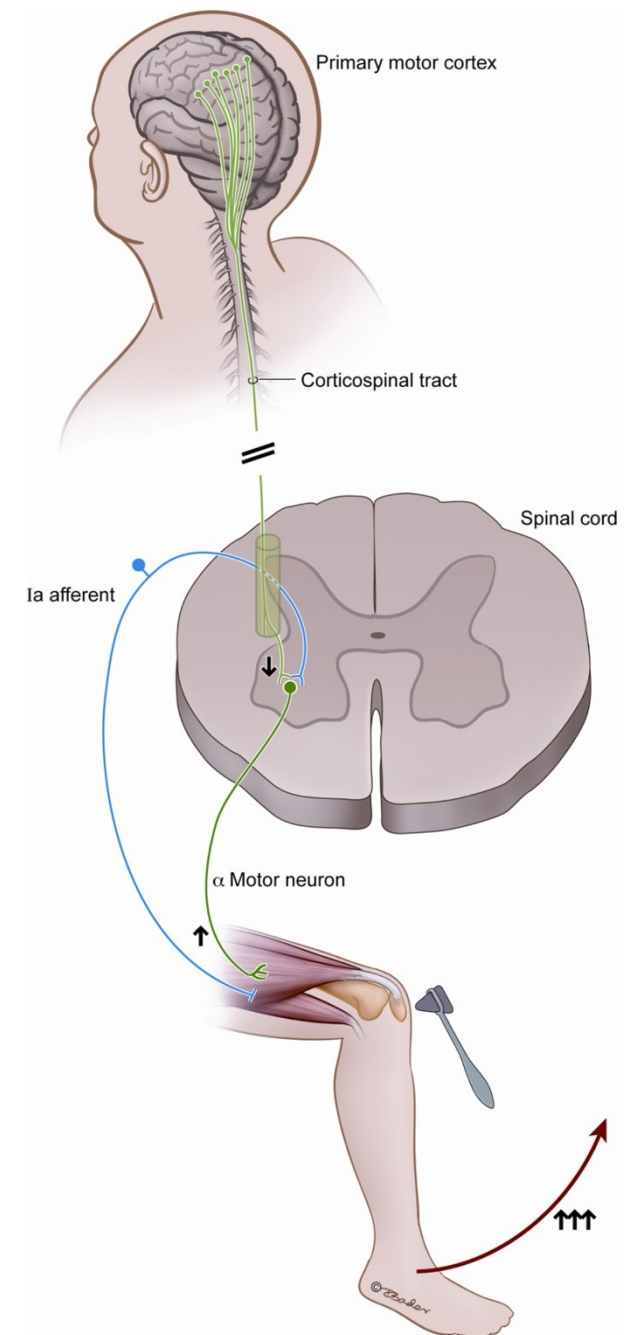


**11**

# **Motor system I**

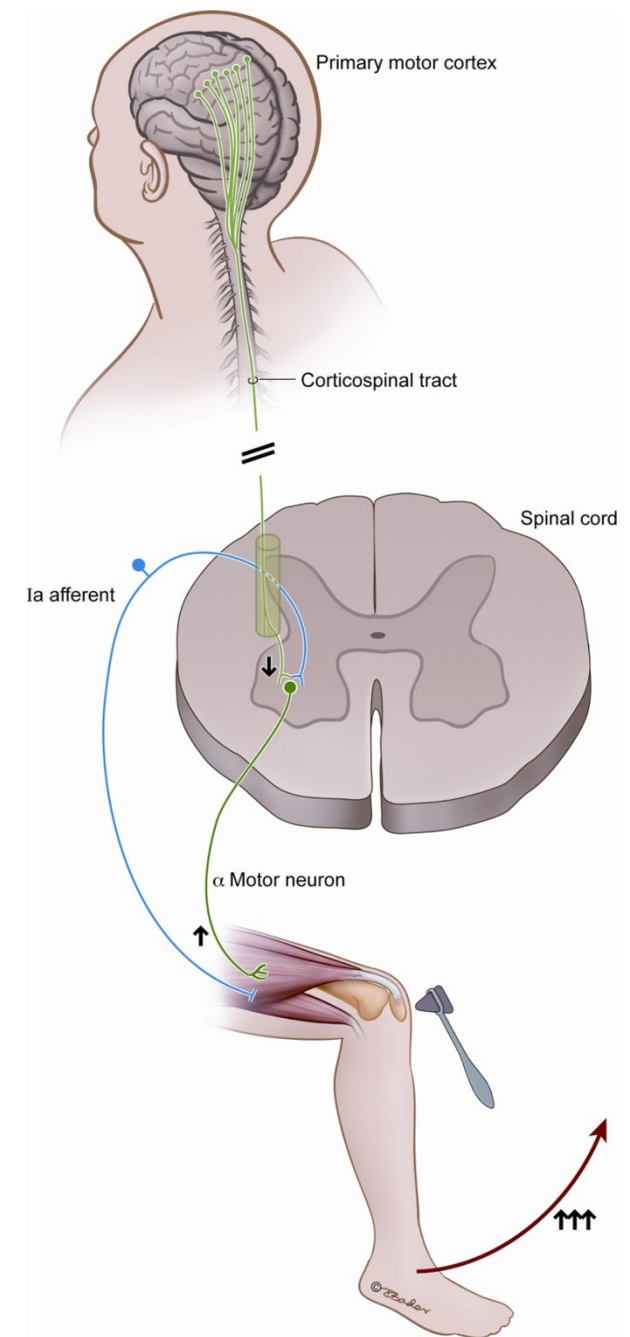
# Introduction

- Skeletal muscle contraction is initiated by lower motor neuron



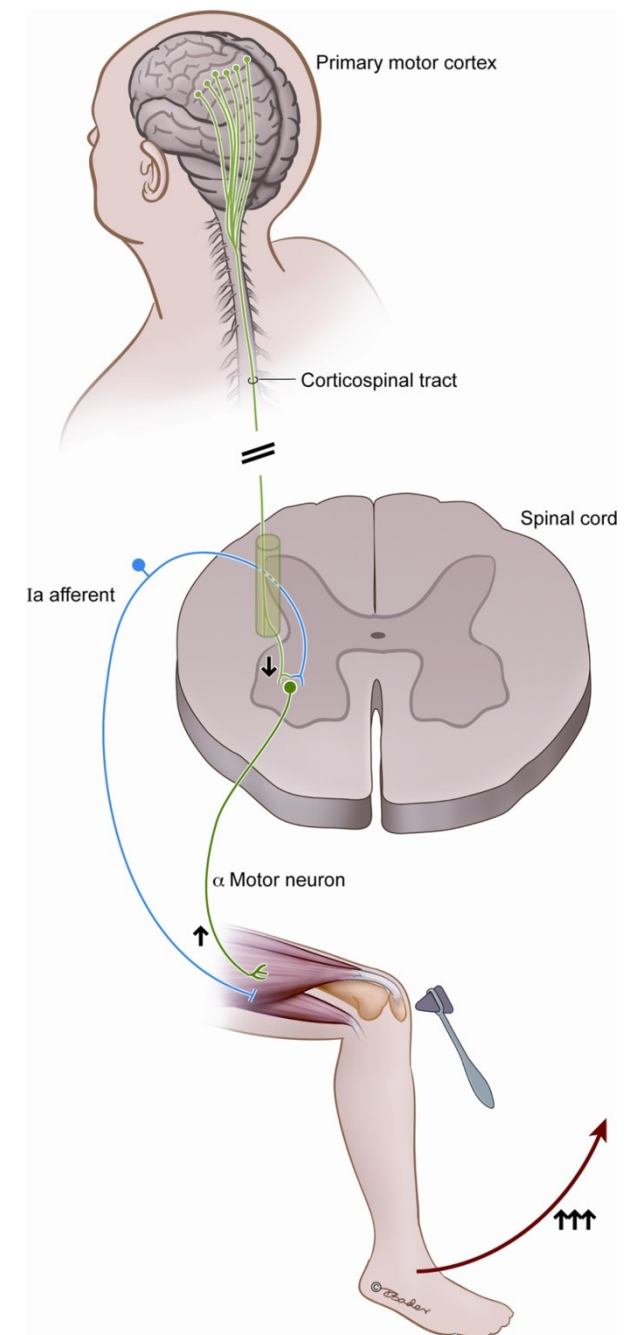
# Introduction

- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron is a part of local reflex circuits



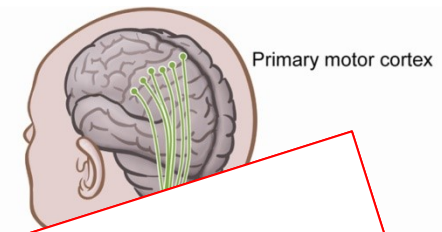
# Introduction

- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron is a part of local reflex circuits
- The information from several sources is integrated in the lower motor neuron
  - Higher levels of CNS
    - Upper motor neuron, tectum, n. ruber, brain stem
  - Proprioception



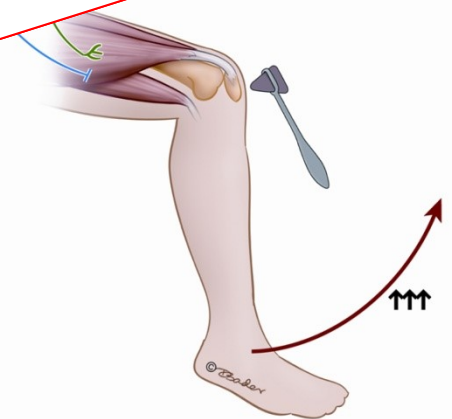
# Introduction

- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS



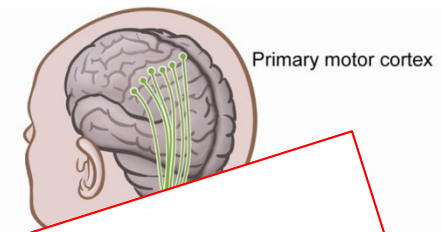
**Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS**

Spinal cord



# Introduction

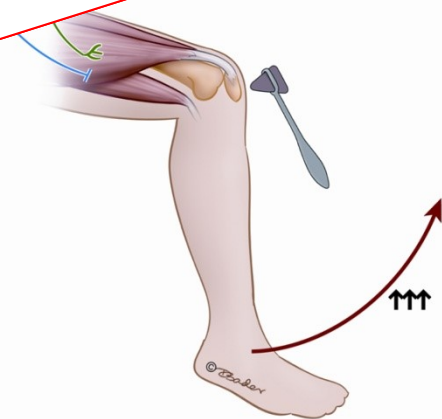
- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS



**Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS**

**Proprioception is crucial for the regulation of local circuit activity**

Spinal cord



# Lower motor neuron

- **$\alpha$  motoneuron**

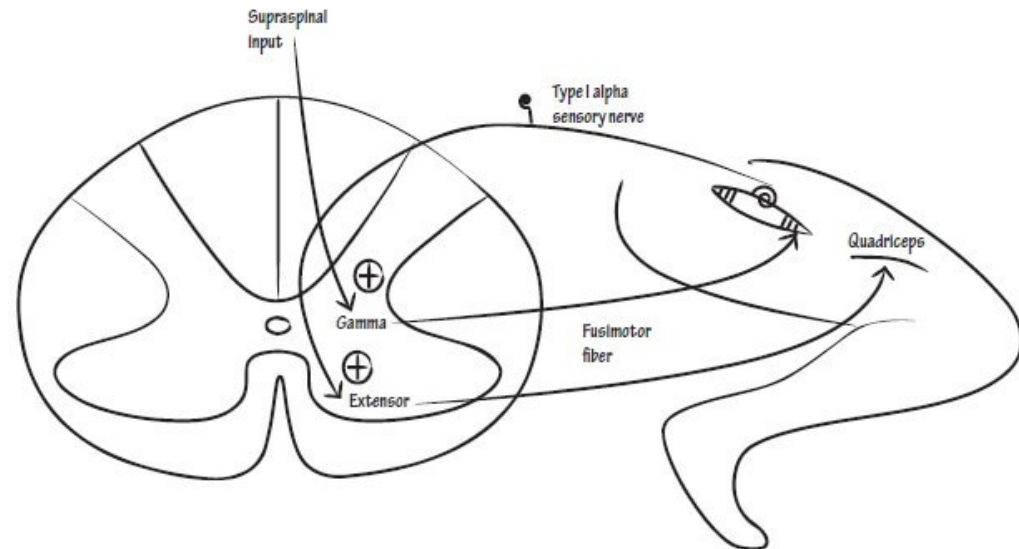
- Innervation of contractile elements
- Extrafusal fibers
- Muscle contraction

- **$\gamma$  motoneuron**

- Innervation of muscle spindles
- Intrafusal fibers
- Alignment of muscle spindles
- Gamma loop

- **$\beta$  motoneuron**

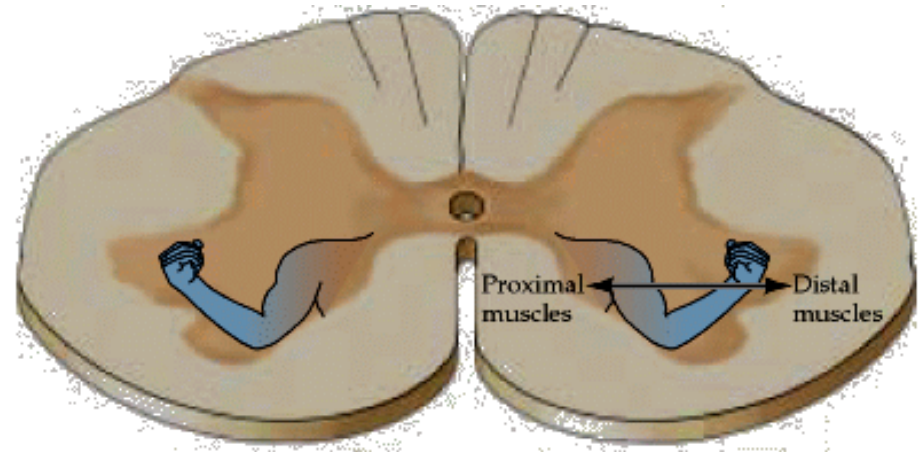
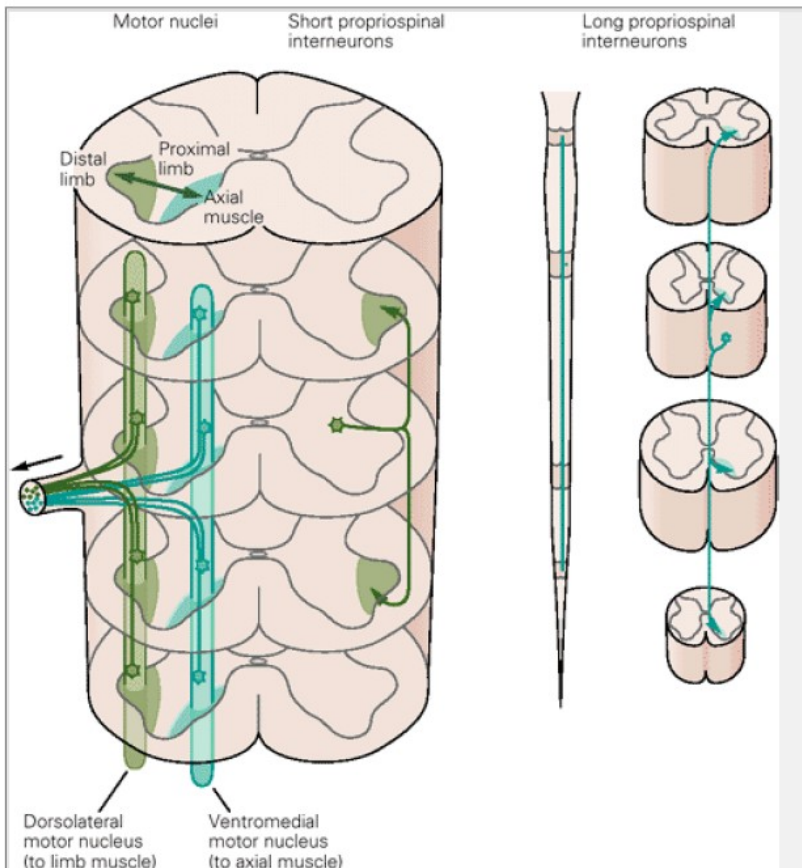
- Both extrafusal and intrafusal fibers



<http://epomedicine.com/wp-content/uploads/2016/07/gamma-loop.jpg>

# Lower motor neuron

## Topography





# Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus

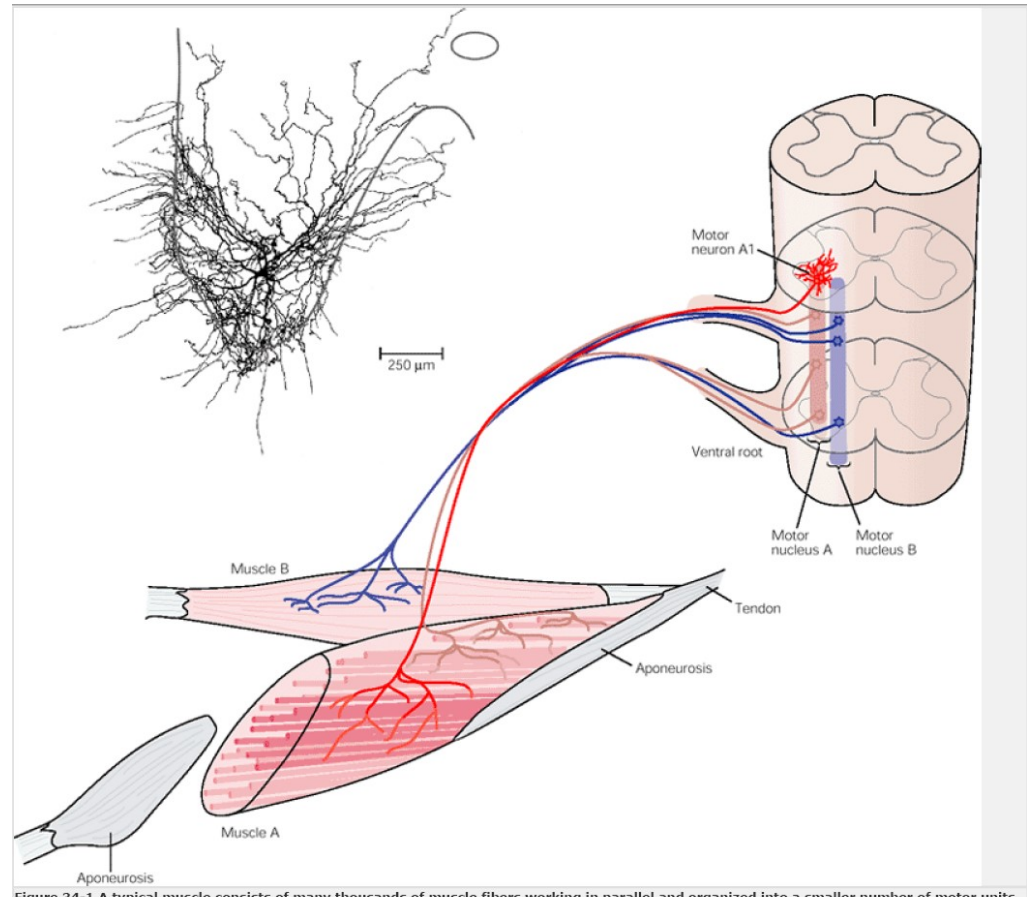


Figure 24-1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

# Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus
- Each motoneuron innervate from 100 to 1000 muscle fibers and one muscle fiber is innervated by a single motoneuron

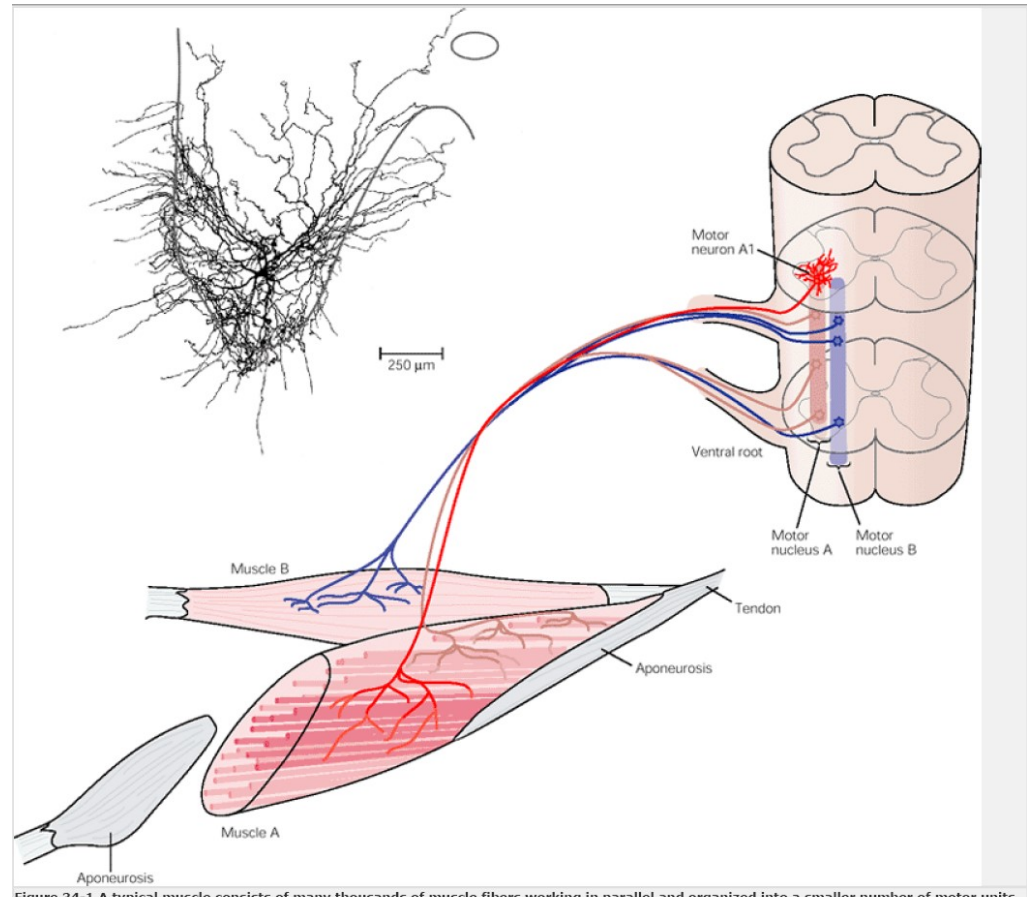


Figure 24-1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

# Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus
- Each motoneuron innervate from 100 to 1000 muscle fibers and one muscle fiber is innervated by a single motoneuron
- The ensemble of muscle fibers innervated by a single neuron and corresponding motoneuron constitutes the motor unit

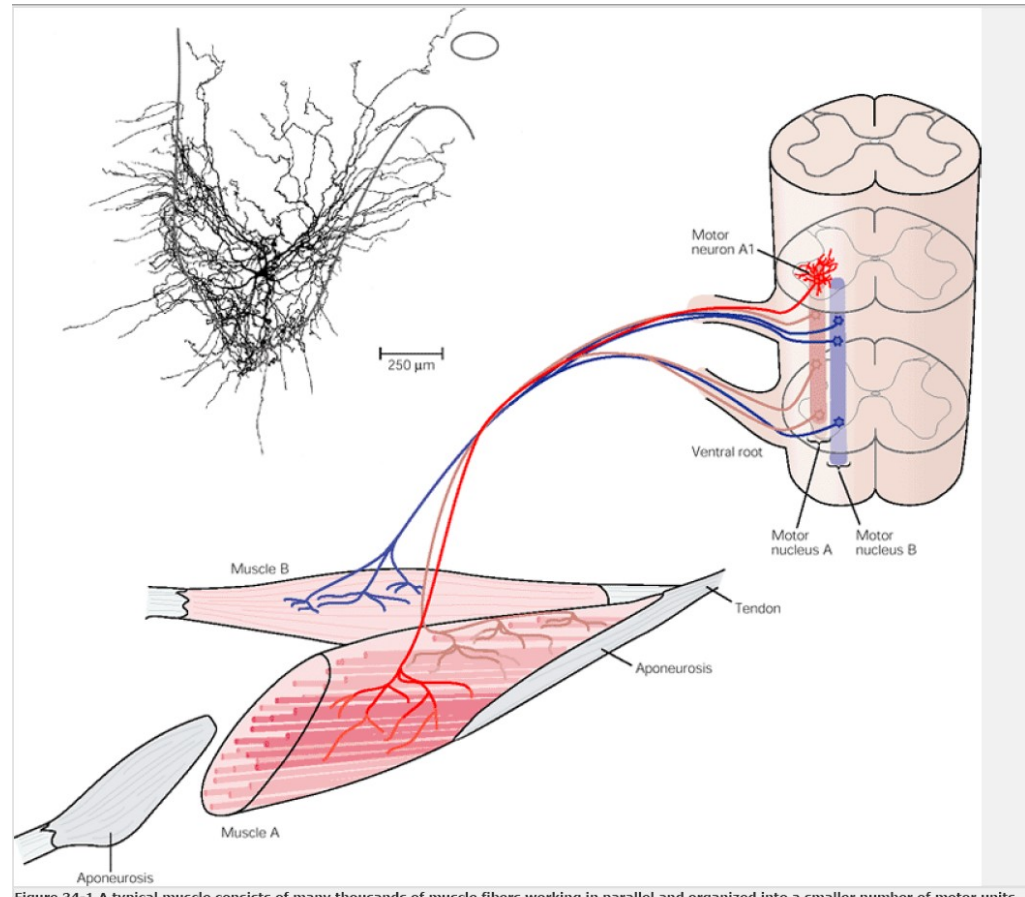


Figure 24-1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

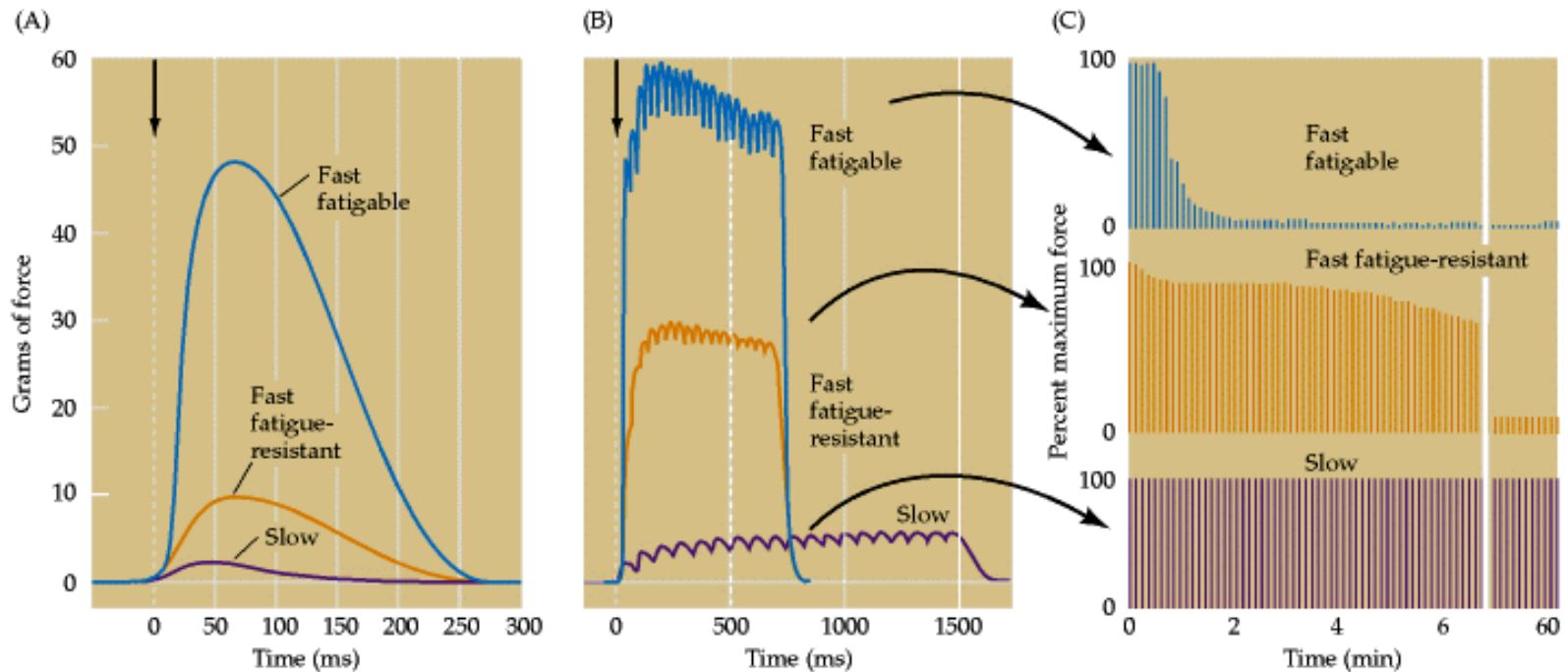
# Types of muscle fibers

## Fast fibers

- Performance
- Fast fatigue-resistant – normal performance
- Fast fatigable – high performance

## Slow fibers

- Endurance
- Fatigue resistant



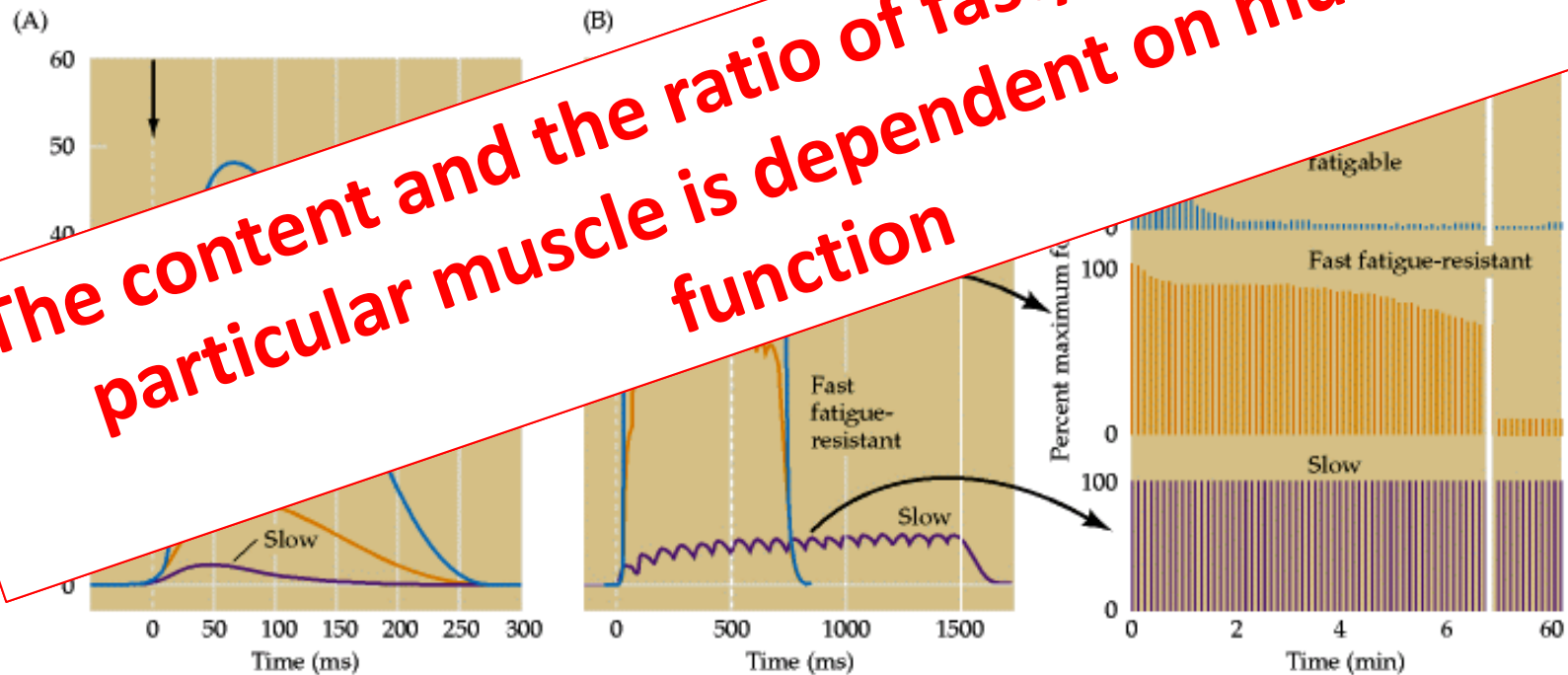
# Types of muscle fibers

## Fast fibers

- Performance
- Fast fatigue-resistant – normal performance
- Fast fatigable – high performance

## Slow fibers

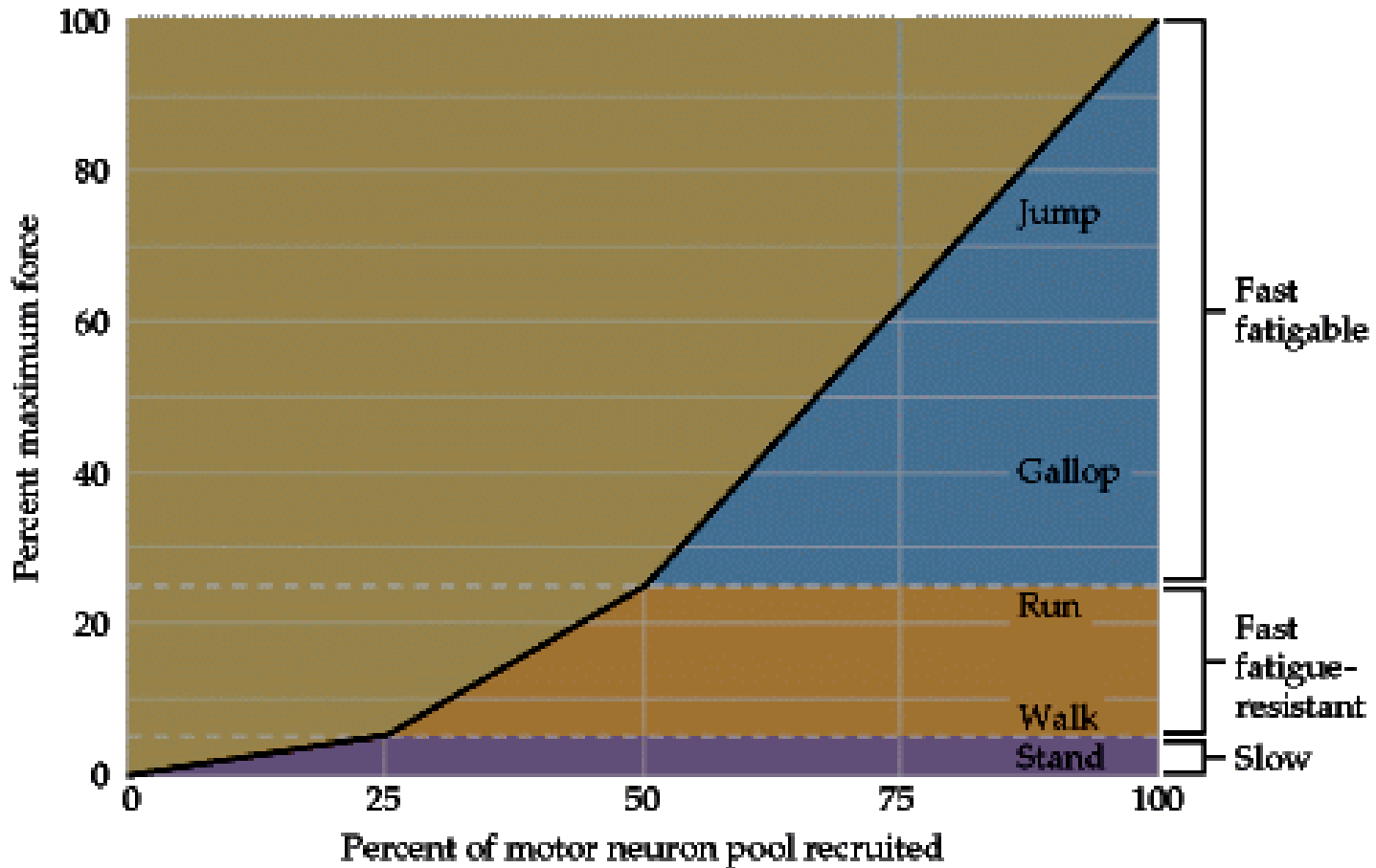
- Endurance



**The content and the ratio of fast/slow fibers in particular muscle is dependent on muscle function**

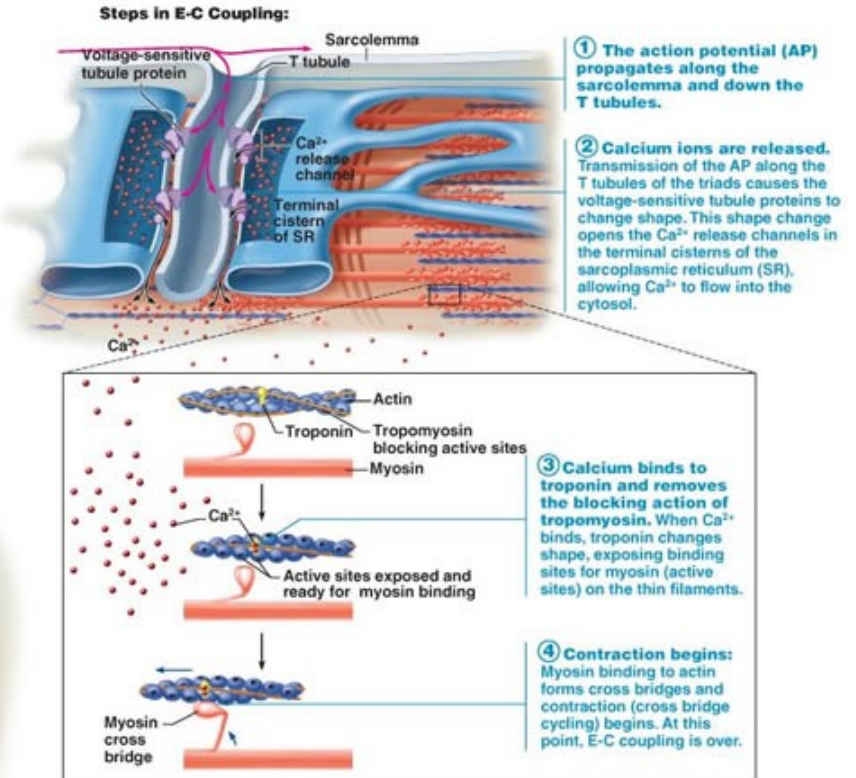
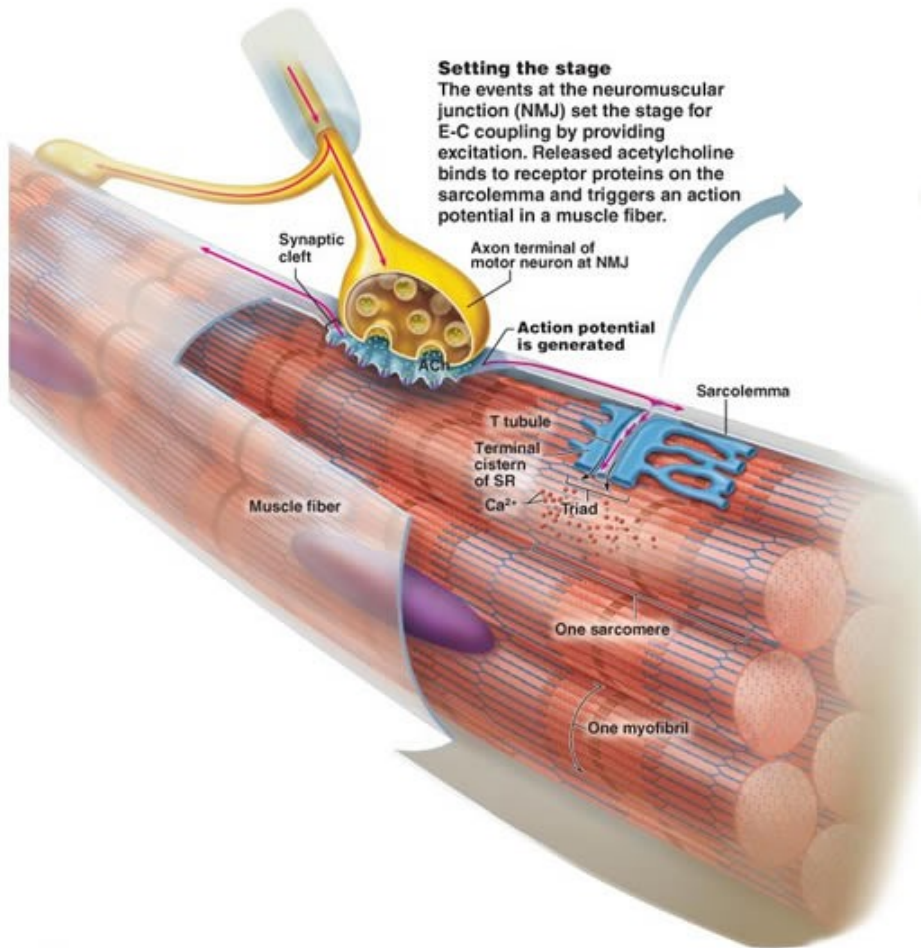
# The recruitment of motor neurons

m. gastrocnemius in a cat





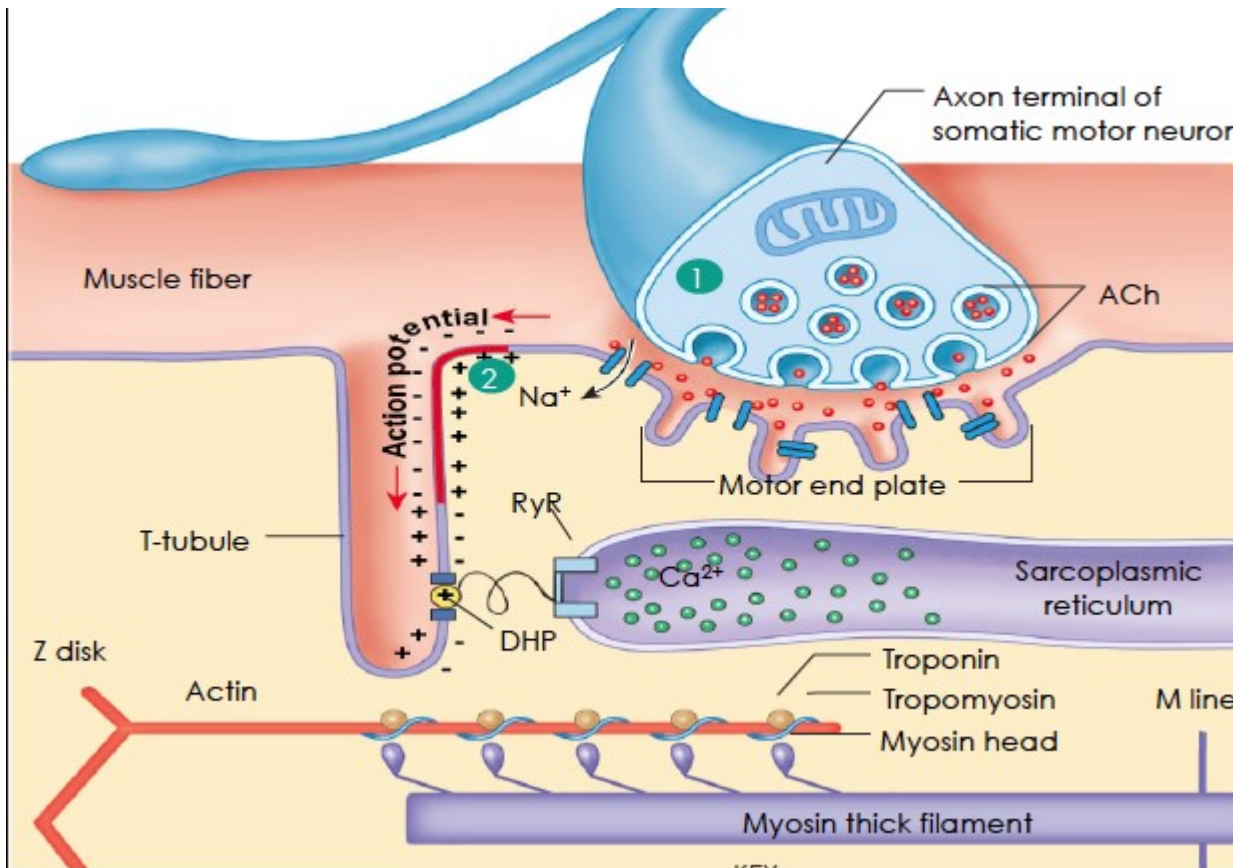
# Neuromuscular junction



## The aftermath

When the muscle AP ceases, the voltage-sensitive tubule proteins return to their original shape, closing the Ca<sup>2+</sup> release channels of the SR. Ca<sup>2+</sup> levels in the sarcoplasm fall as Ca<sup>2+</sup> is continually pumped back into the SR by active transport. Without Ca<sup>2+</sup>, the blocking action of tropomyosin is restored, myosin-actin interaction is inhibited, and relaxation occurs. Each time an AP arrives at the neuromuscular junction, the sequence of E-C coupling is repeated.

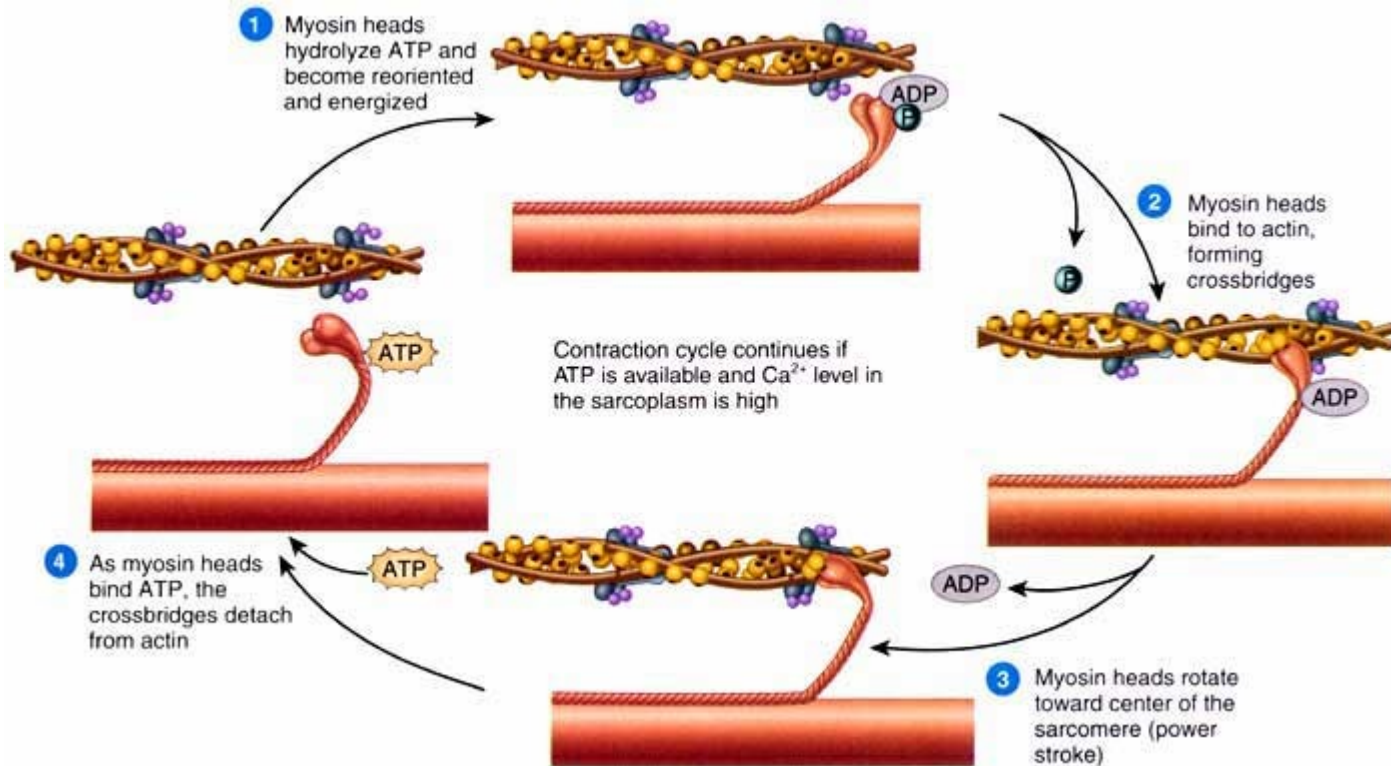
# Neuromuscular junction



<https://s3.amazonaws.com/classconnection/803/flashcards/9818803/png/initiation-151586429D6310D1C56.png>

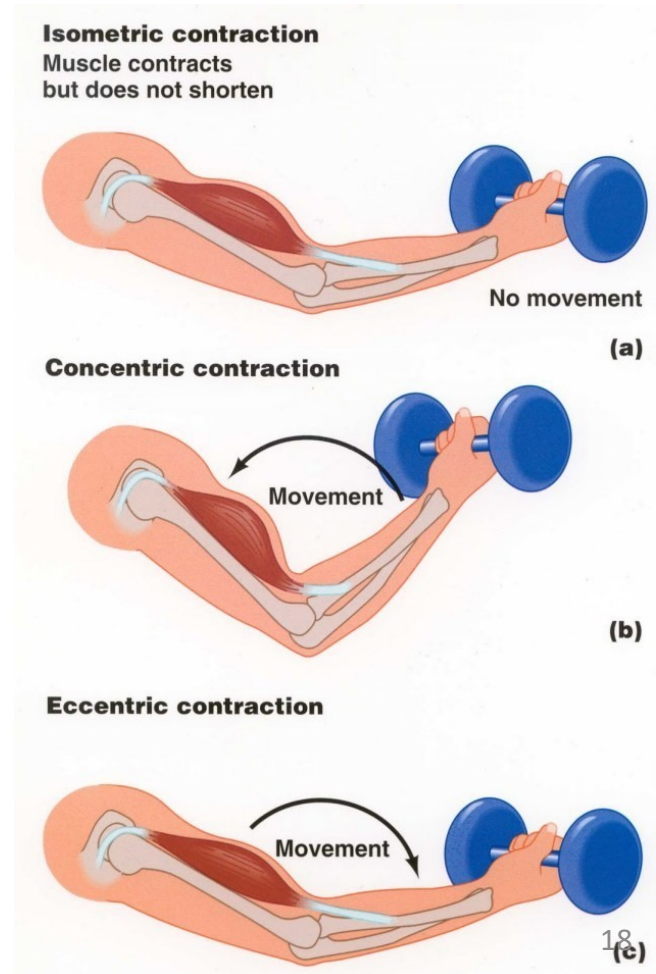
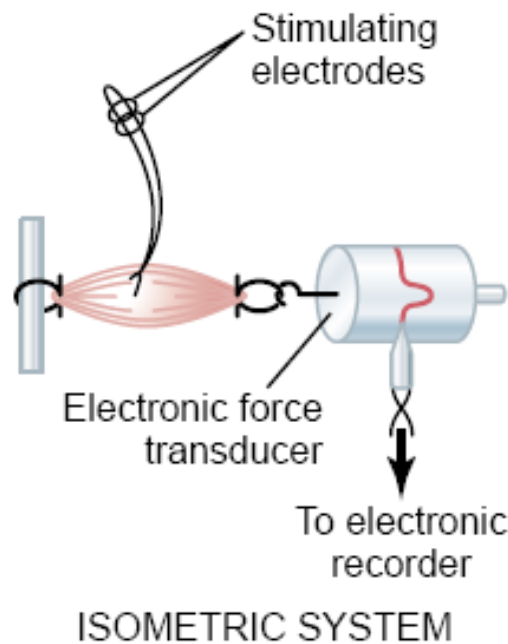
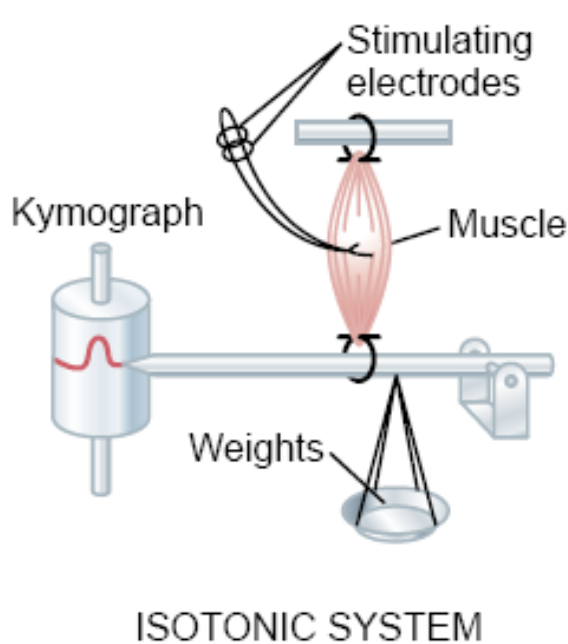


# Muscle fibers



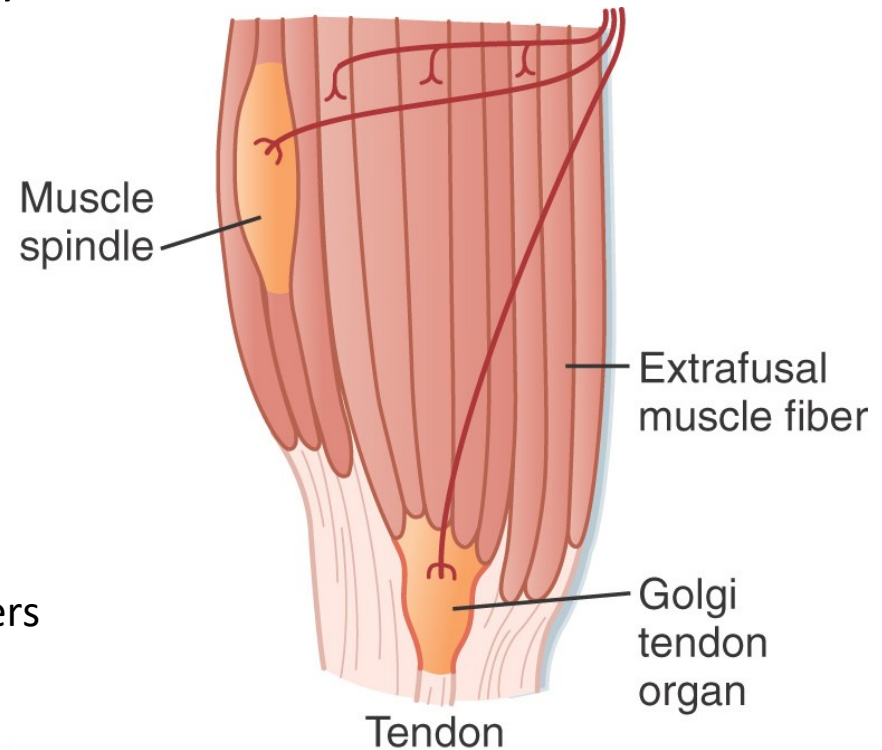
# Types of muscle contraction

- Isotonic contraction
  - Constant tension
  - Concentric x excentric contraction
- Isometric contraction
  - Constant length



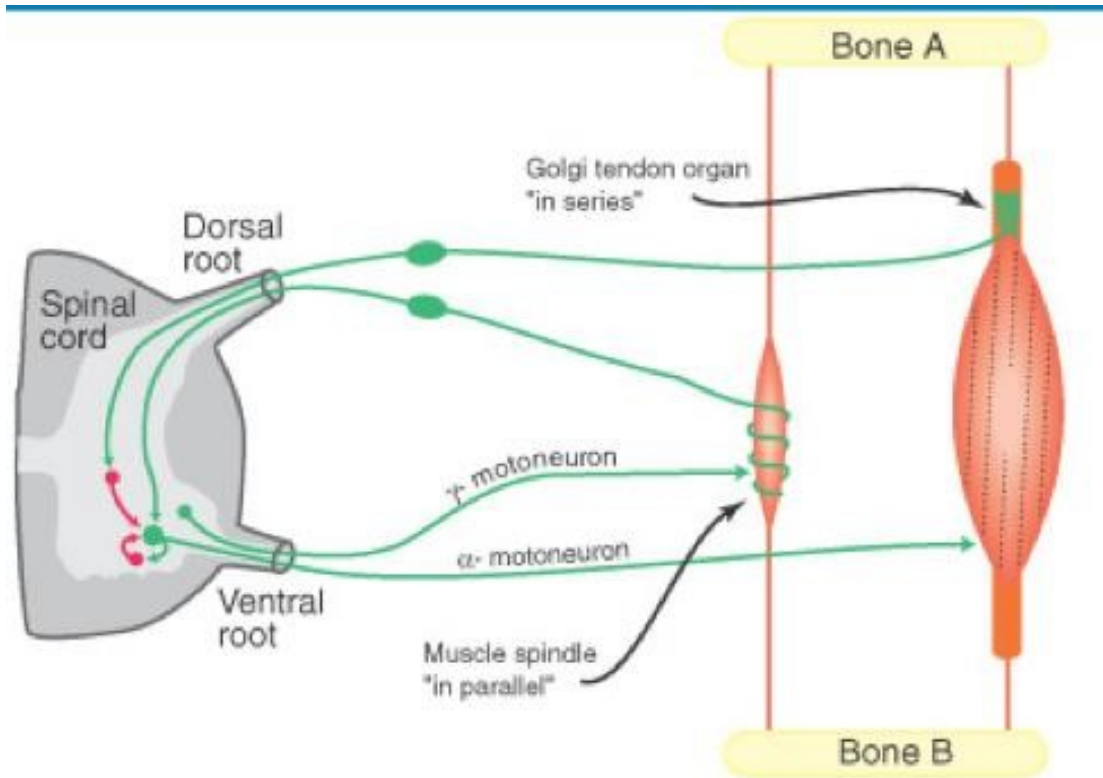
# Proprioception

- Information about the position of body parts in relation to each other  
(The sum of information about lengths of particular muscles)
- Information about movement  
(The force and speed of muscle contraction)
- Reflex regulation of muscle activity
- Muscle spindles
  - Lie in parallel with extrafusal muscle fibers
- Golgi tendon organ
  - Arranged in series with extrafusal muscles



<http://www.slideshare.net/CsillaEgri/presentations>

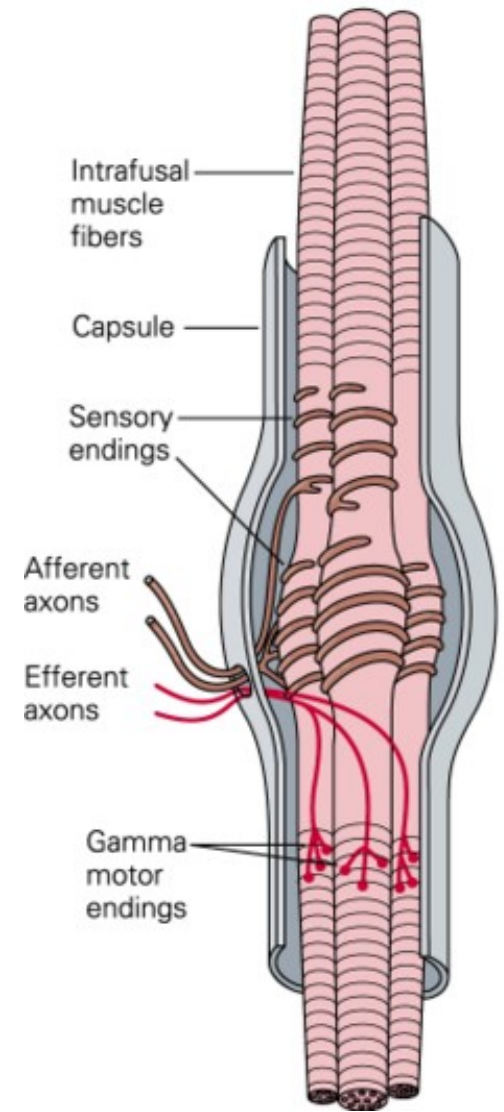
# Muscle spindle and Golgi tendon organ



[http://images.persianblog.ir/559630\\_iXFiuRo0.jpg](http://images.persianblog.ir/559630_iXFiuRo0.jpg)

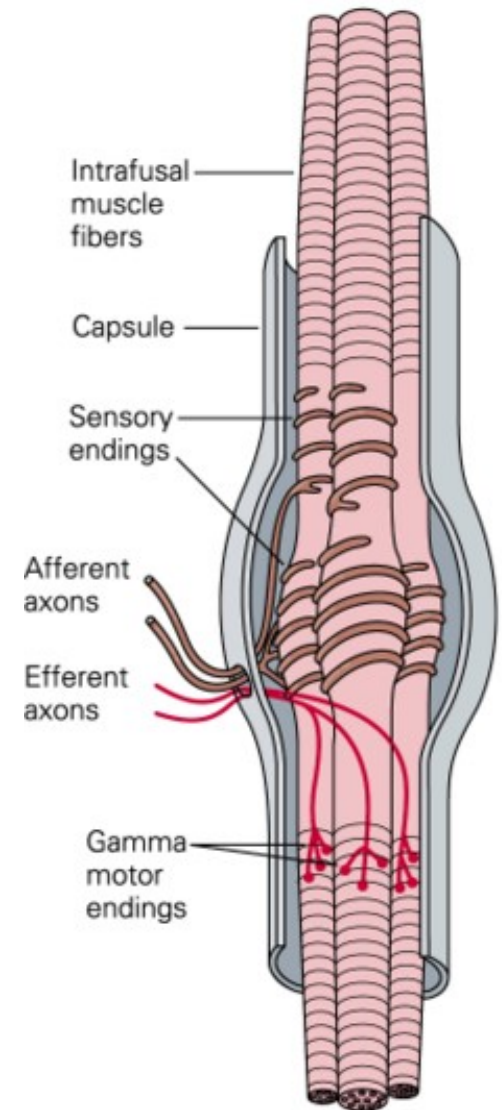
# Muscle spindles

- No-force generating contractile structures
- The contractility is for spindle length adjustment
- Encapsulated structure filled with a fluid
- Intrafusal fibers



# Muscle spindles

- No-force generating contractile structures
- The contractility is for spindle length adjustment
- Encapsulated structure filled with a fluid
- Intrafusal fibers
  - Lie in parallel with extrafusal muscle fibers (Stretch/shorten along with extrafusal fibers)
  - Efferent connections (into muscle spindle)
    - $\gamma$  motoneuron
  - Afferent connections (from muscle spindle)
    - Information about change in muscle length
    - Reflex regulation of the  $\alpha$  motoneuron activity

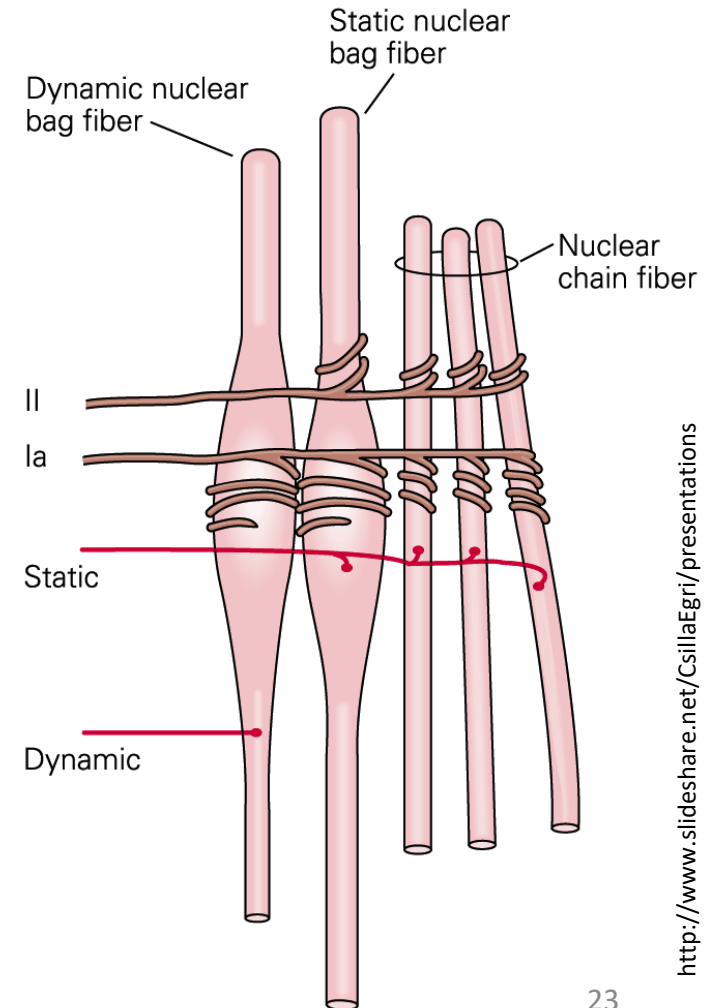




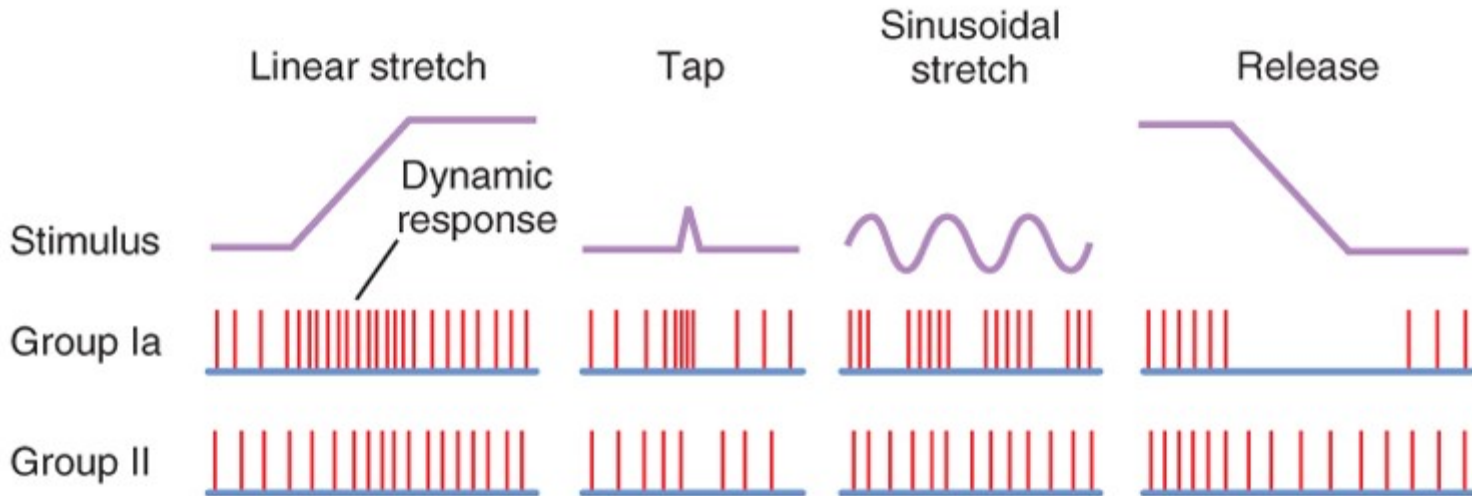
# Muscle spindle

- Static fibers
- Dynamic fibers
- Afferent connections (from spindle)
  - II – static fibers
    - Information about muscle length (position)
    - Ia – static and dynamic fibers
    - Information about muscle length and contraction (movement)
  - Reflex regulation of the  $\alpha$  motoneuron activity
- Efferent connections (into spindle)
  - Static  $\gamma$  motoneurons
  - Dynamic  $\gamma$  motoneurons
  - Spindle length adjustment

B Intrafusal fibers of the muscle spindle



# Afferent signaling from muscle spindles



## II – Static fibers

- Static response

## Ia – Static and dynamic fibers

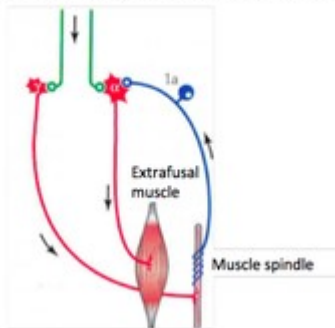
- Static and dynamic response



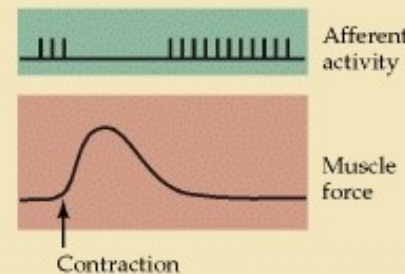
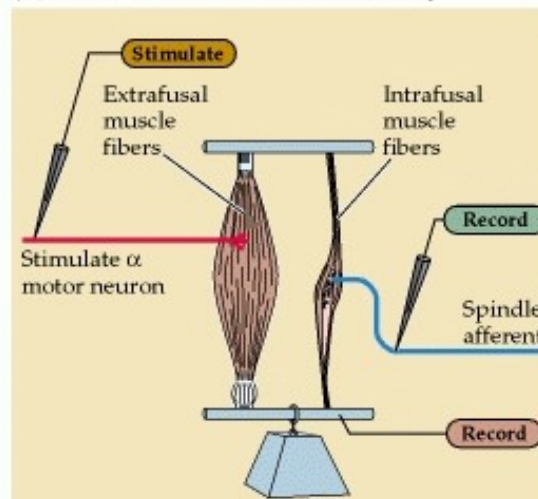
# Efferent signaling into the muscle spindle

- $\gamma$  motoneurons adjust the length of intrafusla fibers
- Regulation of sensitivity
- $\alpha$  and  $\gamma$  coactivation

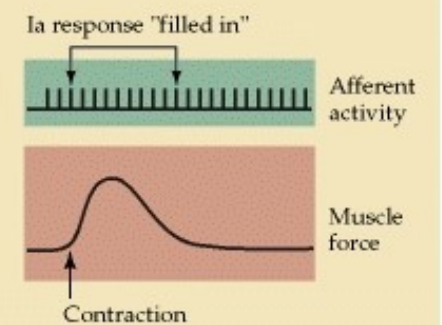
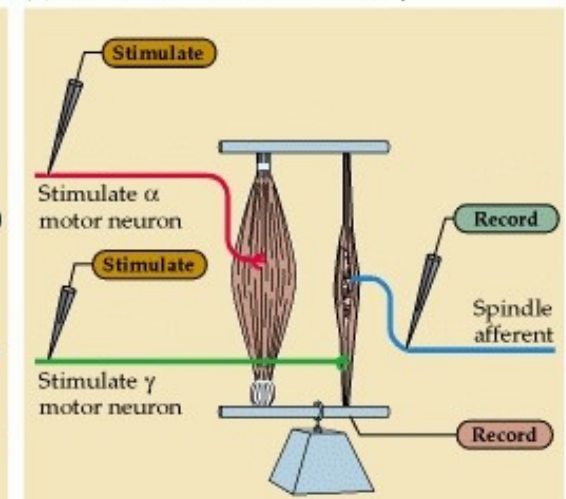
The CNS co-activates alpha and gamma motoneurons



(A)  $\alpha$  Motor neuron activation without  $\gamma$

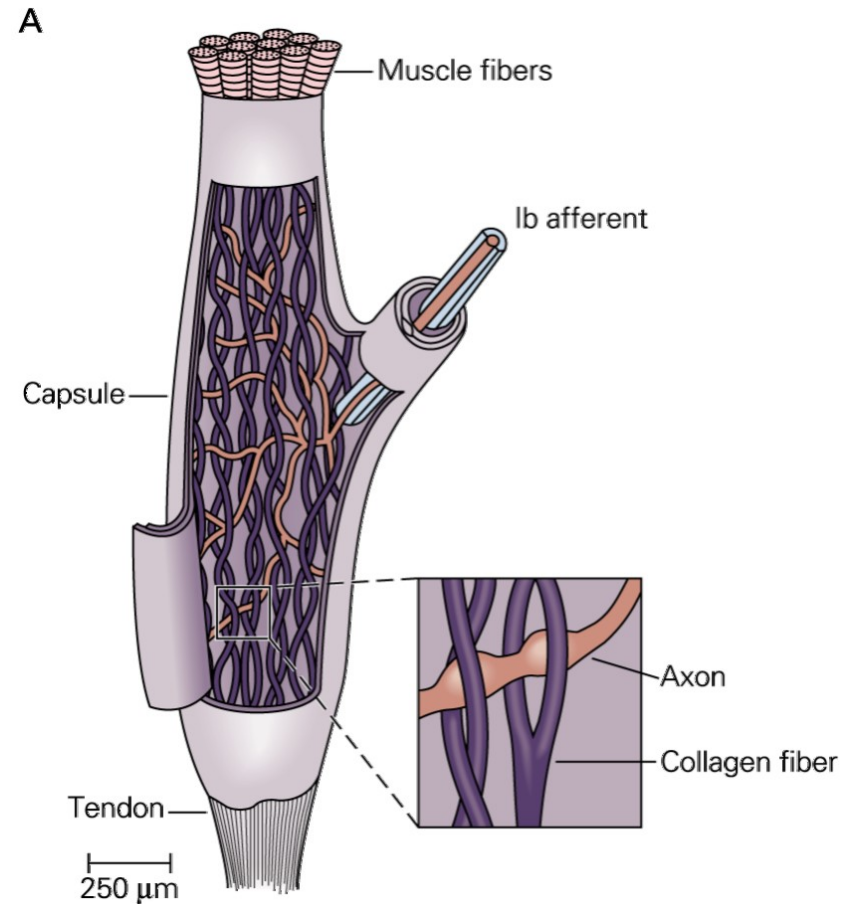


(B)  $\alpha$  Motor neuron activation with  $\gamma$

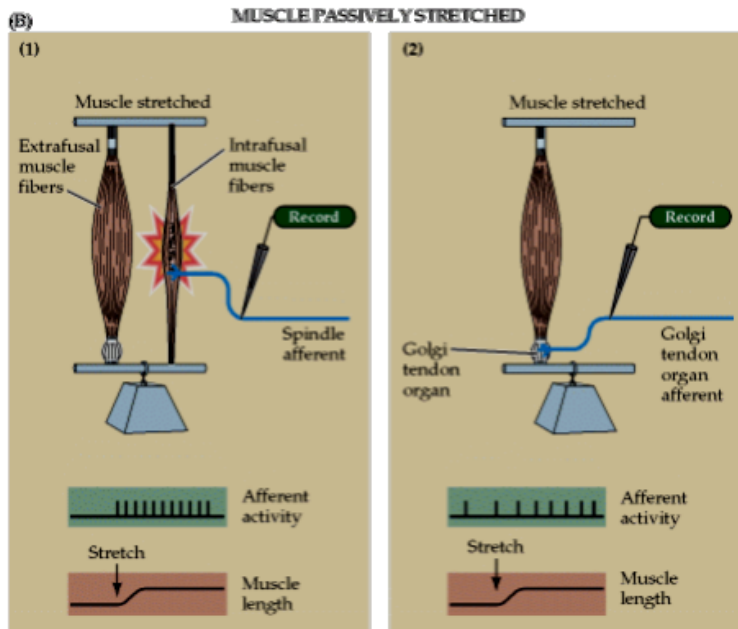


# Golgi tendon organs

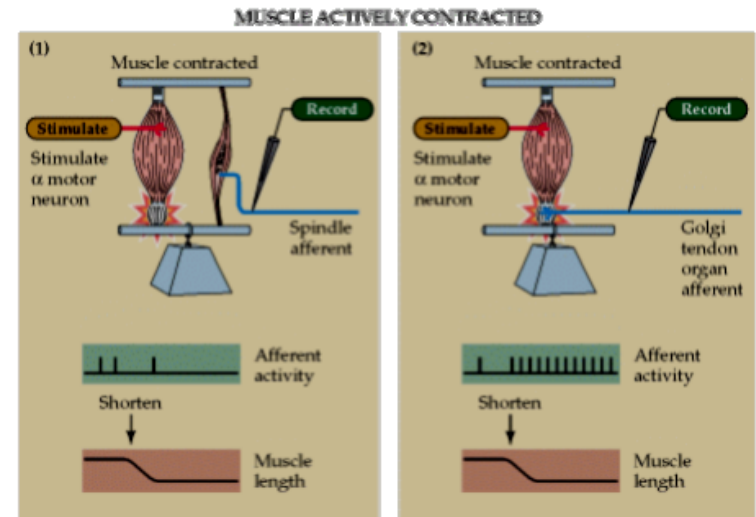
- Non-contractile encapsulated structures
- Collagen fibers
- Ia fibers
- Mechanoreception
- Arranged in series with extrafusal muscles
- Information about changes in tendon tension/force
- Reflex regulation of the  $\alpha$  motoneuron activity



# Reaction of muscle spindles and the Golgi tendon organs to muscle fiber stretch/contraction

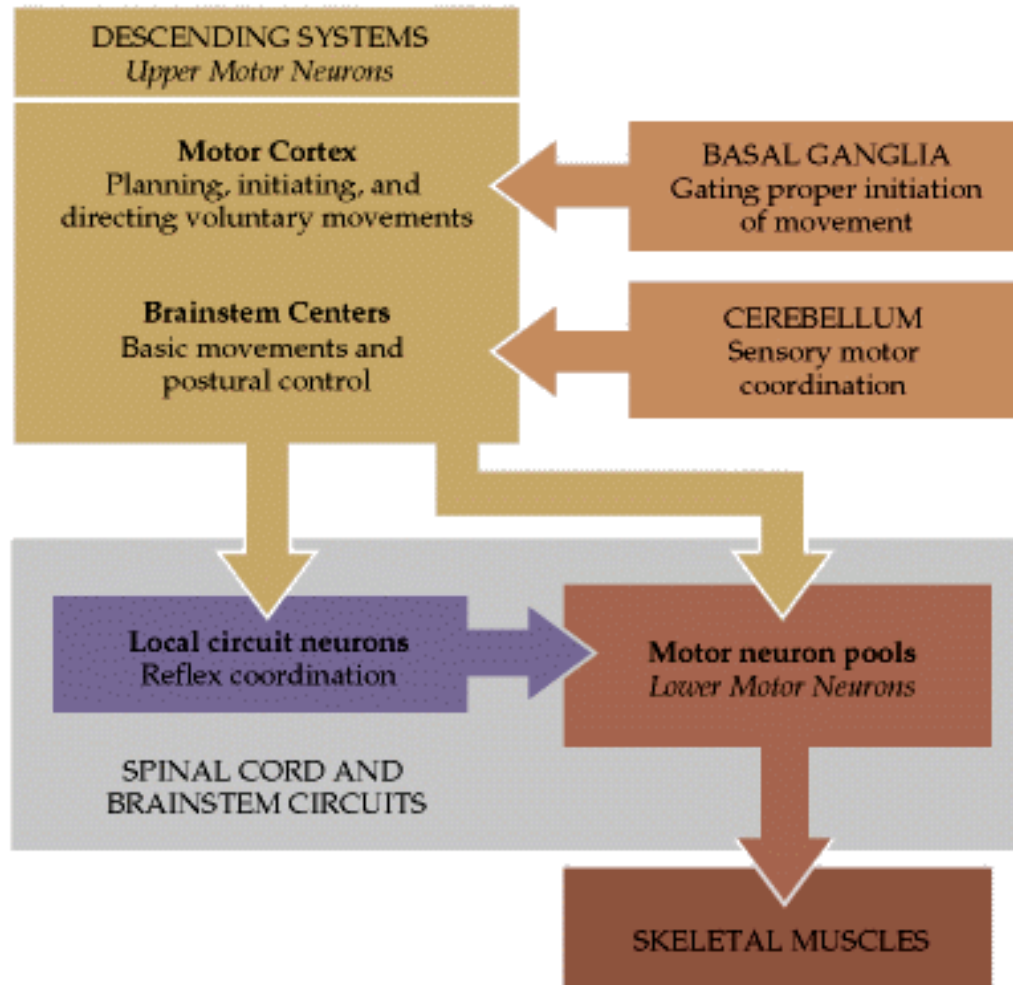


Stretch (passive)  
Muscle spindles reaction

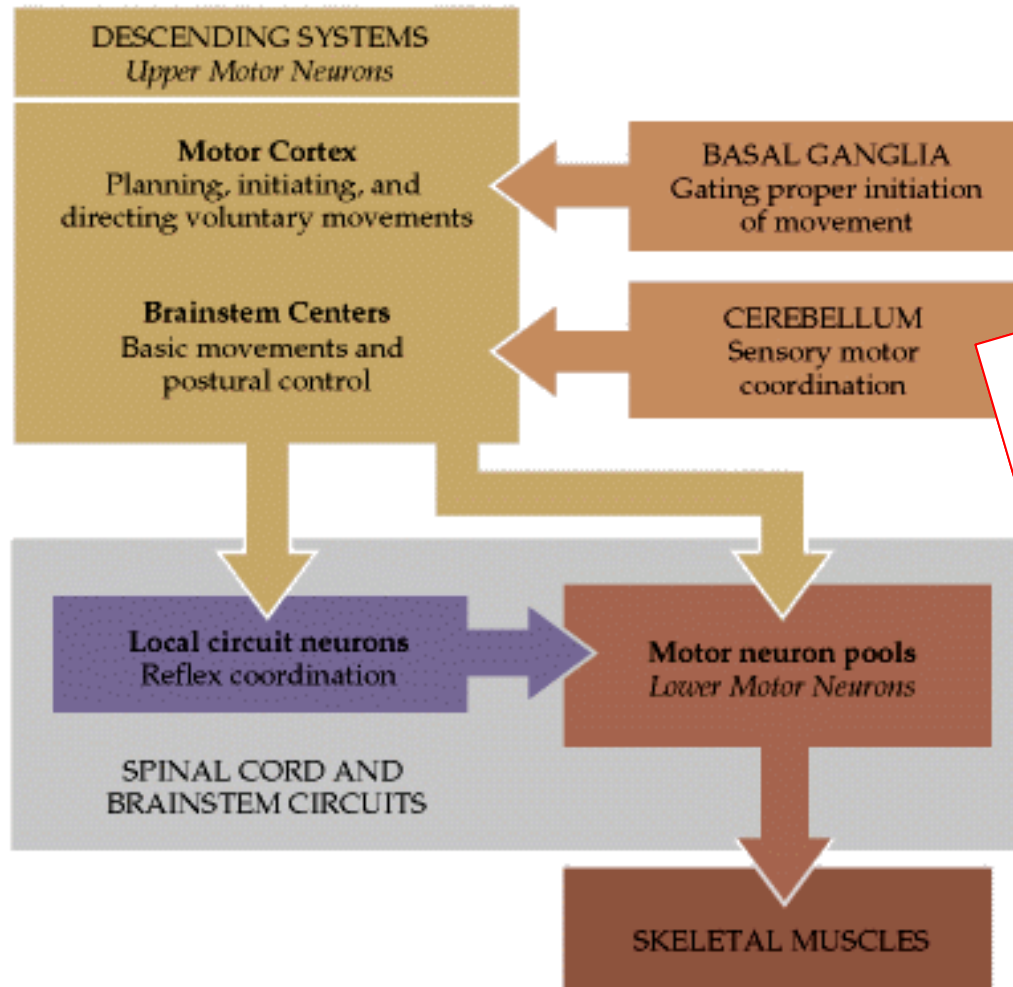


Contraction (active)  
Golgi tendon organ reaction

# Hierarchic organization of motor system



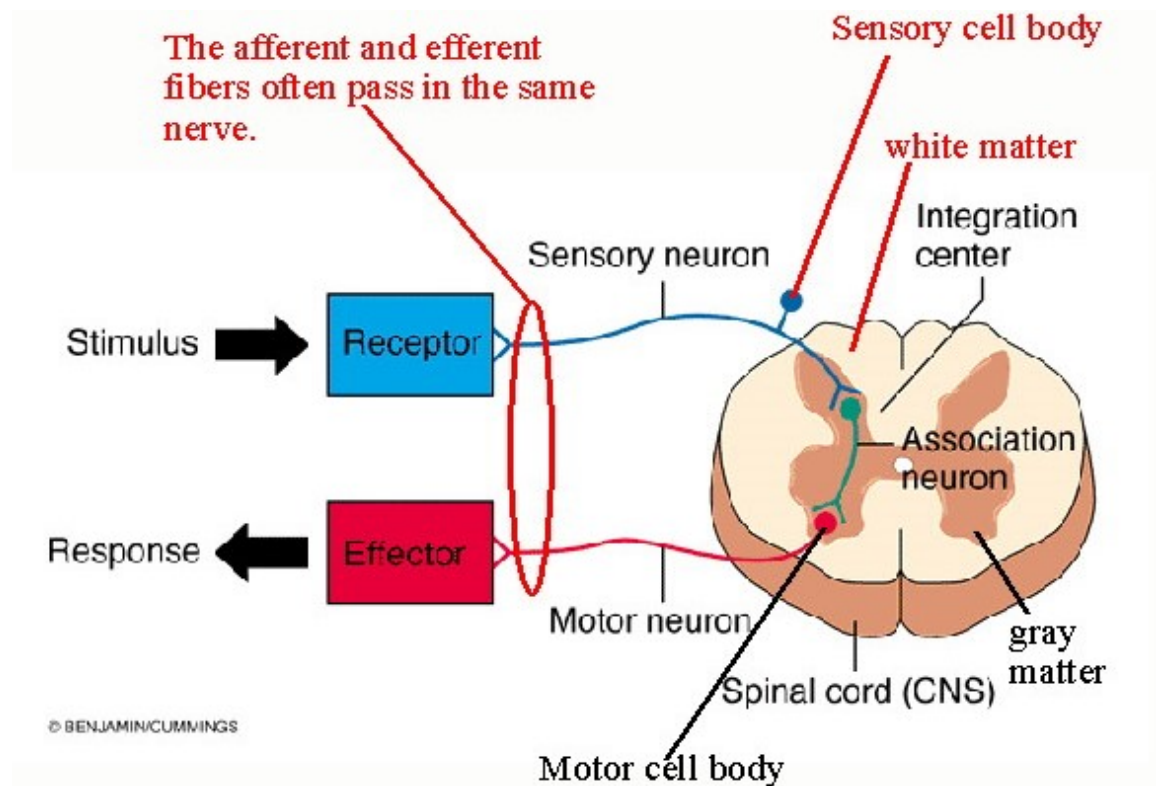
# Hierarchic organization of motor system



**Reflex movement**  
**Rhythmic movement**  
**Voluntary movement**

# Reflex

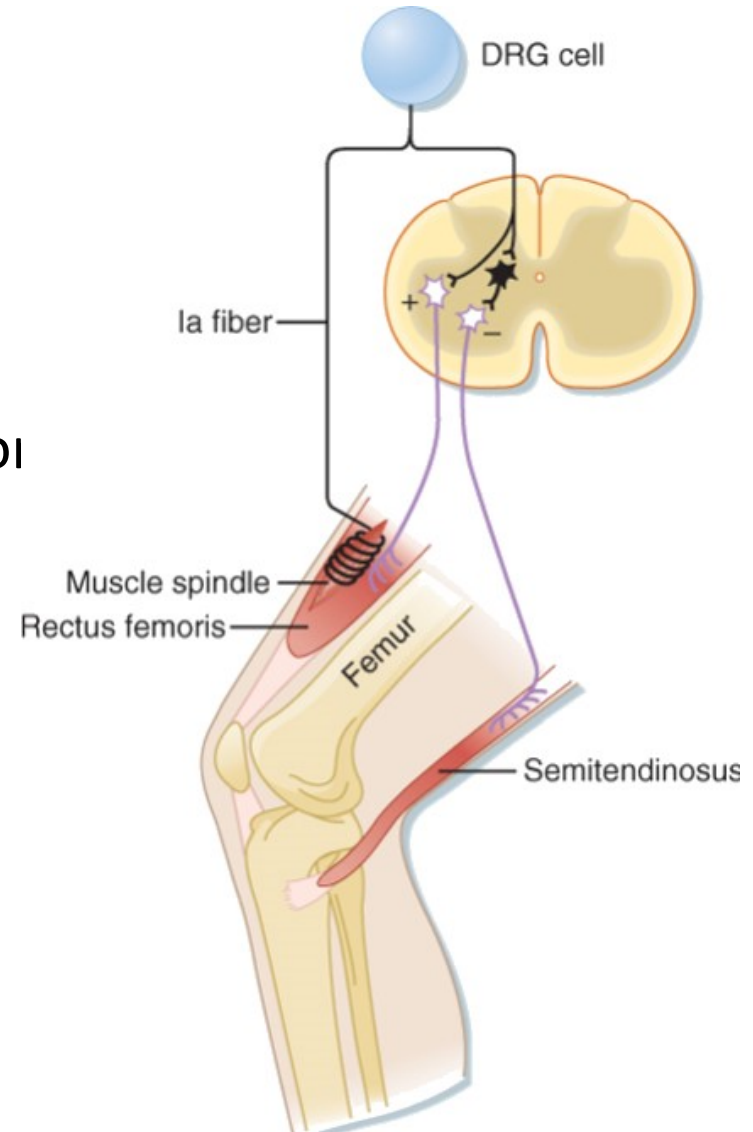
- Reflex movement
  - Stereotype (predictable)
  - Involuntary
- Proprioceptive
- Exteroceptive
- Monosynaptic
- Polysynaptic
- Monosegmental
- Polysegmental

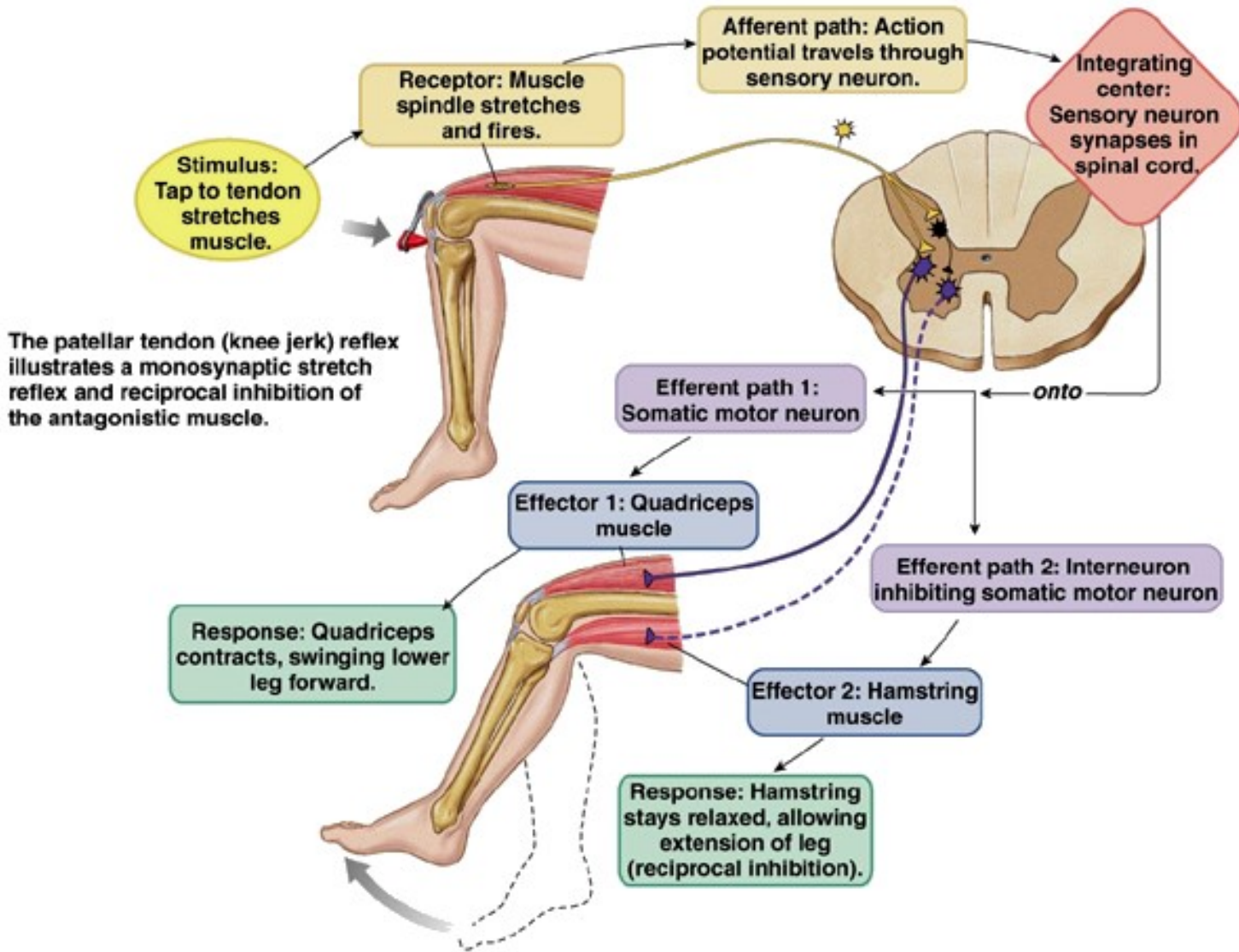




# Proprioceptive reflex

- Myotatic reflex
  - Monosynaptic
  - Monosegmental
  - Muscle spindle
- Homonymous muscle - activation
- Antagonist muscle - inhibition
- Phasic response (Ia)
  - Protection against overstretch of extrafusal fibers
- Tonic response (Ia a II)
  - Maintains muscle tone



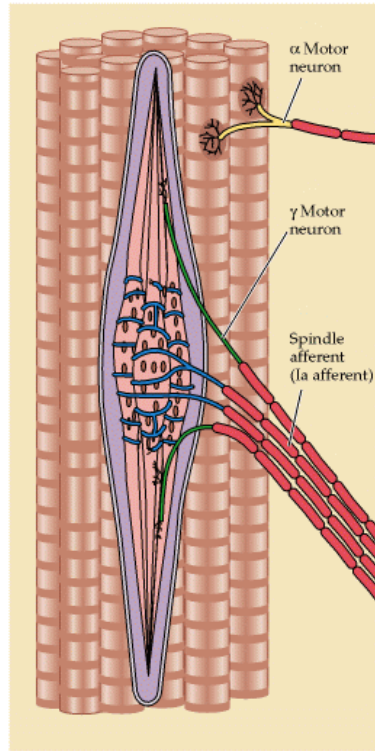


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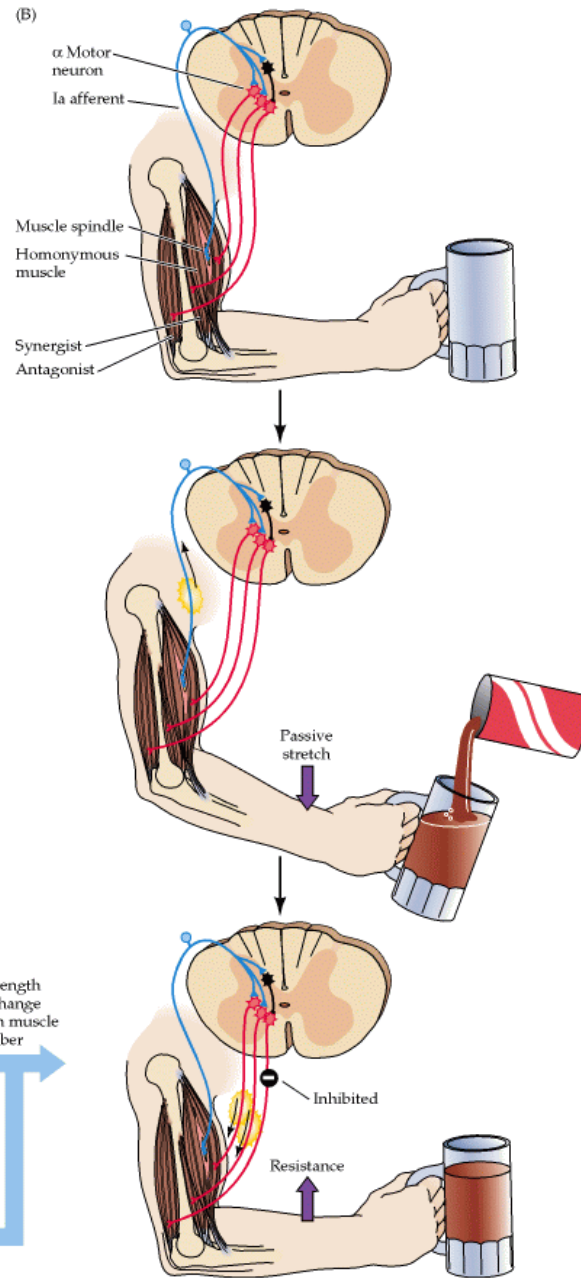
Fig. 13-7



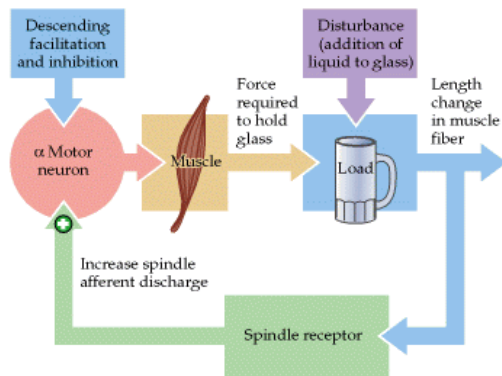
(A) Muscle spindle



(B)

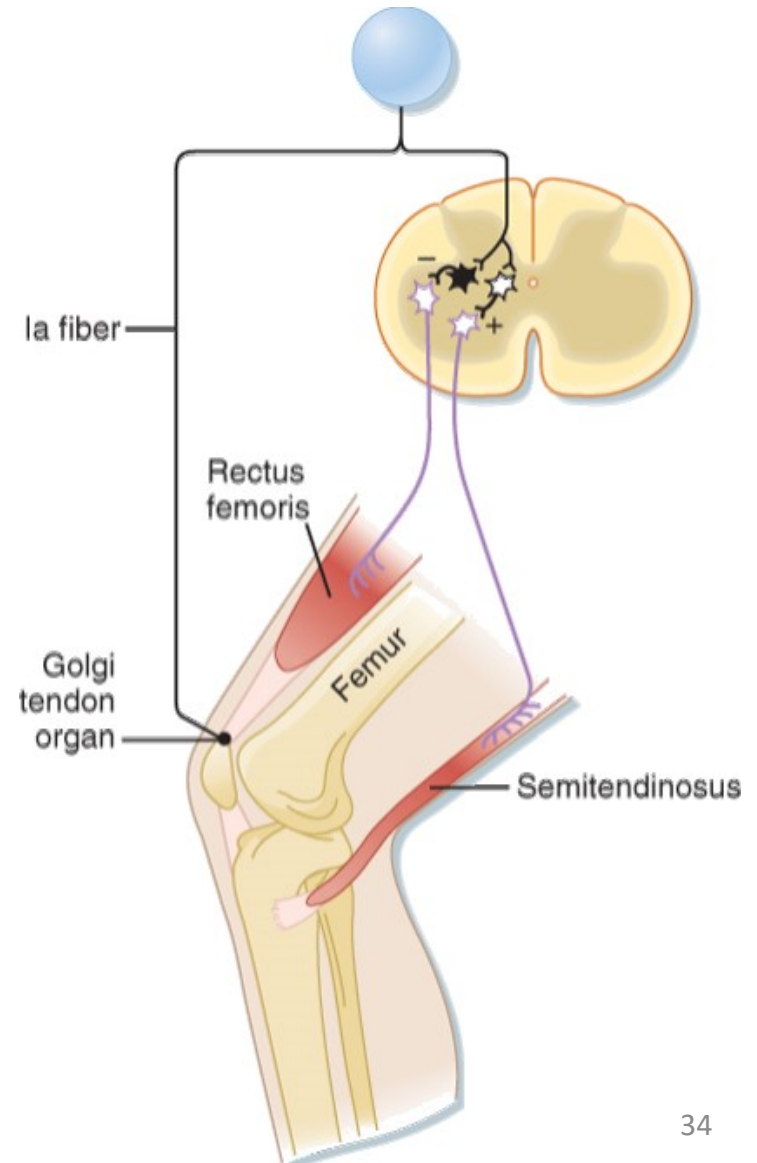


(C)

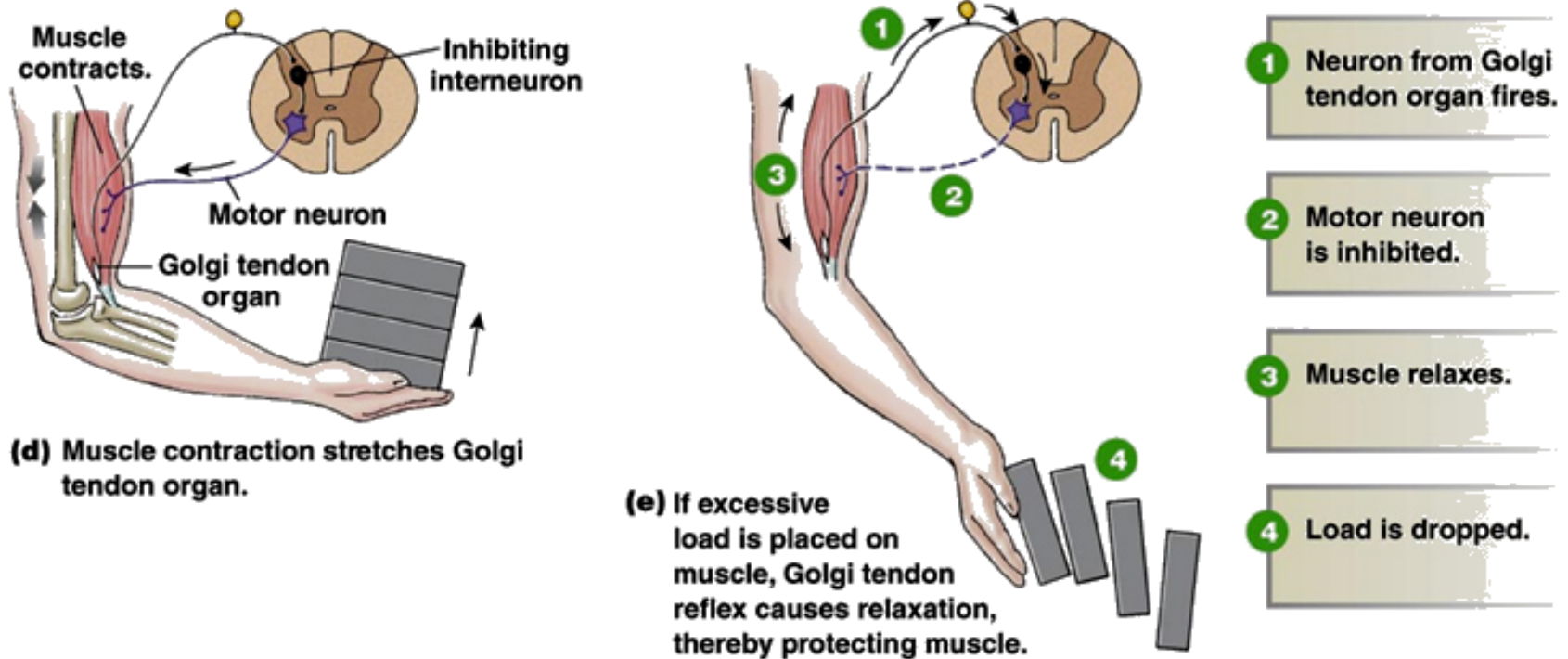


# Proprioceptive reflex

- Inverse myotatic reflex
  - Monosegmental
  - Disynaptic/polysynaptic
  - Golgi tendon organ
- Homonymous muscle – inhibition
- Antagonist muscle – activation
- Protection against muscle damage caused by extensive force



**Golgi tendon reflex** protects the muscle from excessively heavy loads by causing the muscle to relax and drop the load.

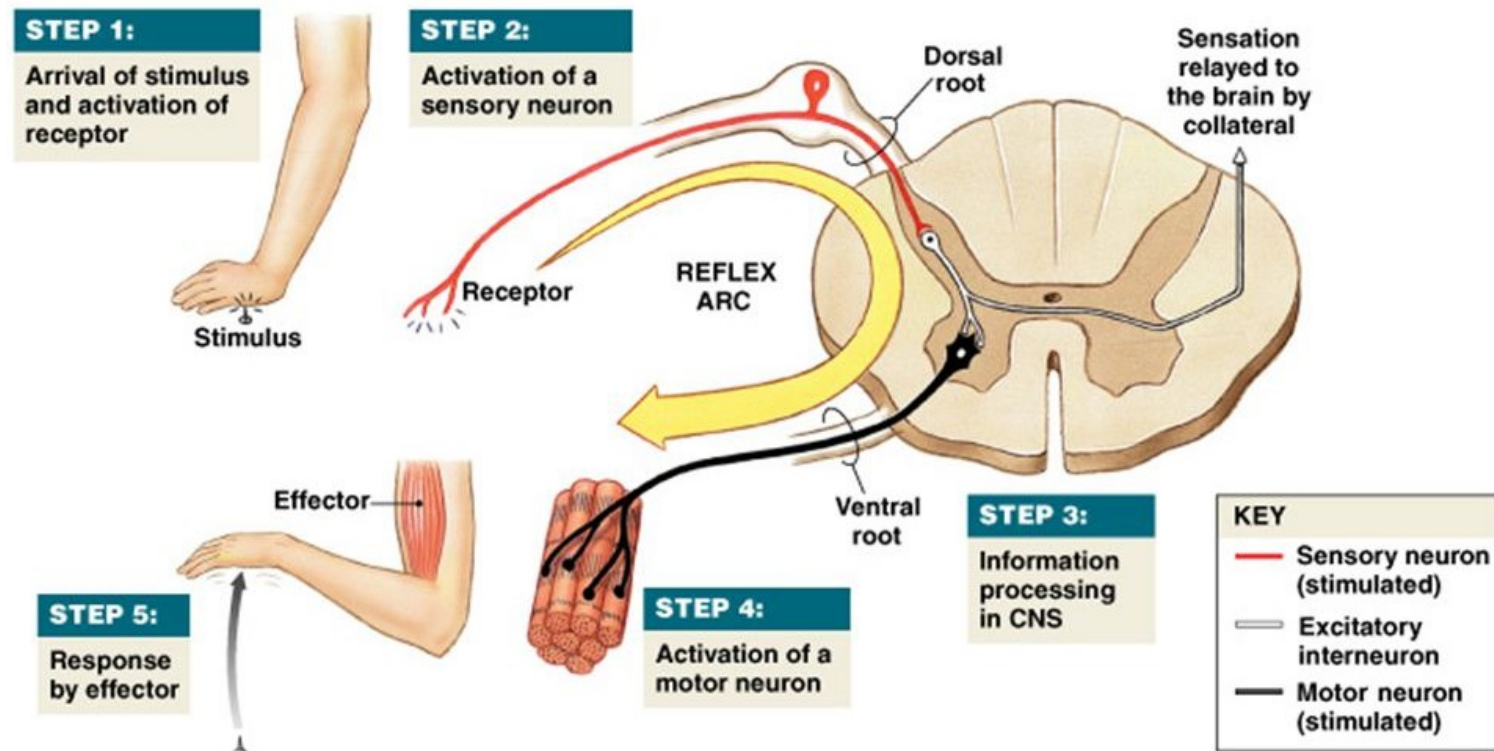


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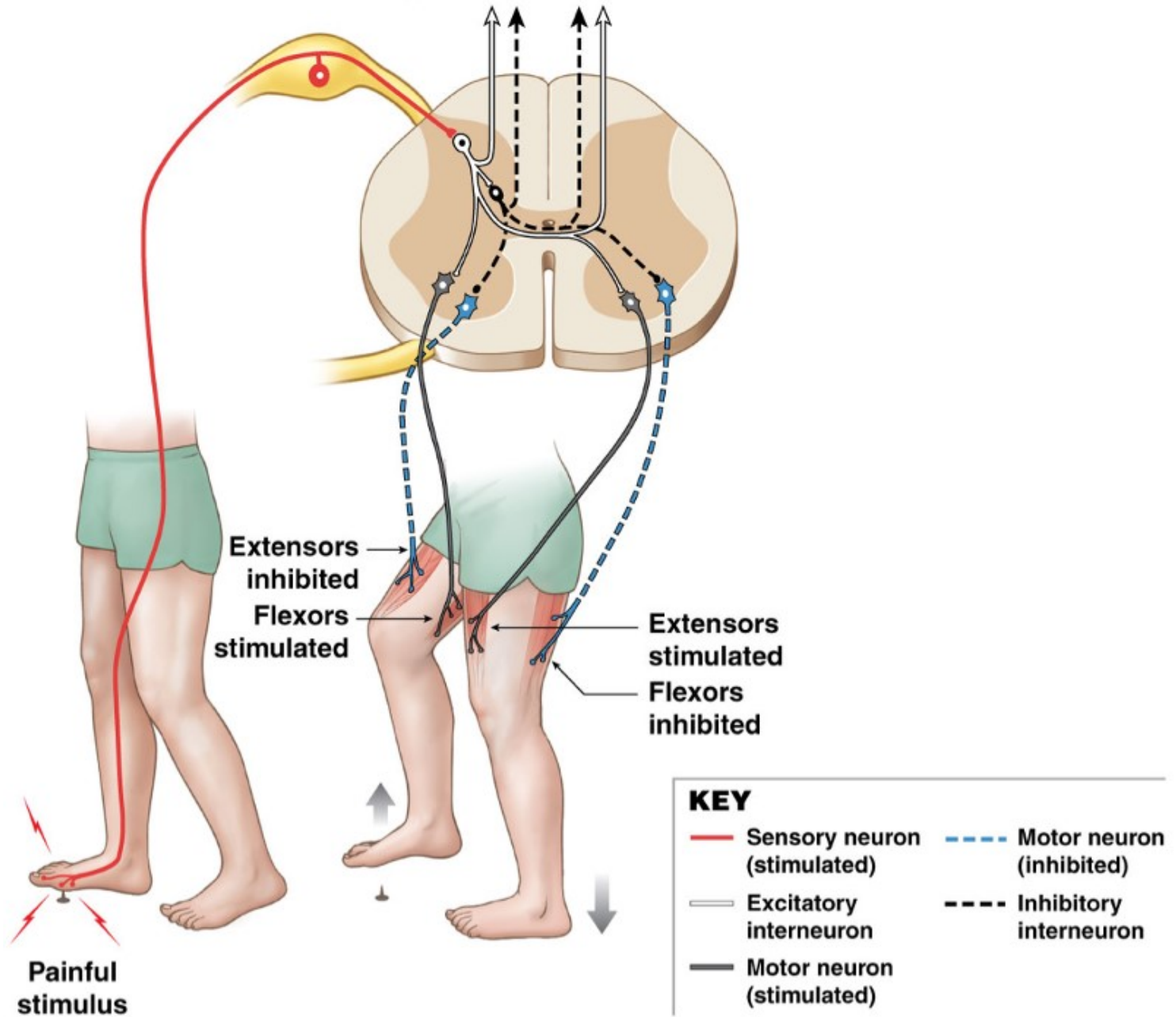
Fig. 13-6b

# Exteroceptive reflex

- Polysynaptic
- Polysegmental

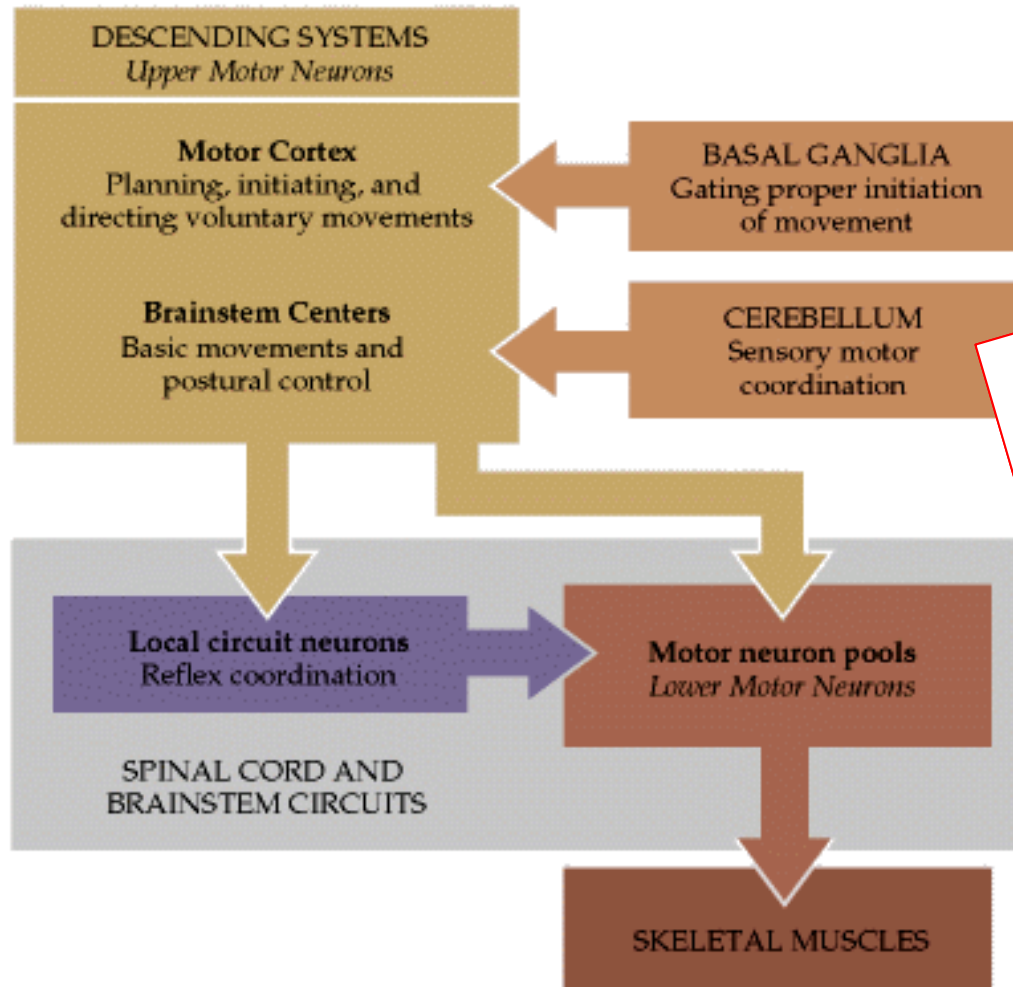


To motor neurons in other segments of the spinal cord





# Hierarchic organization of motor system



**Reflex movement**  
**Rhythmic movement**  
**Voluntary movement**