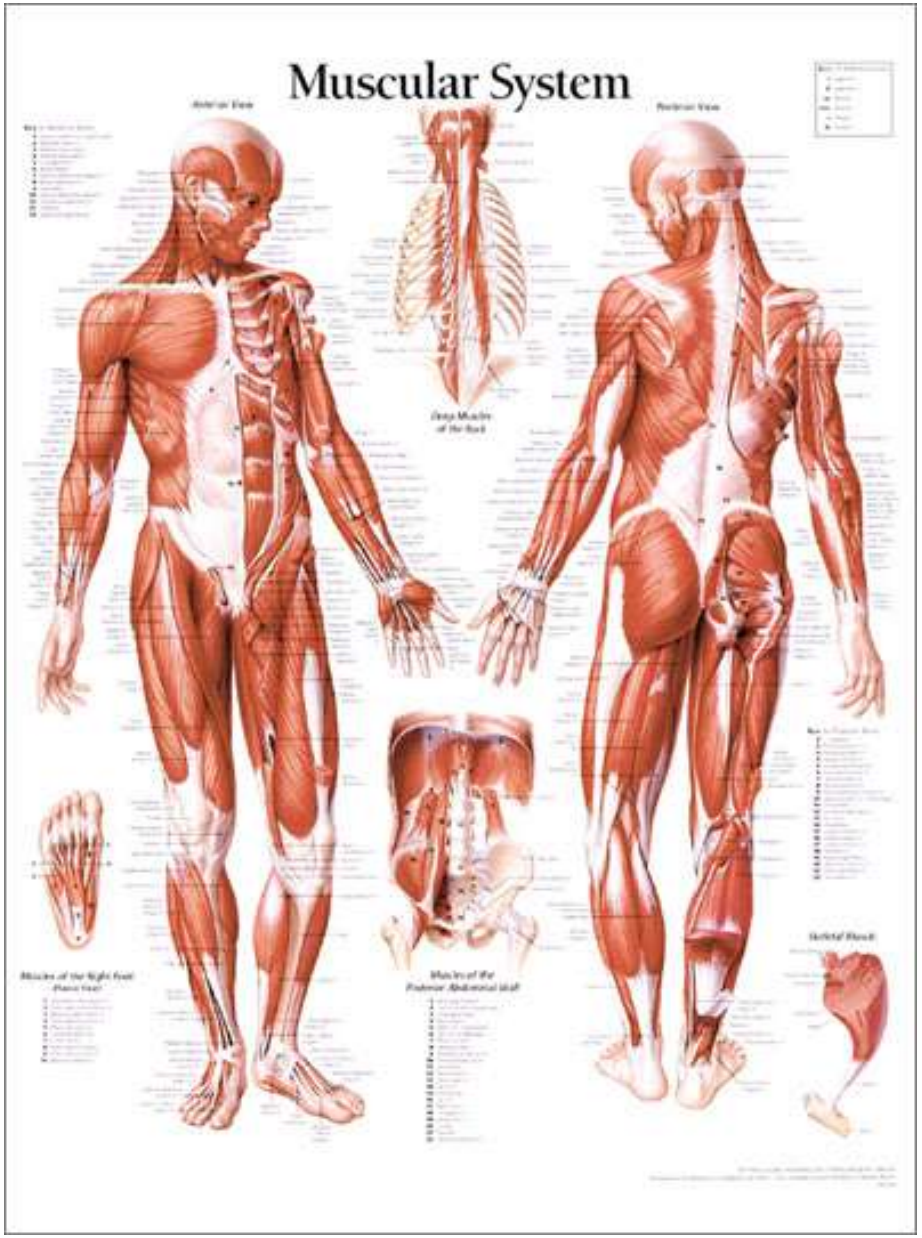
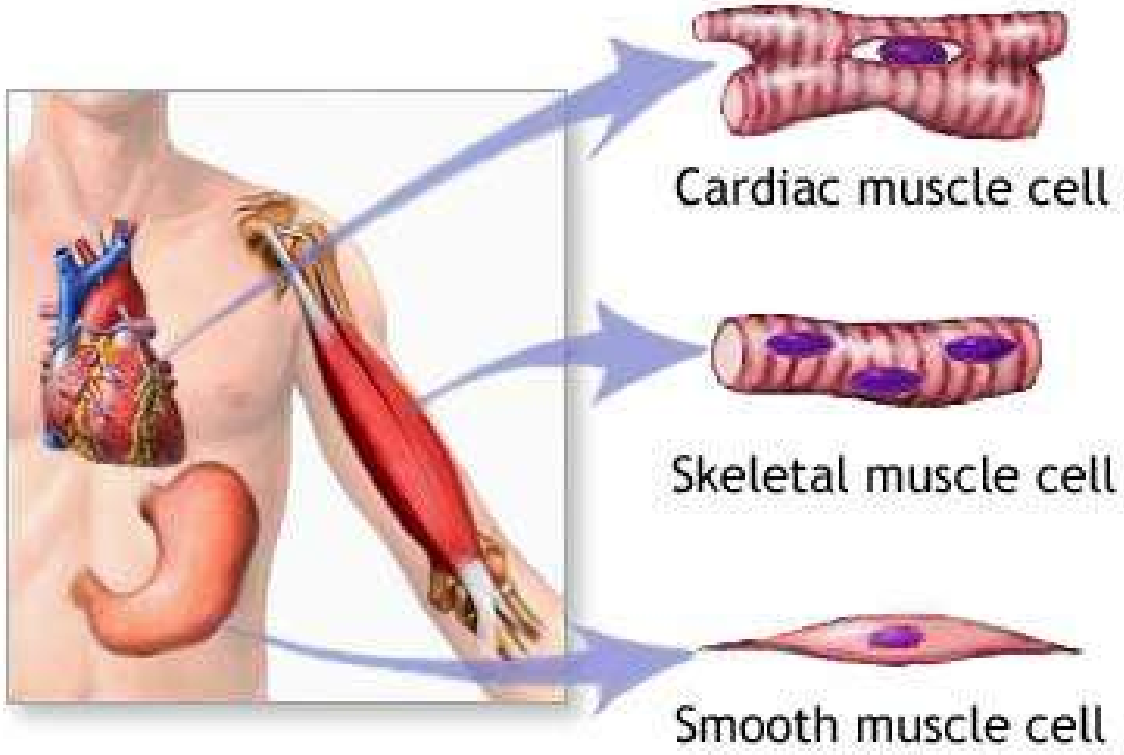
NOTES:
The Muscular System (Ch 6, part 1)



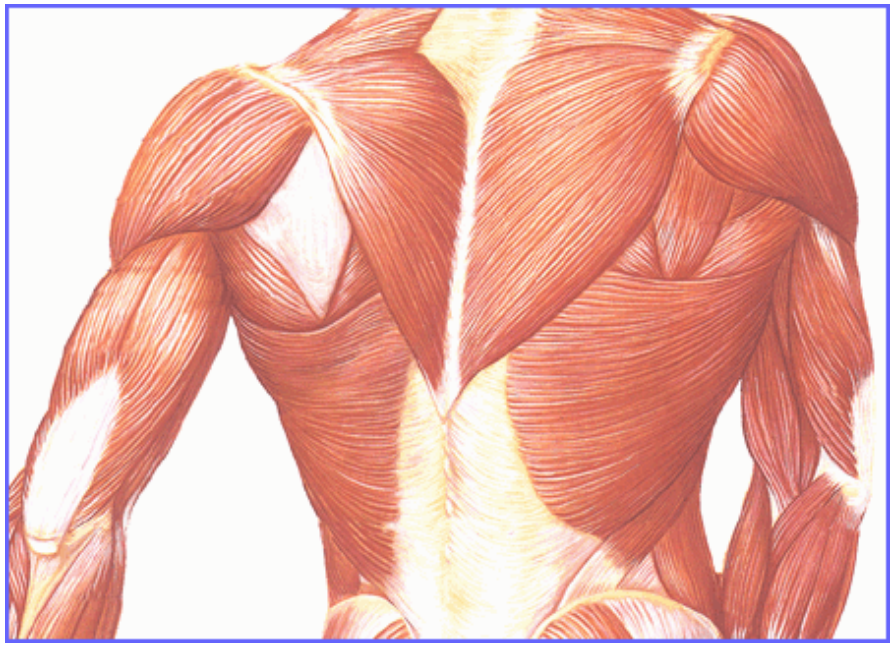
The muscular system consists of three types of muscle tissue:

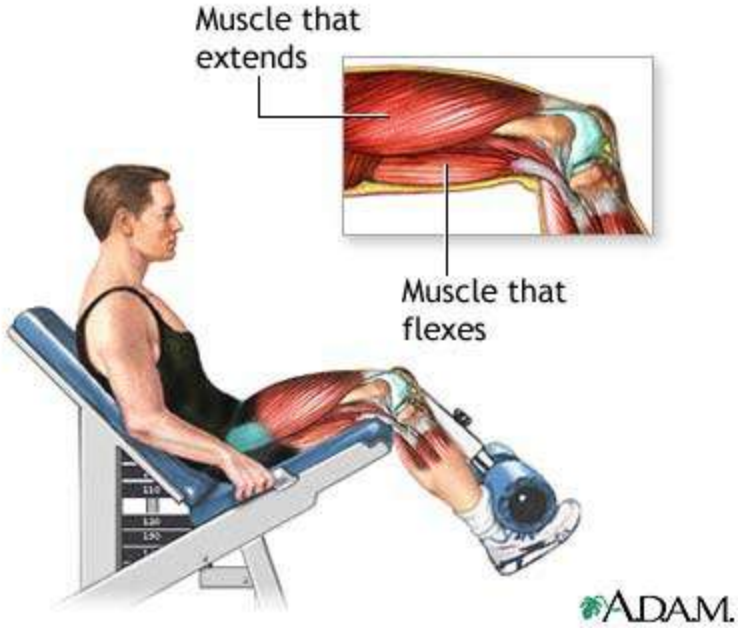
- ***Skeletal***
- ***Smooth***
- ***Cardiac***



STRUCTURE OF A SKELETAL MUSCLE:

*Individual muscles are the organs of the muscular system. They contain **skeletal muscle tissue, nervous tissue, blood, and connective tissues.***





Connective Tissue Coverings:

- **FASCIA**:

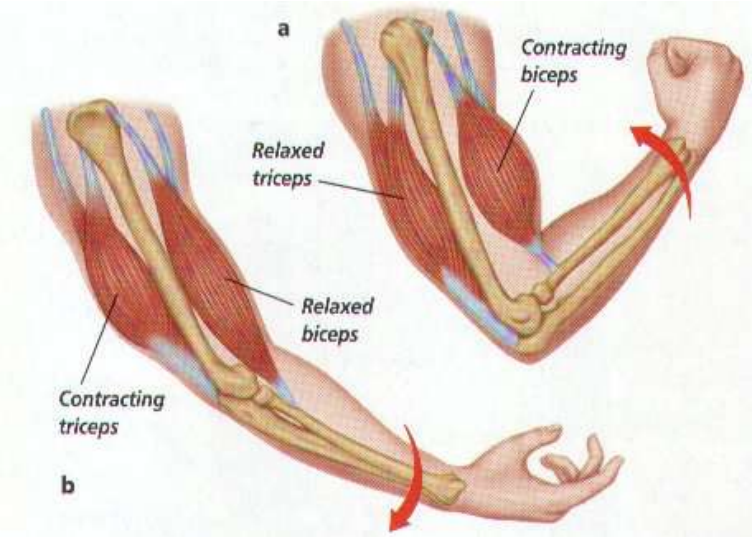
-covers skeletal muscles

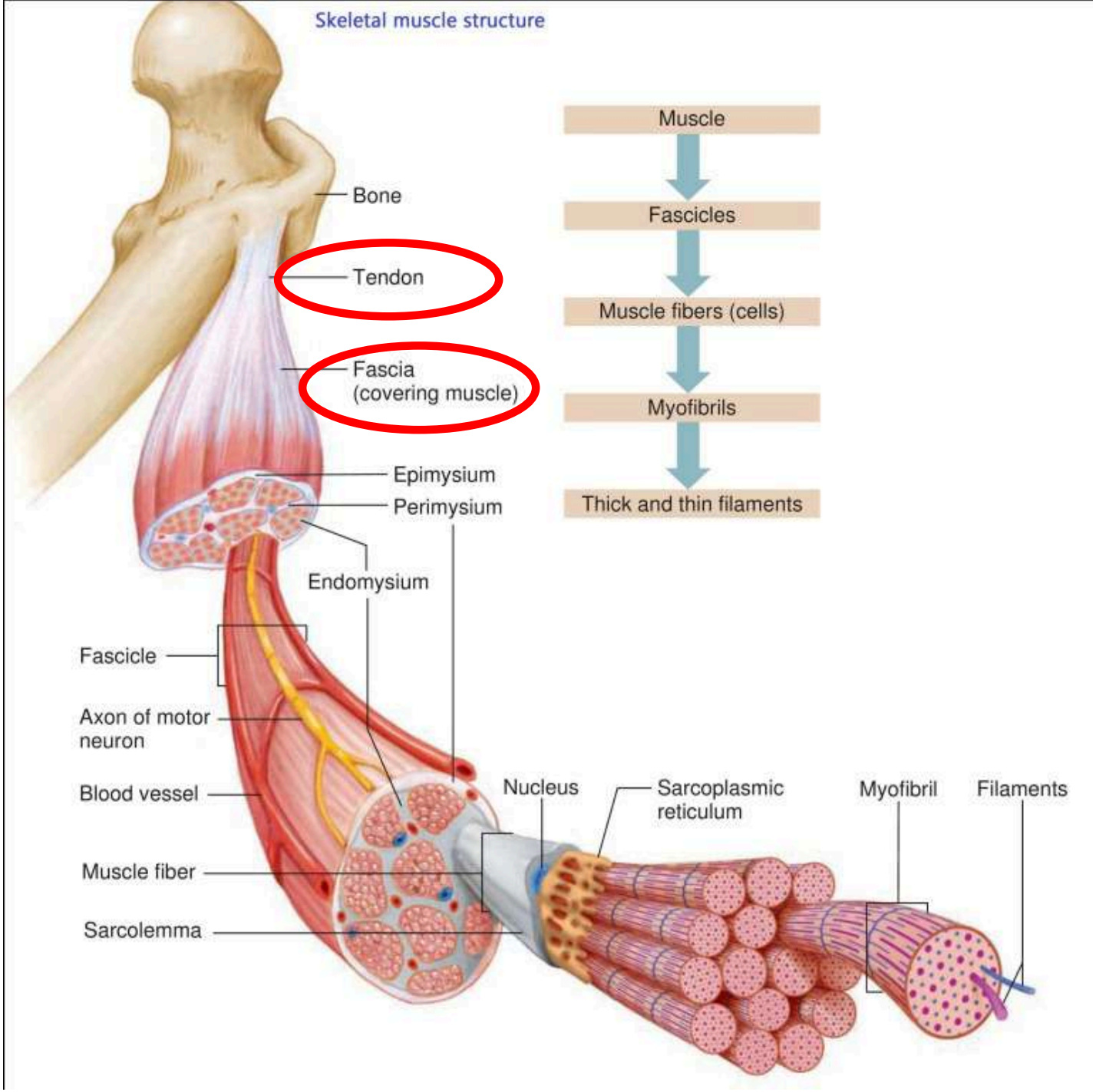
-separates individual skeletal muscles from adjacent muscles

-hold muscles in position

-may project beyond muscle to form a cordlike **TENDON**

-fibers in tendon may intertwine with fibers in a bone's periosteum, attaching muscle to bone!




Skeletal muscle structure
Muscle
Fascicles
Muscle fibers (cells)
Myofibrils
Thick and thin filaments
Bone
Tendon
Fascia
(covering muscle)
Epimysium
Perimysium
Endomysium
Fascicle
Axon of motor neuron
Blood vessel
Muscle fiber
Sarcolemma
Nucleus
Sarcoplasmic reticulum
Myofibril
Filaments

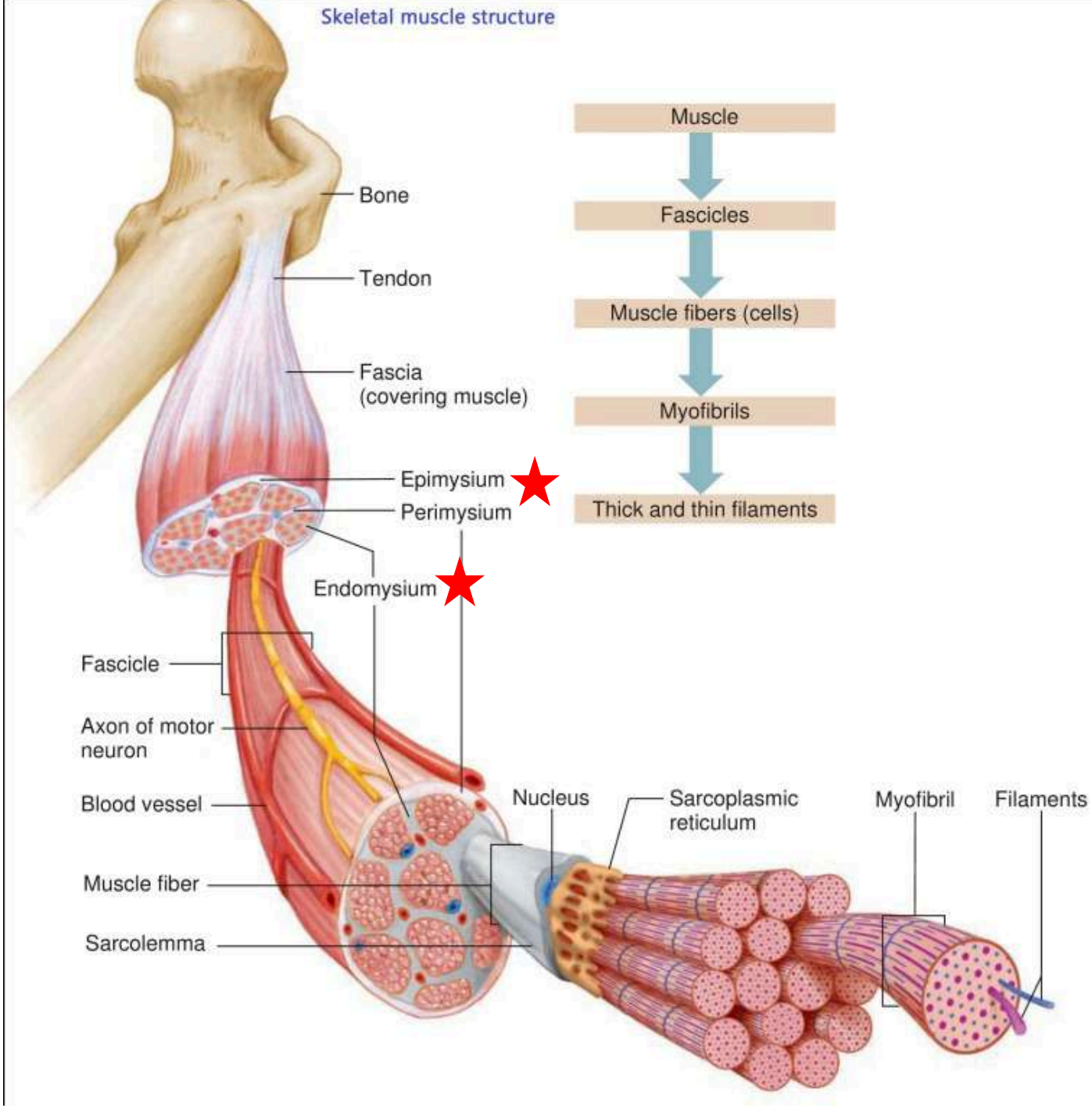
- **OTHER CONNECTIVE TISSUES**:

-attach muscles to bones or to other muscles

-a network of connective tissue extends throughout the muscular system

-include these tissues:

- **epimysium**: closely surrounds a skeletal muscle (underneath the fascia)
- **perimysium**: extends inward from the epimysium and separates the muscle tissue into small compartments called **FASCICLES**
- **endomysium**: surrounds each individual muscle fiber within a fascicle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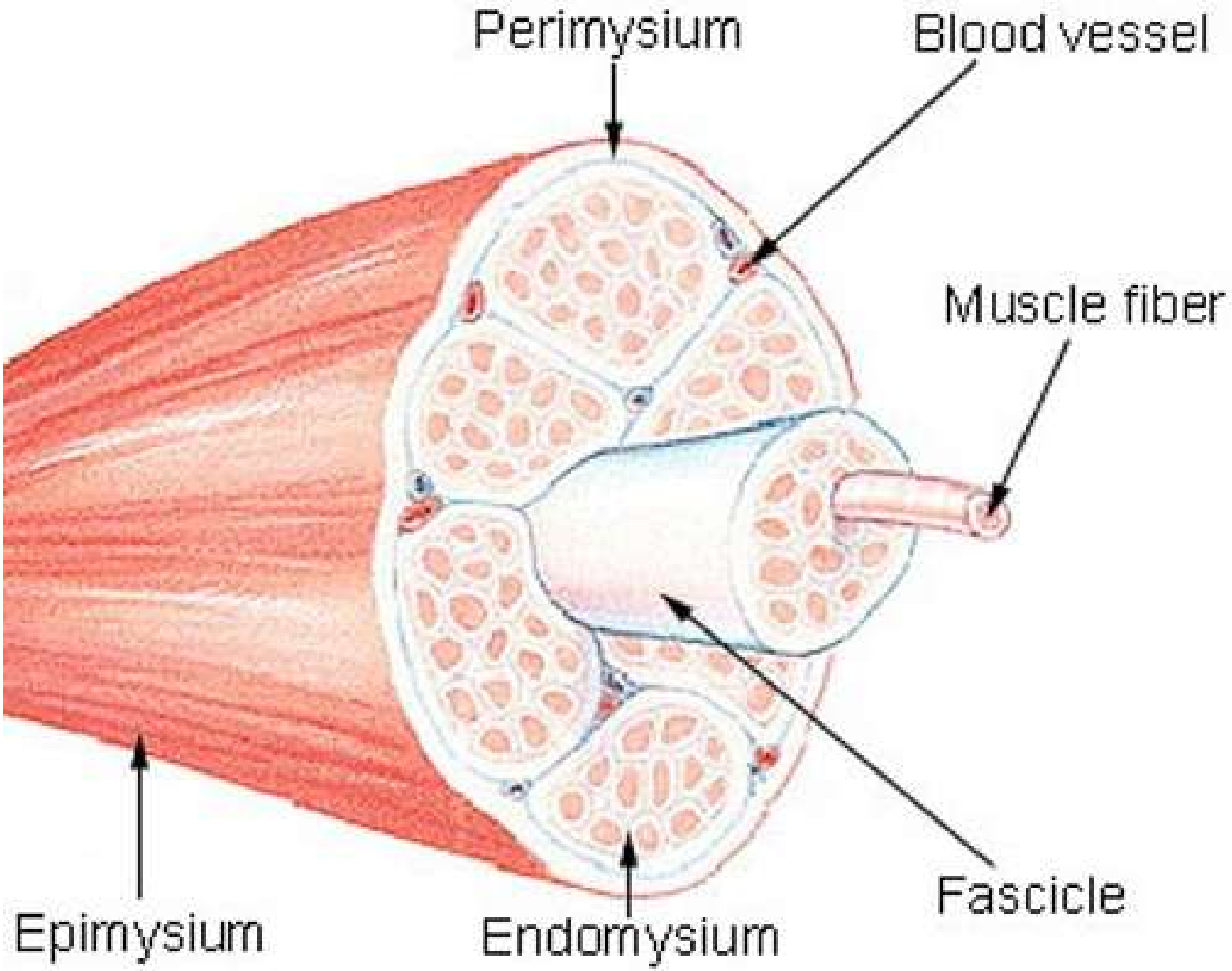
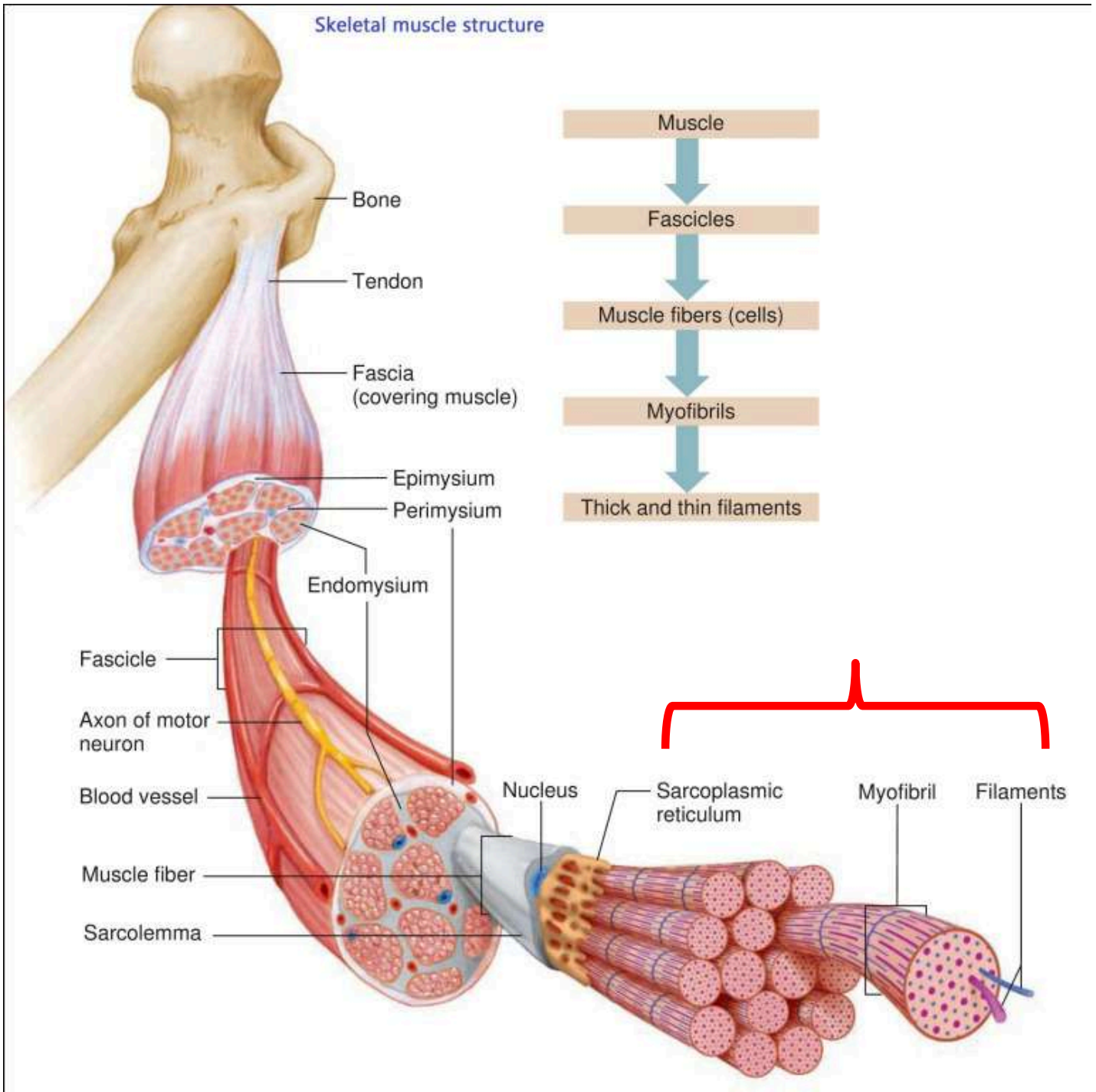

Perimysium
Blood vessel
Muscle fiber
Epimysium
Endomysium
Fascicle

Skeletal Muscle Fibers:

➔ each muscle fiber is a single muscle cell, which is the unit of contraction

➔ just beneath the cell membrane (**SARCOLEMMA**), the cytoplasm (**SARCOPLASM**) contains:

* many small, oval nuclei
* mitochondria
* **SARCOPLASMIC RETICULUM** (a modified endoplasmic reticulum)
* **MYOFIBRILS (of actin and myosin)**


Skeletal muscle structure
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Nucleus
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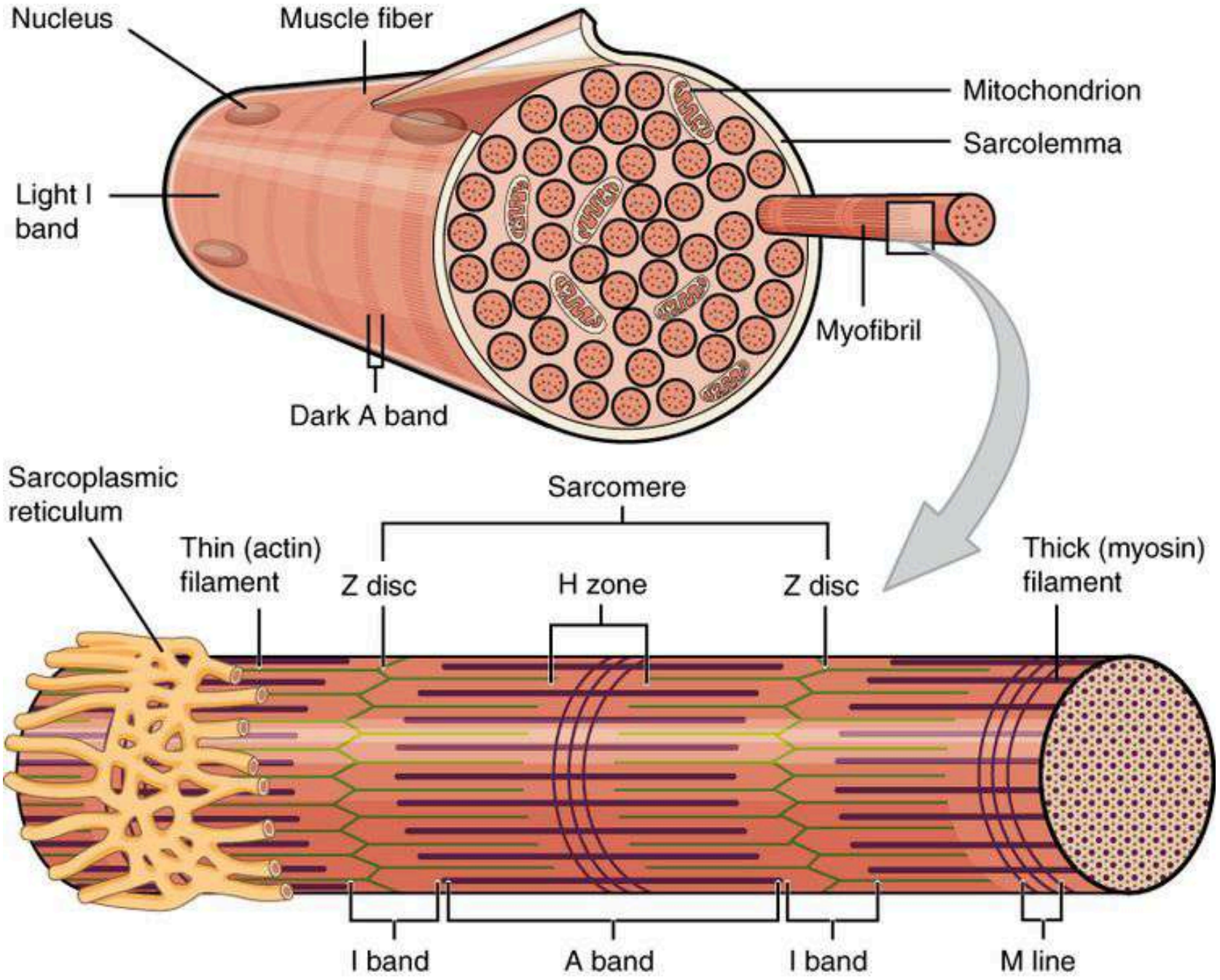
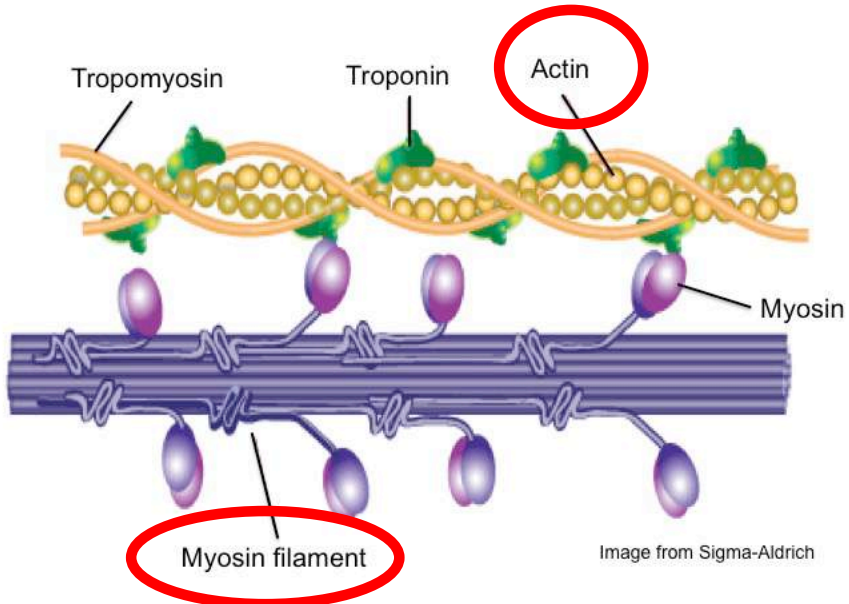
Filaments

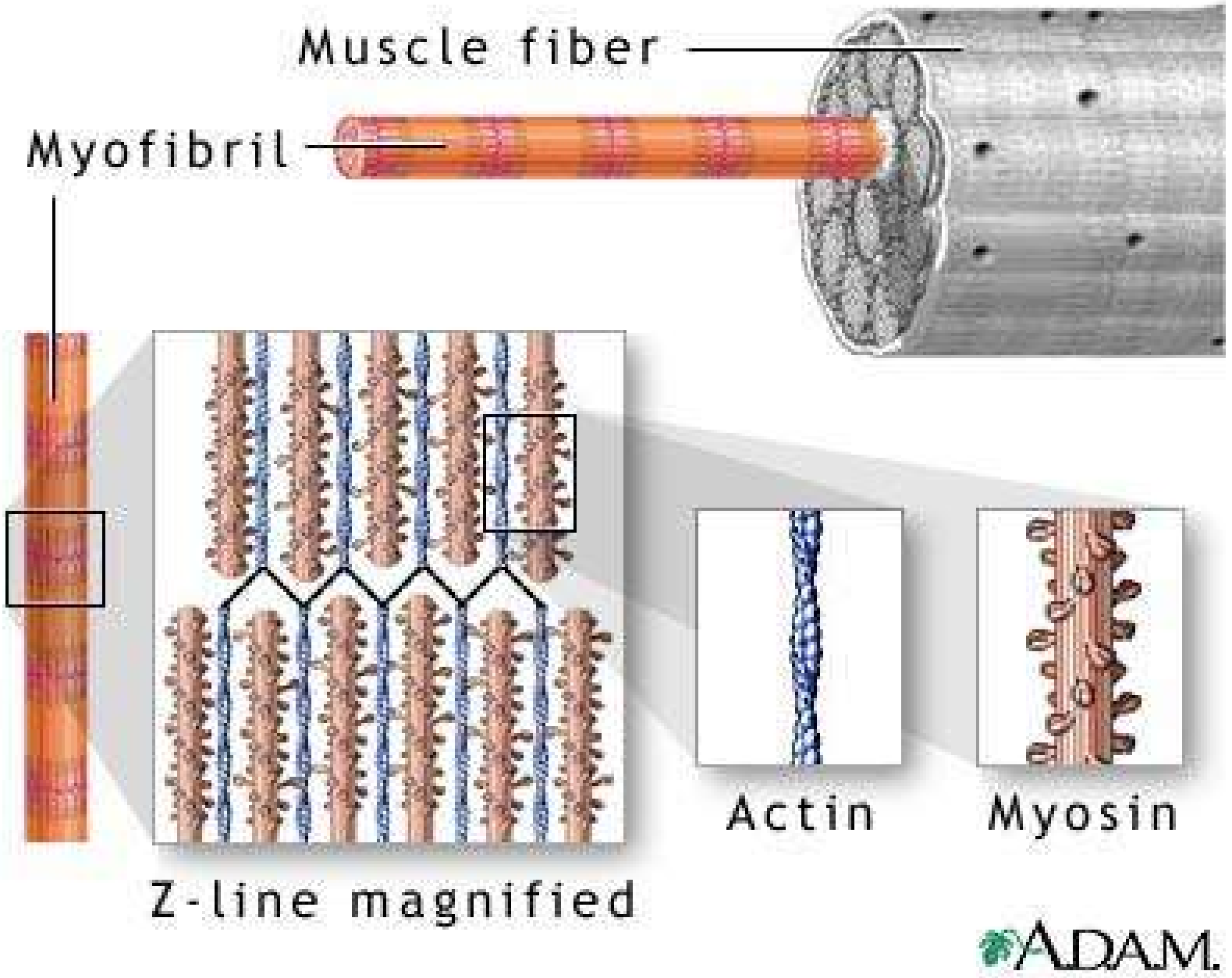

Nucleus
Muscle fiber
Mitochondrion
Sarcolemma
Light I band
Myofibril
Dark A band
Sarcoplasmic reticulum
Sarcomere
Thin (actin) filament
Z disc
H zone
Z disc
Thick (myosin) filament
I band
A band
I band
M line

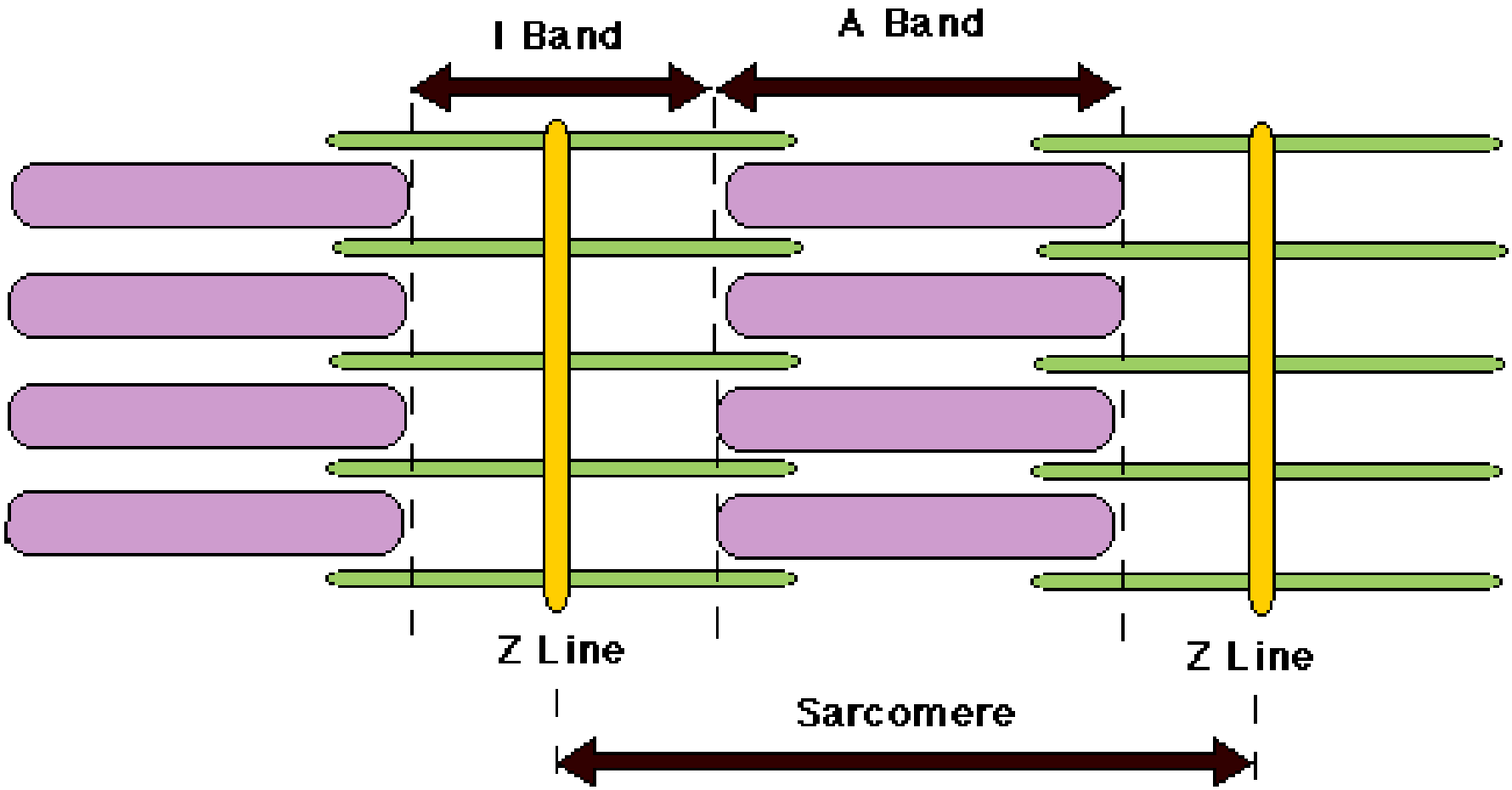
Skeletal Muscle Fibers:

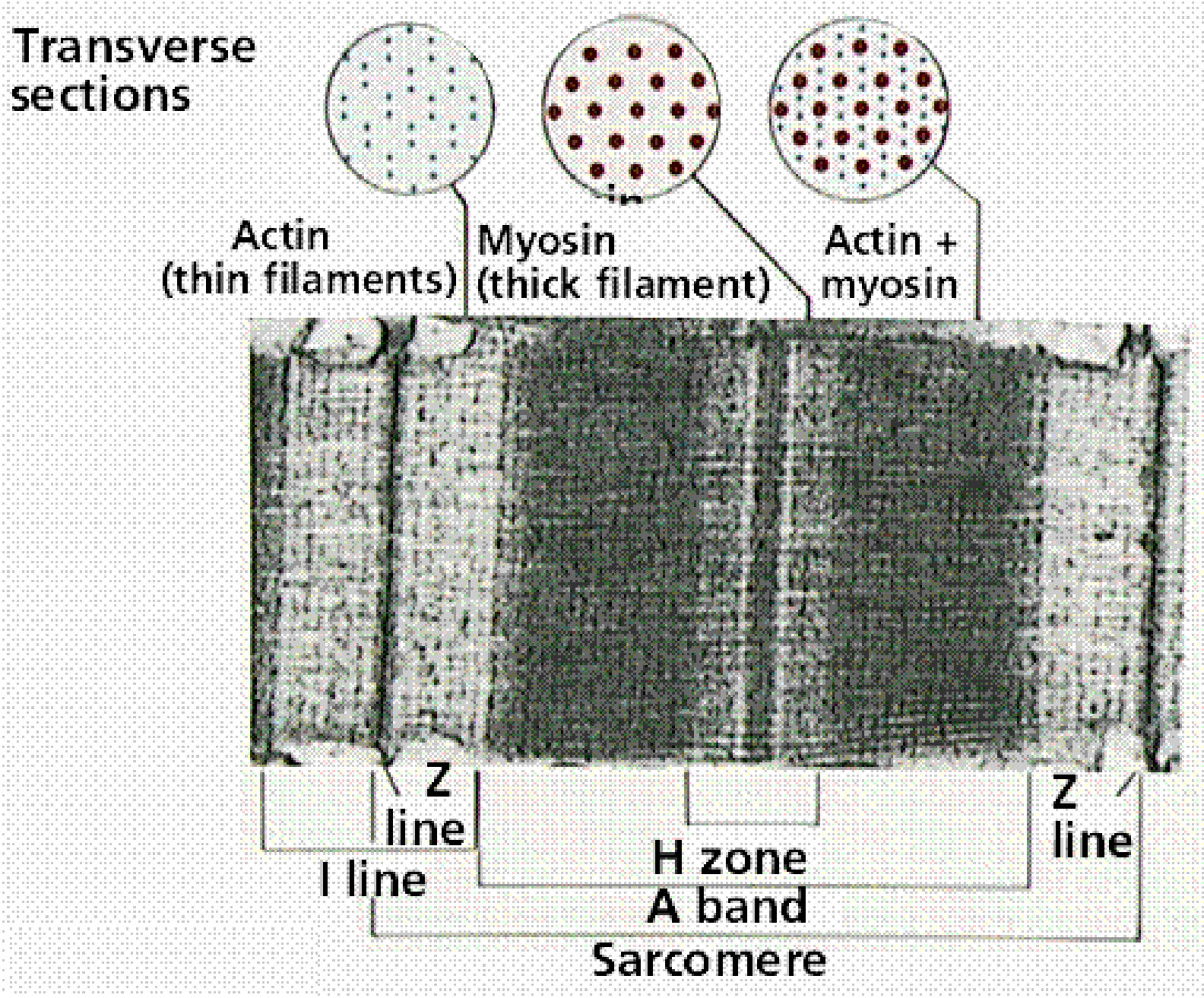
the organization of actin and myosin filaments produces **STRIATIONS (bands)

the thick (myosin) and thin (actin) filaments are organized into structural units called **SARCOMERES



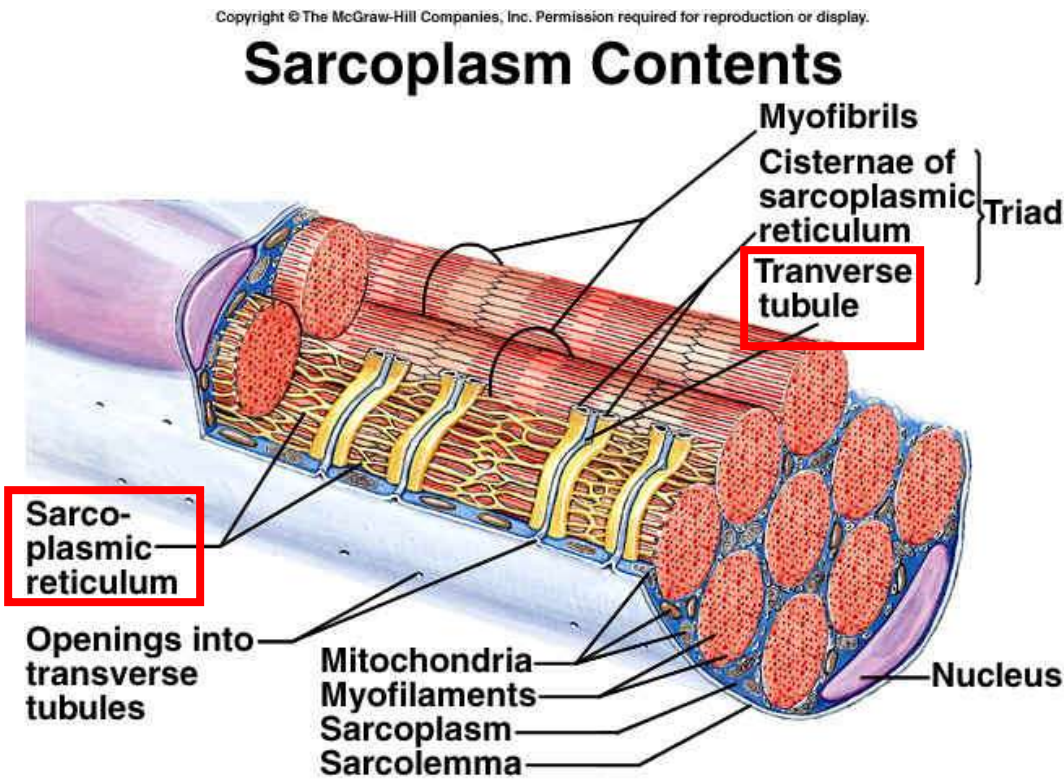

Muscle fiber
Myofibril
Actin
Myosin
Z-line magnified
A.D.A.M.


I Band
A Band
Z Line
Z Line
Sarcomere


Transverse sections
Actin (thin filaments)
Myosin (thick filament)
Actin + myosin
Z line
I line
H zone
A band
Z line
Sarcomere

Also part of a muscle fiber…

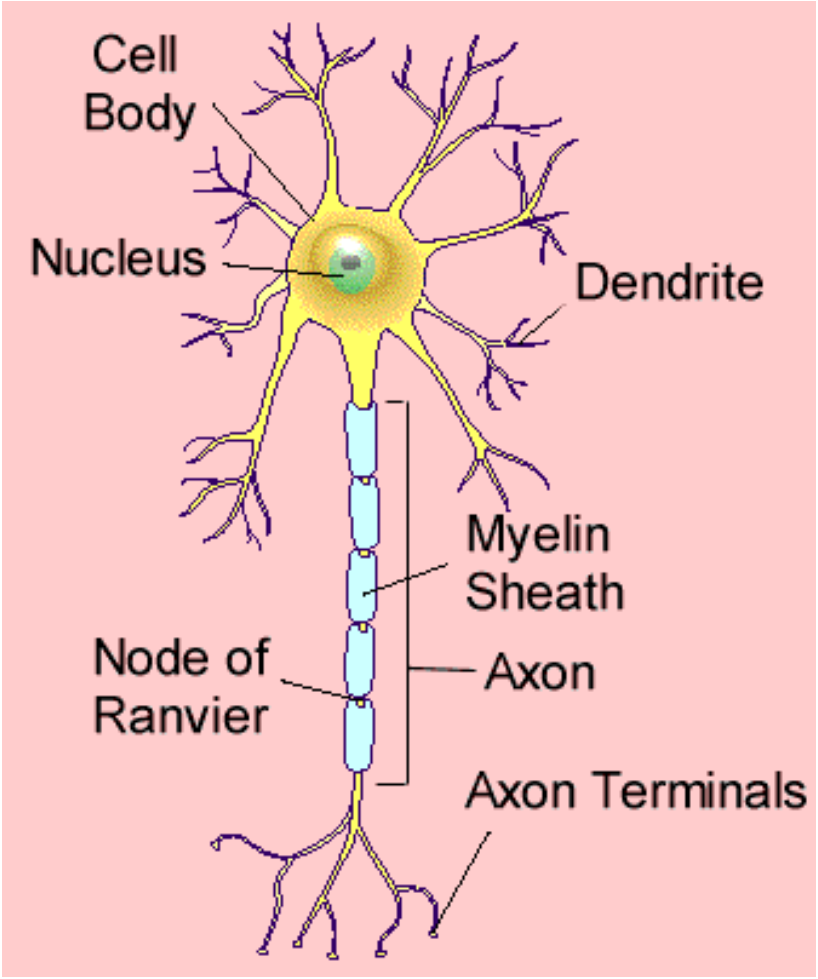
__TRANSVERSE TUBULES**__ (T tubules) extend inward from the cell membrane and associate with the __**SARCOPLASMIC RETICULUM**__ (whose membranes surround each myofibril)

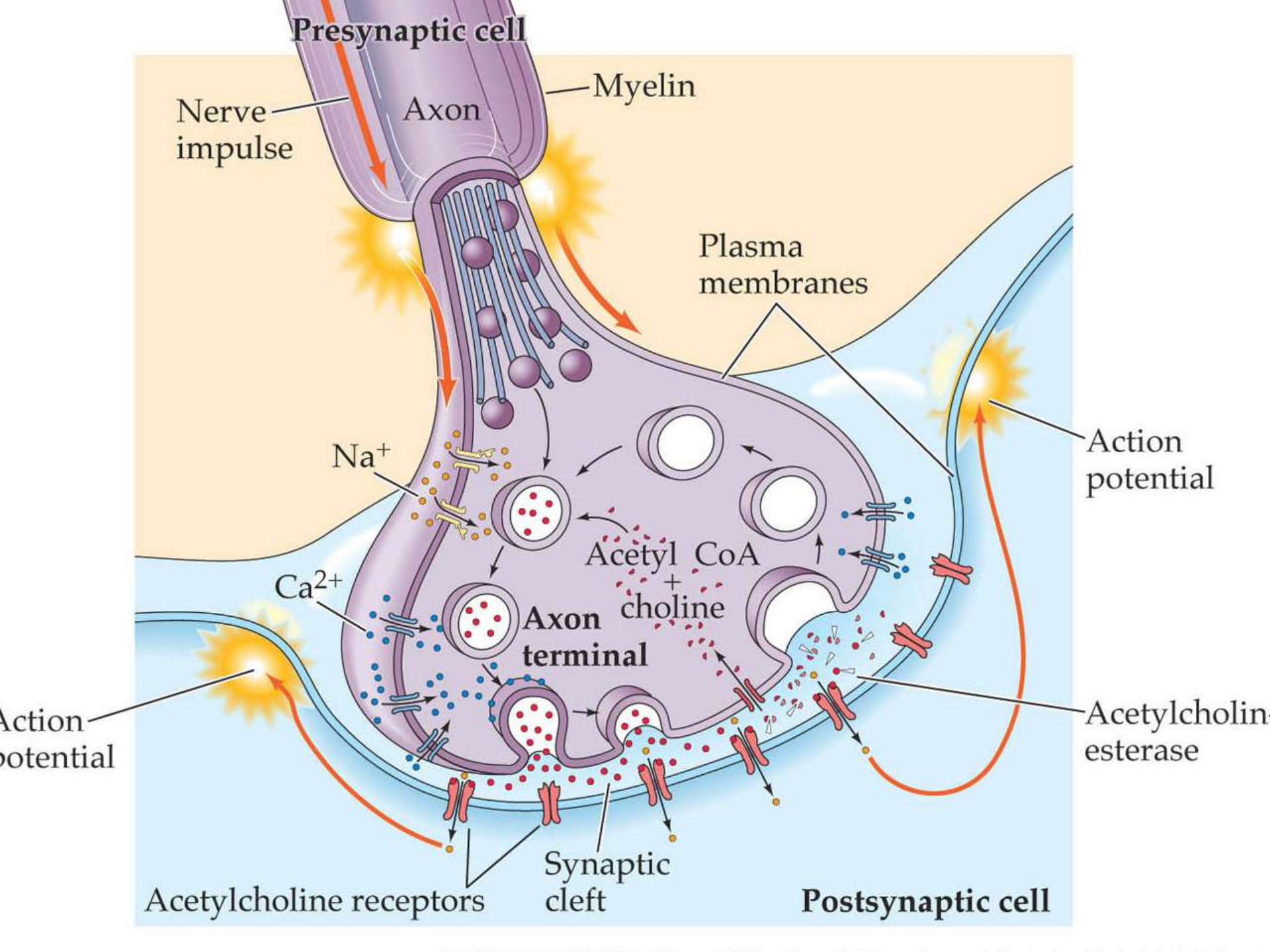


Neuromuscular Junction:

➔ **MOTOR NEURONS** stimulate muscle fibers to contract

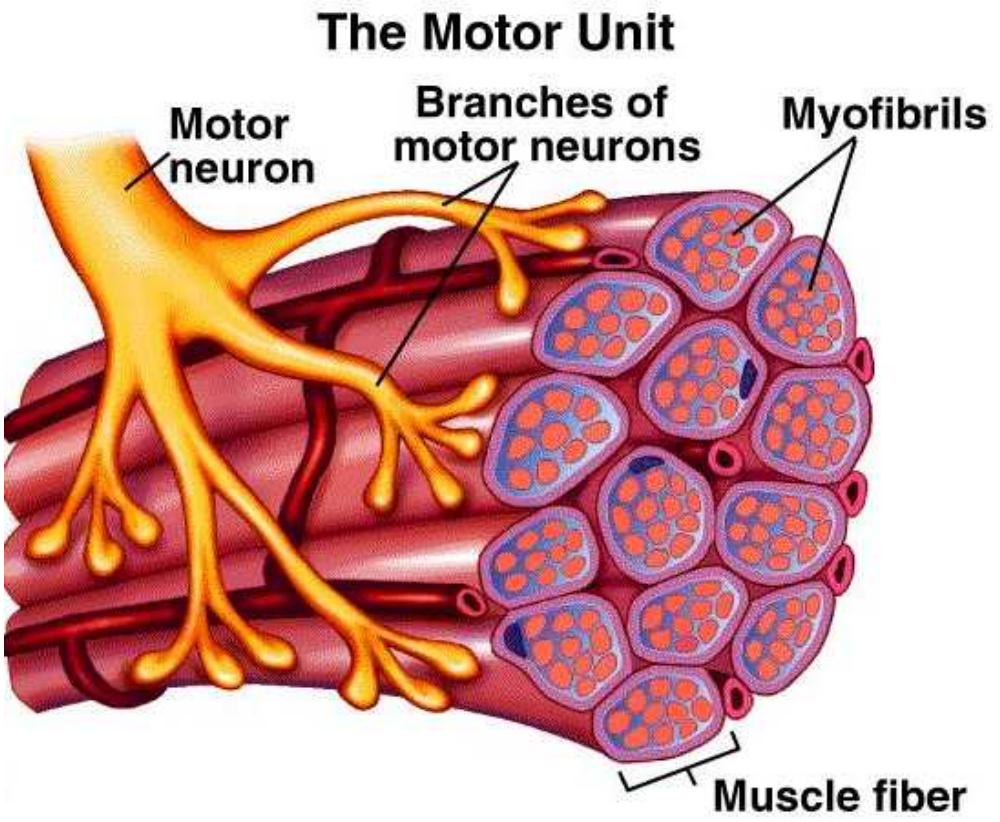
➔ in response to a nerve impulse, the end of a motor neuron axon secretes a **NEUROTRANSMITTER**, which stimulates the muscle fiber to contract




Presynaptic cell
Nerve impulse
Axon
Myelin
Plasma membranes
Action potential
Na^+
Ca^{2+}
Acetyl CoA + choline
Axon terminal
Action potential
Acetylcholinesterase
Acetylcholine receptors
Synaptic cleft
Postsynaptic cell

Neuromuscular Junction:

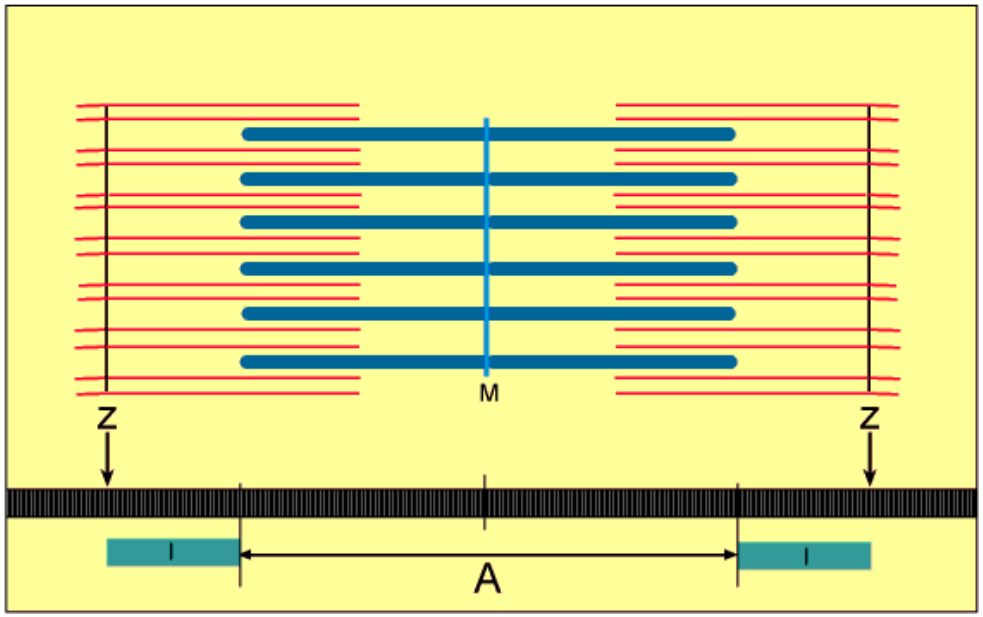
➔one **MOTOR NEURON** and the **MUSCLE FIBERS** associated with it constitute a **MOTOR UNIT**



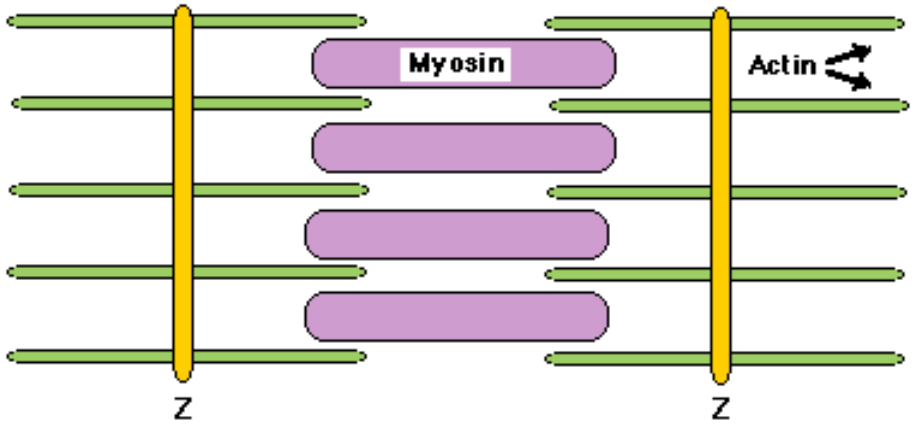
➔ all muscle fibers of a motor unit contract together!

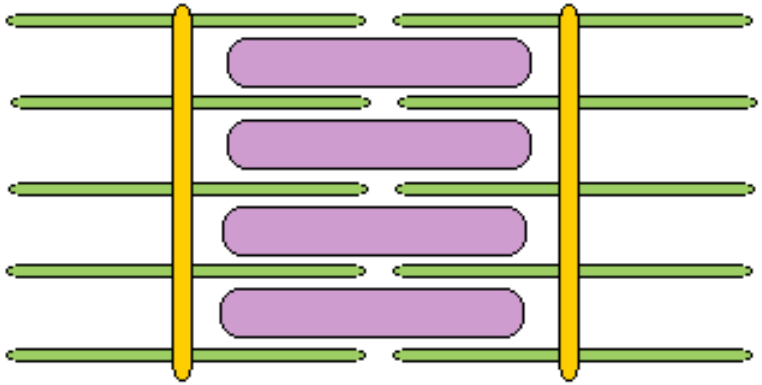
SKELETAL MUSCLE CONTRACTION

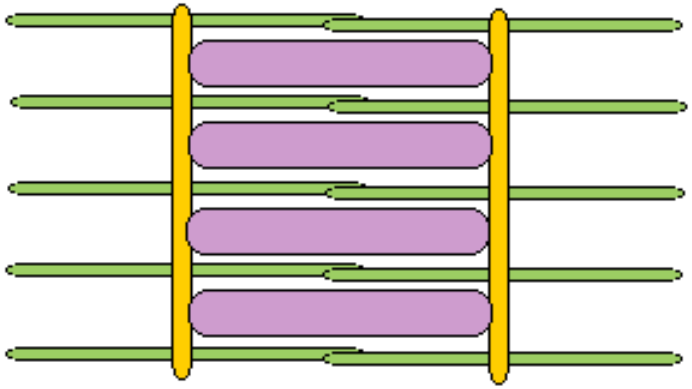
Muscle fiber contraction results from a sliding movement of actin and myosin filaments.



(known as the **SLIDING FILAMENT MODEL** in which individual sarcomeres shorten)

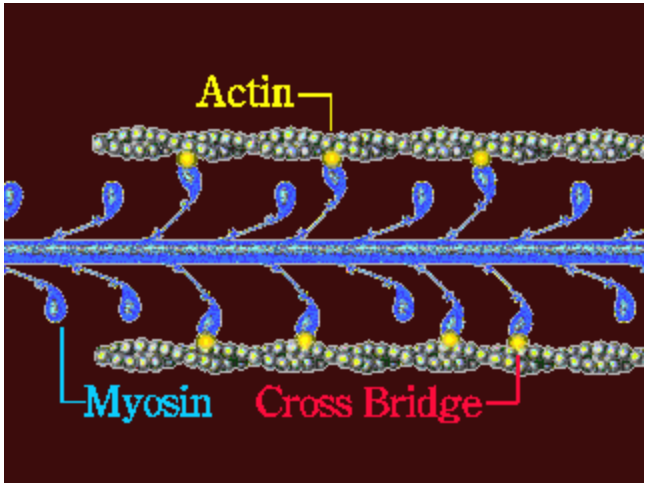

Myosin
Actin
Z
Z



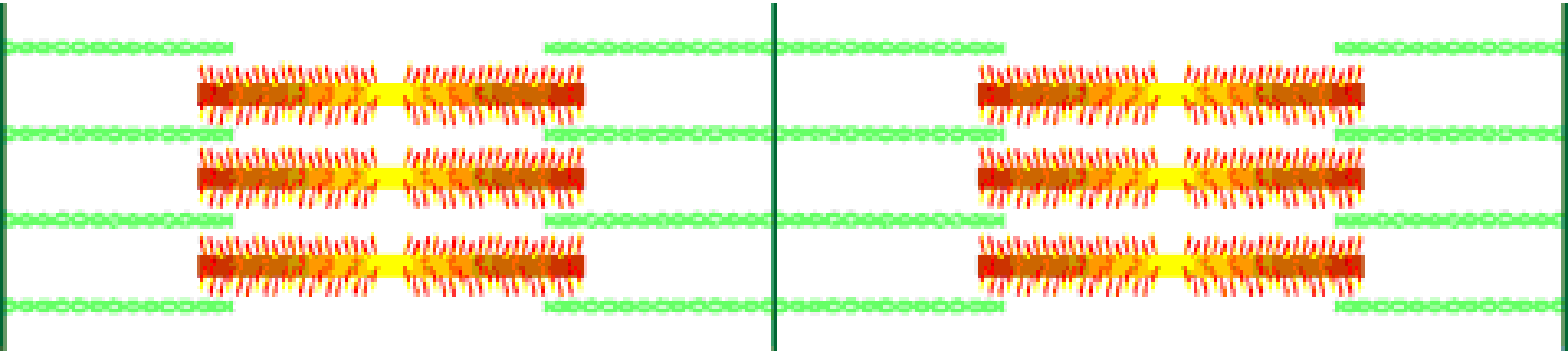


Role of MYOSIN and ACTIN:

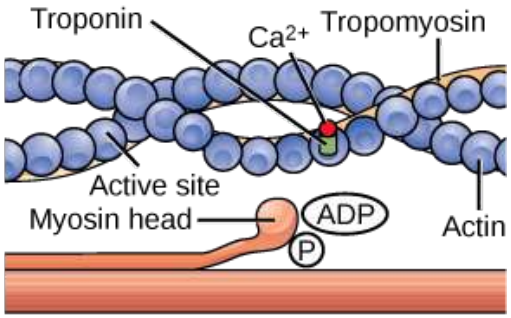
➔ **cross-bridges** of myosin filaments form linkages with actin filaments



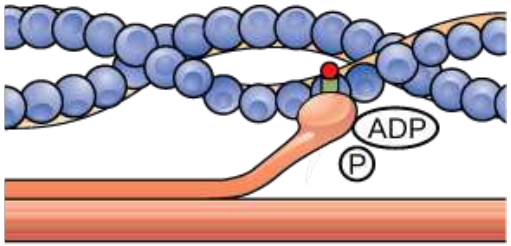
➔ the reaction between actin and myosin filaments generates the force of contraction



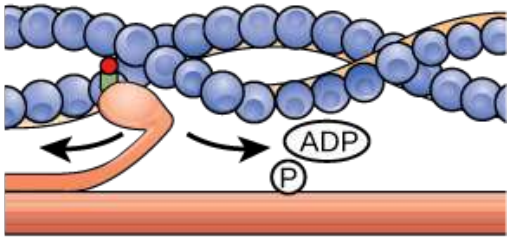
1. The active site on actin is exposed as Ca^{2+} binds troponin.



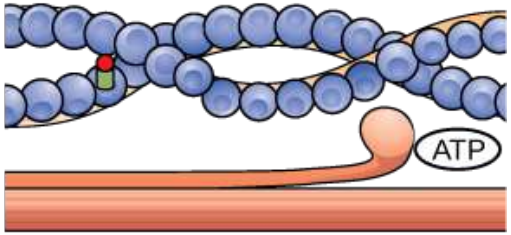
2. The myosin head forms a cross-bridge with actin.



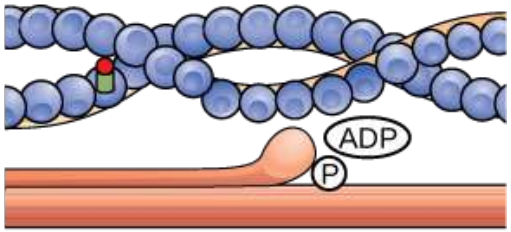
3. During the power stroke, the myosin head bends, and ADP and phosphate are released.

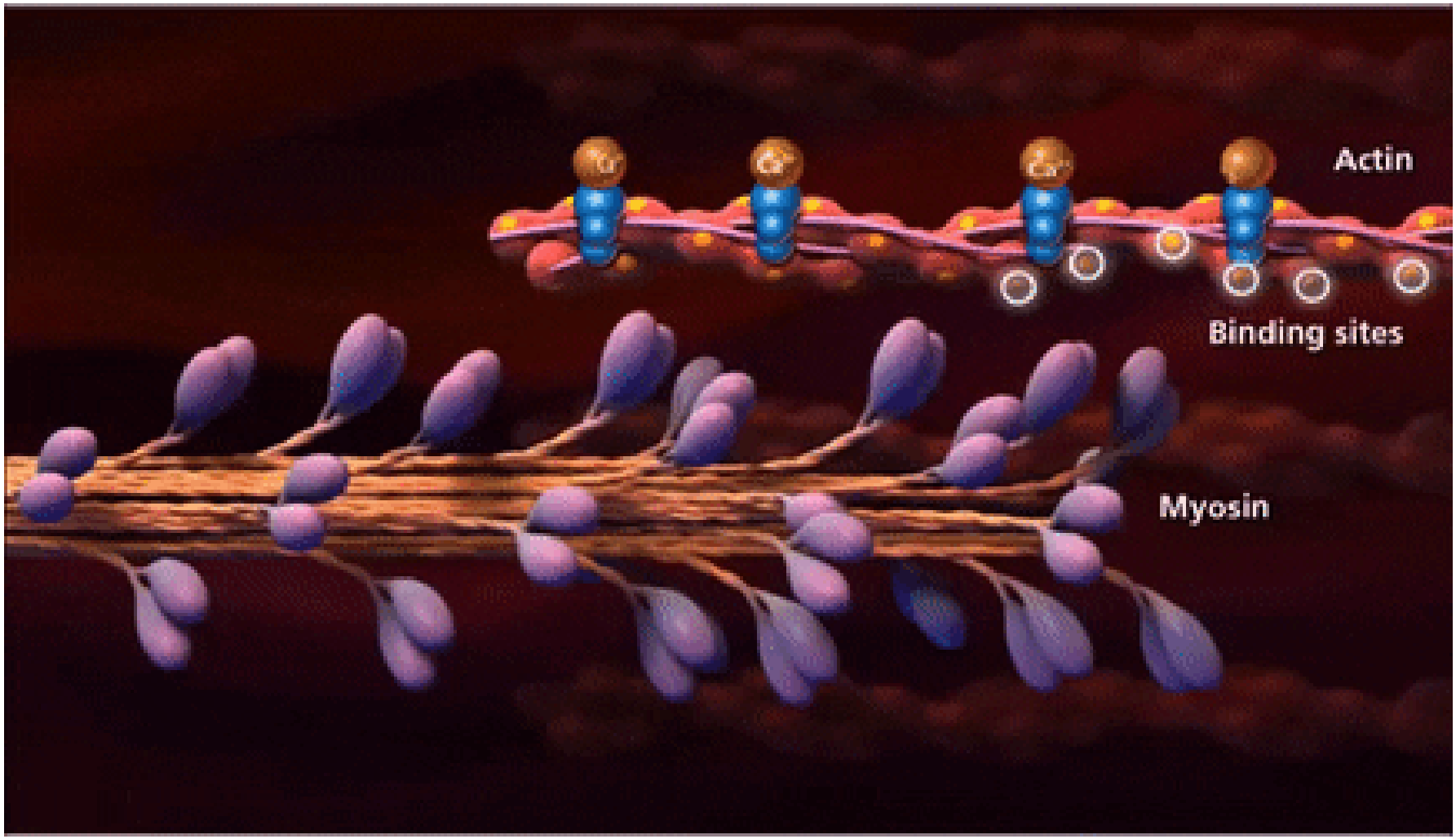


4. A new molecule of ATP attaches to the myosin head, causing the cross-bridge to detach.



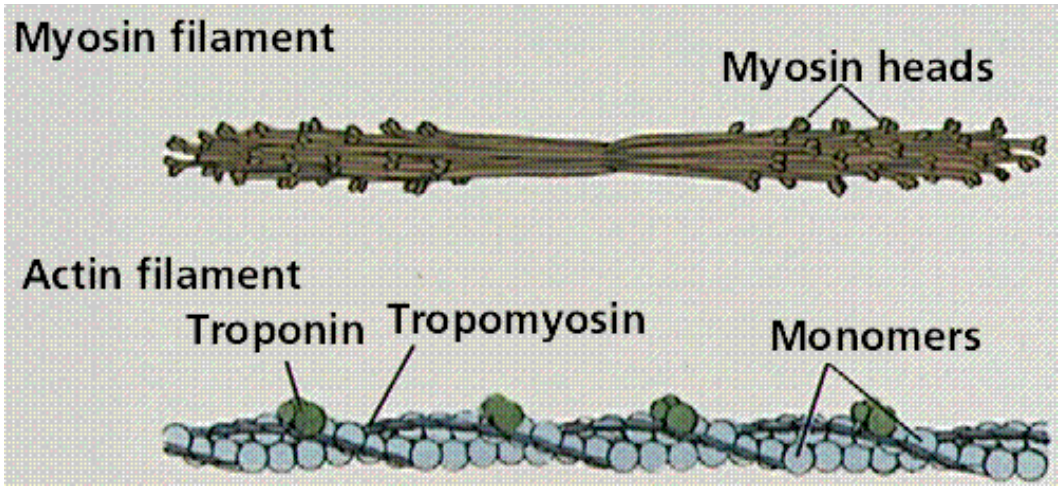
5. ATP hydrolyzes to ADP and phosphate, which returns the myosin to the “cocked” position.



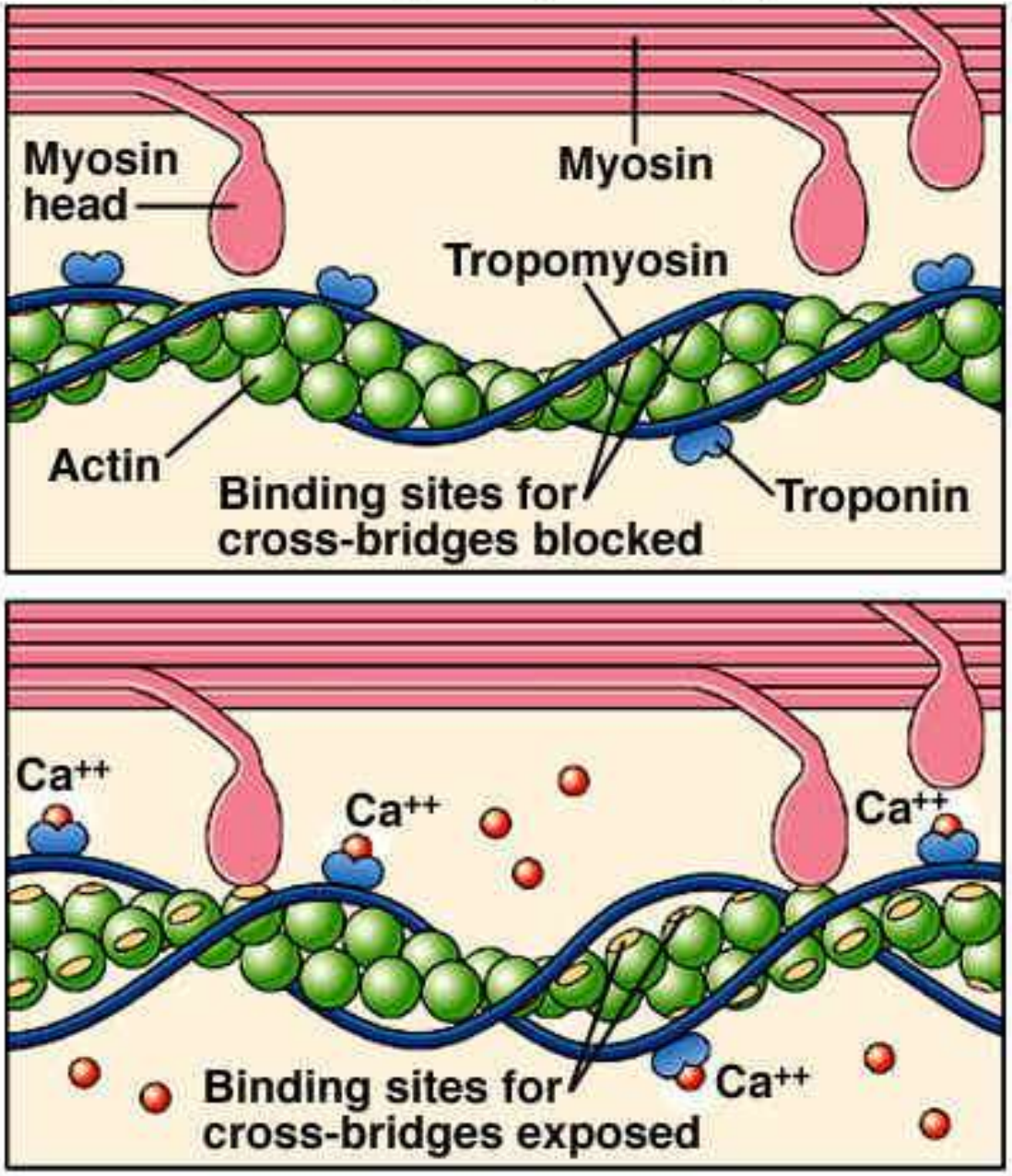

Actin
Binding sites
Myosin

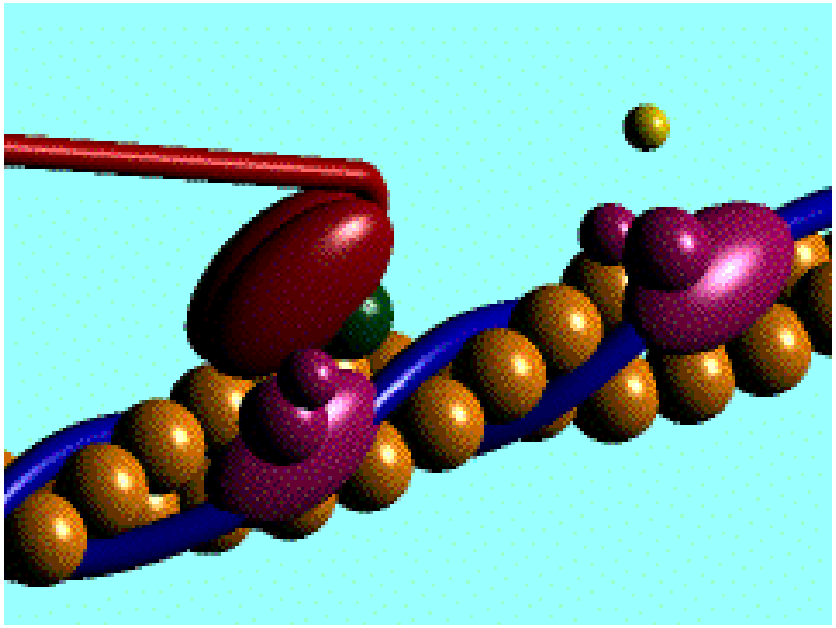
OTHER PROTEINS INVOLVED:

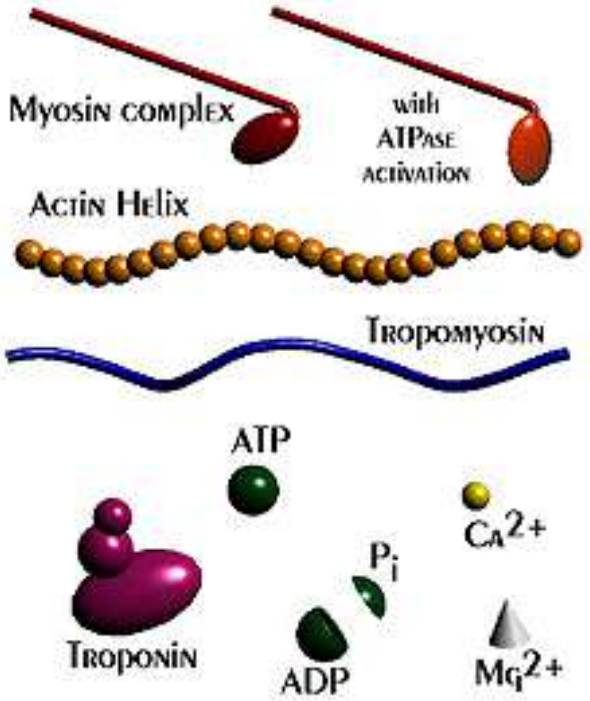
- **TROPONIN and TROPOMYOSIN**: together form a complex that **covers the myosin-binding sites on actin**; by covering these binding sites, myosin cannot bind to actin and a contraction cannot occur.



Role of Calcium in Muscle Contraction






Myosin complex
with
ATPase
activation
Actin Helix
Tropomyosin
ATP
Troponin
ADP
Pi
Ca2+
Mg2+

Stimulus for and Steps of…a CONTRACTION:

> **ACETYLCHOLINE** (**a neurotransmitter**) is released from the distal end of a motor neuron axon and stimulates a skeletal muscle fiber

> acetylcholine causes the muscle fiber to conduct an impulse over the surface of the fiber that reaches deep within the fiber through the **TRANSVERSE TUBULES**

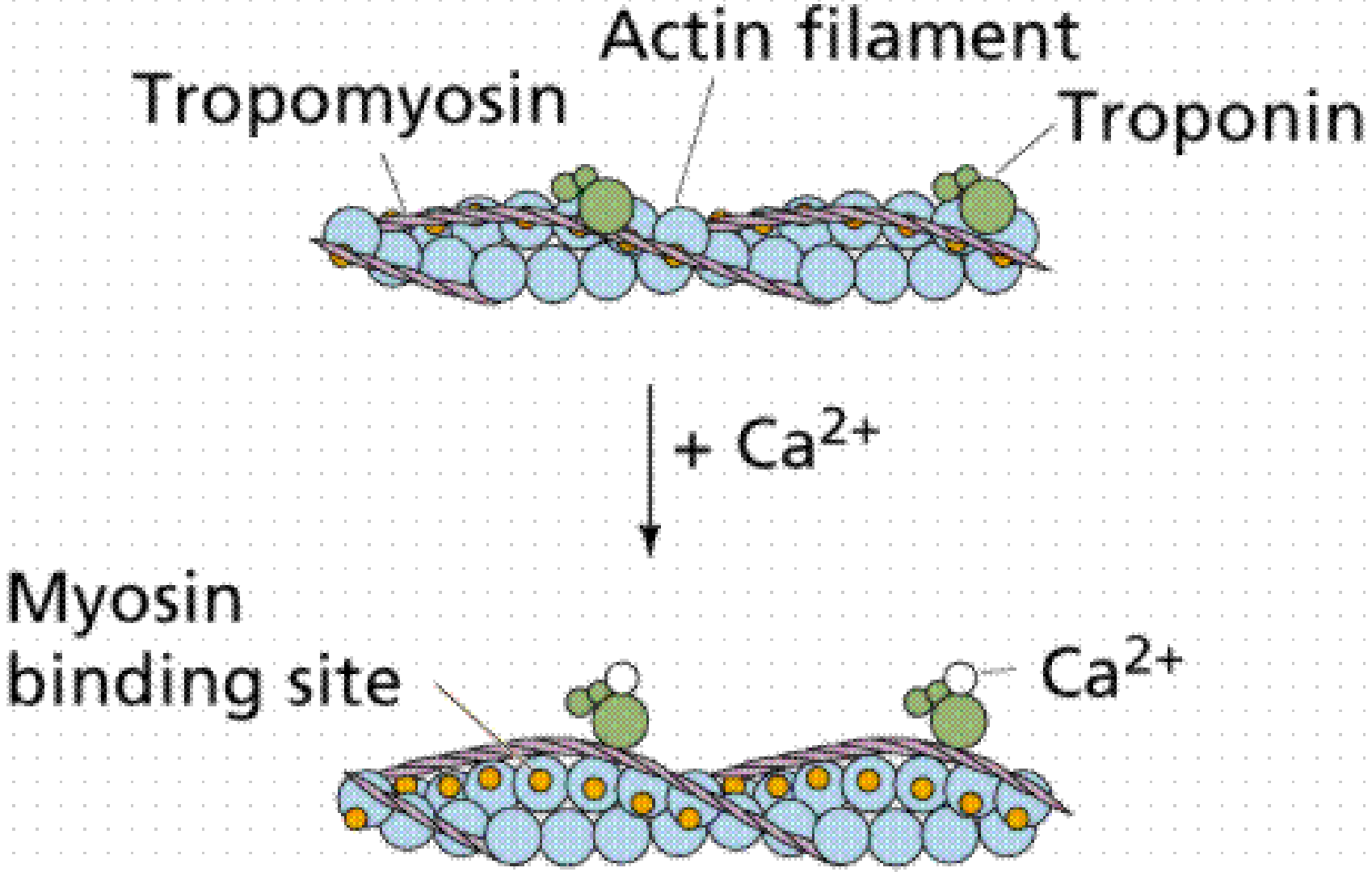
> a muscle impulse signals the sarcoplasmic reticulum to release **CALCIUM IONS**

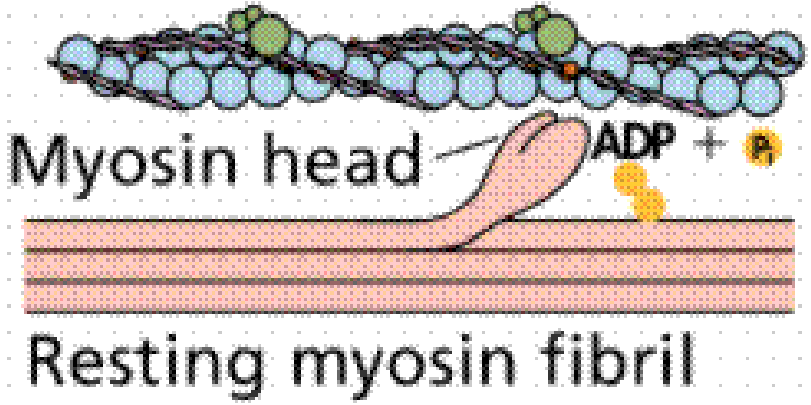
Steps of a Muscle Contraction…

> calcium ions bind to troponin protein & tropomyosin is pulled aside, uncovering the myosin-binding sites on actin

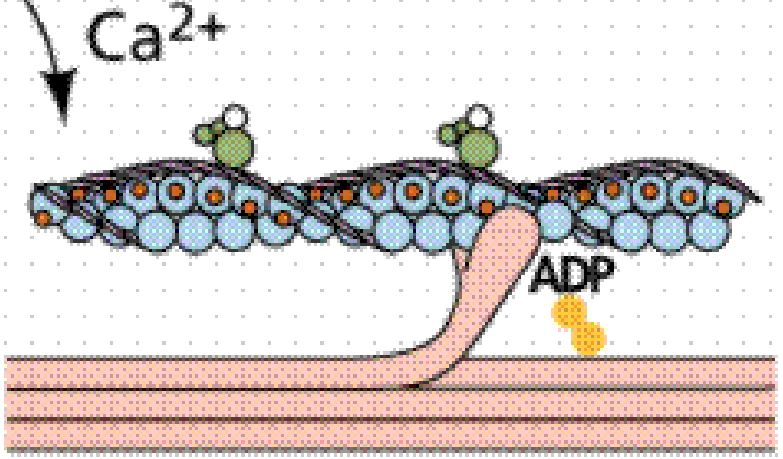
> linkages form between **actin and myosin**

> the myosin cross-bridges pull on actin filaments, shortening the fiber

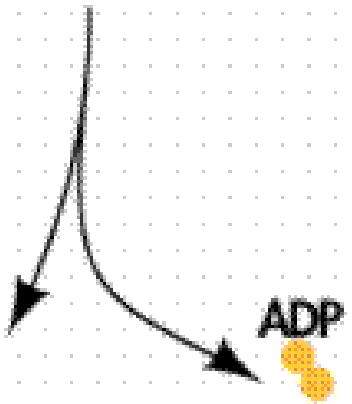

Actin filament
Tropomyosin
Troponin
+ Ca^{2+}
Myosin
binding site
Ca^{2+}

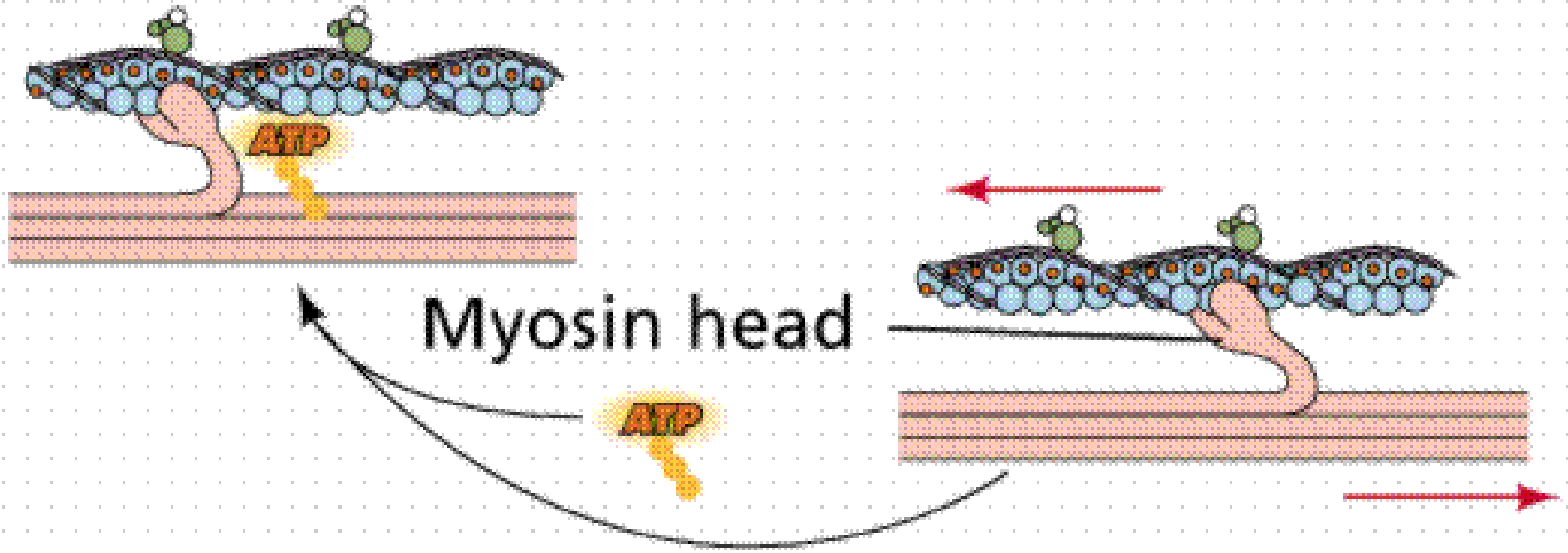


1. Action potential causes depolarization and release of Ca^{2+}



2. Ca^{2+} exposes myosin binding sites; myosin heads bind to actin

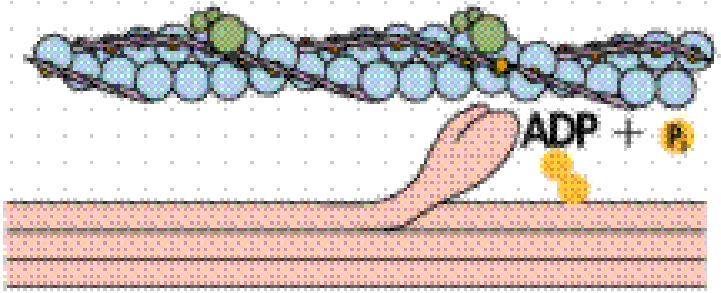




4. ATP binds to myosin, causing it to release actin

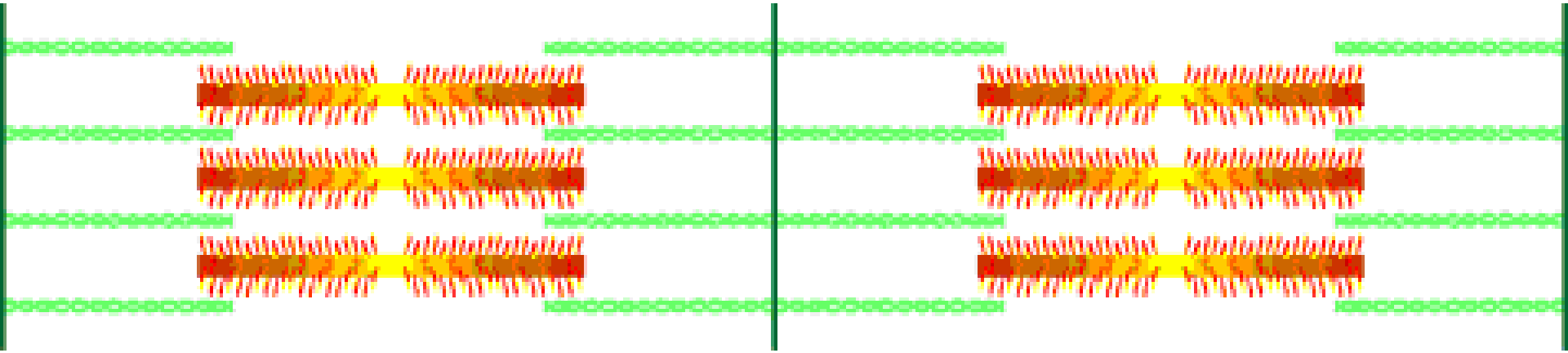
3. Power stroke; filaments slide past one another

5. ATP is hydrolyzed and myosin heads return to resting position



6. If Ca^{2+} is returned to sarcoplasmic reticulum, muscle relaxes

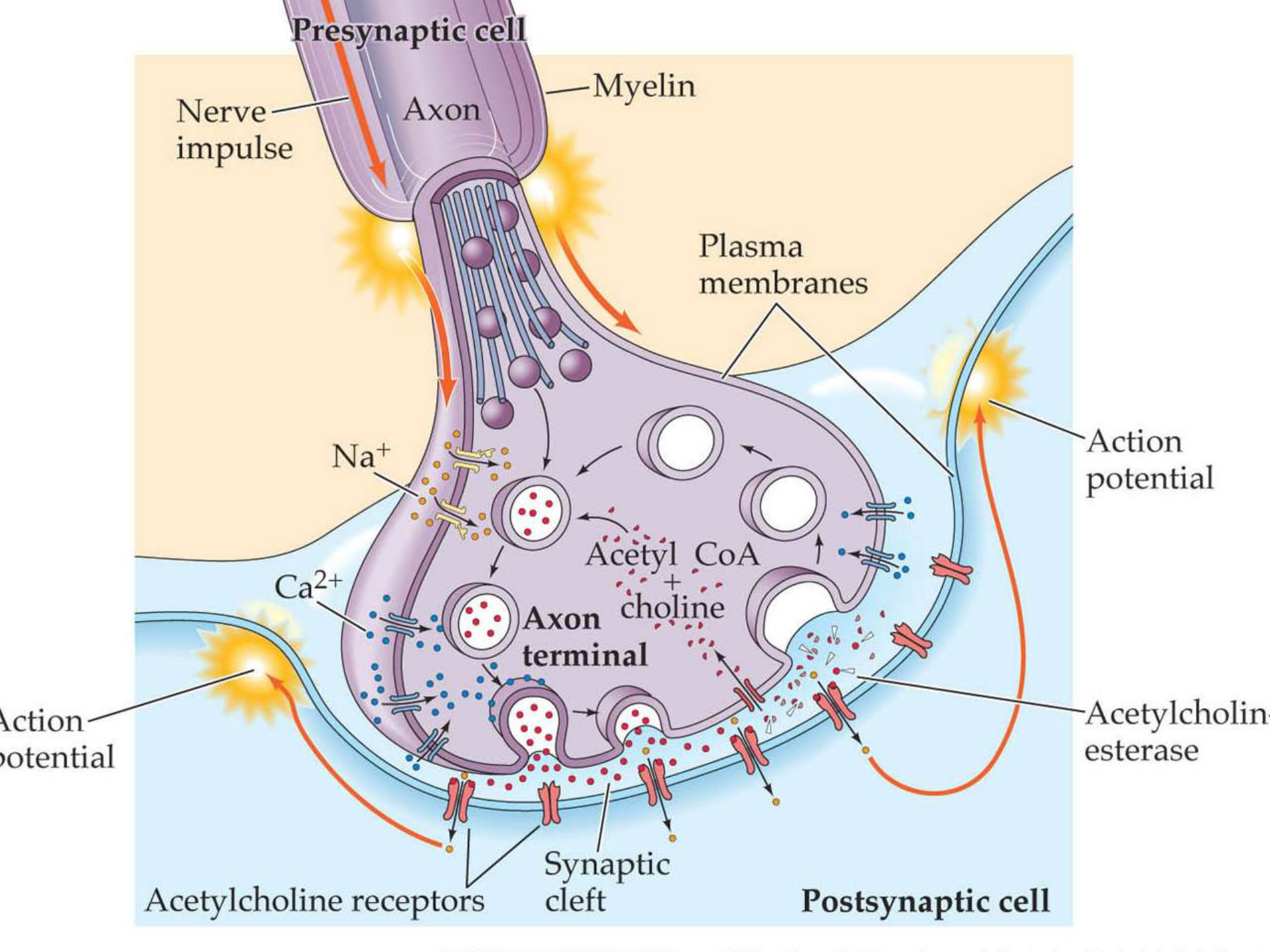
7. If Ca^{2+} remains available, the cycle repeats and muscle contraction continues



The end of a contraction…

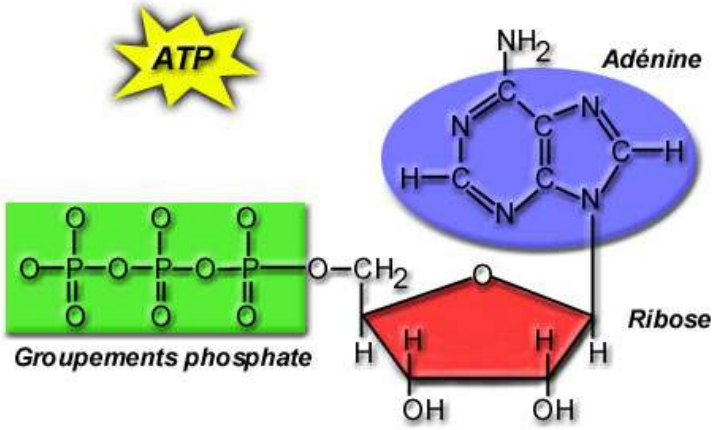
> the muscle fiber relaxes (and the contraction ends) when **cross-bridges release from actin** and when **calcium ions are actively transported back into the sarcoplasmic reticulum** (without calcium present, the troponin-tropomyosin complex re-covers the myosin-binding sites on actin)

> acetylcholine is broken down by the enzyme **ACETYLCHOLINESTERASE**


Presynaptic cell
Nerve impulse
Axon
Myelin
Plasma membranes
Action potential
Na^+
Ca^{2+}
Acetyl CoA + choline
Axon terminal
Action potential
Acetylcholinesterase
Acetylcholine receptors
Synaptic cleft
Postsynaptic cell

Energy Sources for Contraction

- **ATP** supplies the energy for muscle fiber contraction



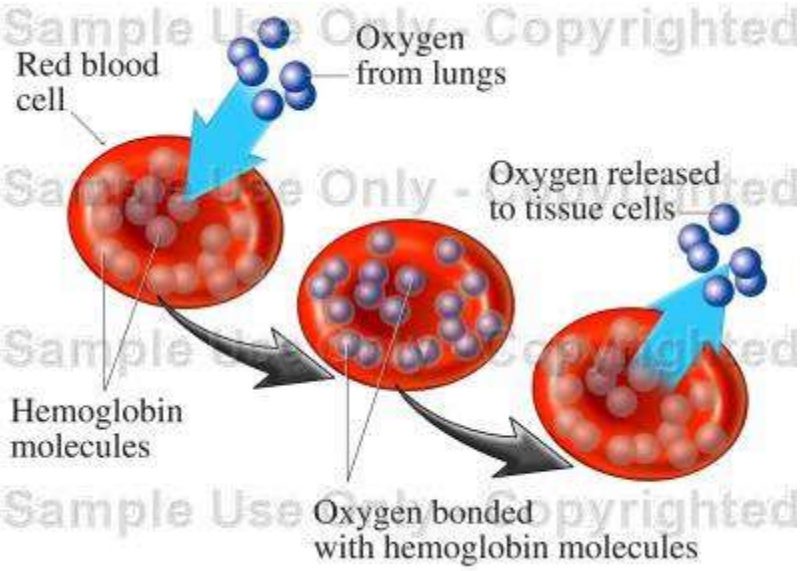
- for sustained muscle contractions, a molecule called **creatine phosphate** is used to make more ATP

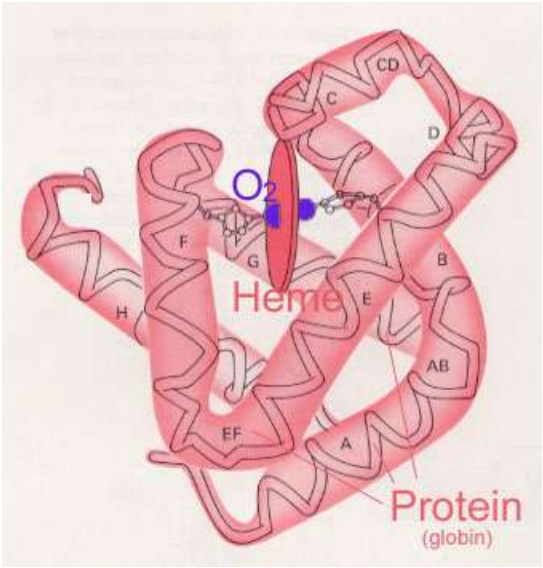
Oxygen Supply and Cellular Respiration

- aerobic respiration requires oxygen

- red blood cells carry oxygen to body cells (oxygen binds to **HEMOGLOBIN** in the RBCs)

- **MYOGLOBIN** in muscle cells temporarily stores oxygen





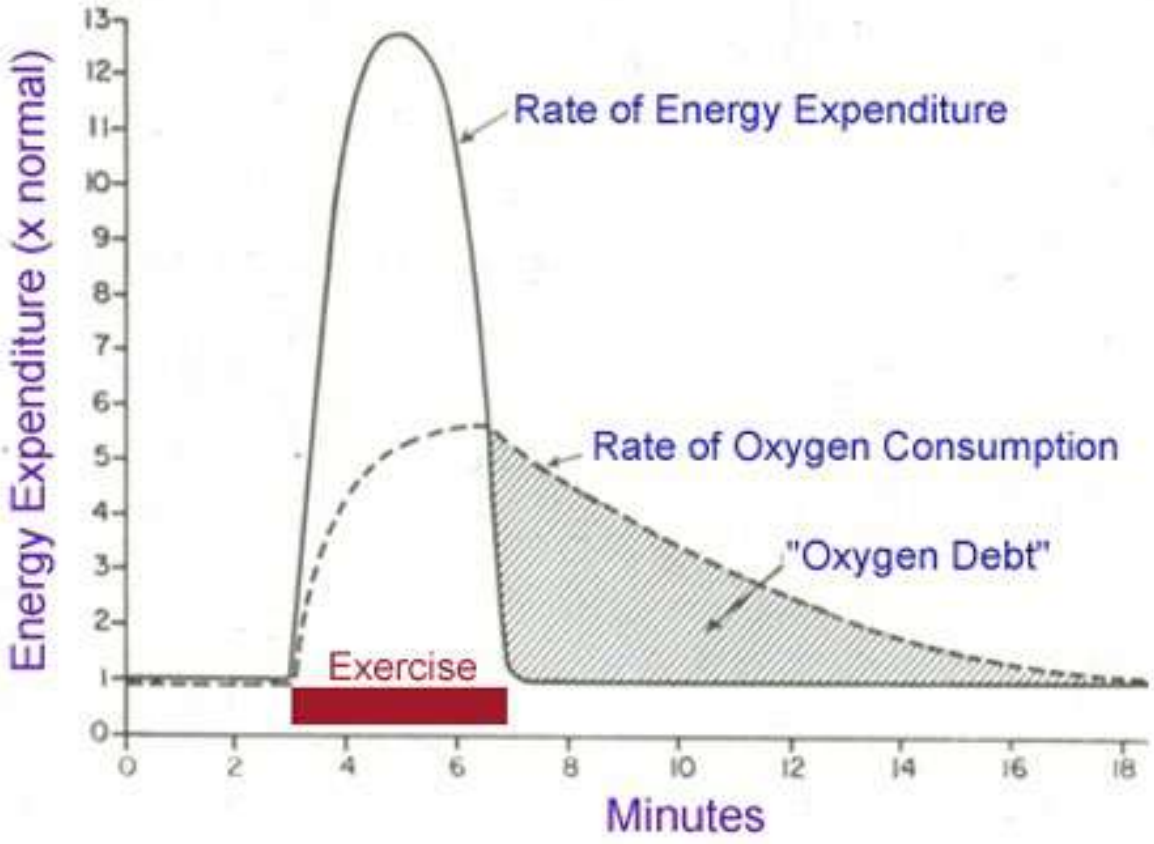
Oxygen Debt

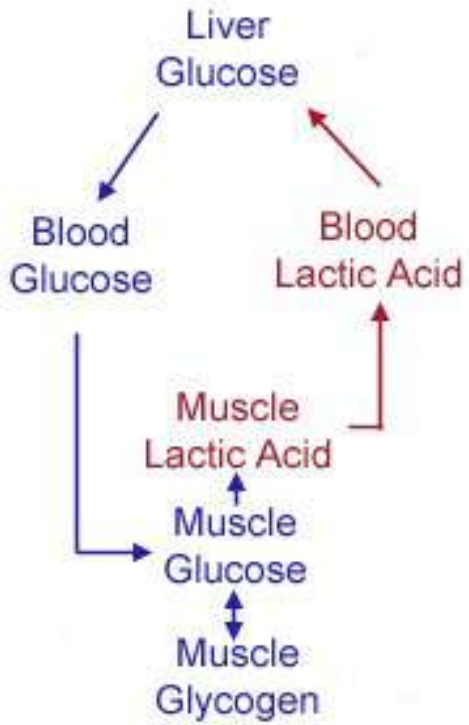
- during rest or moderate exercise, muscles receive enough oxygen to respire aerobically

- during strenuous exercise, oxygen deficiency may cause **LACTIC ACID** to accumulate

- **OXYGEN DEBT** is the amount of oxygen required to convert accumulated lactic acid to glucose and to restore supplies of ATP

the metabolic capacity of a muscle may change with training!

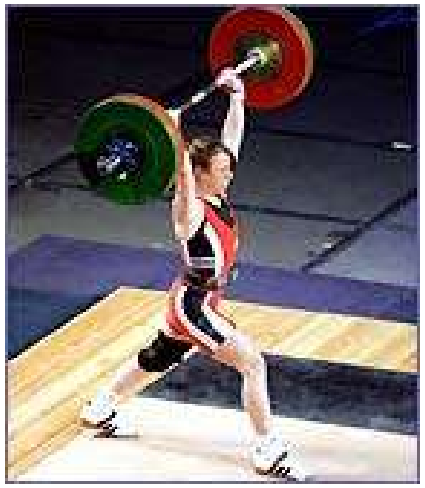

Energy Expenditure (x normal)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Rate of Energy Expenditure
Rate of Oxygen Consumption
"Oxygen Debt"
Exercise
0
2
4
6
8
10
12
14
16
18
Minutes


Liver
Glucose
Blood
Glucose
Blood
Lactic Acid
Muscle
Lactic Acid
Muscle
Glucose
Muscle
Glycogen

Muscle Fatigue:

- a fatigued muscle loses its ability to contract

- muscle fatigue is usually due to **accumulated lactic acid**



Heat Production

muscle action is an important source of body heat!