Behavioral Neuroscience A
13: Voluntary Body Movement

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https://youtu.be/Gur4Fe990Bk

Lecture Video at above link.

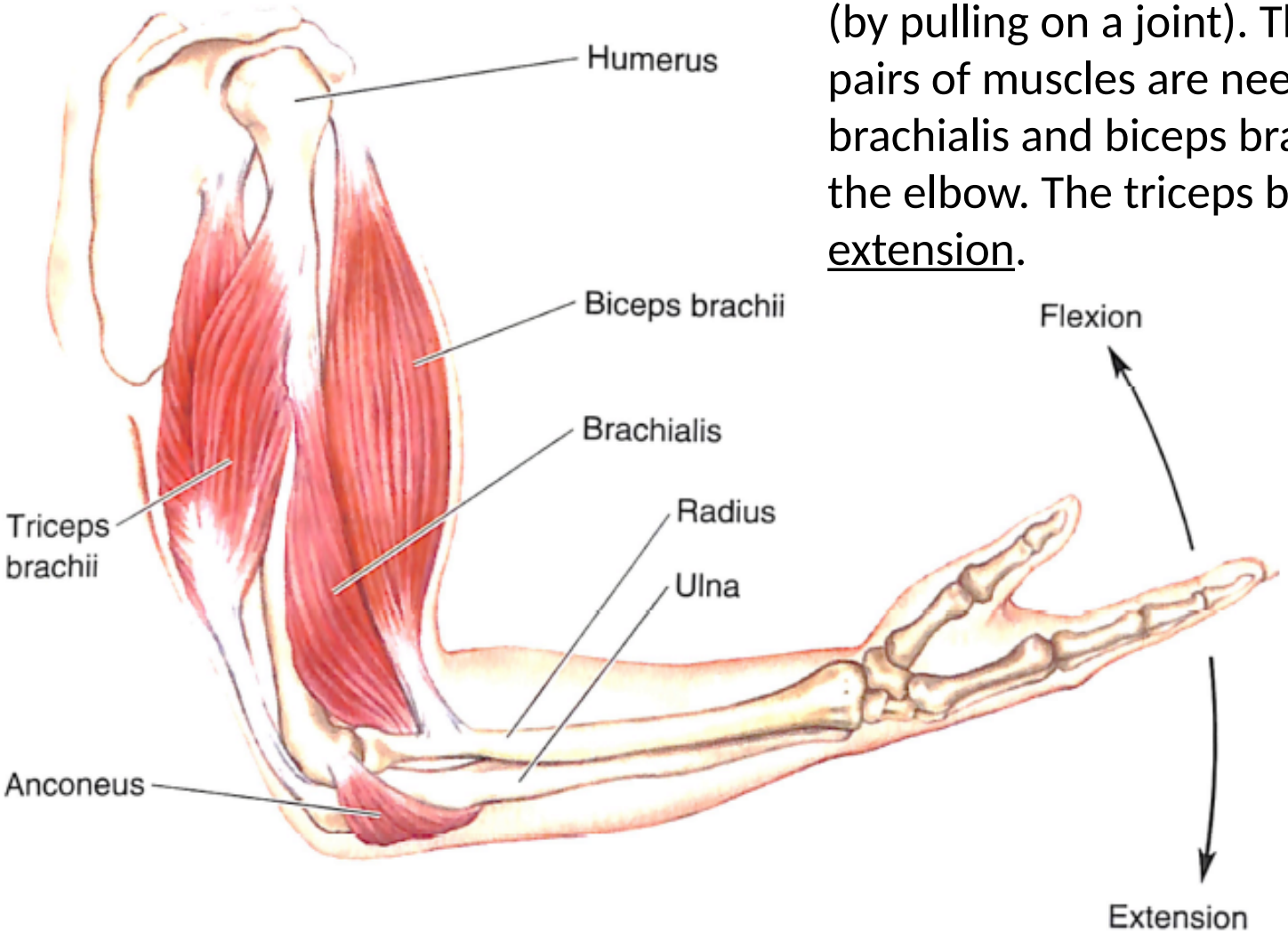
Today's Topics

Body movement:

1) Muscle physiology
2) Muscle contraction
3) Proprioception and spinal cord reflexes

How muscles work: Flex/Extend

Muscles cause movements by contraction (by pulling on a joint). Thus, antagonistic pairs of muscles are needed, for example: brachialis and biceps brachii cause flexion of the elbow. The triceps brachii causes extension.



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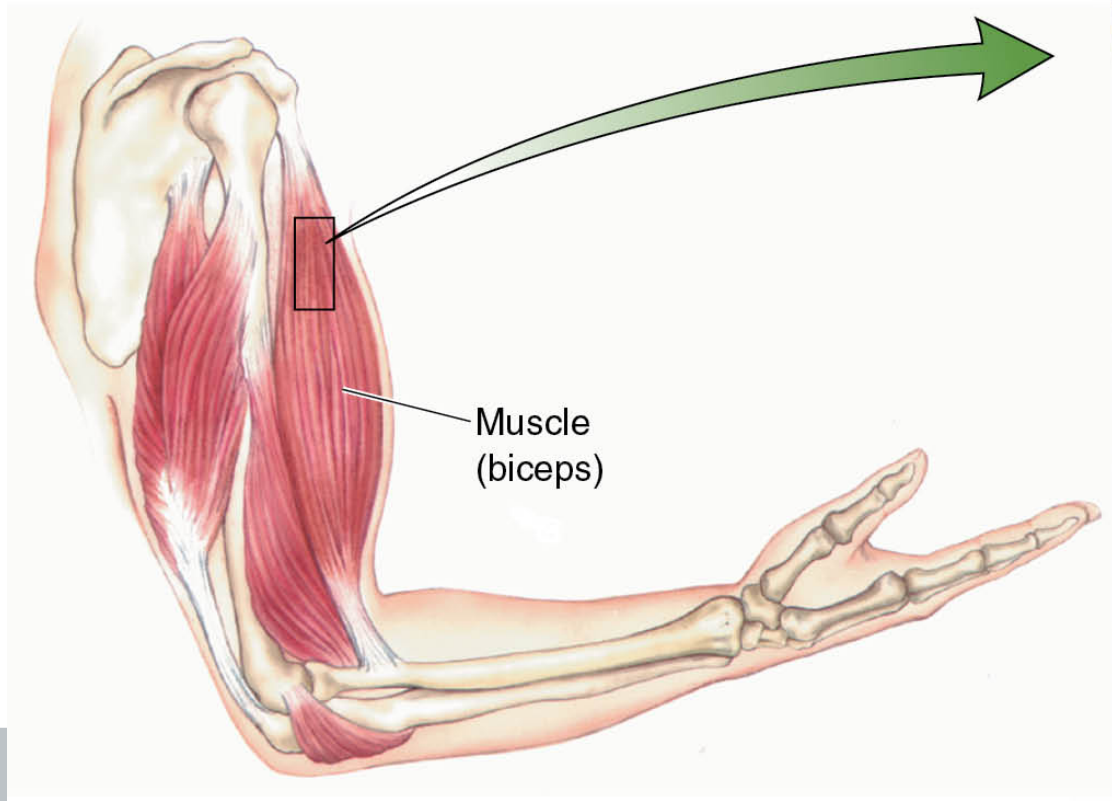
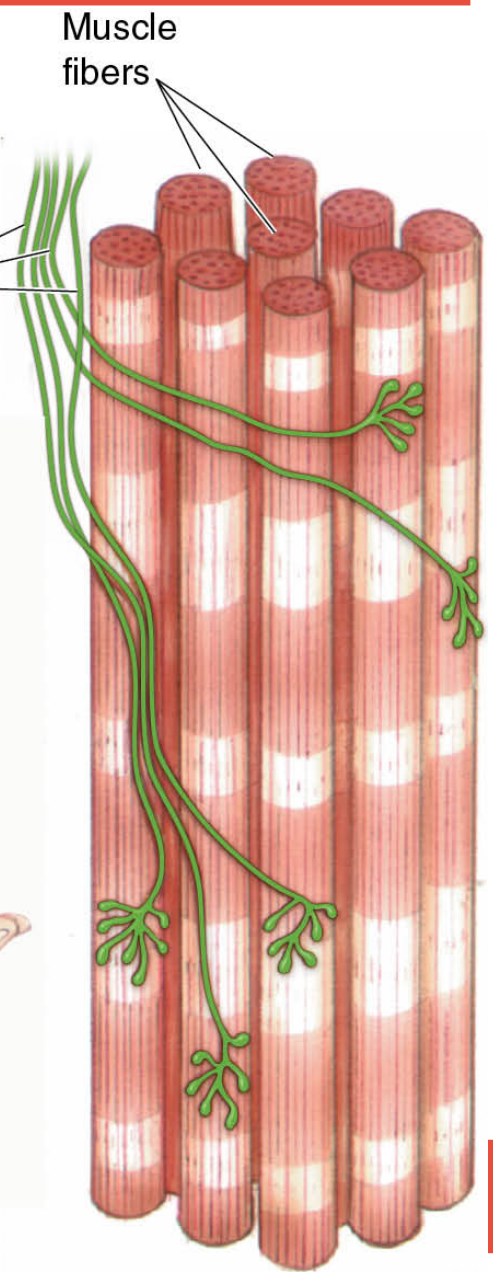
How muscles work: Muscle fibers

Muscles can be categorized as smooth (digestive tract, arteries) and striated muscles (cardiac, skeletal muscles). Within each muscle are hundreds of muscle fibers, and each fiber is innervated by a single axon of the CNS.

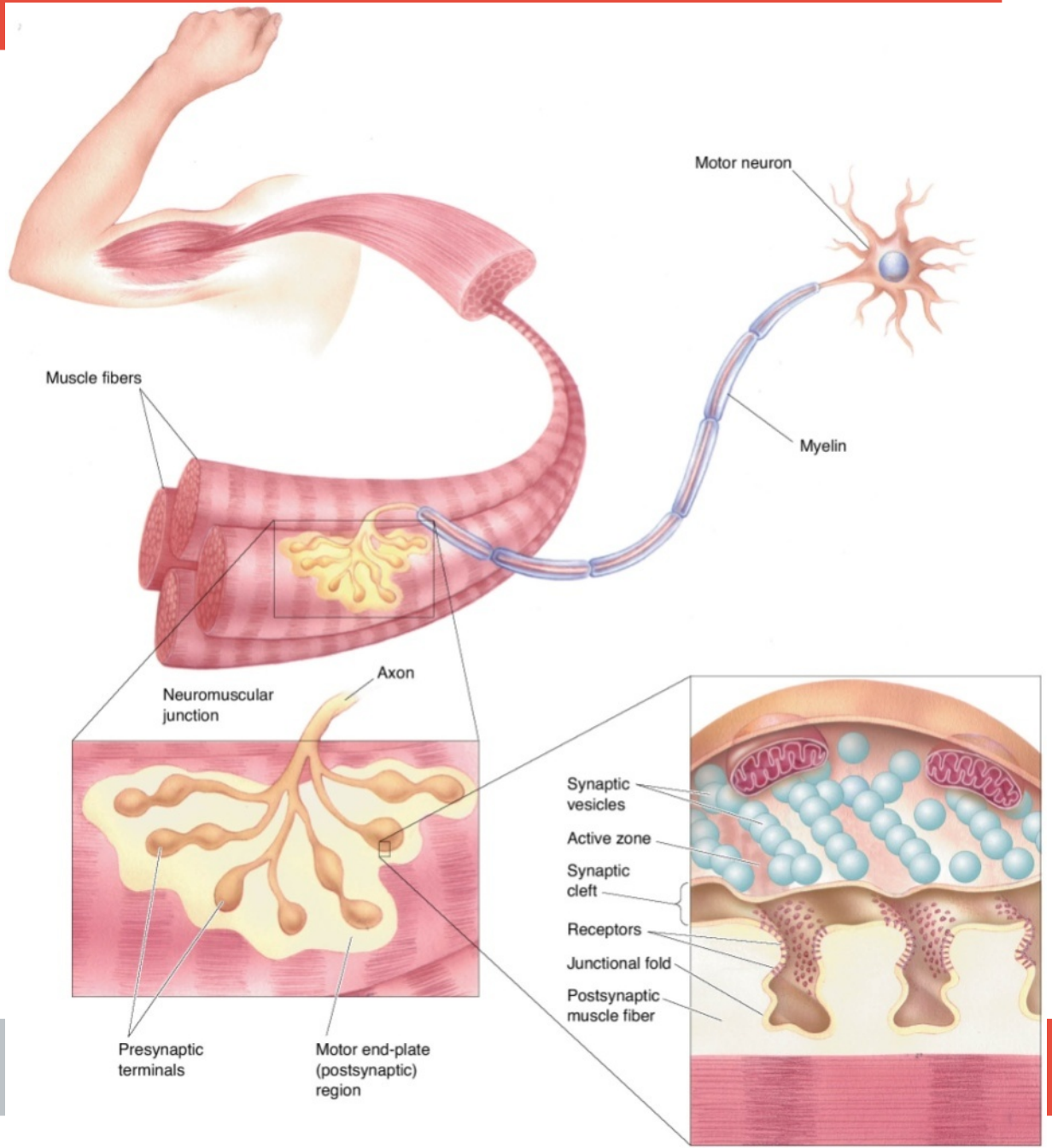




Neuromusclular Junction

Muscles fibers are innervated by motor neurons via the neuromuscular junctions.

The neurotransmitter of the neuromuscular junction is <u>acetylcholine</u>.



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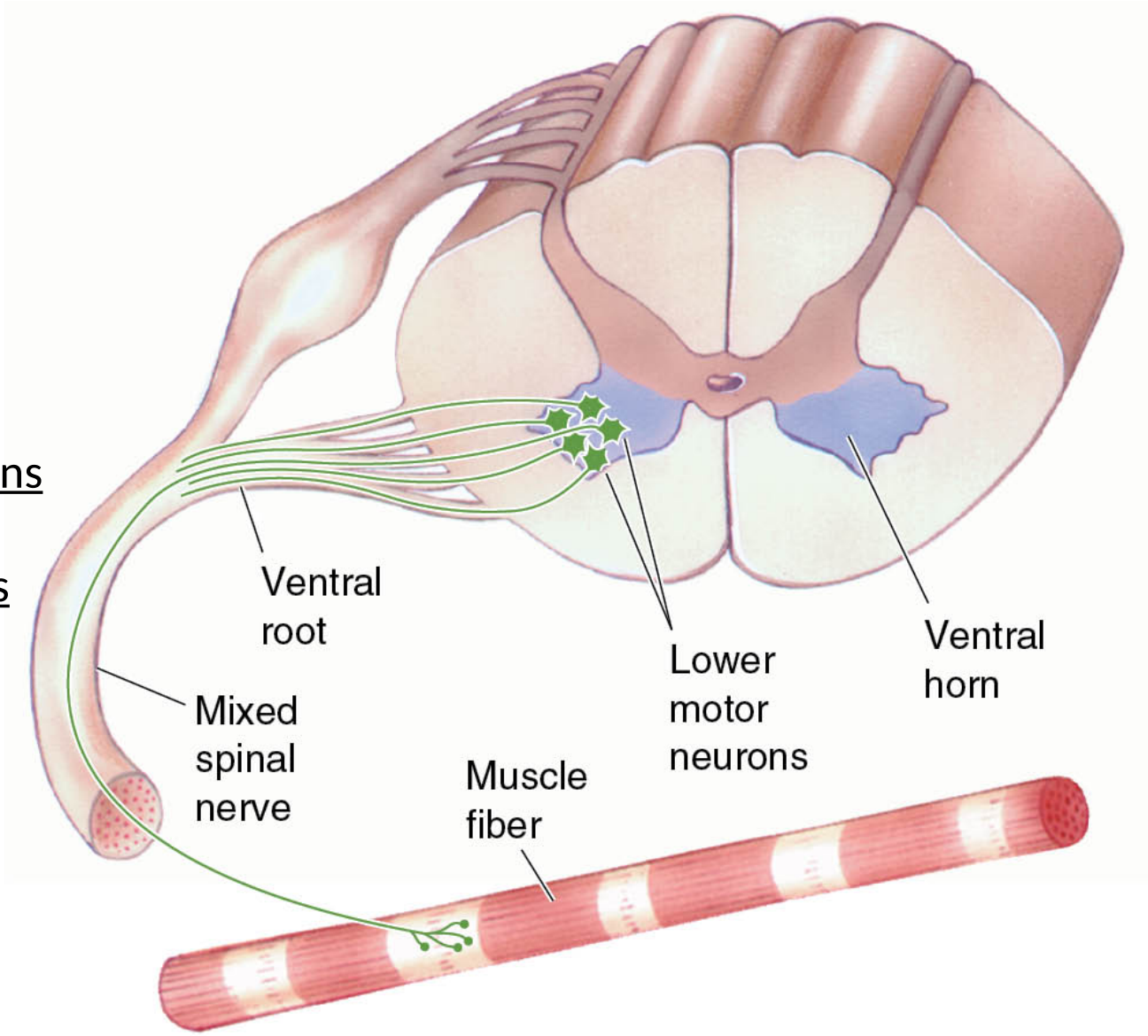
Spinal cord motor neurons

Efferent neural fibers pass through the ventral root of the spinal cord.

(Afferent fibers, i.e., somatosensory fibers, pass through the dorsal root).

Only the lower motor neurons directly activate the muscle fibers. Upper motor neurons are located in the brain and provide input to the spinal cord.



Spinal cord motor neurons

The nerves belong to the spinal segments, named for the vertebrae of origin:

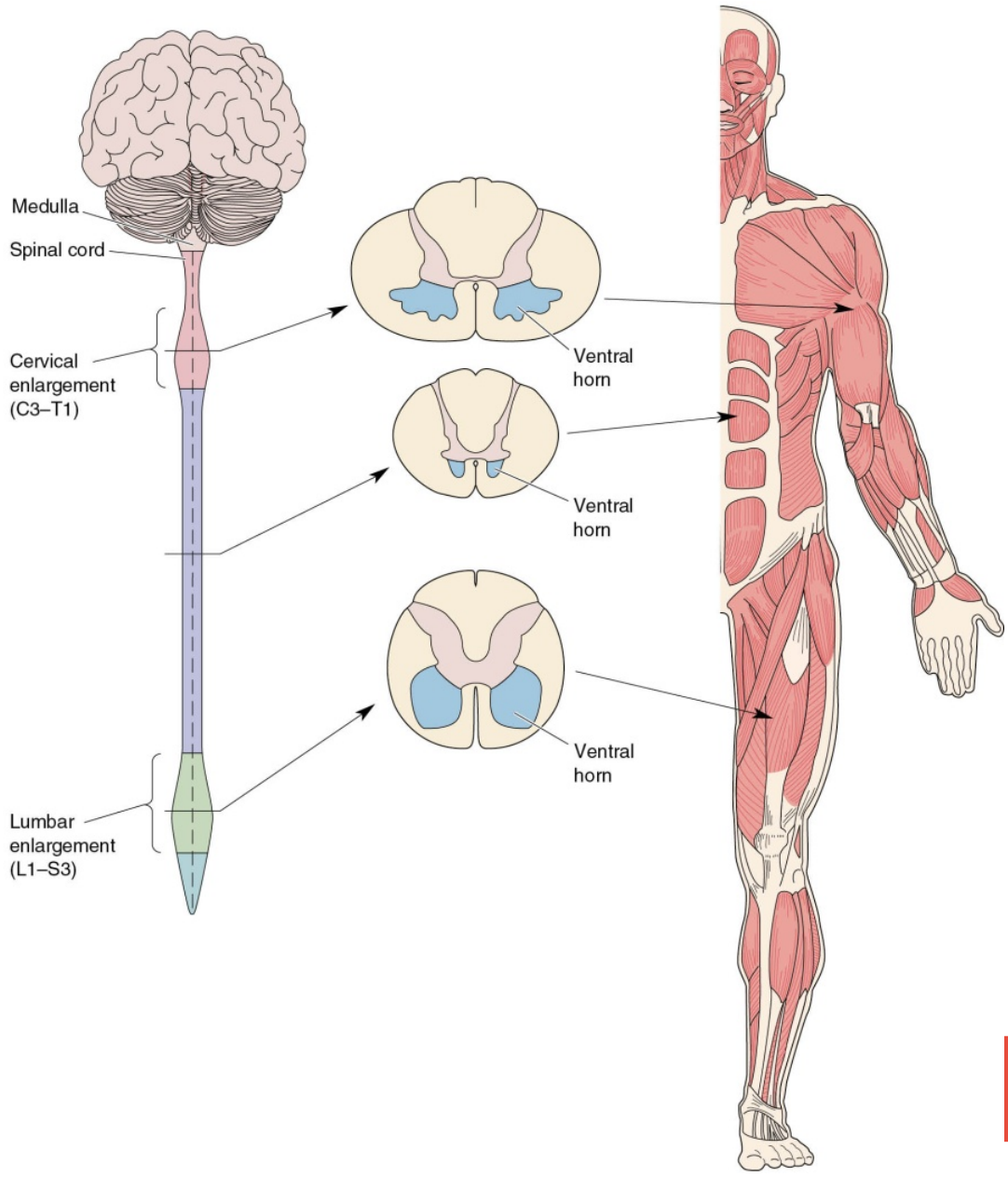
Cervical vertebrae: C1-C8

Thoracic vertebrae: T1-T12

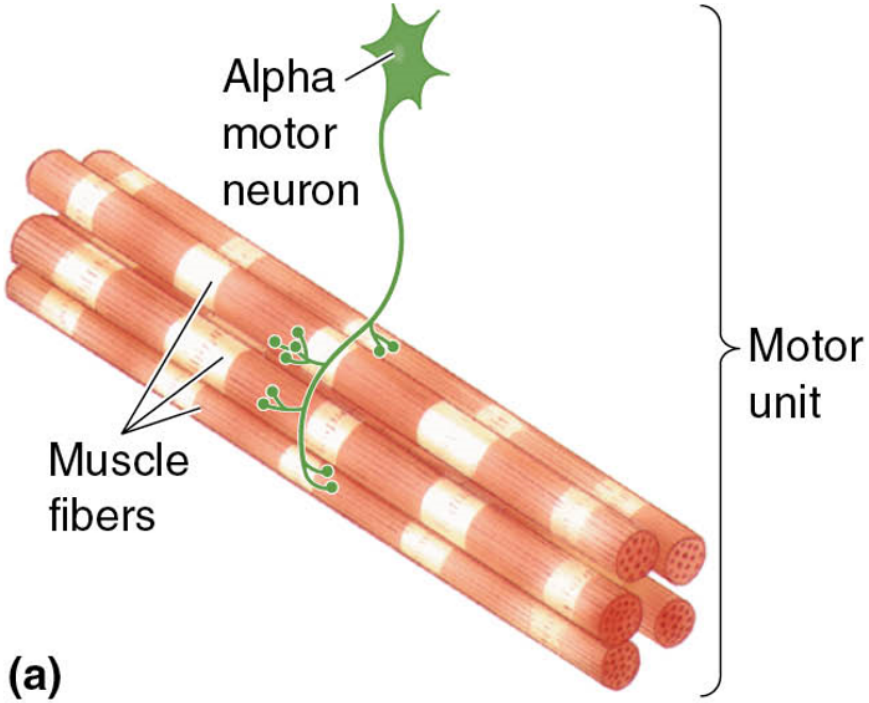
Lumbar vertebrae: L1-L5

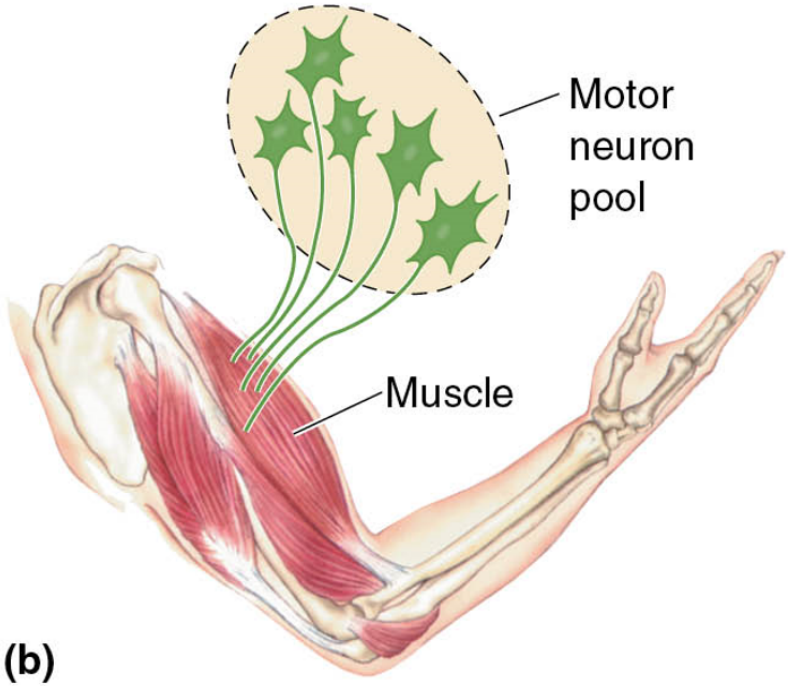
Sacrum: S1-S5

The cervical and lumbar enlargements contain the neurons innervating arm and leg musculature.



Motor unit and motor pool





Alpha motor neurons trigger muscle contraction directly.

Motor neuron pool: pool of alpha motor neurons that innervate one muscle.

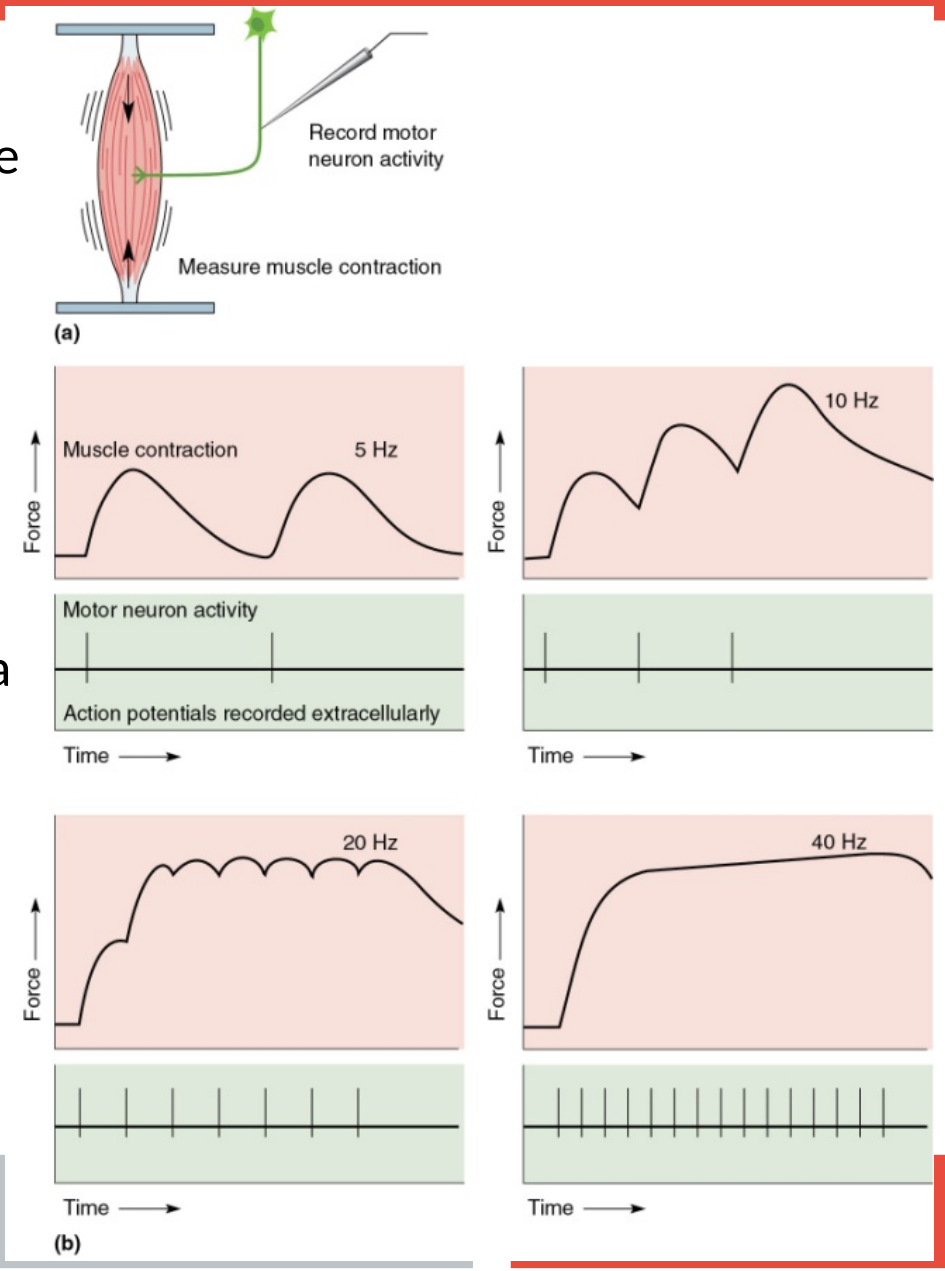
Motor unit: alpha motor neuron + innervated muscle fibers.

Control of muscle contraction

The central nervous system controls muscle contraction by:

1) Firing rate: summation of subsequent muscle twitches increase tension in the muscle fibers (see graph to the left).

2) Recruiting more motor units: a single muscle is part of several motor units (alpha motor neuron + innervated fibers). Increasing the amount of contracted fibers will increase muscle tension.



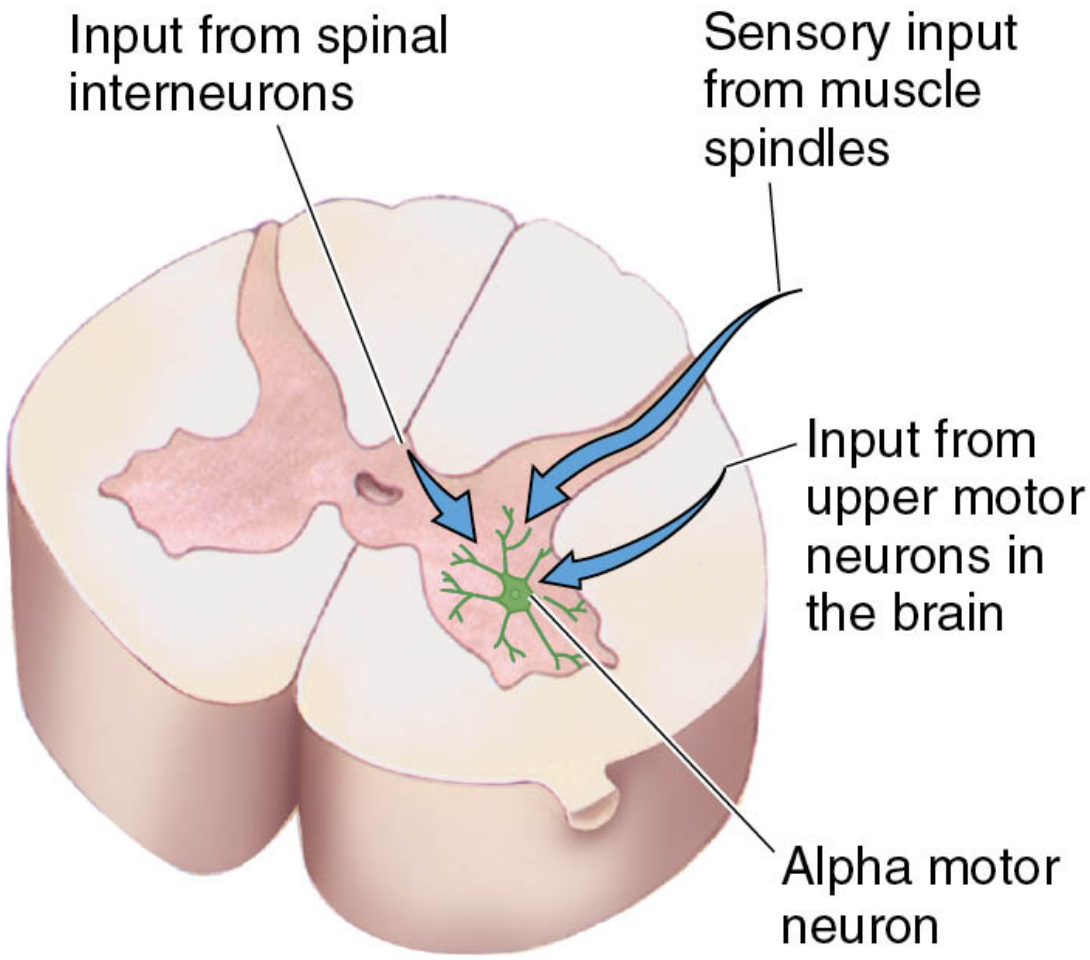
Spinal cord alpha motor neurons

The alpha motor neurons get input from:

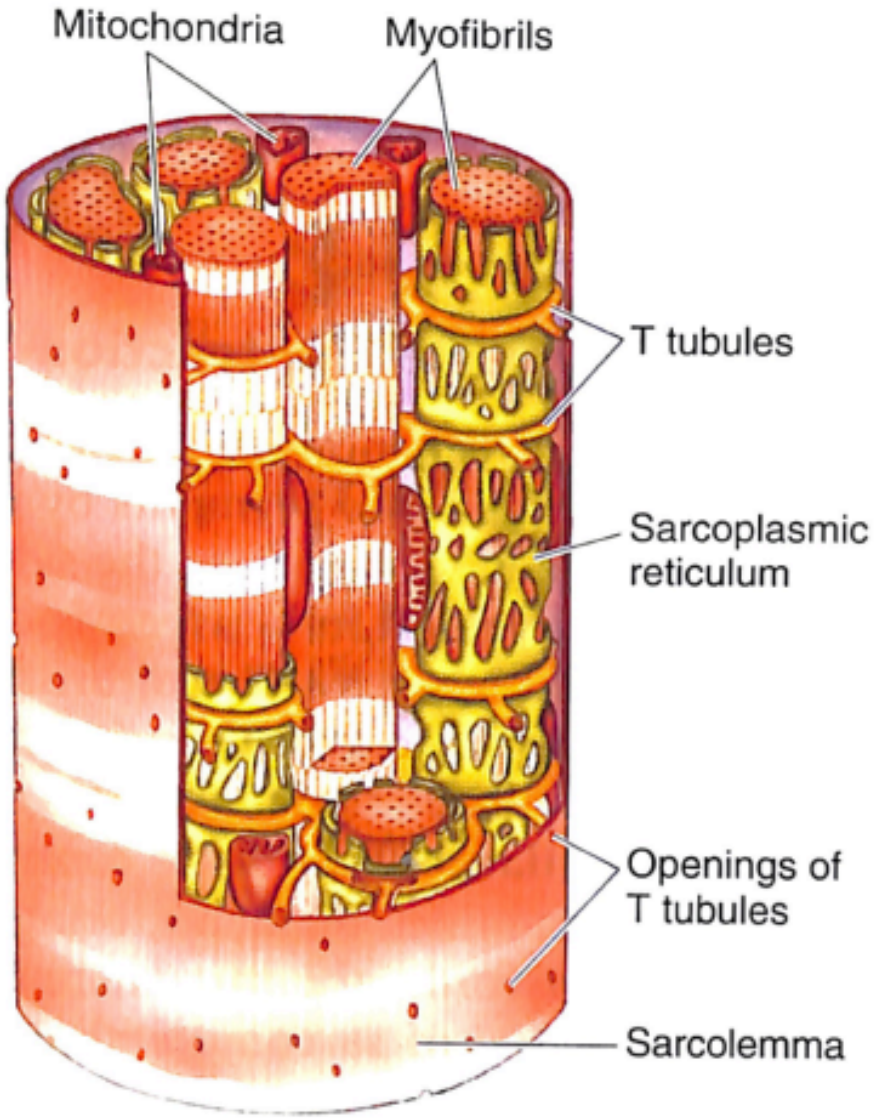
1) upper motor neurons (in the brain) to initiate voluntary movements.

2) muscle spindles: a feedback loop that controls muscle length.

3) spinal interneurons, involved in spinal motor circuits/programs.



Muscle fiber: details



The muscle fiber is formed in development by fusion of muscle precursor cells.

Myofibrils contract in response to an action potential

T tubules extend the extracellular space into the muscle fiber.

Sarcoplasmic reticulum stores and reuptakes Ca^{2+} (calcium).

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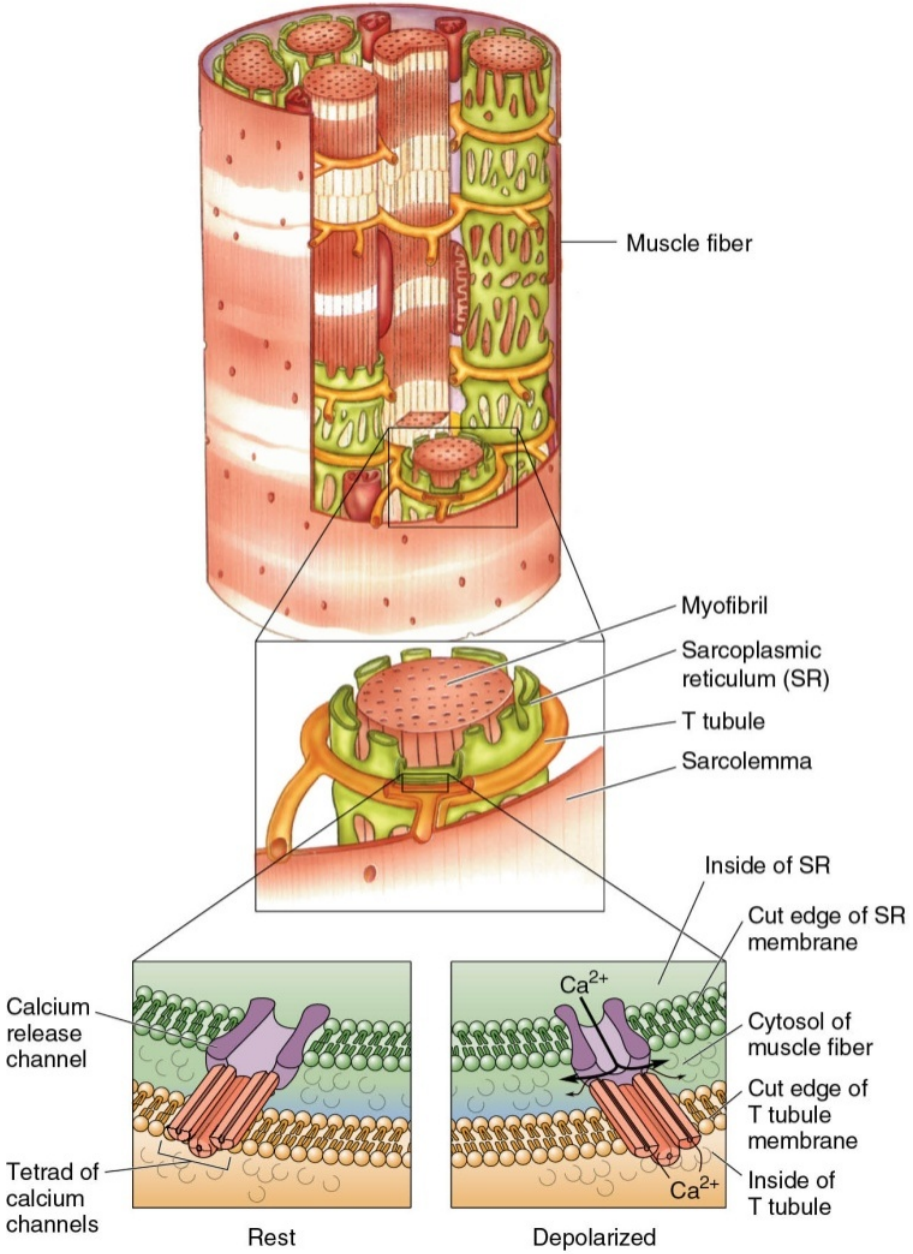
Muscle contraction



<u>Excitation</u> by alpha motor neuron:

1) Action potential in alpha motor neuron.
2) Acetylcholine released at neuromuscular junction.
3) Acetylcholine receptor channels in sarcolemma open-> depolarization.
4) Voltage-gated Na^+ (sodium) channels open which leads to an action potential in the muscle fiber.
5) Voltage-gated Ca^{2+} (calcium) channels open. -> flow of Ca^{2+} from sarcoplasmic reticulum and from the extracellular fluid into the cytosol.

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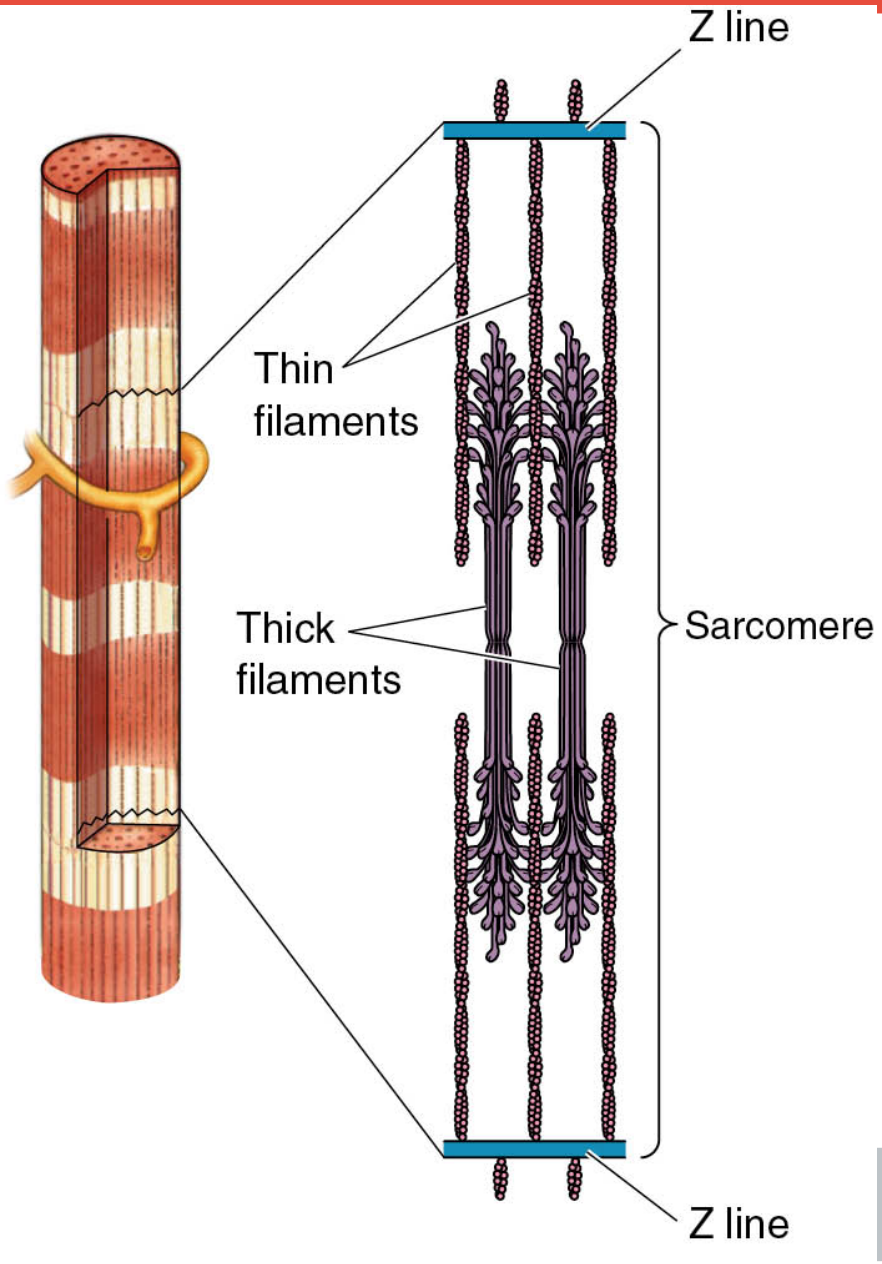
Muscle contraction



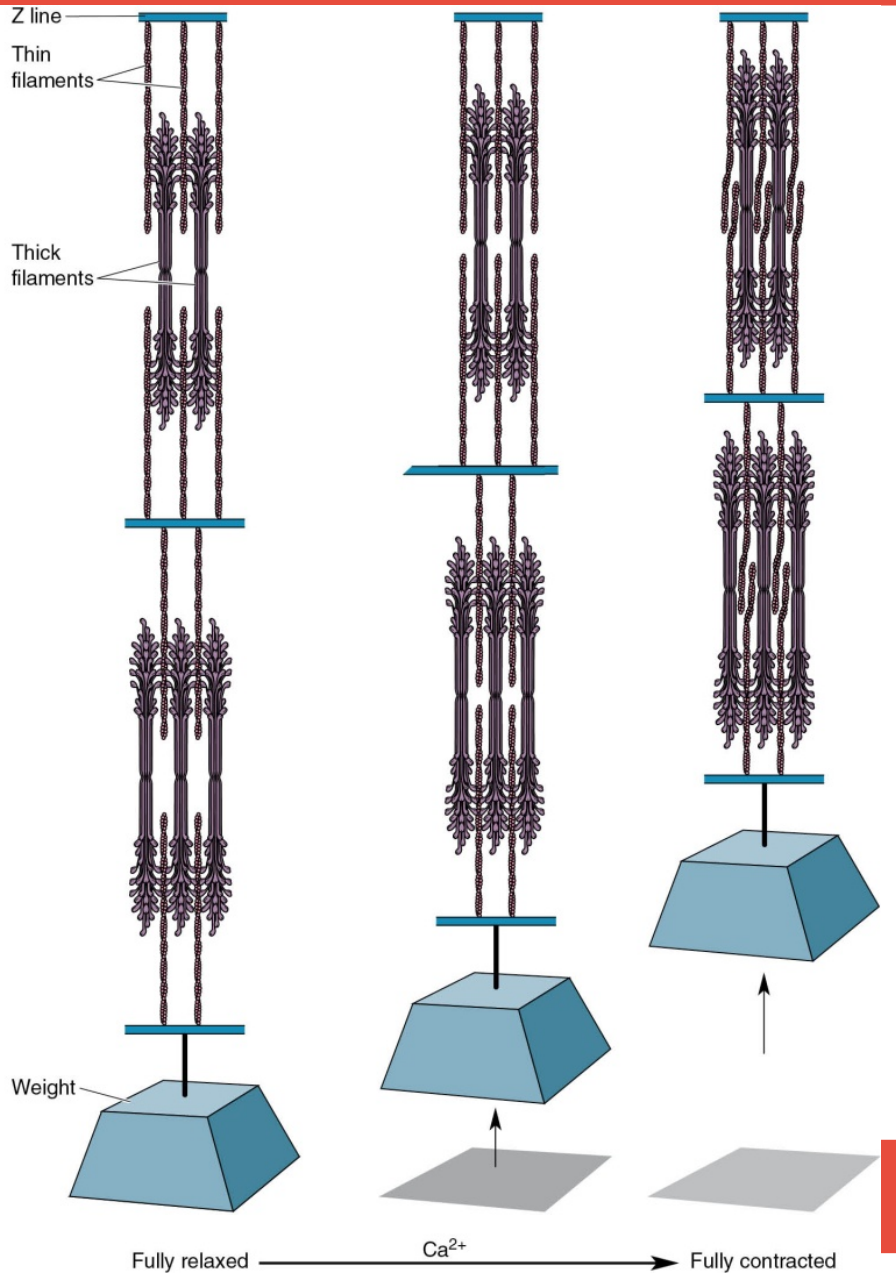
Myofibrils contain sarcomeres consisting of:

Z lines
Thin filaments -> Actin
Thick filaments -> Myosin

Muscle contraction

Muscle contraction is a sliding of the thin filaments along the thick filaments.

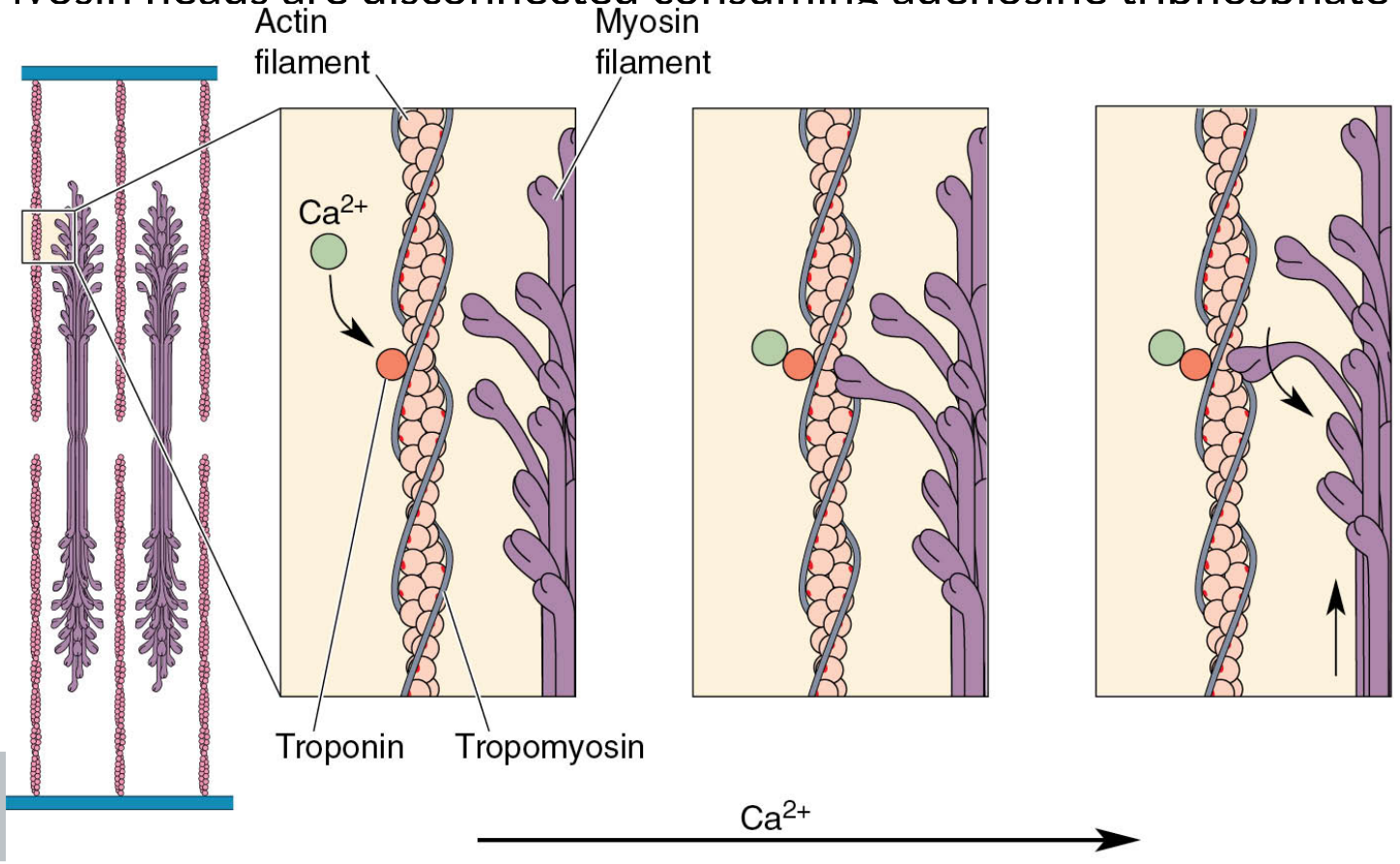
For this sliding, Ca^{2+} is needed.



Muscle contraction

Contraction:

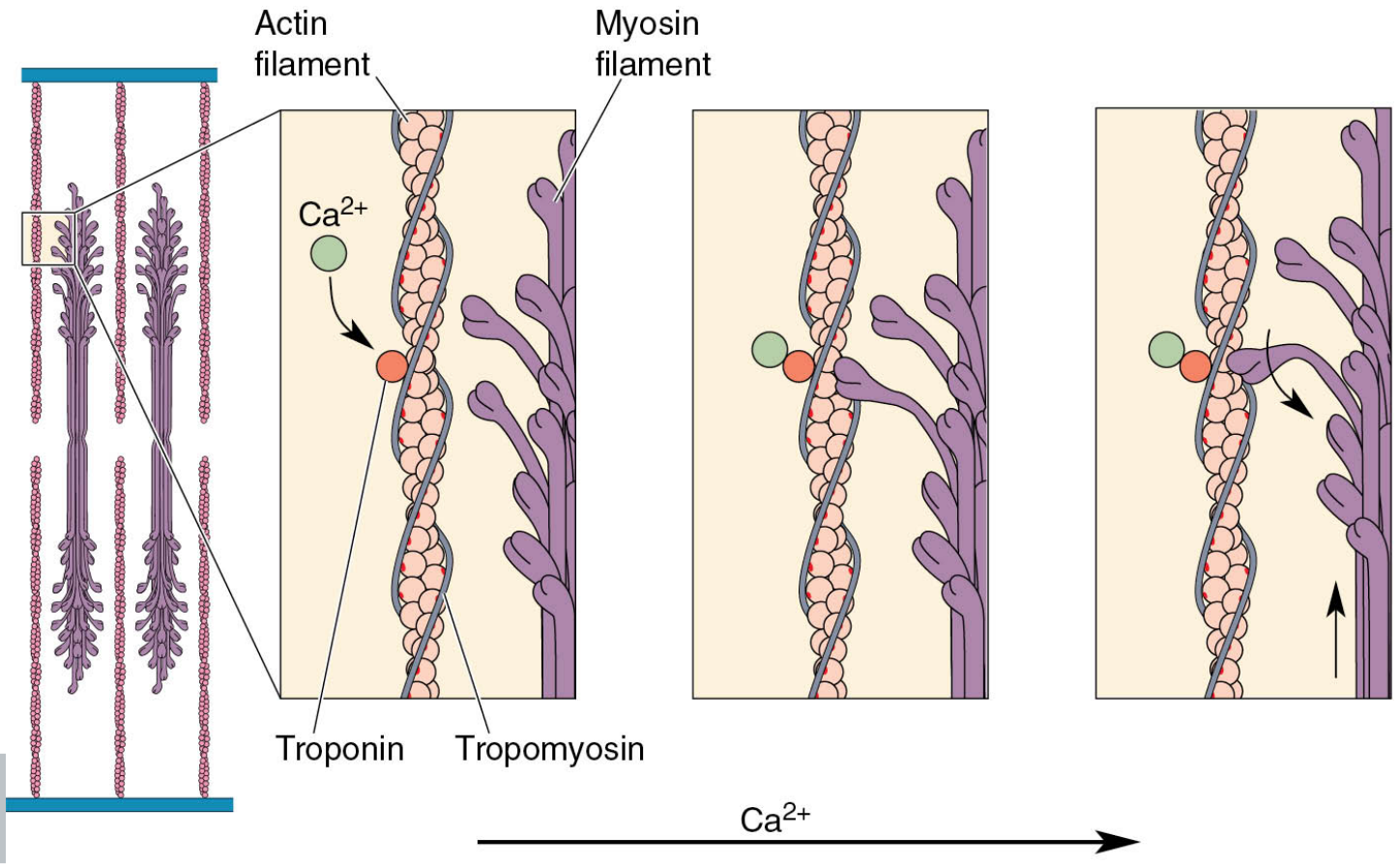
1) Release of Ca^{2+} into the cell -> Ca^{2+} binds to troponin.
2) Tropomyosin shifts and exposes binding sites on actin.
3) Myosin heads can bind to actin.
4) Myosin head pivot (like an oar in a rowing boat).
5) Myosin heads are disconnected consuming adenosine triphosphate (ATP).



Muscle contraction

Relaxation:

1) When the excitation of the muscle fiber ends, sarcolemma and T tubules will return to resting potential.
2) Ca^{2+} is sequestered by the sarcoplasmic reticulum (by an ATP-driven pump).
3) Myosin binding sites on actin are covered by tropomyosin.



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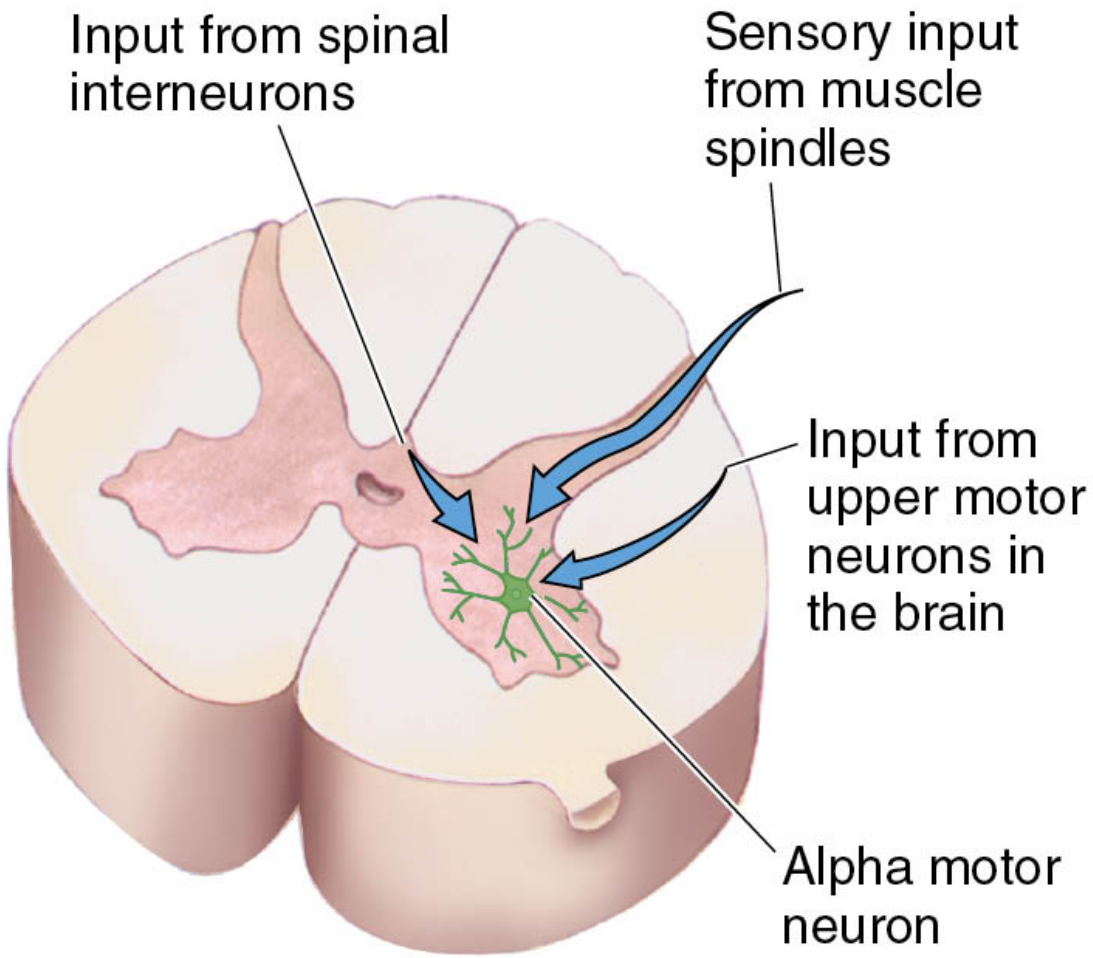
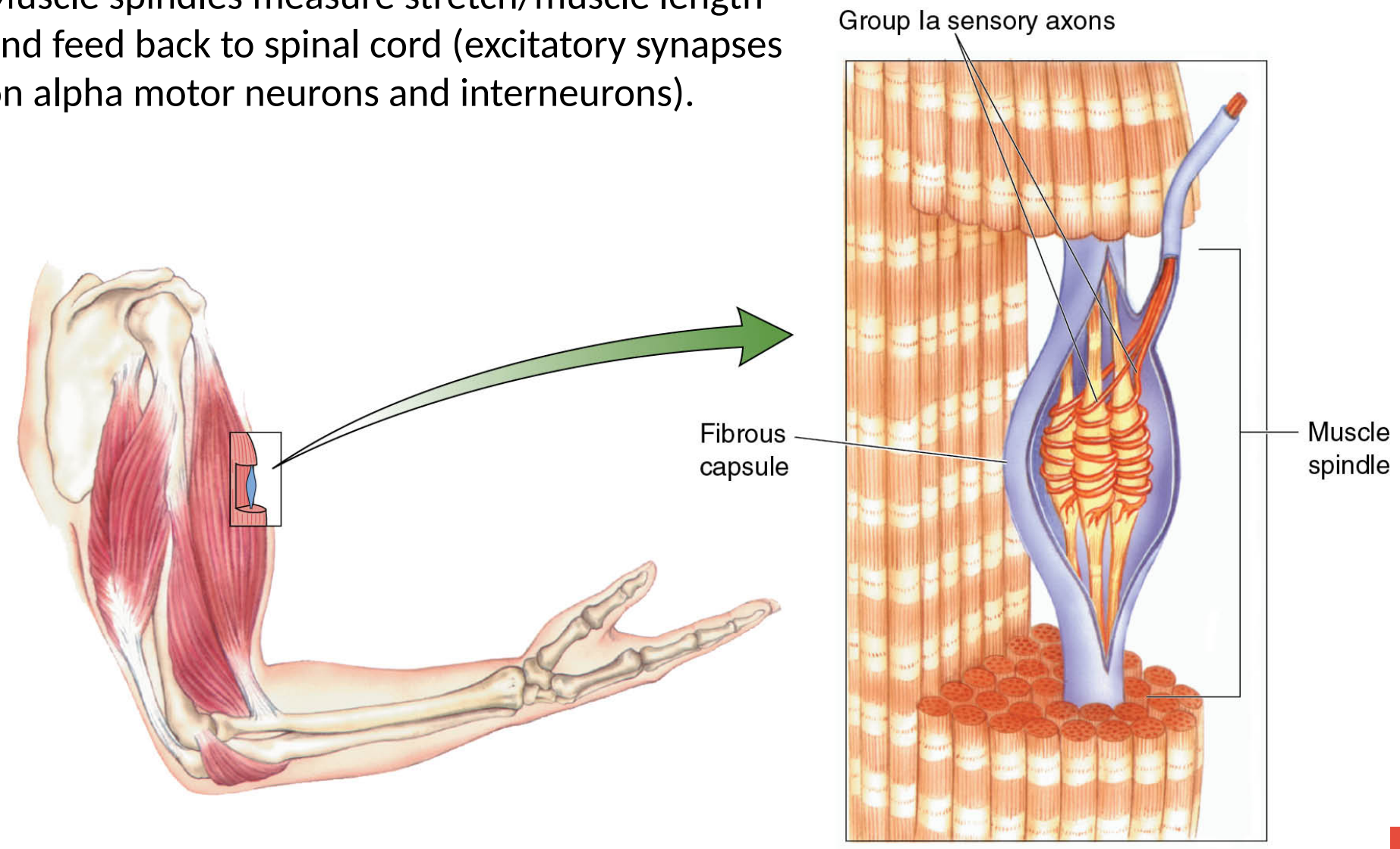


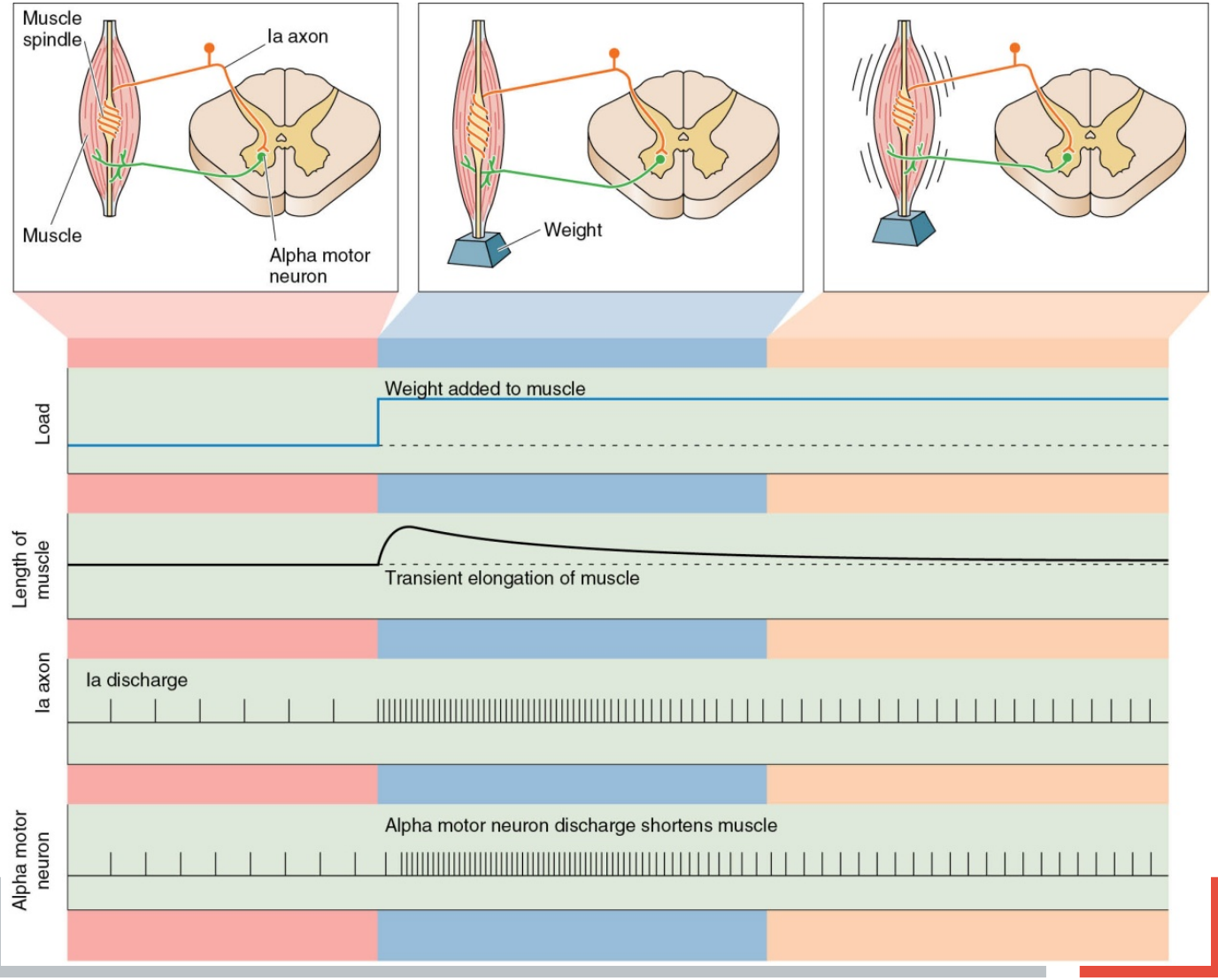
Proprioception: How you can feel your muscles and joints (muscle spindle)

Muscle spindles measure stretch/muscle length and feed back to spinal cord (excitatory synapses on alpha motor neurons and interneurons).

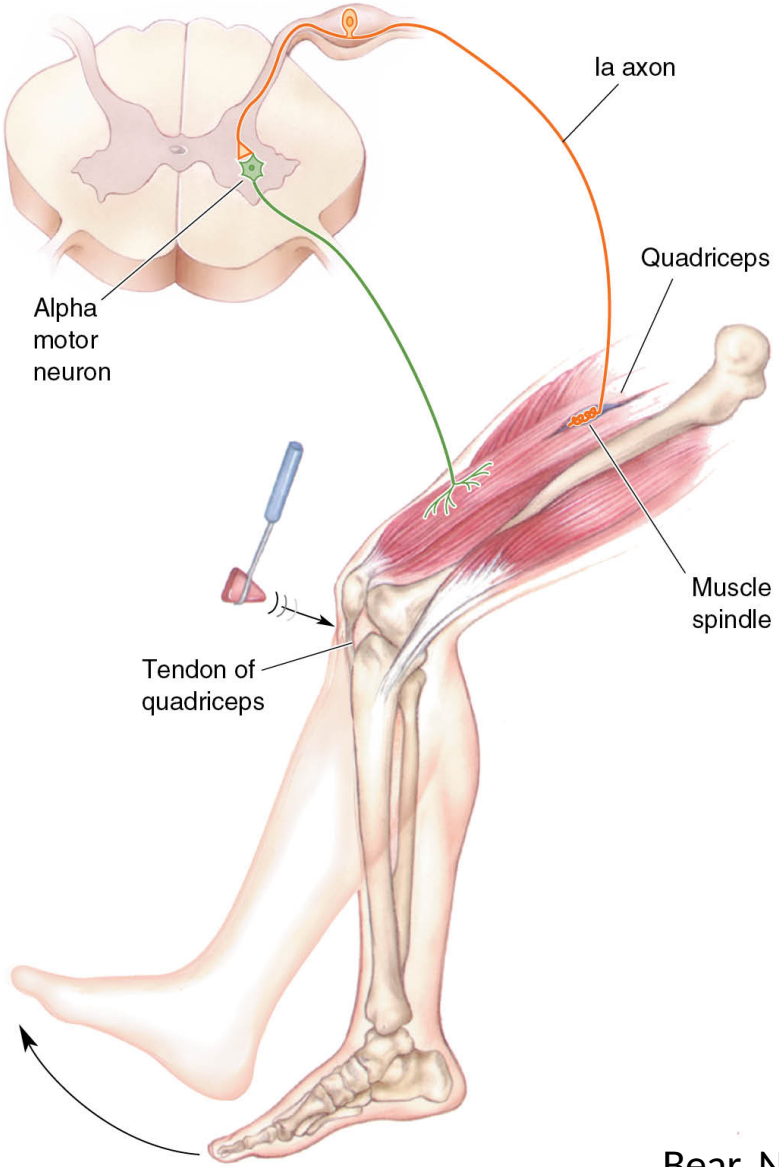


Proprioception: Muscle spindle

Thus, when the muscle is passively stretched (by a weight), the excitatory input on alpha motor neurons leads to contraction of the muscle.



Stretch reflex



The knee-jerk reflex is an example for a monosynaptic myotatic (muscle stretch) reflex:

1) Quadriceps is stretched by a hammer.
2) Muscle spindle sensory neurons are active.
3) Ia sensory axons excite alpha motor neurons in the spinal cord.
4) Quadriceps contracts.
5) Leg extends.

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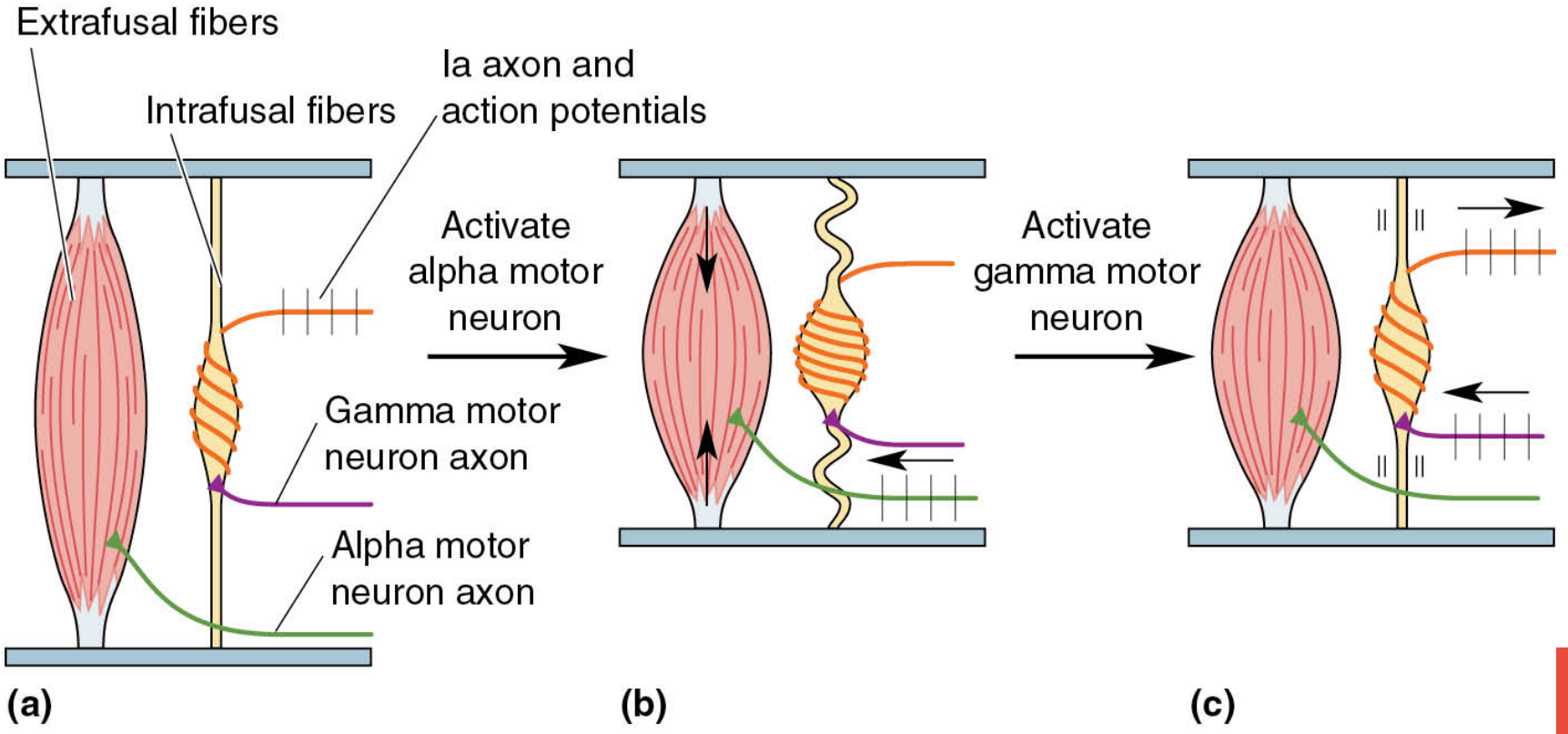
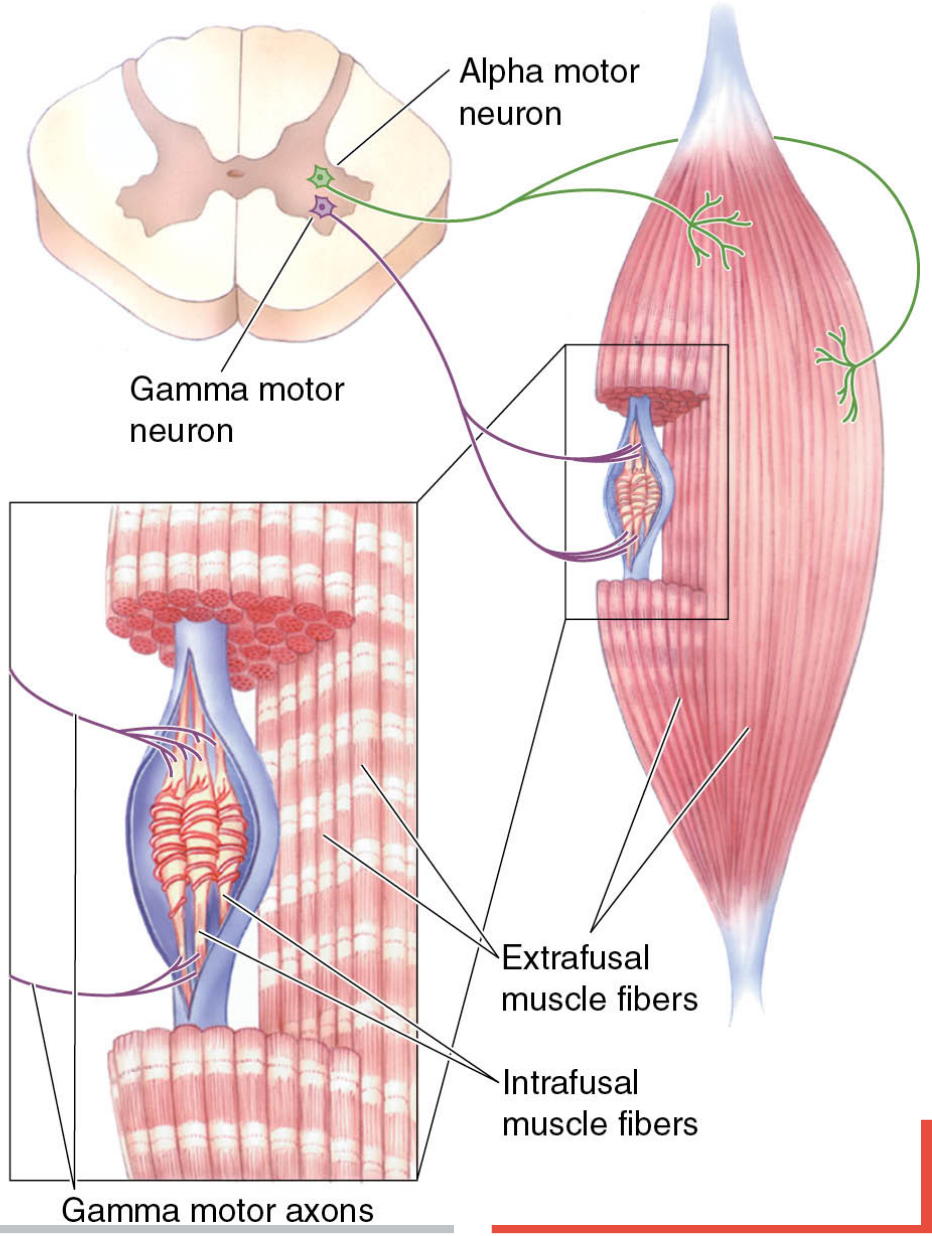
Gamma motor neurons

If activation by alpha motor neurons leads to a contraction of extrafusal muscle fibers, the muscle spindles become slack (b).
However, during normal voluntary movements, gamma motor neurons are activated too (by descending commands from the brain) and contract the intrafusal fibers, so that the muscle spindle can still respond to stretch (c).



Gamma Motor neurons

Thus, the intrafusal muscle fibers controlled by the gamma motor neurons are a system to keep the muscle spindles responsive when the extrafusal muscles (the 'main' muscles) are contracted.

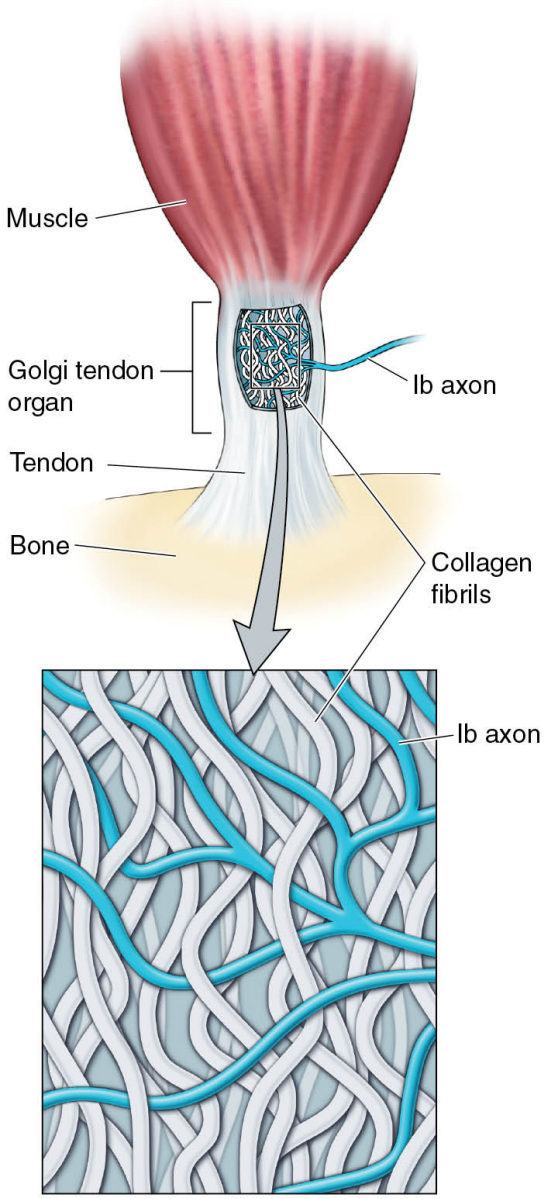


Proprioception: Golgi Tendon Organ

Golgi tendon organs measure muscle tension (force in the contracting muscle). They are located at the junction of a muscle and a tendon (which connects the muscle to the bone).

They are innervated by Ib sensory axons (slightly smaller than Ia of the muscle spindles).

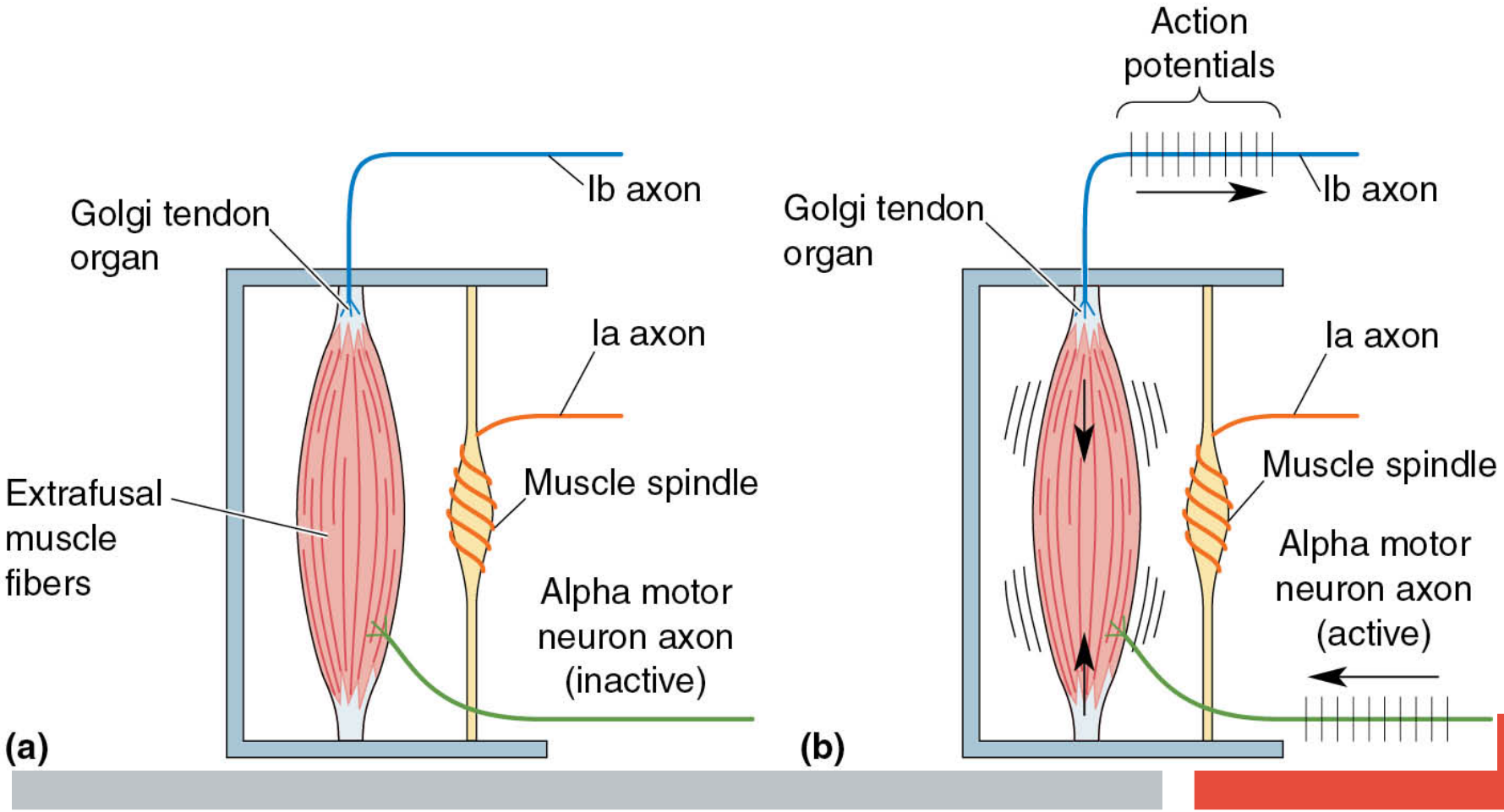
Mechanosensitive ion channels open and allow for action potentials, when the tendon's collagen fibrils straighten/squeeze the Ib axons during muscle tension.



Proprioception: Golgi Tendon Organ

Muscle spindles are arranged in parallel to extrafusal muscle fibers. They encode muscle length.

Golgi tendon organs are arranged in series to extrafusal muscle fibers. They encode muscle tension.

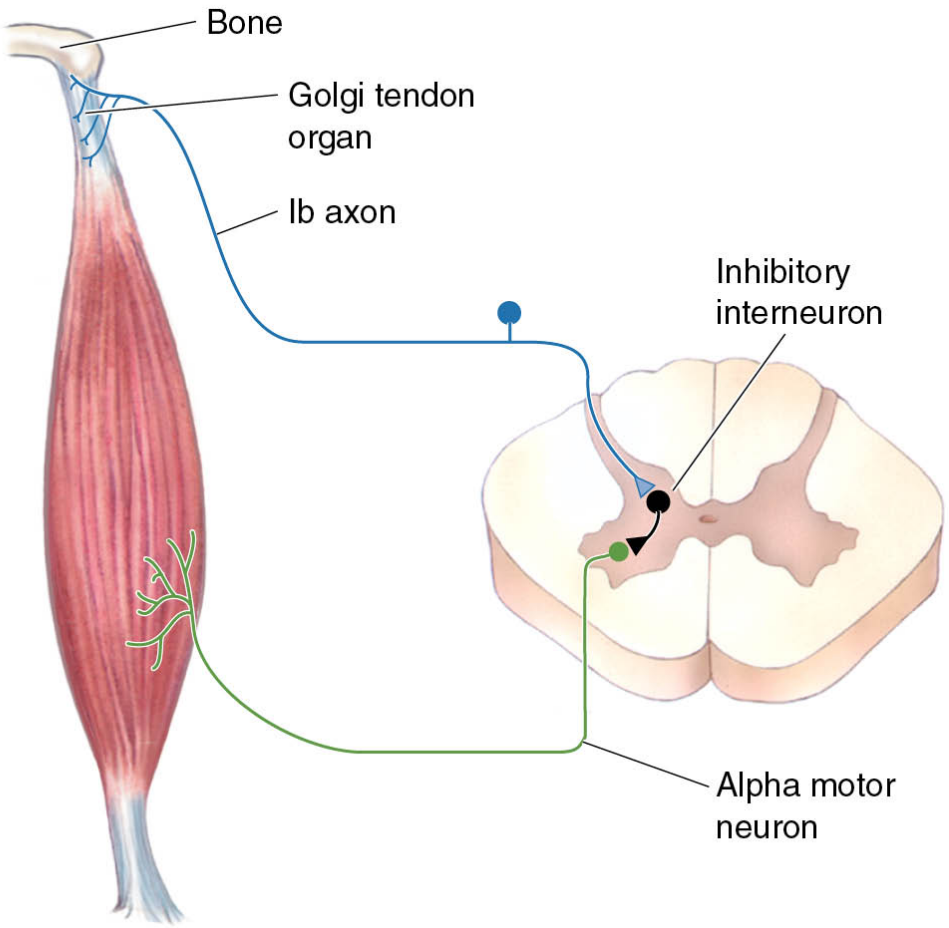


Golgi Tendon Reflex

When muscle tension is getting too high, the Golgi tendon organs excite inhibitory interneurons in the spinal cord.

These in turn inhibit the alpha motor neurons and muscle contraction.

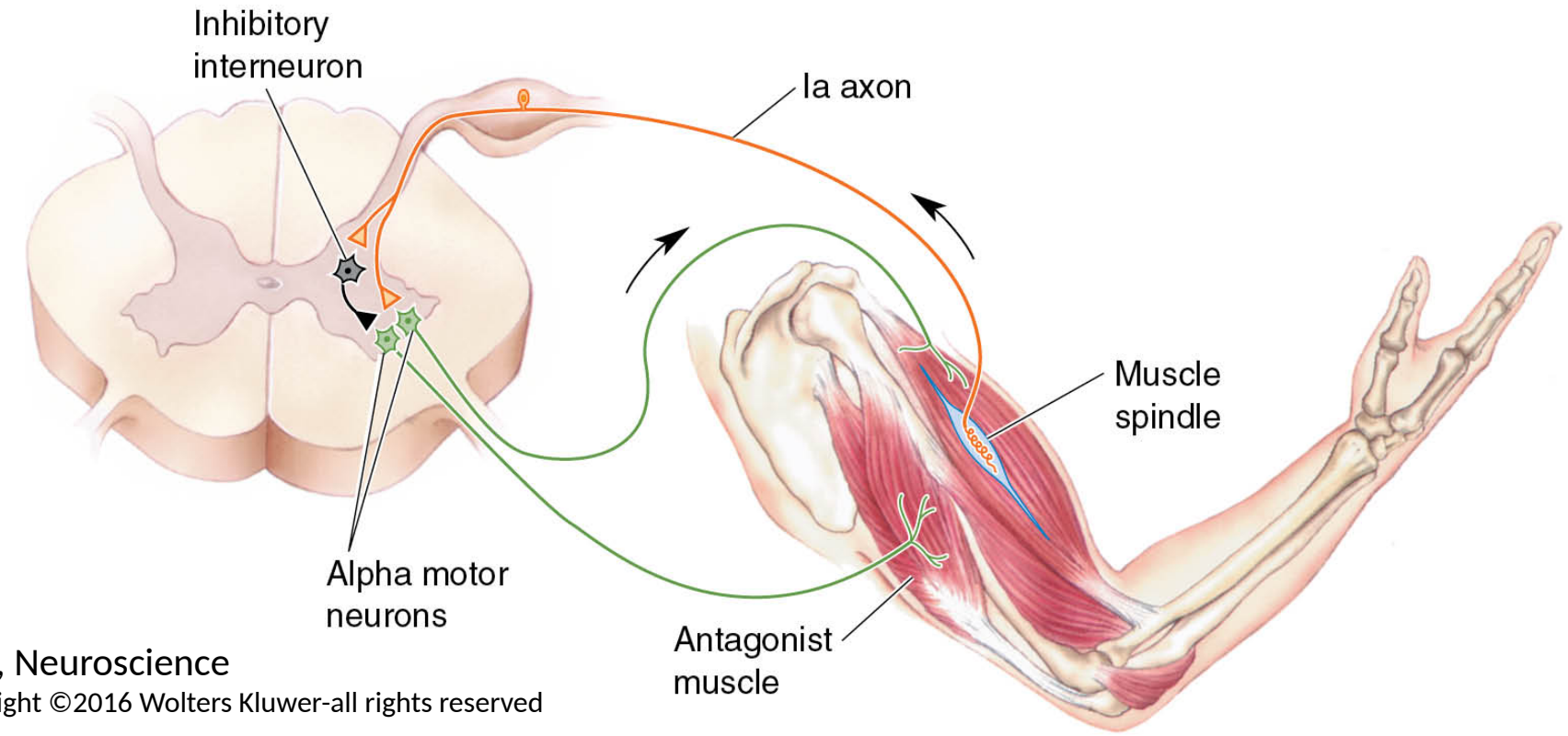
This can help to protect from overload and for keeping the muscle tension in an optimal range (allowing for fine motor acts).



Extensor/Flexor Reciprocal Inhibition

During the stretch reflex, increased muscle length leads to activation of the muscle spindle, the corresponding Ia axon and the alpha motor neuron, which in turn will contract the muscle.

In addition, the antagonist muscle should not contract: therefore, the Ia axon activates an inhibitory interneuron that inhibits the alpha motor neuron of the antagonist muscle.



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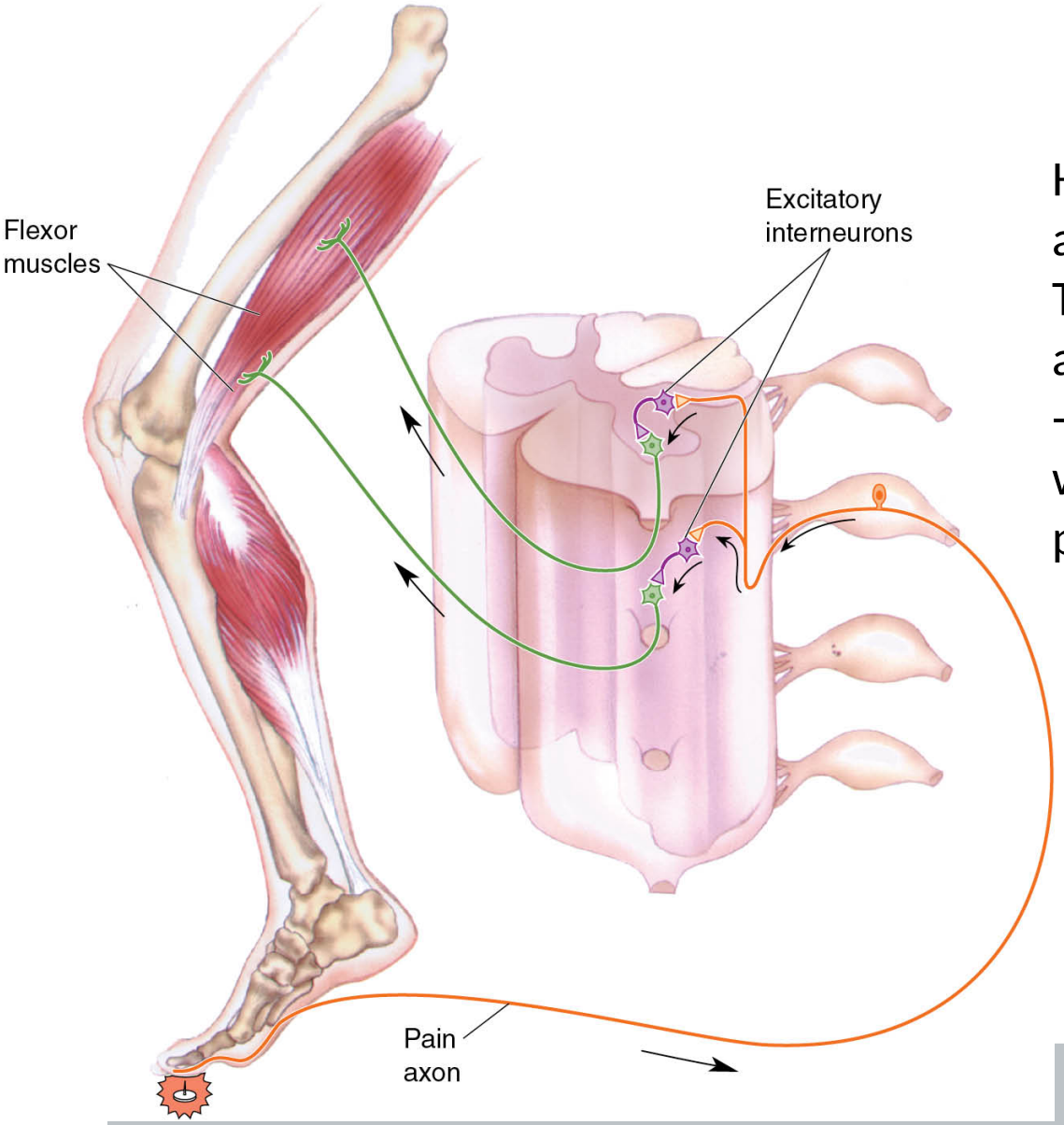
Polysynaptic flexor reflex



Here, a pain receptor neuron activates excitatory interneurons. The interneurons excite the alpha motor neurons.
-> Flexor muscle contraction to withdraw limb from the source of pain.

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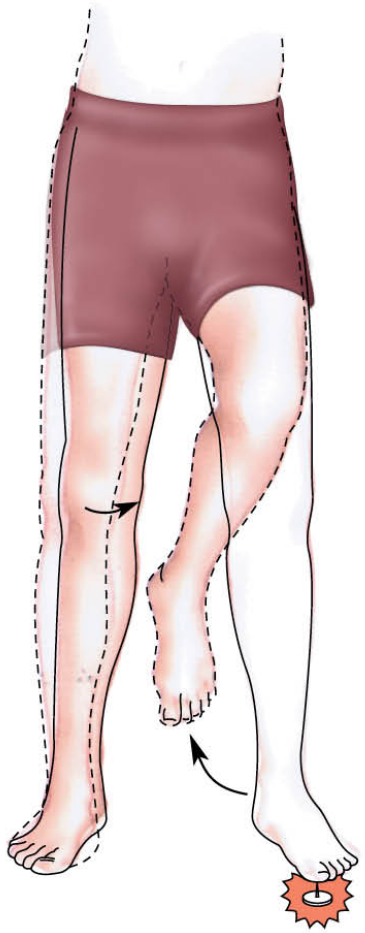
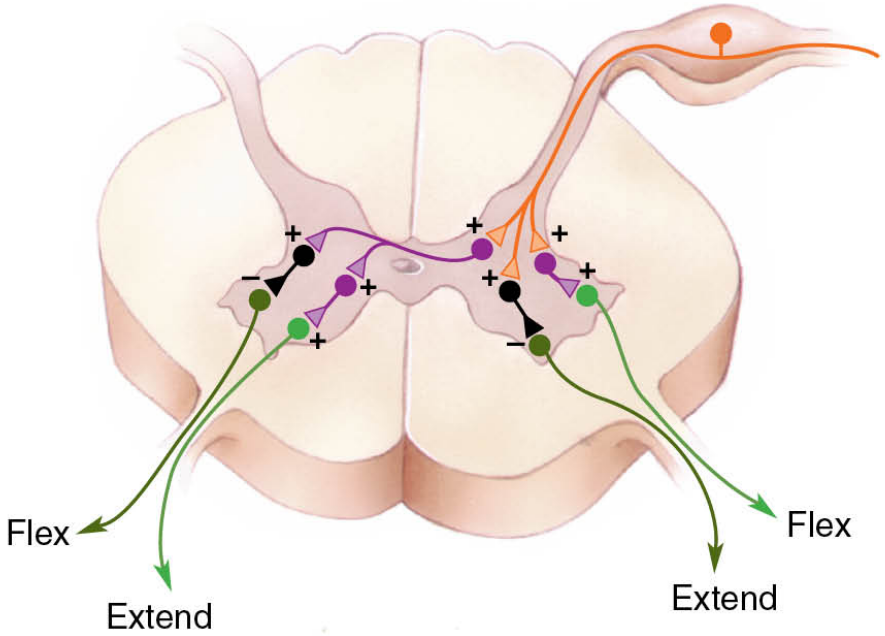
Cross-extensor Reflex

Flexion on one side to avoid pain can cause instability.
Thus, the crossed-extensor reflex causes extension and stabilization on the other side via interneurons (-: inhibitory, +: excitatory).





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Summary / Next Lecture

- Today, we have discussed muscles, the muscle fibers, their innervation, and how a nerve impulse is converted into physical contraction.

- Next week, we will learn about how this process is controlled by the brain.

Movement planning and control

- Motor pathways
- Motor cortex
- Supplementary motor area and premotor cortex
- Basal ganglia
- Cerebellum