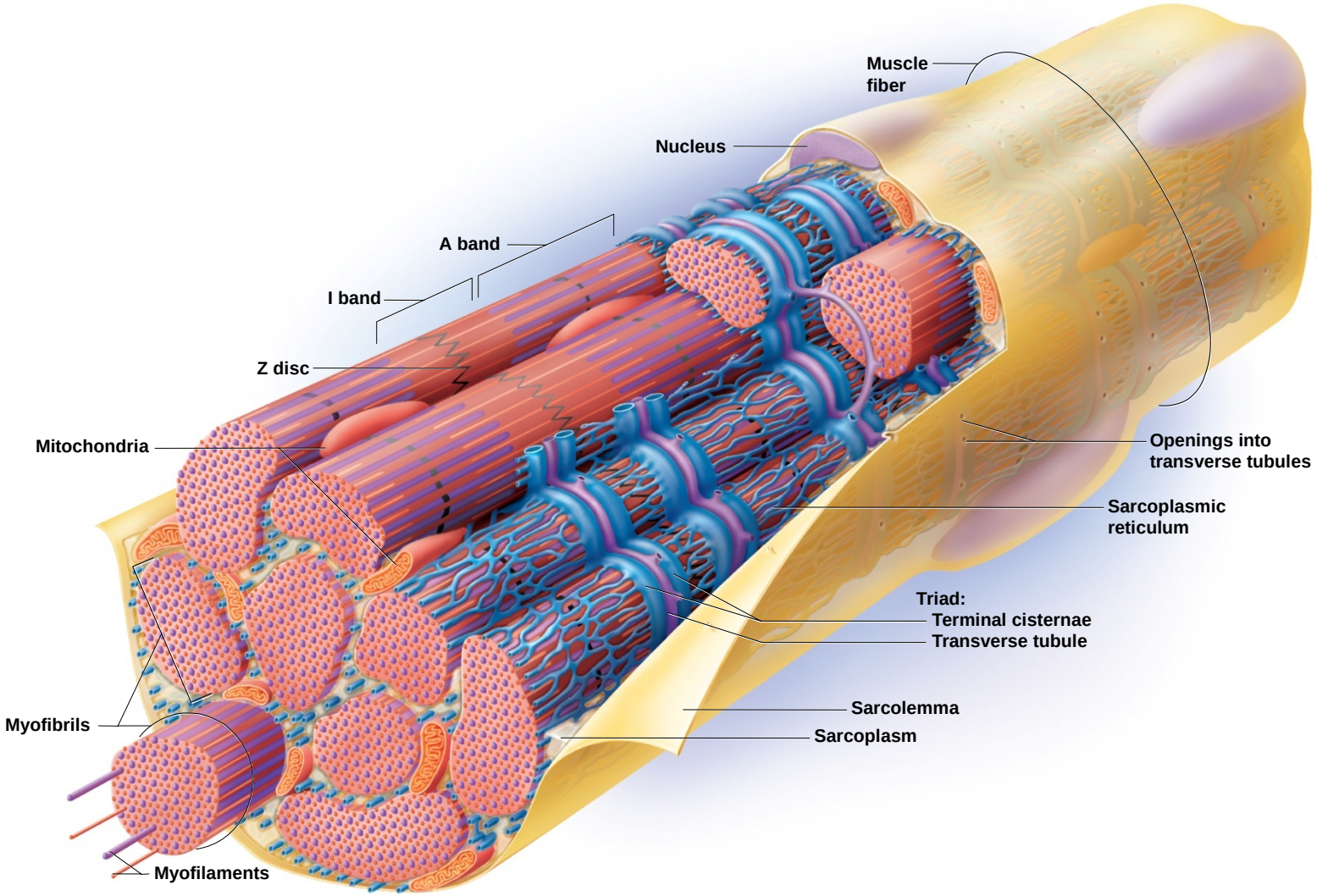
(c) Maximally contracted muscle



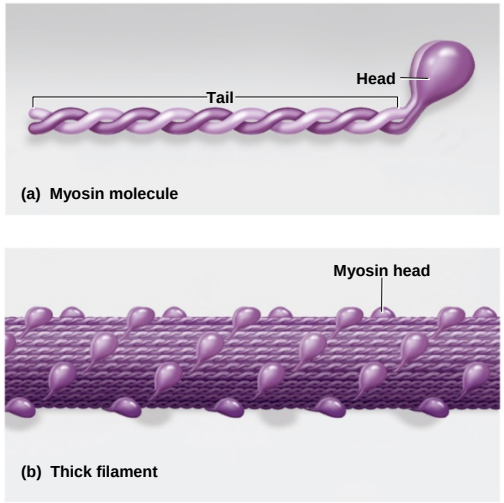
Courtesy Hiroyouki Sasaki, Yale E. Goldman and Clara Franzini-Armstrong


Z disc
M line
Z disc
H zone
I band
A band
I band
Sarcomere
TEM 21,600x
Courtesy Denah Appelt and Clara Franzini-Armstrong

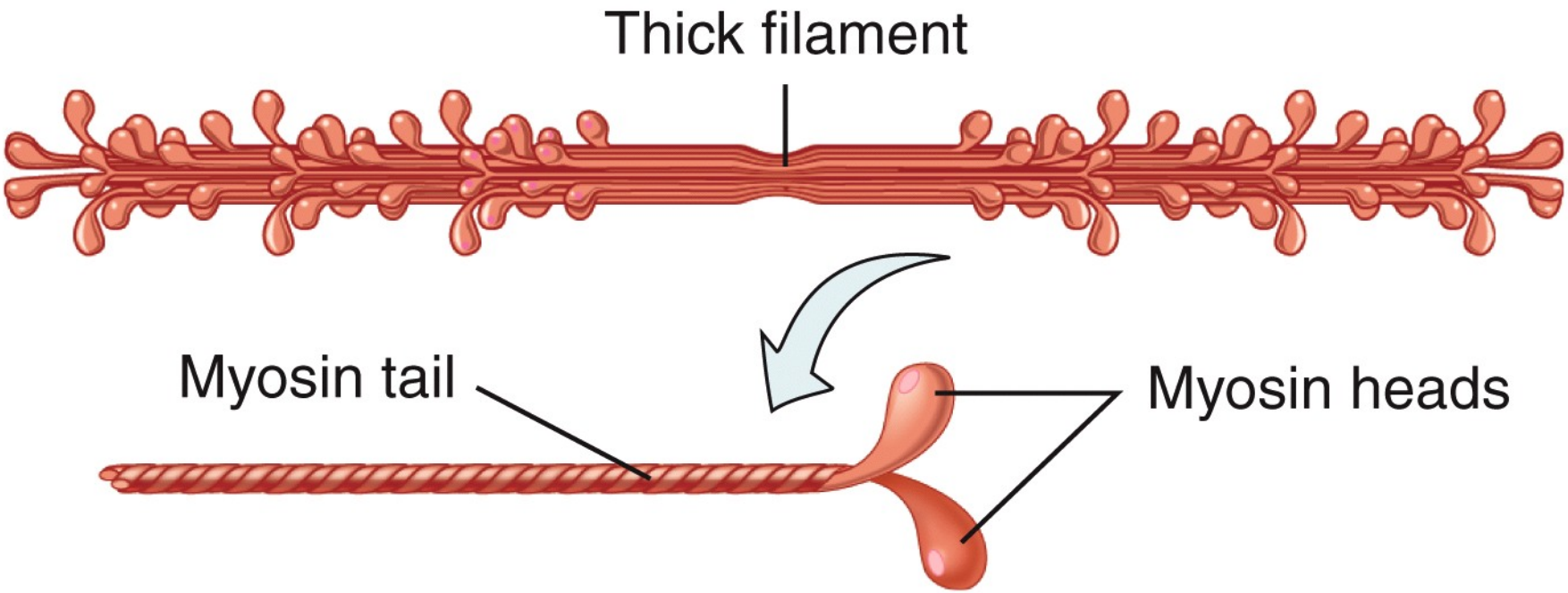
Structure of a Skeletal Muscle Fiber



Thick Myofilaments



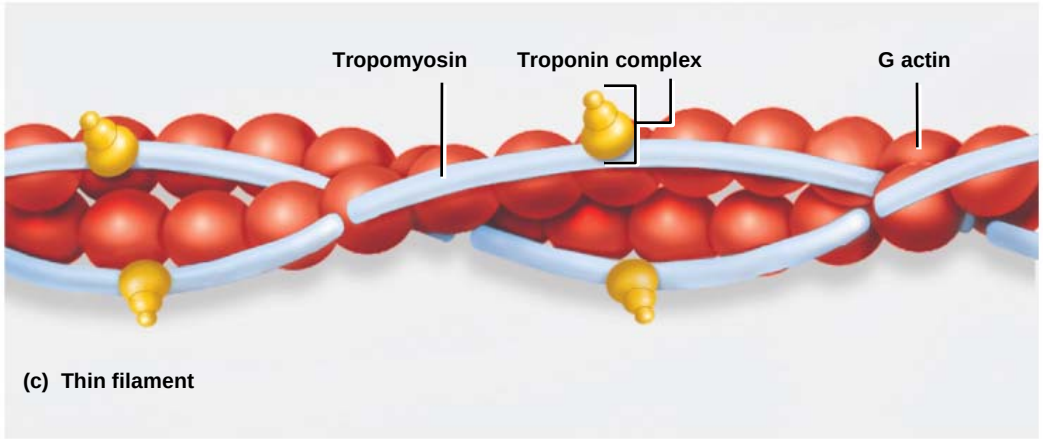
- made of several hundred **myosin** molecules
  - shaped like a golf club
    - two chains intertwined to form a shaft-like tail
    - double globular head
  - heads directed outward in a helical array around the bundle
    - heads on one half of the thick filament angle to the left
    - heads on the other half angle to the right
    - bare zone with no heads in the middle

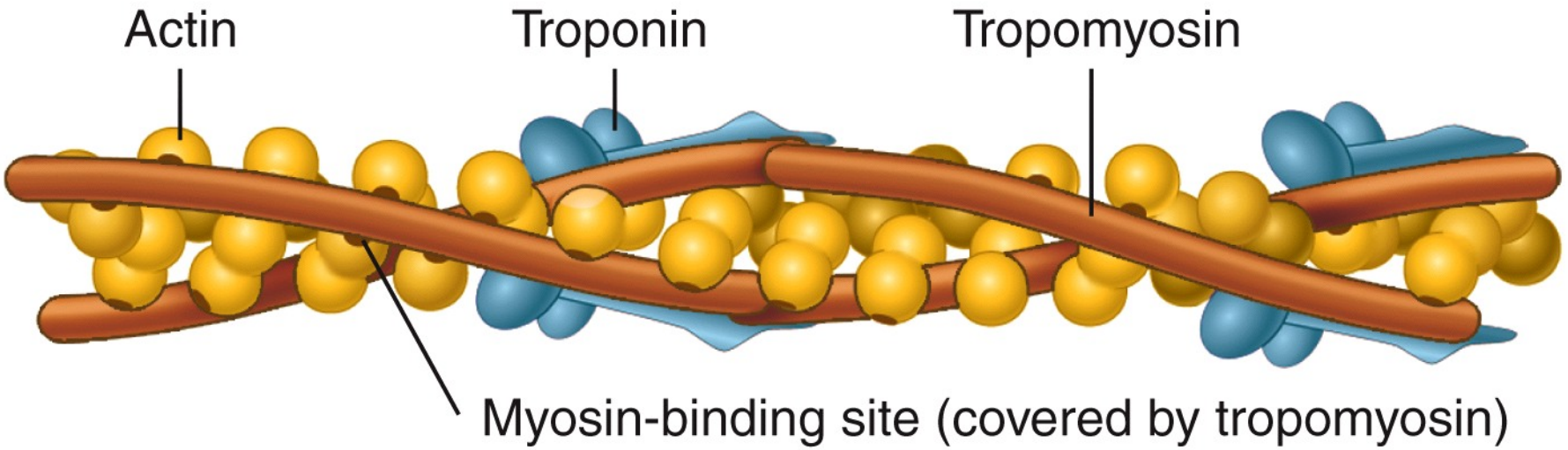


(a) A thick filament and a myosin molecule

Thin Myofilaments

- fibrous (F) actin - two intertwined strands
  - string of globular (G) actin subunits each with an active site that can bind to head of myosin molecule
- tropomyosin molecules
  - each blocking 6 or 7 active sites on G actin subunits
- troponin molecule - small, calcium-binding protein on each tropomyosin molecule

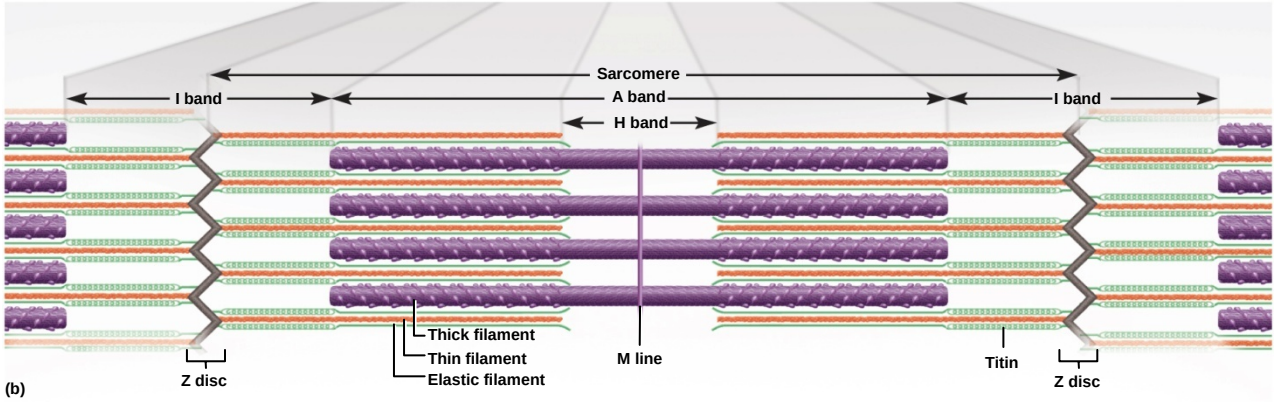




(b) Portion of a thin filament

Elastic Myofilaments

- **titin (connectin)**
  - huge springy protein
  - flank each thick filament and anchor it to the Z disc
  - helps stabilize the thick filament
  - center it between the thin filaments
  - prevents over stretching


Sarcomere
I band
A band
I band
H band
Thick filament
Thin filament
Elastic filament
M line
Titin
Z disc
Z disc
(b)

Regulatory and Contractile Proteins

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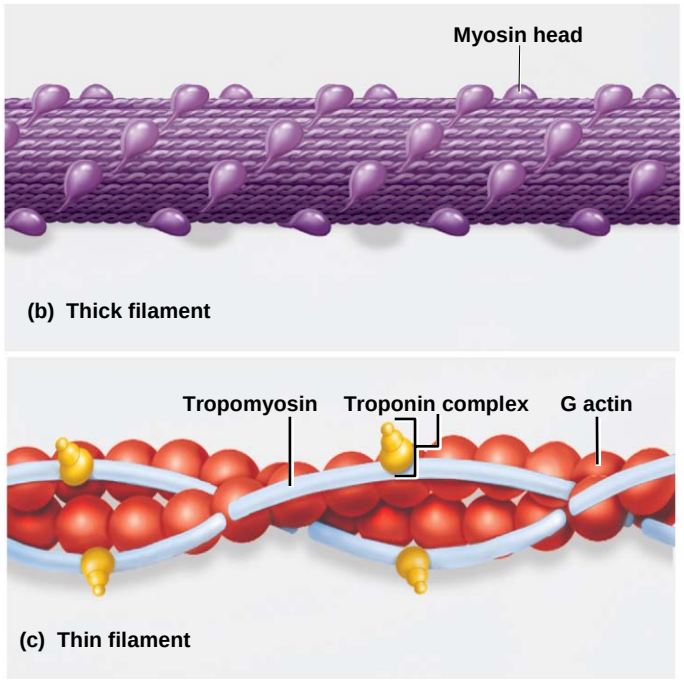

- contractile proteins – myosin (motor protein) and actin (myosin pulls on actin to bring Z-discs together)
- regulatory proteins - tropomyosin and troponin
  - like a switch that determine when the fiber can contract and when it cannot
  - contraction activated by release of calcium into sarcoplasm and its binding to troponin,
  - troponin changes shape and moves tropomyosin off the active sites on actin

Overlap of Thick and Thin Filaments

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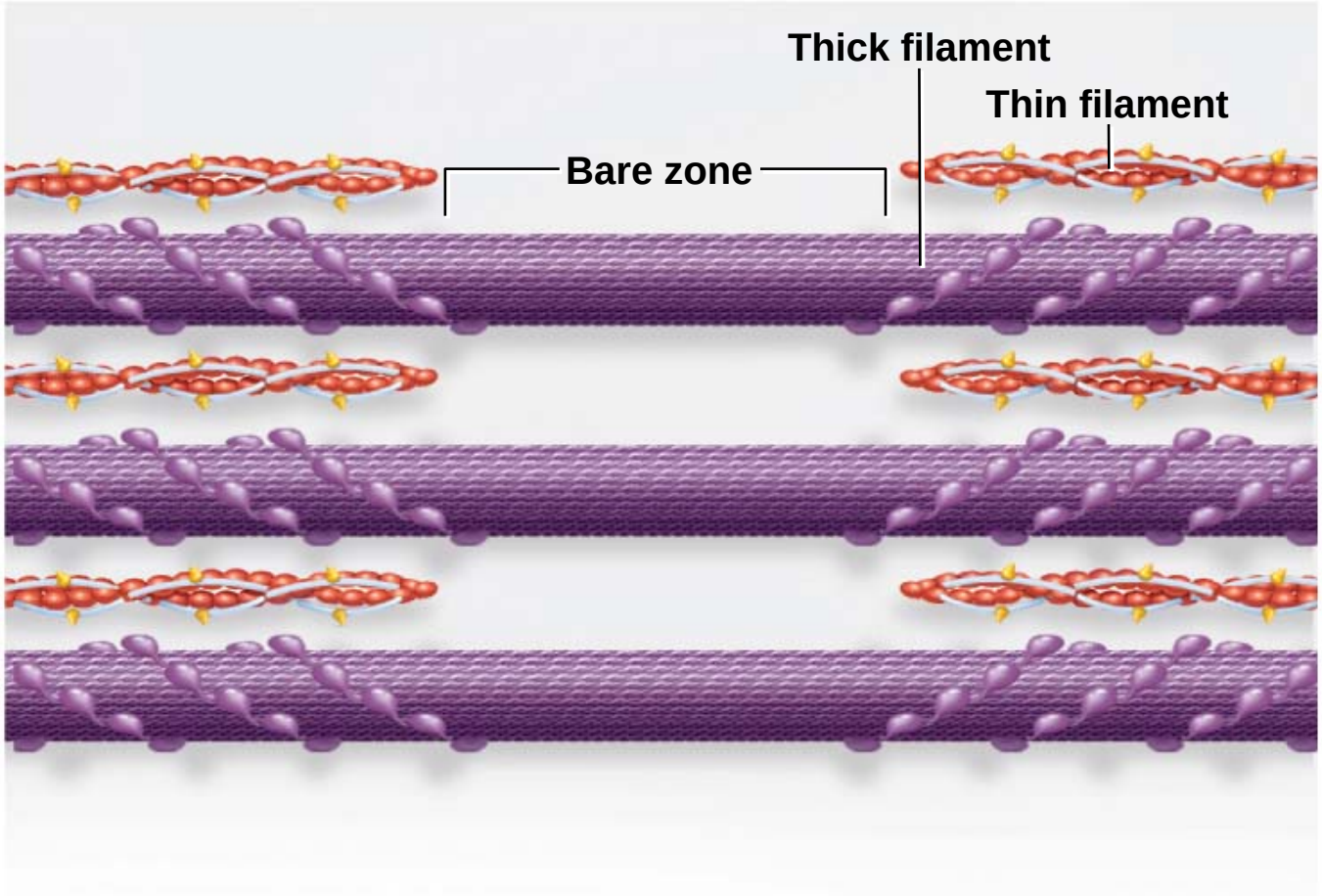
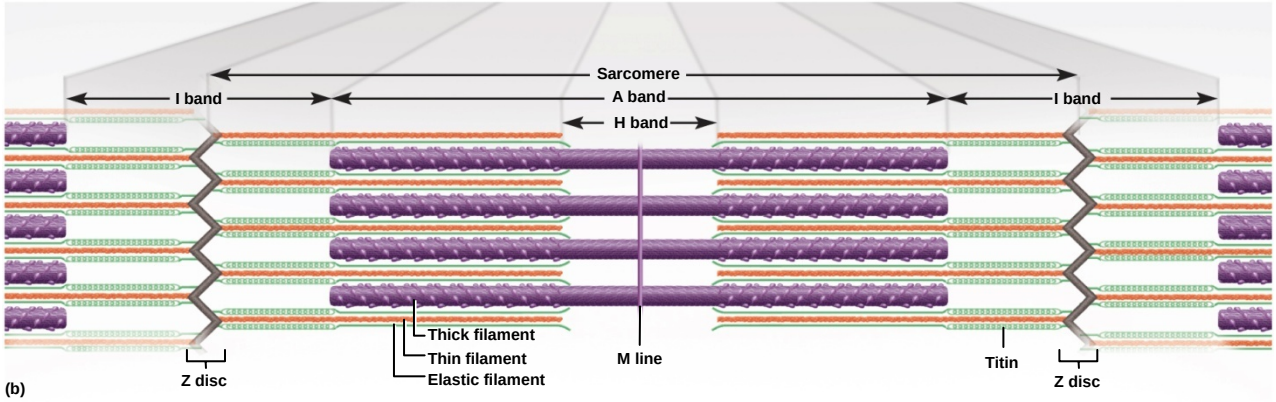


Portion of a sarcomere showing the overlap of thick and thin filaments


Sarcomere
I band
A band
I band
H band
Thick filament
Thin filament
Elastic filament
M line
Titin
Z disc
Z disc
(b)

Accessory Proteins

- Connect contractile proteins to connective tissue surrounding muscle fiber
- Series of proteins (seven or more)
- Associated with thick or thin filaments
  - anchor the myofilaments
  - regulate length of myofilaments
  - alignment of myofilaments for maximum effectiveness

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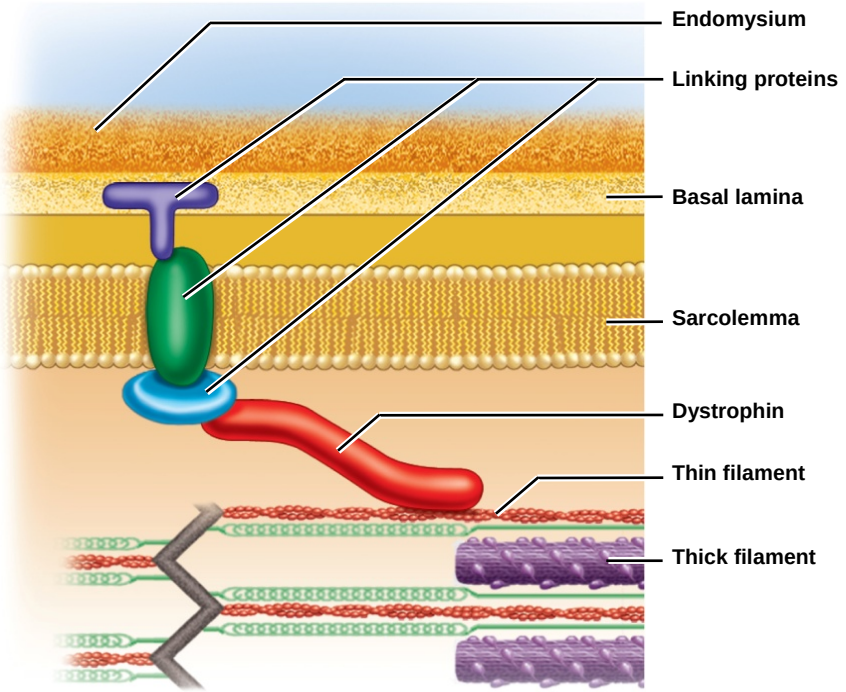

Accessory Proteins

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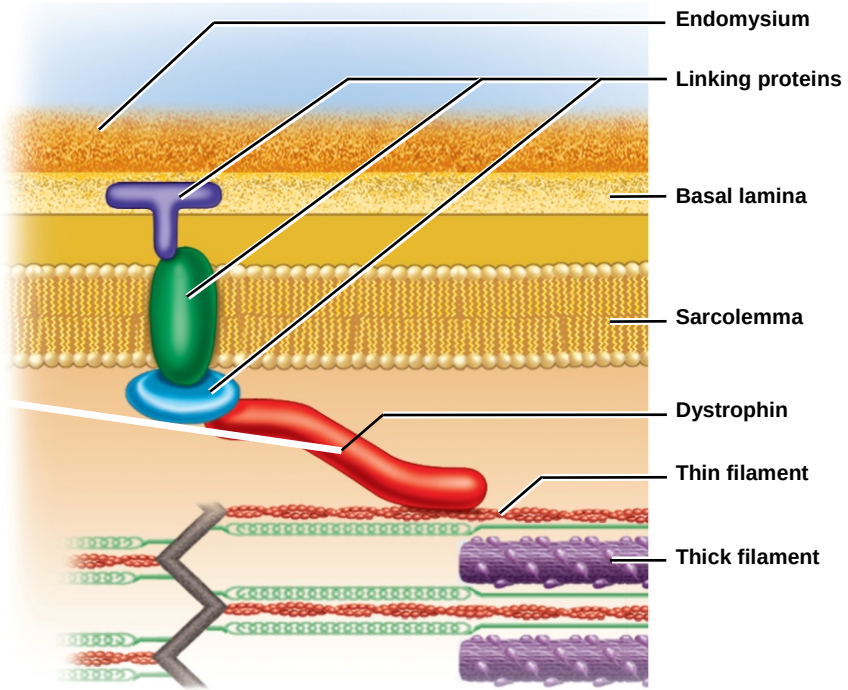
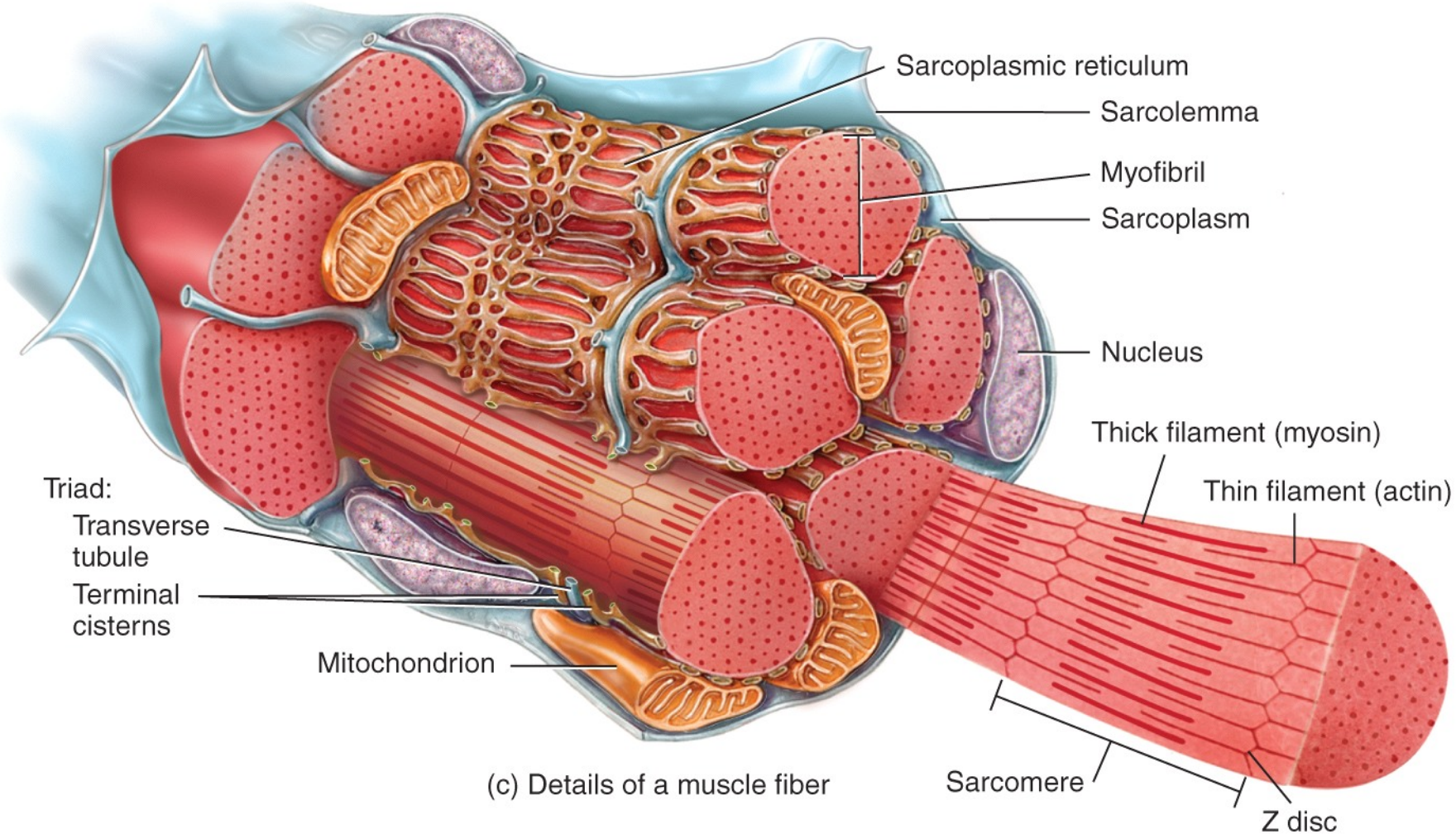


Dystrophin

- most clinically important
- links actin in outermost myofilaments to transmembrane proteins
- eventually links to fibrous endomysium surrounding the entire muscle cell
- transfers forces of muscle contraction to connective tissue around muscle cell
- genetic defects in dystrophin produce disabling disease muscular dystrophy



(c) Details of a muscle fiber