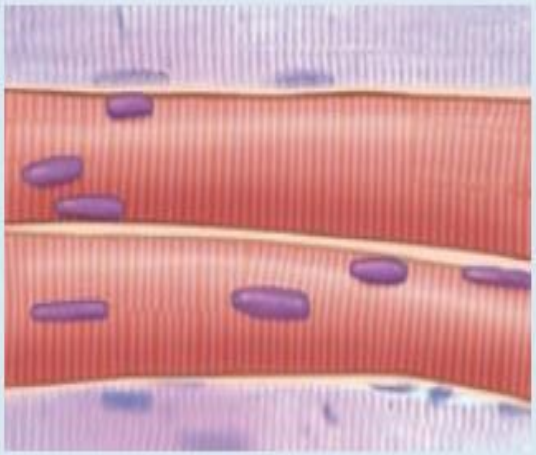
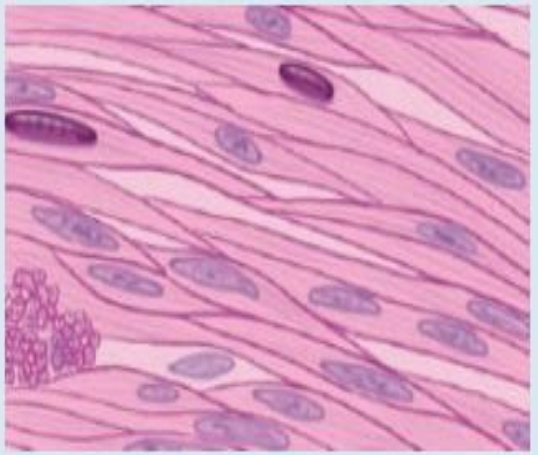
Skeletal Muscle

Ass. Prof Dr. Heba Hassan Abd El-Gawad

Types of muscles

Skeletal Muscle	Cardiac Muscle	Smooth Muscle
		

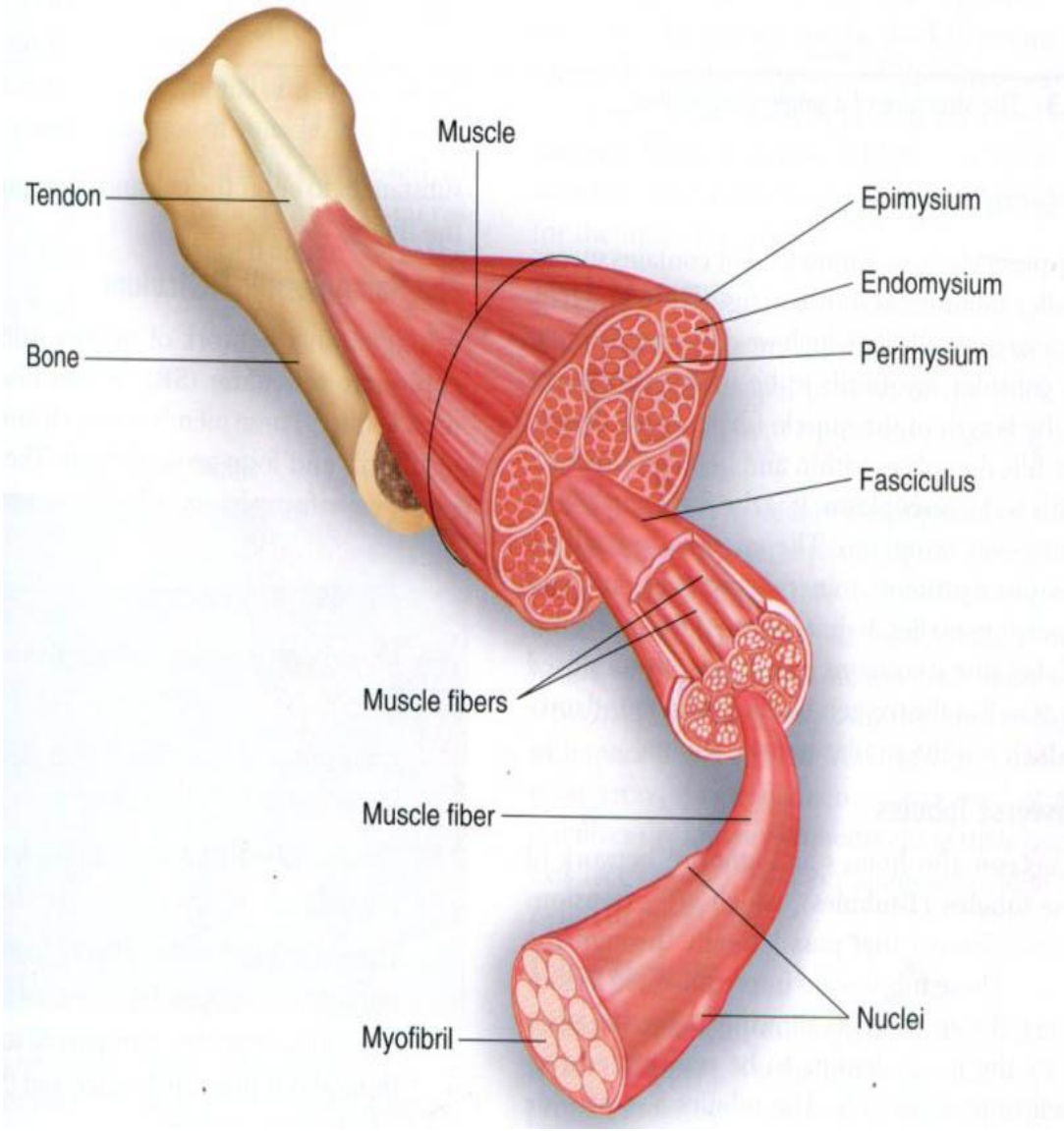
Types of muscles

- **Skeletal muscle** contains bundles of very long, multinucleated cells with cross-striations. Their contraction is quick, forceful, and under voluntary control.
- **Cardiac muscle** also has cross-striations and is composed of elongated cells bound to one another at structures called intercalated discs that are unique to cardiac muscle. Contraction is involuntary, vigorous, and rhythmic.
- **Smooth muscle** consists of collections of fusiform cells that lack striations and have slow, involuntary contractions

Skeletal muscle

- They are called skeletal as they are attached to the skeleton

- They are voluntary in action because they are under the control of will.



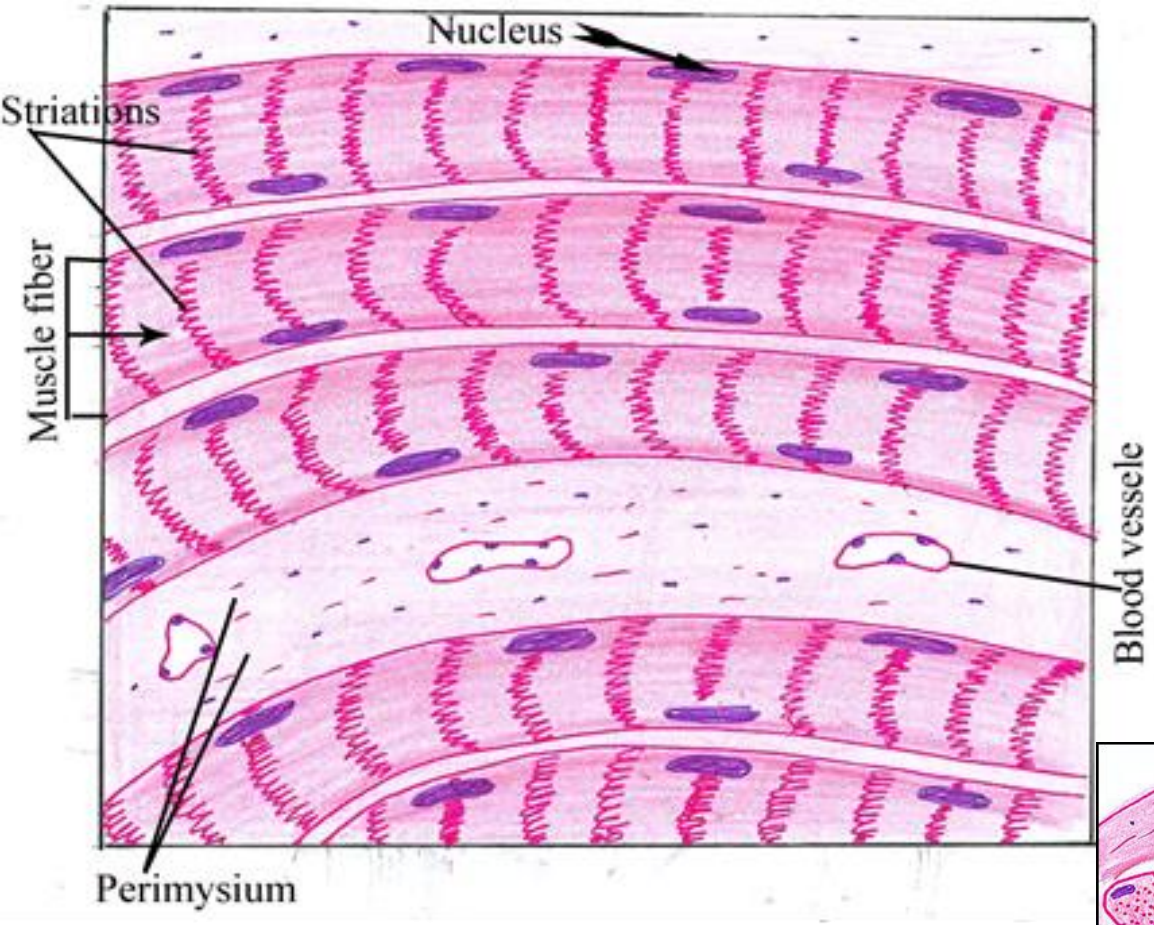
Organization of a Skeletal Muscle

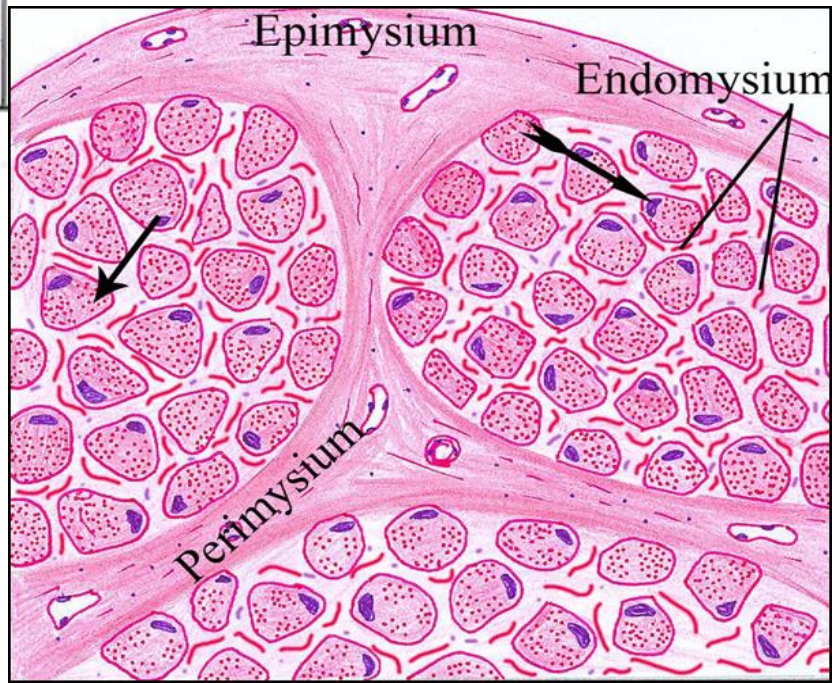
- **The epimysium:** an external sheath of dense connective tissue, surrounds the entire muscle. Septa of this tissue extend inward, carrying the larger nerves, blood vessels, and lymphatics of the muscle.
- **The perimysium:** is a thin connective tissue layer that immediately surrounds each bundle of muscle fibers termed a fascicle. Each fascicle of muscle fibers makes up a functional unit in which the fibers work together. Nerves, blood vessels, and lymphatics penetrate the perimysium to supply each fascicle.
- **The endomysium:** a very thin, delicate layer of reticular fibers and scattered fibroblasts surrounds the external lamina of individual muscle fiber.

Skeletal muscle

L.M:

- Muscle fibers are very long tubular cells. They are about (10-100 μm) in diameter and several centimeters in length "up to 40cm".
- Skeletal muscle fibers contain many peripherally placed nuclei located just beneath the plasma membrane (sarcolemma)
- A small population of reserve progenitor cells called muscle satellite cells located on the external surface of muscle fibers inside the external lamina. Satellite cells proliferate and produce new muscle fibers following muscle injury.


Nucleus
Striations
Muscle fiber
Blood vessele
Perimysium


Epimysium
Endomysium
Perimysium

- The cytoplasm (sarcoplasm) contains longitudinal, cylindrical fibrils (myofibrils).

- In longitudinal section, skeletal muscle fibers show cross-striations in the form of alternating **dark (A)** and light (I) bands.

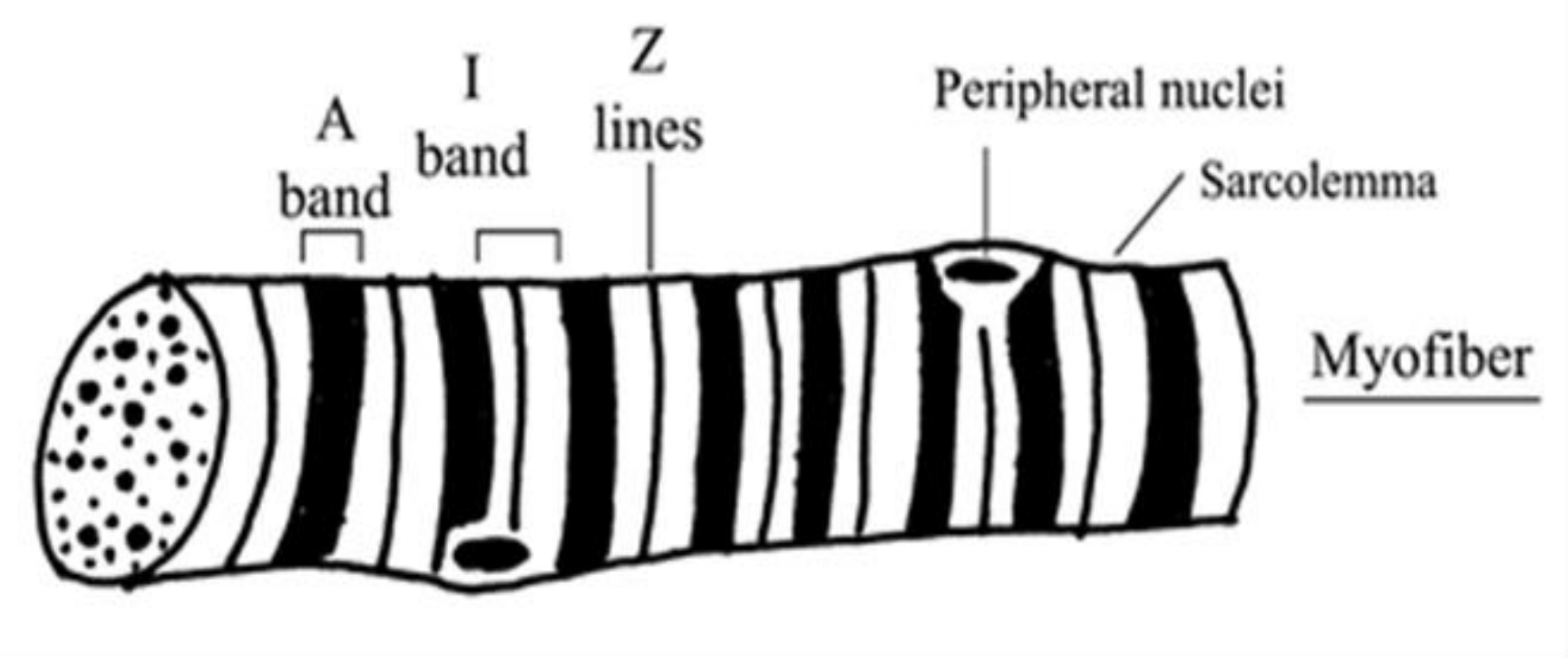
- In transverse sections, the muscle fibers appear rounded or polygonal in shape, the cytoplasm filled with dark dots representing the myofibrils

EM: The sarcoplasm of the skeletal muscle fiber contains:

1. ***Myofibrils:*** they are long, parallel cylindrical structures, formed of the contractile proteins (microfilaments)
2. ***Sarcoplasmic reticulum:*** It is well developed and highly modified SER. It is responsible for storing and releasing of Ca^{++} needed for contraction.
3. ***Long mitochondria*** are found near to the nucleus and form longitudinal rows between the myofibrils.
4. ***A small Golgi*** is associated with one nuclear pole.
5. ***Glycogen*** *and few* ***lipid droplets***.
6. ***Myoglobin pigment*** is oxygen-binding protein that is responsible for the red brown color of muscle and is related to oxygen supply for the muscle.

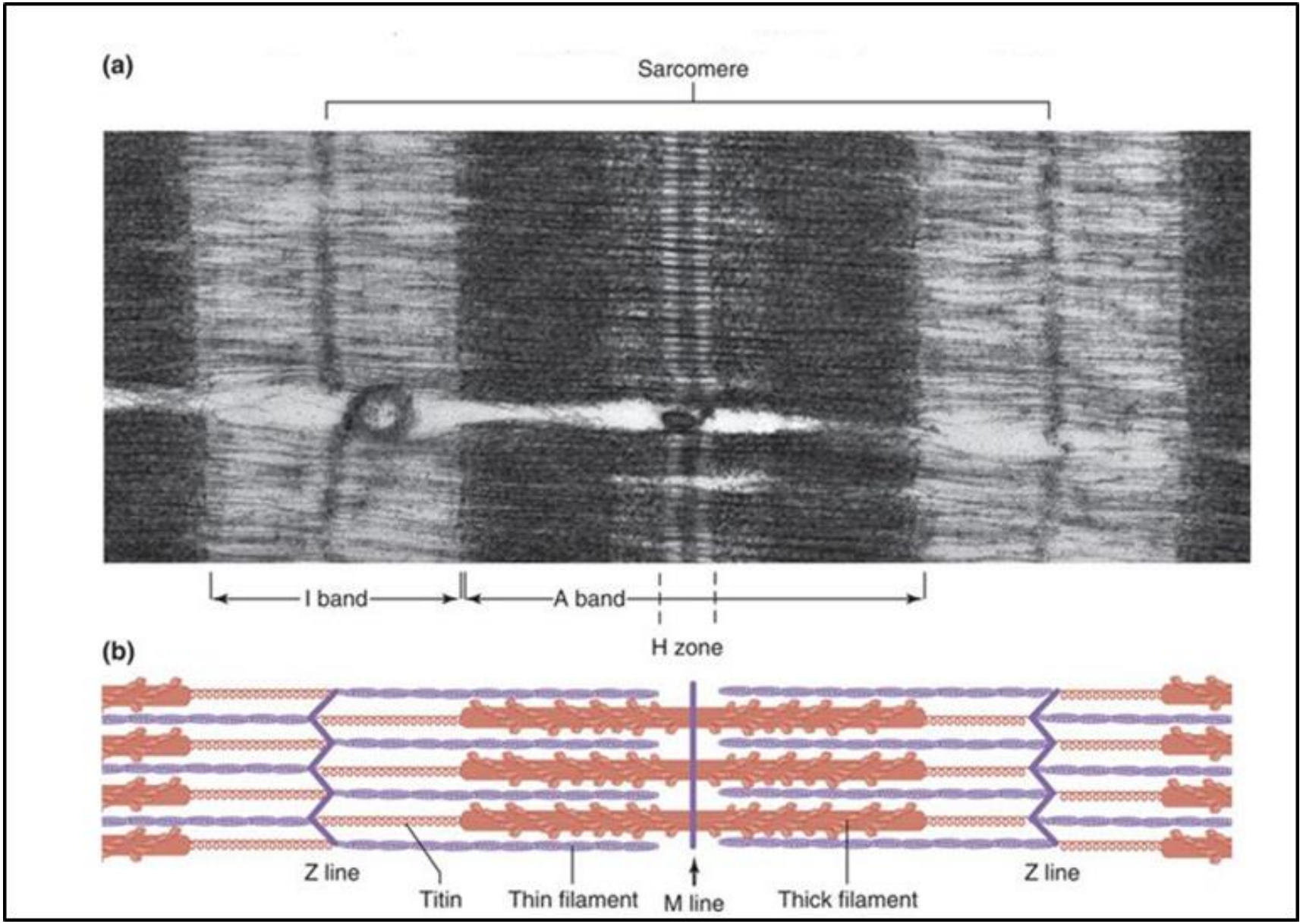
Myofibrils and myofilaments

- Longitudinally sectioned skeletal muscle fibers show cross striations of alternating light and dark bands. The dark bands are called A bands (anisotropic or birefringent in polarized light microscopy); the light bands are called I bands (isotropic, do not alter polarized light). In the **TEM** , each I band is seen to be bisected by a dark transverse line, the Z disc. The repetitive functional subunit of the contractile apparatus, the sarcomere, extends from Z disc to Z disc and is about 2.5 µm long in resting muscle.



Sarcomere is the part of the myofibril between two successive Z lines. Sarcomere is the functional unit of the muscle fiber. Each sarcomere contains one complete A band separating two halves I bands on both sides of the A band.

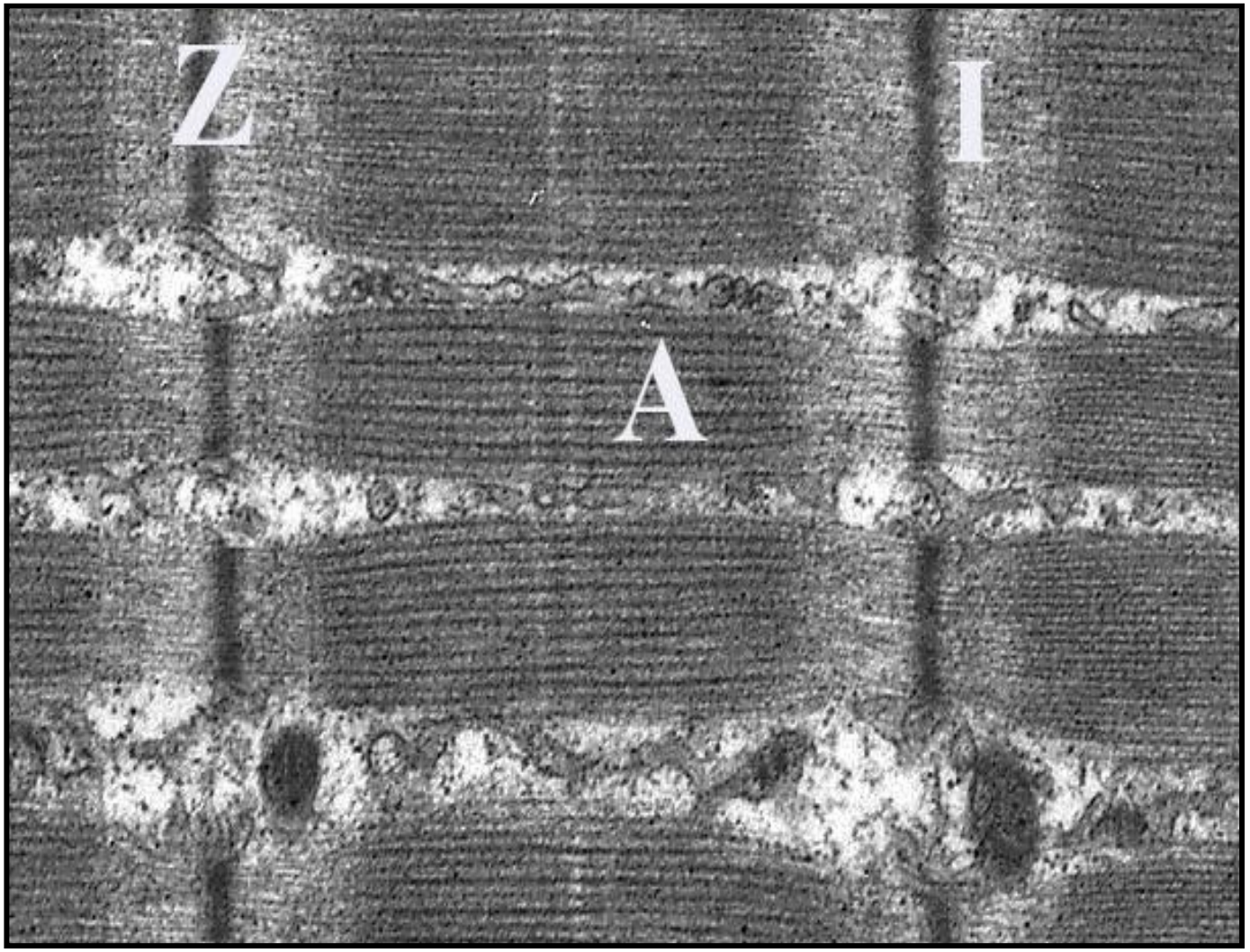
EM


(a)
Sarcomere
I band
A band
H zone
(b)
Z line
Titin
Thin filament
M line
Thick filament
Z line

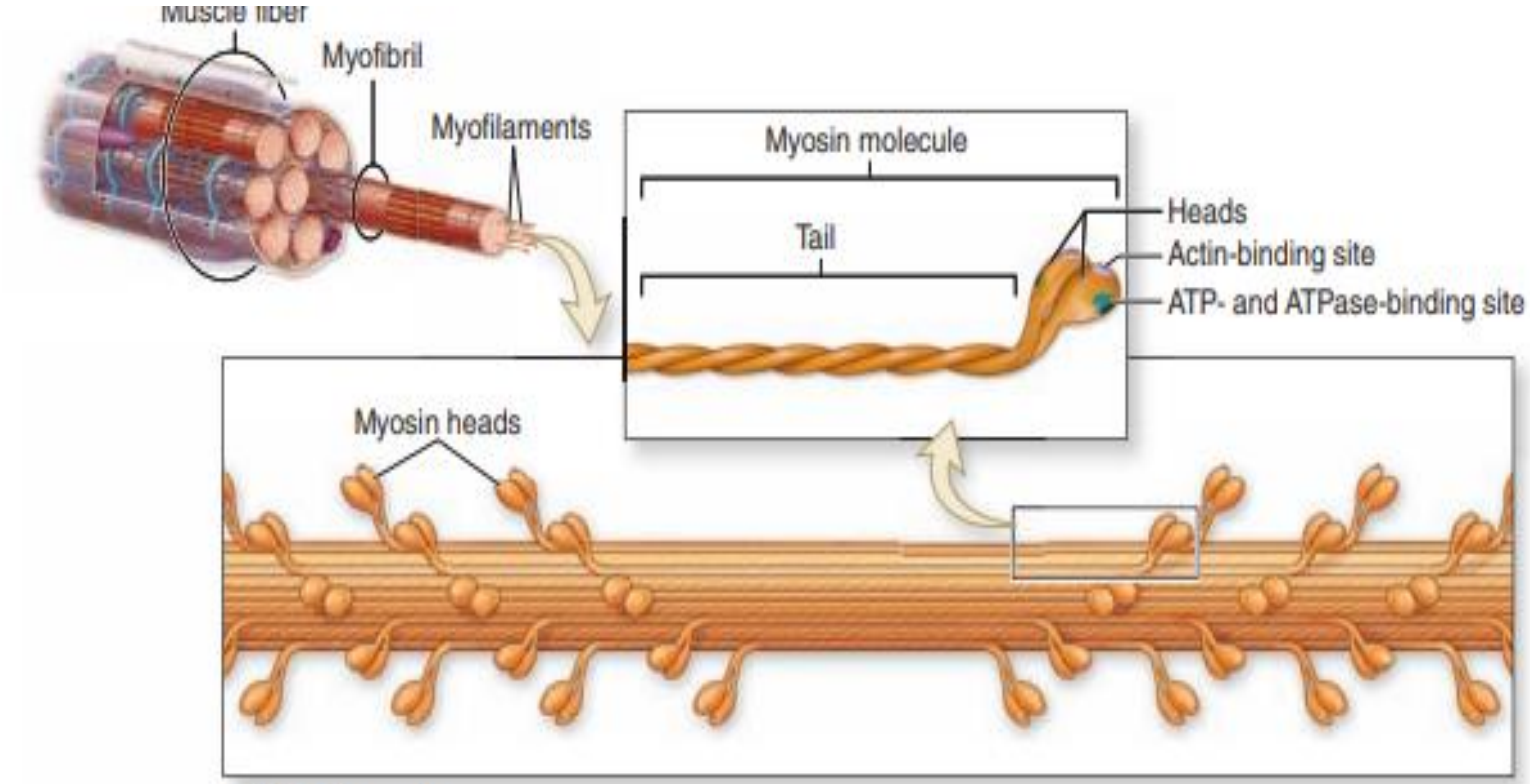
- The A and I banding pattern in sarcomeres is due mainly to the regular arrangement of thick and thin myofilaments, composed of **myosin** and **F-actin**, respectively.

- A band contains myosin and actin myofilaments.
- H zone is a paler central region in the A band and consists only of myosin myofilaments.
- H zone is bisected by dark M line, which is the site of attachment of myosin myofilaments.
- I bands contains actin myofilaments only which are attached to Z lines.

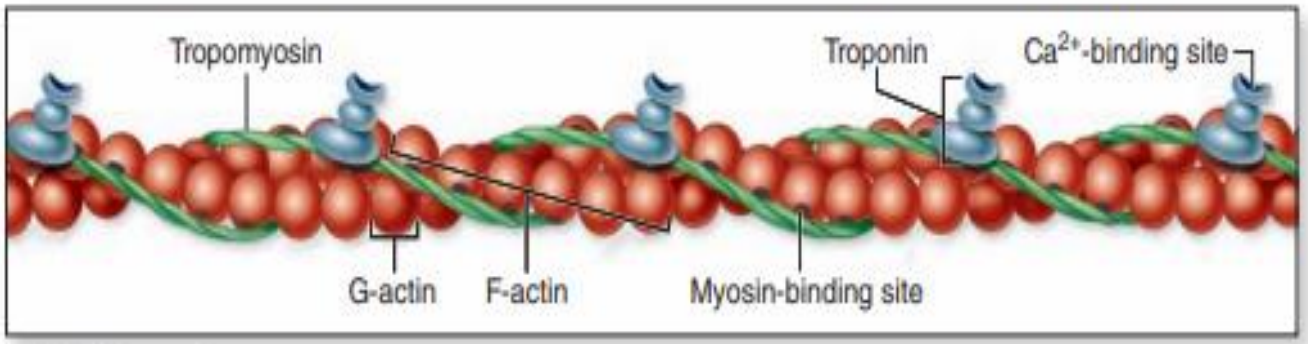
LS skeletal ms showing sarcomere



- **Myosin** is a large complex with two identical heavy chains and two pairs of light chains.
- **Myosin heavy chains** are thin, rodlike motor proteins twisted together as **myosin tails**.
- Globular projections containing the four **myosin light chains** form **a head** at one end of each heavy chain.
- The myosin heads bind both **actin**, forming transient cross bridges between the thick and thin filaments, and **ATP,** catalyzing energy release. Several hundred myosin molecules are arranged within each thick filament with overlapping rodlike portions and the globular heads directed toward either end.



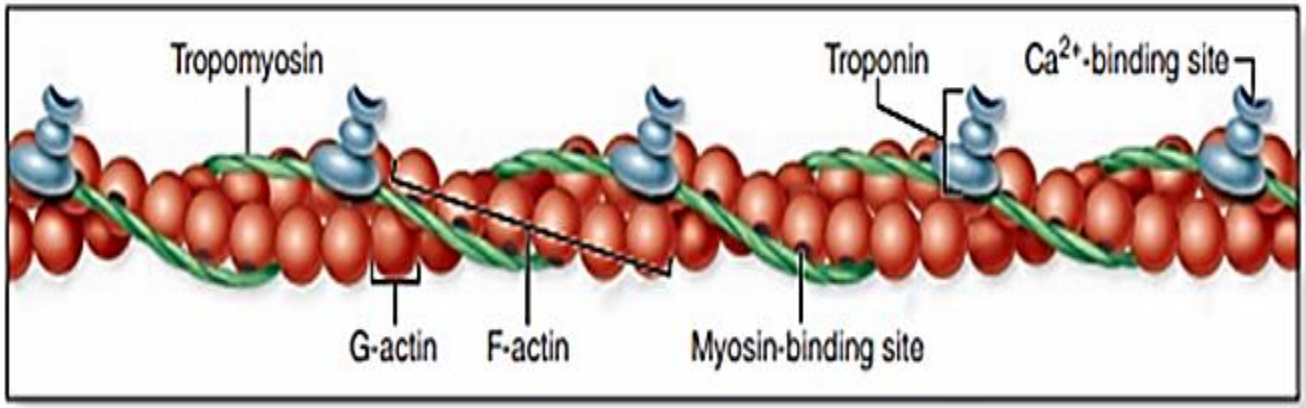
a Thick filament



b Thin filament

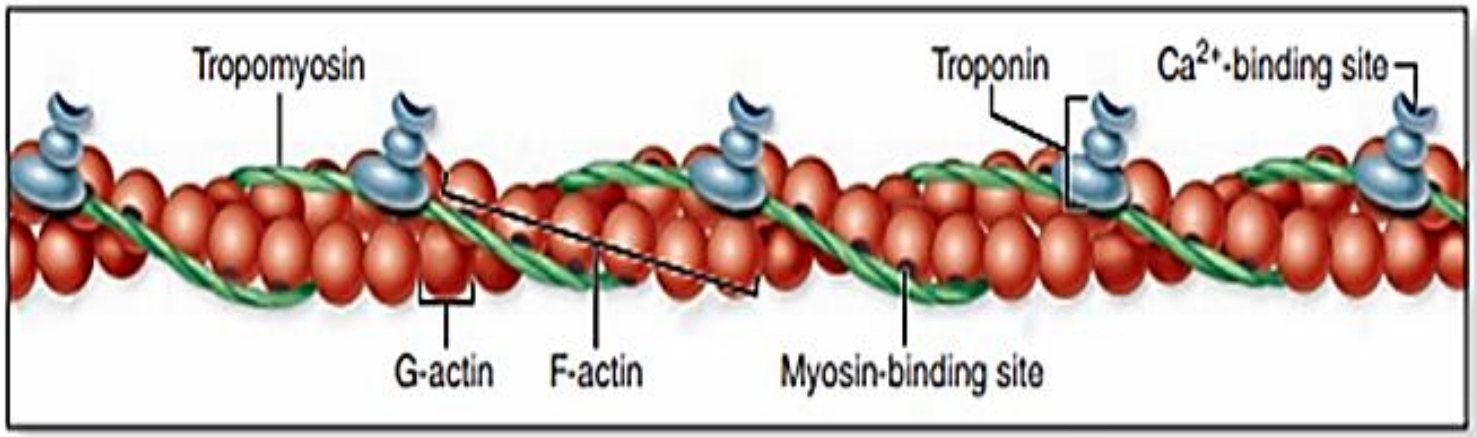
- **G-actin** monomers form F-actin filaments (two twisted actin strands)

- The thin, helical actin filaments run between the thick filaments. Each G-actin monomer contains a binding site for myosin.
- Actin filaments are anchored perpendicularly on the Z disc by the actin-binding protein **α-actinin** and exhibit opposite polarity on each side of this disc.



b Thin filament

- Thin filaments are also tightly associated with two regulatory proteins:
- ■ **Tropomyosin**, two polypeptide chains located in the groove between the two twisted actin strands.
- ■ **Troponin**, a complex of three subunits: **TnT**, which attaches to tropomyosin; **TnC**, which binds Ca2+; and **TnI**, which regulates the actin-myosin interaction. Troponin complexes attach at specific sites regularly spaced along each tropomyosin molecule.



b Thin filament

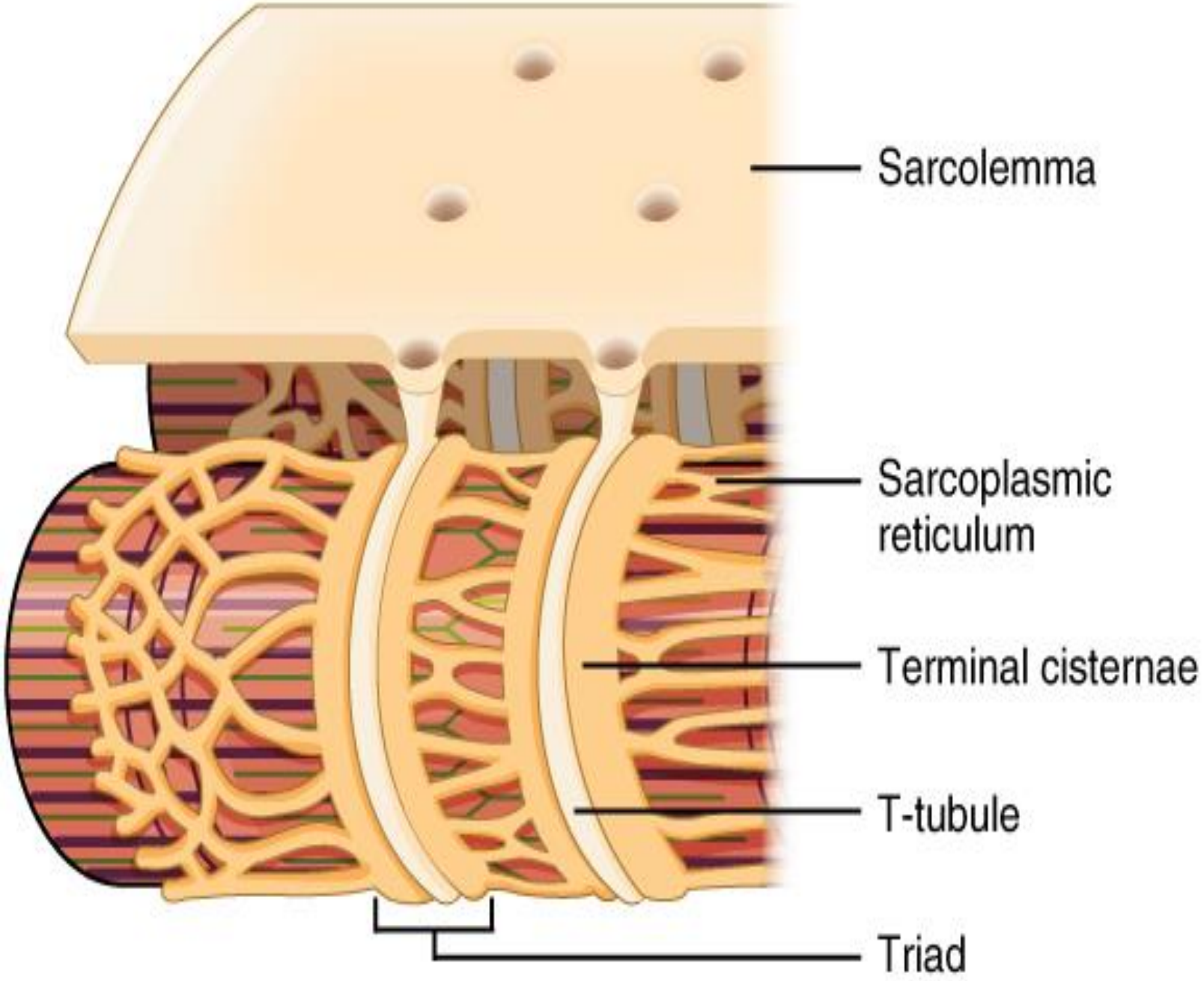
- An important accessory protein in I bands is **titin**, the largest protein in the body, with scaffolding and elastic properties, which supports the thick myofilaments and connects them to the Z disc.
- Another very large accessory protein, **nebulin** which binds each thin myofilament laterally, helps anchor them to α-actinin, and specifies the length of the actin polymers during myogenesis.
- Bisecting the H zone is the M line containing a myosin-binding protein **myomesin** that holds the thick filaments in place, and creatine kinase. This enzyme catalyzes transfer of phosphate groups from phosphocreatine, a storage form of high-energy phosphate groups, to ADP, helping to supply ATP for muscle contraction.

Sarcoplasmic Reticulum & Transverse Tubule System

- In skeletal muscle fibers the smooth ER, or sarcoplasmic reticulum, is specialized for Ca2+ sequestration. Depolarization of the sarcoplasmic reticulum membrane is initiated at specialized motor nerve synapses on the sarcolemma to trigger Ca2+ release from sarcoplasmic reticulum throughout the fiber simultaneously and cause uniform contraction of all myofibrils.

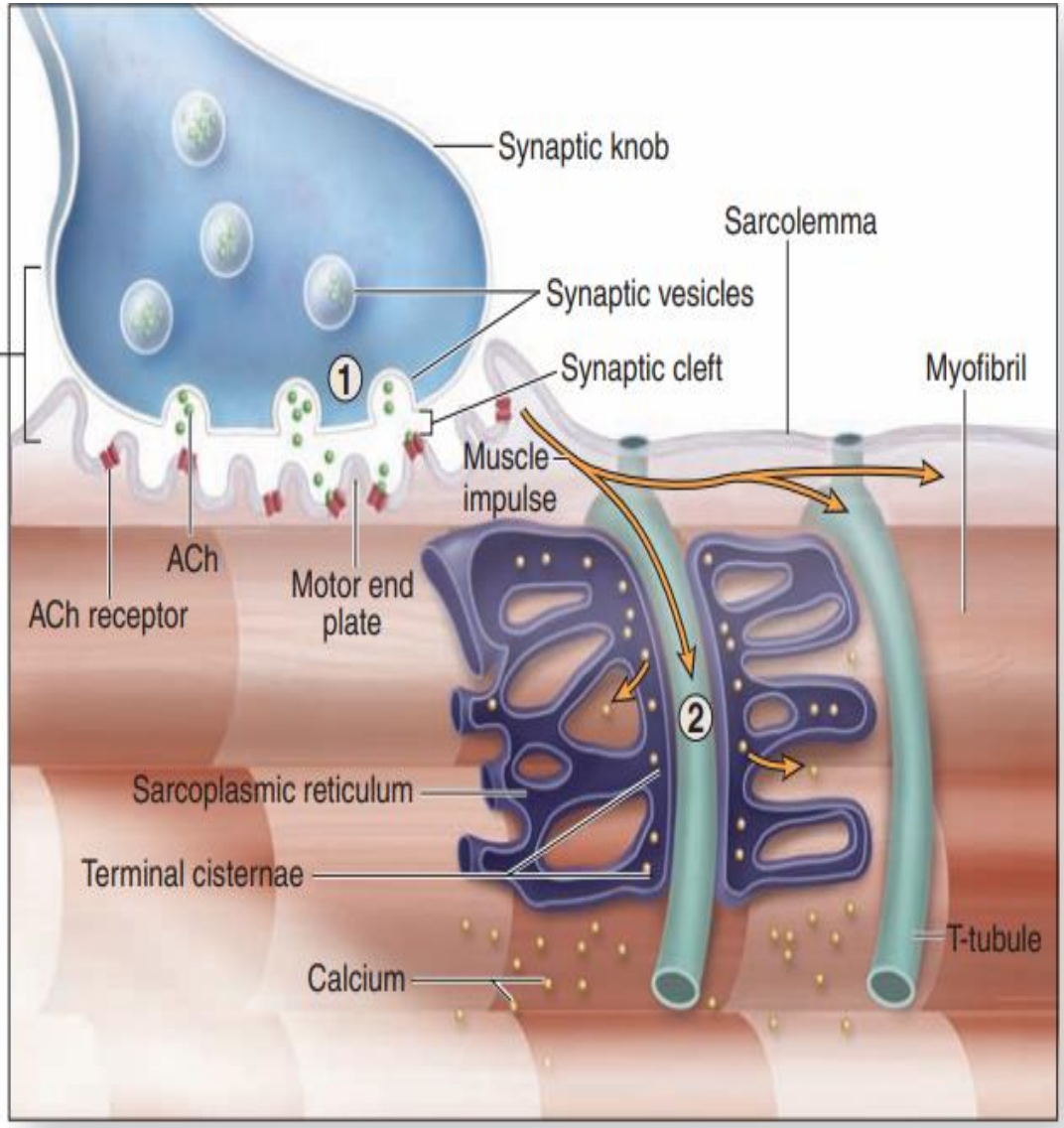
- the sarcolemma is folded into a system of transverse or T tubules. These long fingerlike invaginations of the cell membrane penetrate deeply into the sarcoplasm and encircle every myofibril near the aligned A- and I-band boundaries of sarcomeres.

- Adjacent to each side of every T tubule are expanded terminal cisterns of the sarcoplasmic reticulum. In longitudinal TEM sections, this complex of a T tubule with two closely associated small cisterns of sarcoplasmic reticulum on each side is known as **a triad**.


Sarcolemma
Sarcoplasmic reticulum
Terminal cisternae
T-tubule
Triad

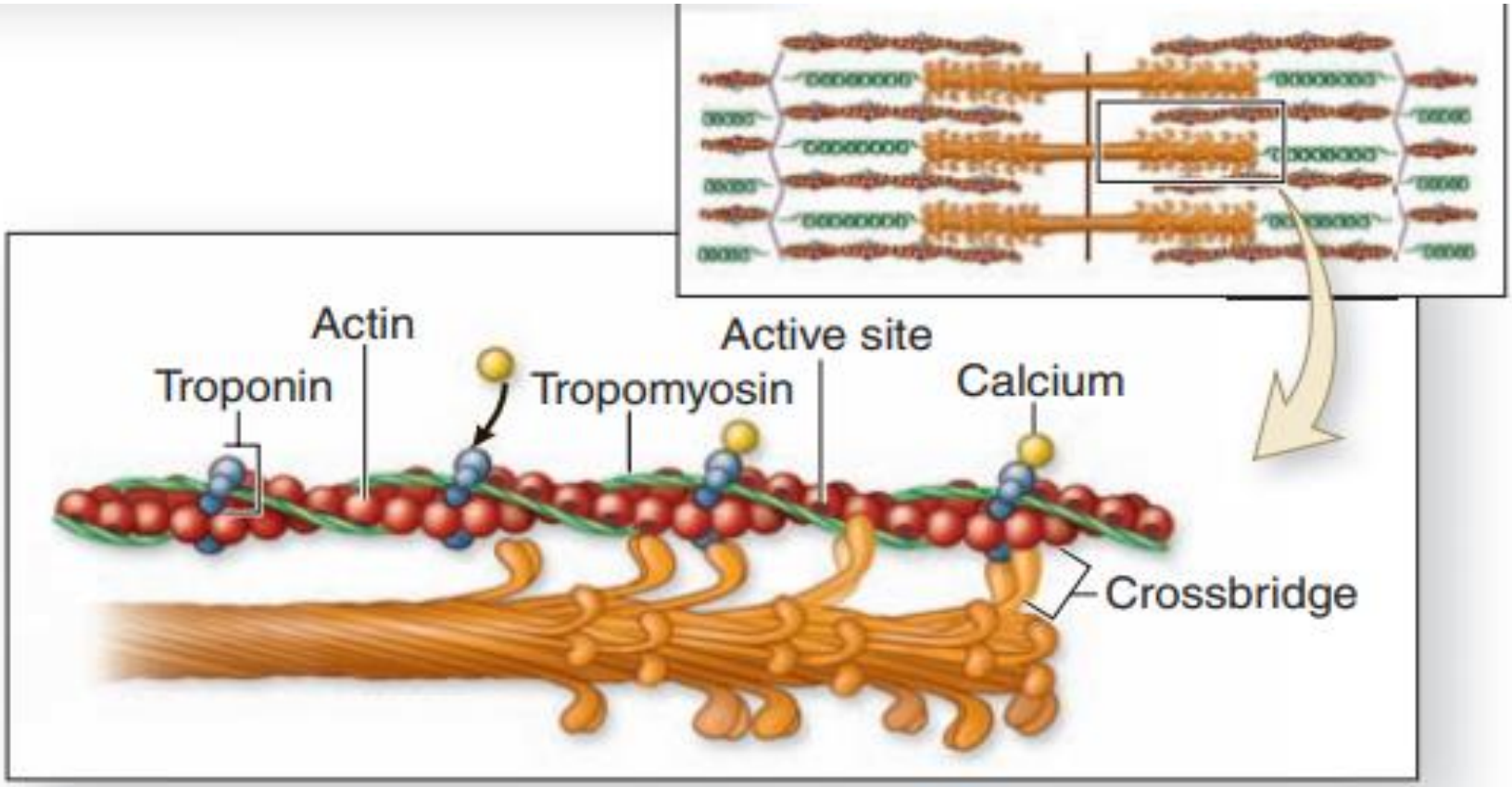
- After depolarization of the sarcoplasmic reticulum membrane, calcium ions concentrated within these cisternae are released through Ca2+ channels in the membrane into cytoplasm surrounding the thick and thin filaments. Ca2+ binds troponin and allows bridging between actin and myosin molecules. When the membrane depolarization ends, the sarcoplasmic reticulum pumps Ca2+ back into the cisternae, ending contractile activity.

Events of muscle contraction

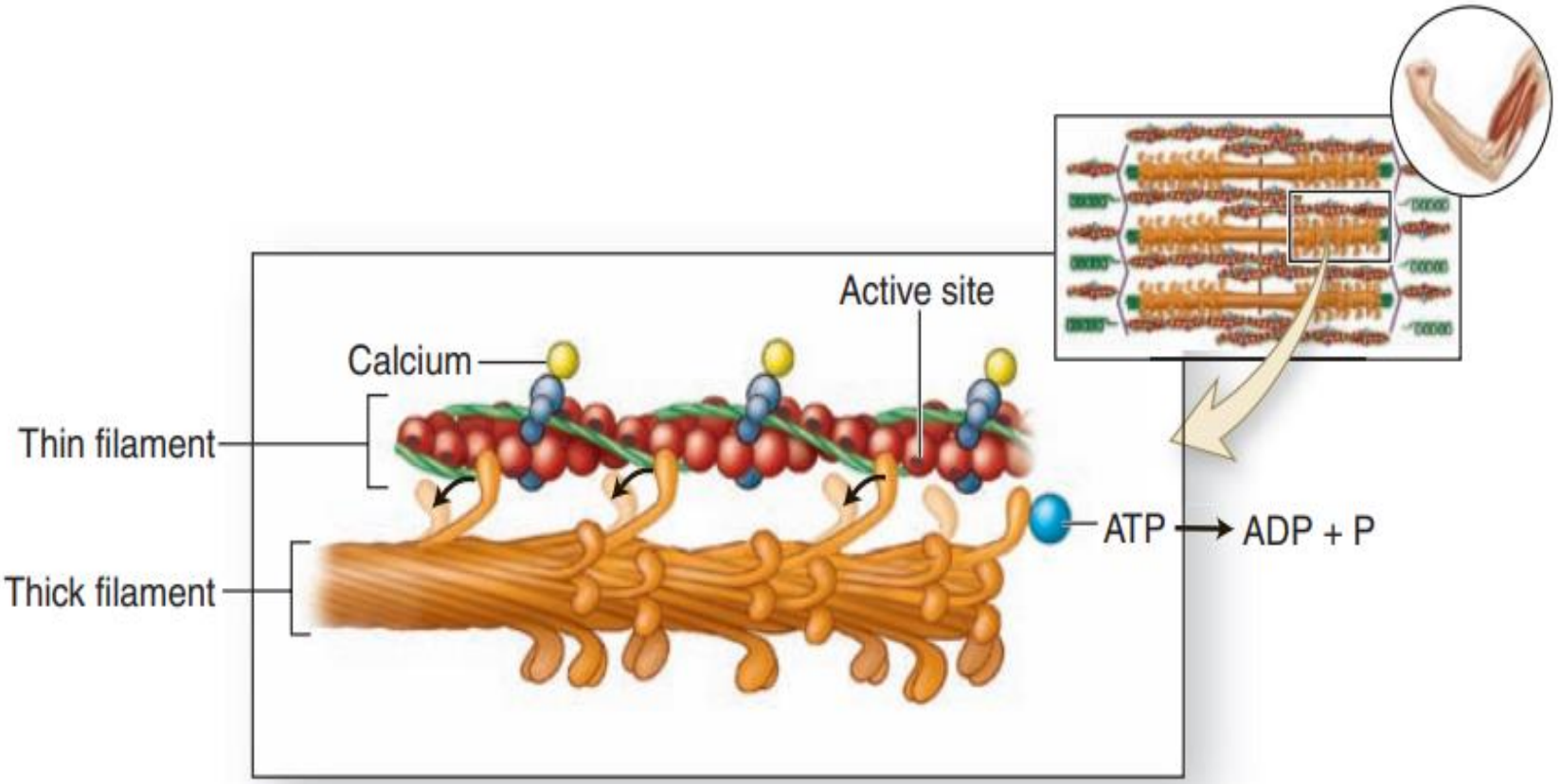


(1) A nerve impulse triggers release of ACh from the synaptic knob into the synaptic cleft. ACh binds to ACh receptors in the motor end plate of the neuromuscular junction, initiating a muscle impulse in the sarcolemma of the muscle fiber.

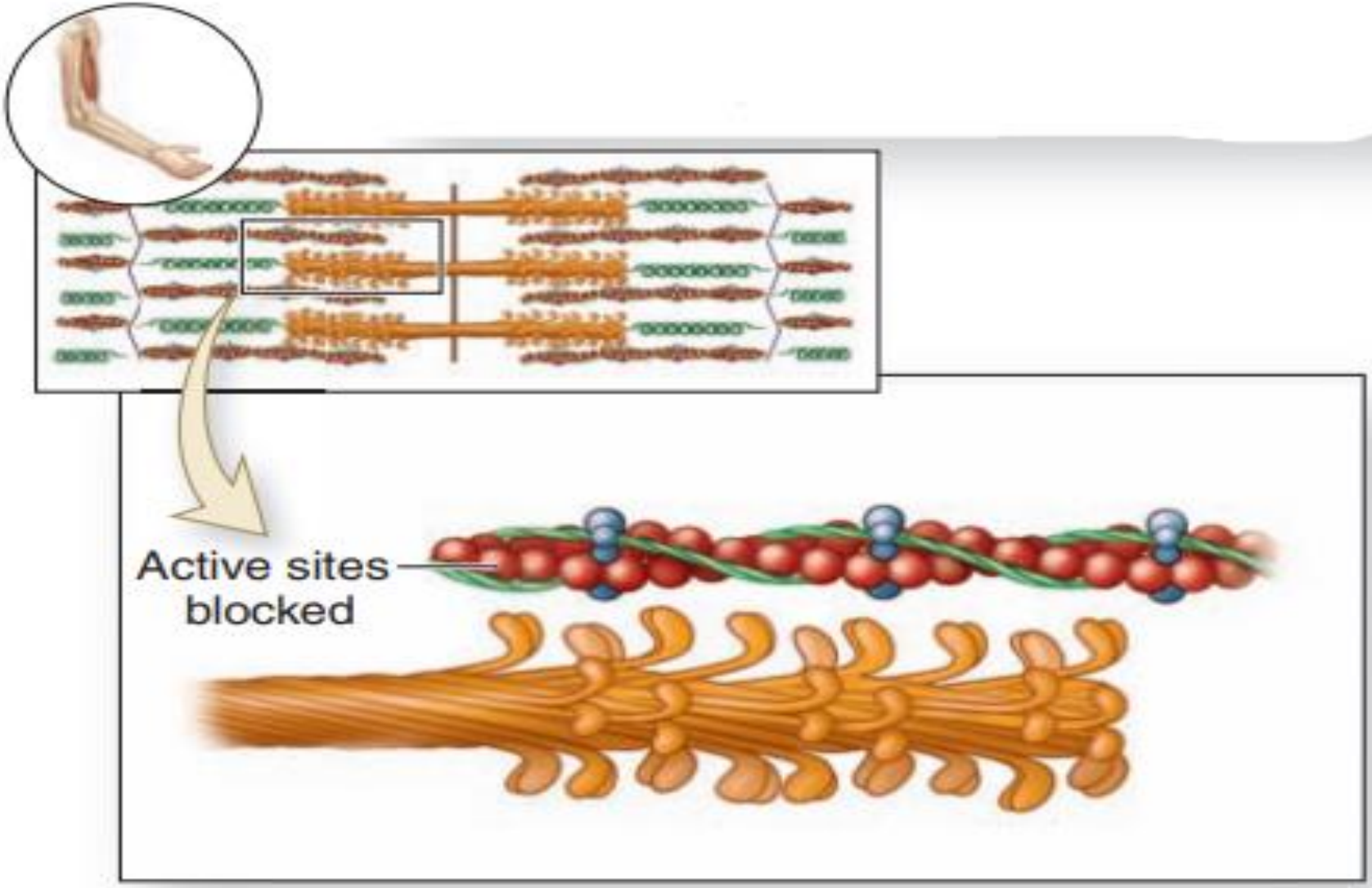
(2) As the muscle impulse spreads quickly from the sarcolemma along T tubules, calcium ions are released from terminal cisternae into the sarcoplasm.



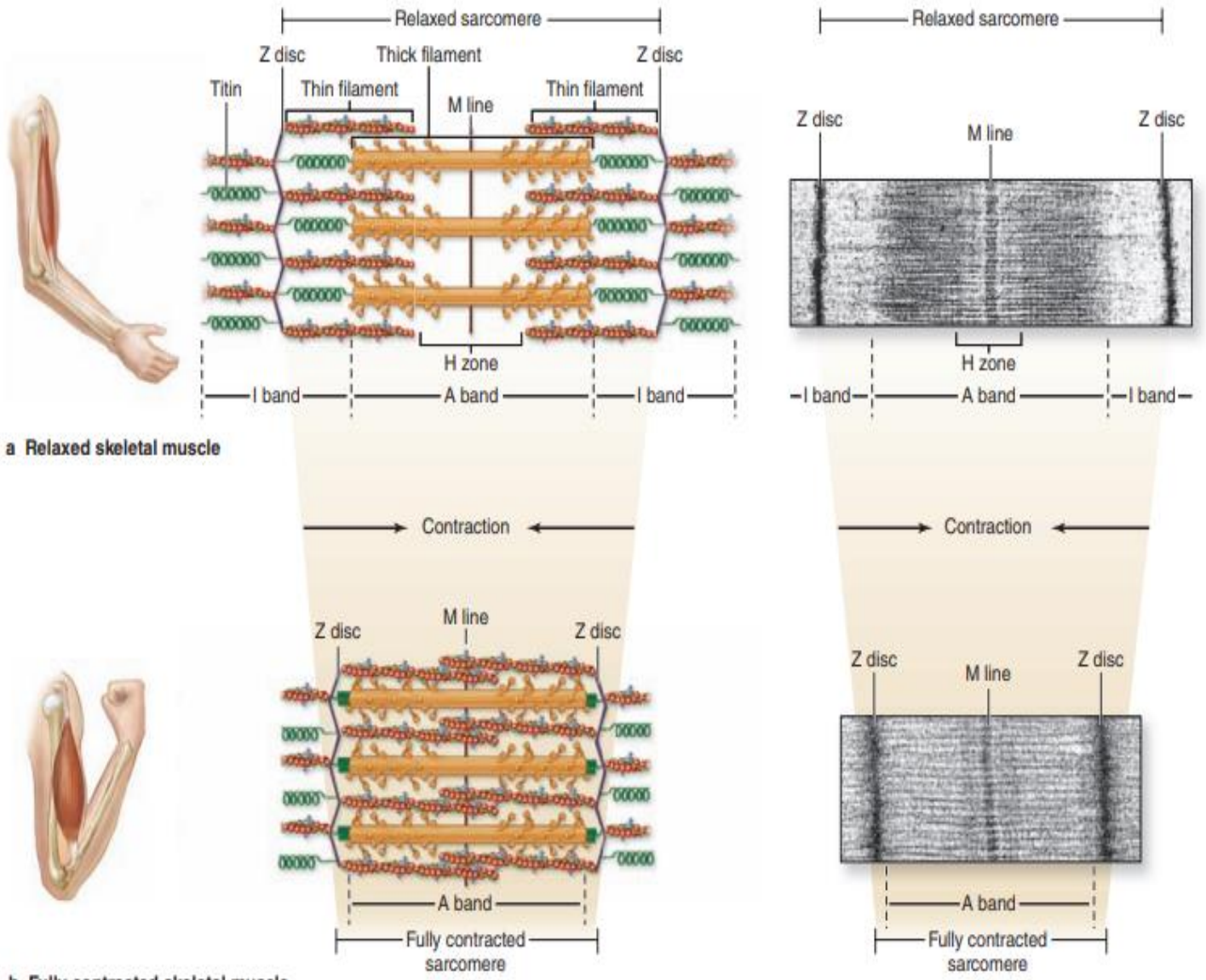
③ Calcium ions bind to troponin. Troponin changes shape, moving tropomyosin on the actin to expose active sites on actin molecules of thin filaments. Myosin heads of thick filaments attach to exposed active sites to form crossbridges.



④ Myosin heads pivot, moving thin filaments toward the sarcomere center. ATP binds myosin heads and is broken down into ADP and P. Myosin heads detach from thin filaments and return to their prepivot position. The repeating cycle of *attach-pivot-detach-return* slides thick and thin filaments past one another. The sarcomere shortens and the muscle contracts. The cycle continues as long as calcium ions remain bound to troponin to keep active sites exposed.



⑤ When the impulse stops, calcium ions are actively transported into the sarcoplasmic reticulum, tropomyosin re-covers active sites, and filaments passively slide back to their relaxed state.


Relaxed sarcomere
Z disc
Thick filament
Z disc
Titin
Thin filament
M line
Thin filament
H zone
I band
A band
I band
Relaxed sarcomere
Z disc
M line
Z disc
H zone
I band
A band
I band
a Relaxed skeletal muscle
Contraction
M line
Z disc
Z disc
A band
Fully contracted sarcomere
Contraction
Z disc
M line
Z disc
A band
Fully contracted sarcomere
b Fully contracted skeletal muscle

Major characteristics of skeletal muscle fiber types.

	Slow, Oxidative Fibers (Type I)	Fast, Oxidative-Glycolytic Fibers (Type IIa)	Fast, Glycolytic Fibers (Type IIb)
Mitochondria	Numerous	Numerous	Sparse
Capillaries	Numerous	Numerous	Sparse
Fiber diameter	Small	Intermediate	Large
Size of motor unit	Small	Intermediate	Large
Myoglobin content	High (red fibers)	High (red fibers)	Low (white fibers)
Glycogen content	Low	Intermediate	High
Major source of ATP	Oxidative phosphorylation	Oxidative phosphorylation	Anaerobic glycolysis
Glycolytic enzyme activity	Low	Intermediate	High
Rate of fatigue	Slow	Intermediate	Fast
Myosin-ATPase activity	Low	High	High
Speed of contraction	Slow	Fast	Fast
Typical major locations	Postural muscles of back	Major muscles of legs	Extraocular muscles