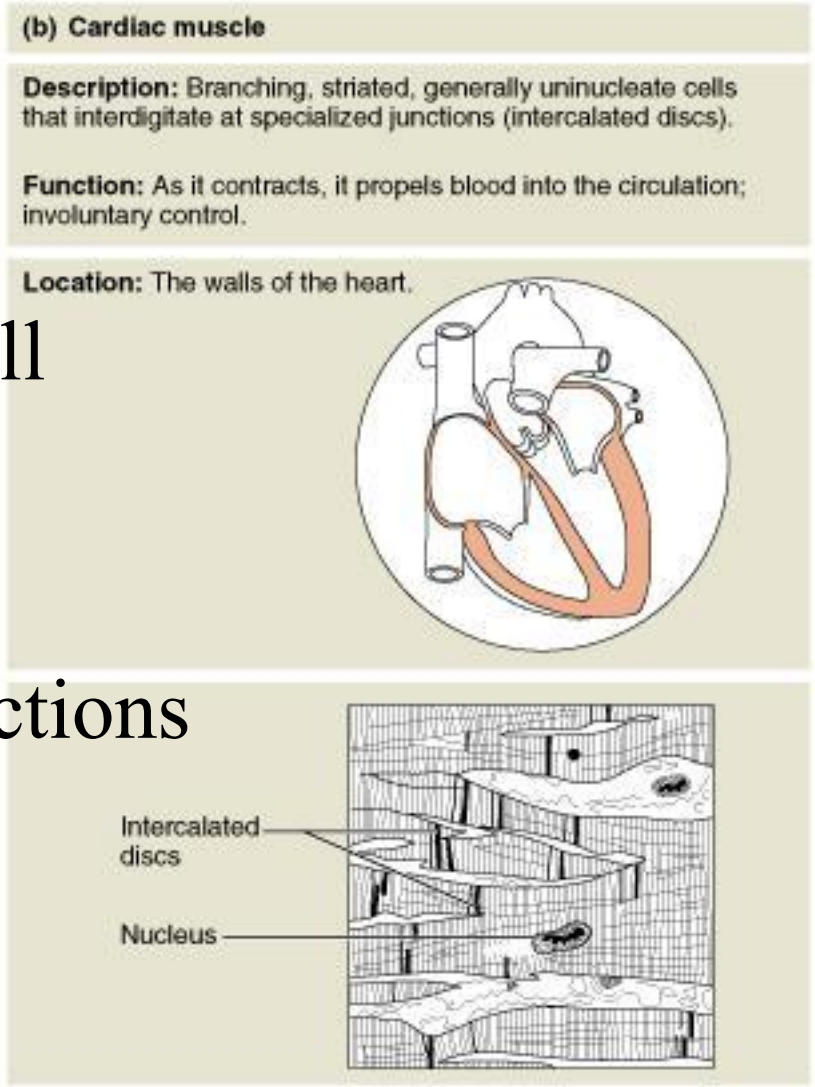
# Muscle Physiology

# Muscle Tissue

- Skeletal Muscle
- Cardiac Muscle
- Smooth Muscle

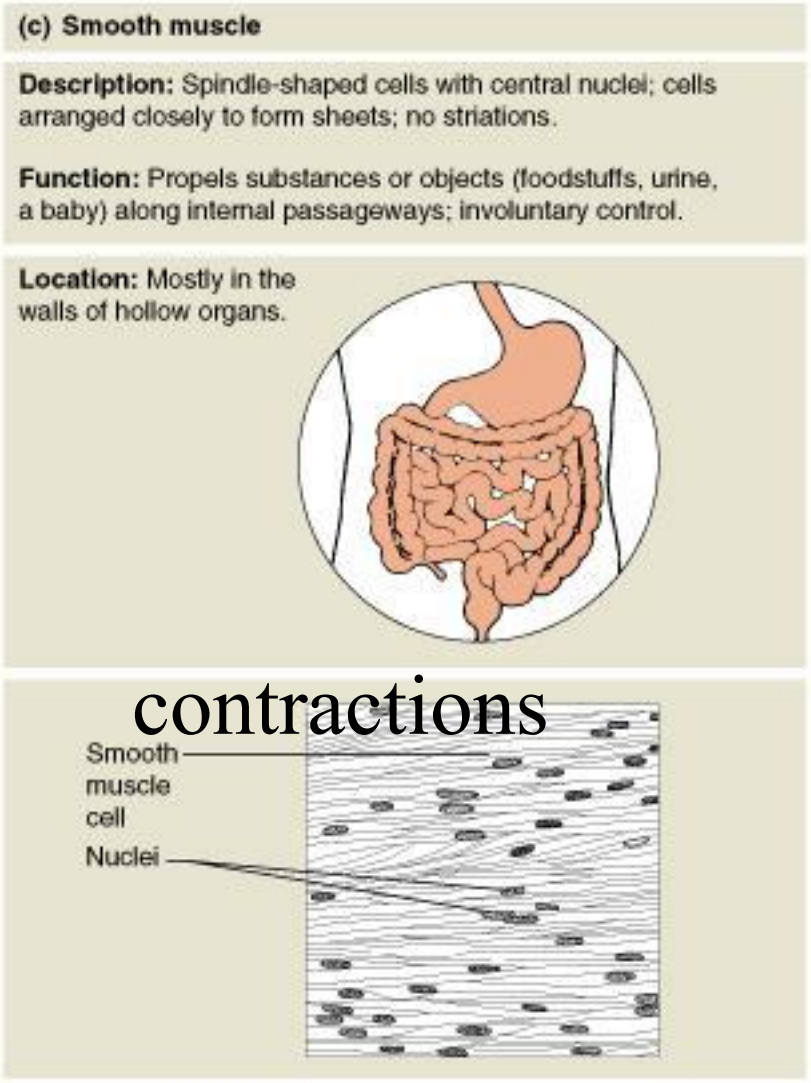
# Cardiac Muscle

- Branching cells
- One/two nuclei per cell
- Striated
- Involuntary
- Medium speed contractions



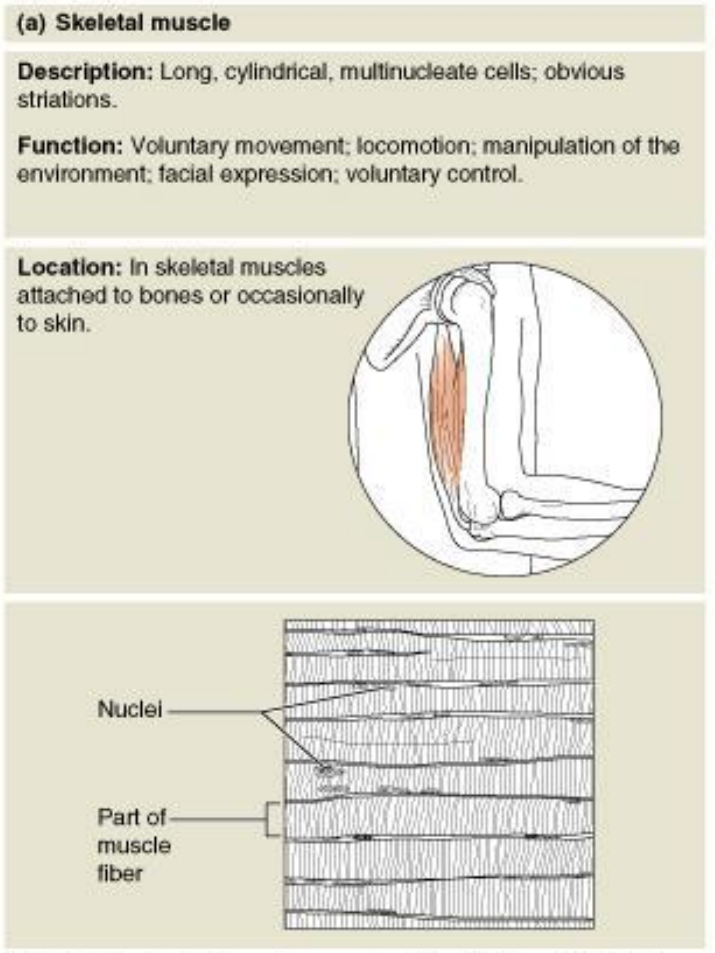
# Smooth Muscle

- Fusiform cells
- One nucleus per cell
- Nonstriated
- Involuntary
- Slow, wave-like contractions



# Skeletal Muscle

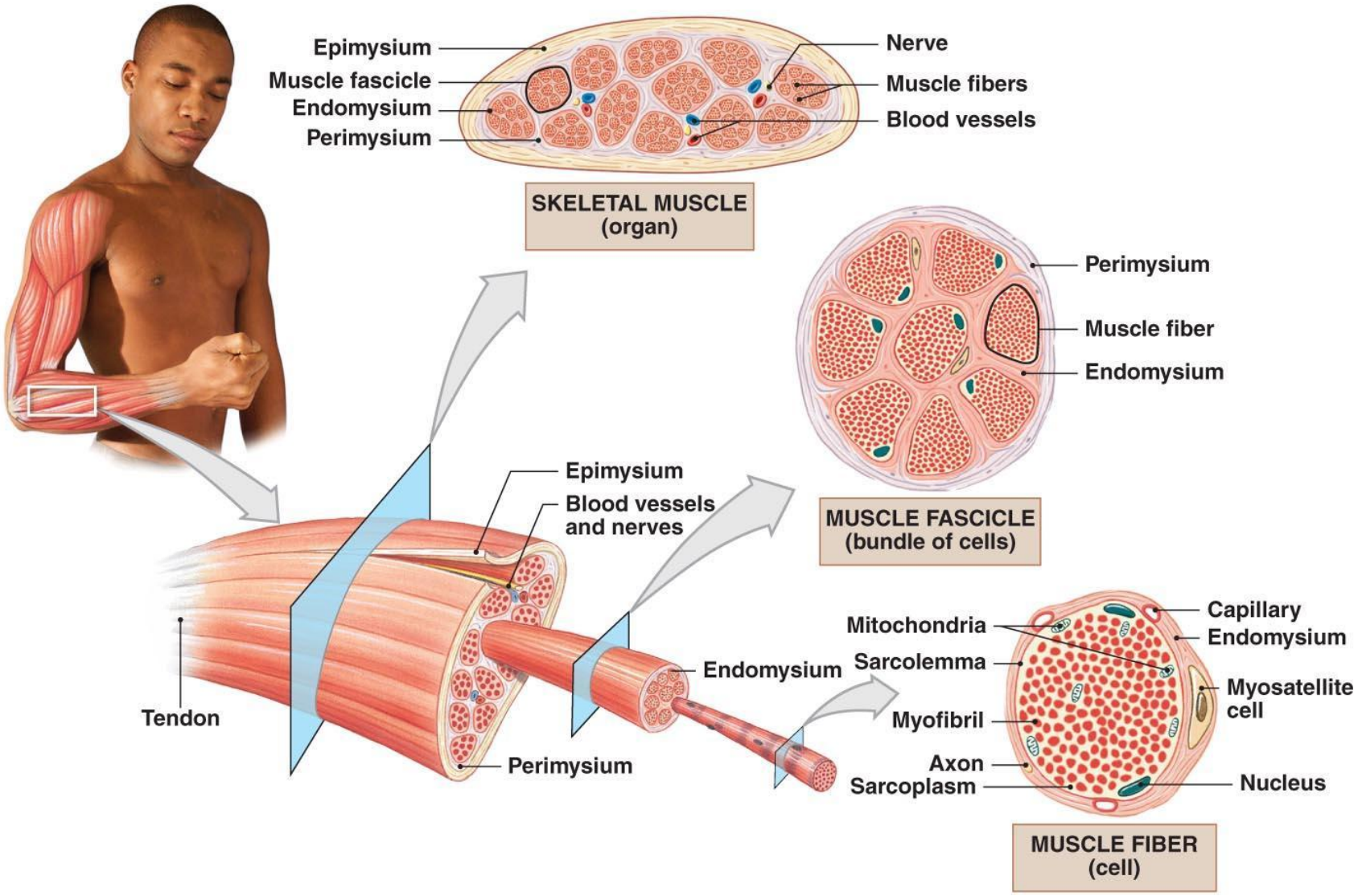
- Long cylindrical cells
- Many nuclei per cell
- Striated
- Voluntary
- Rapid contractions



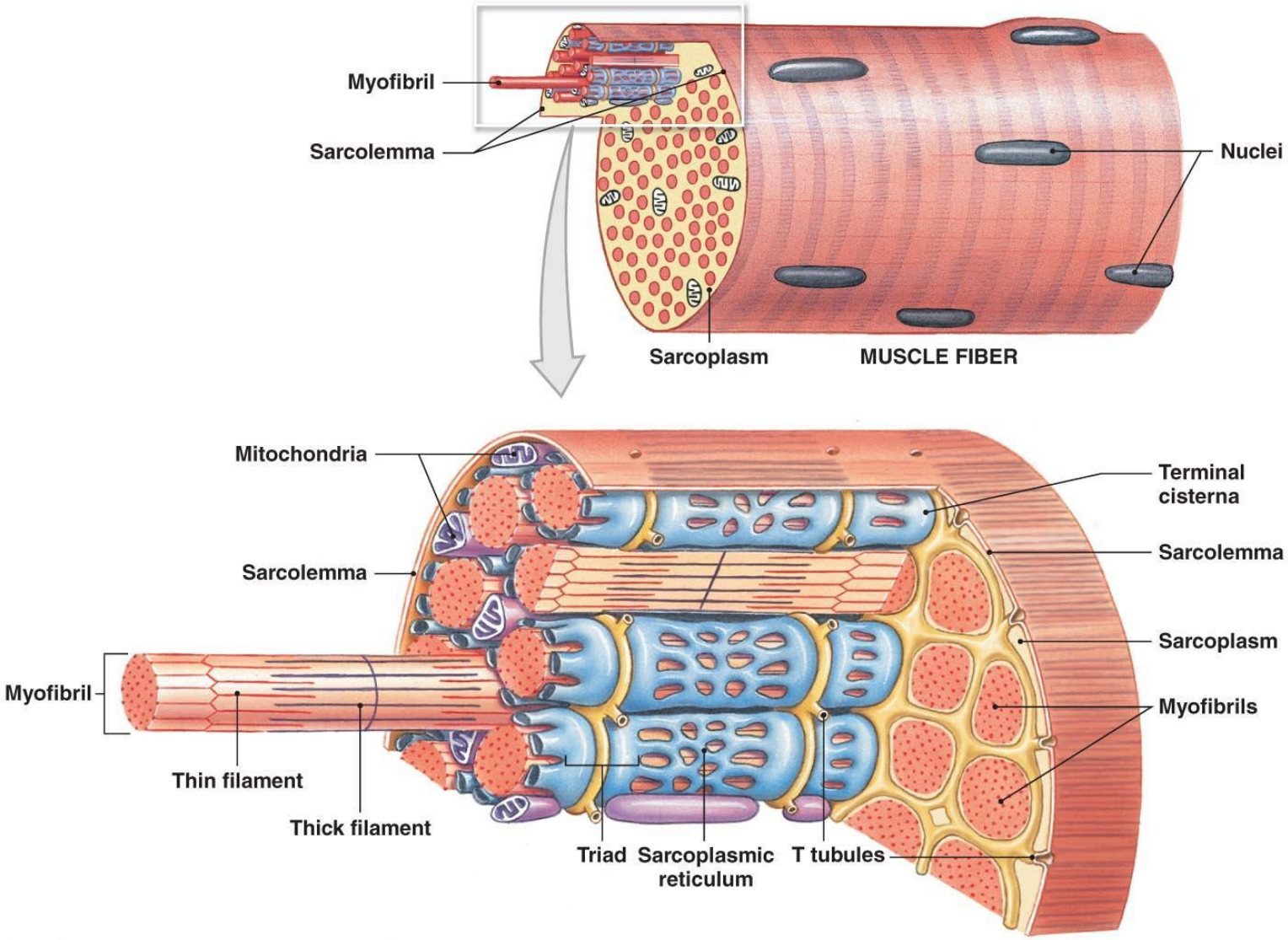
# Skeletal Muscle

- Produce movement
- Maintain posture & body position
- Support Soft Tissues
- Guard entrance / exits
- Maintain body temperature
- Store nutrient reserves

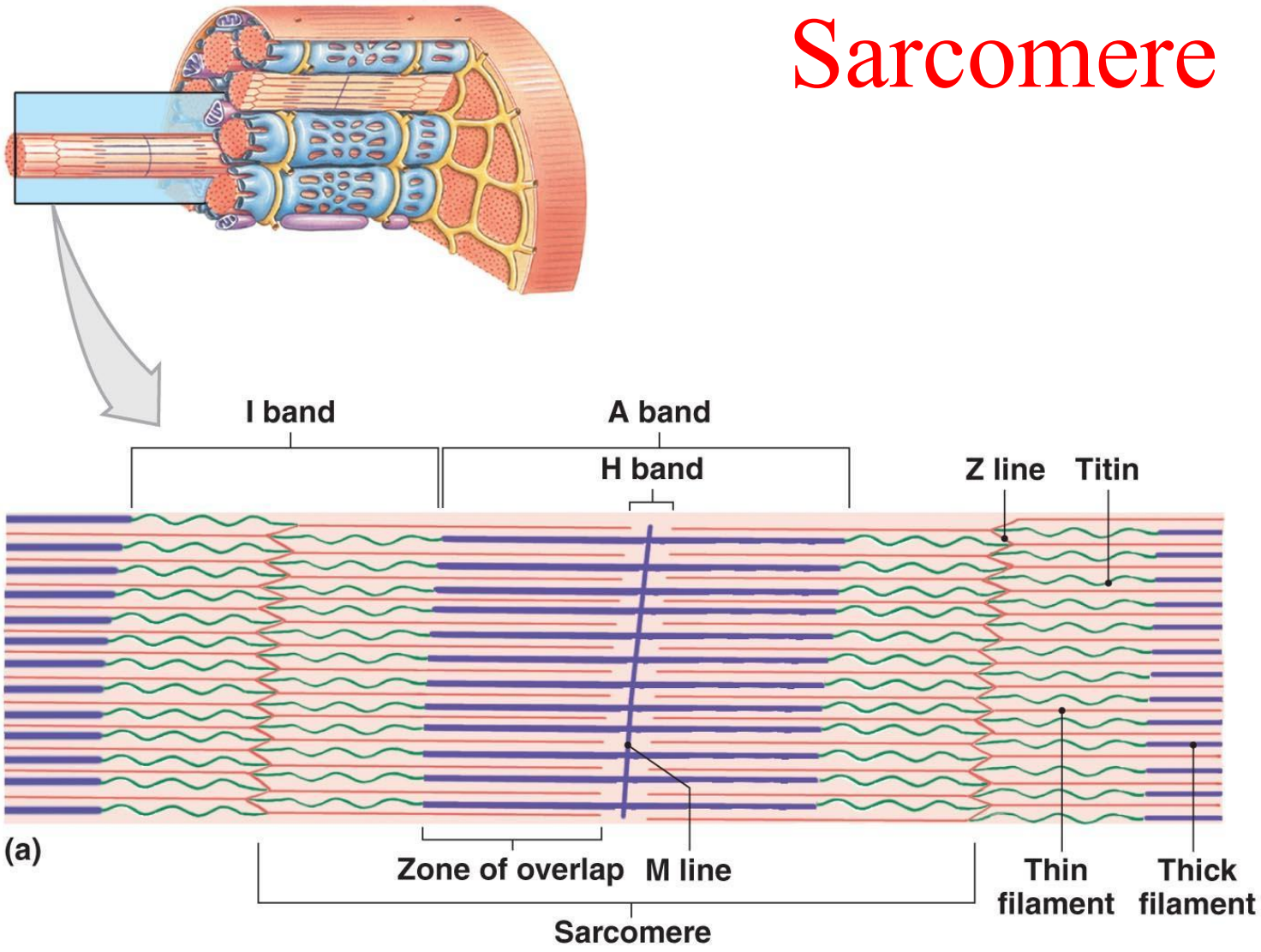
# Skeletal Muscle Structure

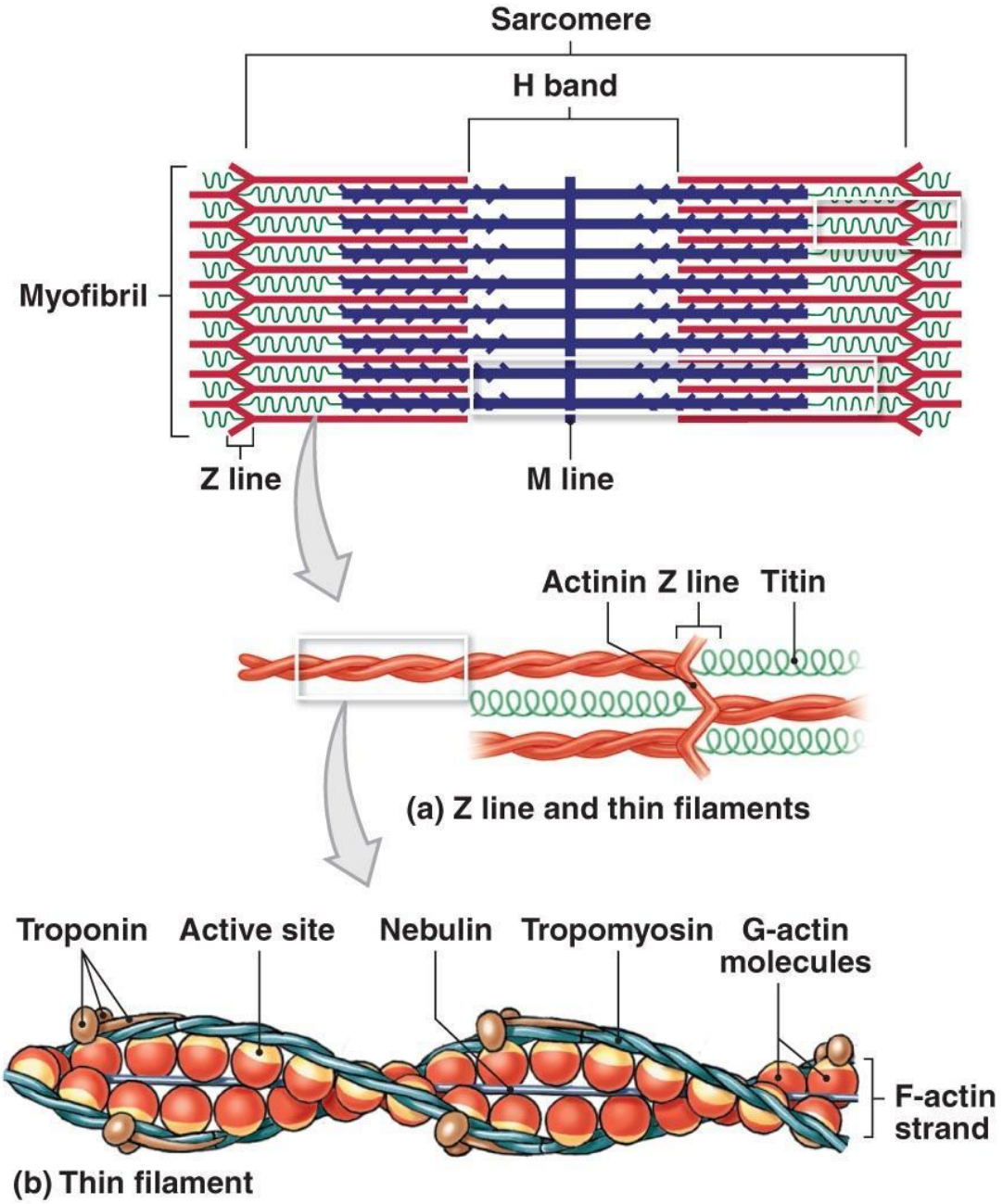


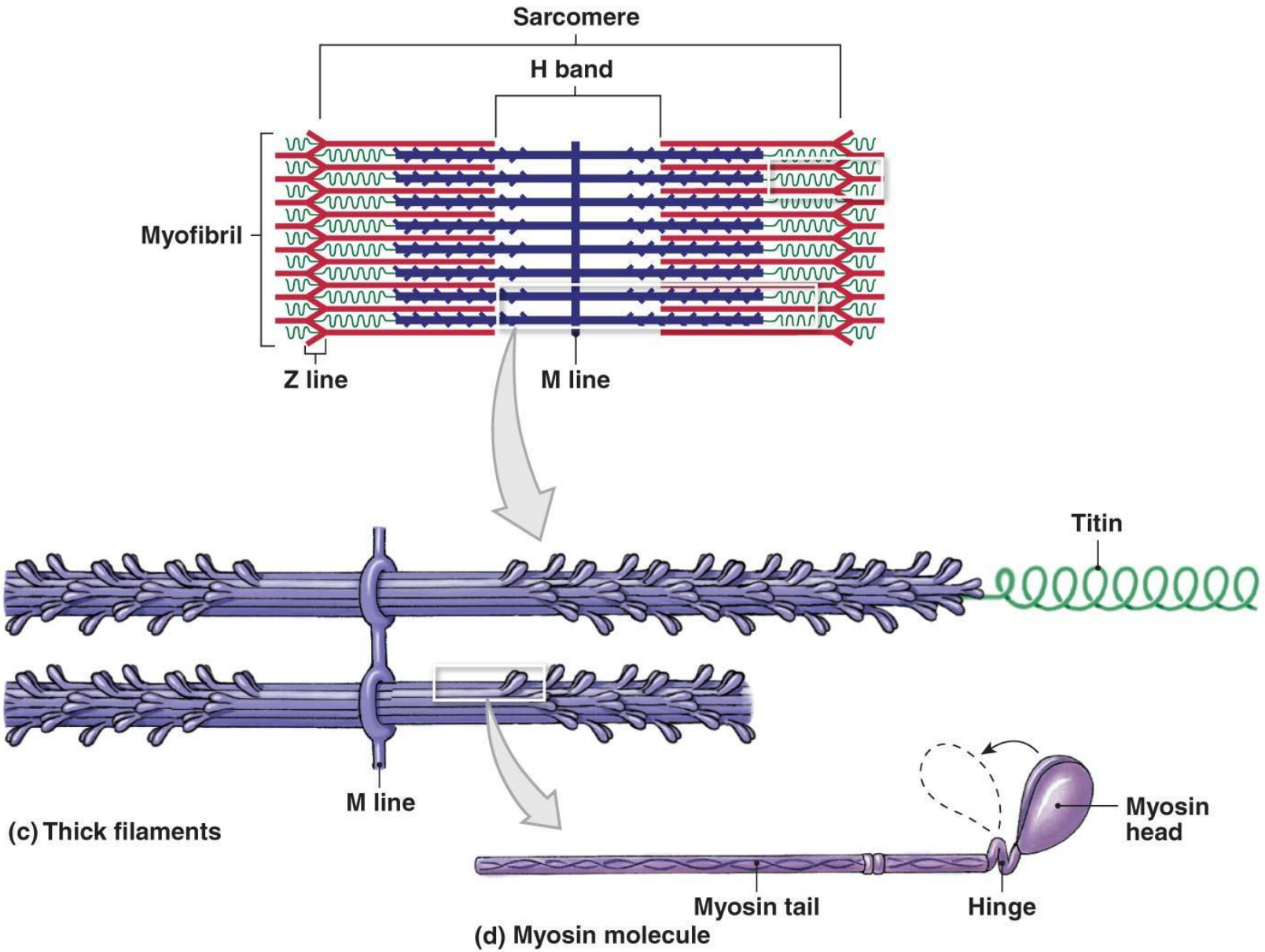
# Skeletal Muscle Fiber

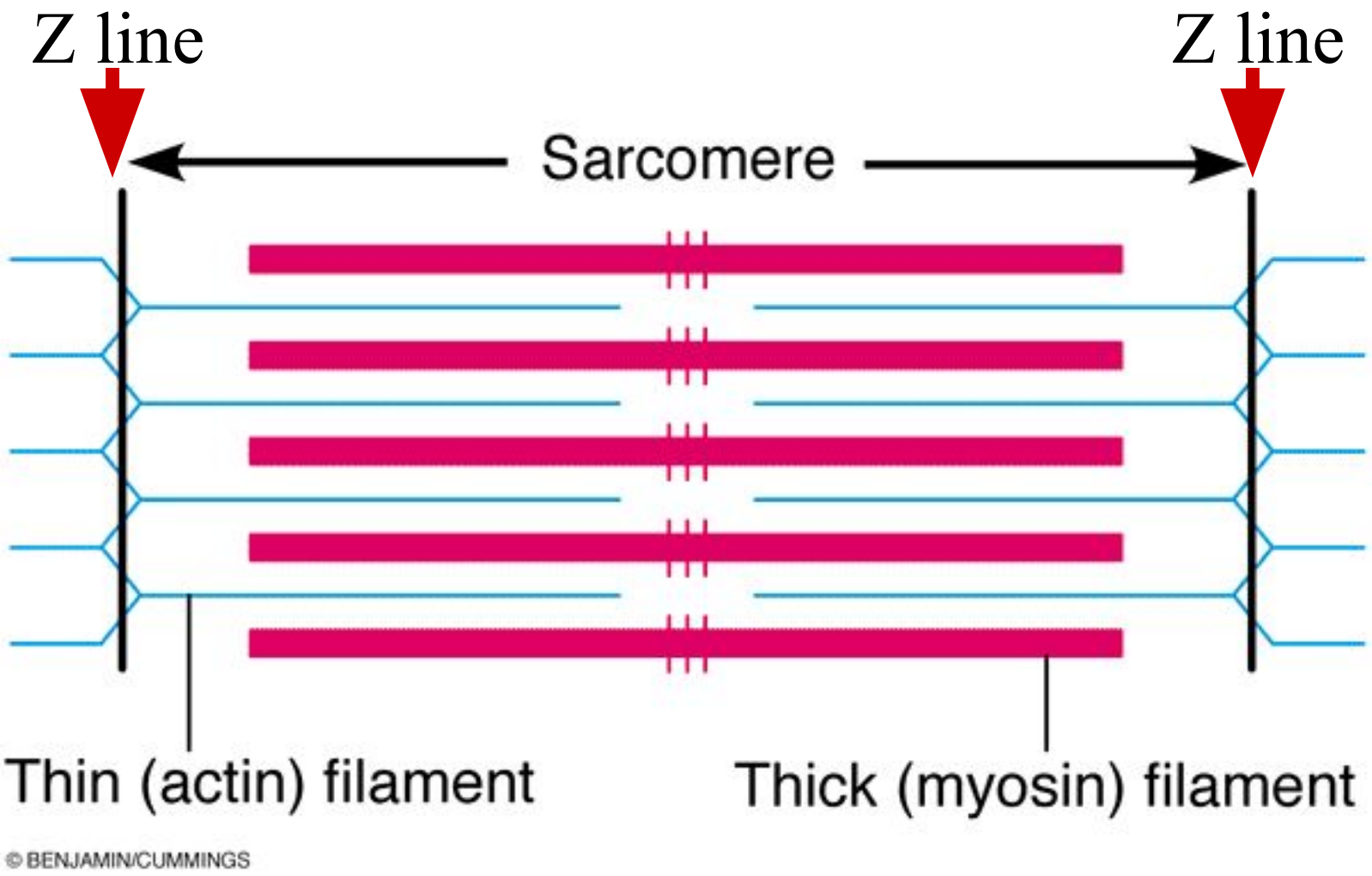


# Sarcomere

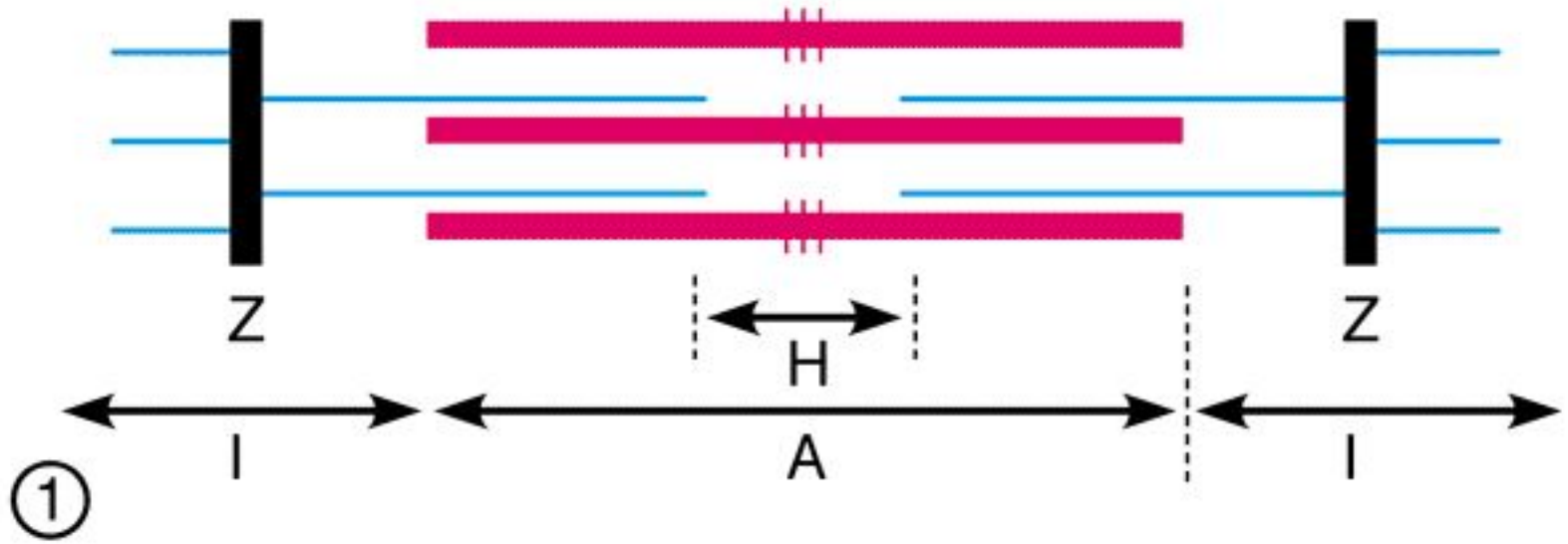

I band
A band
H band
Z line
Titin
(a)
Zone of overlap
M line
Thin filament
Thick filament
Sarcomere


Sarcomere
H band
Myofibril
Z line
M line
Actinin
Z line
Titin
(a) Z line and thin filaments
Troponin
Active site
Nebulin
Tropomyosin
G-actin molecules
F-actin strand
(b) Thin filament

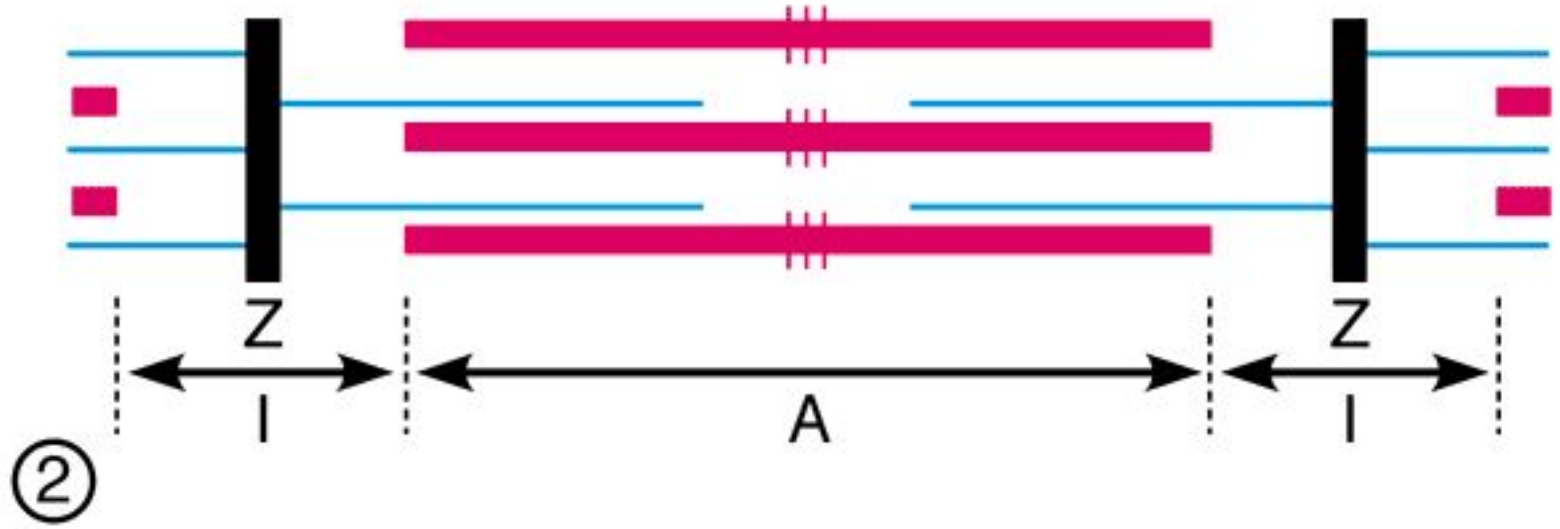

Sarcomere
H band
Myofibril
Z line
M line
Titin
M line
(c) Thick filaments
Myosin head
Myosin tail
Hinge
(d) Myosin molecule


Z line
Z line
Sarcomere
Thin (actin) filament
Thick (myosin) filament
© BENJAMIN/CUMMINGS

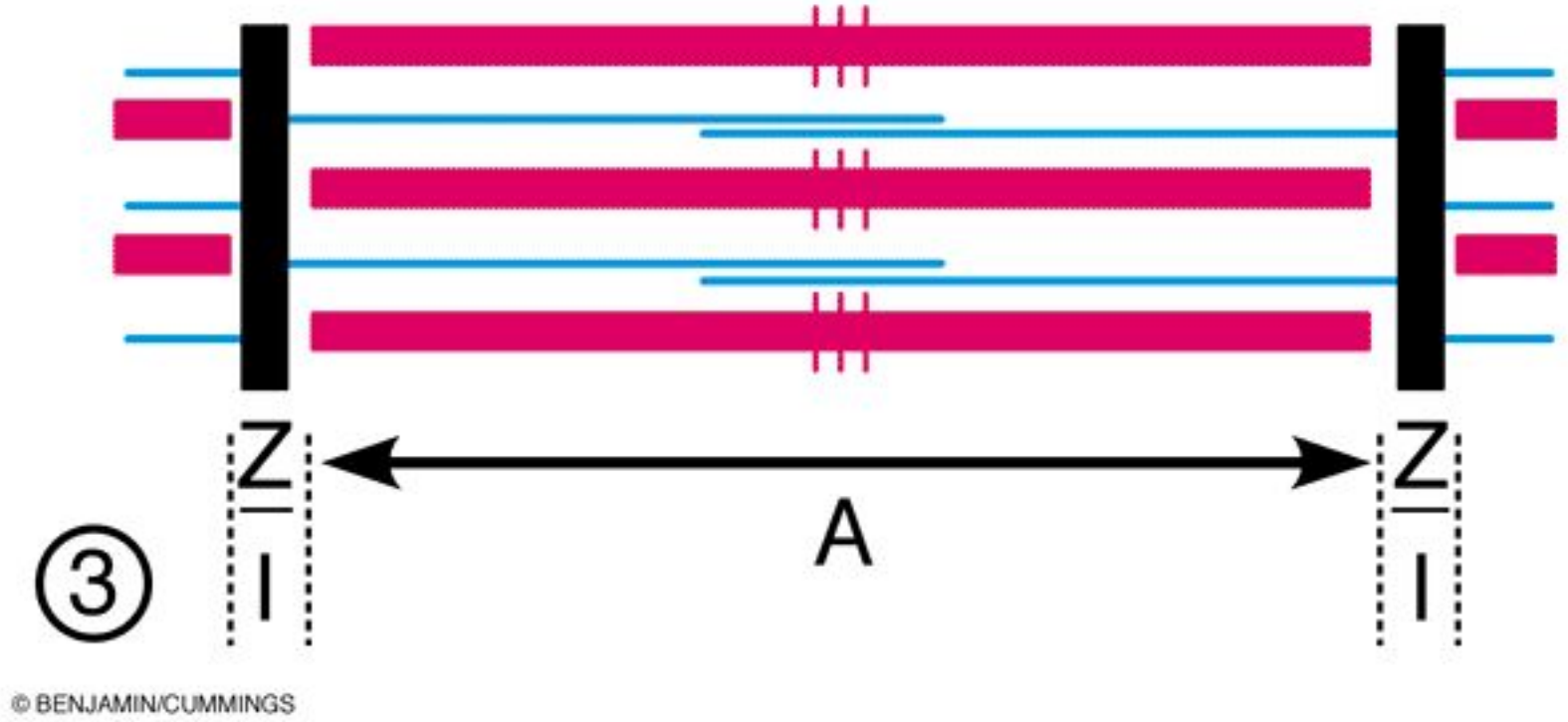
# Sarcomere Relaxed

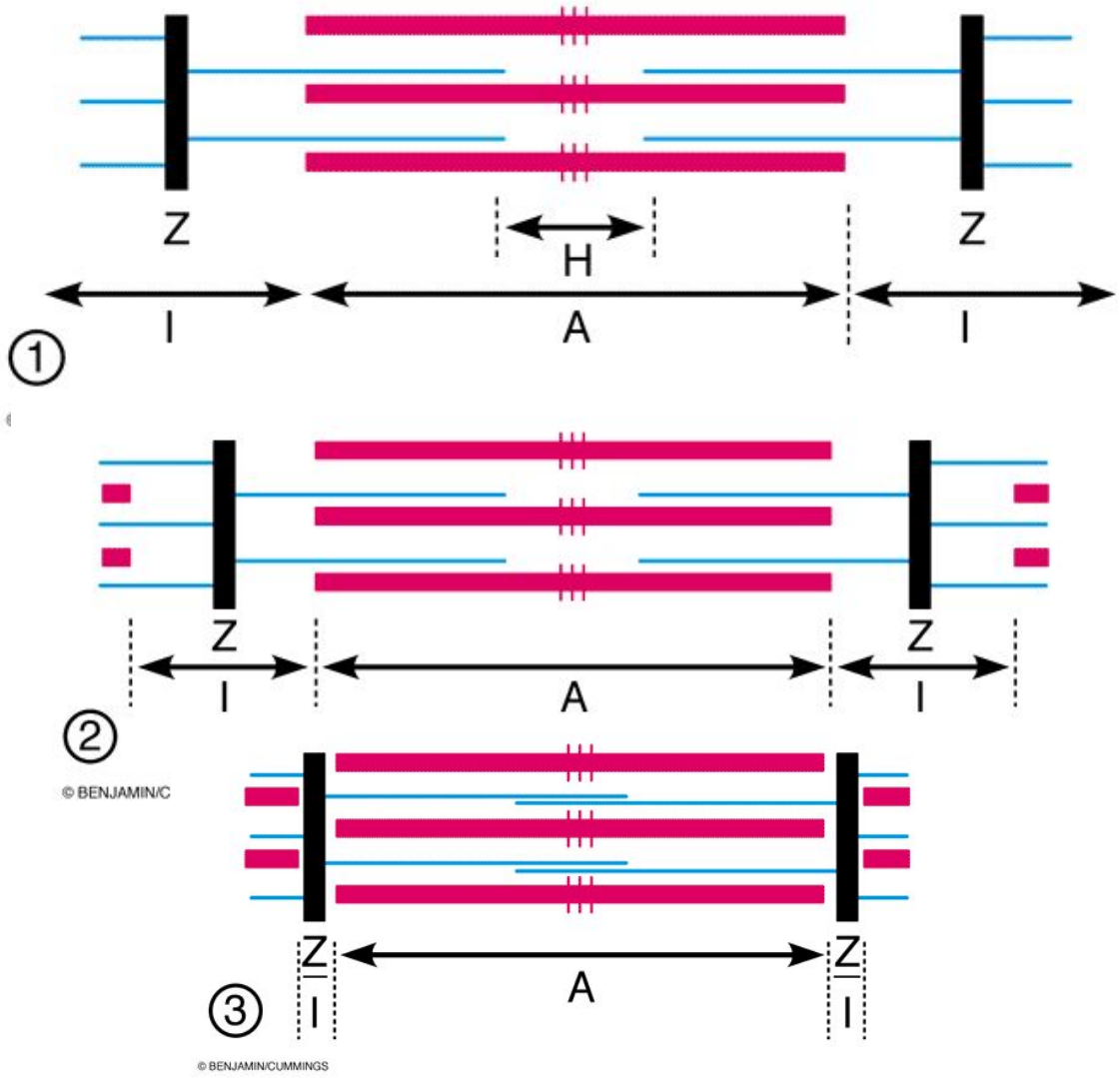


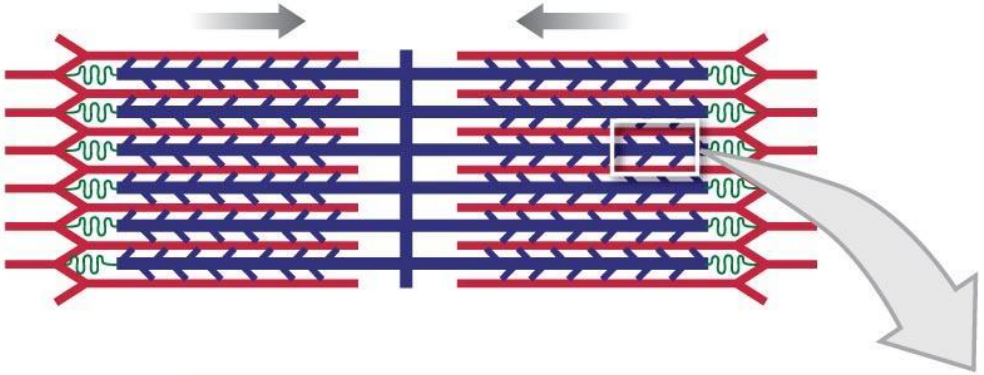
# Sarcomere Partially Contracted



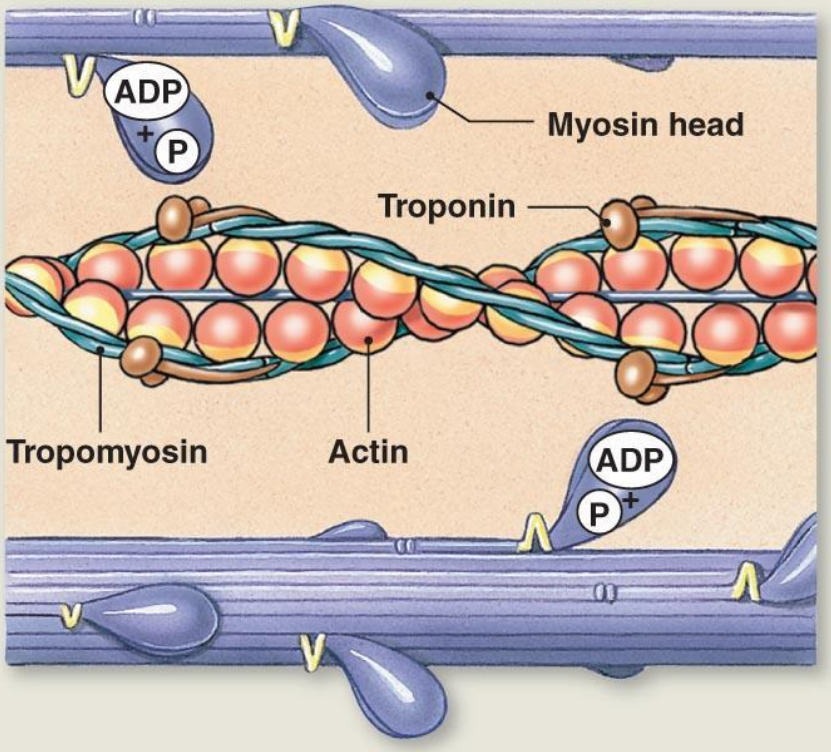
# Sarcomere Completely Contracted



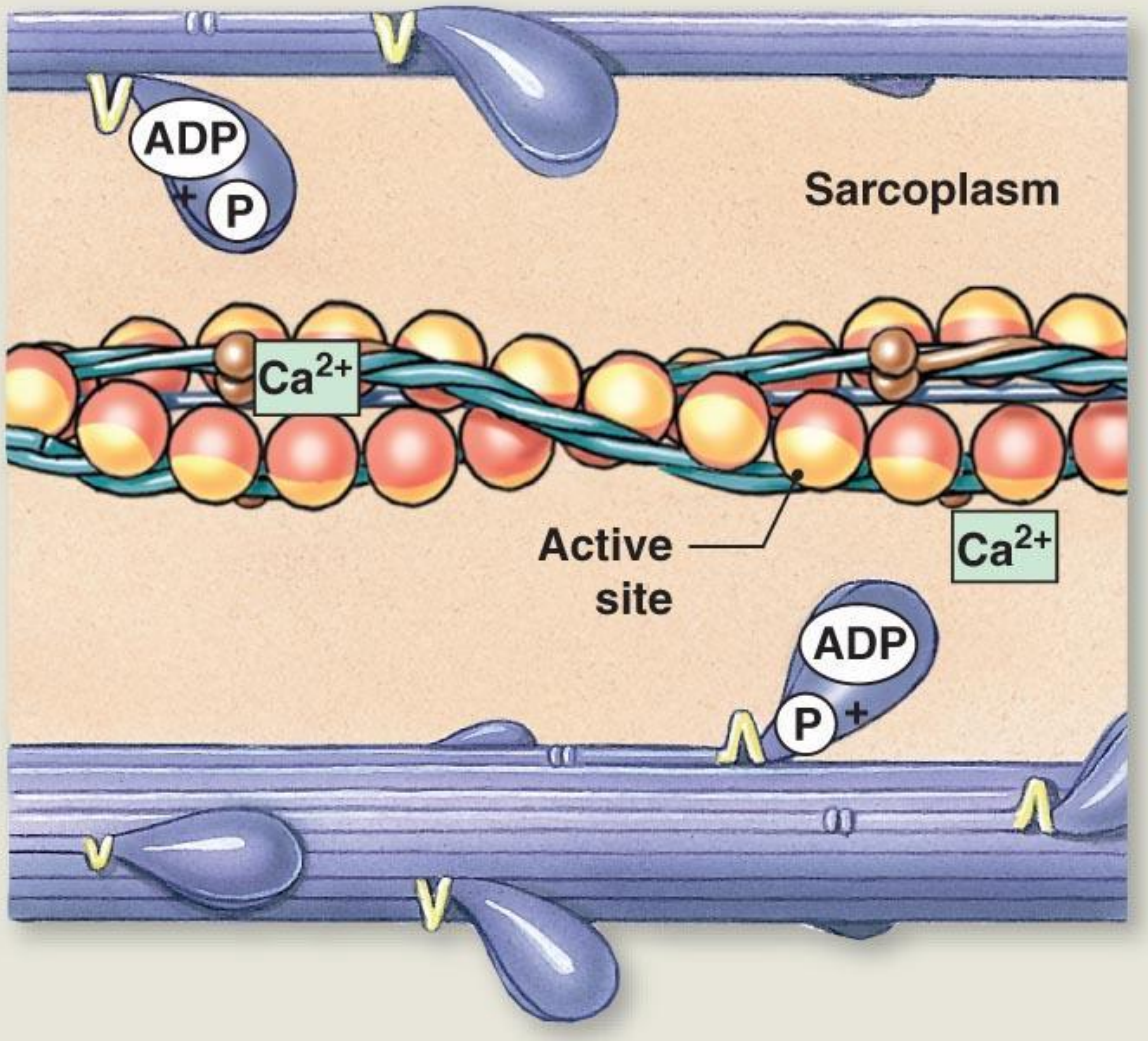

Z
H
Z
I
A
I
①
Z
Z
I
A
I
②
© BENJAMIN/C
Z
A
Z
I
I
③
© BENJAMIN/CUMMINGS



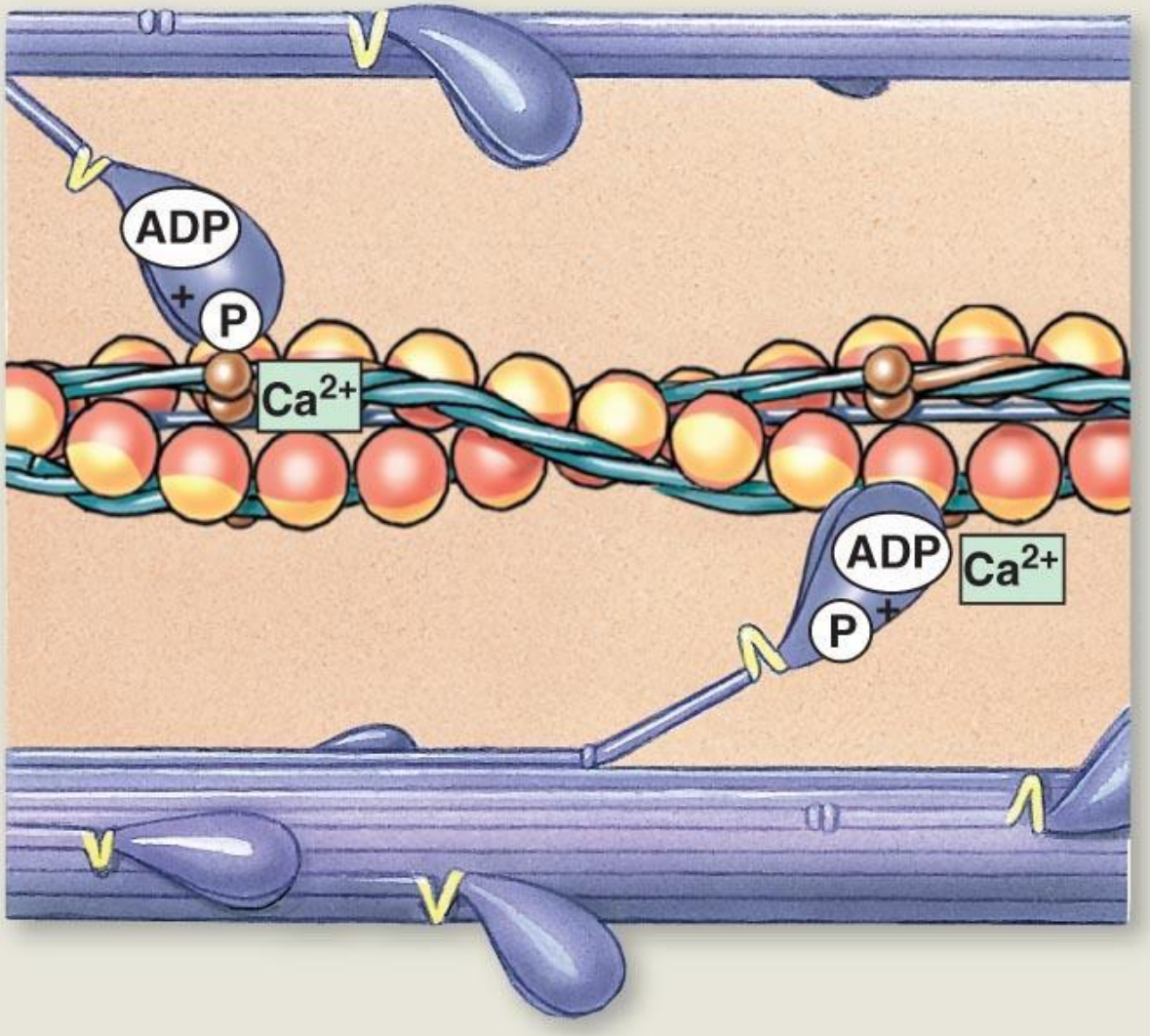
## RESTING SARCOMERE



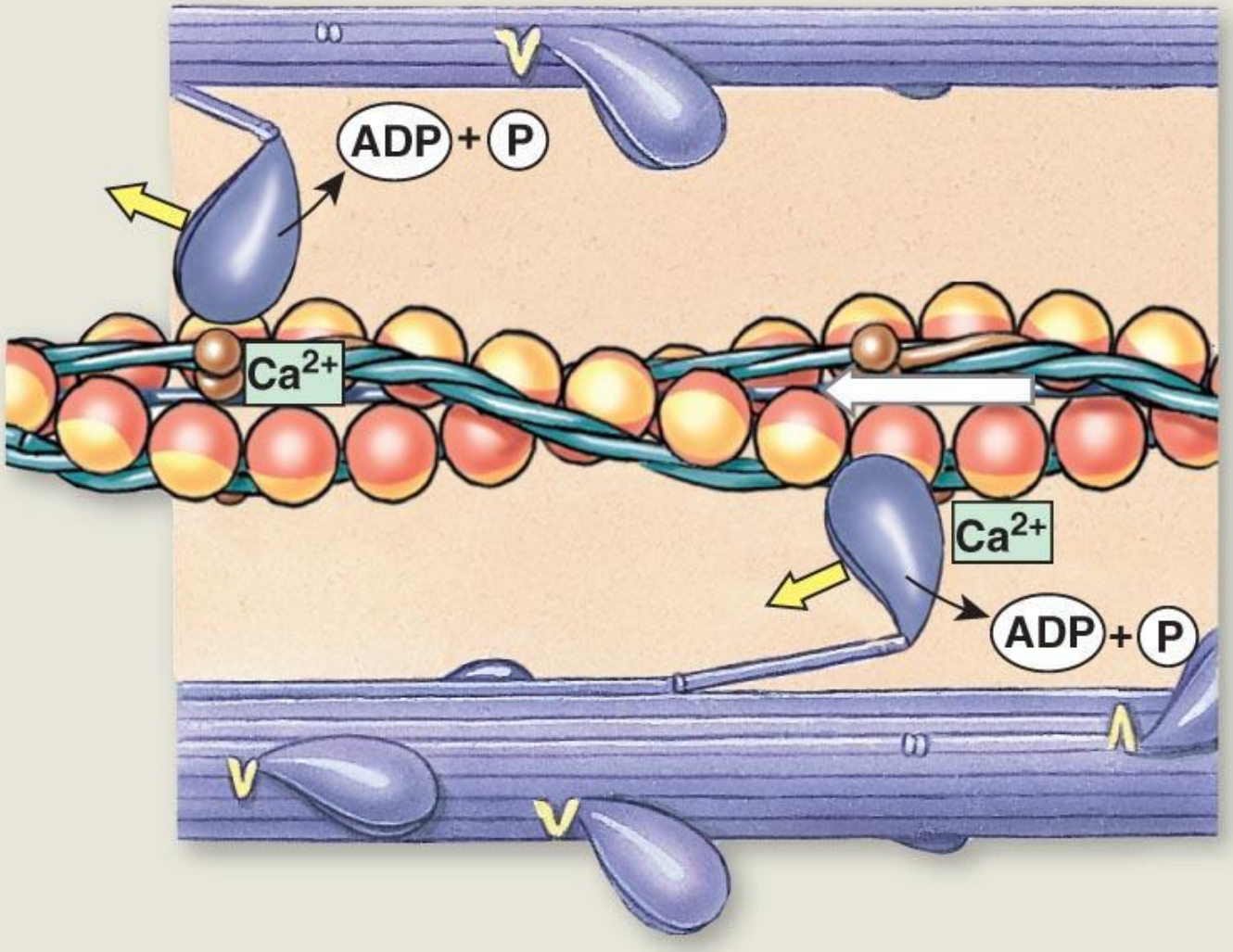
## STEP 1 ACTIVE-SITE EXPOSURE



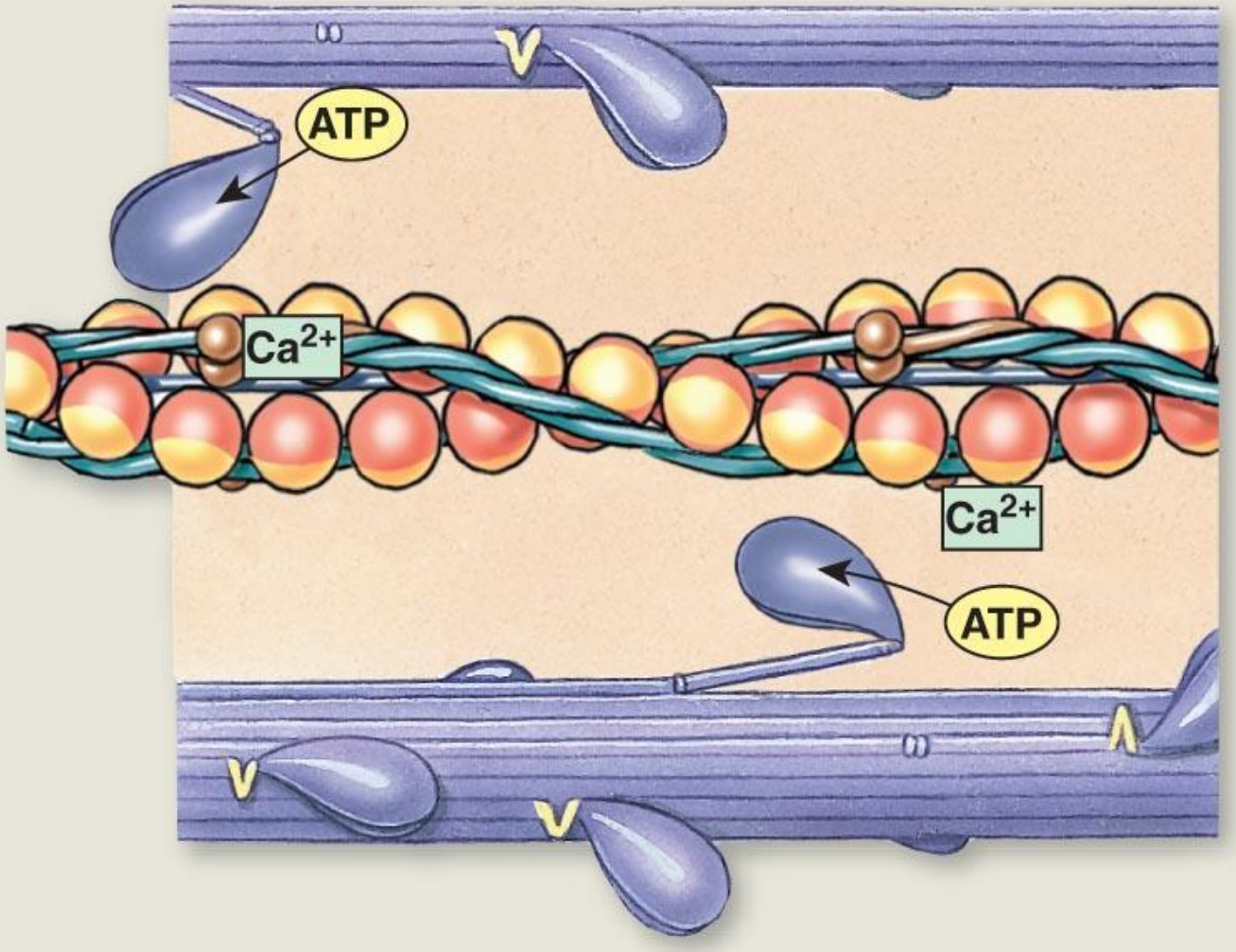
# STEP 2 CROSS-BRIDGE FORMATION



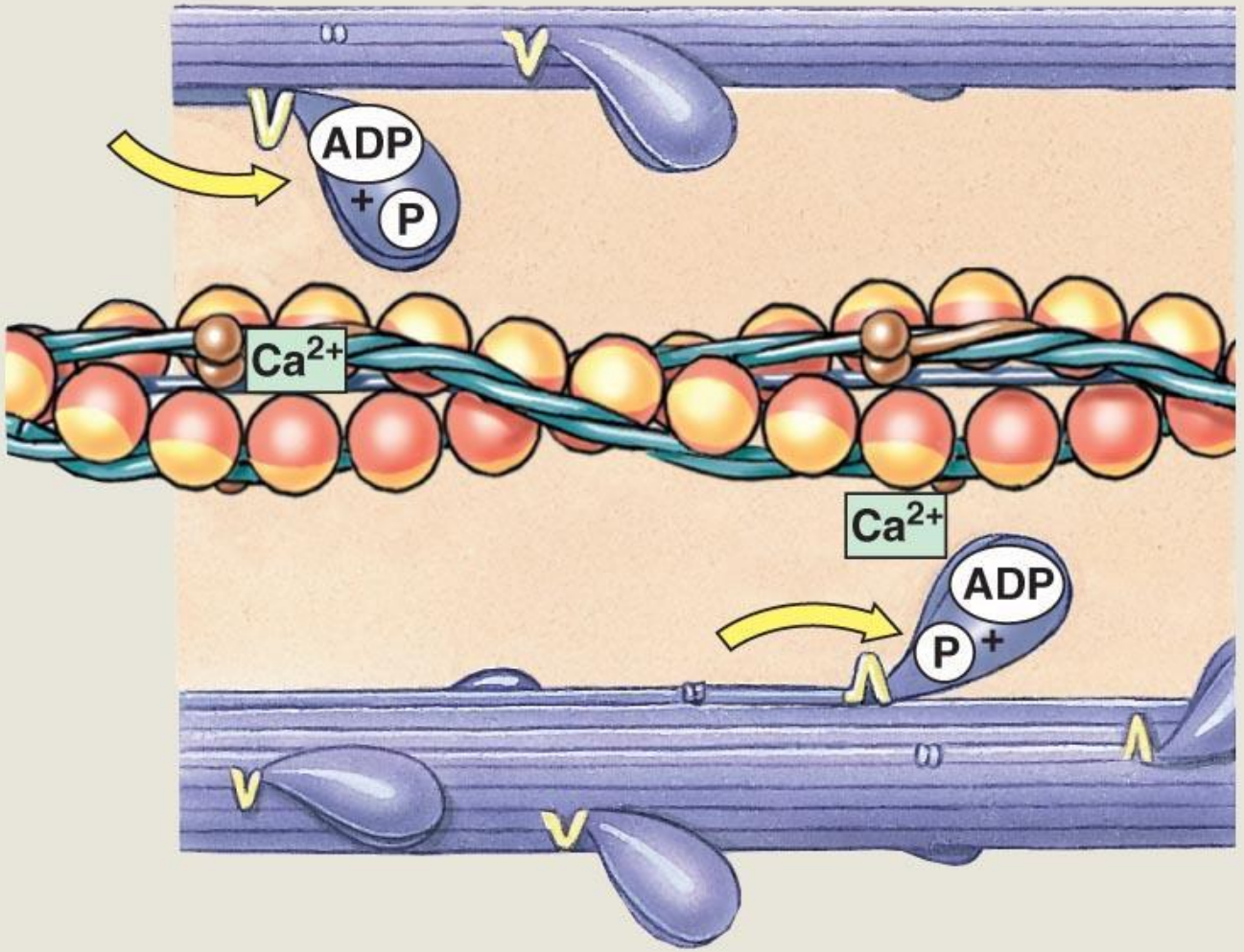
# STEP 3 PIVOTING OF MYOSIN HEAD

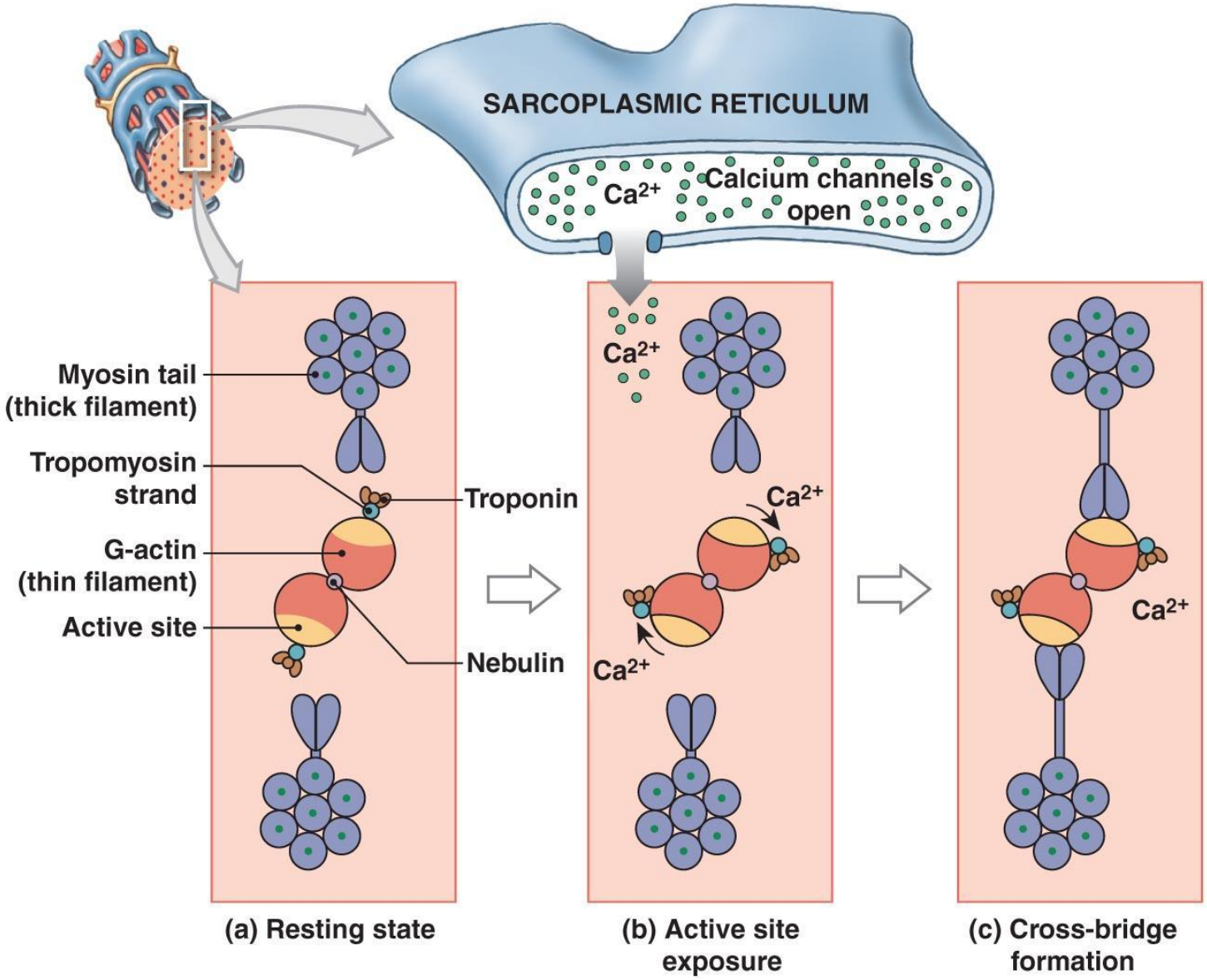


# STEP 4 CROSS-BRIDGE DETACHMENT

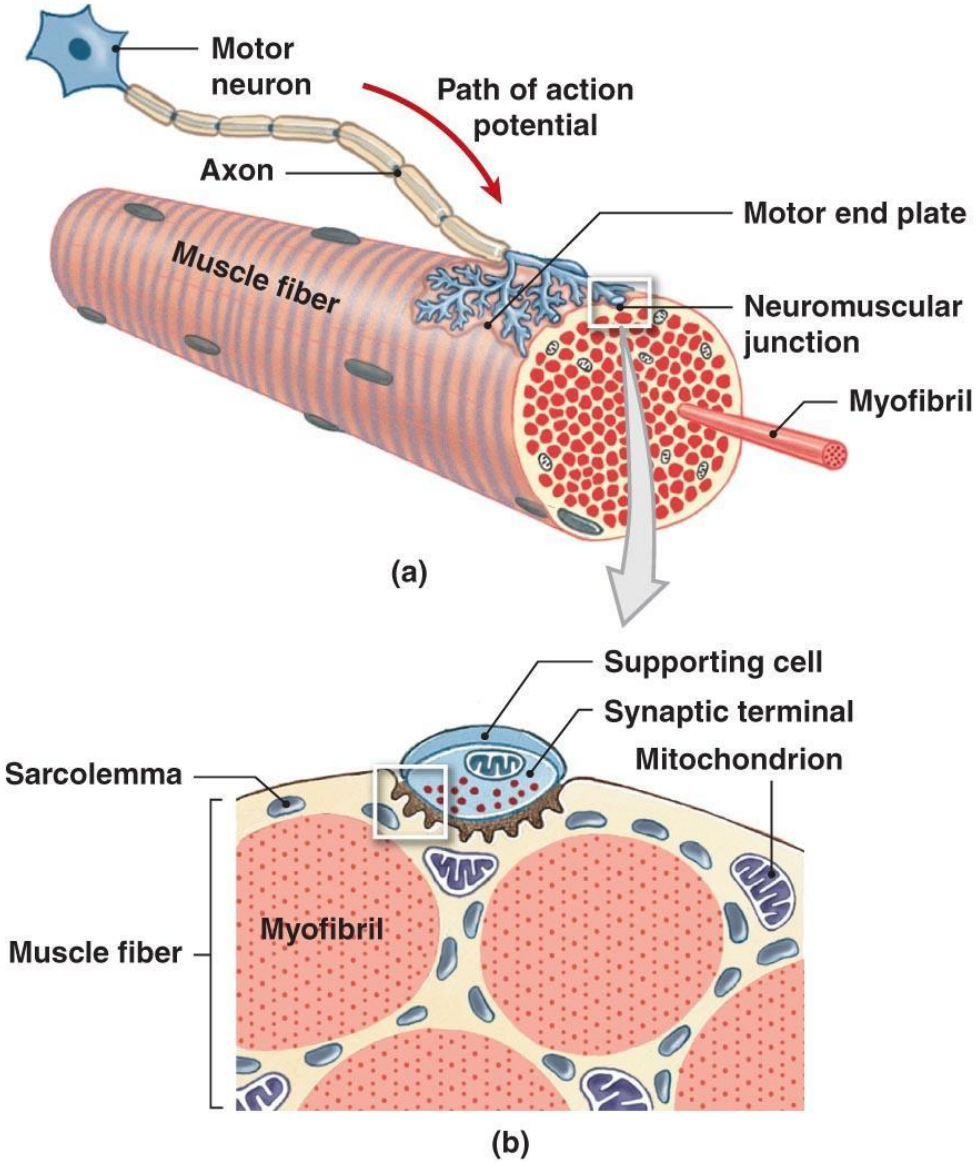


# STEP 5 MYOSIN REACTIVATION



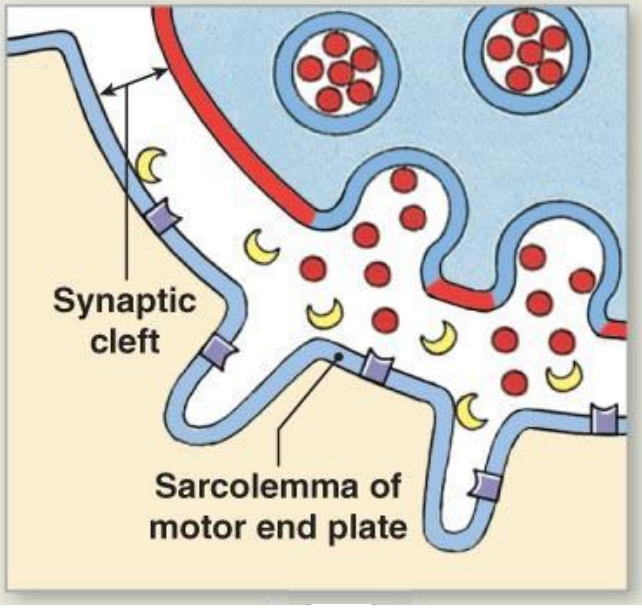

SARCOPLASMIC RETICULUM
Ca2+
Calcium channels open
Myosin tail (thick filament)
Tropomyosin strand
G-actin (thin filament)
Active site
Troponin
Nebulin
Ca2+
Ca2+
Ca2+
Ca2+
(a) Resting state
(b) Active site exposure
(c) Cross-bridge formation

# Neuromuscular Junction



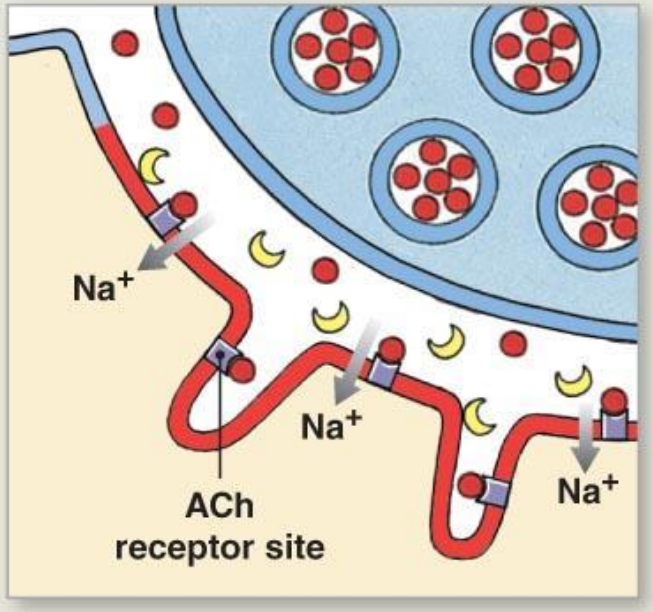
## STEP 2 Release of acetylcholine

Vesicles in the synaptic terminal fuse with the neuronal membrane and dump their contents into the synaptic cleft.



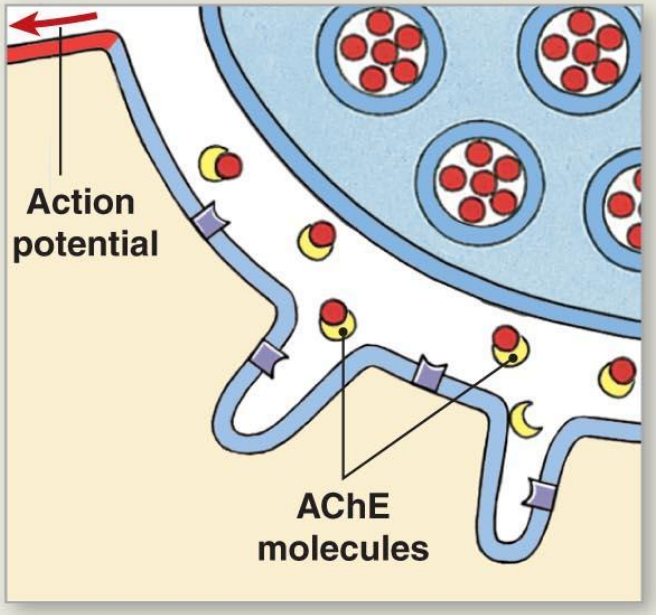

## STEP 3 ACh binding at the motor end plate

The binding of ACh to the receptors increases the membrane permeability to sodium ions. Sodium ions then rush into the cell.



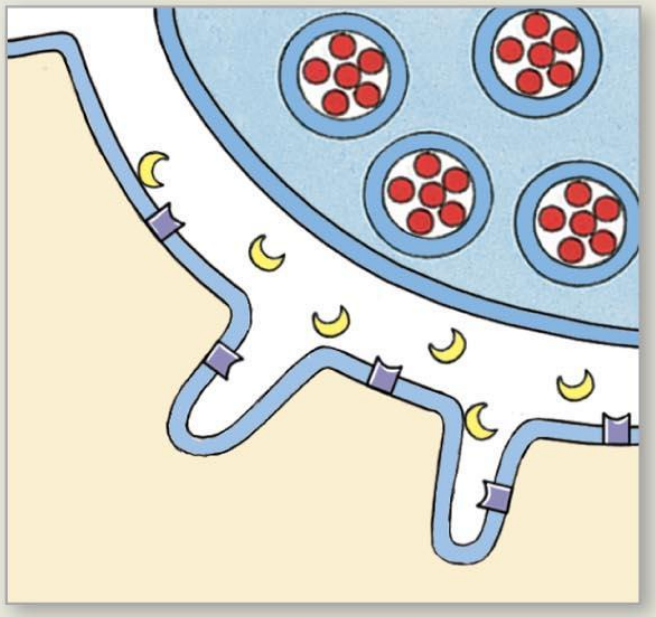
## STEP 4 Appearance of an action potential in the sarcolemma

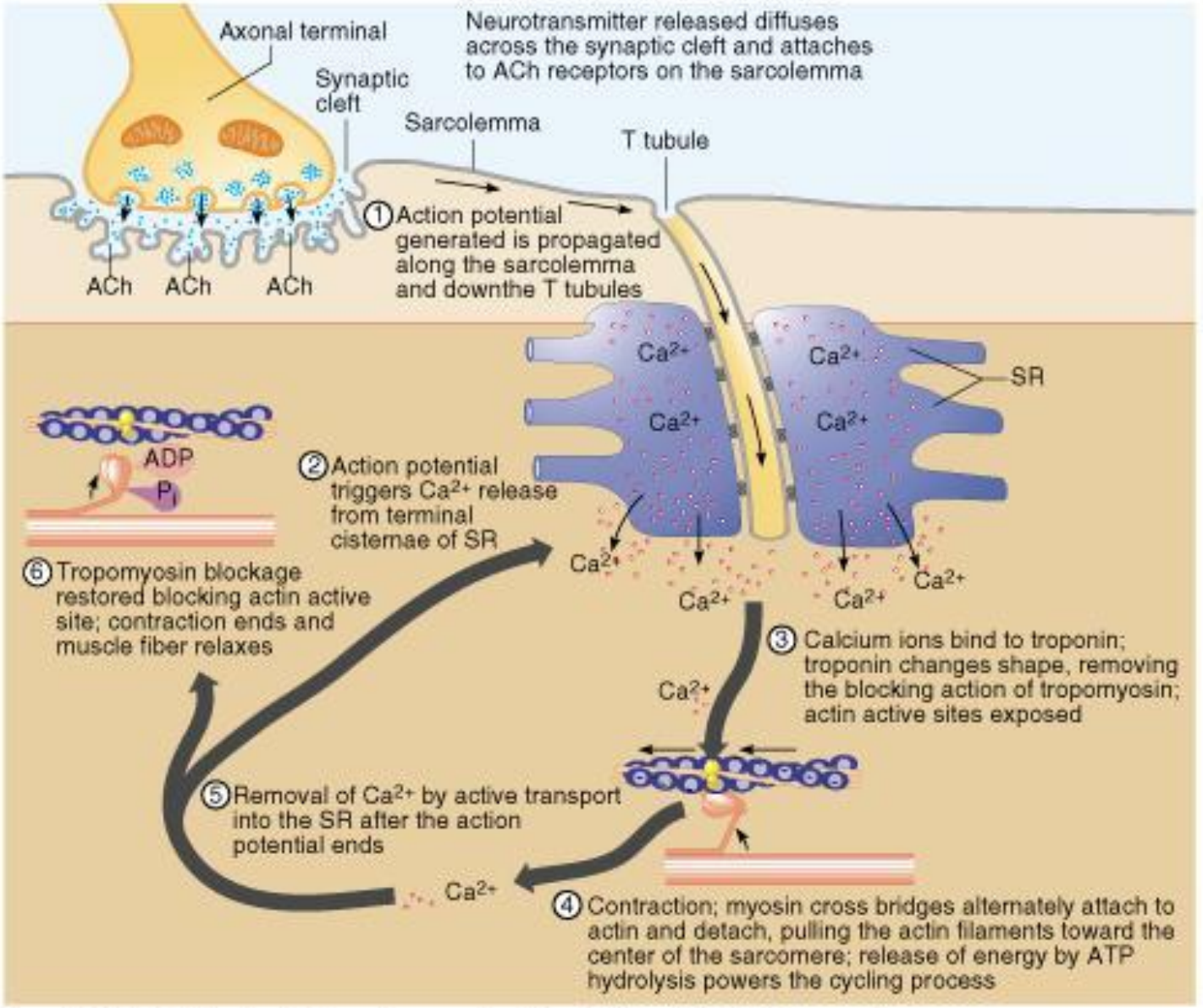
An action potential spreads across the surface of the sarcolemma. While this occurs, AChE breaks down the ACh.



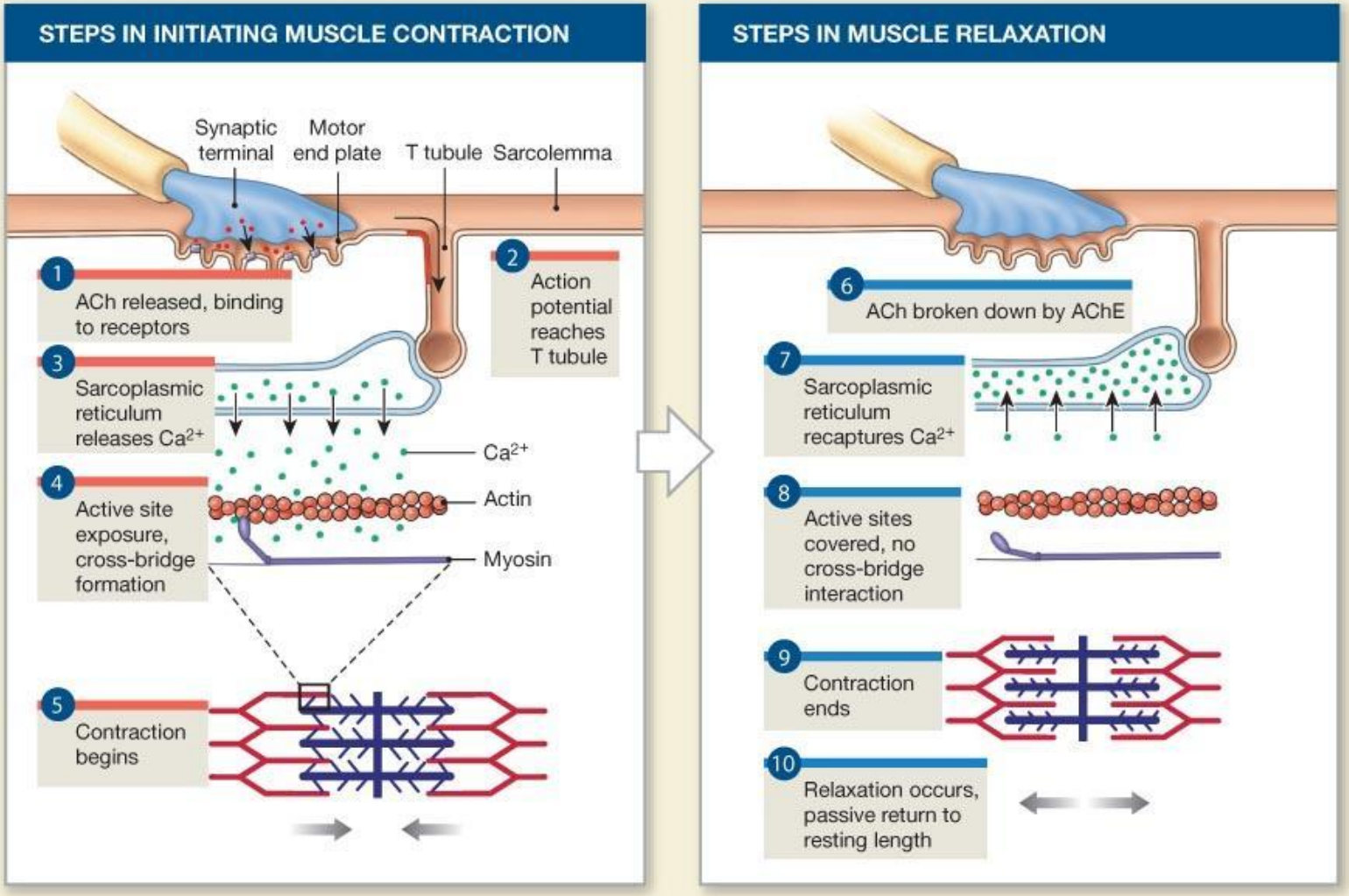

## STEP 5 Return to initial state

If another action potential arrives at the NMJ, the cycle begins again at step 1.





## SUMMARY TABLE 10–1 Steps Involved In Skeletal Muscle Contraction



# Single Fiber Tension

The all–or–none principle

As a whole, a muscle fiber is either contracted or relaxed

Tension of a Single Muscle Fiber

Depends on

The number of pivoting cross-bridges

The fiber's resting length at the time of stimulation

The frequency of stimulation

Length–tension relationship

-Number of pivoting cross-bridges depends on:

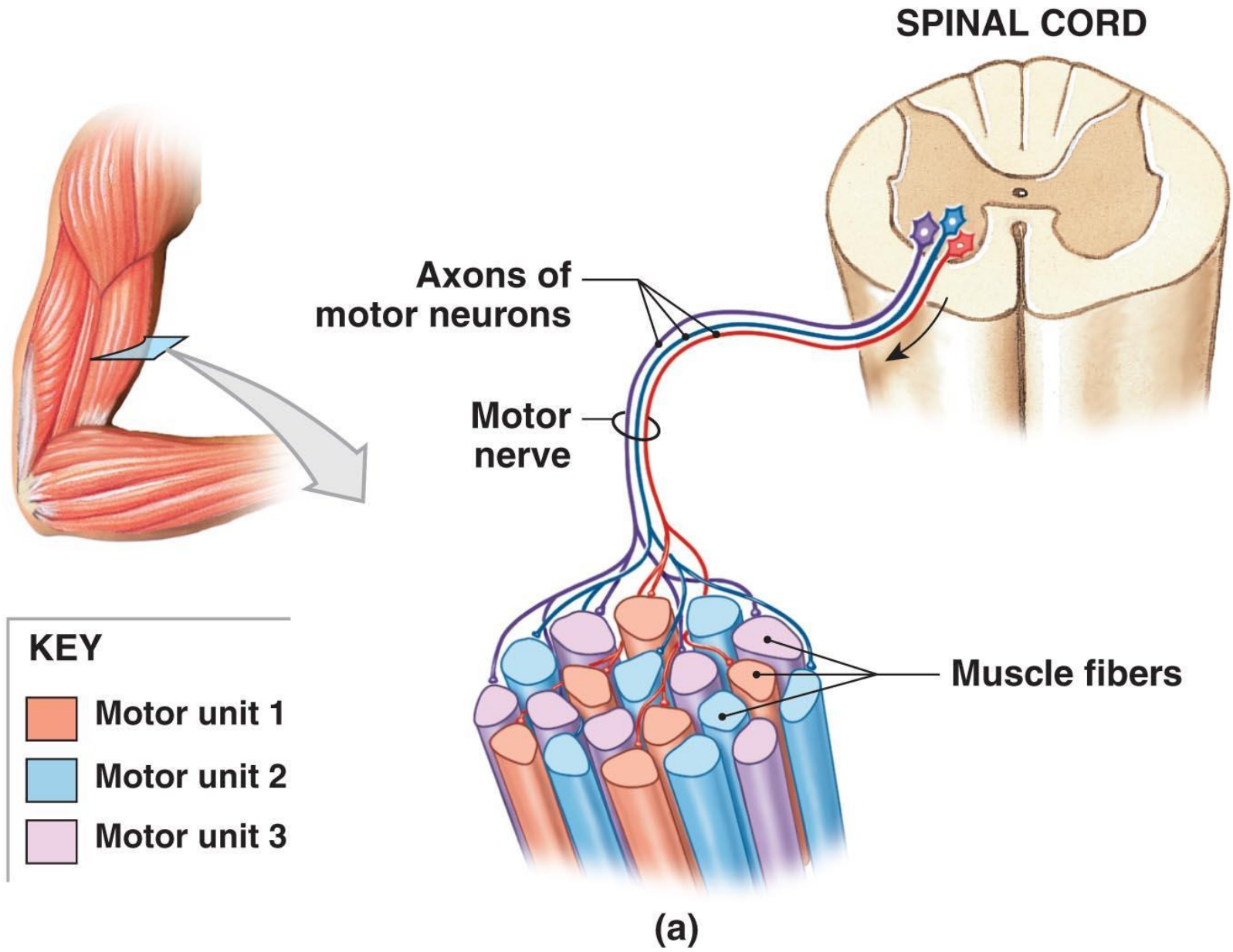
amount of overlap between thick and thin fibers

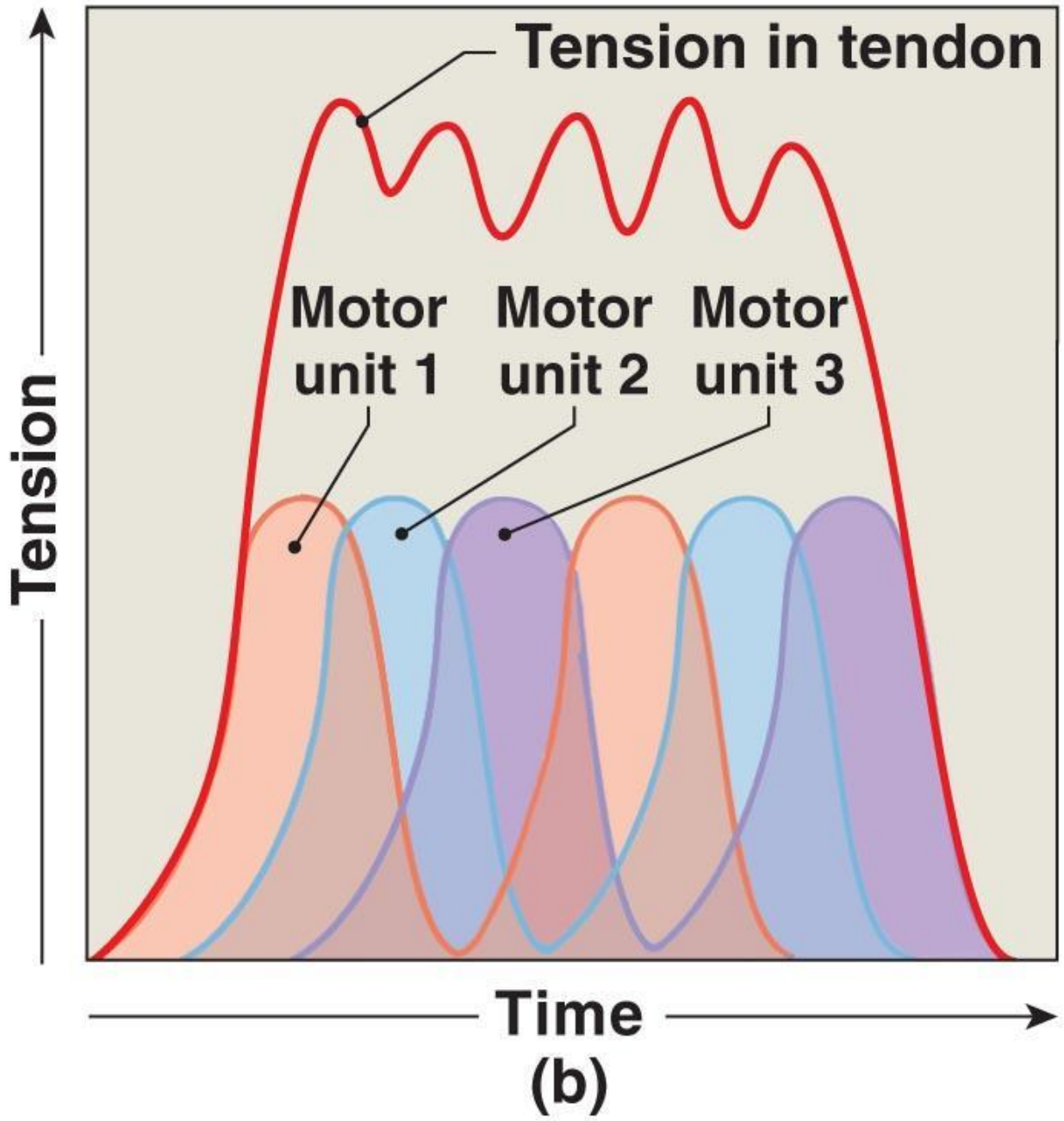
-Optimum overlap produces greatest amount of tension:

too much or too little reduces efficiency

-Normal resting sarcomere length:

is 75% to 130% of optimal length


SPINAL CORD
Axons of motor neurons
Motor nerve
Muscle fibers
KEY
Motor unit 1
Motor unit 2
Motor unit 3
(a)


Tension in tendon
Motor unit 1
Motor unit 2
Motor unit 3
Tension
Time

(b)

# Muscle Contraction Types

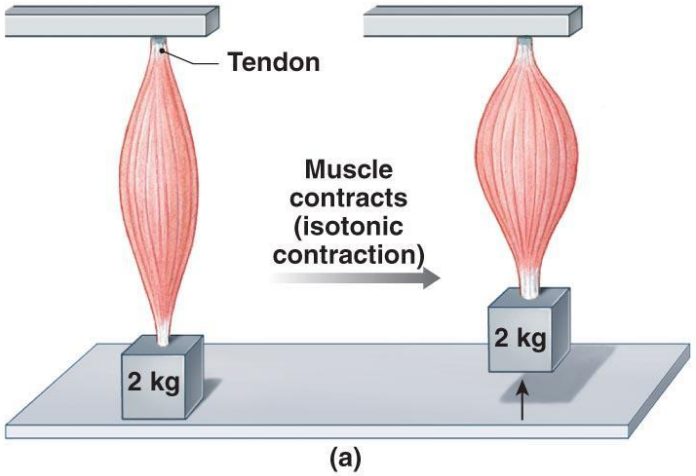
Isotonic contraction

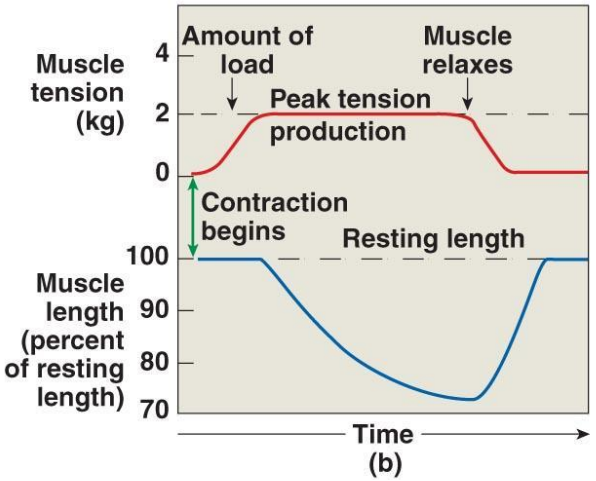
Isometric contraction

# Muscle Contraction Types

Isotonic contraction

Isometric contraction

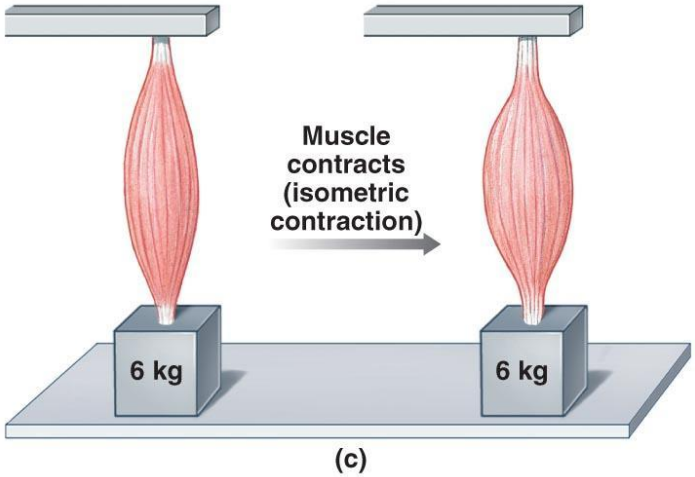


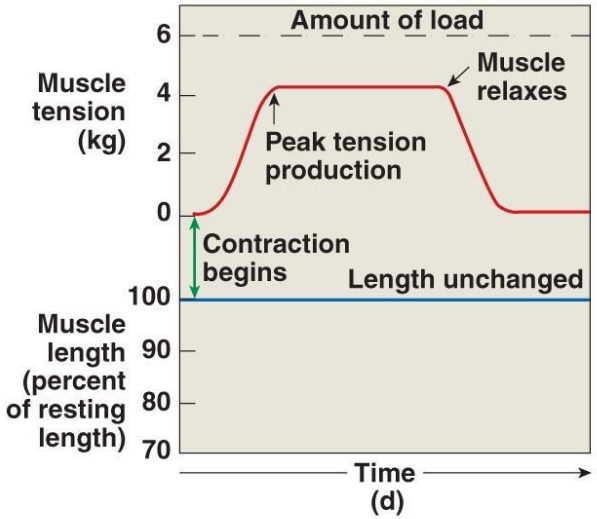
# Muscle Contraction Types

Isotonic contraction

Isometric contraction

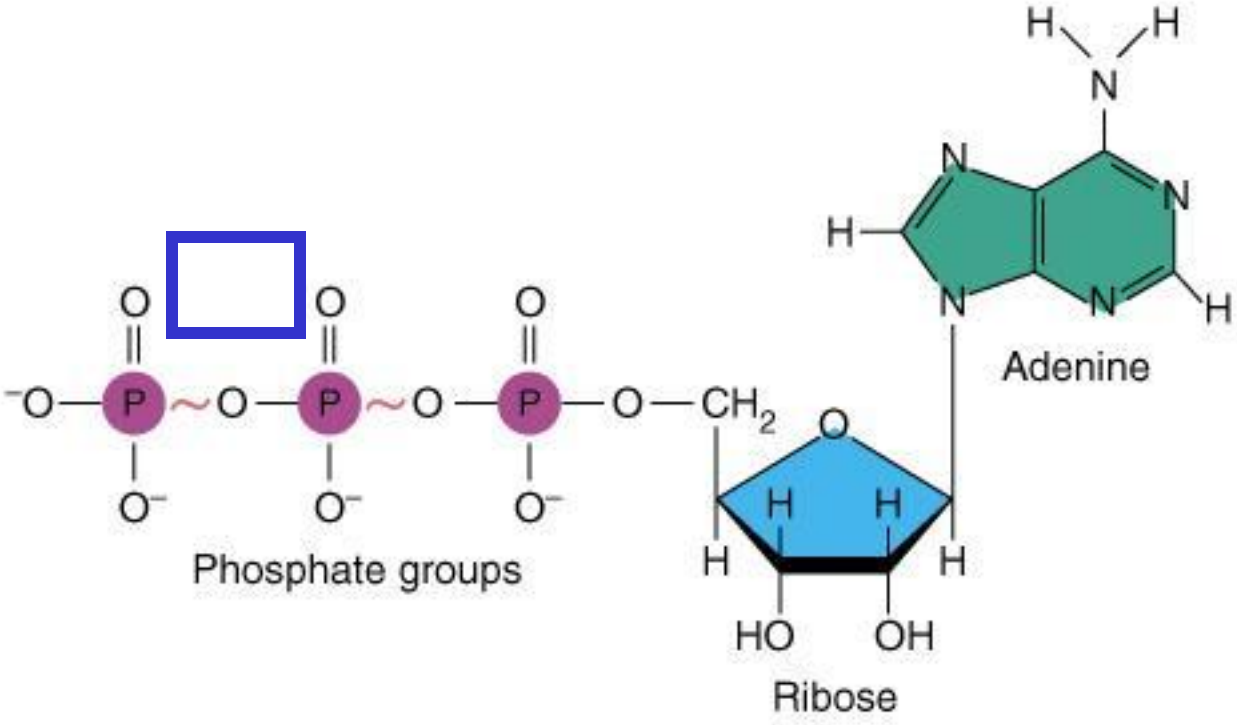



(c)



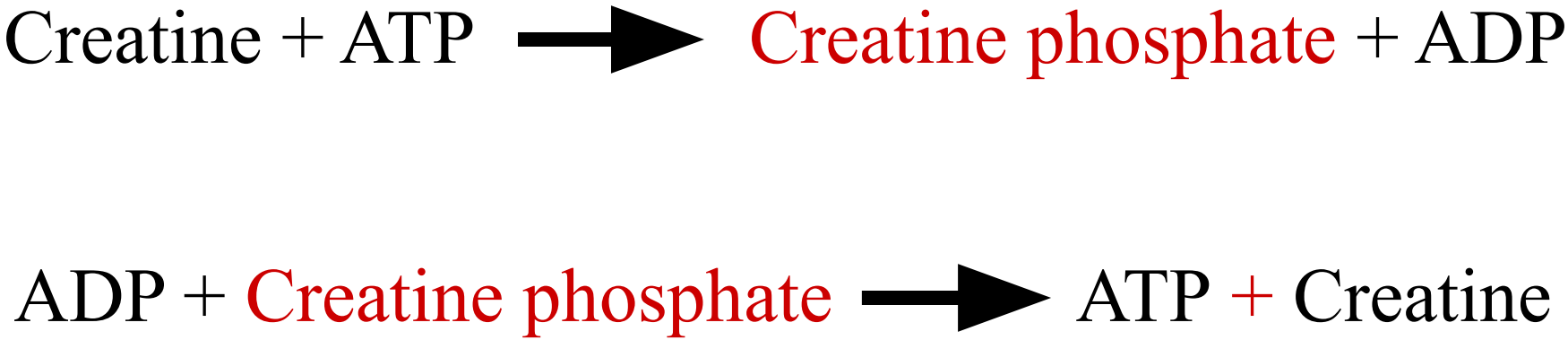

(d)

# ATP as Energy Source



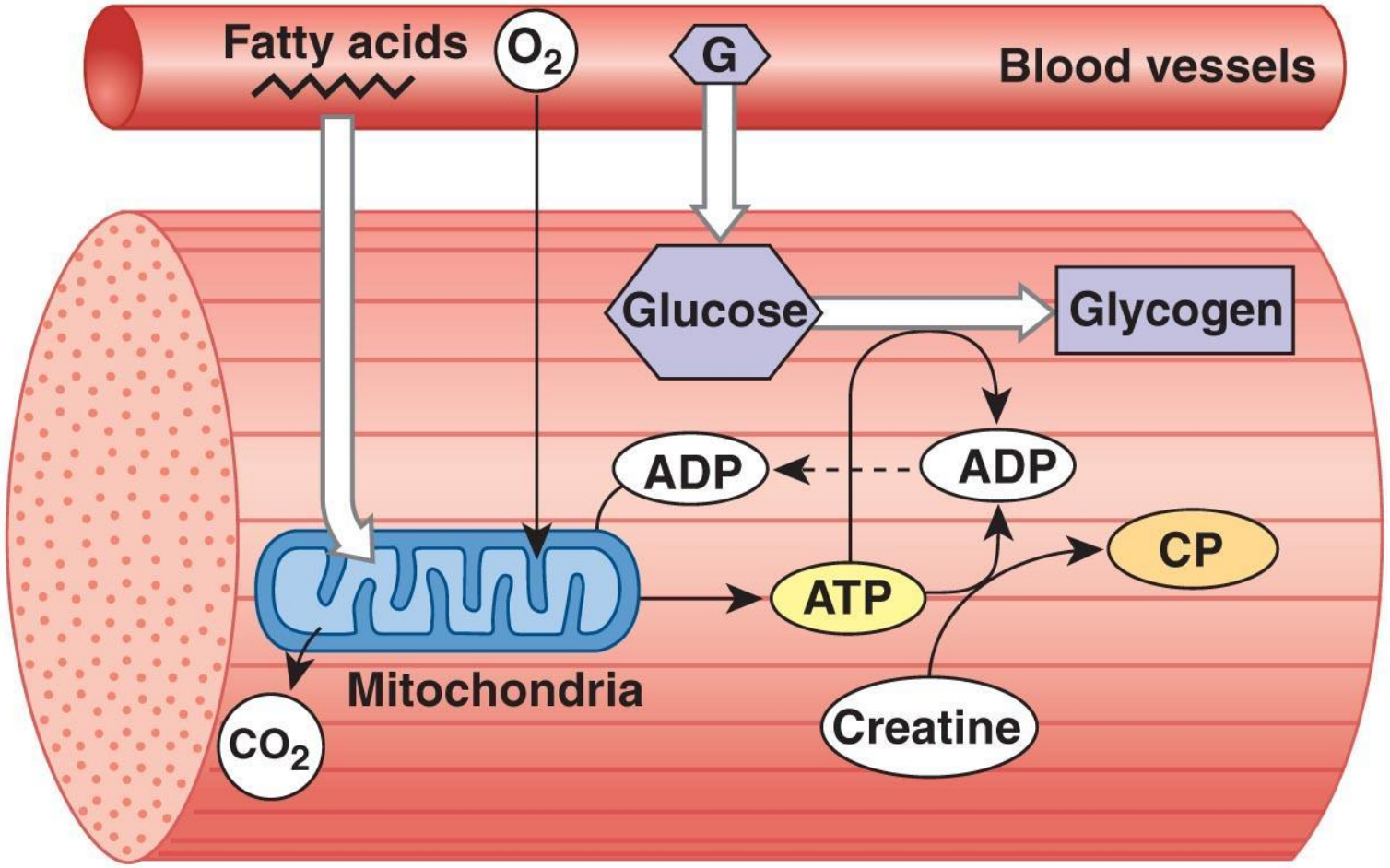
# Creatine

Molecule capable of storing ATP energy

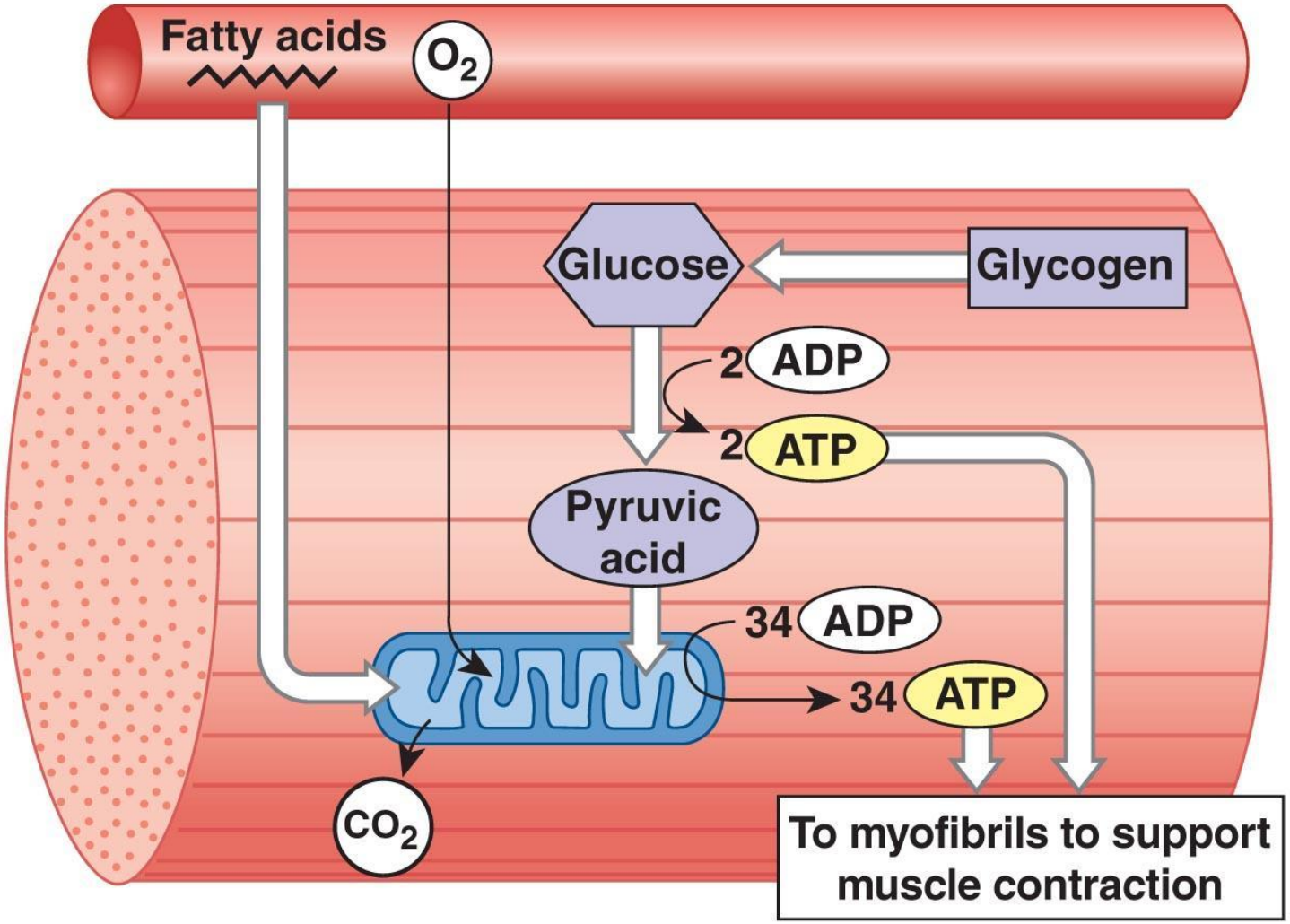


# Metabolism

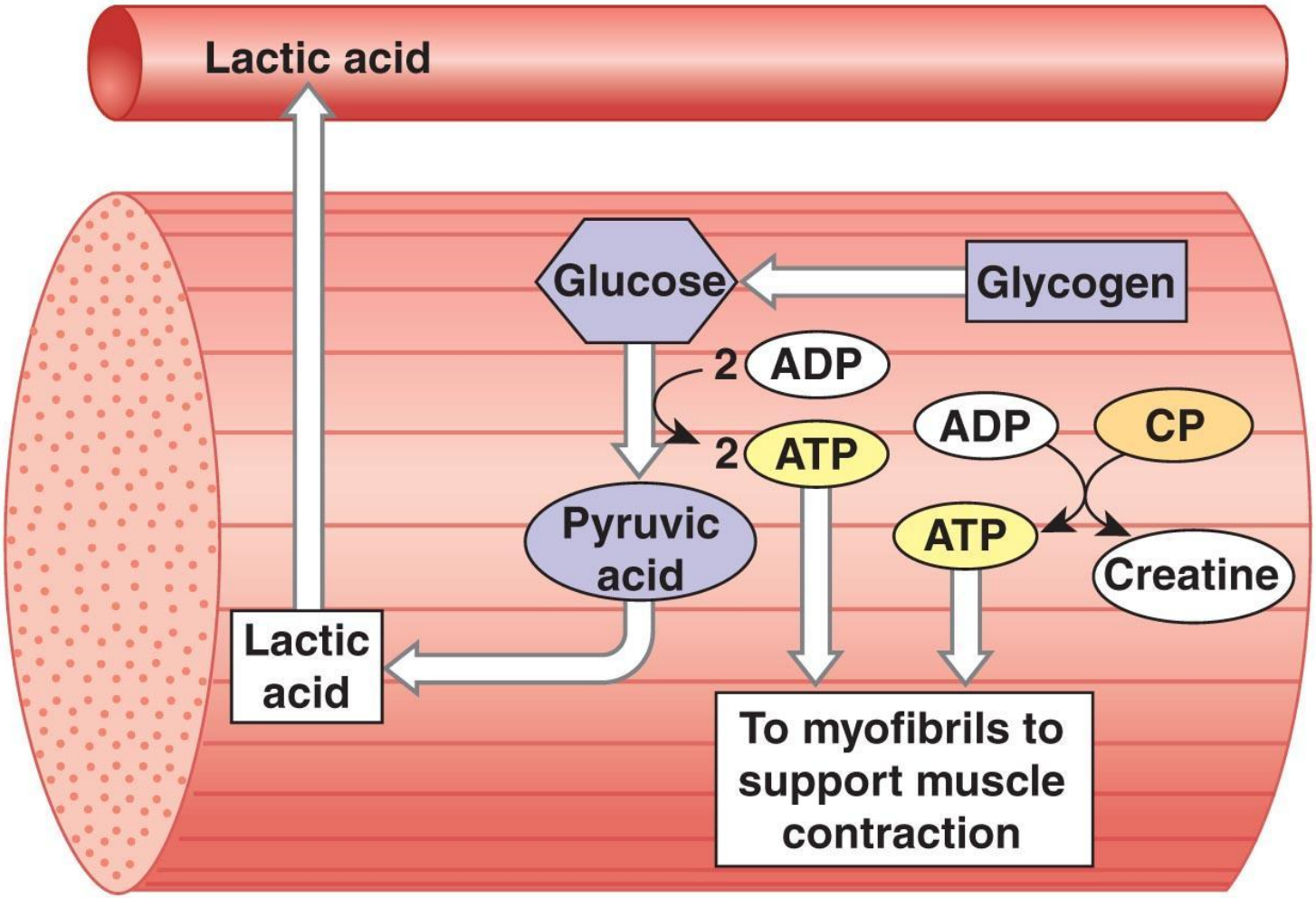
- Aerobic metabolism
  - 95% of cell demand
  - Kreb's cycle
  - 1 pyruvic acid molecule  17 ATP
- Anaerobic metabolism
  - Glycolysis  2 pyruvic acids + 2 ATP
  - Provides substrates for aerobic metabolism
  - As pyruvic acid builds converted to lactic acid




(a) Resting muscle: Fatty acids are catabolized; the ATP produced is used to build energy reserves of ATP, CP, and glycogen.




(b) Moderate activity: Glucose and fatty acids are catabolized; the ATP produced is used to power contraction.




(c) Peak activity: Most ATP is produced through glycolysis, with lactic acid as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.

# Muscle Fatigue

- **Muscle Fatigue**
  - When muscles can no longer perform a required activity, they are **fatigued**
- **Results of Muscle Fatigue**
  - Depletion of metabolic reserves
  - Damage to sarcolemma and sarcoplasmic reticulum
  - Low pH (lactic acid)
  - Muscle exhaustion and pain

# Muscle Hypertrophy

- Muscle growth from heavy training
  - Increases diameter of muscle fibers
  - Increases number of myofibrils
  - Increases mitochondria, glycogen reserves

# Muscle Atrophy

- Lack of muscle activity
  - Reduces muscle size, tone, and power

# Steroid Hormones

- Stimulate muscle growth and hypertrophy
  - Growth hormone
  - Testosterone
  - Thyroid hormones
  - Epinephrine

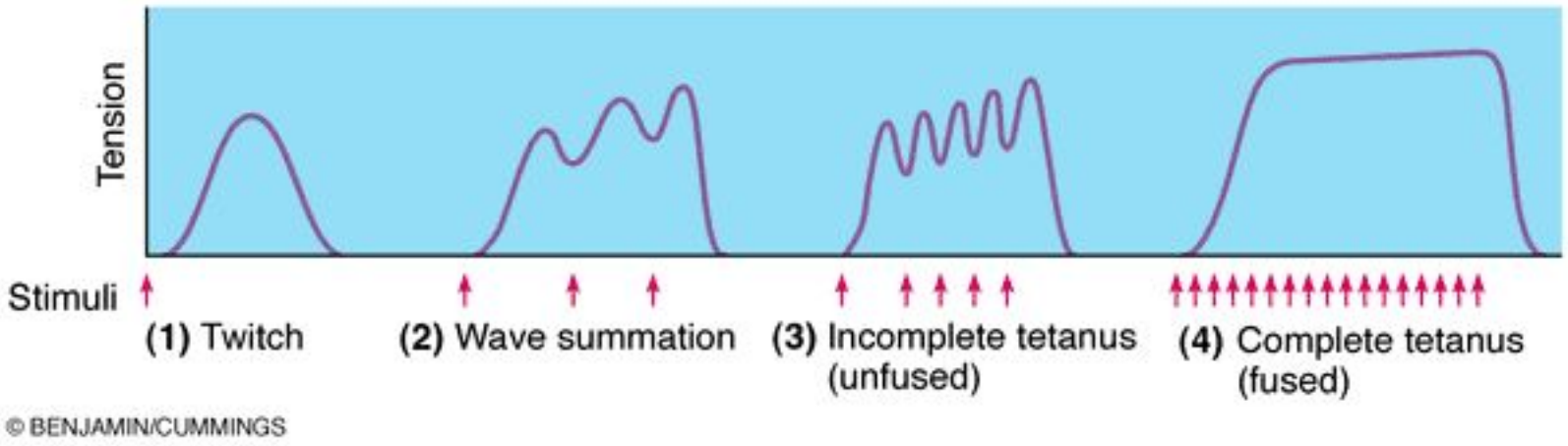
# Muscle Tonus

- Tightness of a muscle
- Some fibers always contracted

# Tetany

- Sustained contraction of a muscle
- Result of a rapid succession of nerve impulses

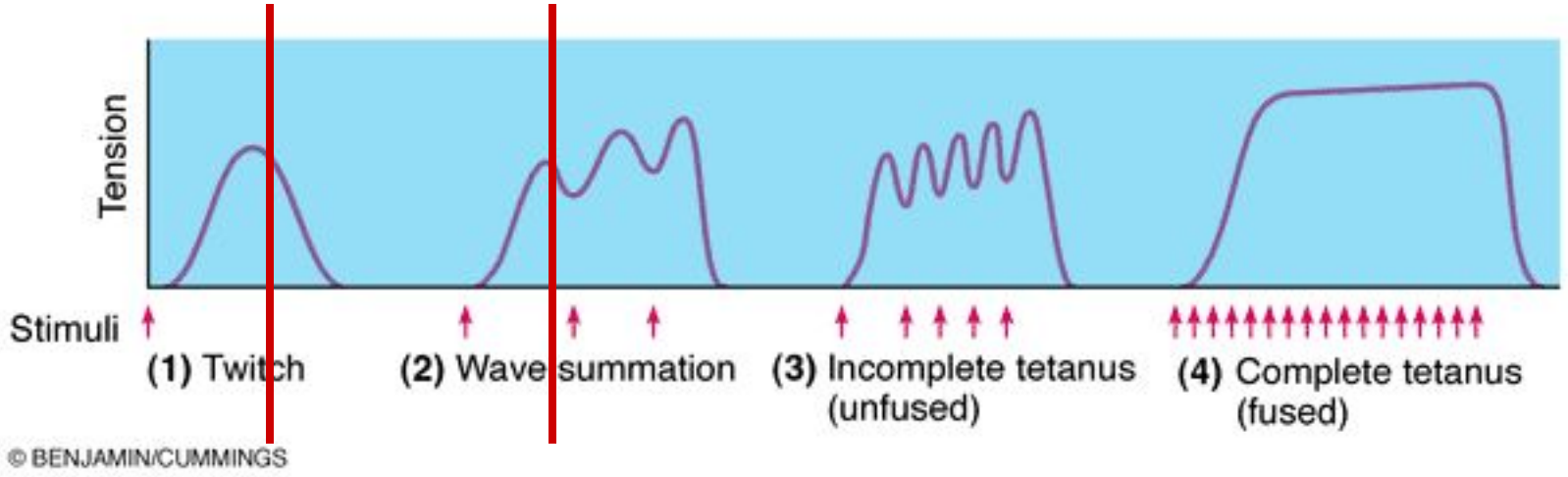
# Tetanus


Tension
Stimuli
(1) Twitch
(2) Wave summation
(3) Incomplete tetanus (unfused)
(4) Complete tetanus (fused)
© BENJAMIN/CUMMINGS

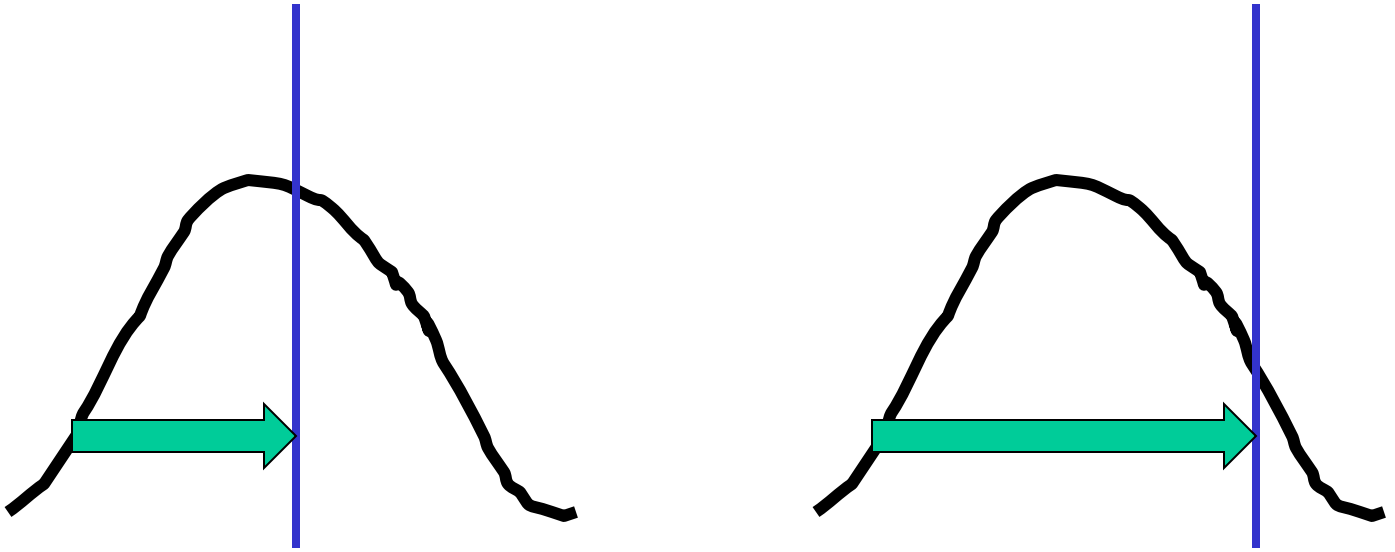
# Refractory Period

- Brief period of time in which muscle cells will not respond to a stimulus

# Refractory


Tension
Stimuli
(1) Twitch
(2) Wave summation
(3) Incomplete tetanus (unfused)
(4) Complete tetanus (fused)
© BENJAMIN/CUMMINGS

# Refractory Periods



Skeletal Muscle

Cardiac Muscle