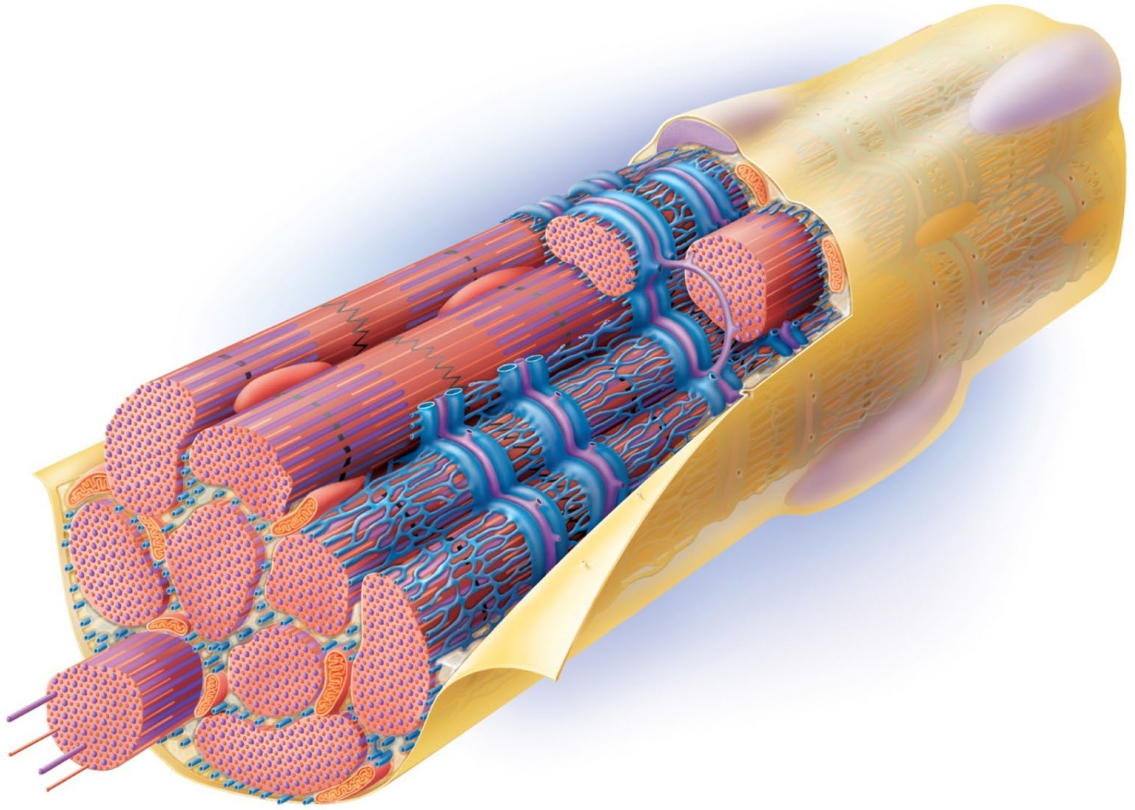
Chapter 11.1

Skeletal Muscle Structure and Function



Introduction to Muscle Physiology

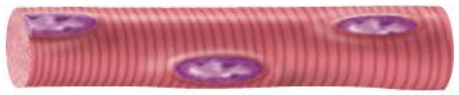
- All muscle cells (skeletal, cardiac, and smooth) change ATP's chemical energy into muscle mechanical energy
- Contraction occurs as a "muscle cell shortens".

–What happens when skeletal muscle cells shortens?

–How do we explained muscle contraction using molecular-biology?

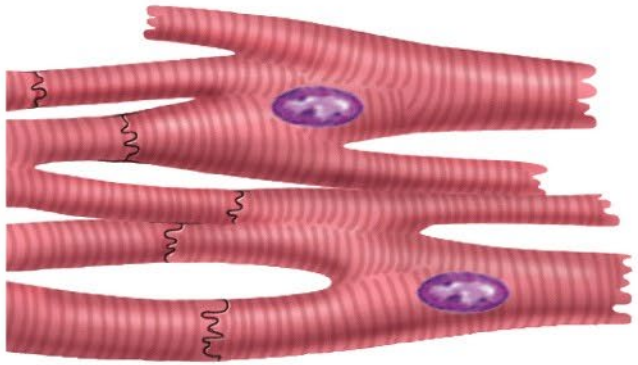
- *In this lecture we will focus on the structure and function of skeletal muscle cells. These cells are called muscle fibers.*
- *I will briefly define cardiac and smooth muscle function here but will cover cardiac muscle in detail in Unit 3*

Skeletal muscle



- Voluntary
- Striated
- Multi-nucleated

Cardiac muscle

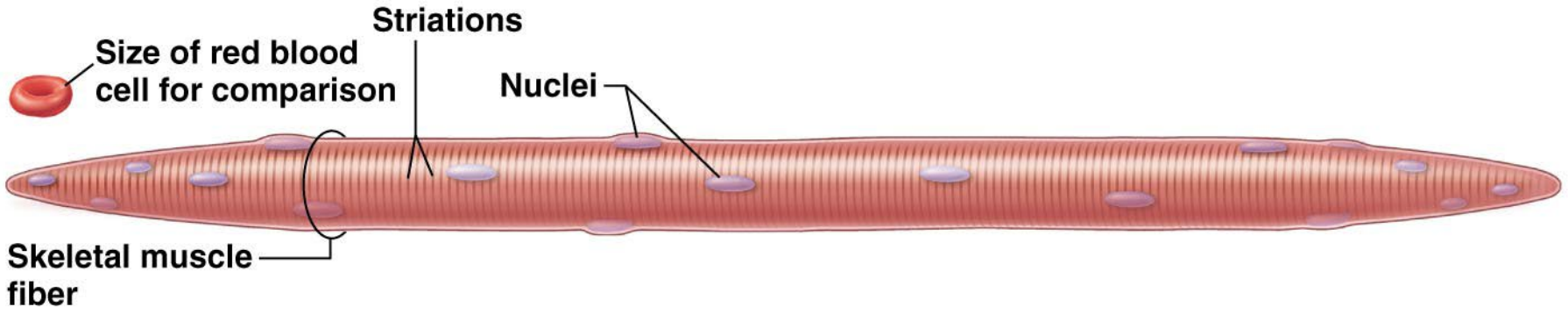


- Involuntary
- Striated
- One nucleus

Smooth muscle

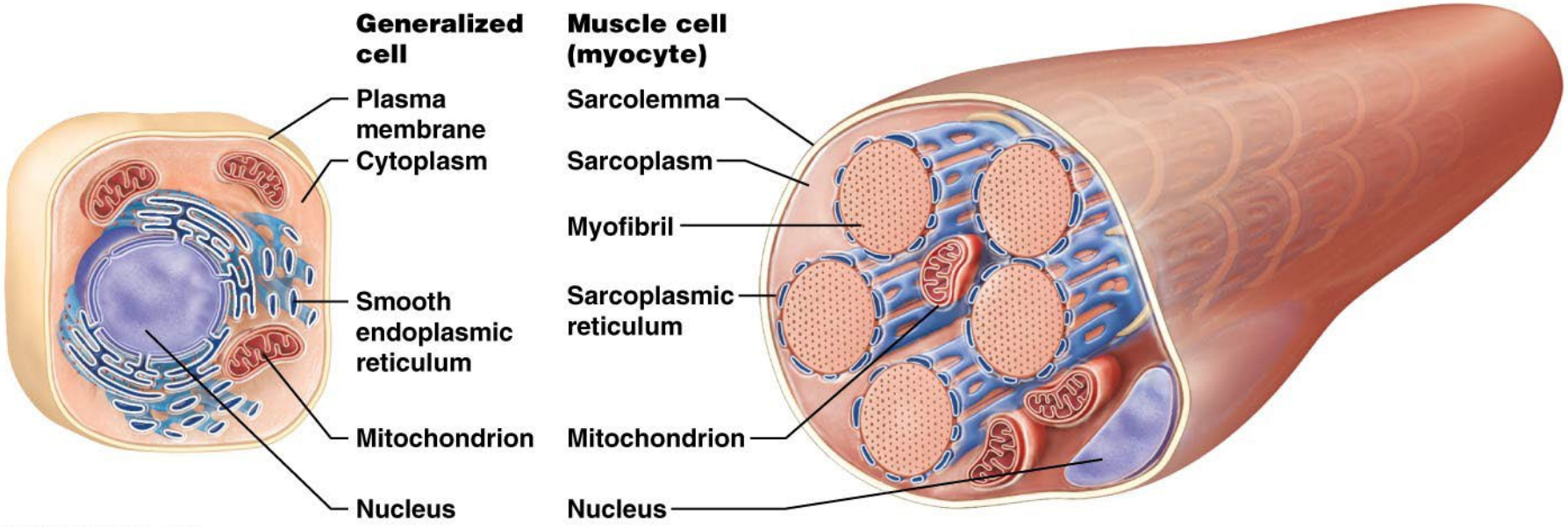
- Involuntary
- Non-striated
- One nucleus

Size and shape of a skeletal muscle fiber compared to a typical cell.



Why do we call a skeletal muscle cell a muscle fiber?

A common cell (left) compared to a skeletal muscle fiber (right).



Note: skeletal muscle fibers are “multi-nucleated”

Four Connective Tissues Membranes of a Skeletal Muscle

- 1) Endomysium

–thin sleeve of loose connective tissue surrounding each **muscle fiber**

–allows room for capillaries and nerve fibers to reach each muscle fiber

- 2) Perimysium

–slightly thicker layer of connective tissue

–**fascicles** – bundles of muscle fibers wrapped in perimysium

–carry larger nerves and blood vessels, and stretch receptors

Four Connective Tissues of a Skeletal Muscle

- 3) Epimysium

–fibrous sheath surrounding the entire muscle

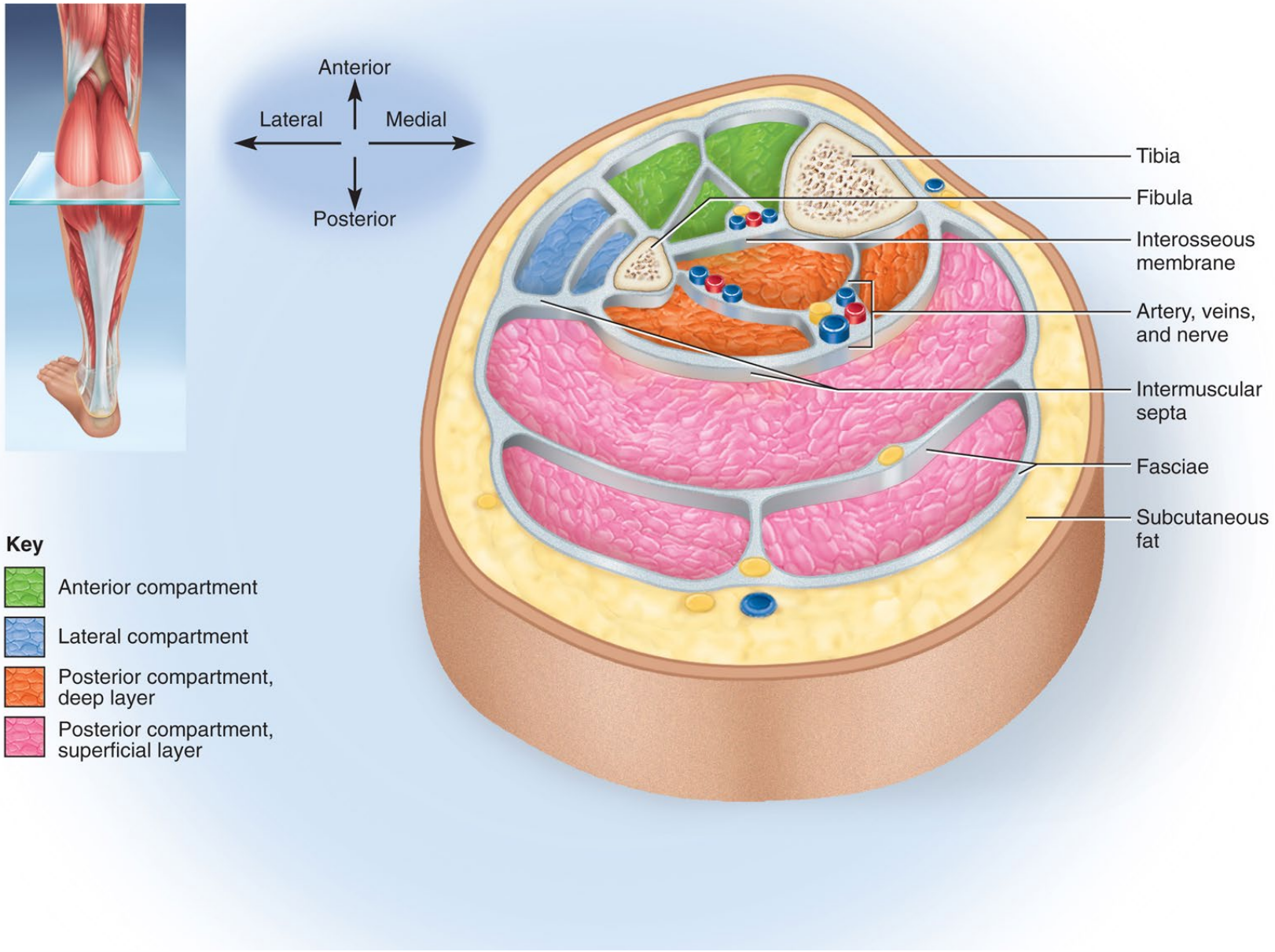
–outer surface grades into the fascia

–inner surface sends projections between fascicles to form perimysium

- 4) Fascia = sheet of connective tissue that may separate and/or connect neighboring muscles from each other /// also between all other organ systems throughout body

–**Compartment Syndrome** /// CNN science reporter, Miles Obrien had his arm amputated 12 hours after a heavy case “bruised his arm”.

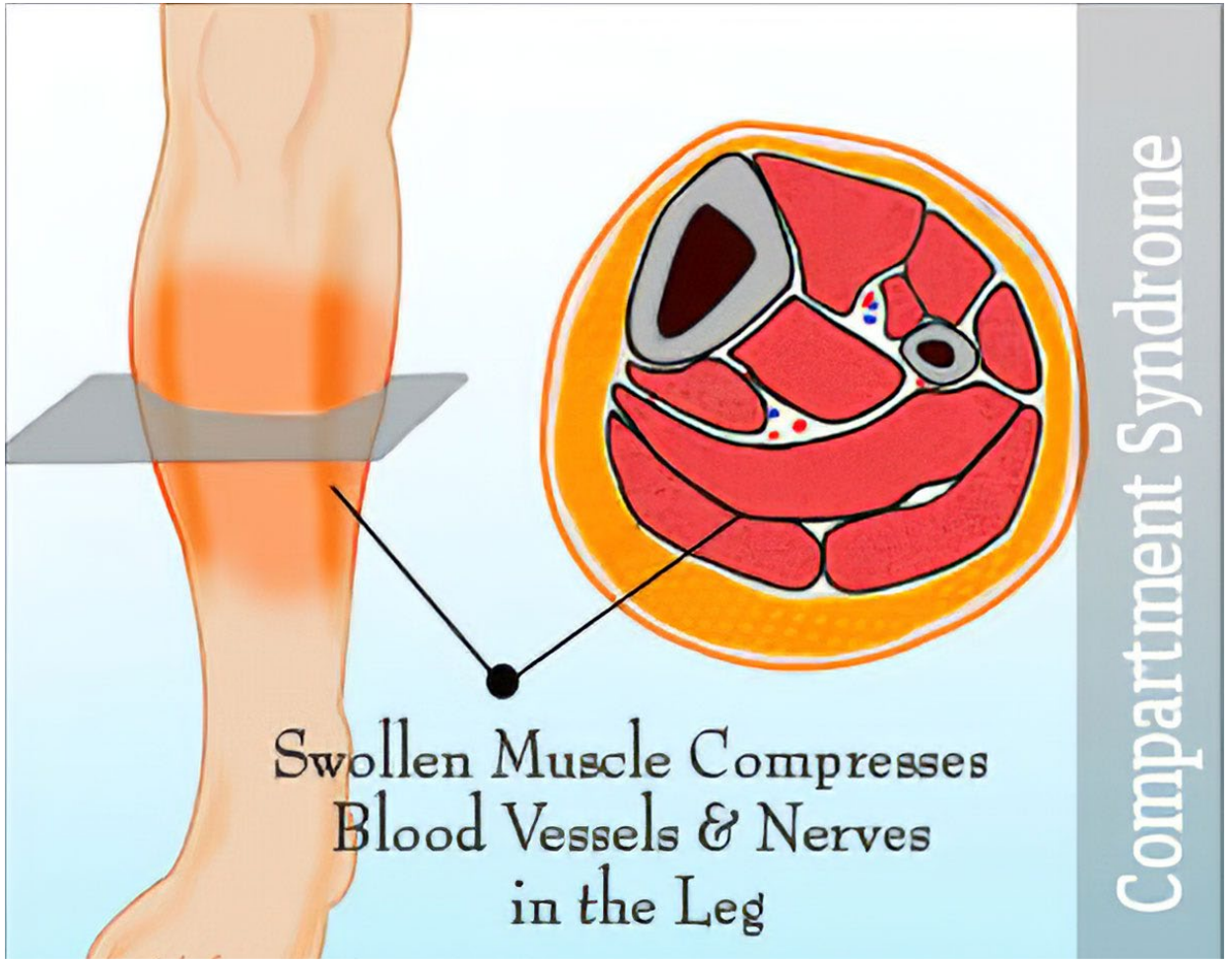
–Why? What happened?



What is compartment syndrome? (See next slide)

Compartment syndrome is a painful condition caused by excessive pressure buildup within a closed muscle compartment, which can lead to muscle and nerve damage by restricting blood flow. Symptoms include severe, disproportionate pain, swelling, numbness, tingling, and weakness. It can be an emergency requiring urgent surgery (fasciotomy) to prevent permanent tissue damage, and occurs in two main forms: acute (from severe injuries like fractures or burns) and chronic (from intense, repetitive exercise

If compartment syndrome is not treated, severe complications can arise, including permanent muscle and nerve damage, chronic pain, loss of feeling, muscle contractures, paralysis, and even amputation or death. The prolonged pressure deprives tissues of oxygen, leading to tissue death, and the release of toxins from dead muscle can cause kidney failure and other systemic issues. Acute compartment syndrome is a medical emergency requiring immediate surgical intervention to prevent irreversible harm.



Muscle Indirect Attachments to Bone

•tendons bridge the gap between muscle fiber's ends and bony attachment

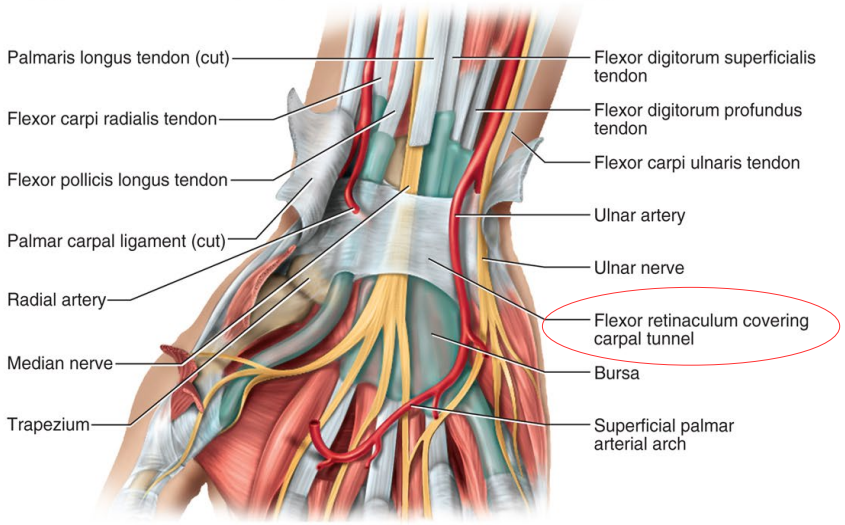
•the collagen fibers of the endomysium, perimysium, and epimysium continue to become the tendon /// these fibers weave themselves into the periosteum and penetrate beyond periosteum into the matrix of bone (weaving into the collagen fibers of the bone matrix

•very strong structural continuity from muscle into bone /// e.g. *biceps brachii, Achilles tendon*

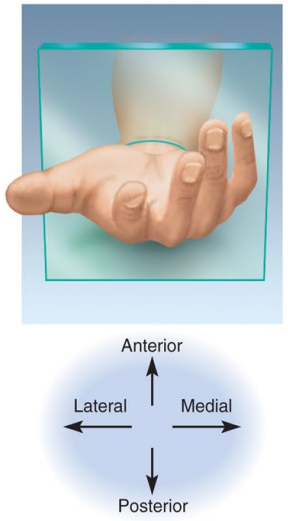
•aponeurosis – tendon is a broad, flat sheet *(palmar aponeurosis)*

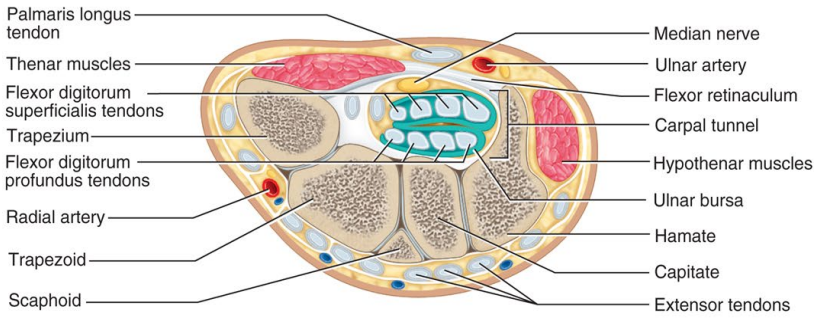
•retinaculum – connective tissue band which tendons from separate muscles pass through

What is a retinaculum? Clinical significance? – connective tissue band /// tendons from separate muscles may pass through the retinaculum /// inflammation swells tissue but retinaculum unable to expand which results in pain (carpal tunnel syndrome)



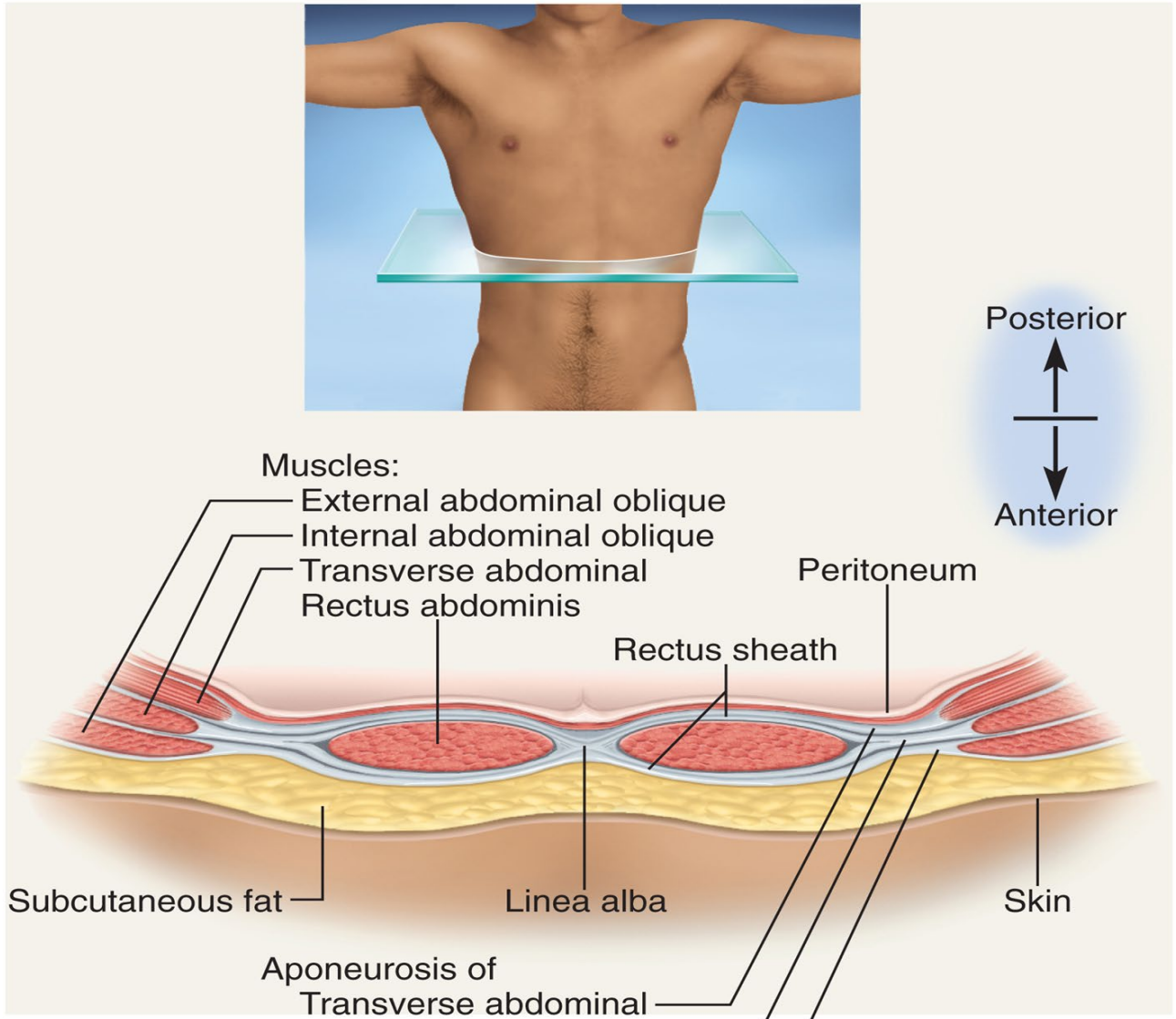
(a) Anterior view



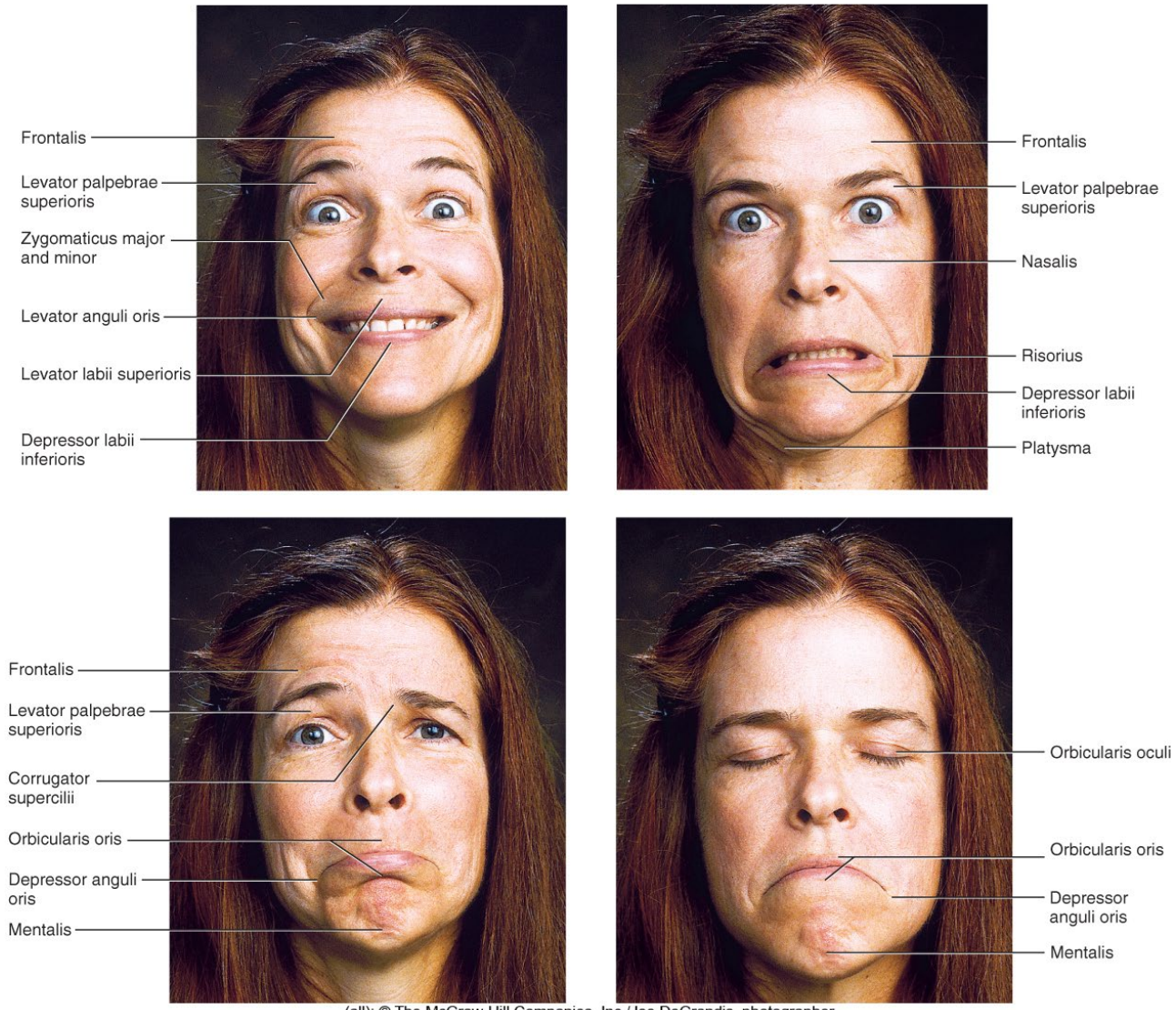


(b) Cross section

Muscles May Also Be Arranged in Layers



Some skeletal muscles do not insert onto the periosteum/bone but attach to the dermis of the skin or to the tendons of another muscle – e.g. muscles of facial expression (see next slide)



Classify Muslces by Their A Function

Action

– the effects produced by a muscle

–to produce or prevent movement

Prime mover (agonist)

–muscle that produces most of force during a joint action

Synergist

–muscle that aids the prime mover

–stabilizes the nearby joint

–modifies the direction of movement

Functional Groups of Muscles

Antagonist

–opposes the prime mover

–relaxes to give prime mover control over an action

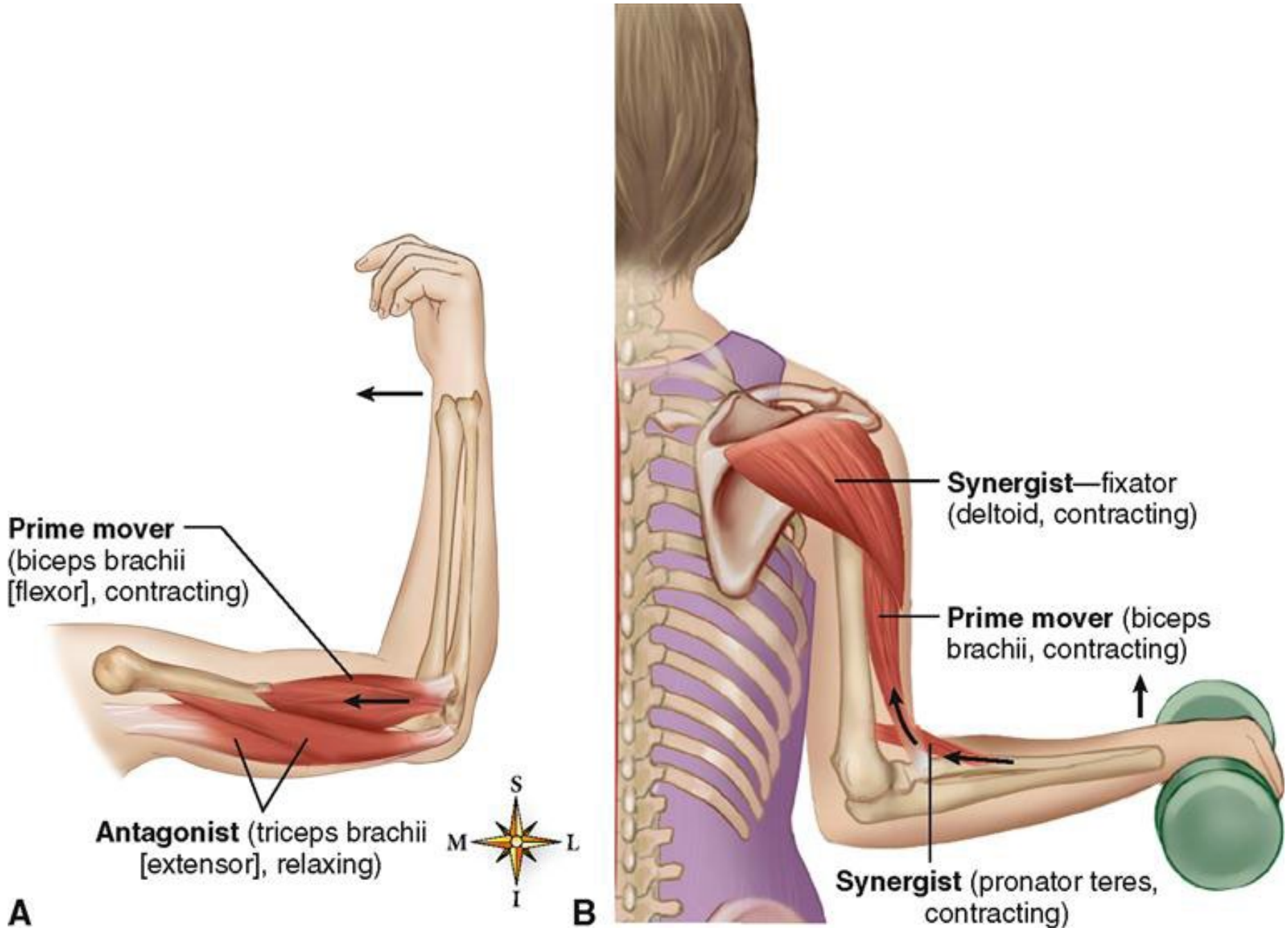
–preventing excessive movement and injury

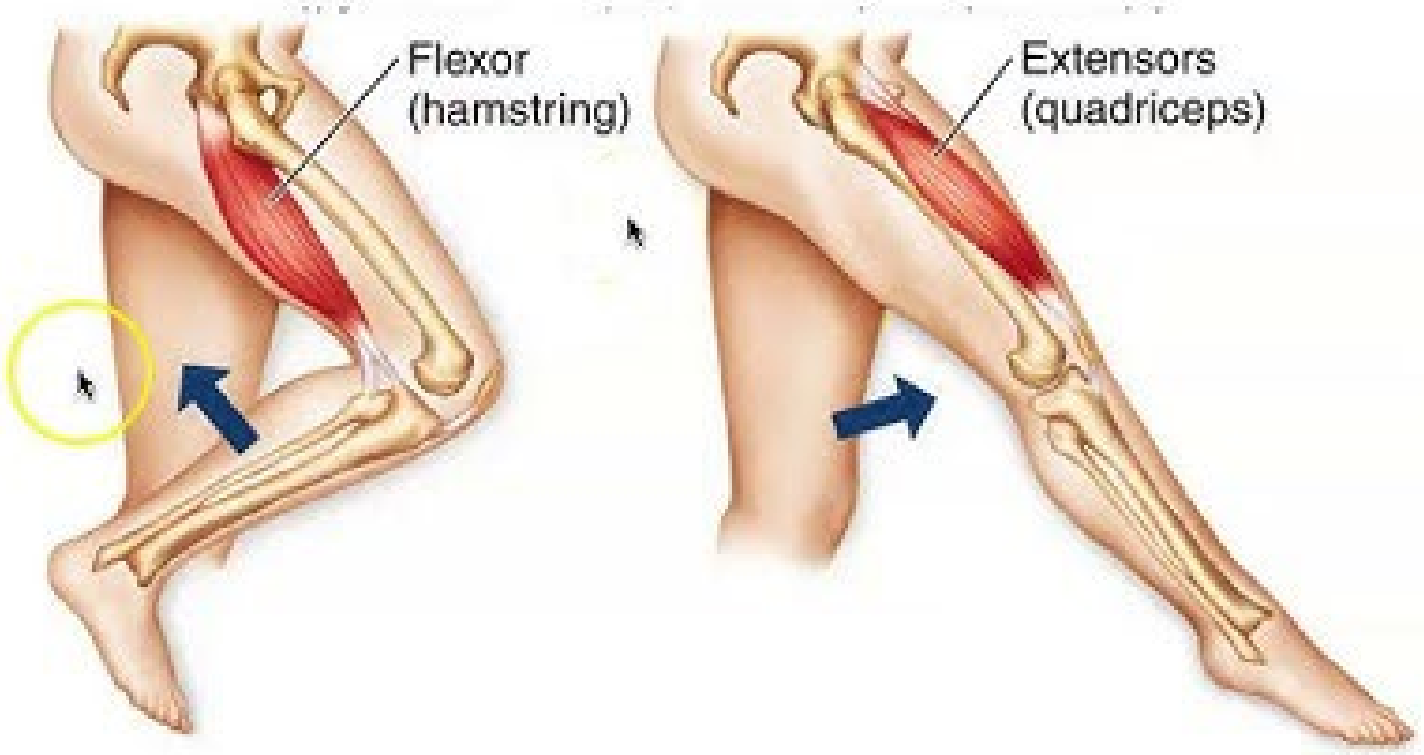
–**antagonistic pairs** – muscles that act on opposite sides of a joint

Fixator

–muscle that prevents movement of bone

–allows other muscles to exert force to produce movement.


Prime mover
(biceps brachii
[flexor], contracting)
Antagonist (triceps brachii
[extensor], relaxing)
S
M
L
I
A
B
Synergist—fixator
(deltoid, contracting)
Prime mover (biceps
brachii, contracting)
Synergist (pronator teres,
contracting)

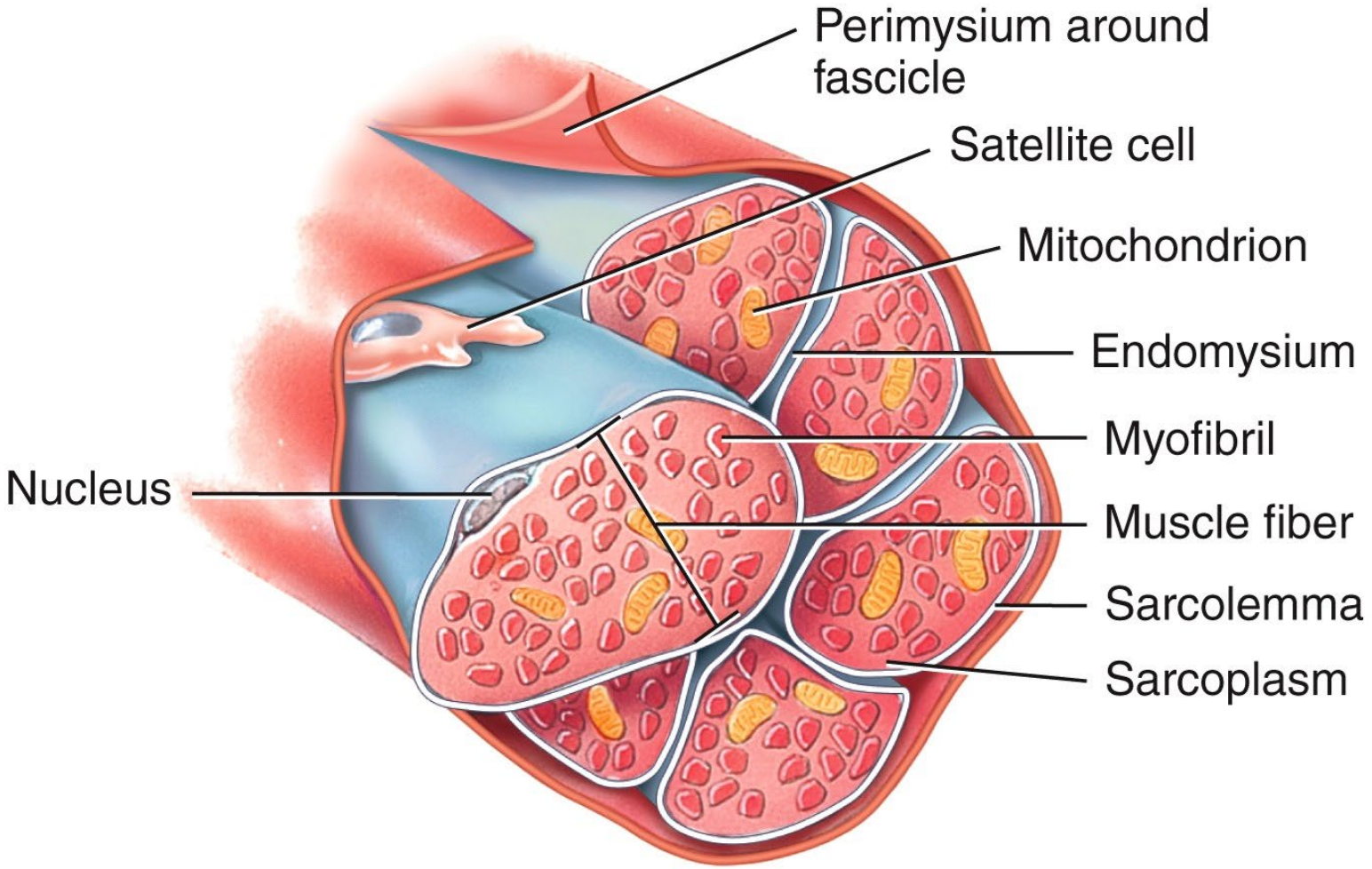


Knee flexors (3 hamstrings) are antagonists to the Knee extensors (the 4 quads)

The 3 hamstrings are synergists to each other for knee Flexion.
The 4 Quad muscles are synergists for knee Extension

The Sliding Filament Theory of Skeletal Muscle

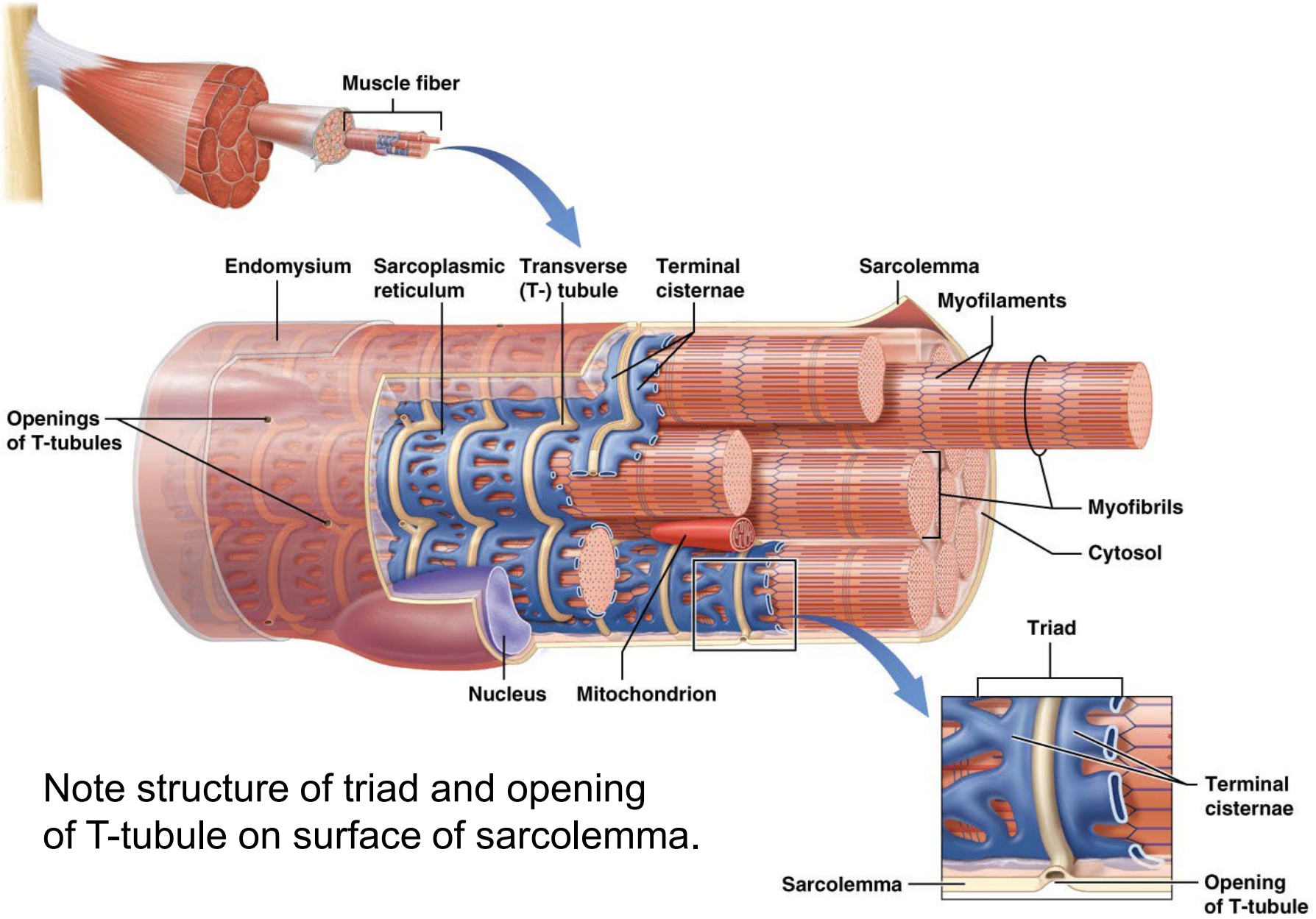
- In the early 1950s, a hypothesis to explain skeletal muscle function was to think proteins folded together like an accordion
- With the discovery of the electron microscope, scientist could “see” the thin and thick proteins inside the skeletal muscle.
- These proteins did not shorten during contraction (no accordion like action) – therefore
- Original hypothesis was wrong so …….
- New hypothesis was formulated suggesting muscle fiber shortened by the proteins sliding across each other.
- This hypothesis was proven to be “true” and is now called the sliding filament theory.



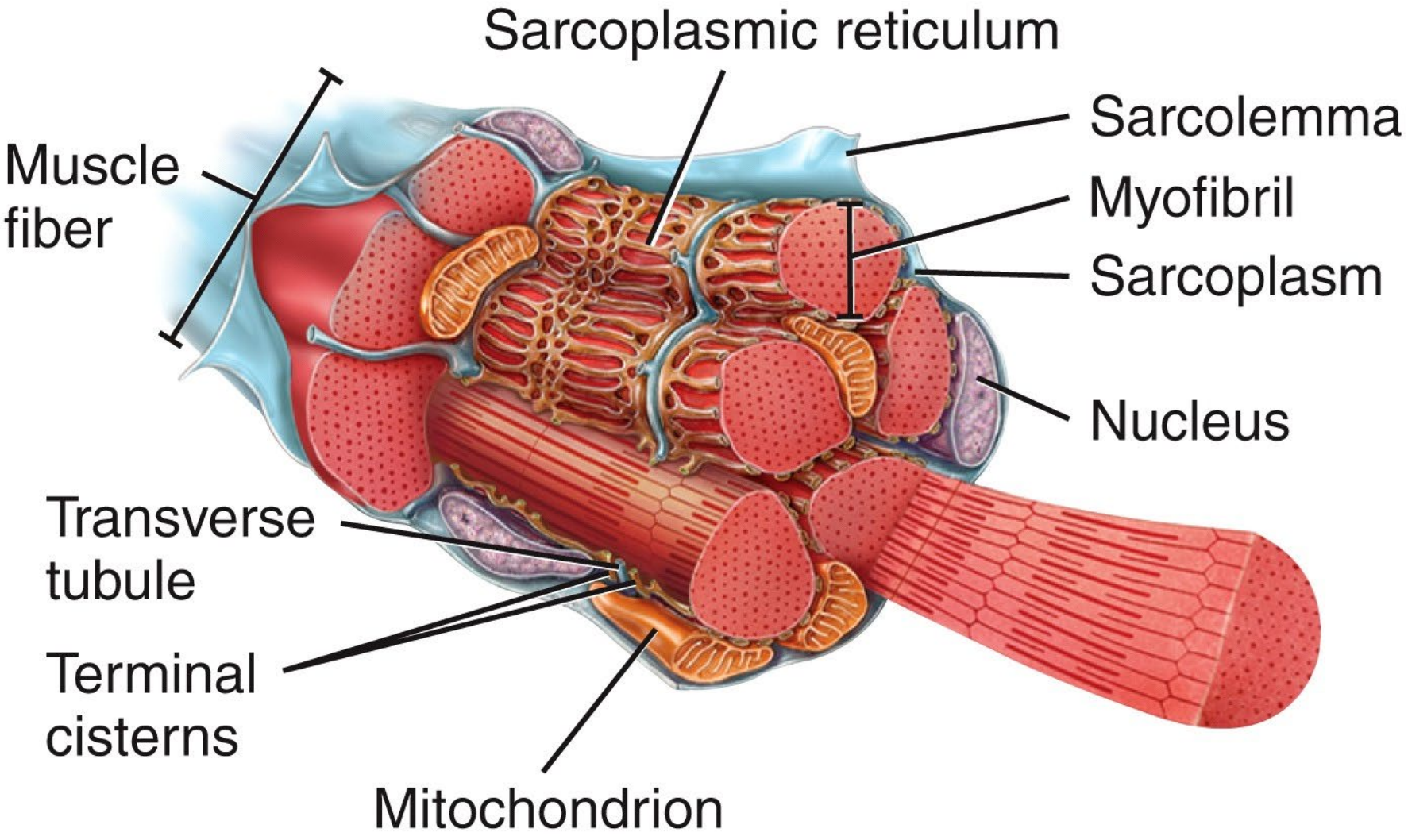
(b) Organization of a fascicle

> What type of CT is used to encapsulate the skeletal muscle organ?
> What type of CT is used to make tendons?
> What is the significance?

Structure of a skeletal muscle fiber.



Note structure of triad and opening of T-tubule on surface of sarcolemma.



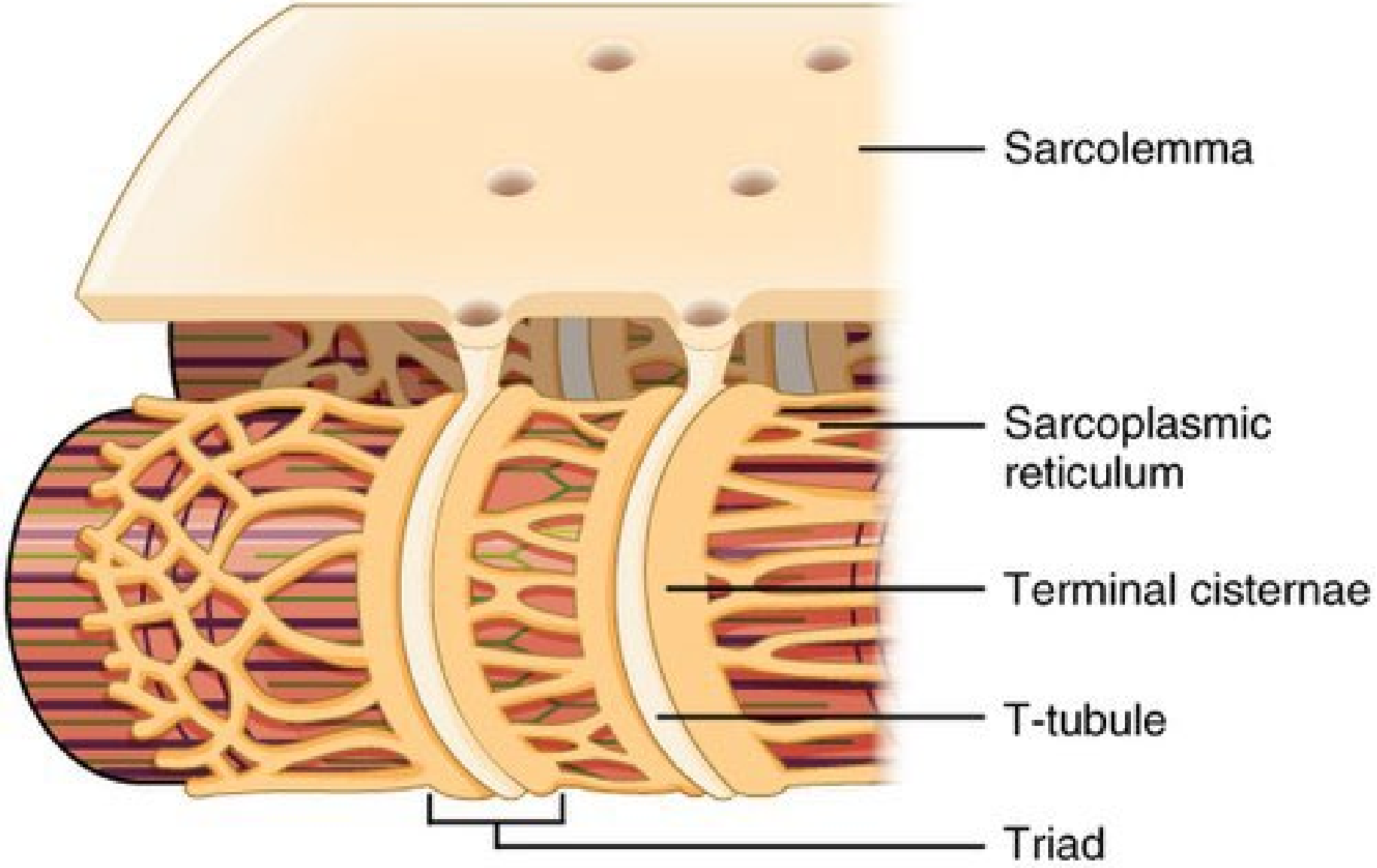
Muscle Fiber = Skeletal Muscle Cell

Skeletal Muscle Cell = Muscle Fiber

- Sarcolemma - plasma membrane of a muscle fiber
- Sarcoplasm - cytoplasm of a muscle fiber
- Glycogen – stored in abundance to provide local source of energy used at start of exercise
- Myoglobin – able to bind oxygen and store oxygen inside fiber – small source of oxygen which will be used to produce ATP, used at start of exercise
- Myofibrils - long protein bundles that occupies the main portion of the sarcoplasm
- Myofilaments – the actin and myosin protein polymers
- Multiple nuclei - flattened nuclei pressed against the inside of the sarcolemma

Skeletal Muscle Cell = Muscle Fiber

- Mitochondria // packed in spaces between myofibrils
- Sarcoplasmic reticulum (SR) // smooth ER that forms a network around each myofibril – calcium reservoir /// calcium will activate 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



Triad // a T tubule and two terminal cisterns

Skeletal Muscle Cell = Muscle Fiber

- Myoblasts // many stem cells in embryonic development fuse to form a muscle fiber – this is how the fiber becomes multinucleated

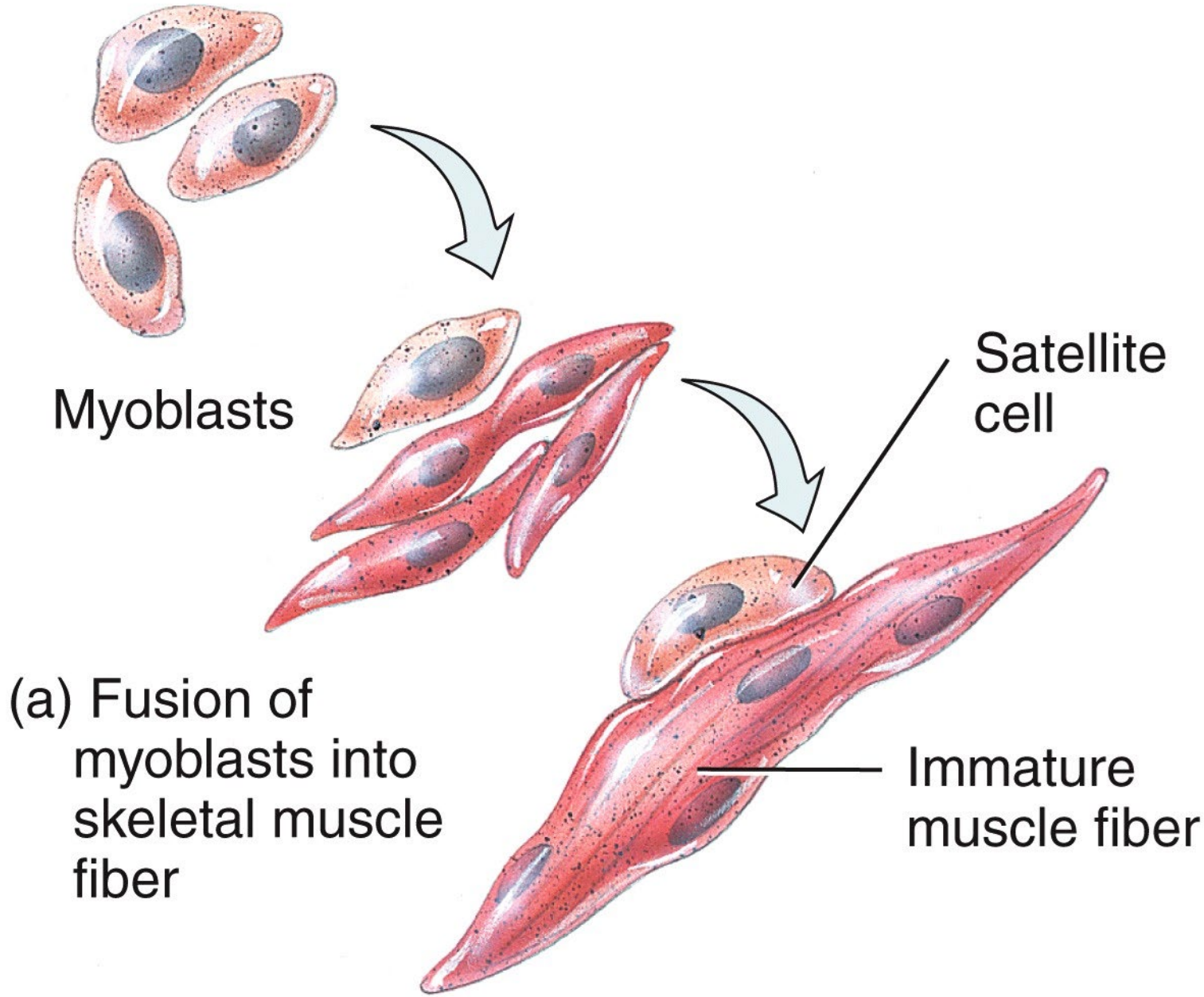
- Satellite cells – unspecialized myoblasts remaining between the muscle fiber and endomysium // may multiply and produce new muscle fibers to some degree

- Repair by fibrosis // Muscle fibers not able to undergo mitosis

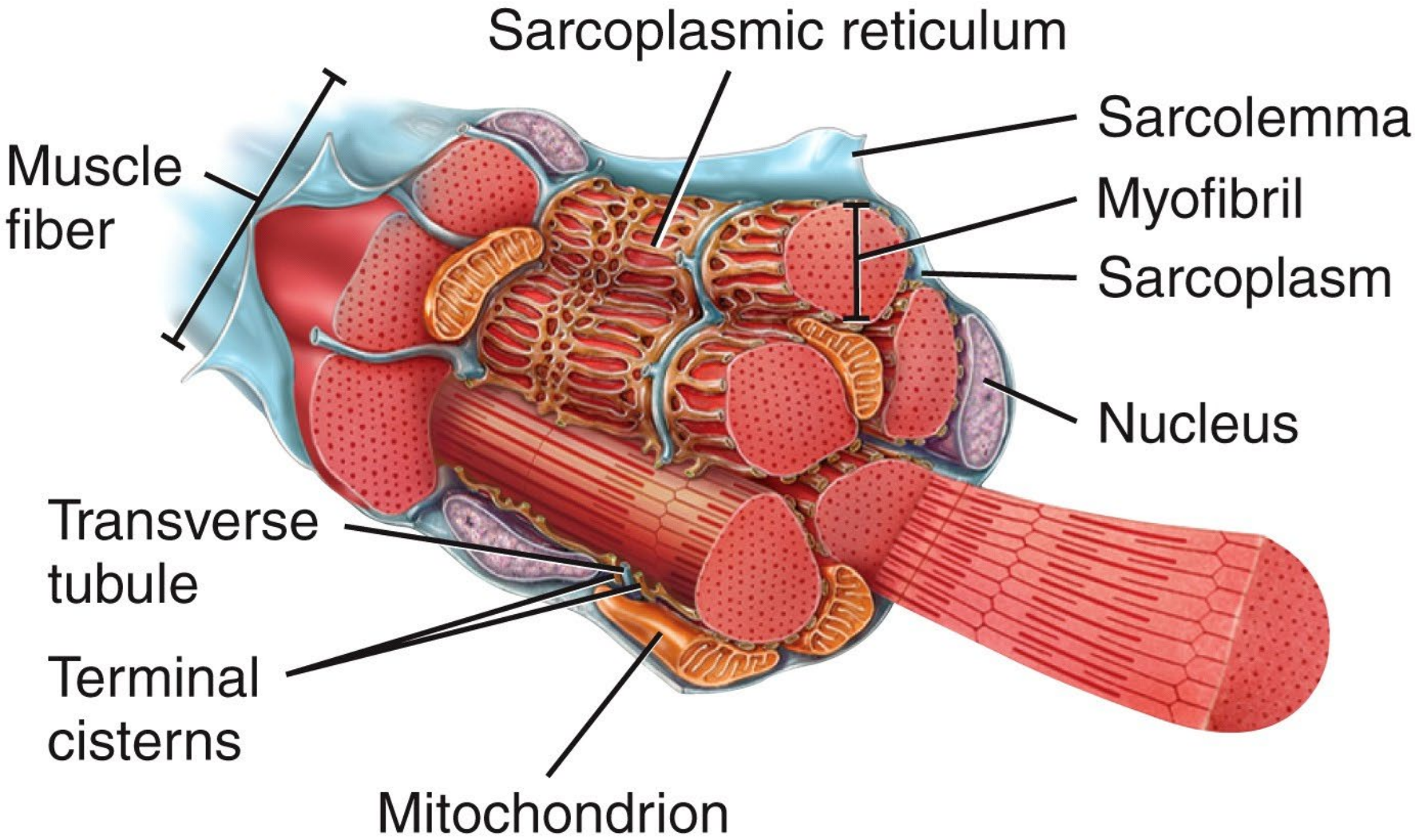
–Skeletal fibers are in G zero.

–Unable to regenerate new functional cells /// severe damaged muscle fibers are replaced with scar tissue

–Fibrosis – fibroblast and connective tissue replace lost muscle fibers (Why do baseball pictures lose pitch velocity as they age?)



(a) Fusion of myoblasts into skeletal muscle fiber

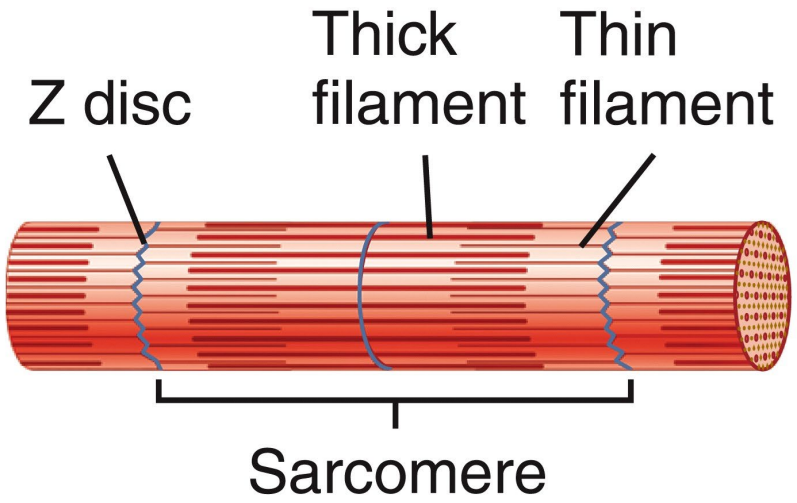

Sarcoplasmic reticulum
Sarcolemma
Muscle fiber
Myofibril
Sarcoplasm
Nucleus
Transverse tubule
Terminal cisterns
Mitochondrion

Sarcomeres

- Sarcomere = segment from Z disc to Z disc
- Functional contractile unit of a muscle fiber
- Muscle cells shorten because their individual sarcomeres shorten

–Z disc (Z lines) are pulled closer together

–thick and thin filaments slide past (over) each other



Sarcomeres

- Neither thick nor thin filaments change their length during conctraction

- Only the amount of overlap changes

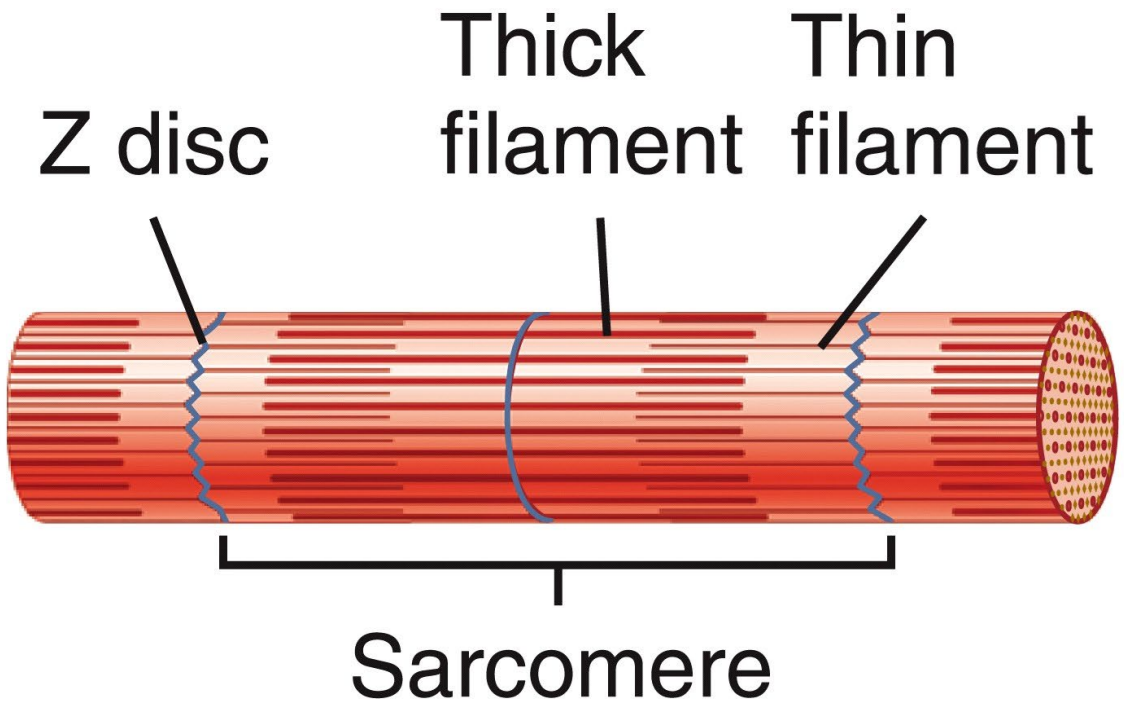
- During contraction (i.e. shortening) – force generated by sarcomere is transferred from the myofibrils to the endomysium by way of linking proteins (e.g. dystrophin) - force transferred to connective tissue's (endomysium / perimysium / epimysium) of the muscle fiber and then to the tendons.

- continuous and direct transfer of force through CT from endomysium surrounding one muscle fiber, to perimysium, , to epimysium, to tendon, to periosteum, to sharpe fibers, and ultimately into the bone matrix

•this physical force is also used to influence bone remodeling

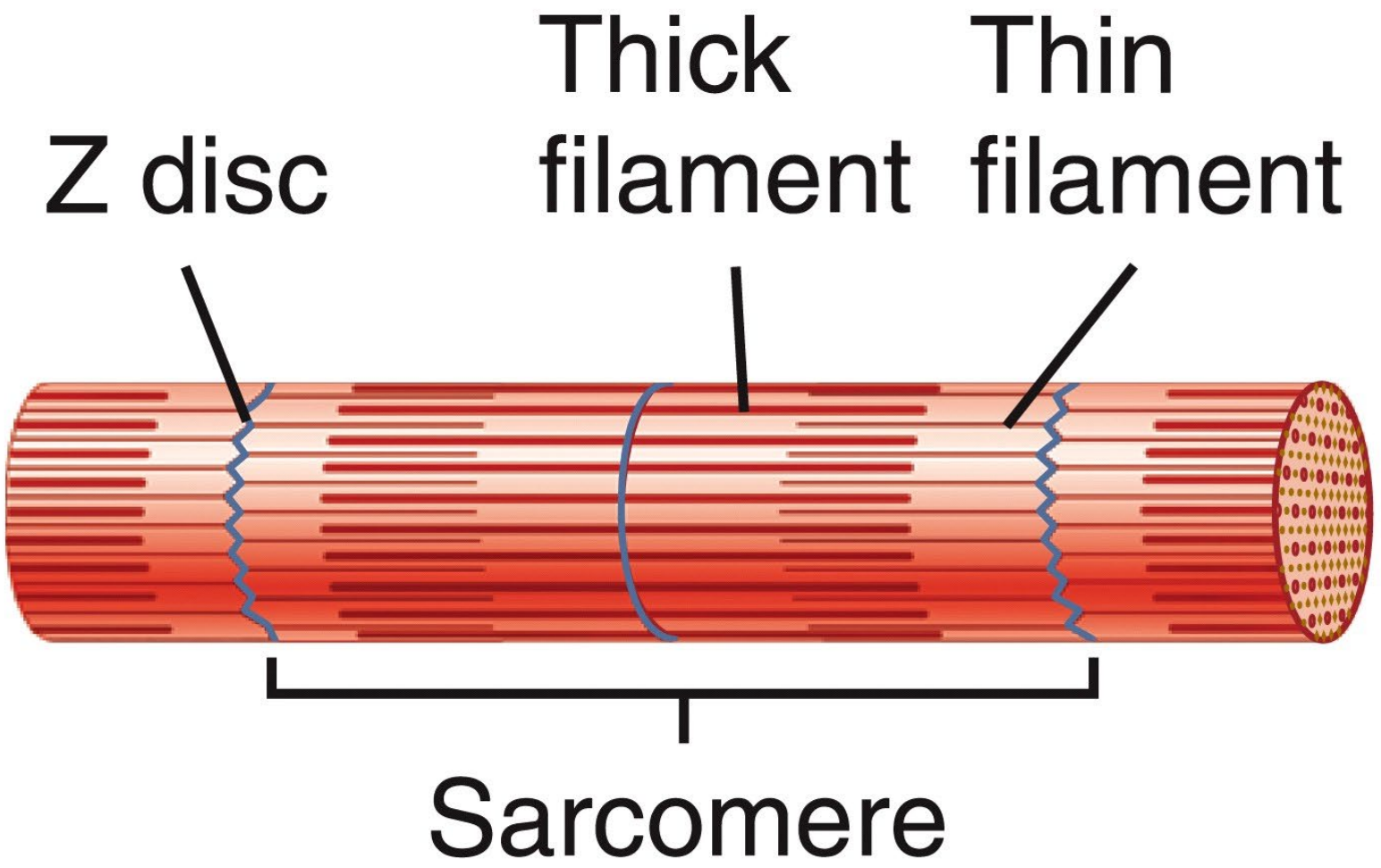
•mechanical force regulates osteoblast (builds bone) and osteoclast (removes bone)

Striations, Sarcomeres, and the Sliding Filament Theory



- *Sarcomere is the functional contractile unit of a muscle fiber*

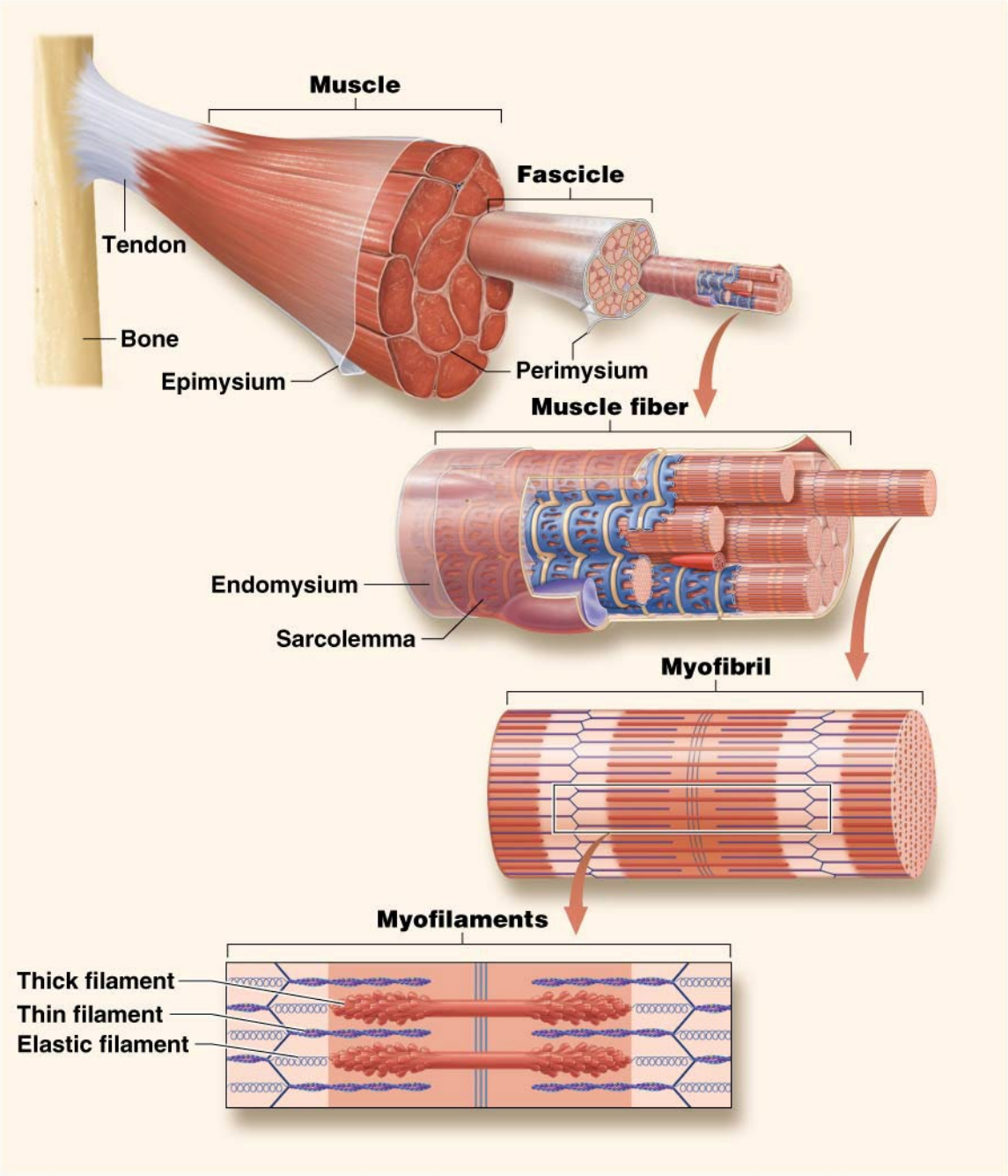
–muscle shortens because protein fibers slide across each other
– sarcomere shorten but the length of individual proteins do not shorten
–pulls z discs closer to each other



Thick filaments = myosin

Thin filaments = actin

The Big Picture of Levels of Organization within a Skeletal Muscle

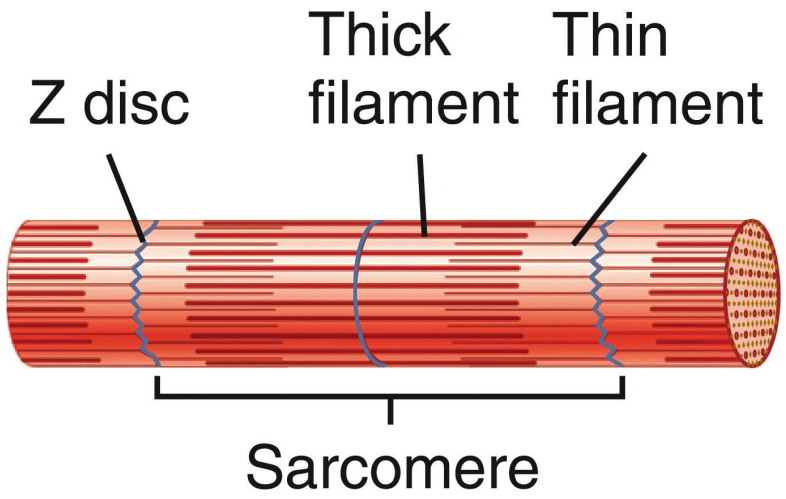


Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

Contractile Proteins (#1)

–Myosin = Thick Filament (ATP binding site and ATPase // also called the *motor protein*)

–Actin = Thin Filament (interacts with myosin to form "cross bridge" between contractile proteins

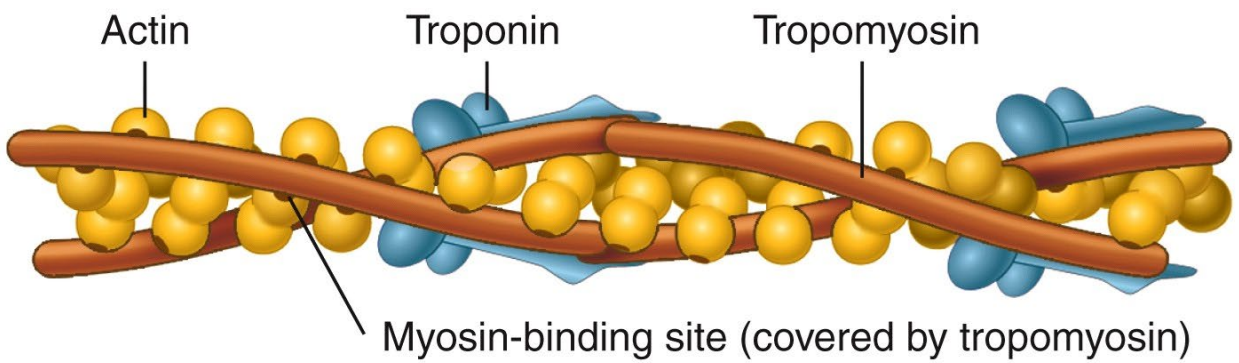


Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

Regulatory Proteins (#2)

–Tropomyosin (when muscle relaxed it blocks myosin binding site)

–Troponin (when calcium binds to troponin, it will cause tromomyosin to move and expose myosin binding sites)



(b) Portion of a thin filament

Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

Linking Proteins (#3)

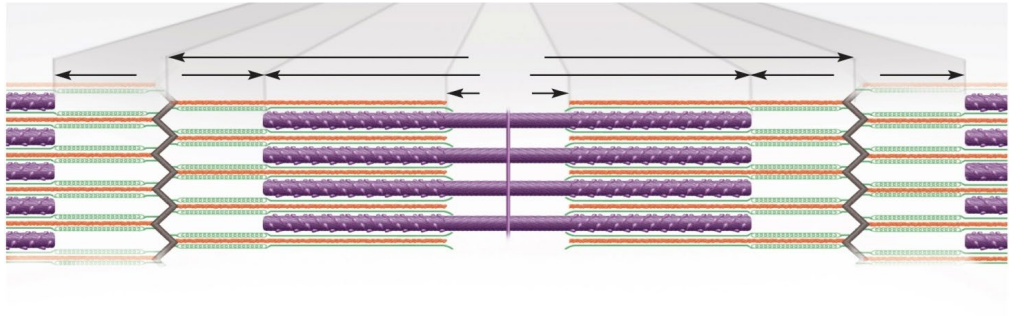
–Titin (know this)- elastic element to hold myosin centered between Z discs / the green filament in this illustration

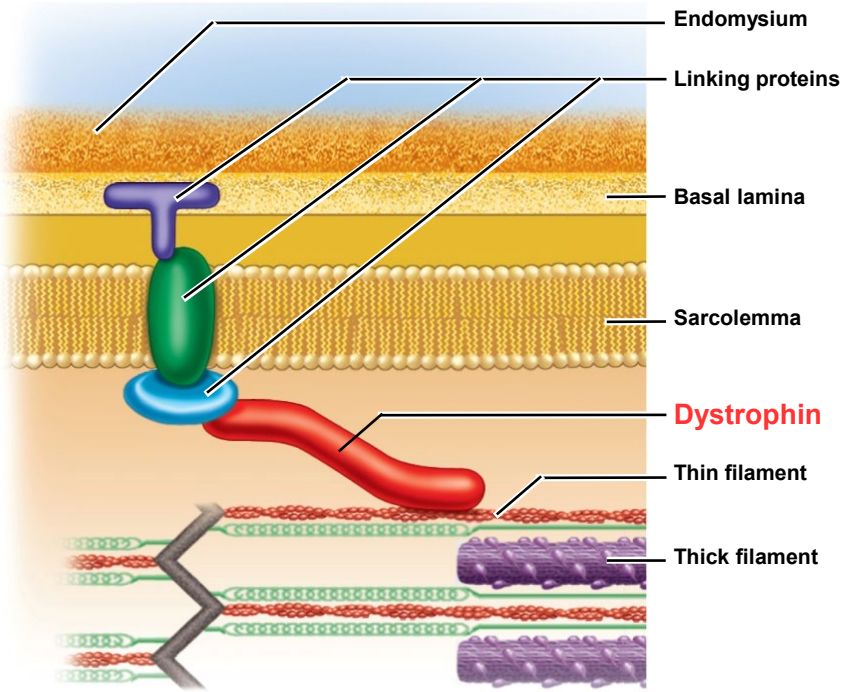
–Alpha-actinin

–Myomesin

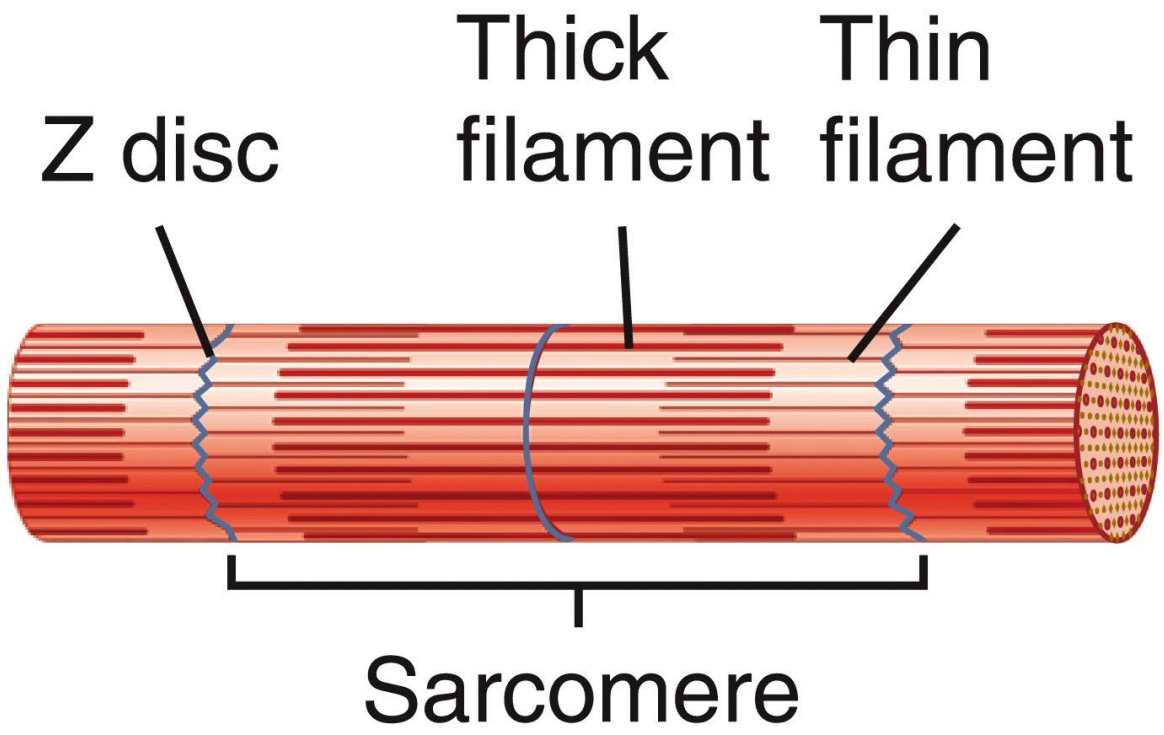
–Nubulin

–Dystrophin





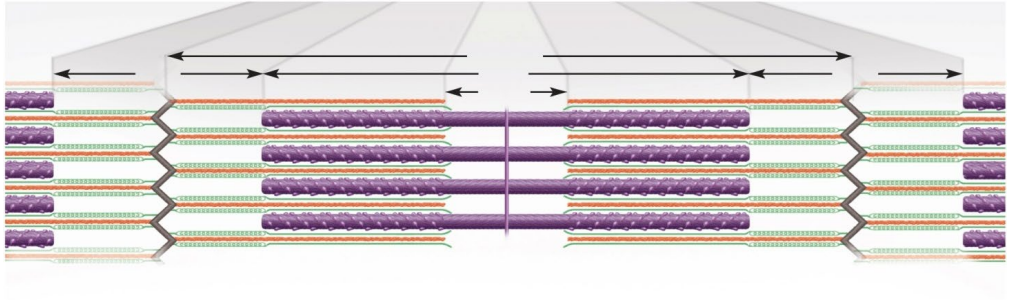
Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

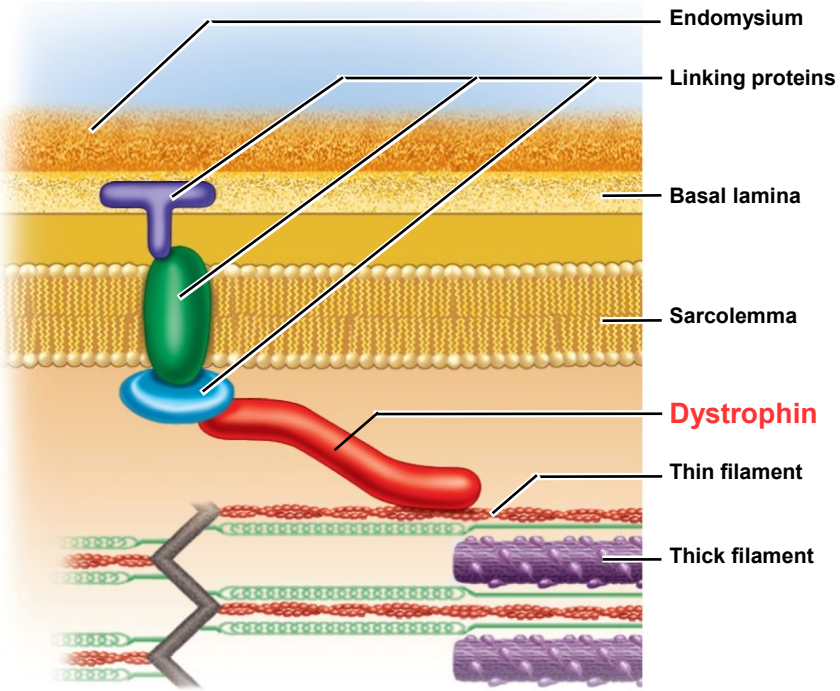


The Z discs form the structural boundaries of one sarcomere.

Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

The "green filaments" are titin proteins. These proteins are elastic attached to the Z discs and myosin molecules. The titin molecule positions the myosin in the center of the sarcomere so there is maximum overlap between the actin and myosin molecules.





Titin An Elastic Myofilaments

Titin (also called connectin)

–huge springy protein

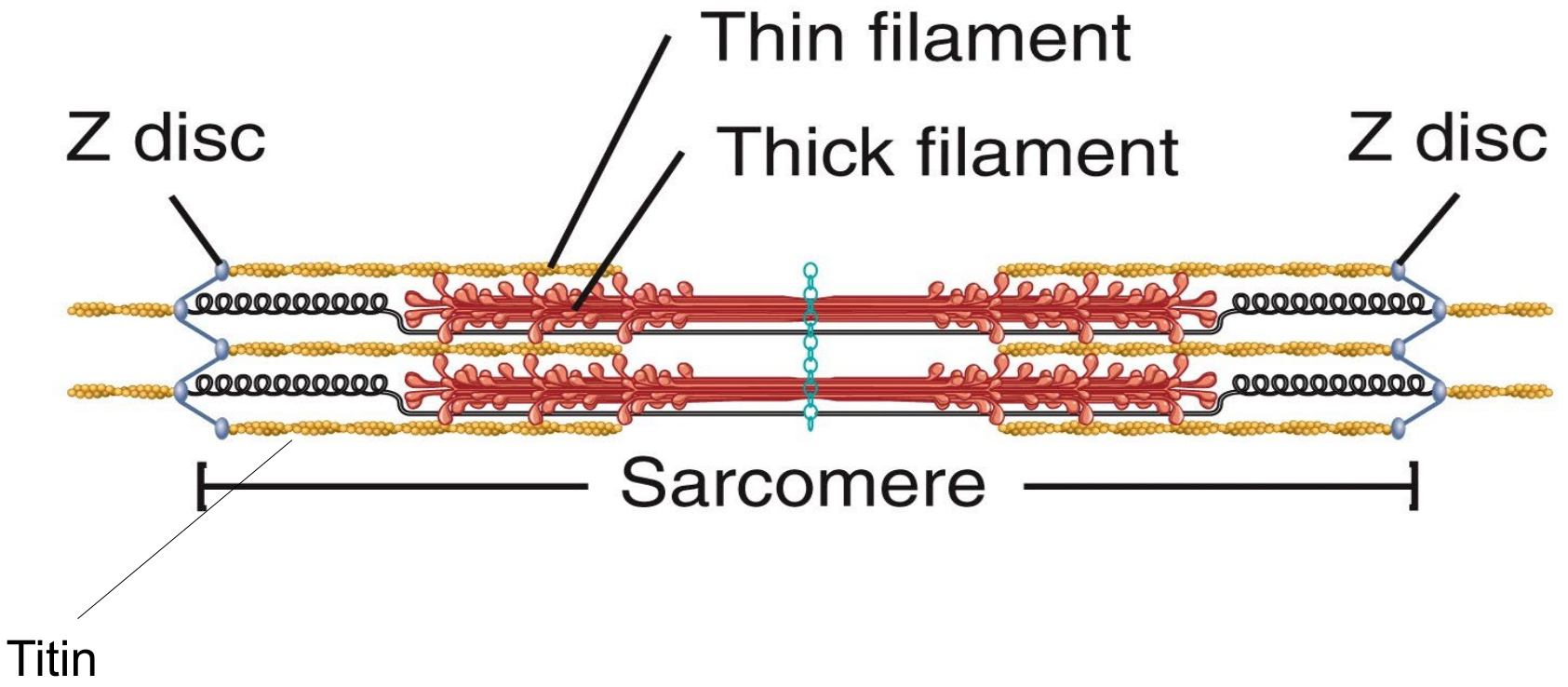
–flank each thick filament and anchor it to the Z disc

–helps stabilize the thick filament

–center myosin between Z disc and sets overlap on actin (i.e. the thin filaments)

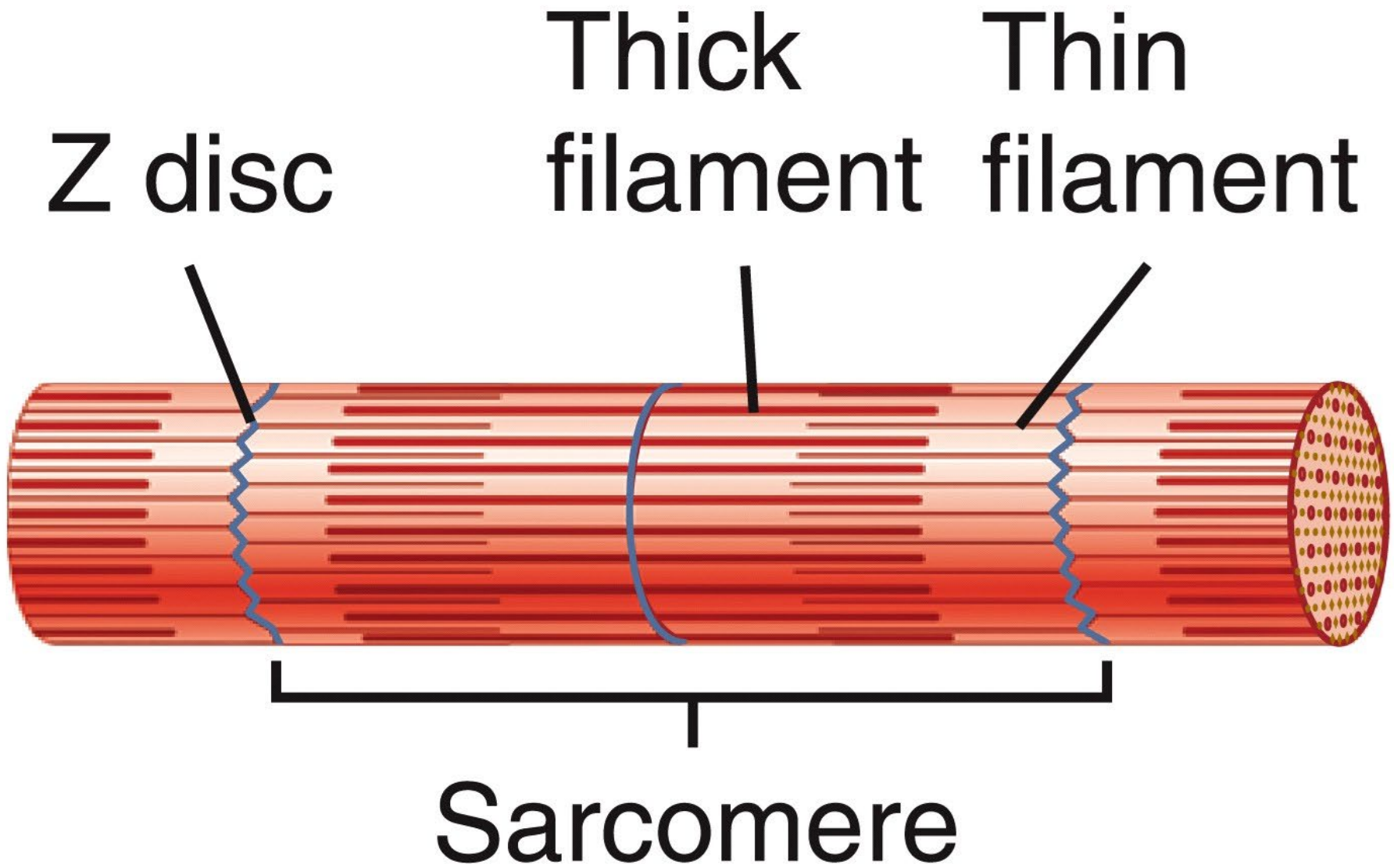
–prevents over stretching

Sarcomere's Five Proteins
(contractile, regulatory, linking, structural, adjustment)

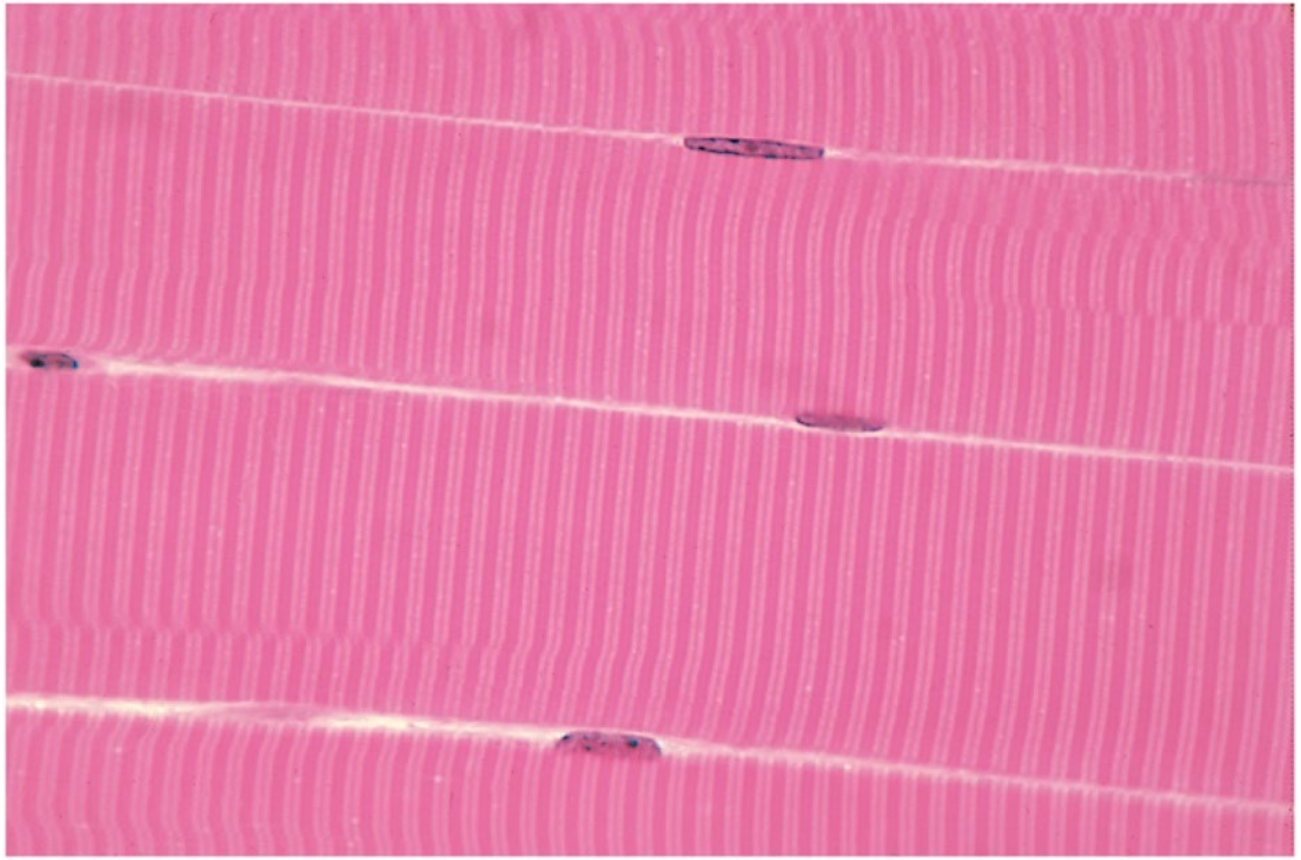


The Z disc is a structural protein which defines the boundary between individual sarcomeres.

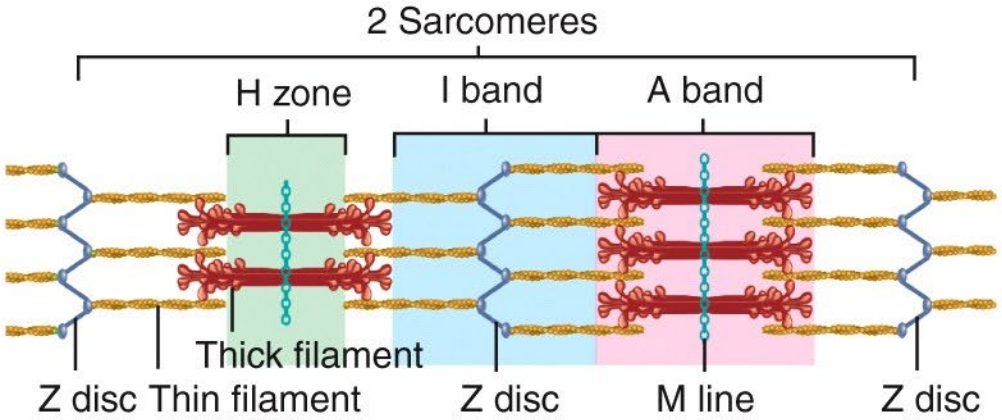
After a skeletal muscle contraction, the sarcomere adjusts itself to a resting length. The titin protein positions the myosin molecule to ensure maximum overlap for cross bridge formation between the myosin and actin protein molecules.


Thick filament
Thin filament
Z disc
Sarcomere

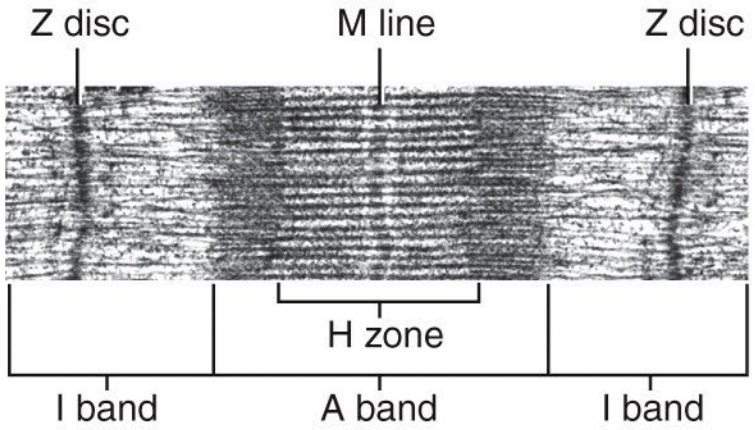
Striations of Skeletal Muscle

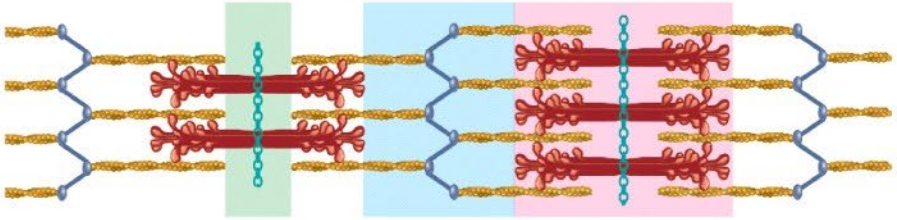


Alternating light and dark transverse bands of myofibrils // results from overlapping of contractile proteins within muscle fibers

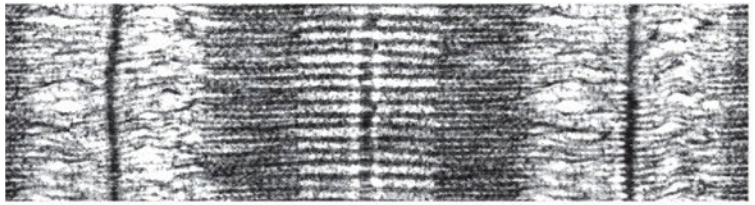


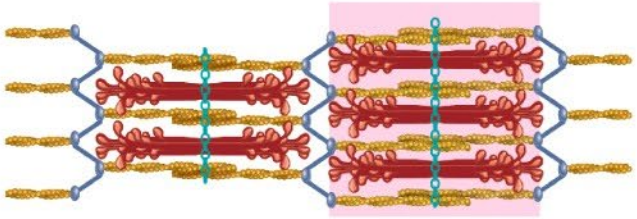
(a) Relaxed muscle



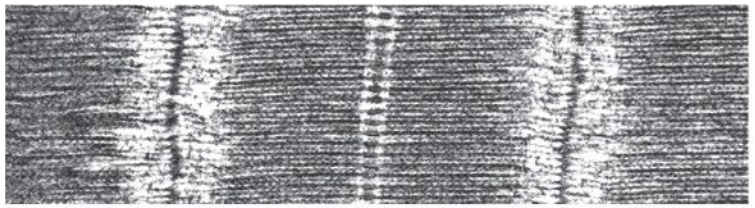


(b) Partially contracted muscle

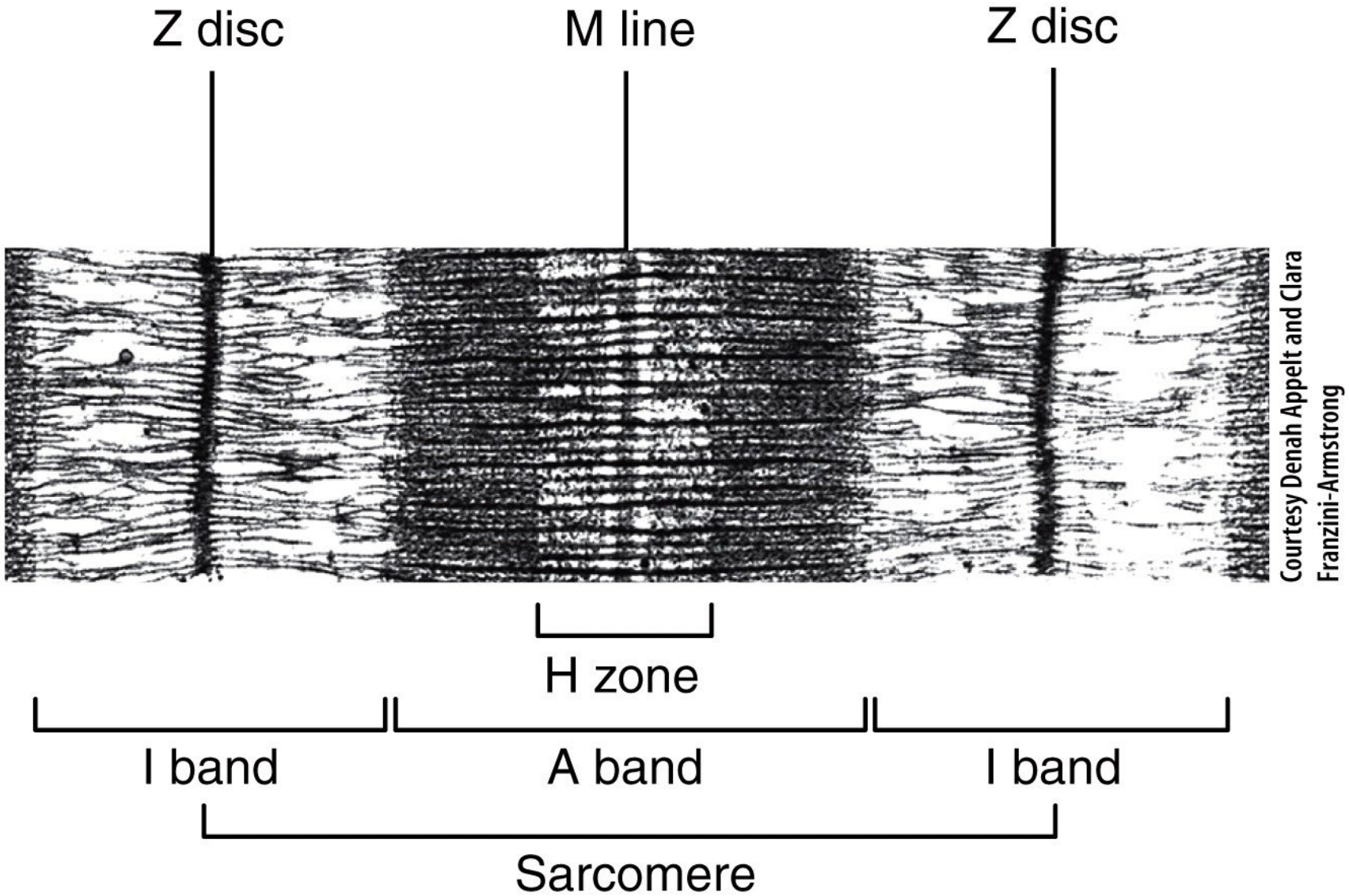




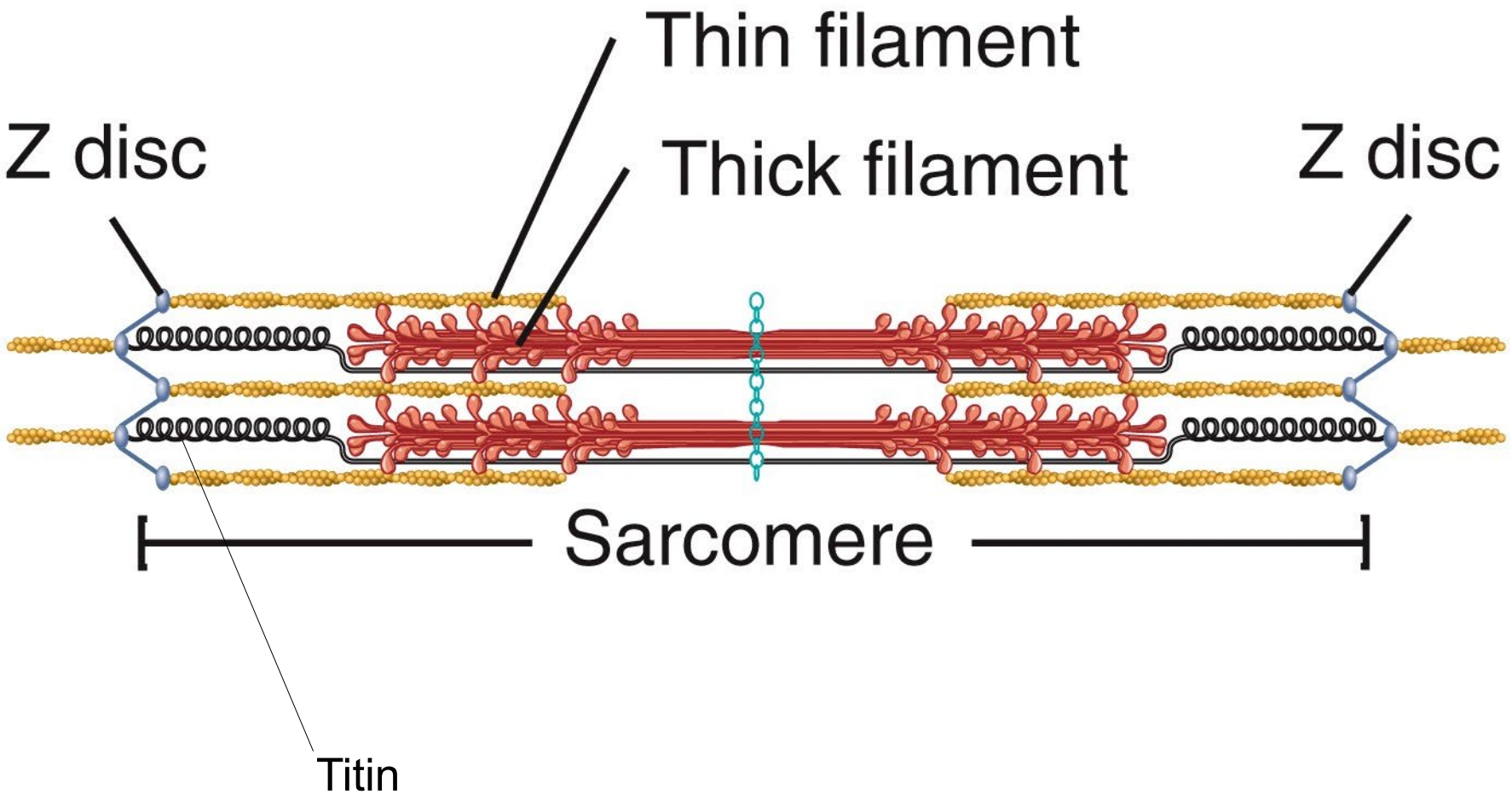
(c) Maximally contracted muscle

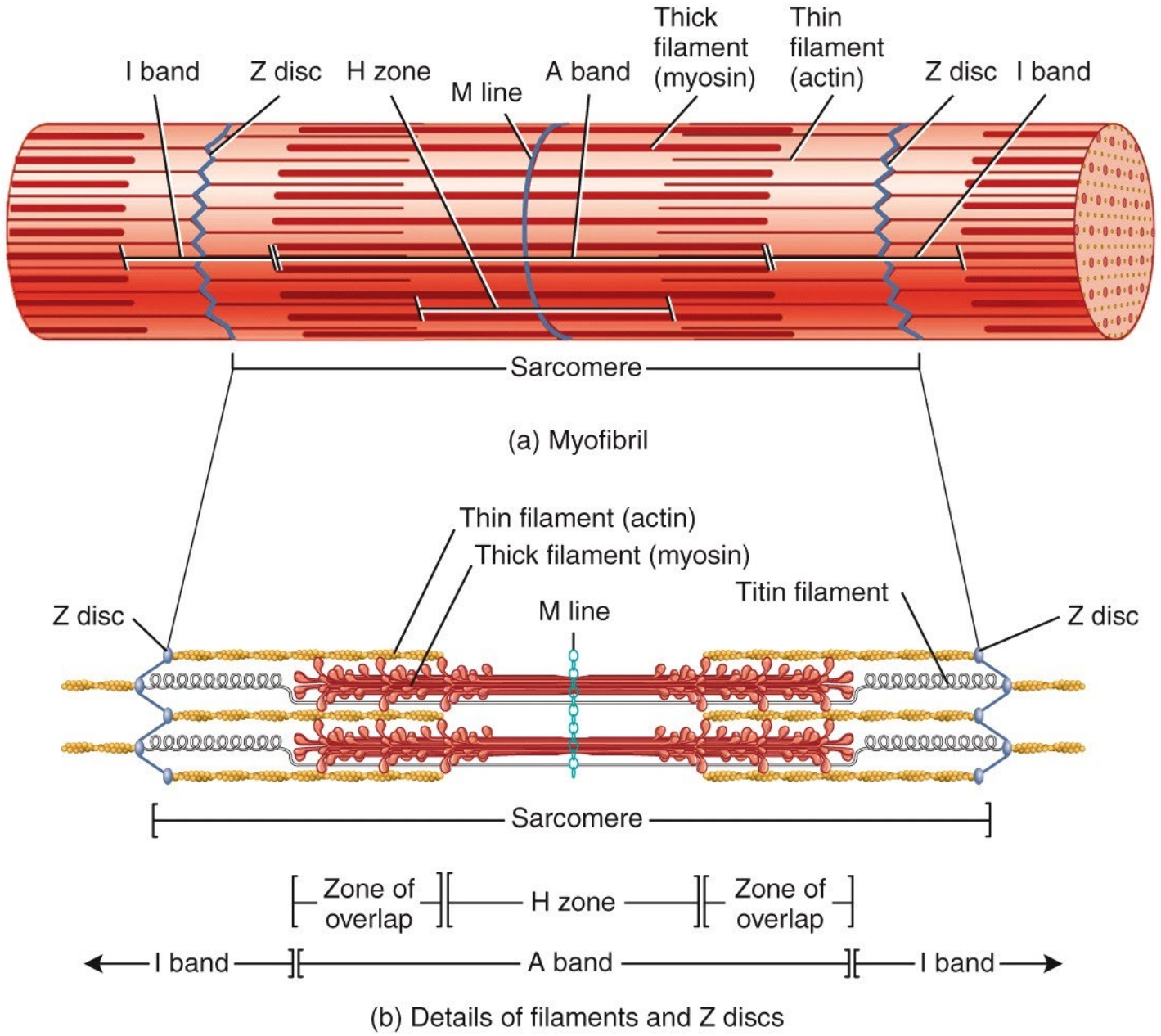


Courtesy Hiroyouki Sasaki, Yale E. Goldman and Clara Franzini-Armstrong

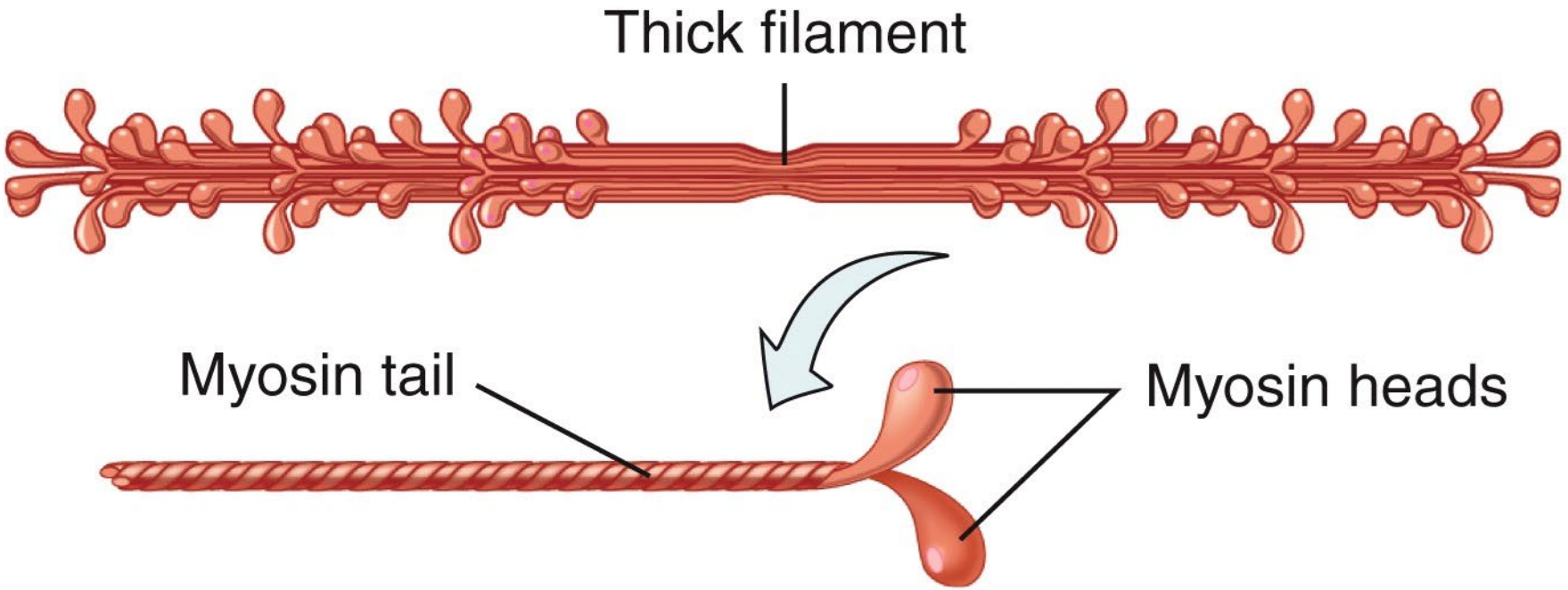

Z disc
M line
Z disc
H zone
I band
A band
I band
Sarcomere
TEM 21,600x
Courtesy Denah Appelt and Clara Franzini-Armstrong

When a muscle contracts, what happens to the Z disc?





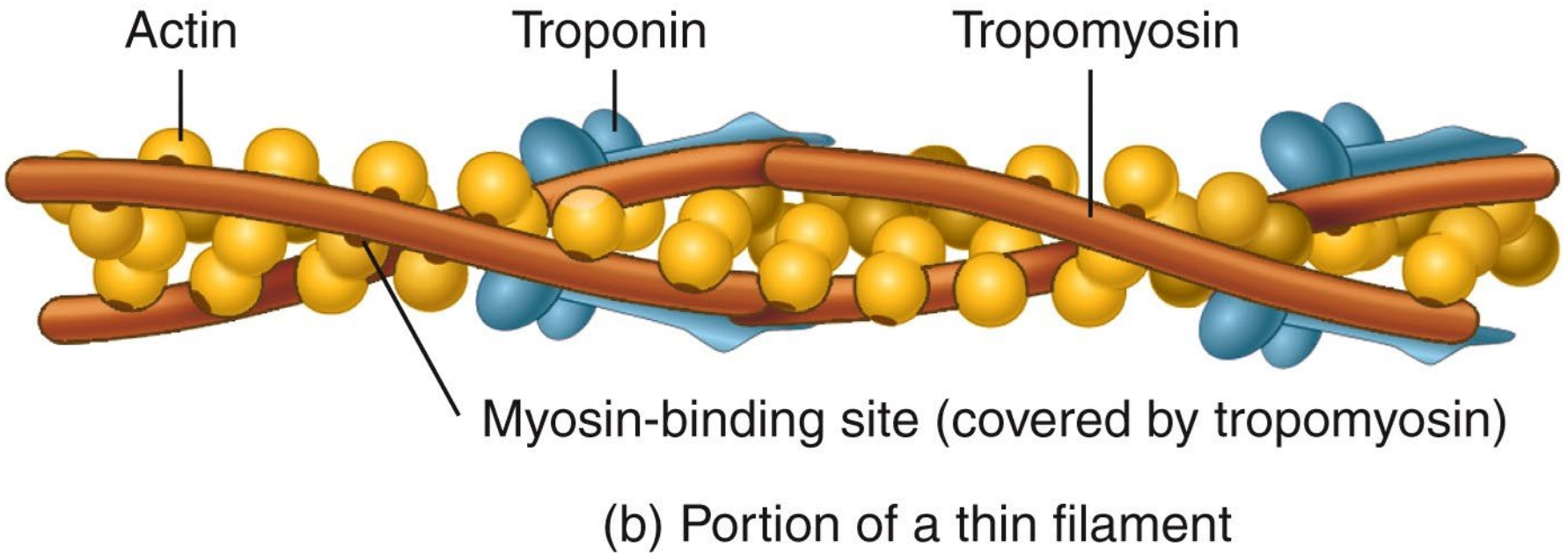
What structure holds the thick filament between the Z discs?



(a) A thick filament and a myosin molecule

How is the myosin head “hinged” to the myosin shaft?

Is the thick filament length changed as the myosin head flex?

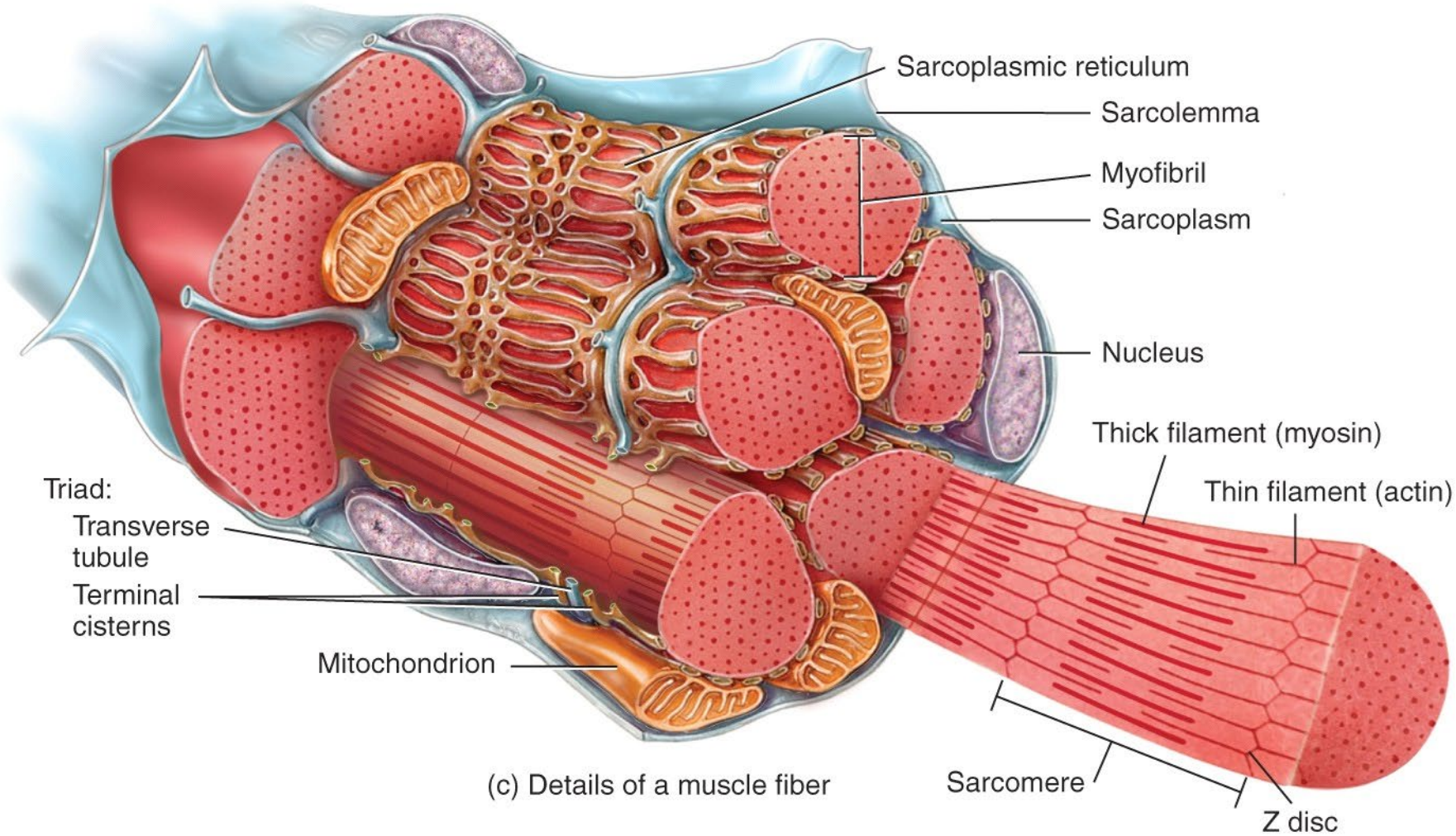


(b) Portion of a thin filament

Why are troponin and tropomyosin called regulatory proteins?

Calcium binds to what molecule?

After calcium binds to a regulatory protein, what happens?



(c) Details of a muscle fiber

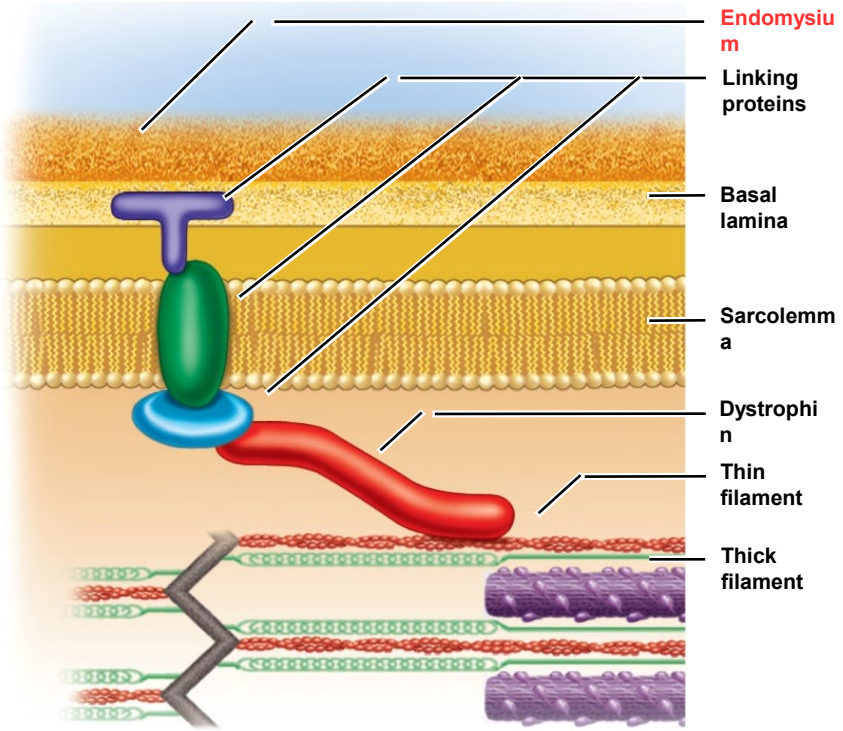
More About Sarcomere's Linking Proteins

- Connect contractile proteins to endomysium (i.e. connective tissue surrounding muscle fiber)
- Series of proteins (seven or more)
- Associated with thick or thin filaments

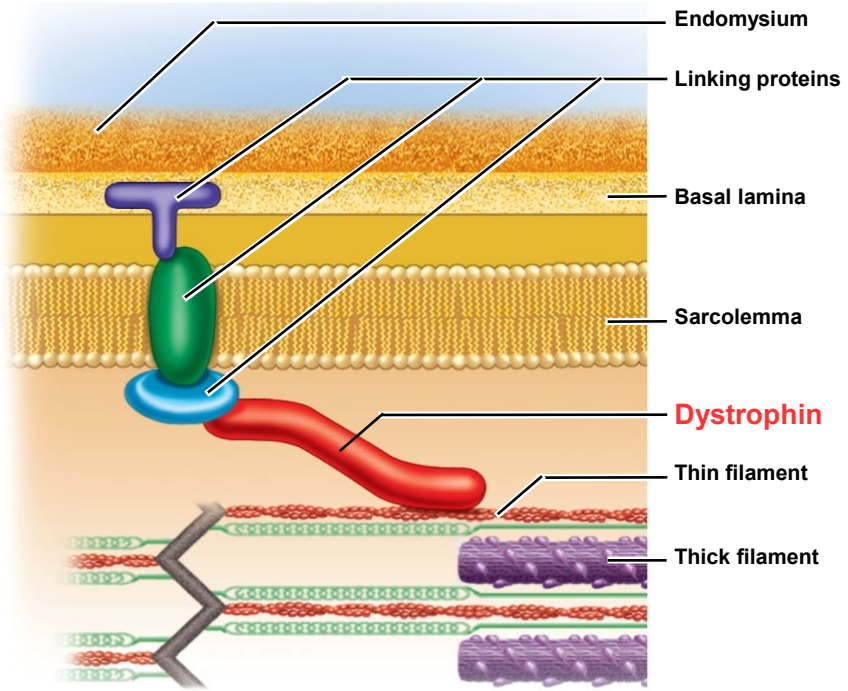
–anchor the myofilaments

–regulate length of myofilaments

–alignment of myofilaments for maximum effectiveness



Sarcomere Linking Proteins



See article about new gene therapy cure for muscular dystrophy!

Dystrophin

–clinically important linking protein

–links actin's myofilaments to transmembrane proteins of the endomysium

–endomysium integrated to other connective tissue surrounding the skeletal muscle

–force of muscle contraction transferred through connective tissue to tendon to skeletal system

–genetic defects in dystrophin produce the disabling disease called muscular dystrophy