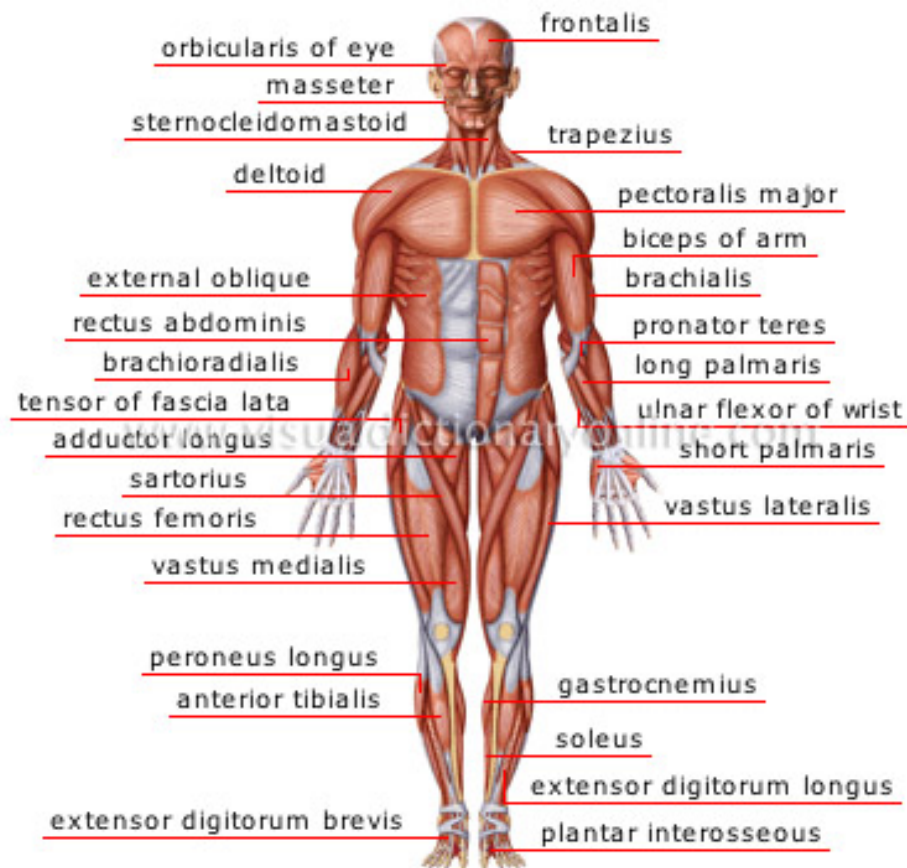


The Muscular System

Specialized tissue that enable the body and its parts to move.

Anterior View



Posterior View



TRIVIA!

- **How many muscles are there in the human body?**
 - Answer: 640 Muscles
 - The muscles make up about 40 % of the body mass.
- **What is the longest muscle in the body?**
 - Answer: *The Sartorius*
 - The **Sartorius** runs from the outside of the hip, down and across to the inside of the knee. It twists and pulls the thigh outwards.
- **What is the smallest muscle in the body?**
 - Answer: *The Stapedius*
 - The **Stapedius** is located deep in the ear. It is only 5mm long and thinner than cotton thread. It is involved in hearing.
- **What is the biggest muscle in the body?**
 - Answer: *The Gluteus Maximus*
 - The **Gluteus Maximus** is located in the buttock. It pulls the leg backwards powerfully for walking and running.

Functions of the Muscles

- Movement
- Maintenance of posture and muscle tone
- Heat production
- Protects the bones and internal organs.

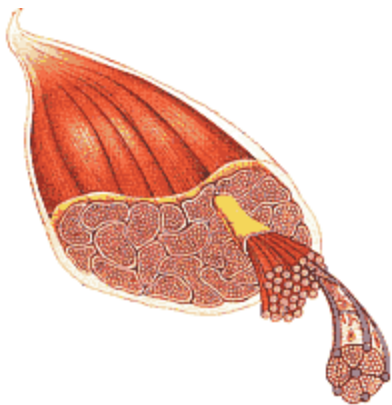
Muscle Classification

- Functionally
 - Voluntarily – can be moved at will
 - Involuntarily – can't be moved intentionally
- Structurally
 - Striated – have stripes across the fiber
 - Smooth – no striations

The 3 Types of Muscles

3 Types of Muscles

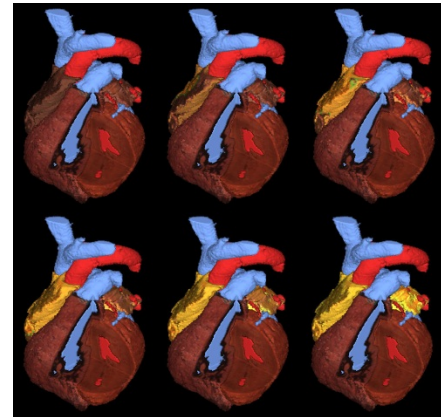
Skeletal Muscle



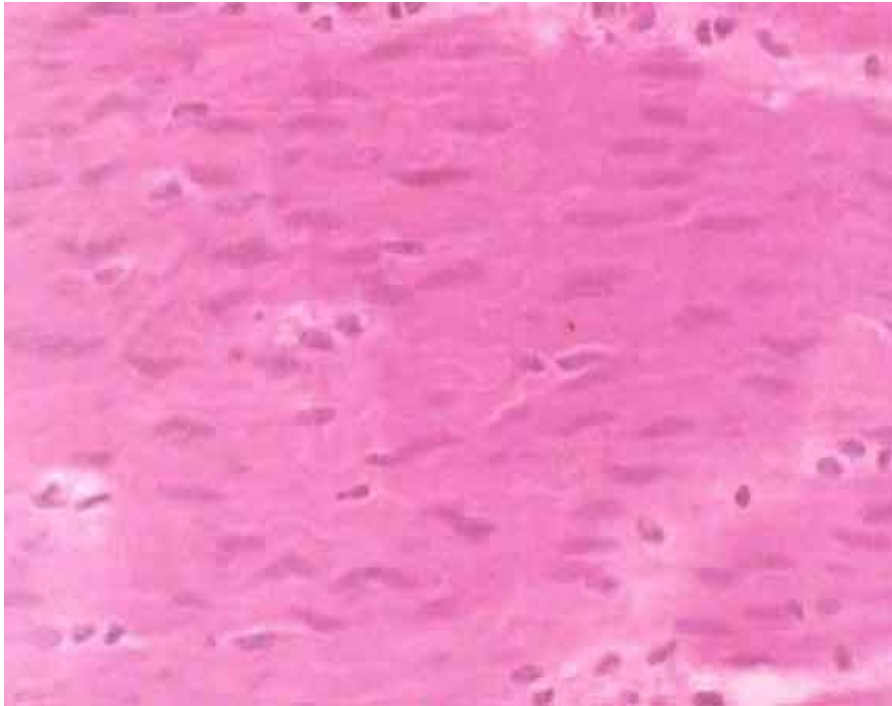
Smooth Muscle



Cardiac Muscle



Smooth Muscle

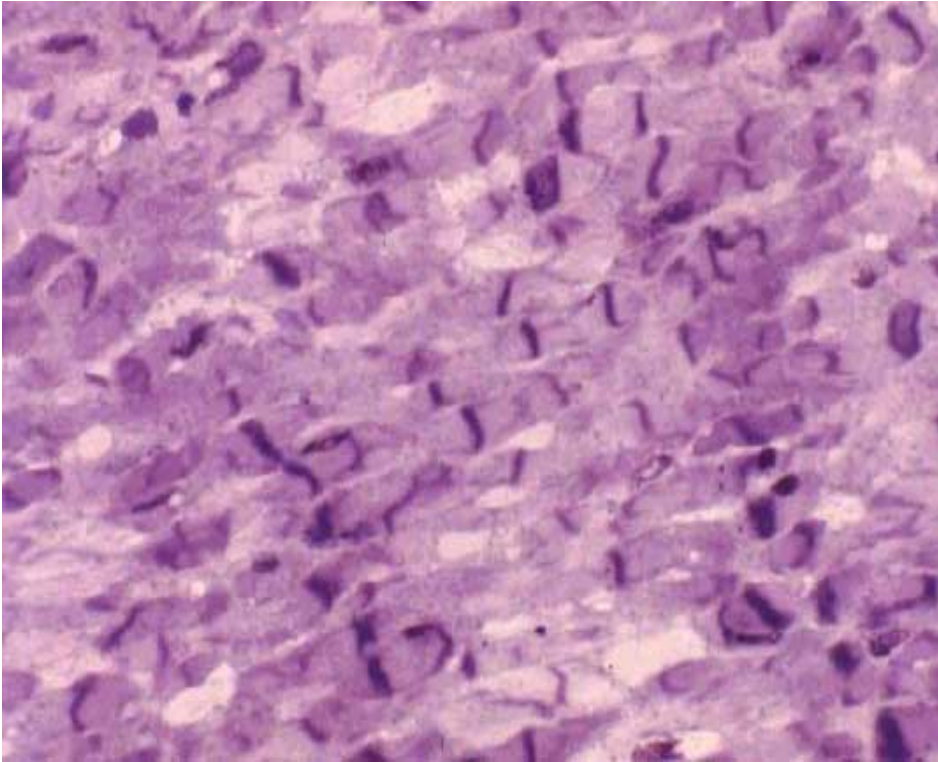


- Fibers are thin and spindle shaped.
- No striations
- Single nuclei
- Involuntary
- Contracts slowly

Smooth Muscle

- **They fatigue... but very slowly**
- **Found in the circulatory system**
 - **Lining of the blood vessels**
 - **Helps in the circulation of the blood**
- **Found in the digestive system**
 - **Esophagus, stomach, intestine**
 - **Controls digestion**
- **Found in the respiratory system**
 - **Controls breathing**
- **Found in the urinary system**
 - **Urinary bladder**
 - **Controls urination**

Cardiac Muscle

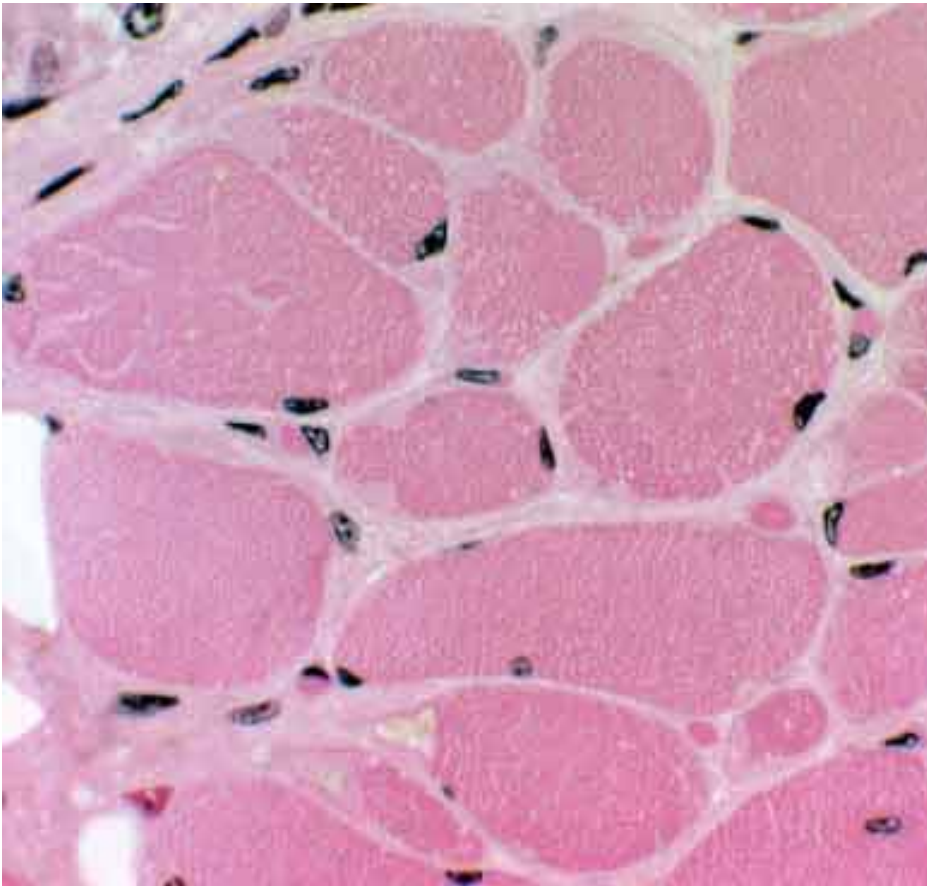


- Cells are branched and appear fused with one another
- Has striations
- Each cell has a central nuclei
- Involuntary

Cardiac Muscle

- Found **ONLY** in the heart
- Contractions of the heart muscles pump blood throughout the body and account for the heartbeat.
- Healthy cardiac muscle **NEVER** fatigues → or else...

Skeletal Muscle



- Fibers are long and cylindrical
- Has many nuclei
- Has striations
 - Have alternating dark and light bands
- Voluntary

Skeletal Muscle

- Attached to skeleton by tendons
- Causes movement of bones at the joints.
- And yes... they do fatigue
- Muscle fatigue activity → what substance forms causing muscle fatigue???
 - Lactic Acid

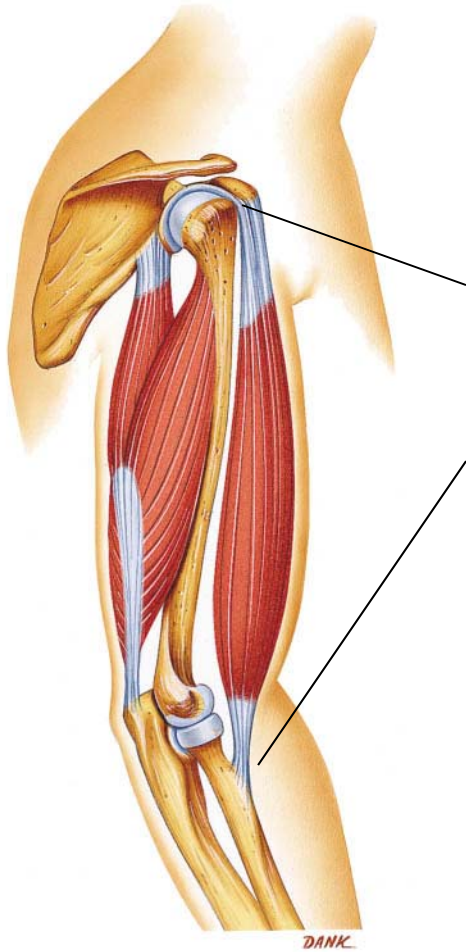
Functions of Skeletal Muscle

- Movement – muscle move bones by pulling not pushing.
 - Synergists – any movement is generally accomplished by more than one muscle. All of the muscles responsible for the movement are synergists.
 - The one that is most responsible for the movement is the Prime Mover (agonist).

Functions of Skeletal Muscle

- Movement
 - Antagonists – muscles and muscle groups usually work in pairs
 - example the biceps flex your arm and its partner the triceps extend your arm. The two muscles are antagonists, i.e. cause opposite actions.
 - when one contracts the other relaxes.
 - Levators – muscle that raise a body part.

Anatomy of the Muscular System



- *Origin*

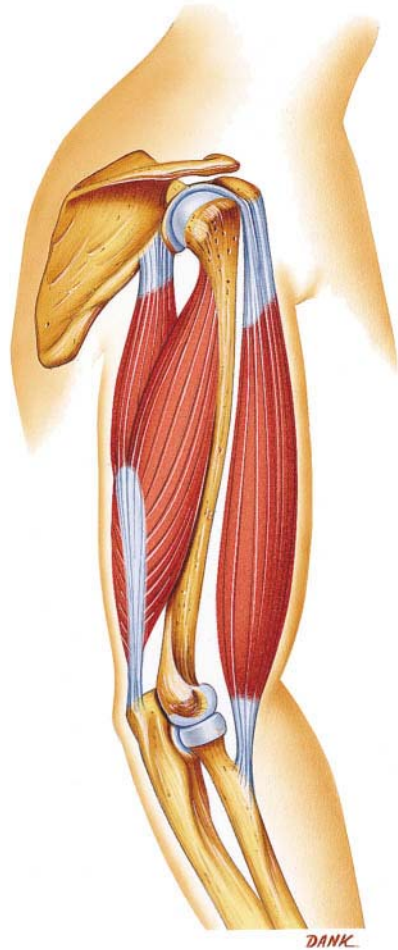
Muscle attachment that remains fixed

- *Insertion*

Muscle attachment that moves

- *Action*

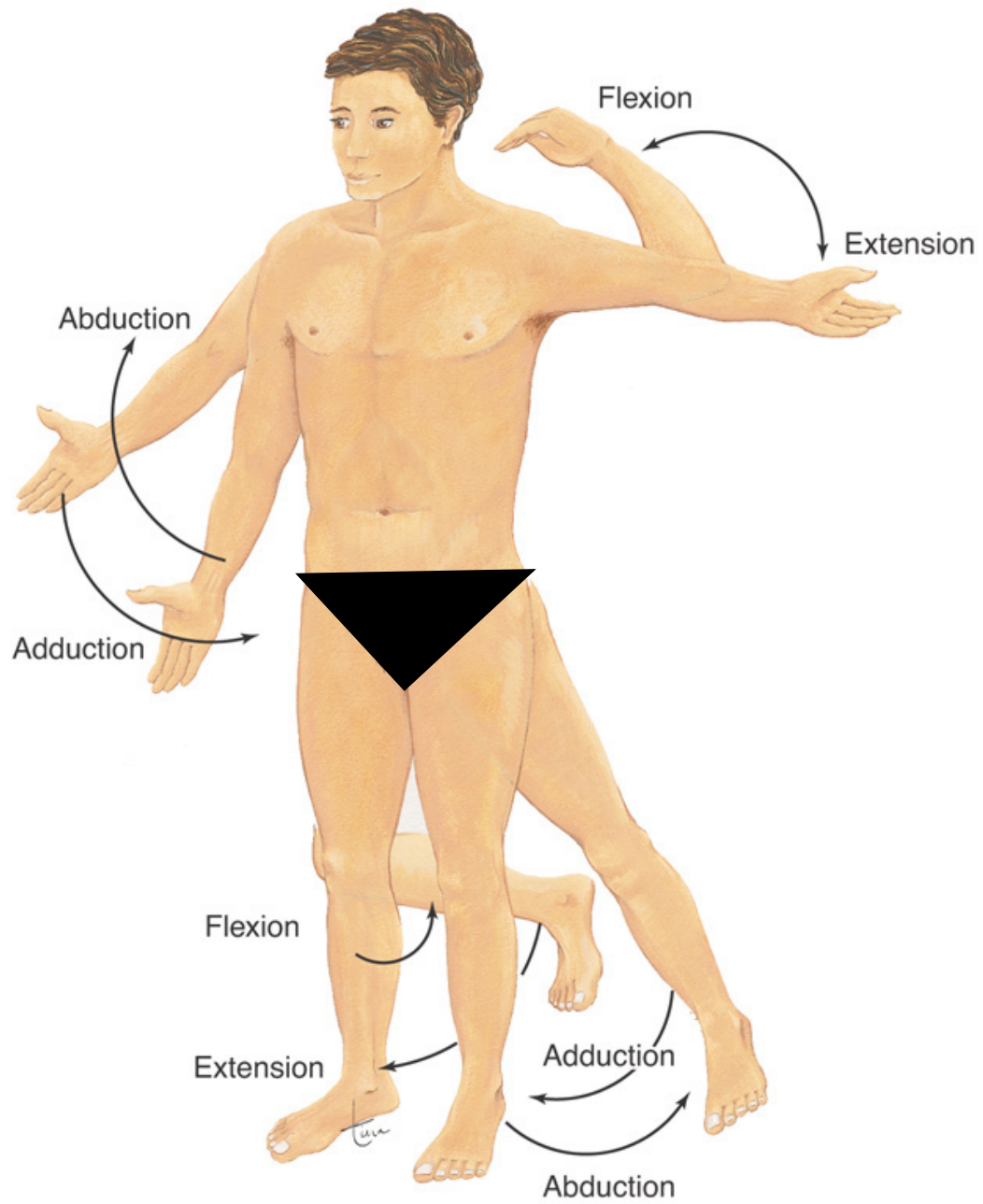
What joint movement a muscle produces
i.e. flexion, extension, abduction, etc.

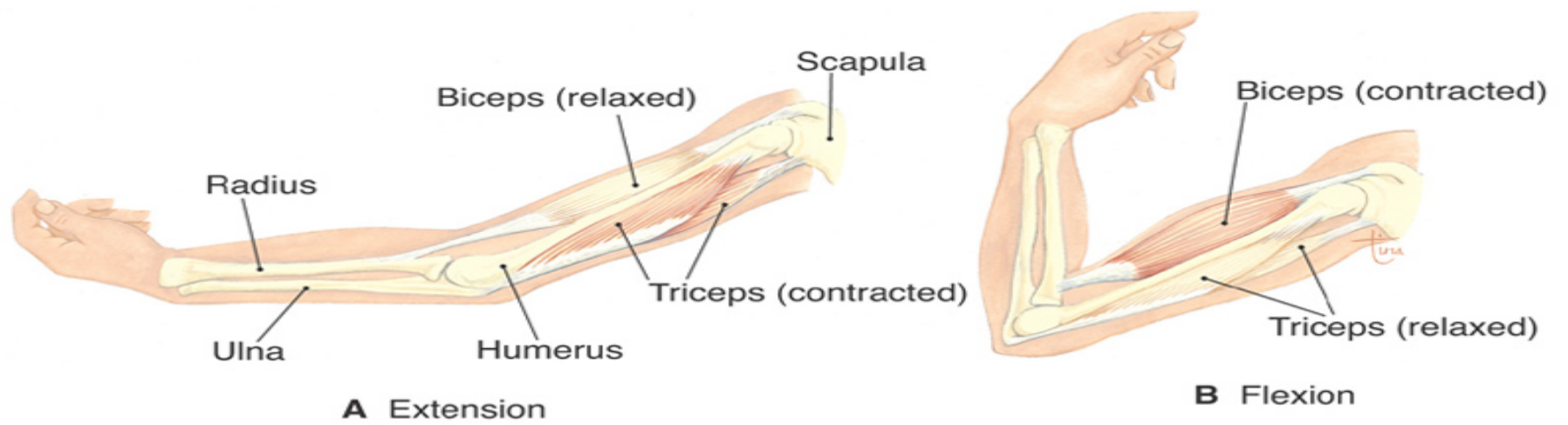


- For muscles to create a movement, they can *only pull*, not push
- Muscles in the body rarely work alone, & are usually arranged in groups surrounding a joint
- A muscle that contracts to create the desired action is known as an **agonist** or **prime mover**
- A muscle that helps the agonist is a **synergist**
- A muscle that opposes the action of the agonist, therefore undoing the desired action is an **antagonist**

Categories of skeletal muscle actions

- Categories Actions
- **Extensor** Increases the angle at a joint
- **Flexor** Decreases the angle at a joint
- **Abductor** Moves limb away from long axis of body
- **Adductor** Moves limb toward long axis of body
- **Levator** Moves insertion upward
- **Depressor** Moves insertion downward
- **Rotator** Rotates a bone along its axis
- **Sphincter** Constricts an opening





Functions of Skeletal Muscle

- Maintenance of posture or muscle tone
 - We are able to maintain our body position because of tonic contractions in our skeletal muscles. These contractions don't produce movement yet hold our muscles in position.
- Heat production – contraction of muscles produces most of the heat required to maintain body temperature.

Structure of Skeletal Muscle

- Composed of striated muscle cells (=muscle fibers) and connective tissue.
 - Most muscles attach to 2 bones that have a moveable joint between them.
 - The attachment to the bone that does not move is the origin.
 - The attachment to the bone that moves is the insertion.
 - Tendons anchor muscle firmly to bones. Tendons are made of dense fibrous connective tissue.
 - Ligaments connect bone to bone at a joint.

Structure of Skeletal Muscle

- Bursae – small fluid filled sacs that lie between some tendons and the bones beneath them. They are made of connective tissue and are lined with synovial membrane that secretes synovial fluid.

Structure of Skeletal Muscle

- Contribution of the nervous system
 - Electrochemical impulses travel from the frontal lobes of the cerebrum via motor nerves to the muscle fibers and cause them to contract.
 - Sensation is a function of the brain – impulses are integrated in the parietal lobes of the cerebrum (conscious muscle sense) and in the cerebellum (unconscious). These activities promote coordination.

Structure of Skeletal Muscle

- Microscopic anatomy
 - Muscle cells (fibers) are grouped in a highly organized way in the muscle. The membrane that surrounds the muscle cell is called the sarcolemma.
 - Muscle cells are filled with 2 types of fine threadlike proteins called myofilaments: myosin (thick) and actin (thin). These structures slide past each other causing the muscle cell to contract or shorten.
 - The myofilaments are arranged in the cells in small units called sarcomeres.

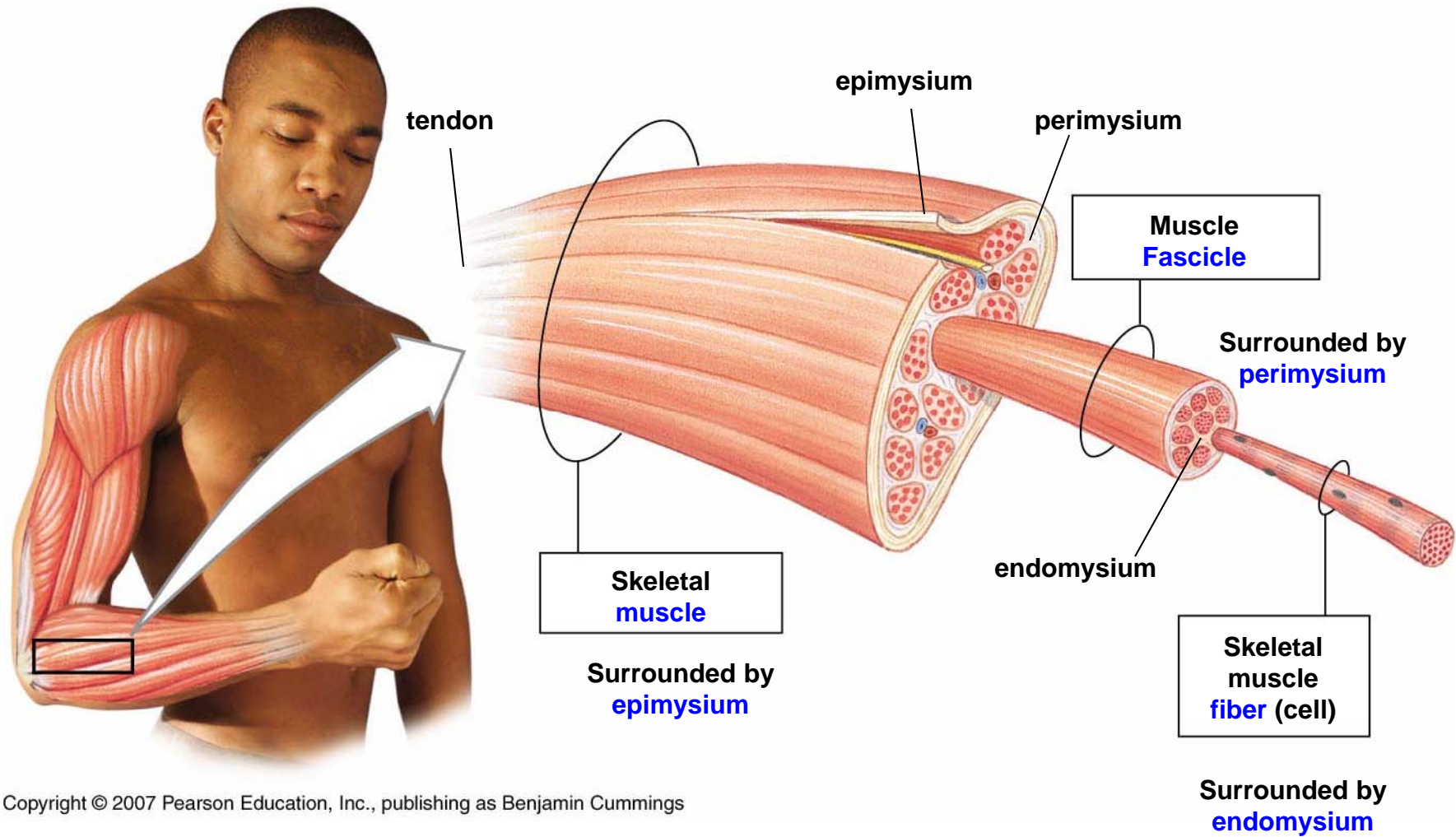
Structure of Skeletal Muscle

- Neuromuscular junction
 - Spot where the axon of a motor nerve nears the muscle fiber.
 - The axon terminal does not touch the muscle but comes close. The space between the axon and the muscle cell is called the synapse.
 - Within the terminal end of the axon are small sacs filled with a neurotransmitter called acetylcholine.

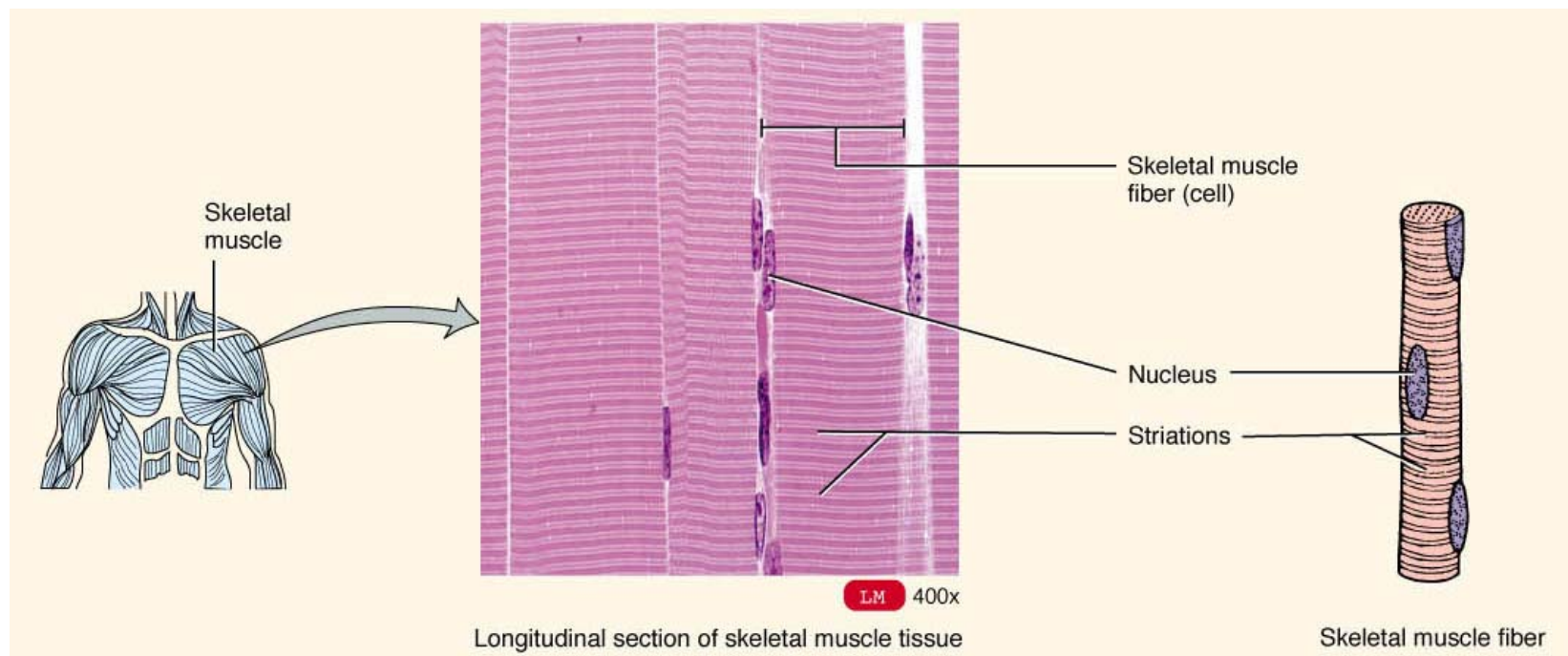
Muscle Contraction

- Sequence
 - Electrical impulse travels down a motor neuron. When it reaches the end, acetylcholine (chemical) is released into the synapse.
 - Acetylcholine bind to special receptors on the muscle cell and causes an electrical impulse to spread over the cell.
 - The sarcomeres shorten and the muscle cell contracts.

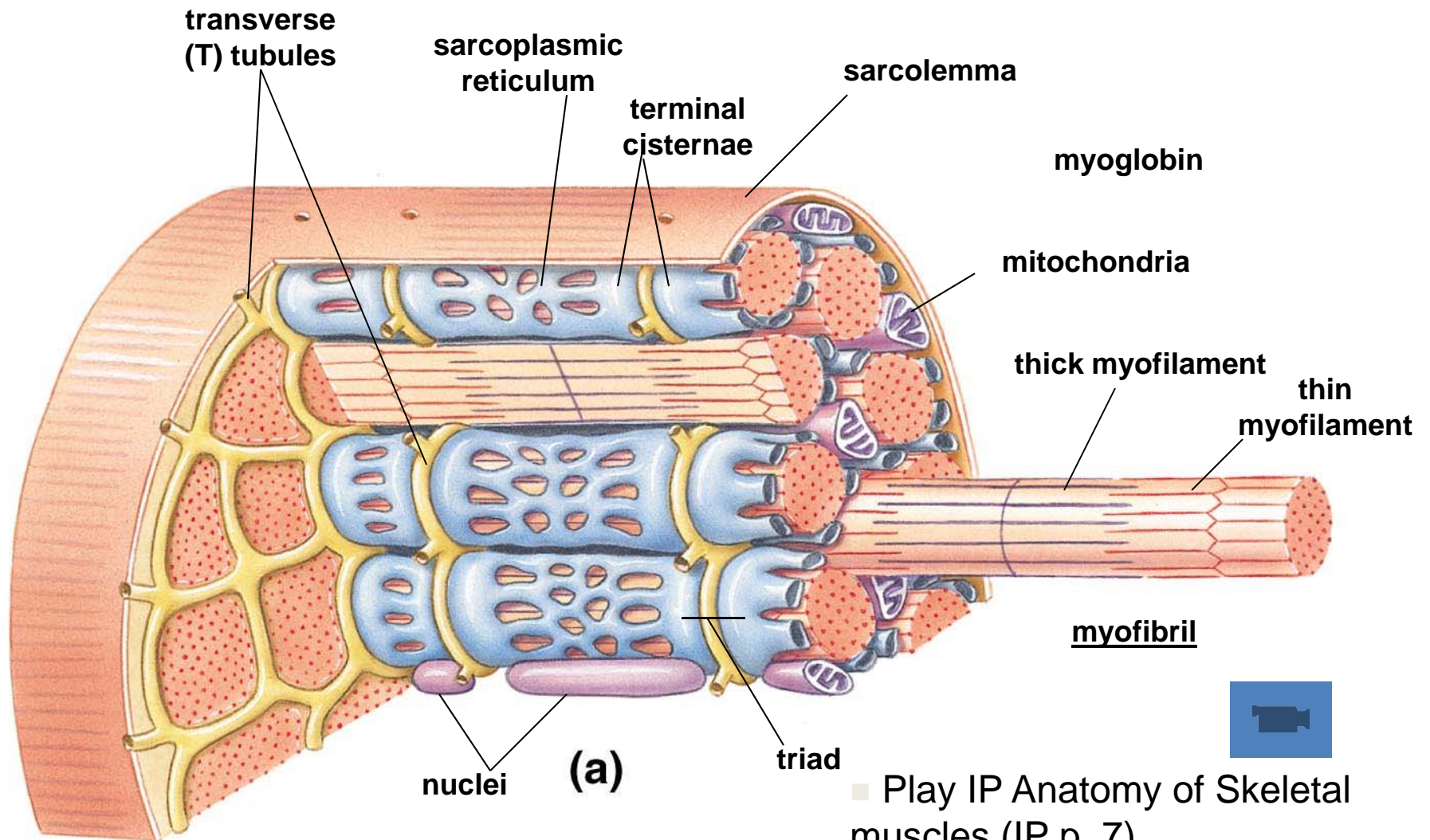
Anatomy of skeletal muscles



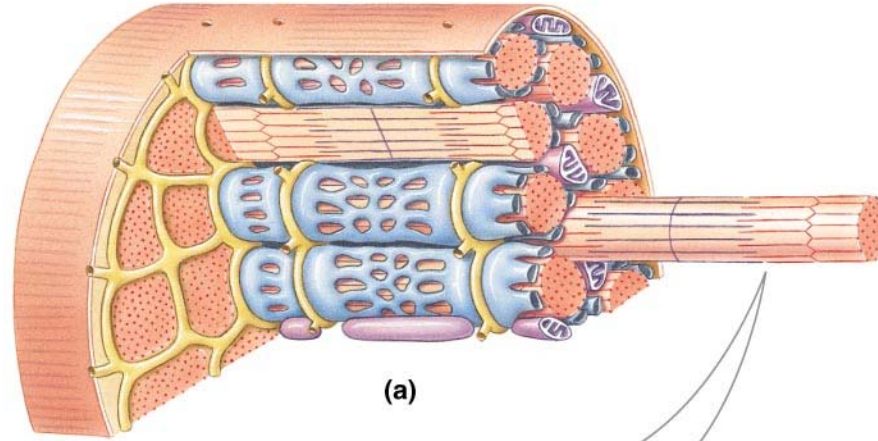
Microanatomy of a Muscle Fiber (cell)



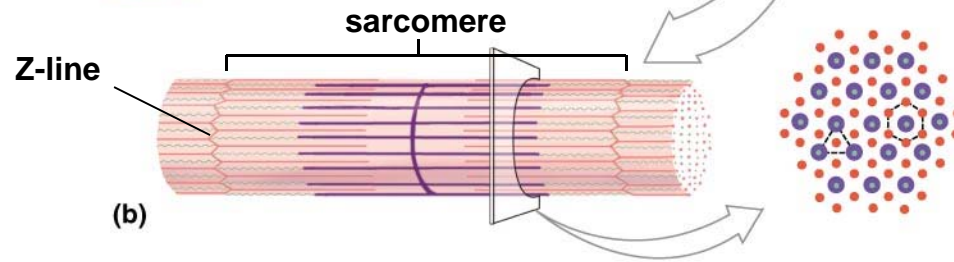
Microanatomy of a Muscle Fiber (Cell)



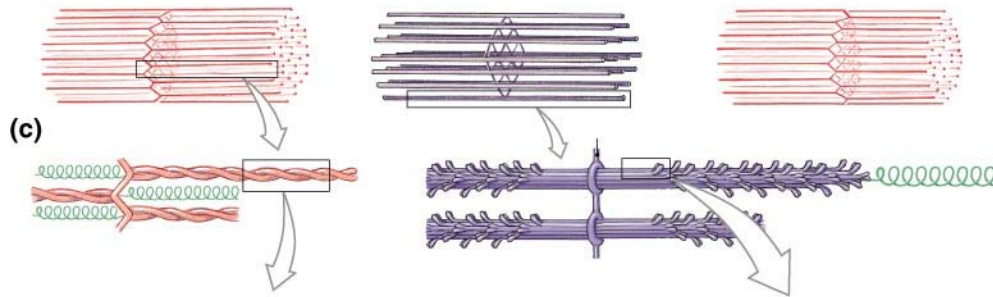
Muscle fiber



Myofibril



Sarcomere



Thin filaments



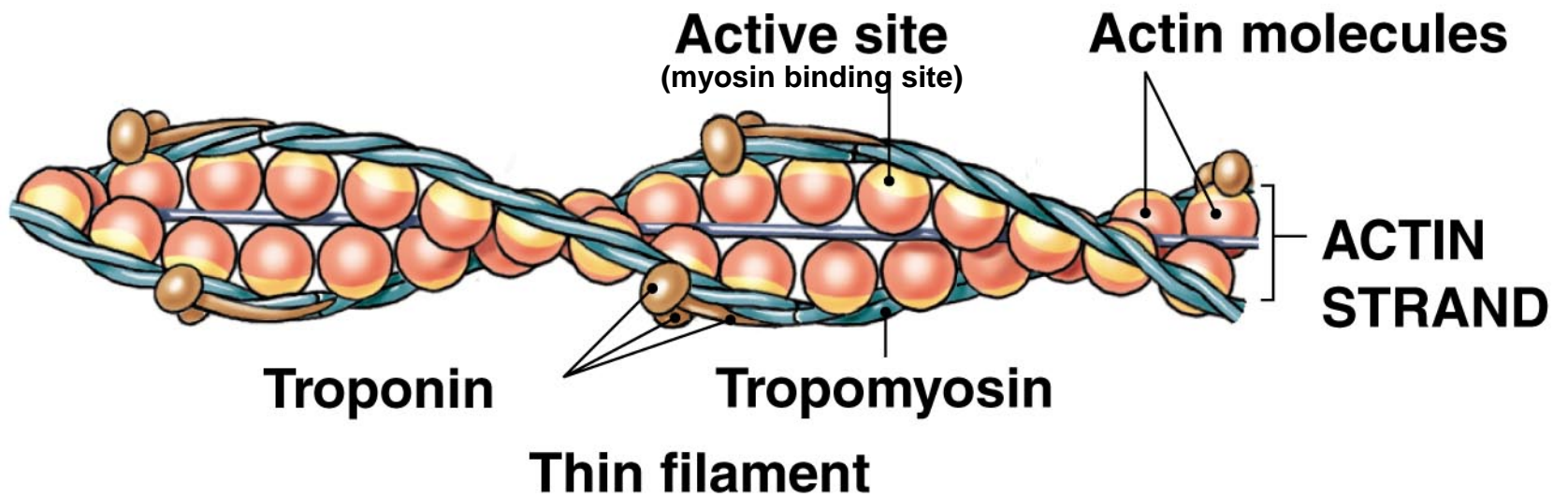
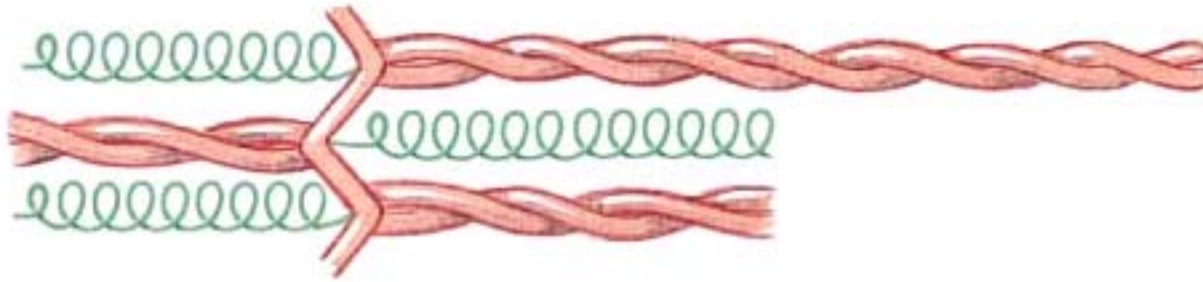
Thin myofilament

Thick filaments

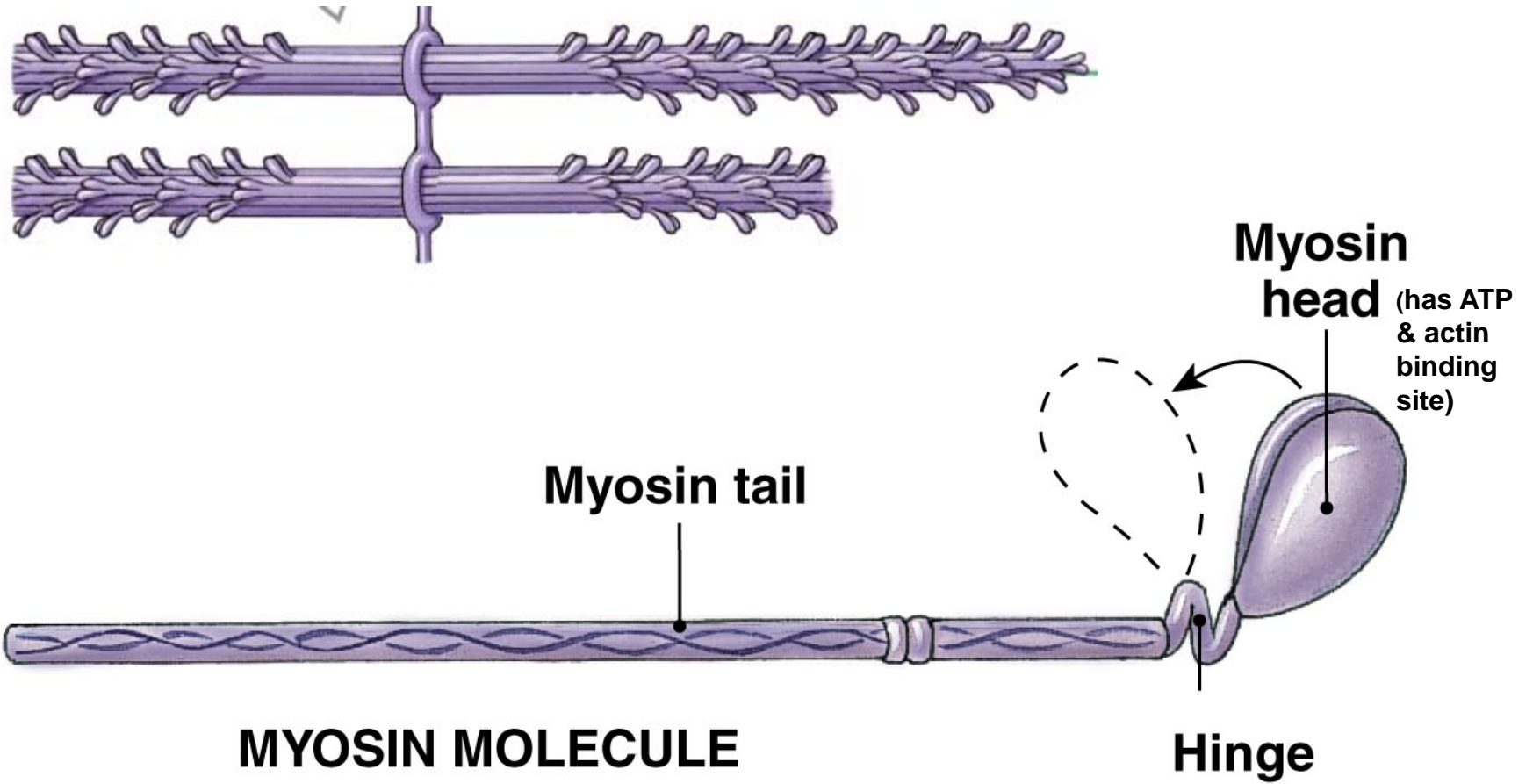


Myosin molecule of thick myofilament

Thin Myofilament



Thick myofilament

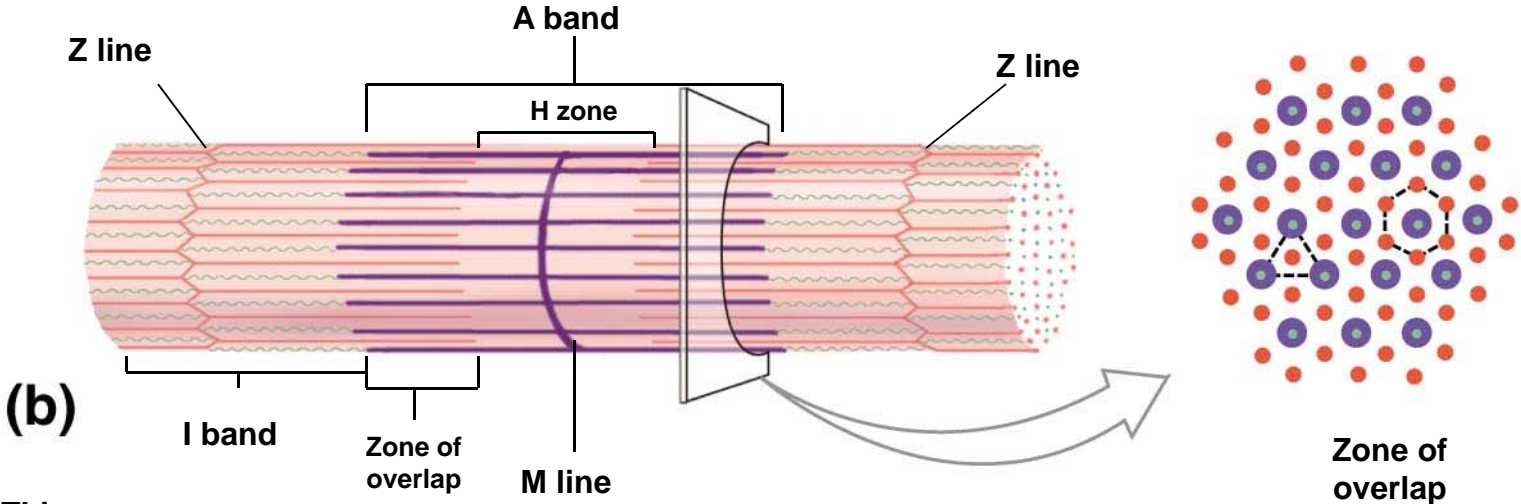


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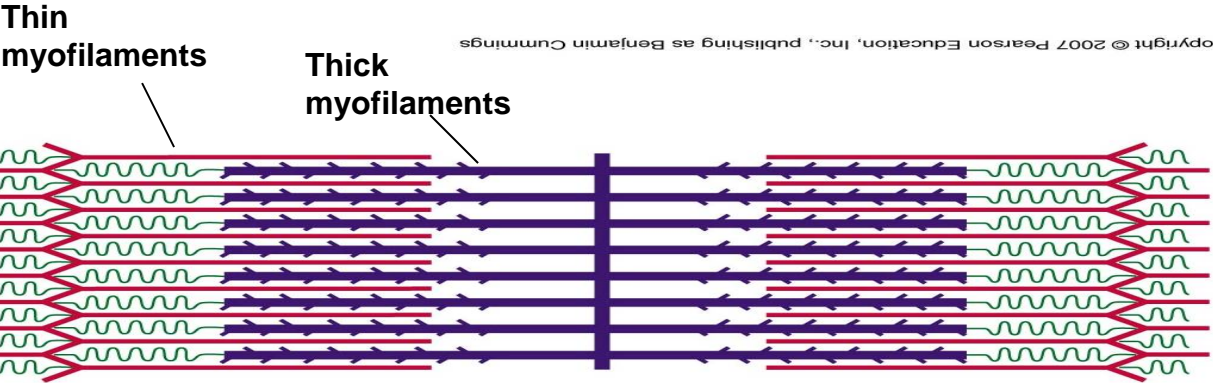
MYOSIN MOLECULE

Hinge

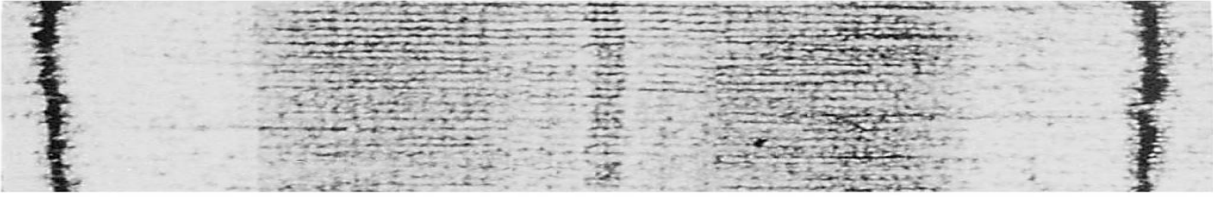
Sarcomere



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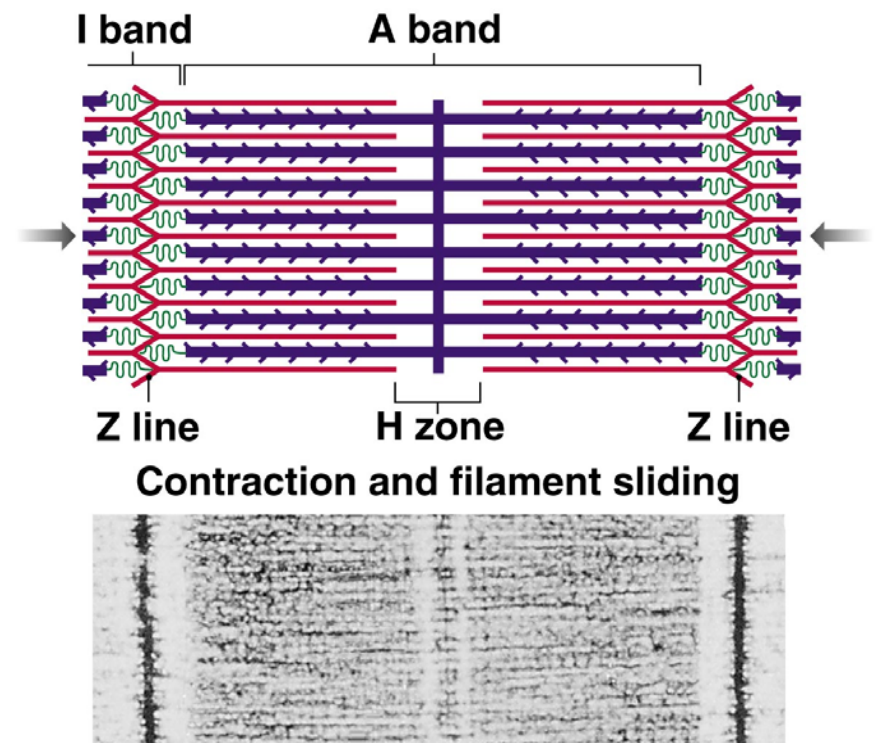
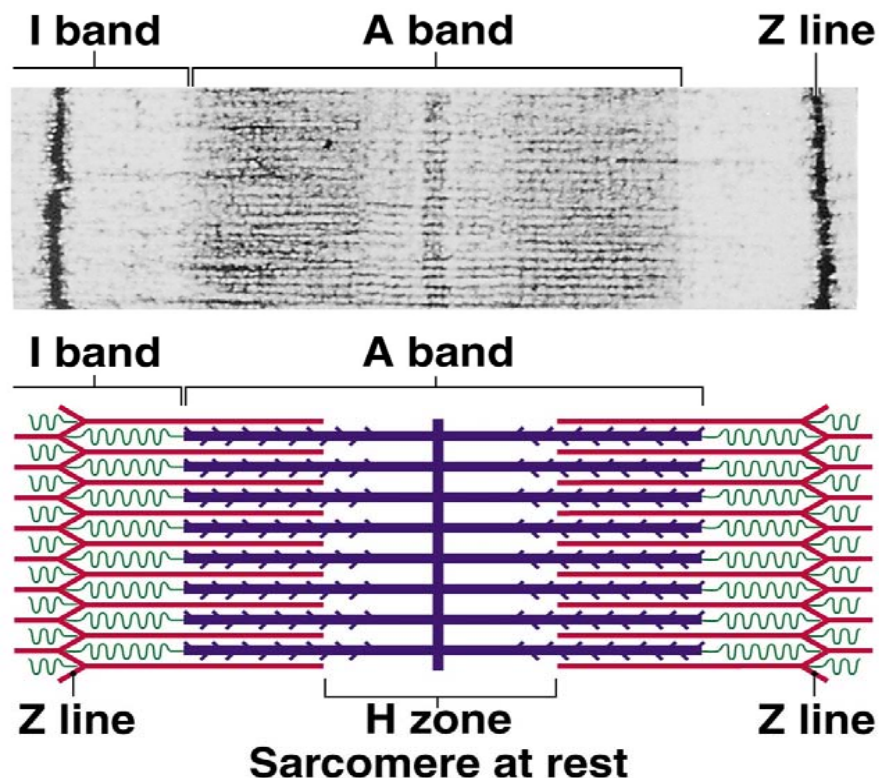


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Sliding Filament Theory

- Myosin heads attach to actin molecules (at binding (active) site)
- Myosin “pulls” on actin, causing thin myofilaments to slide across thick myofilaments, towards the center of the sarcomere
- Sarcomere shortens, I bands get smaller, H zone gets smaller, & zone of overlap increases



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- As sarcomeres shorten, myofibril shortens. As myofibrils shorten, so does muscle fiber
- Once a muscle *fiber* begins to contract, it will contract maximally
- This is known as the “all or none” principle

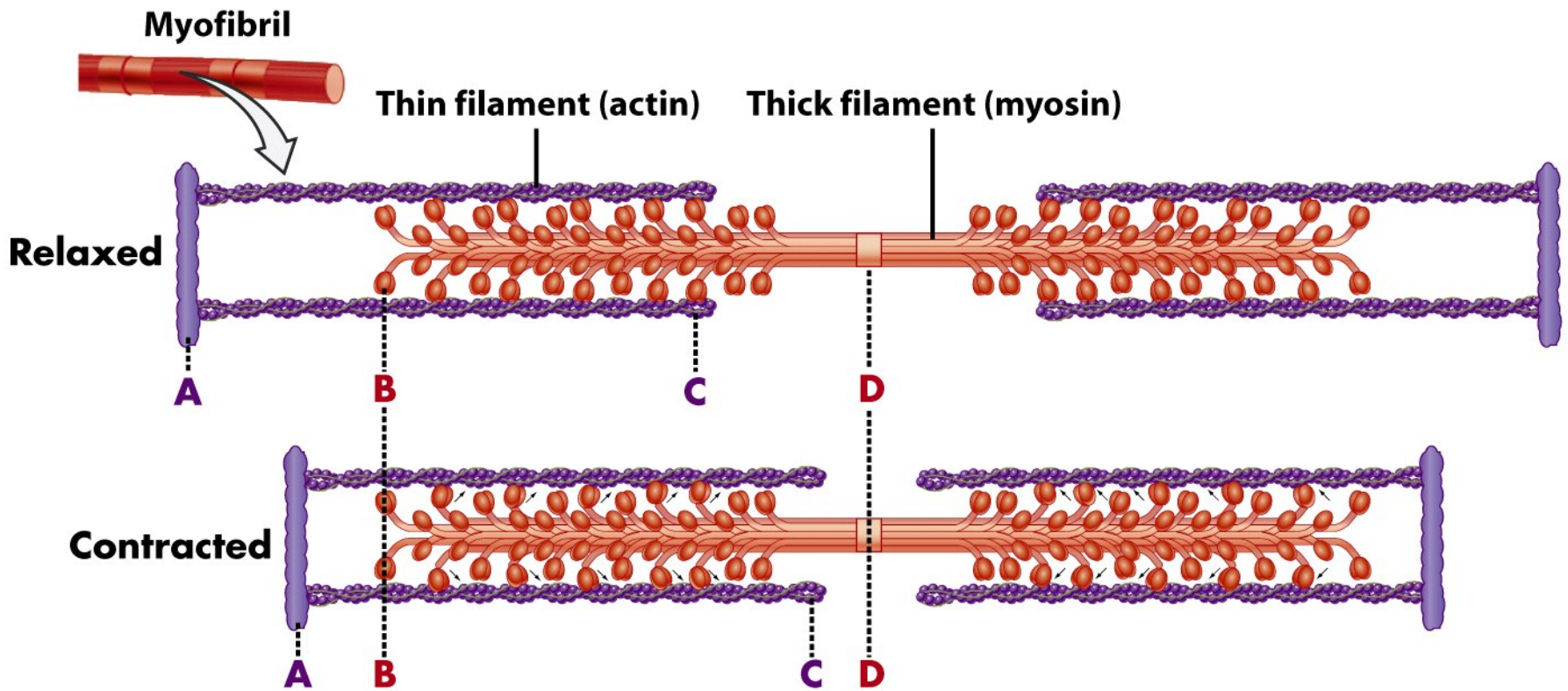
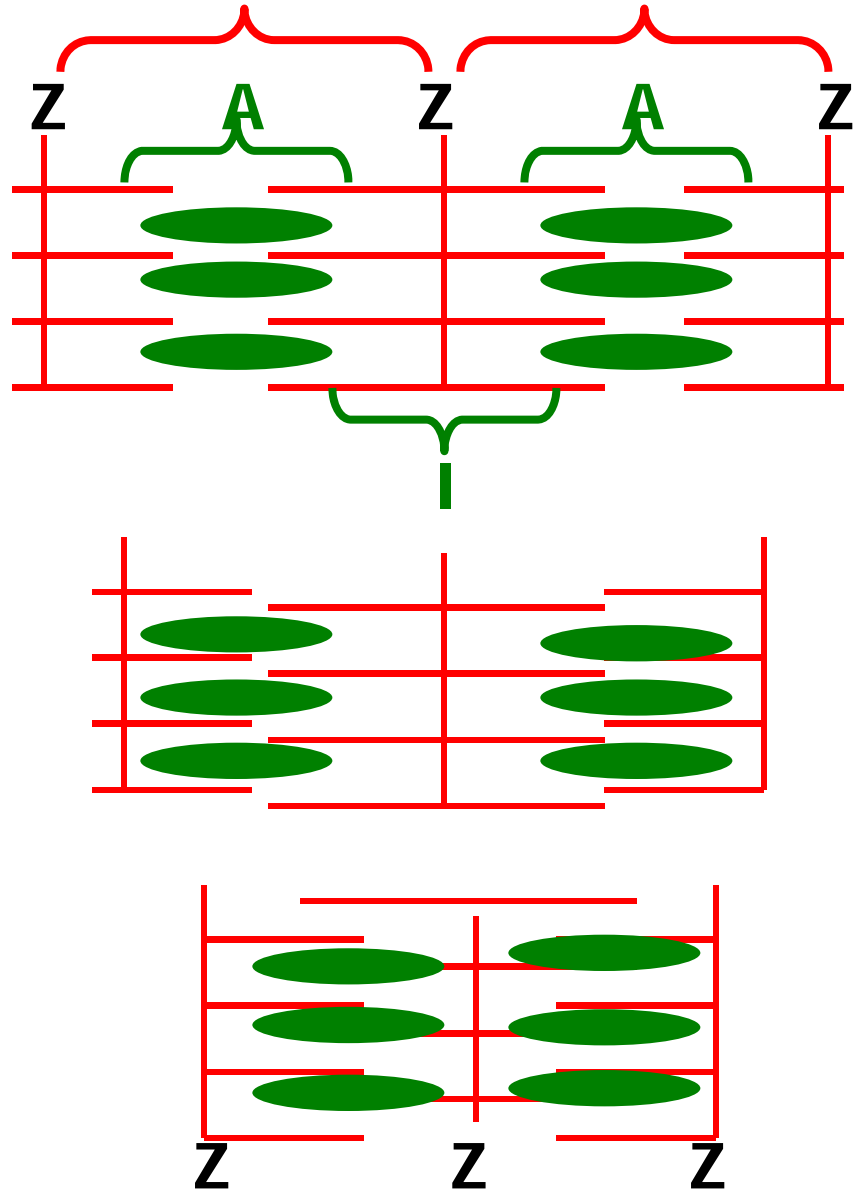


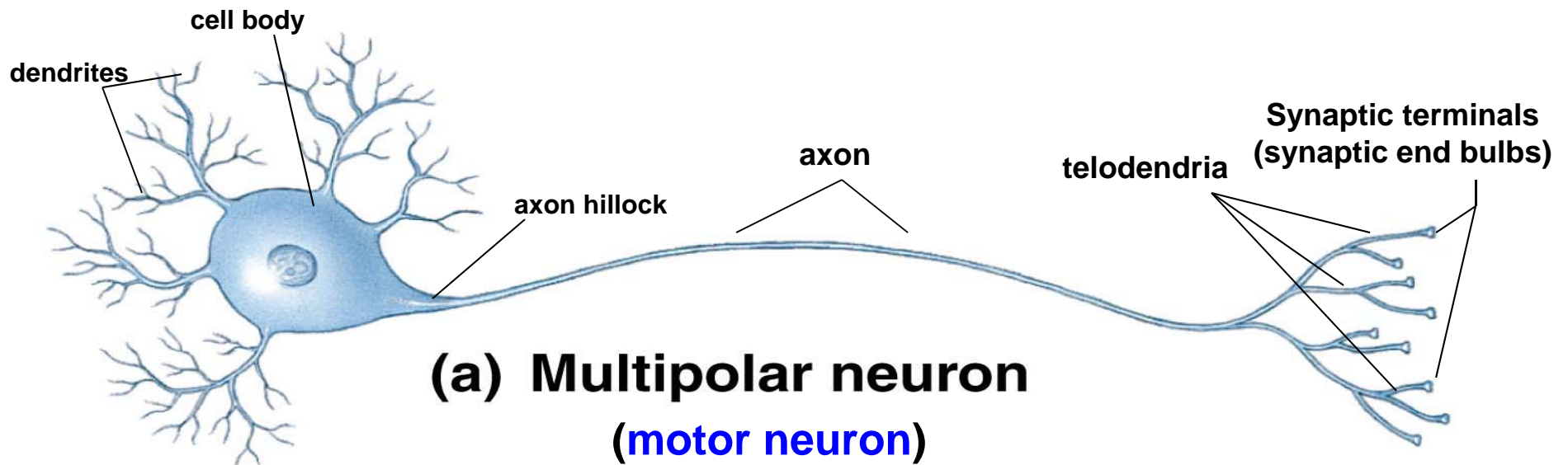
Figure 46-21 Biological Science, 2/e
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Sarcomere

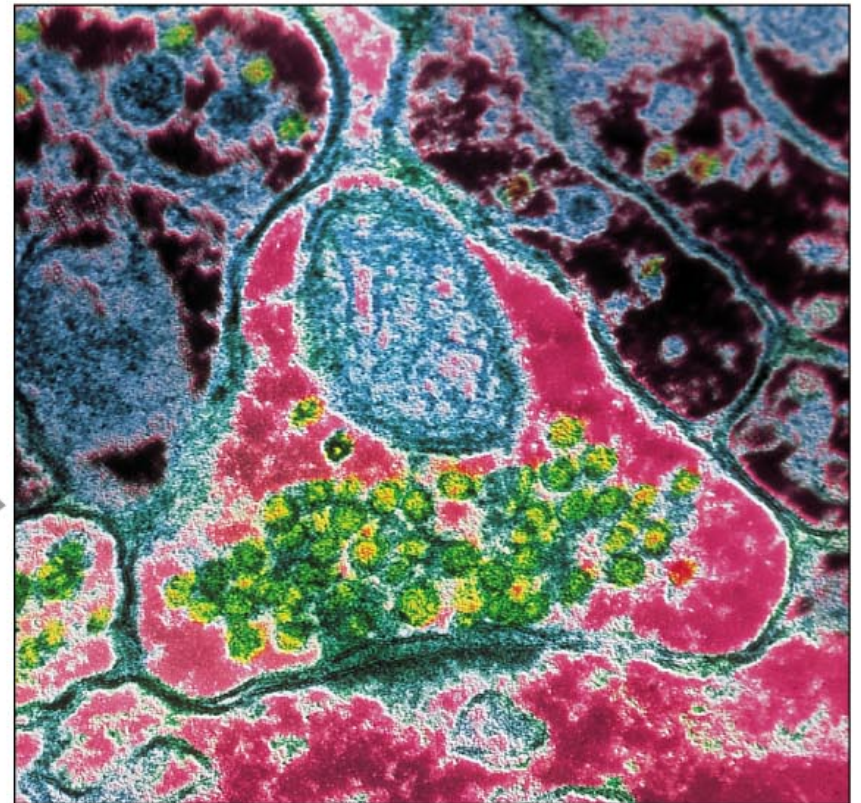
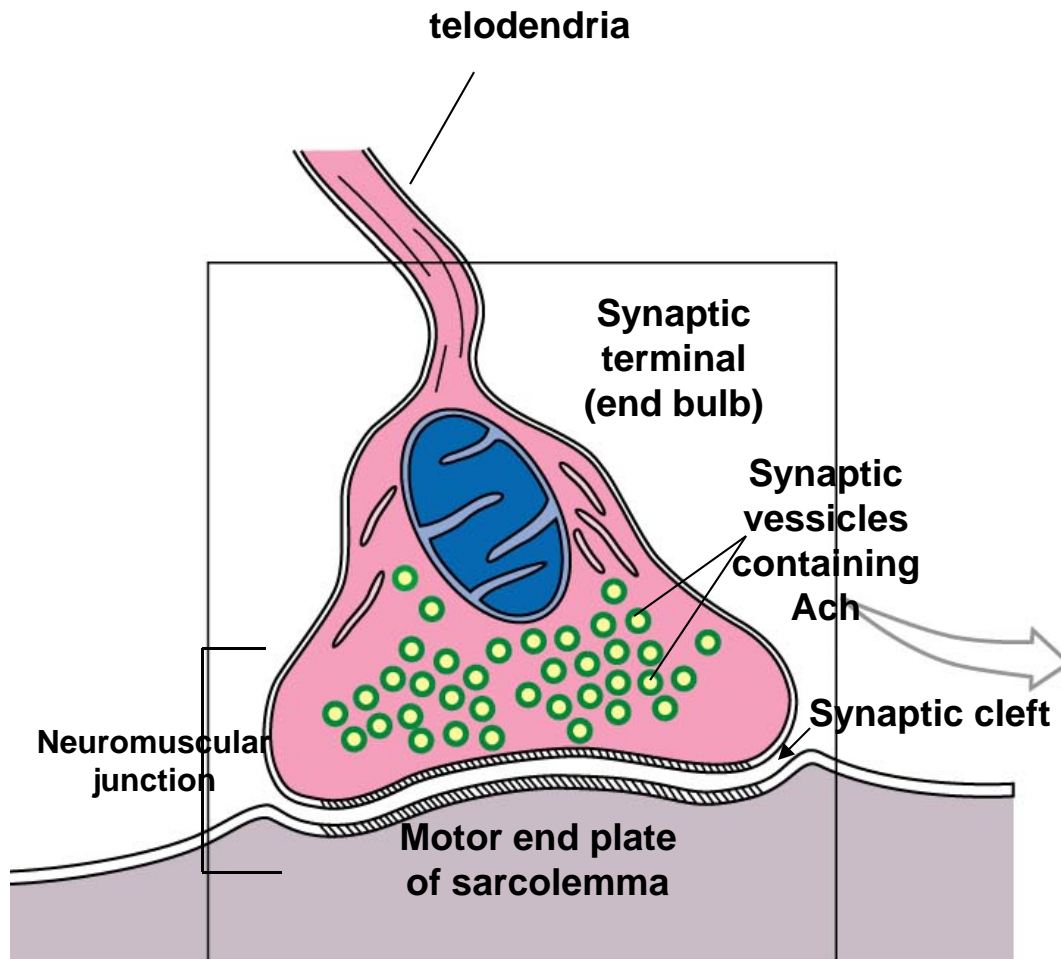


Physiology of skeletal muscle contraction

- Skeletal muscles require stimulation from the nervous system in order to contract
- *Motor neurons* are the cells that cause muscle fibers to contract

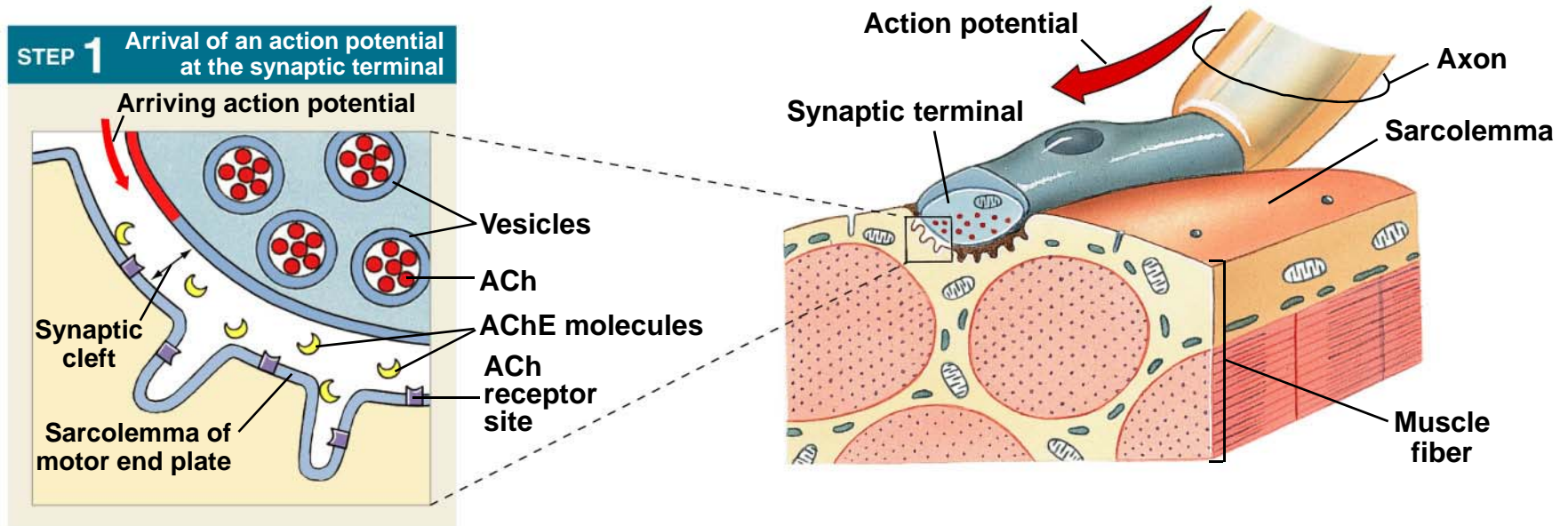


Neuromuscular junction



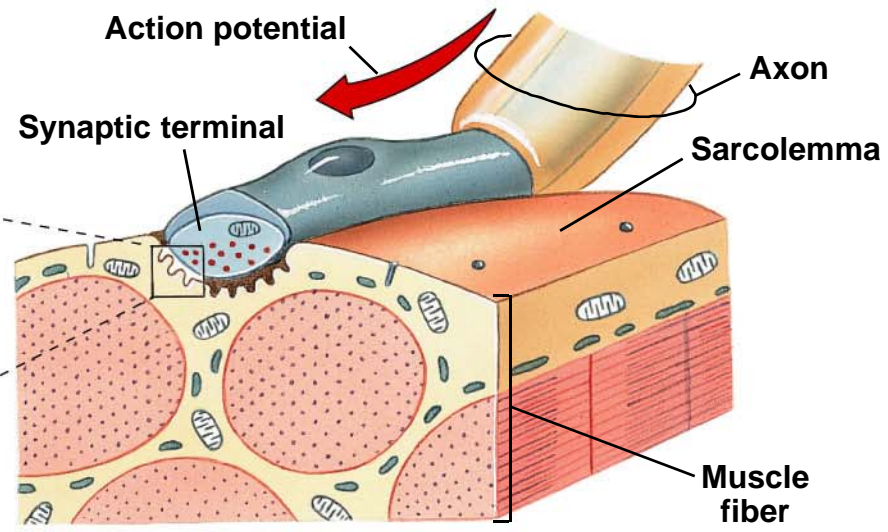
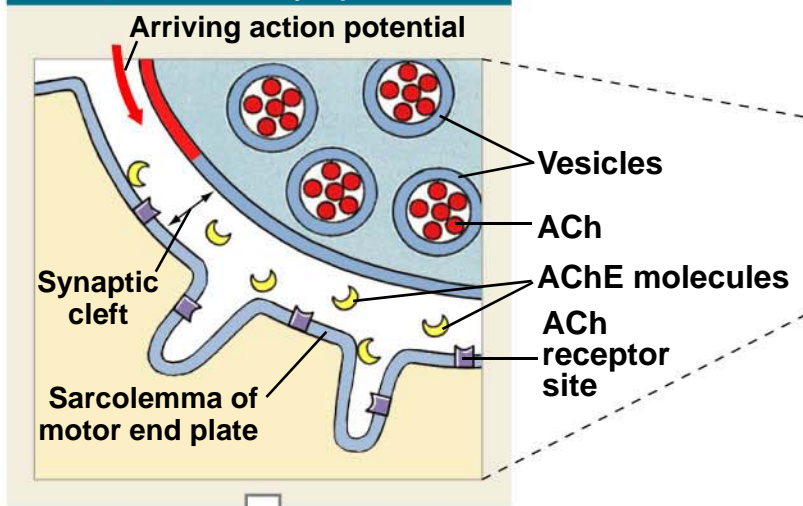
Overview of Events at the neuromuscular junction

- An *action potential (AP)*, an electrical impulse, travels down the axon of the motor neuron to the end bulbs (synaptic terminals)
- The AP causes the synaptic vesicles to fuse with the end bulb membrane, resulting in the release of Acetylcholine (Ach) into the synaptic cleft
- Ach diffuses across the synaptic cleft & binds to Ach receptors on the motor end plate
- The binding of Ach to its receptors causes a new AP to be generated along the muscle cell membrane
- Immediately after it binds to its receptors, Ach will be broken down by Acetylcholinesterase (AchE) – an enzyme present in the synaptic cleft



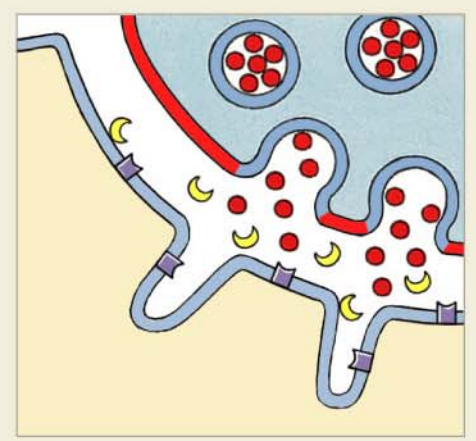
- An *action potential (AP)*, an electrical impulse, travels down the axon of the motor neuron to the end bulbs (synaptic terminals)

STEP 1 Arrival of an action potential at the synaptic terminal

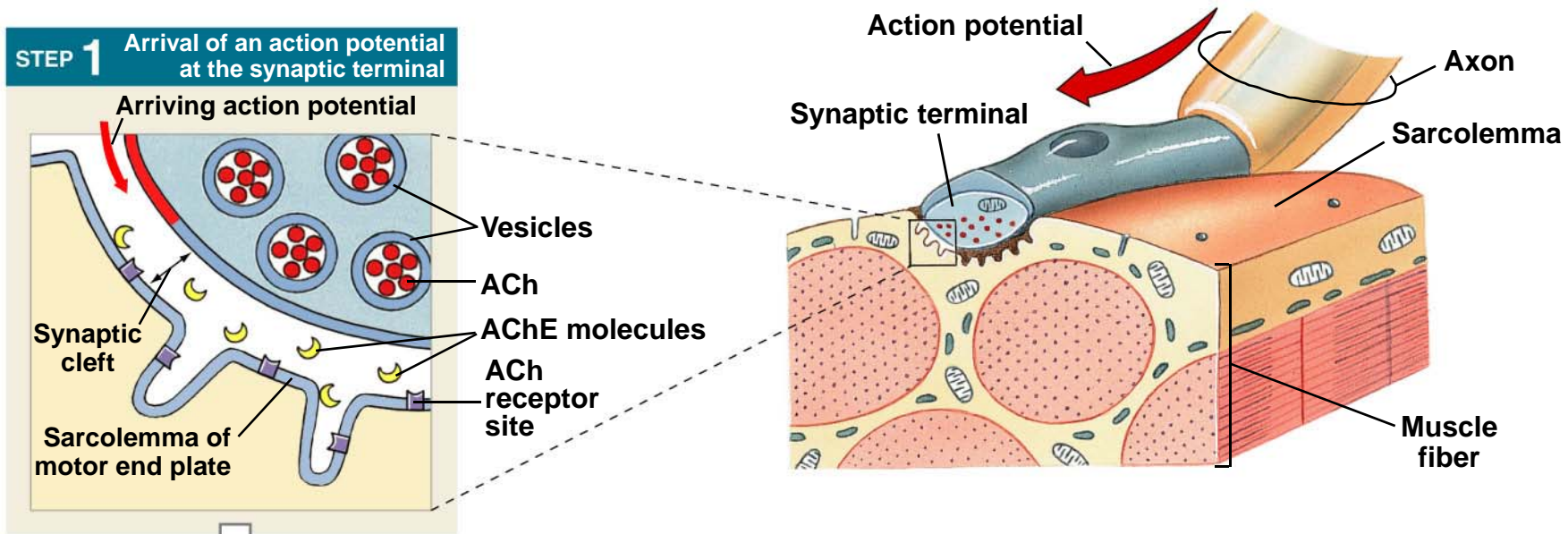


STEP 2 Release of acetylcholine

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

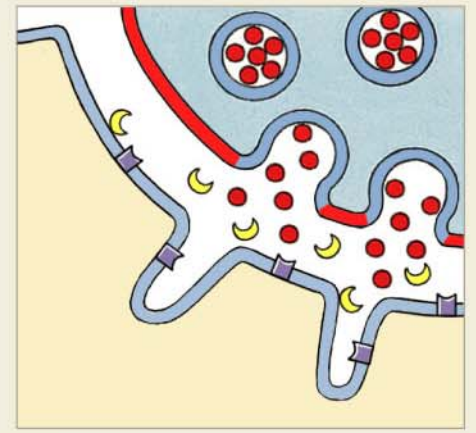


- The AP causes the synaptic vesicles to fuse with the end bulb membrane, resulting in the release of Acetylcholine (ACh) into the synaptic cleft



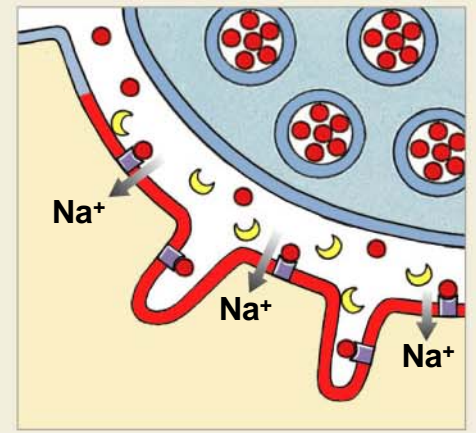
STEP 2 Release of acetylcholine

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



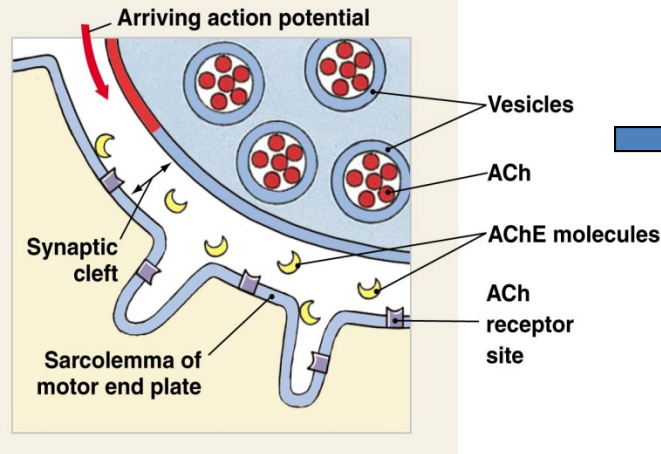
STEP 3 ACh binding at the motor end plate

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



•ACh diffuses across the synaptic cleft & binds to ACh receptors on the motor end plate

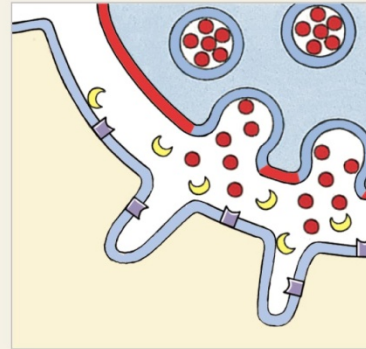
STEP 1 Arrival of an action potential at the synaptic terminal



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STEP 2 Release of acetylcholine

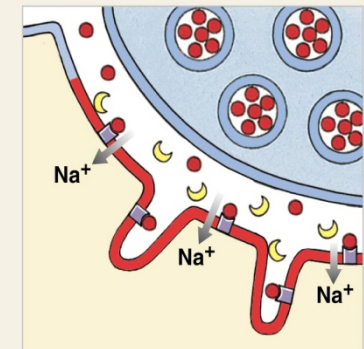
Vesicles in the synaptic terminal fuse with the neuronal membrane and dump their contents into the synaptic cleft.



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STEP 3 ACh binding at the motor end plate

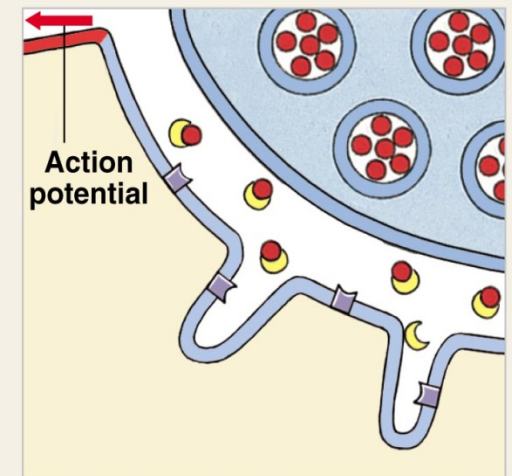
The binding of ACh to the receptors increases the membrane permeability to sodium ions. Sodium ions then rush into the cell.



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STEP 4 Appearance of an action potential in the sarcolemma

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



- The binding of ACh to its receptors causes a new AP to be generated along the muscle cell membrane
- Immediately after it binds to its receptors, ACh will be broken down by Acetylcholinesterase (AChE) – an enzyme present in the synaptic cleft

Physiology of Skeletal Muscle Contraction

STEPS THAT START A CONTRACTION

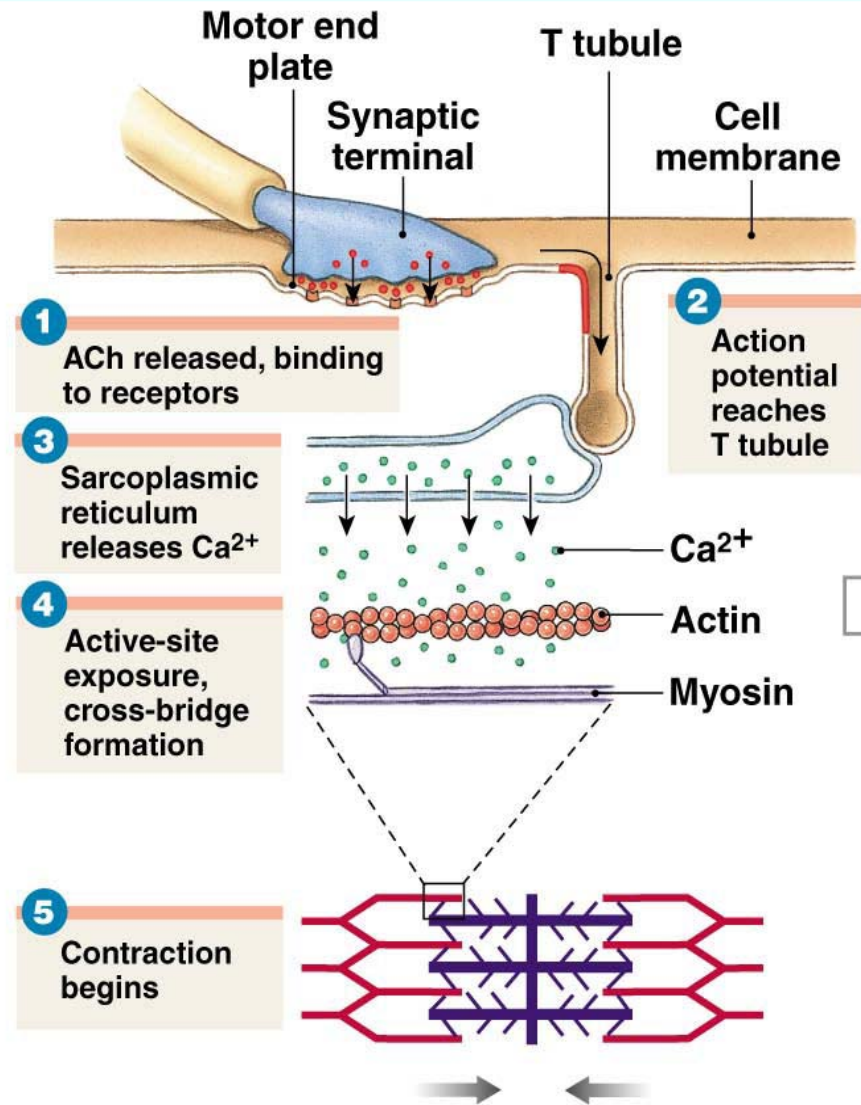
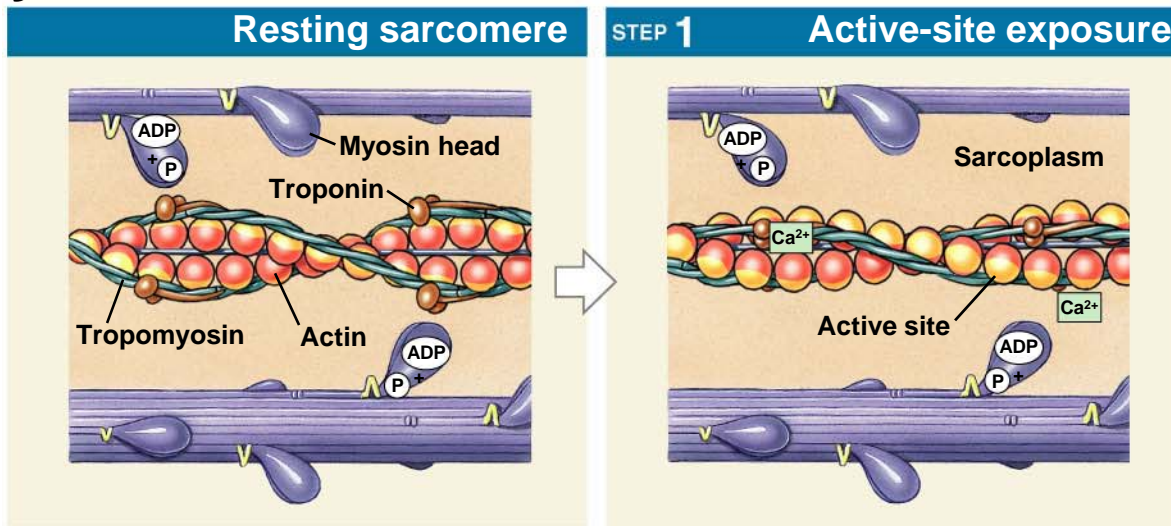


Table 7-1

- Once an action potential (AP) is generated at the motor end plate it will spread like an electrical current along the sarcolemma of the muscle fiber
- The AP will also spread into the T-tubules, exciting the terminal cisternae of the sarcoplasmic reticula
- This will cause Calcium (Ca^{2+}) gates in the SR to open, allowing Ca^{2+} to diffuse into the sarcoplasm
- Calcium will bind to troponin (on the thin myofilament), causing it to change its shape. This then pulls tropomyosin away from the active sites of actin molecules.
- The exposure of the active sites allow the sliding of the filaments

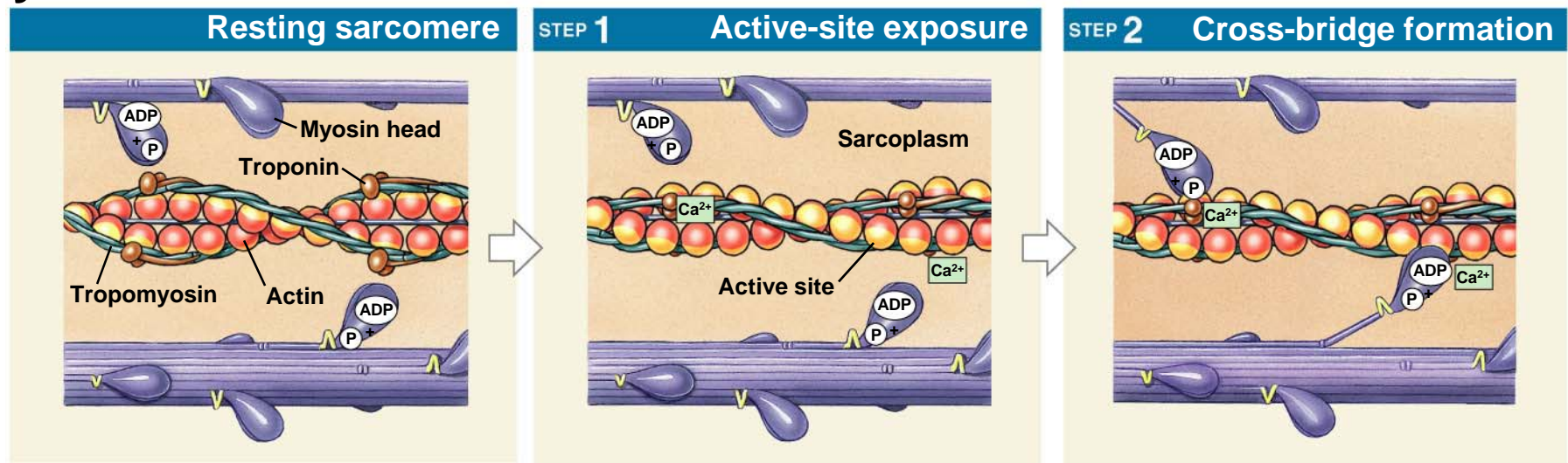
Physiology of skeletal muscle contraction – events at the myofilaments



- Calcium (Ca^{2+}) gates in the SR open, allowing Ca^{2+} to diffuse into the sarcoplasm
- Calcium will bind to troponin (on the thin myofilament), causing it to change its shape.
- This then pulls tropomyosin away from the active sites of actin molecules.

Figure 7-5
3 of 7

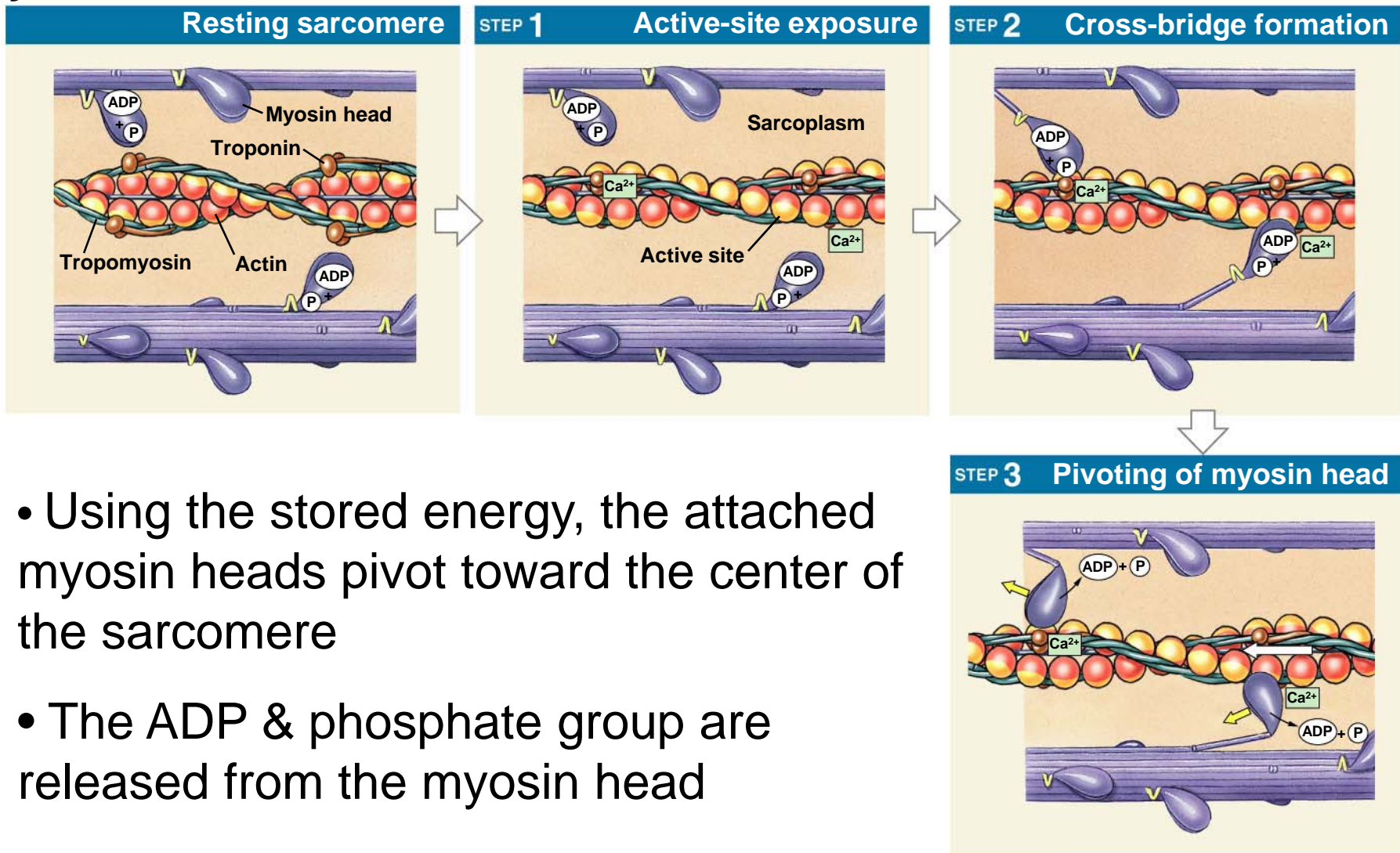
Physiology of skeletal muscle contraction – events at the myofilaments



- Myosin heads are “*energized*” by the presence of ADP + PO₄³⁻ at the ATP binding site (energy is released as phosphate bond of ATP breaks)
- Once the active sites are exposed, the energized myosin heads hook into actin molecules forming *cross-bridges*

Figure 7-5
4 of 7

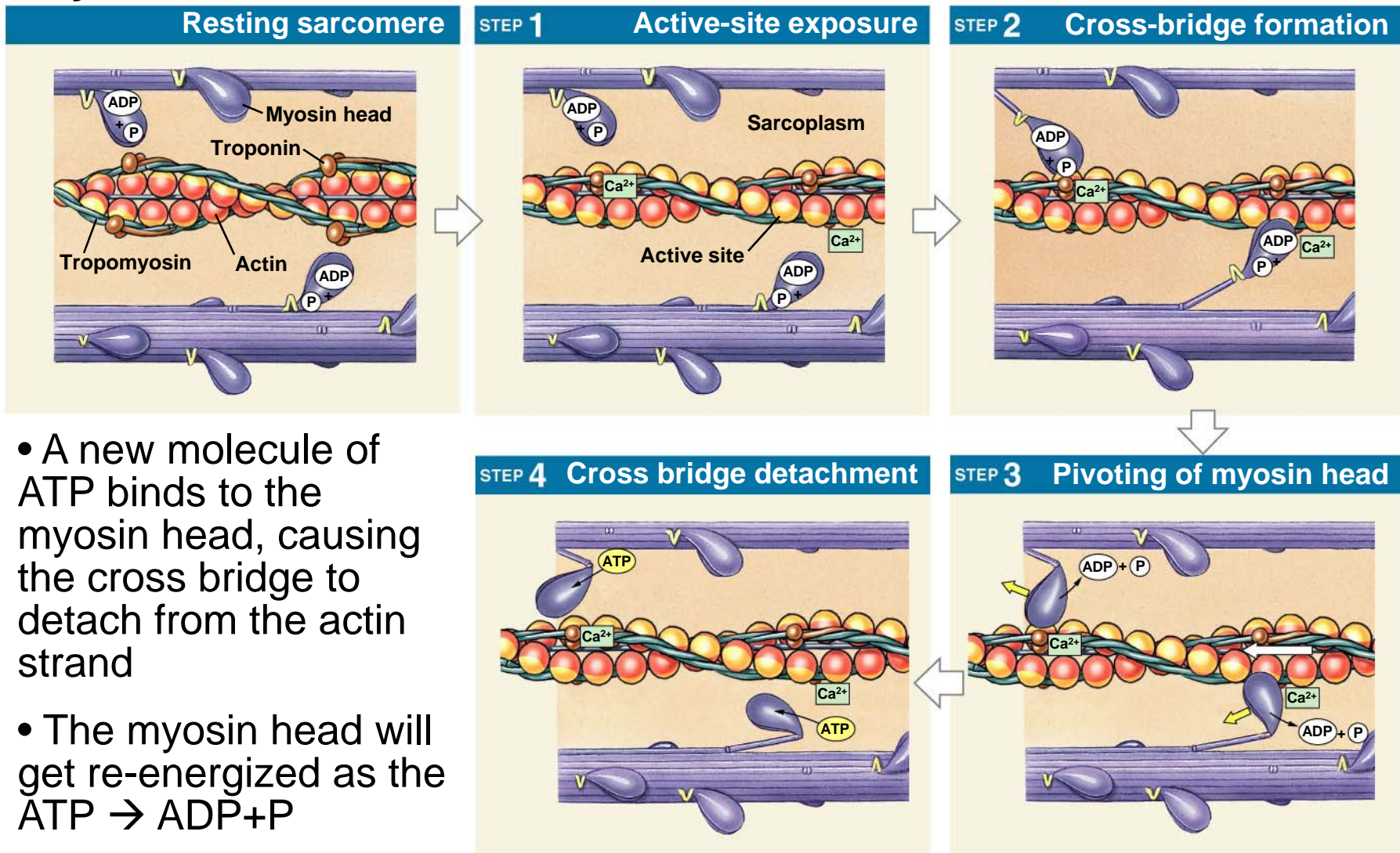
Physiology of skeletal muscle contraction – events at the myofilaments



- Using the stored energy, the attached myosin heads pivot toward the center of the sarcomere
- The ADP & phosphate group are released from the myosin head

Figure 7-5
5 of 7

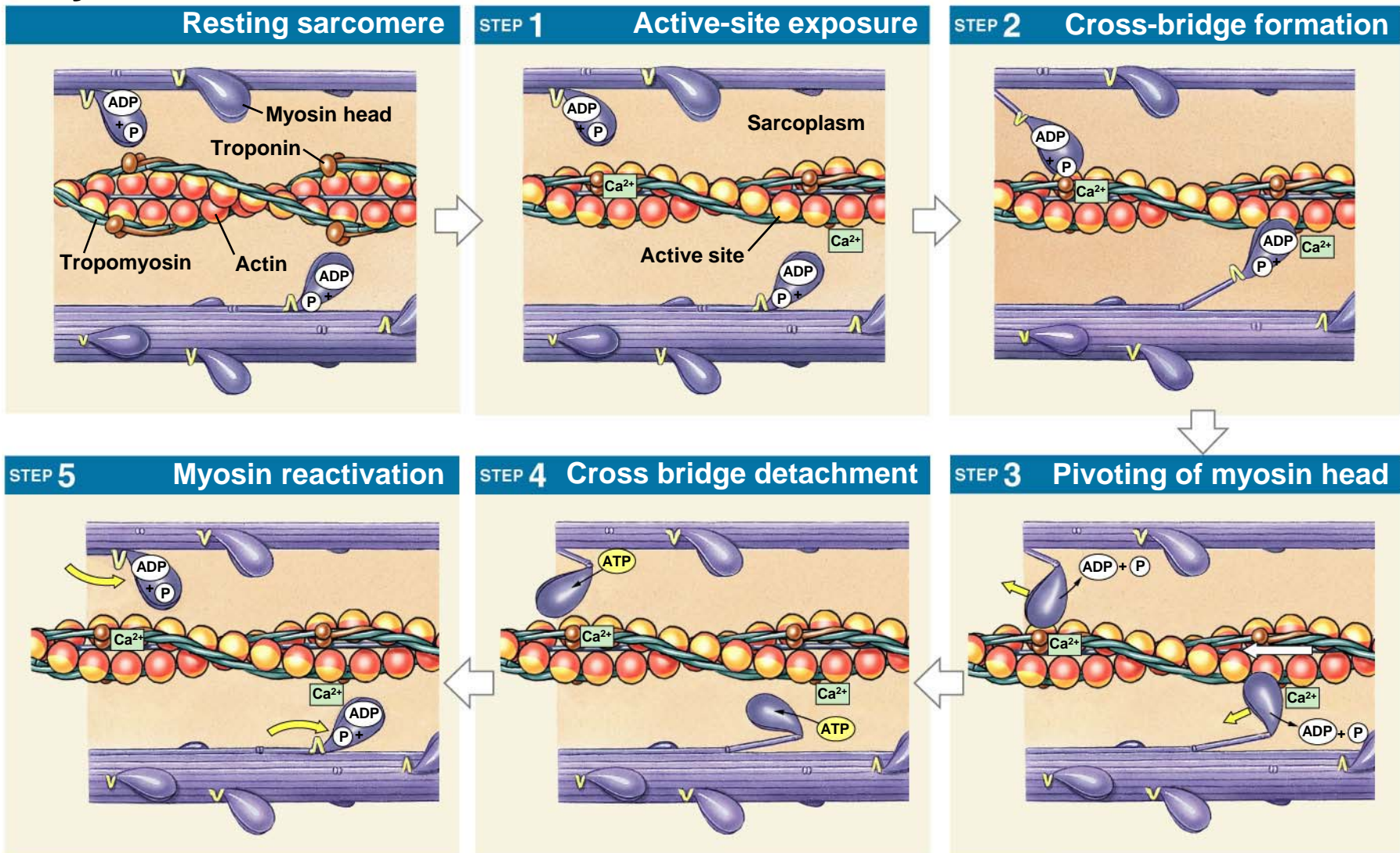
Physiology of skeletal muscle contraction – events at the myofilaments



- A new molecule of ATP binds to the myosin head, causing the cross bridge to detach from the actin strand
- The myosin head will get re-energized as the $ATP \rightarrow ADP+P$

- As long as the active sites are still exposed, the myosin head can bind again to the next active site

Physiology of skeletal muscle contraction – events at the myofilaments

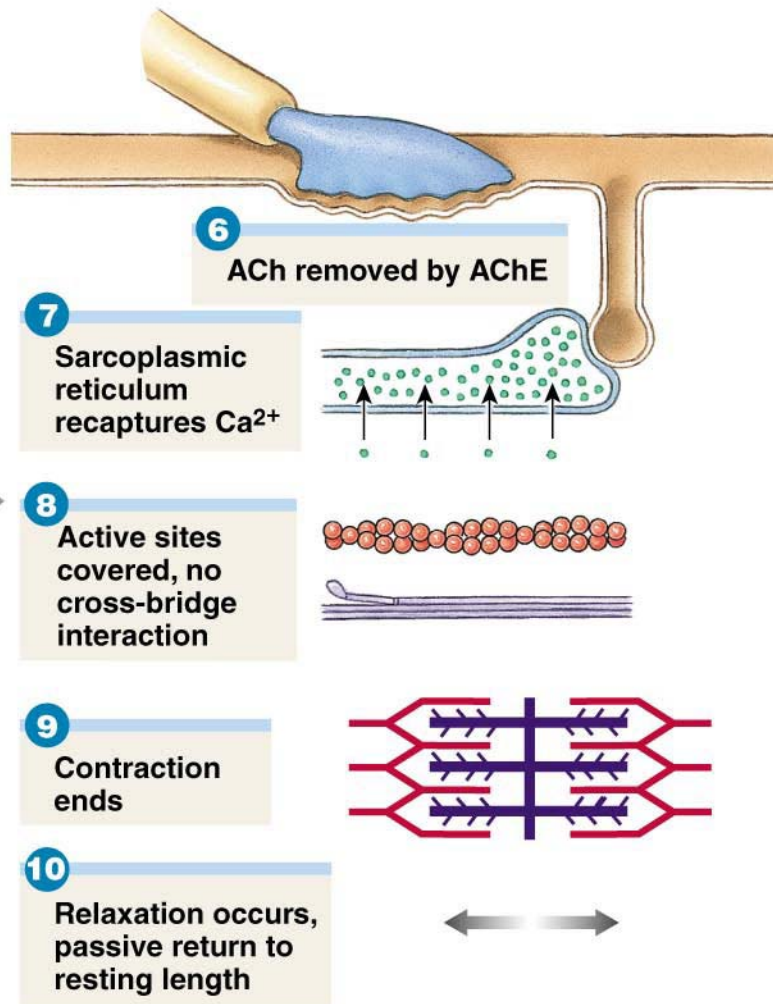


<http://www.youtube.com/watch?v=CepeYFvqmk4> - animation

<http://www.youtube.com/watch?v=kvMFdNw35L0> - animation with Taylor Swift song

Physiology of Skeletal Muscle Contraction

STEPS THAT END A CONTRACTION



- If there are no longer APs generated on the motor neuron, no more Ach will be released
- AchE will remove Ach from the motor end plate, and AP transmission on the muscle fiber will end
- Ca^{2+} gates in the SR will close & Ca^{2+} will be actively transported back into the SR
- With Ca^{2+} removed from the sarcoplasm (& from troponin), tropomyosin will re-cover the active sites of actin
- No more cross-bridge interactions can form
- Thin myofilaments slide back to their resting state

<http://www.youtube.com/watch?v=0kFmbrRJq4w>

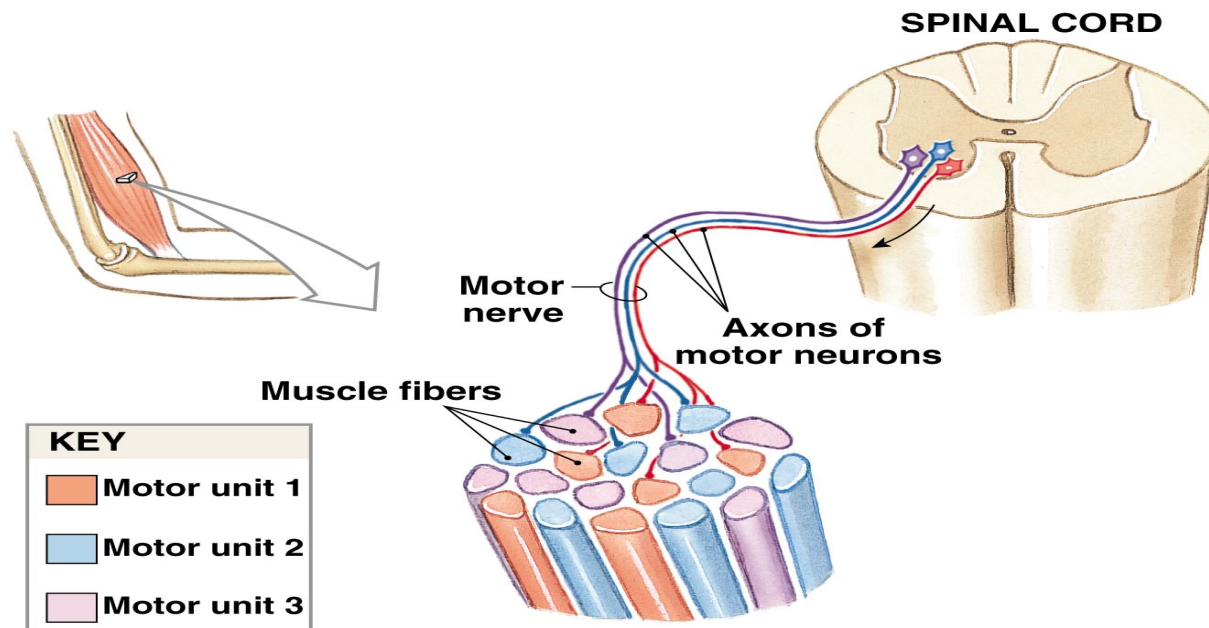
Muscle Fiber Contraction

These physiological processes describe what happen at the cellular level – how skeletal muscle *fibers* contract

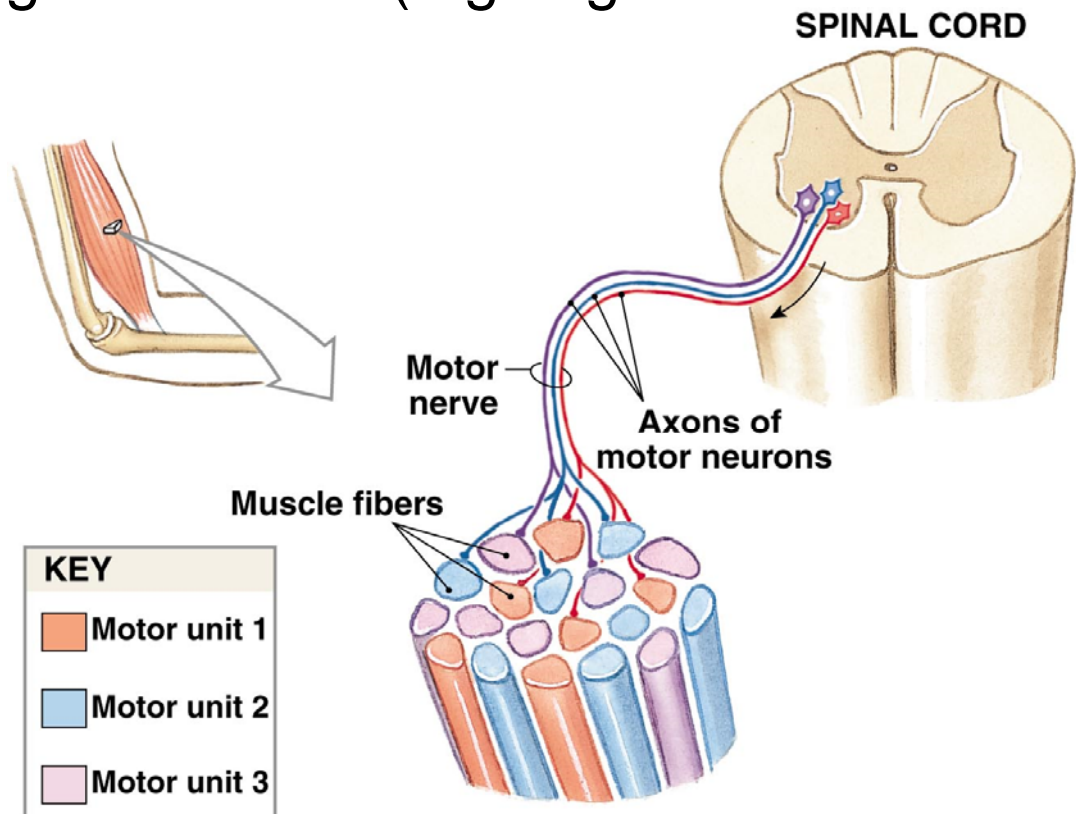
But what about at the organ level? How do skeletal *muscles* (like your biceps brachii) contract to create useful movement?

Muscle Fiber Contraction

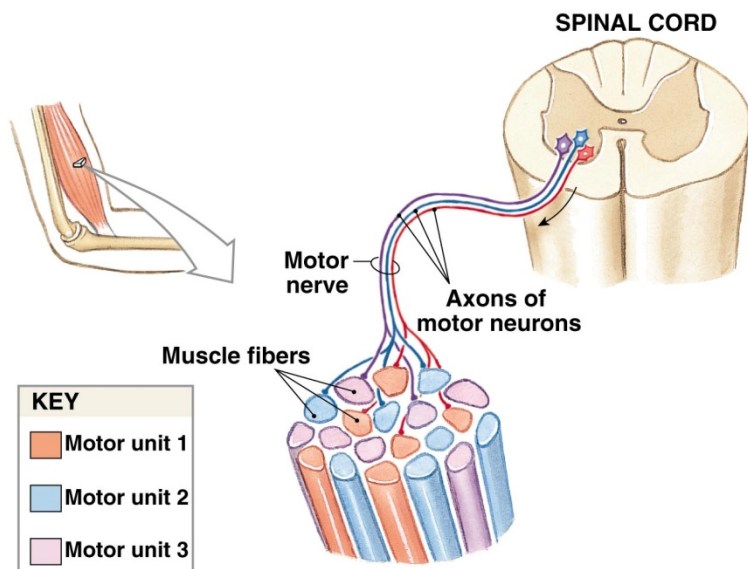
- Skeletal muscles are made up of thousands of muscle fibers
- A single motor neuron may directly control a few fibers within a muscle, or hundreds to thousands of muscle fibers
- All of the muscle fibers controlled by a single motor neuron constitute a **motor unit**



- The size of the motor unit determines how fine the control of movement can be –
 - small motor units → precise control (e.g. eye muscles)
 - large motor units → gross control (e.g. leg muscles)



- **Recruitment** is the ability to activate more motor units as more force (tension) needs to be generated
- **Hypertrophy** – “stressing” a muscle (i.e. exercise) causes more myofilaments/myofibrils to be produced within muscle fibers; allows for more “cross bridges” resulting in more force (strength) as well as larger size



- There are always some motor units active, even when at rest. This creates a resting tension known as **muscle tone**, which helps stabilize bones & joints, & prevents **atrophy**

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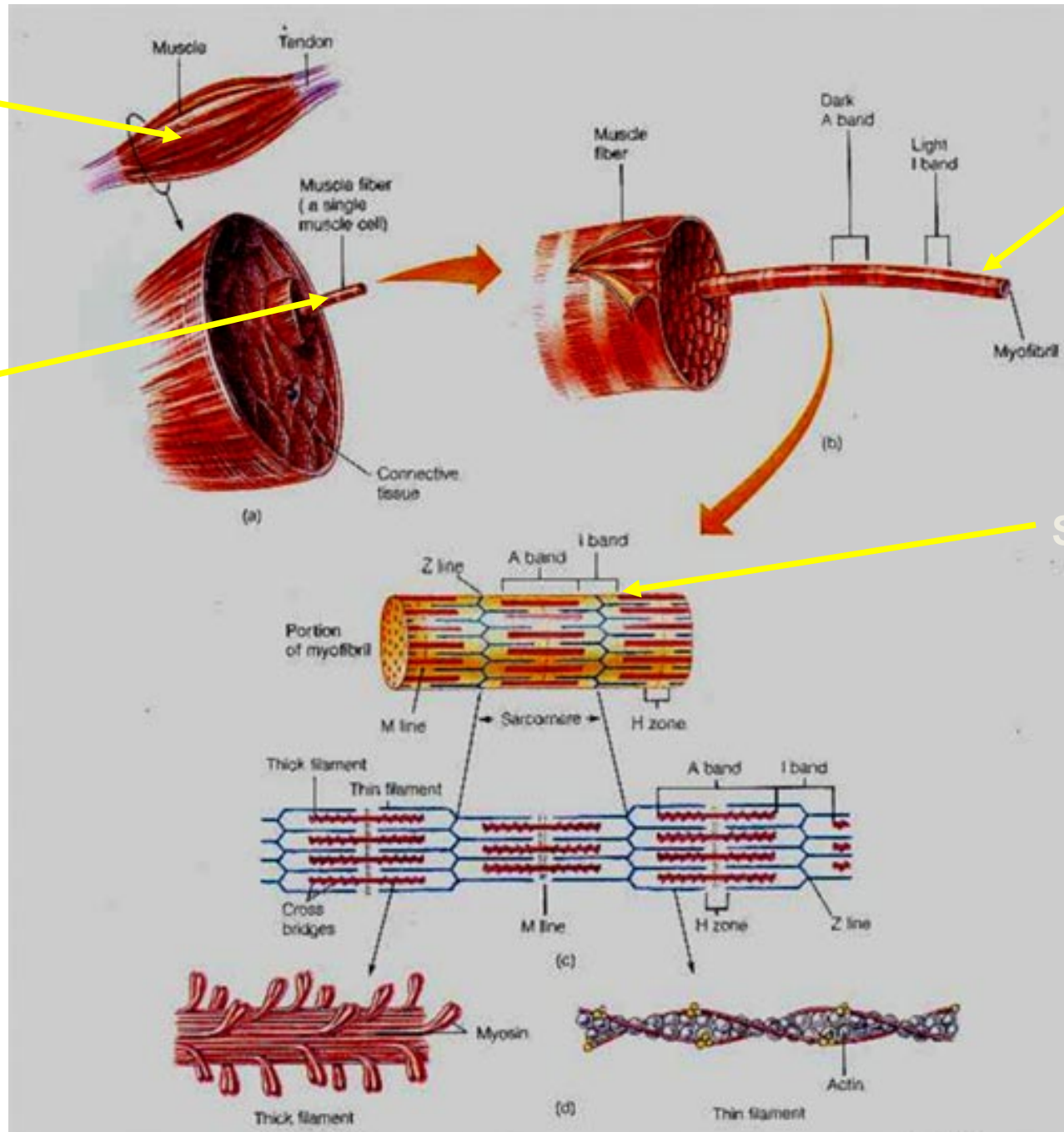


MUSCLE

MUSCLE FIBER

MYOFIBRIL

SARCOMERE



Movement of skeletal muscle

- **These muscles move when the brain sends messages to the muscle**
- **Always work in pairs**
- **2 movements of skeletal muscle**
 - **Contraction (shorten)**
 - **Extension (lengthen)**