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# Motor system-Motor Functions of the Spinal Cord-

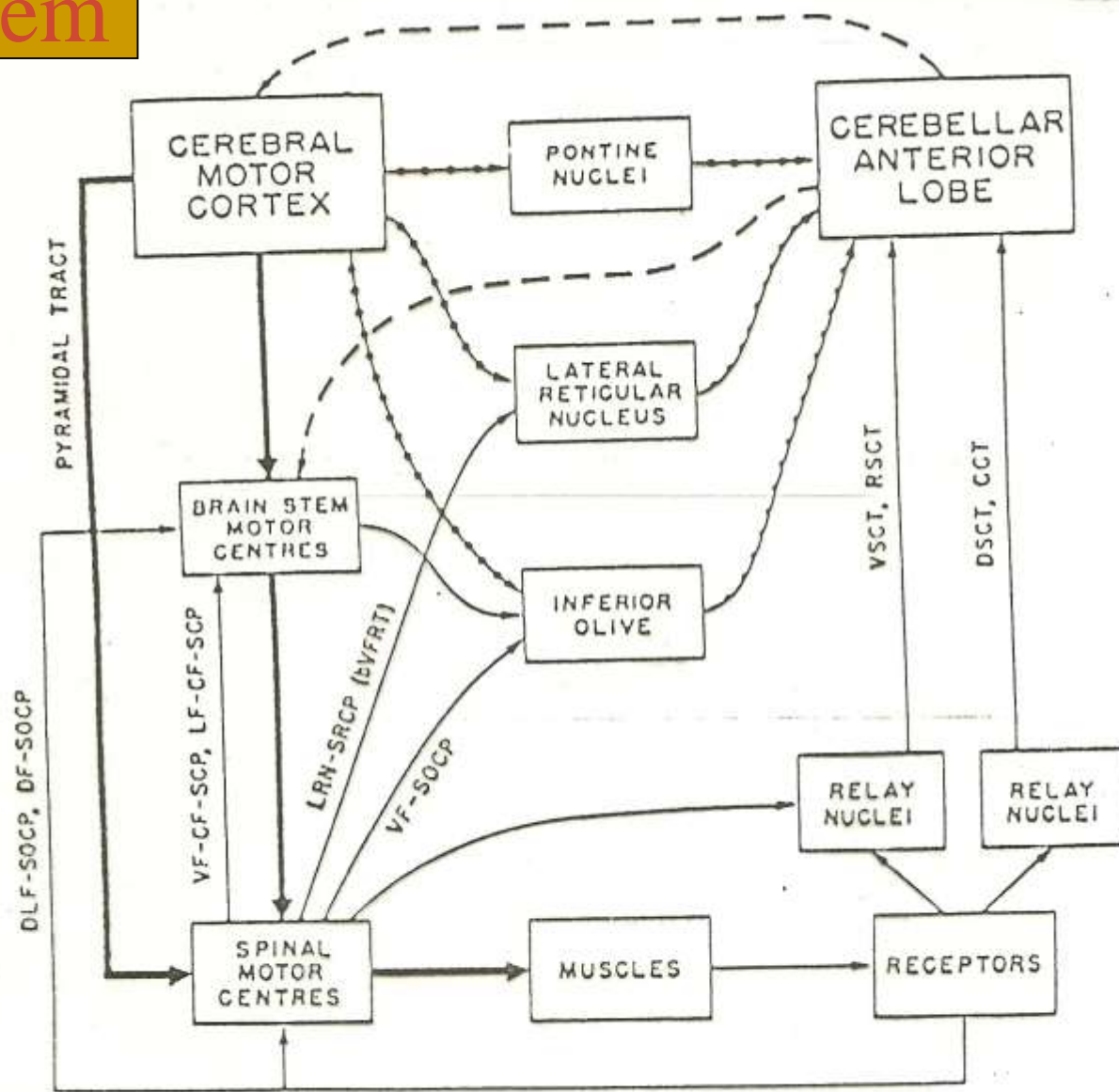
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Faisal I. Mohammed, MD, PhD

# Objectives

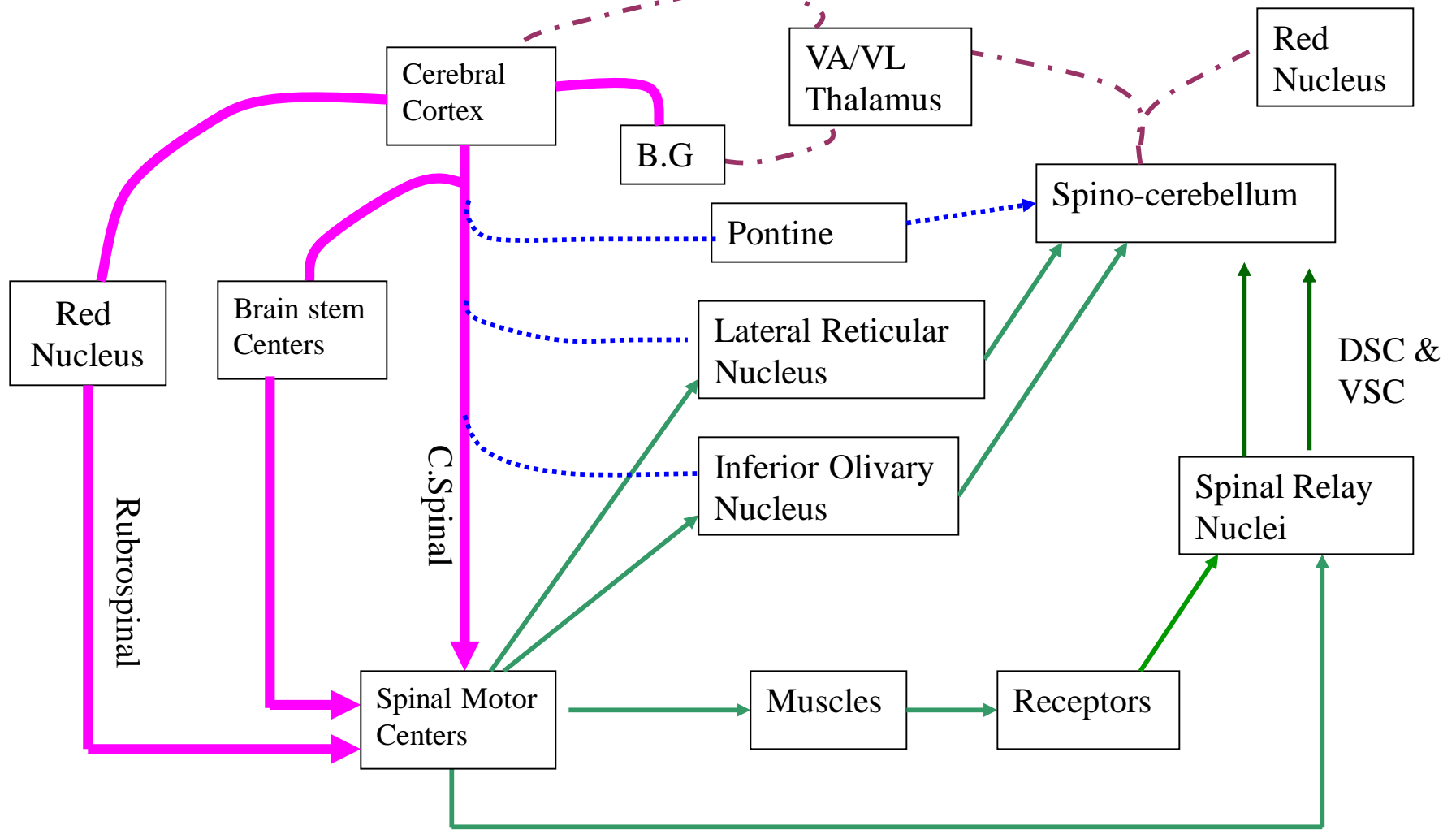
- ❖ List the ascending and descending tracts passing through the spinal cord
- ❖ Describe the muscle spindle
- ❖ Explain the functions and mechanism of action of the muscle spindle system
- ❖ Outline the spinal cord reflex mechanism
- ❖ Follow up the neural circuitry and function of the spinal reflexes (Stretch reflex e.g knee and Ankle jerks, Flexor and crossed extensor reflexes)
- ❖ Demonstrate spinal reflexes
- ❖ Interpret the results of spinal reflexes





# Motor System



MOTOR COMMANDS  $\longrightarrow$   
 COMMAND MONITORING  $\dashrightarrow$

FEED-BACK  $\longrightarrow$   
 CORRECTION  $\dashrightarrow$



-  Motor Command
-  Feed Back
-  Command Monitor
-  Corrective Command

**Motor System**

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# The Spinal Cord is More Than Just a Conduit for Nerve Fibers

- Neuronal circuits for walking and various reflexes are contained within the spinal cord.
- Higher brain centers activate and command these circuits.
  - walking
  - maintaining equilibrium

# Internal Anatomy of Spinal Cord

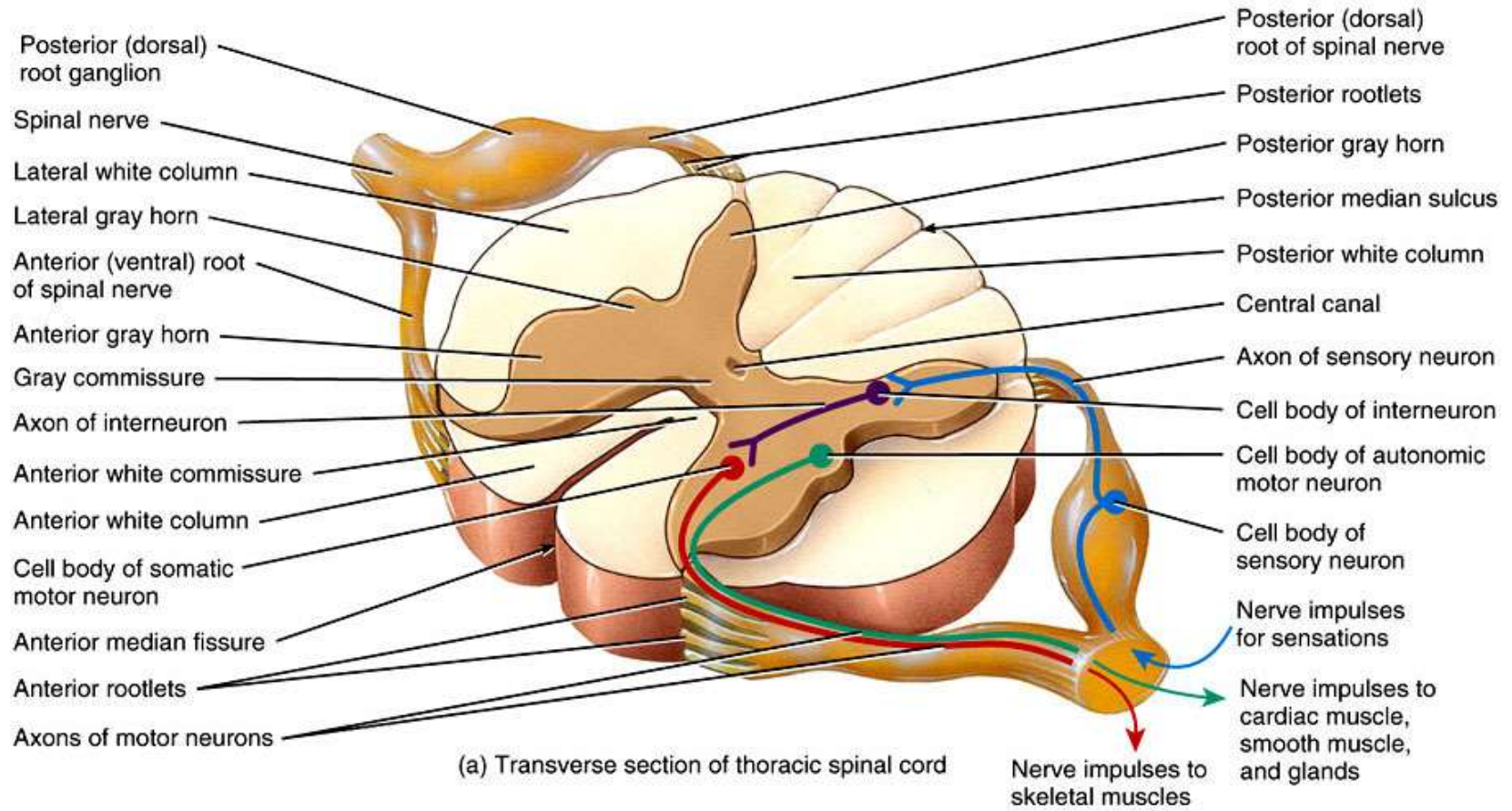
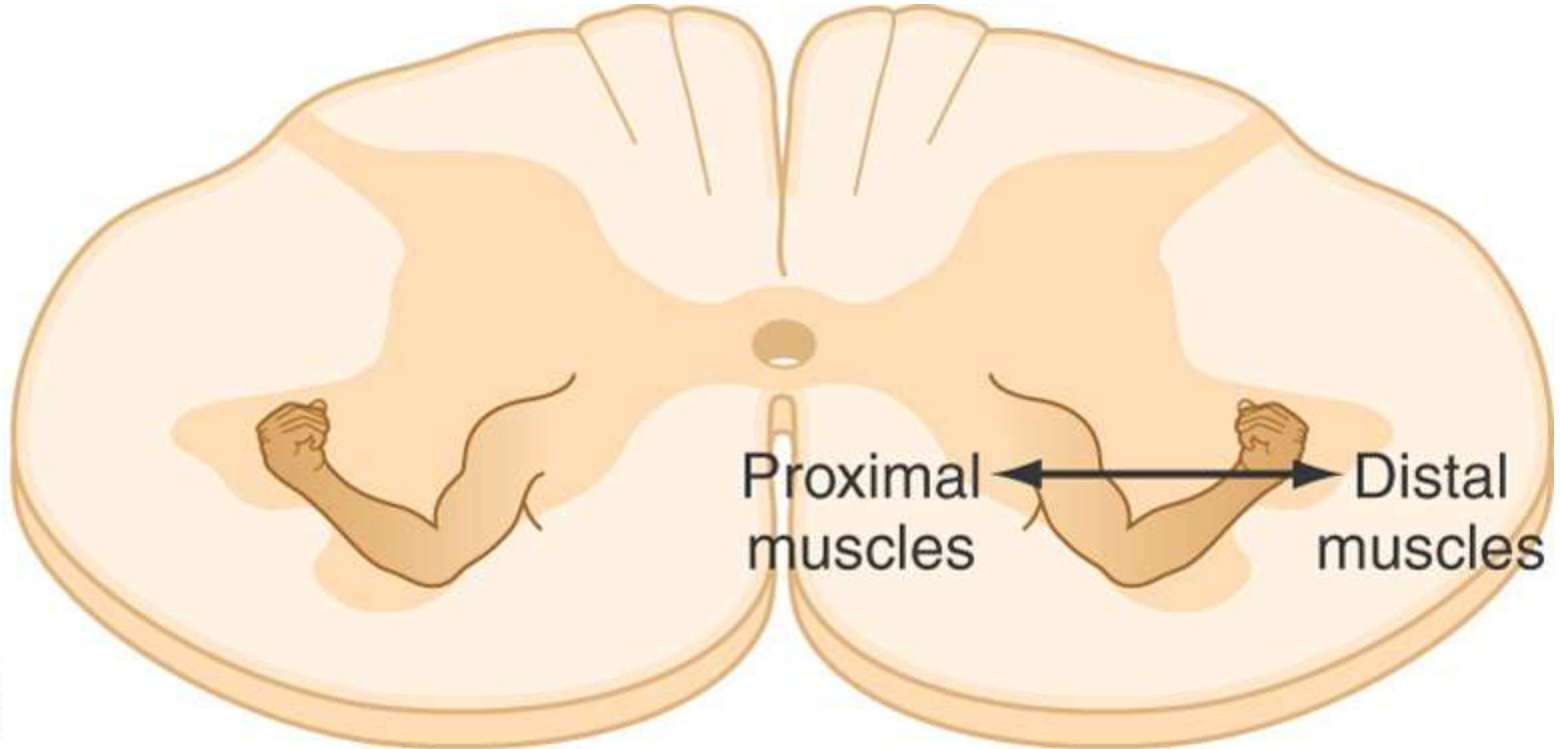
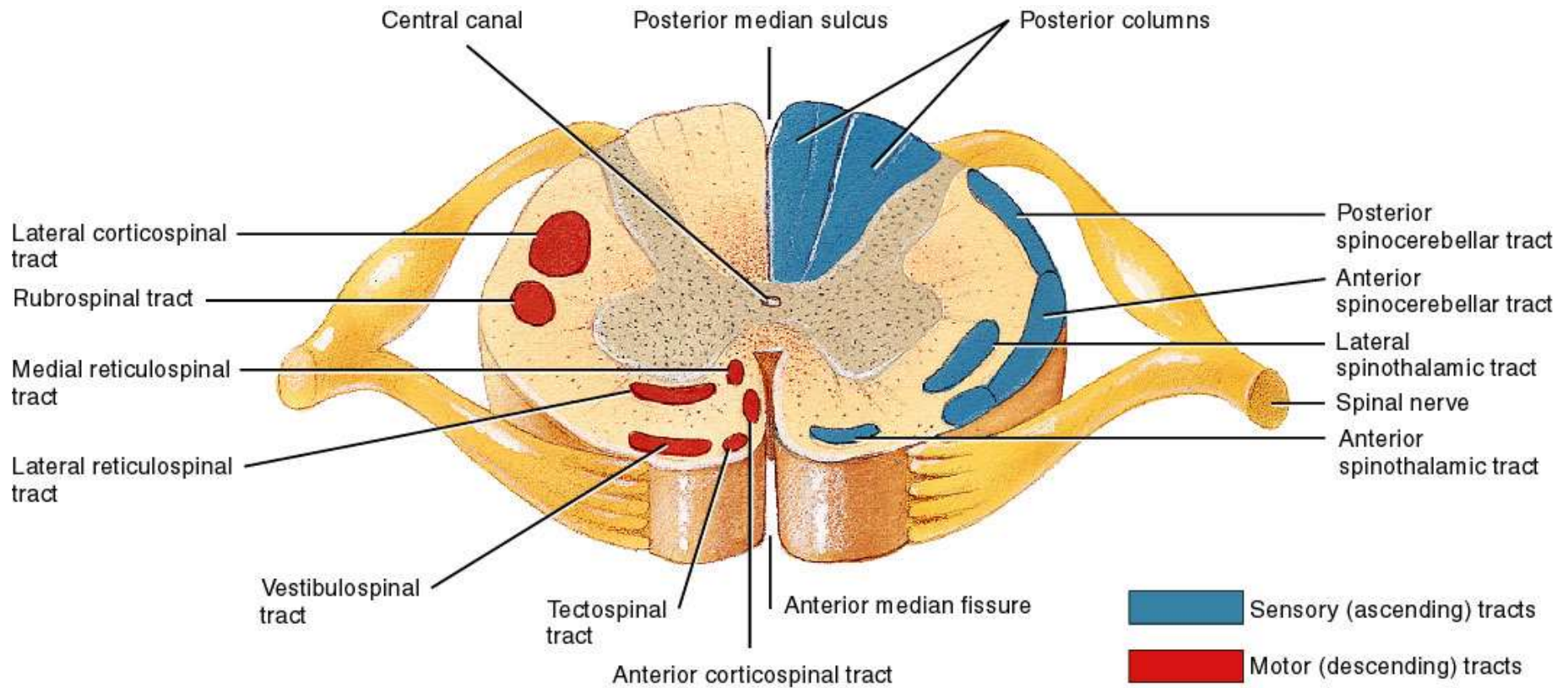


Figure 13.03 Tortora - PAP 12/e

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(Redrawn from Purves D et al[eds]: Neuroscience, 3rd ed. Sunderland, MA, Sinauer, 2004.)



13.04

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# Motor Organization of the Spinal Cord

- Sensory fibers enter the cord and are transmitted to higher centers, or they synapse locally to elicit motor reflexes.
- Motor neurons are located in the anterior portion of the cord.
  - motor neurons are 50 - 100 % bigger than other neurons

# Anterior Motor Neurons

- Alpha motor neurons
  - give rise to large type A alpha fibers (~14 microns).
  - stimulation can excite 3 - 100 *extrafusal* muscle fibers collectively called a motor unit
- Gamma motor neurons
  - give rise to smaller type A gamma fibers (~5 microns)
  - stimulation excites *intrafusal fibers*, a special type of sensory receptor

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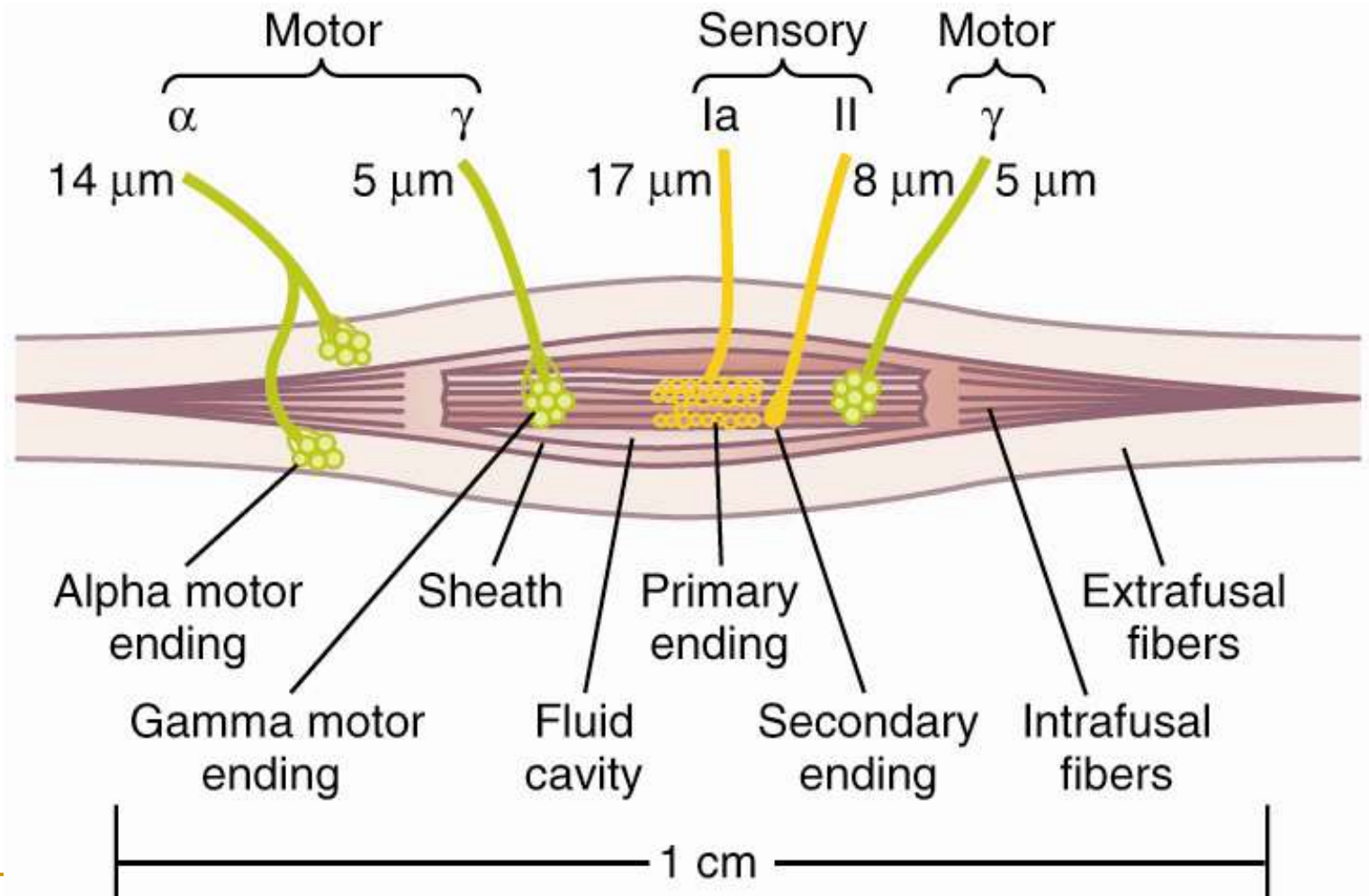
# Interneurons and Propriospinal Fibers

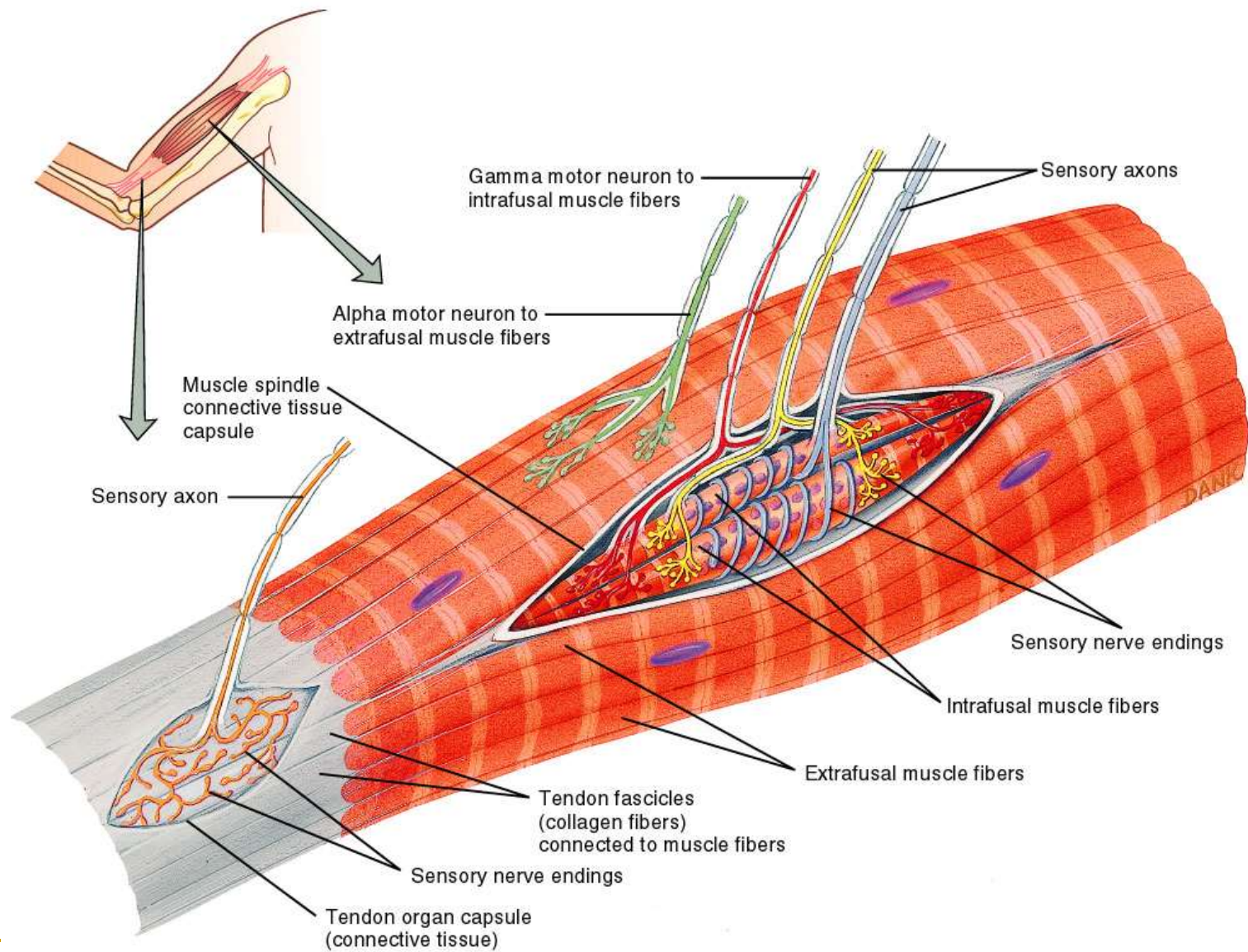
- Interneurons
  - ❑ 30 times as many as anterior motor neurons
  - ❑ small and very excitable
  - ❑ comprise the neural circuitry for the motor reflexes
- Propriospinal fibers
  - ❑ travel up and down the cord for 1 - 2 segments
  - ❑ provide pathways for multisegmental reflexes

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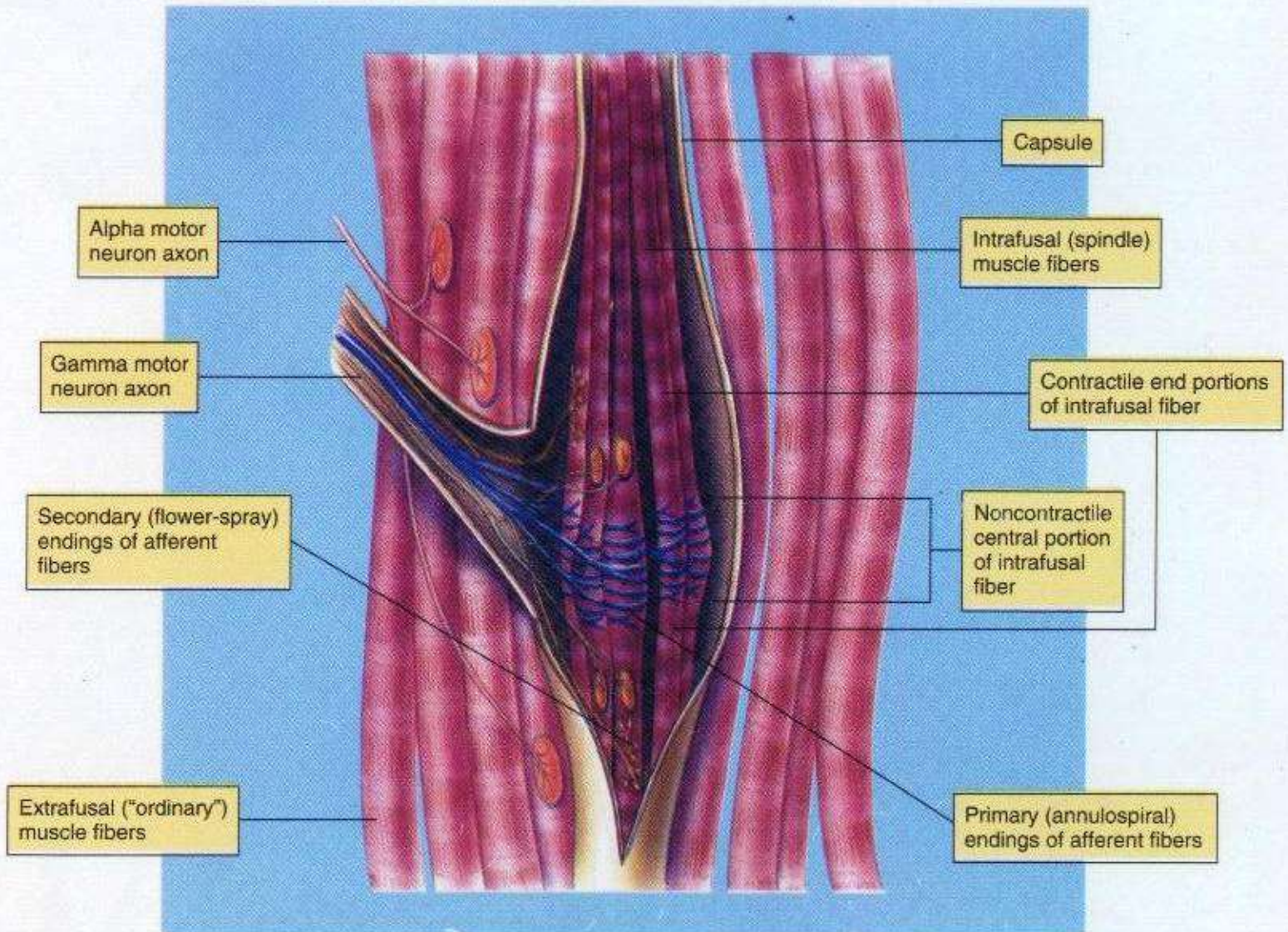
# Sensory Receptors of the Muscle

- Muscle Spindle
  - sense muscle length and change in length
- Golgi Tendon Organ
  - sense tendon tension and change in tension

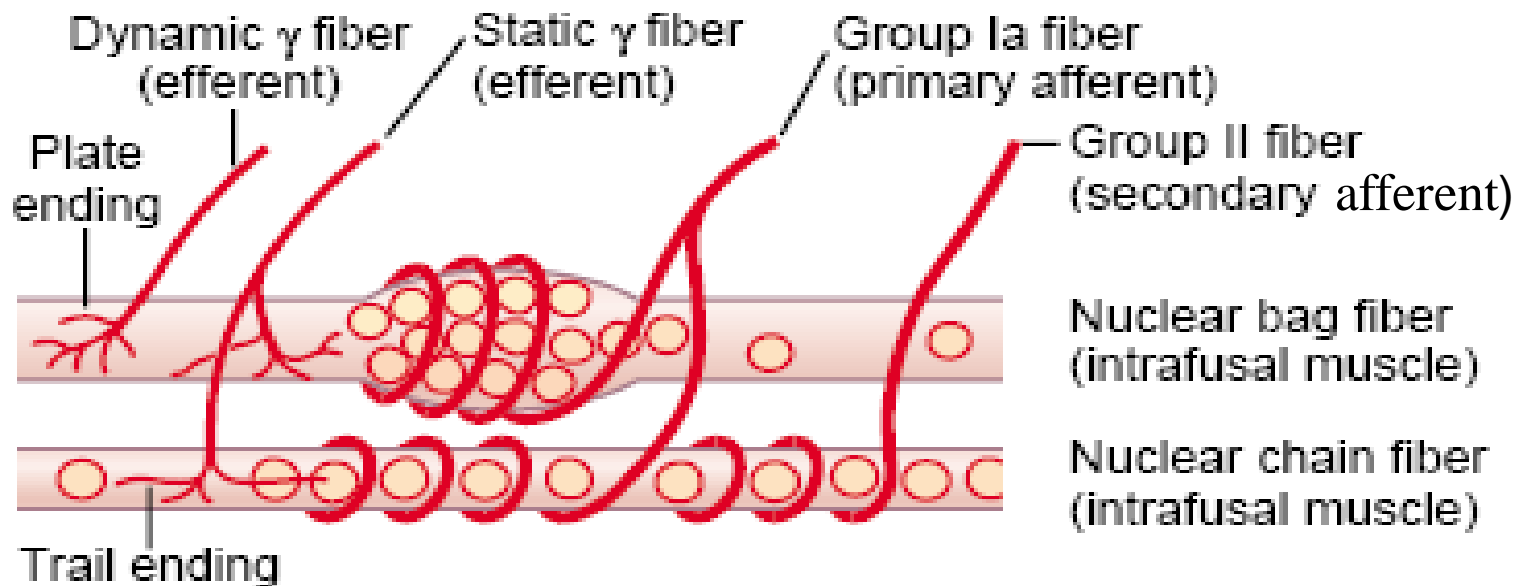




# Muscle Spindle



# Sensory fibers of muscle spindle



**Figure 54-3**

Details of nerve connections from the nuclear bag and nuclear chain muscle spindle fibers. (Modified from Stein RB: Peripheral control of movement. *Physiol Rev* 54:225, 1974.)

# Static Response of the Muscle Spindle

- When the center of spindle is stretched *slowly* - the number of impulses generated by the primary and secondary endings increases in proportion to the *degree of stretch*.
- This is the ‘*static response*’.
- Function of the static nuclear bag and nuclear chain fibers.

# Dynamic Response of the Muscle Spindle

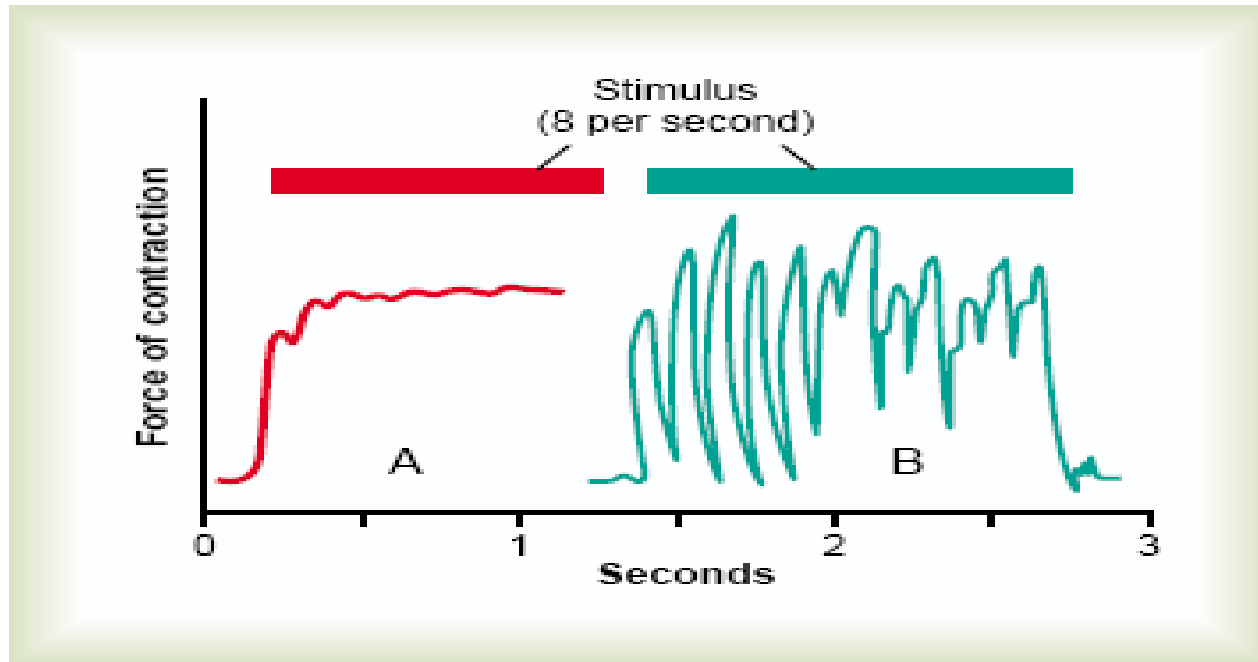
- When the center of the spindle is stretched *rapidly* - the number of impulses generated by the primary endings increases in proportion to the *rate of change* of the length.
- This is the ‘*dynamic response*’.
- Function of the dynamic nuclear bag fiber.

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# Physiologic Function of the Muscle Spindle

- Comparator of length between the intrafusal and extrafusal muscle fiber.
- Opposes a change in length of the muscle.
- When the muscle is stretched the spindle returns it to its original length.
- Leads to the stretch reflex.

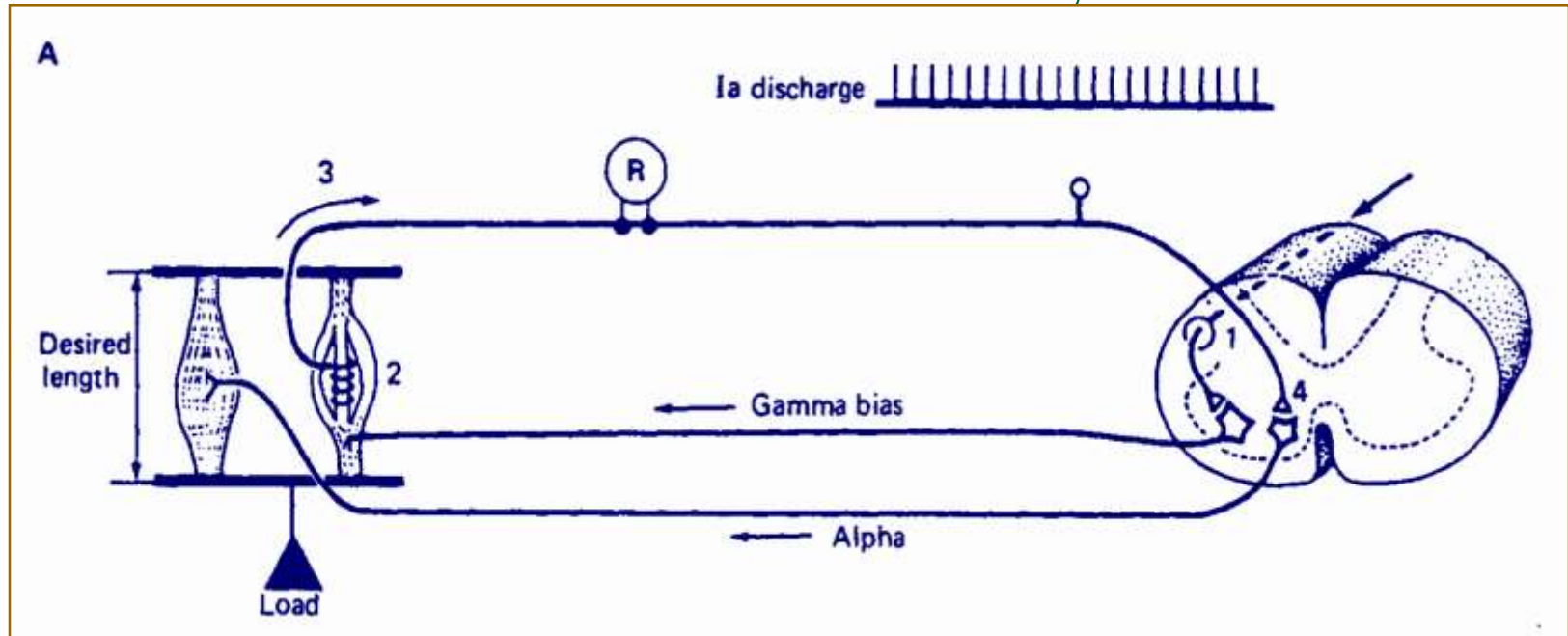
# Smoothing effect of muscle spindle



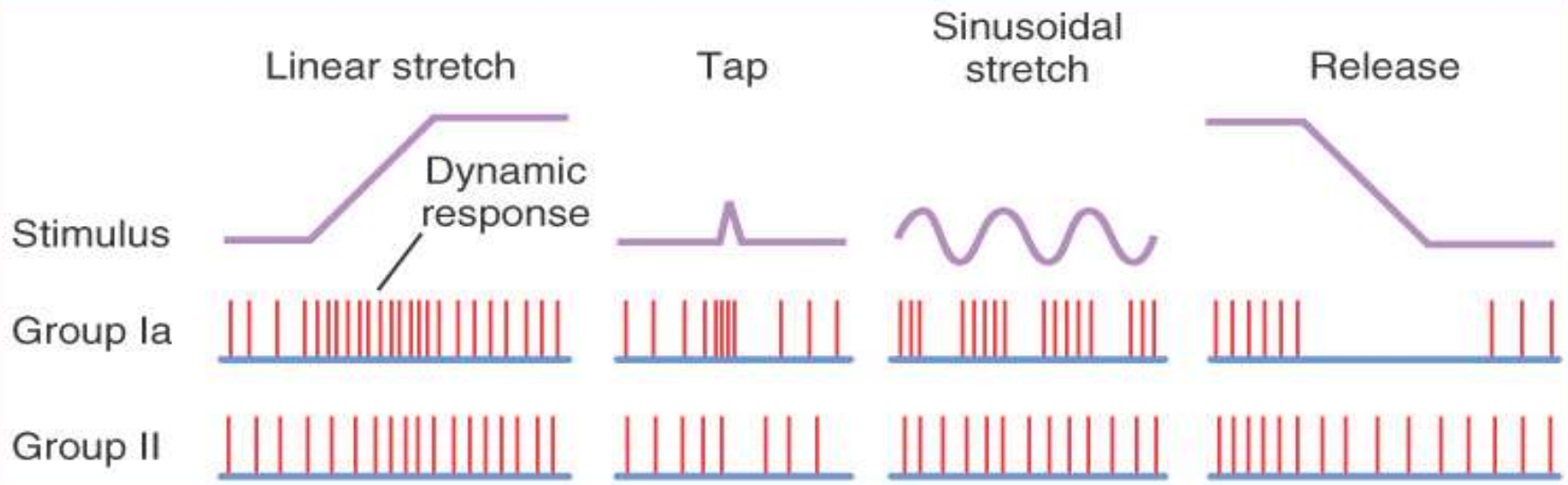
**Figure 54–5**

Muscle contraction caused by a spinal cord signal under two conditions: curve A, in a normal muscle, and curve B, in a muscle whose muscle spindles were denervated by section of the posterior roots of the cord 82 days previously. Note the smoothing effect of the muscle spindle reflex in curve A. (Modified from Creed RS, et al: *Reflex Activity of the Spinal Cord*. New York: Oxford University Press, 1932.)

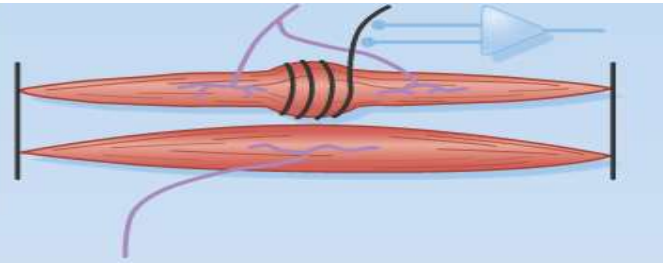
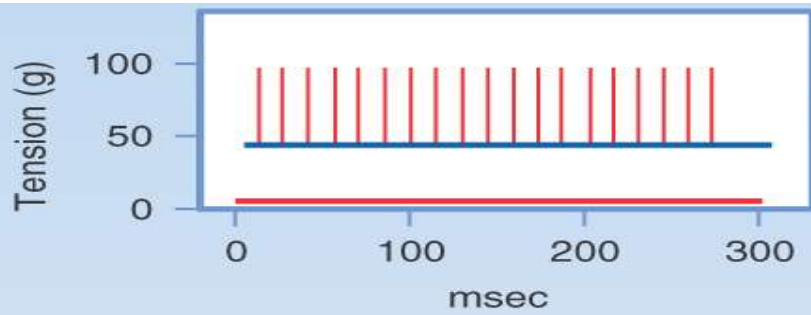
# Function of the Gamma System



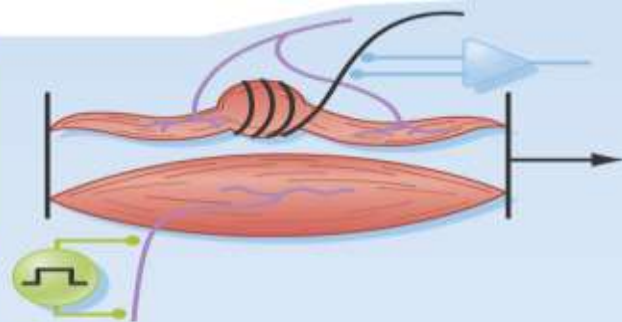
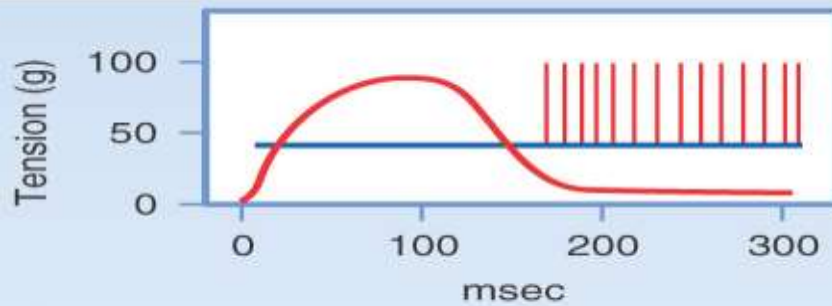
- Spindle is normally tonically active as a result of input from higher brain centers. Alpha-gamma co-activation helps maintain muscle contraction
- **Controls the intensity of the stretch reflex.**
- Performs a damping function by adjusting sensitivity.



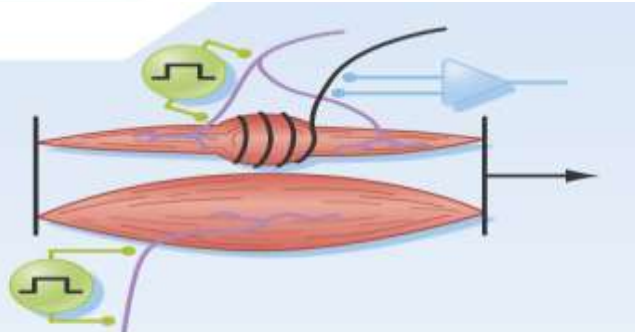
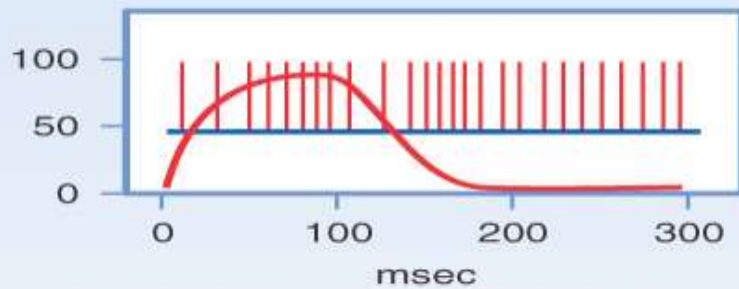
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A Steady stretch



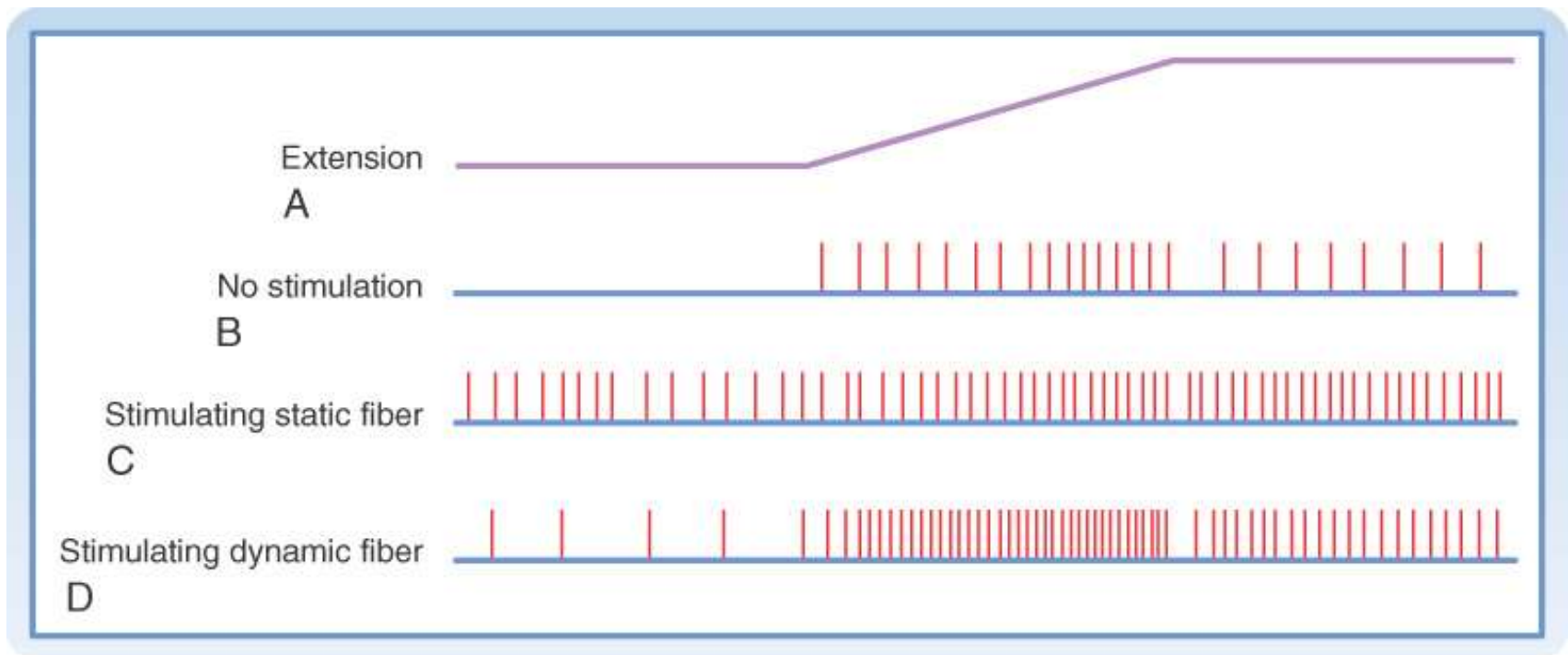
B  $\alpha$  Motor neuron stimulated; muscle shortens



C  $\alpha$  and  $\gamma$  Neurons stimulated together

(Redrawn from Kuffler SW, Nicholls JG: From Neuron to Brain. Sunderland, MA, Sinauer, 1976.)

# Effect of gamma motor fibers (Dynamic and static)



(Redrawn from Crowe A, Matthews PBC: J Physiol 174: 109, 1964.)

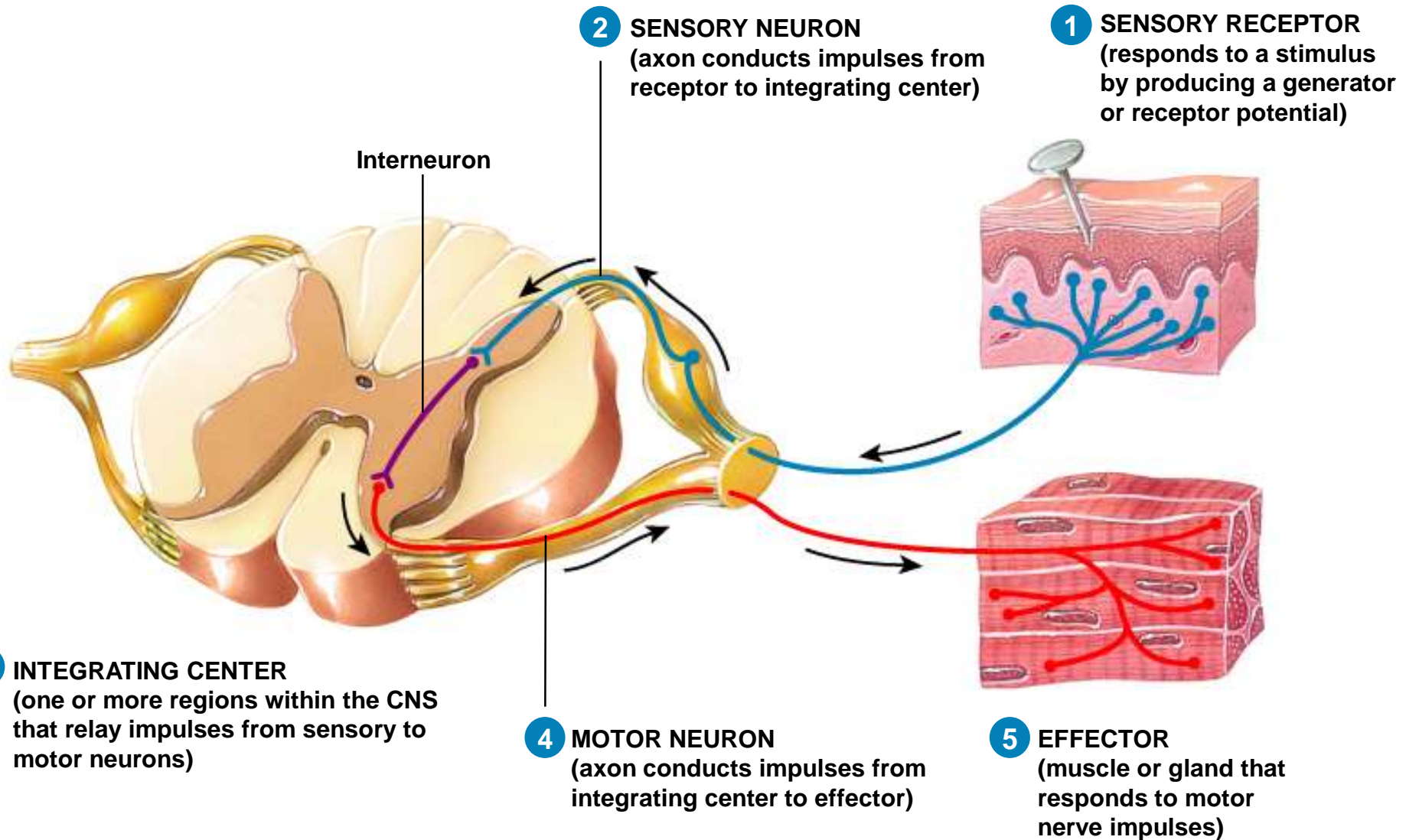
# Control of the Gamma Motor System (Fusimotor System)

- Gamma signal excited by the bulboreticular facilitatory area of the brain stem.
- Secondly by areas that send impulses to this area.
  - cerebellum, basal ganglia, cortex
- Little is known about the precise control of this system.

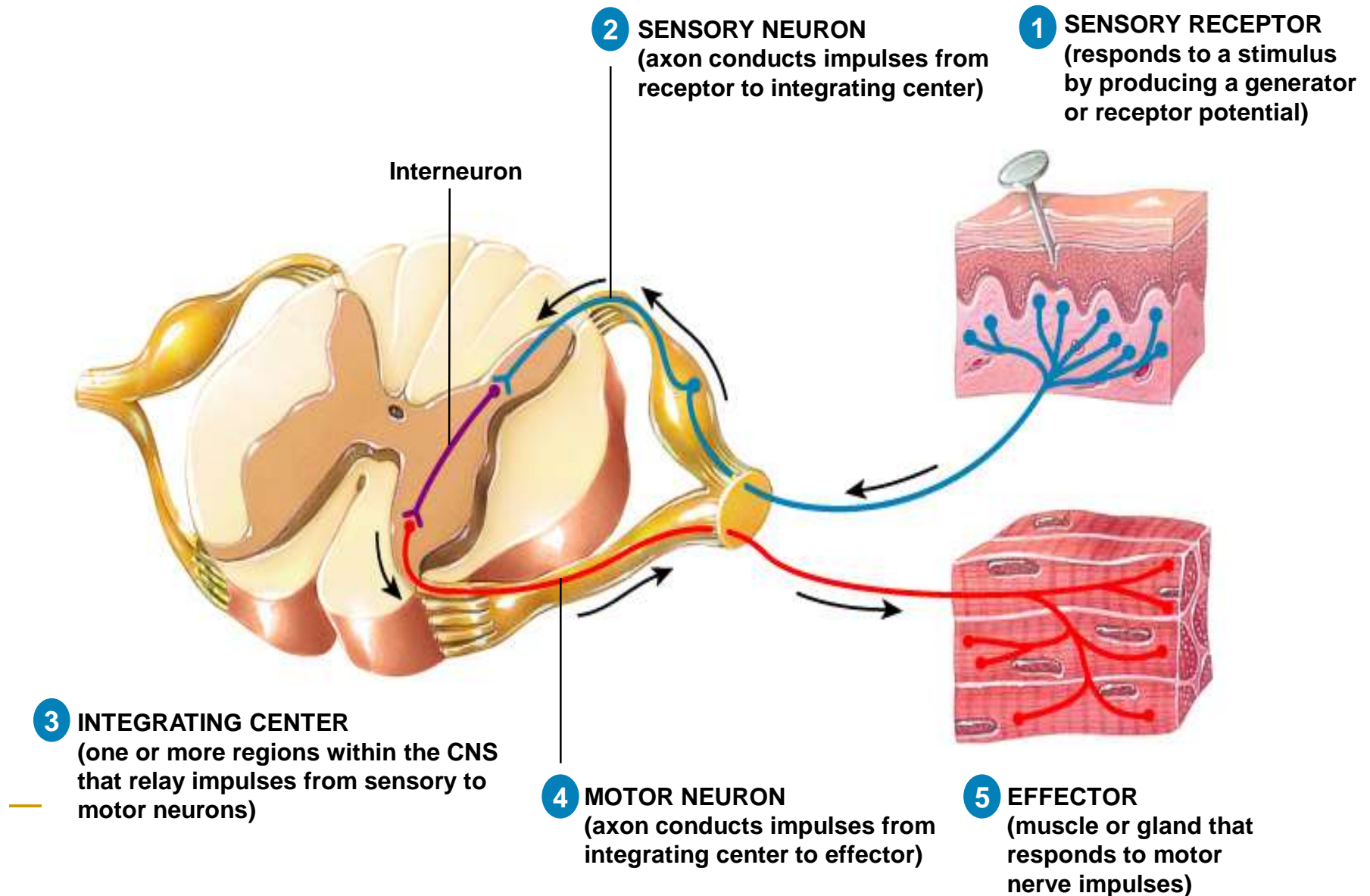
# Clinical Application of the Stretch Reflex

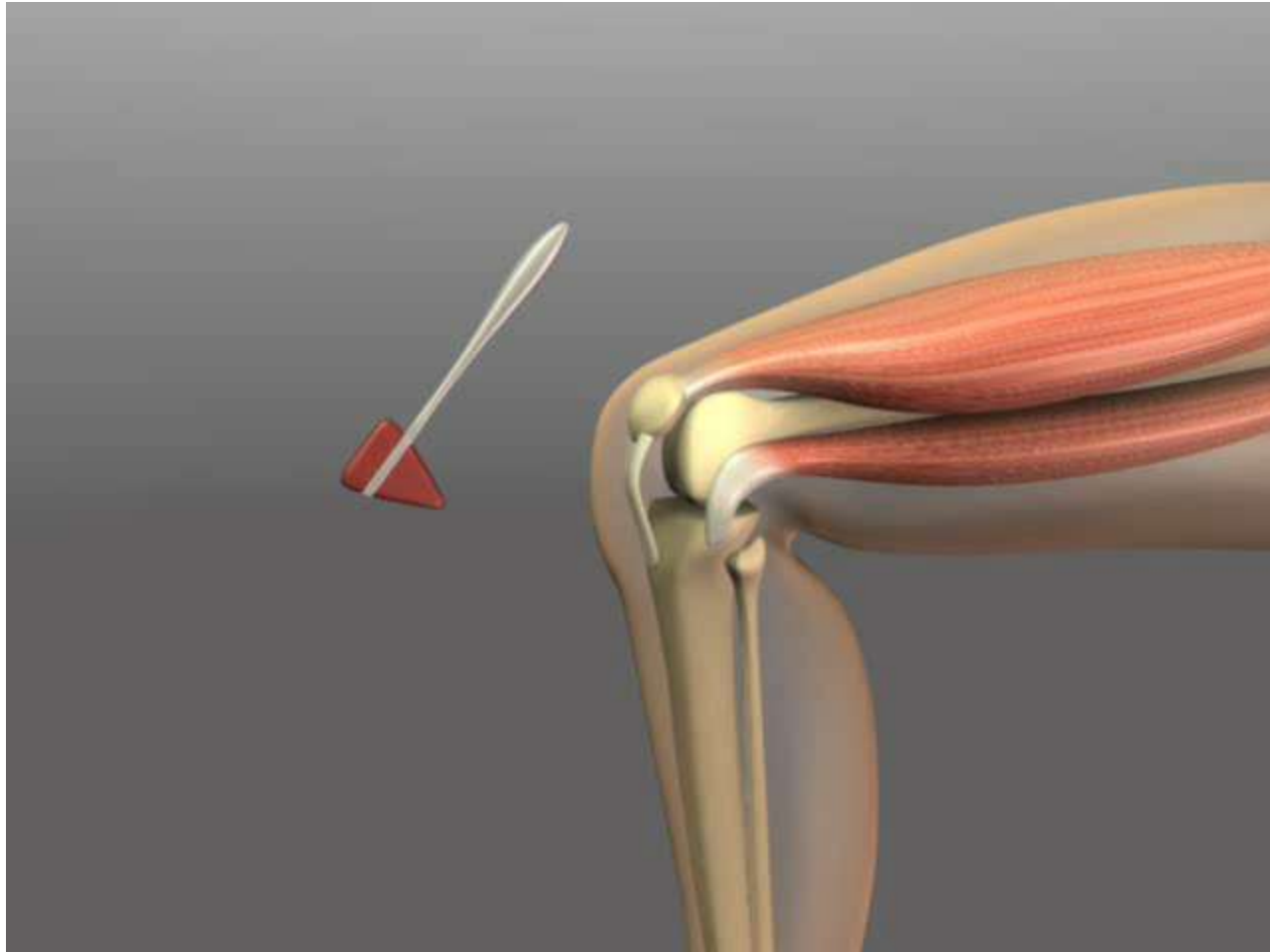
- Knee jerk reflex
  - striking the patellar tendon with a hammer stretches the quadriceps muscle.
  - this initiates a stretch reflex which shortens the muscle and causes the knee to move forward.
- Can be done with almost any muscle.
- Index of the facilitation of the gamma efferents.
- Cortical lesions usually increase muscle stretch reflexes.

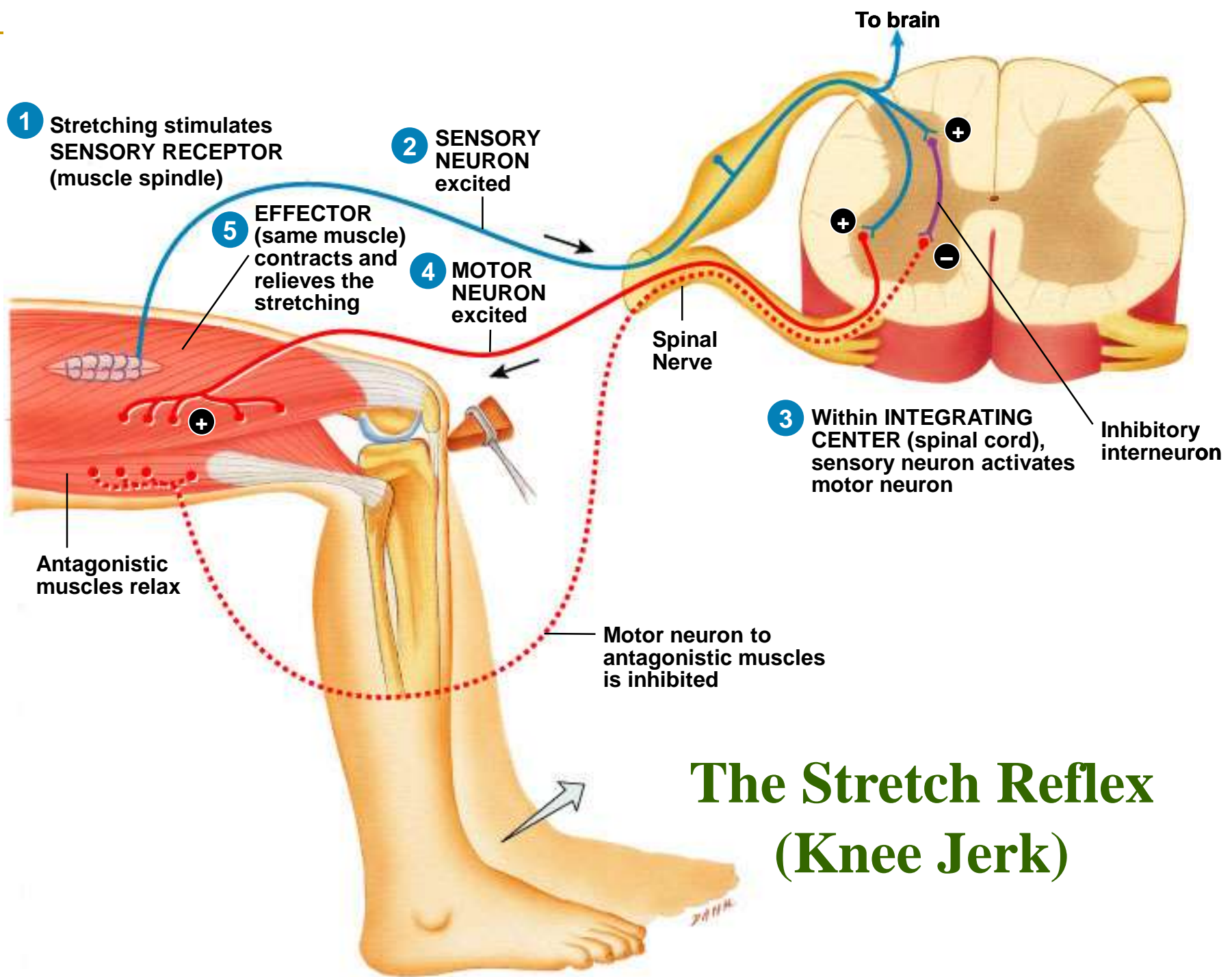
# Reflex Arc



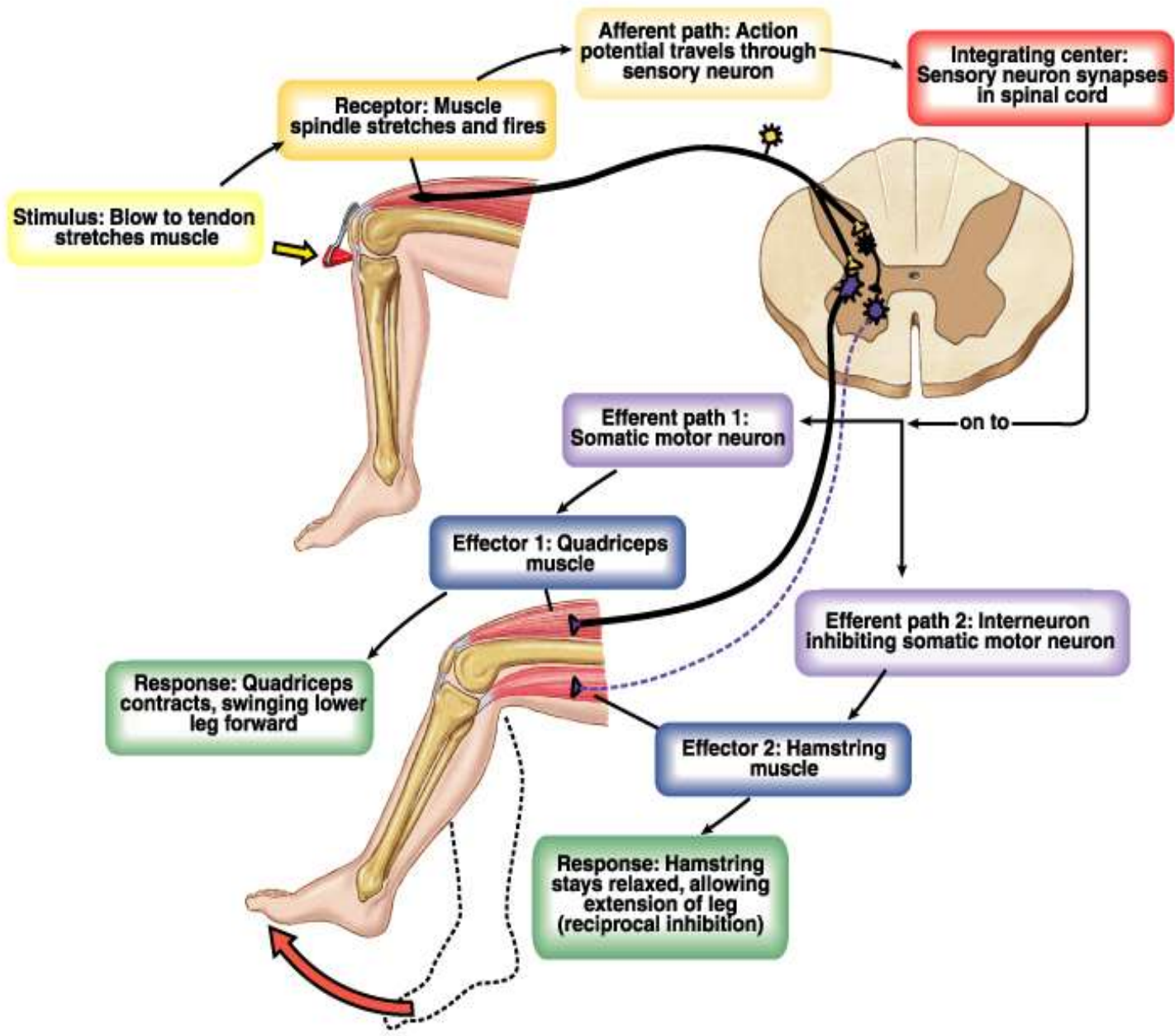
# Reflex Arc







## The Stretch Reflex (Knee Jerk)



# The Stretch Reflex

- ❖ Causes contraction of a skeletal muscle in response to stretching of the muscle.
- ❖ Monosynaptic reflex.
- ❖ Patellar or knee-jerk reflex: Stretching of a muscle → activation of muscle spindles  
→ sensory neuron → spinal cord → motor neuron  
→ muscle contraction. (Excitatory reflex)
- ❖ Ipsilateral.
- ❖ Receptors are located in the same muscle stimulated by lengthening of muscle (stretch)

To brain

**5** EFFECTOR (muscle attached to same tendon) relaxes and relieves excess tension

**4** MOTOR NEURON inhibited

**2** SENSORY NEURON excited

**1** Increased tension stimulates SENSORY RECEPTOR (tendon)

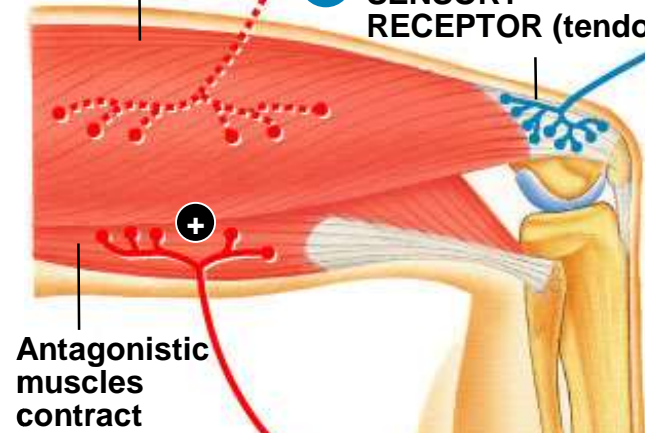
**3** Within INTEGRATING CENTER (spinal cord), sensory neuron activates inhibitory interneuron

Excitatory interneuron

Inhibitory interneuron

Spinal nerve

Motor neuron to antagonistic muscles is excited

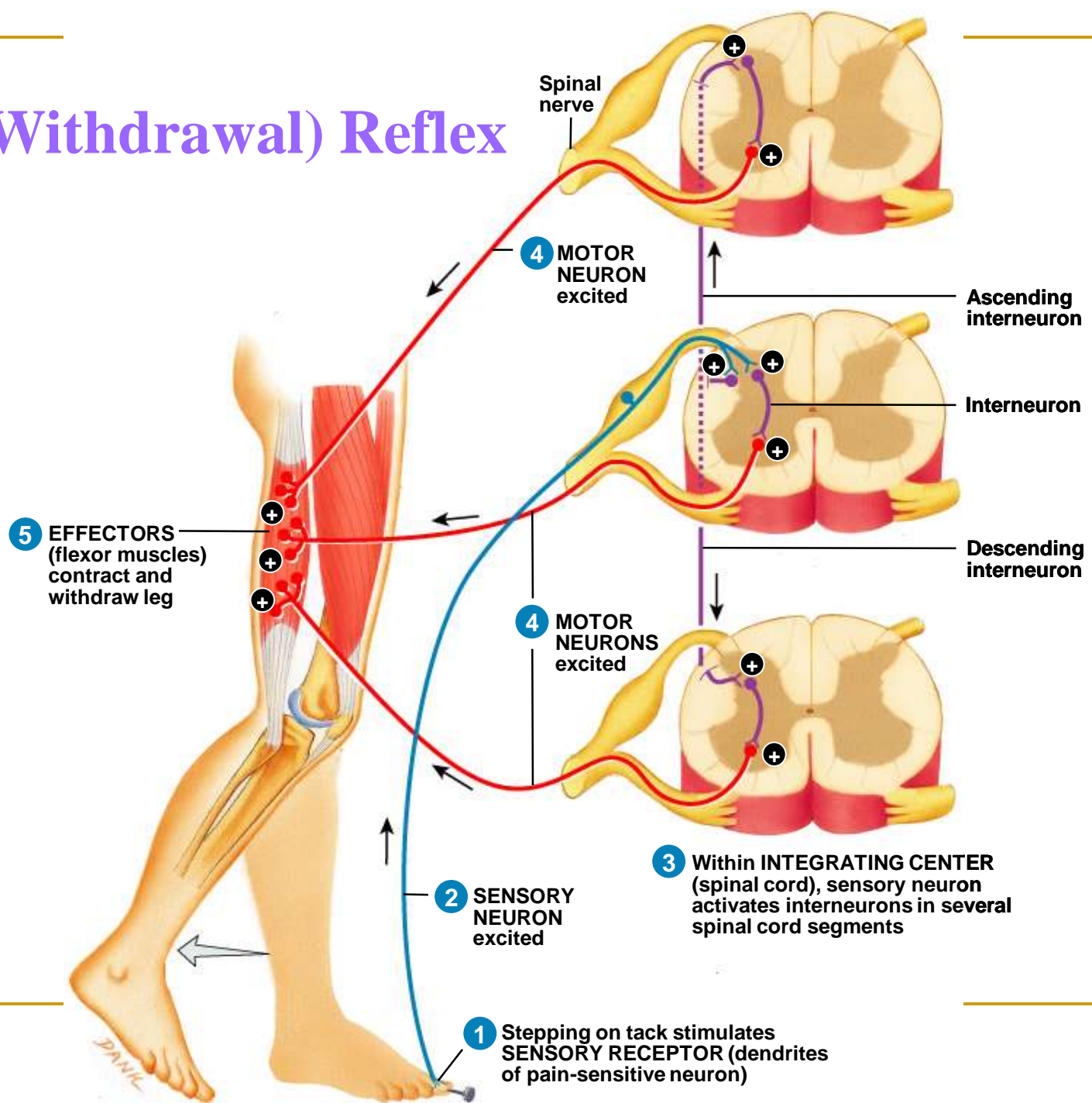


# The Tendon Reflex

# The Tendon Reflex

- ❖ Polysynaptic reflex. ( Di-synaptic)
- ❖ Control muscle tension by causing muscle relaxation when muscle tension is great.
- ❖ Sensory receptors- Golgi tendon organs (same muscle stimulated by tension applied on the muscle in series with muscle fibers)
- ❖ ↑ Tension applied to the tendon → tendon organ stimulation → nerve impulse → spinal cord → motor neuron causes muscle relaxation and relieves tension (inhibitory reflex)

# Flexor (Withdrawal) Reflex



# Flexor (Withdrawal) Reflex

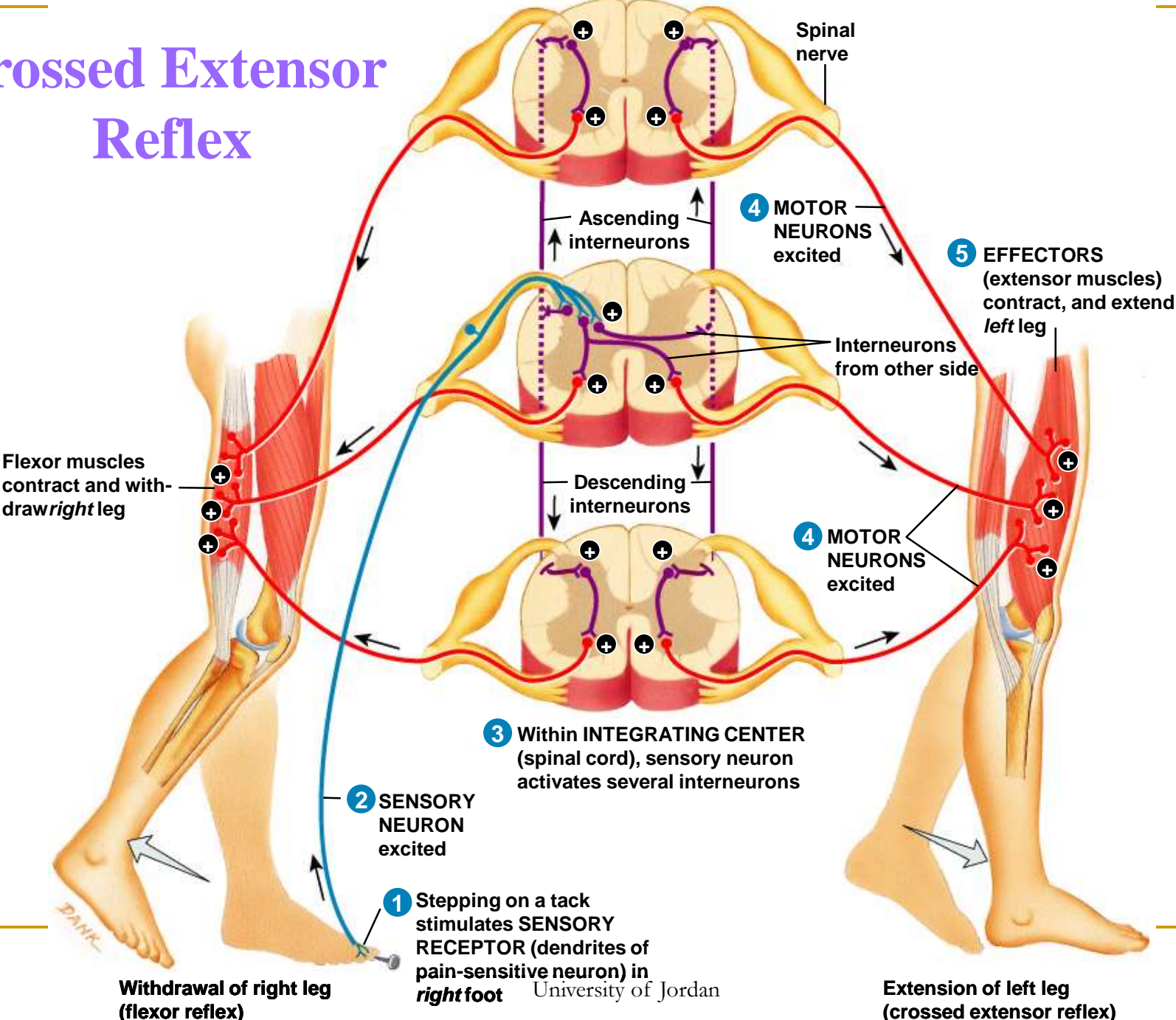
✎ Polysynaptic reflex

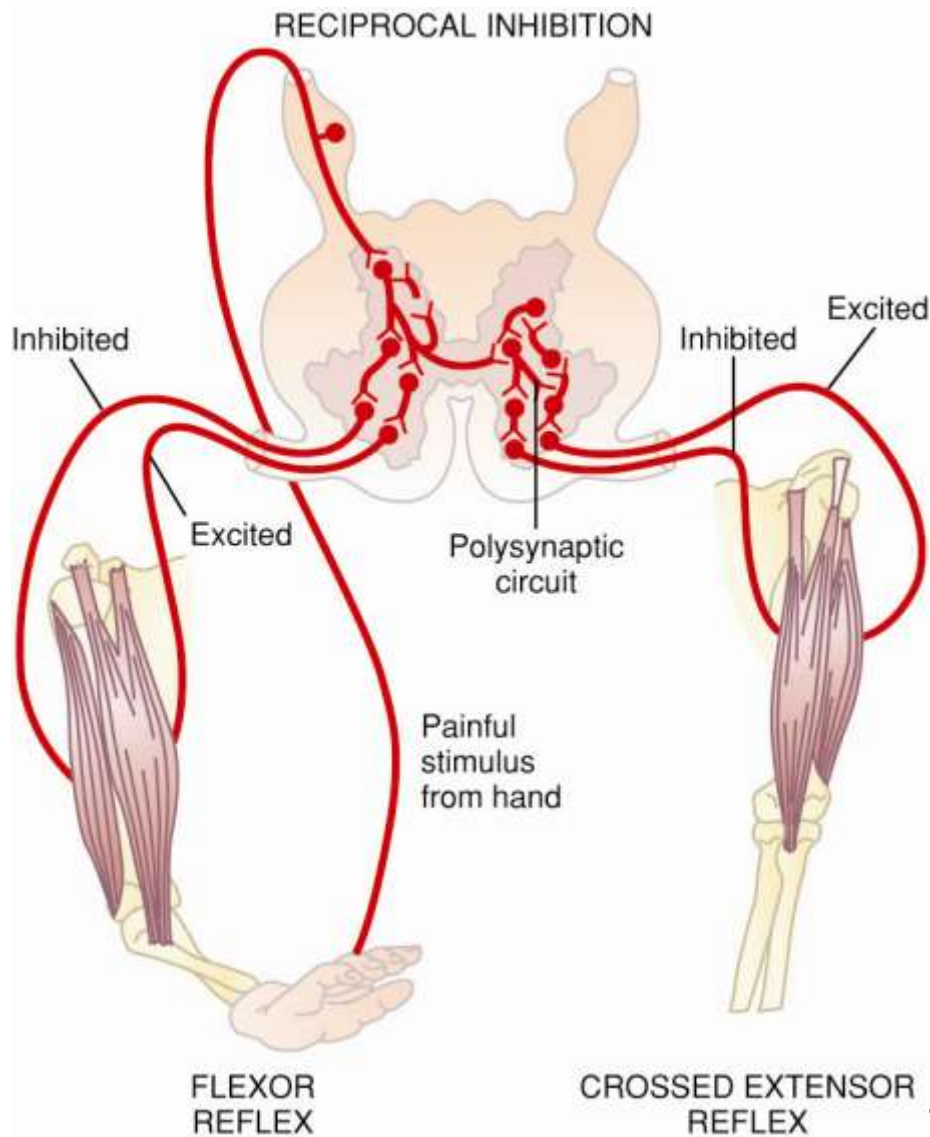
✎ Ipsilateral.

✎ Stepping on a tack (stimulus) → nerve impulse → activation of the interneuron → activation of the motor neuron → muscle contraction → withdrawal of the leg (excitatory reflex)

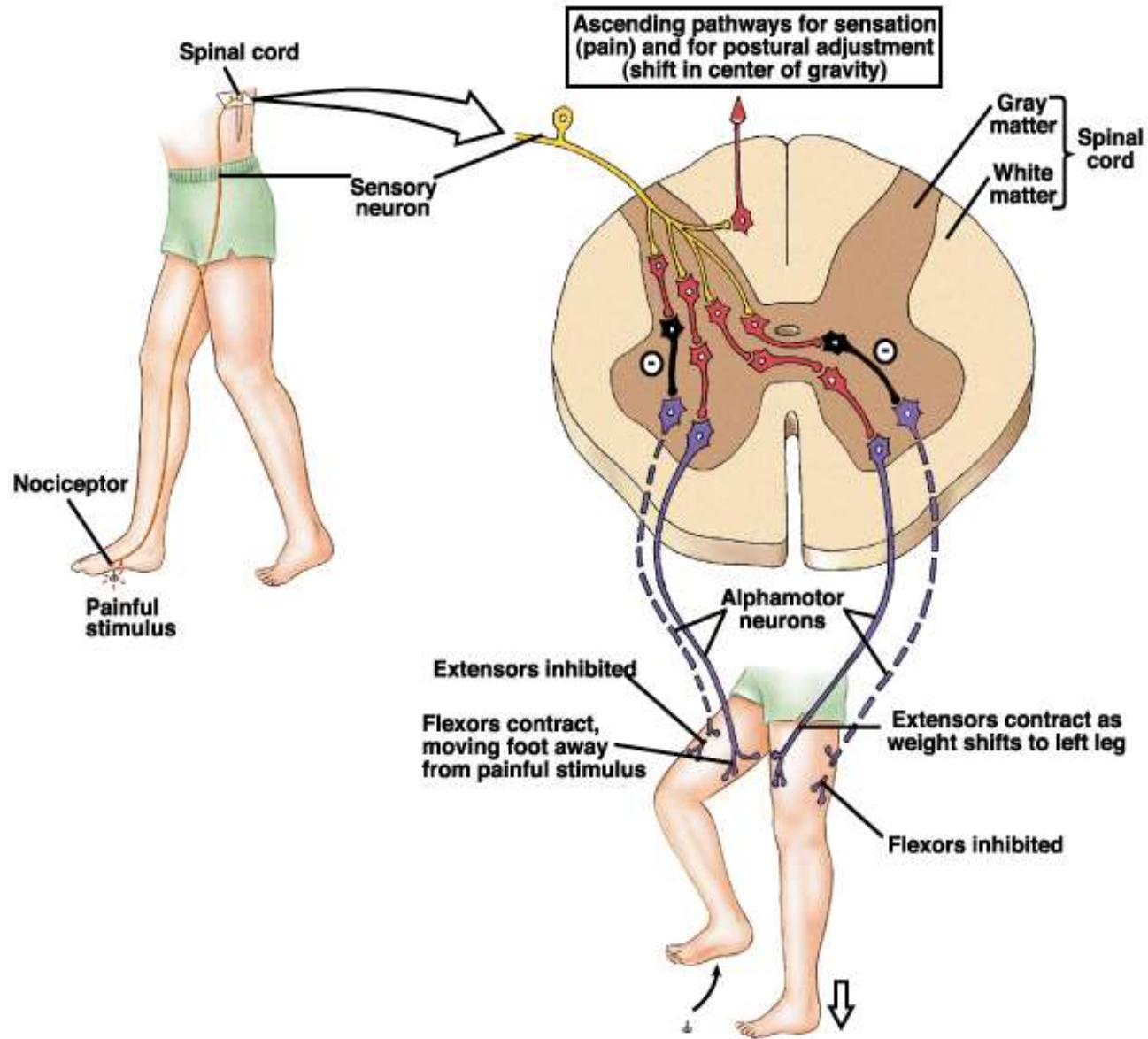
✎ There is reciprocal inhibition (i.e inhibition of antagonist group of muscles on the same side)

# Crossed Extensor Reflex





## Neuronal Circuits for Withdrawal and Crossed Extensor Reflex



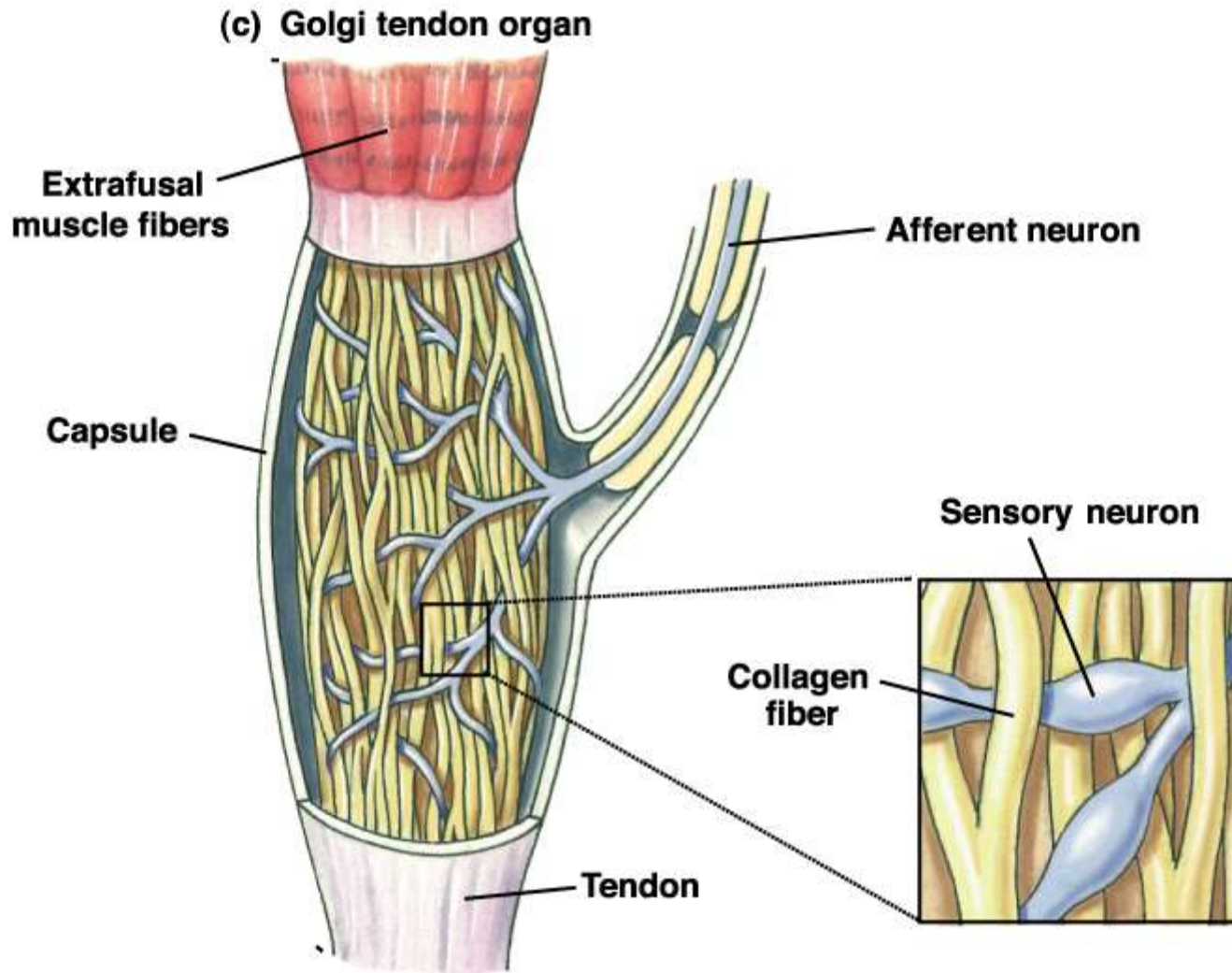
# Crossed Extensor Reflex

- ☺ Polysynaptic reflex.
- ☺ Contralateral reflex.
- ☺ Contraction of muscles that extend joints in the opposite limb in response to a painful stimulus.
- ☺ Stepping on a tack (stimulus) → nerve impulse → activation of several interneuron → activation of the motor neurons → muscle contraction causing flexion of the leg stepping on a tack & extension on the opposite side.
- 📖 There is reciprocal inhibition (i.e inhibition of antagonist group of muscles on the same side)

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# Golgi Tendon Reflex

- Mediated by the golgi tendon organ receptor located in the tendon.
- This receptor responds to tension.
- When the tension becomes too great the reflex inhibits the motor fibers attached to the tendon.
- Function is to equalize force among muscle fibers.



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# Transmission of Stretch Information to Higher Centers

- Muscle spindle and golgi tendon signals are transmitted to higher centers.
- This informs the brain of the tension and stretch of the muscle.
- Information is transmitted at 120 m/sec.
- Important for feedback control of motor activity.

# The Withdrawal Reflexes

- A painful stimulus causes the limb to automatically withdraw from the stimulus.
- Neural pathways for reflex:
  - nociceptor activation transmitted to the spinal cord
  - synapses with pool of interneurons that diverge the to the muscles for withdrawal, inhibit antagonist muscles, and activate reverberating circuits to prolong muscle contraction
  - duration of the afterdischarge depends on strength of the stimulus

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# Crossed Extensor Reflex

- Painful stimulus elicits a flexor reflex in affected limb and an extensor reflex in the opposite limb.
- Extensor reflex begins 0.2 - 0.5 seconds after the painful stimulus.
- Serves to push body away from the stimulus, also to shift weight to the opposite limb.

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# Other Reflexes for Posture and Locomotion

- Pressure on the bottom of the feet cause extensor reflex.
  - more complex than flexor-crossed extensor reflex
- Basic walking reflexes reside in the spinal cord.

# Reflexes that Cause Muscle Spasm

- Pain signals can cause reflex activation and spasm of local muscles.
- Inflammation of peritoneum can cause abdominal muscle spasm.
- Muscle cramps caused by painful stimulus in muscle:
  - can be due to cold, ischemia, or overactivity
  - reflex contraction increases painful stimulus and causes more muscle contraction

# Myograms of flexor and crossed extensor reflexes

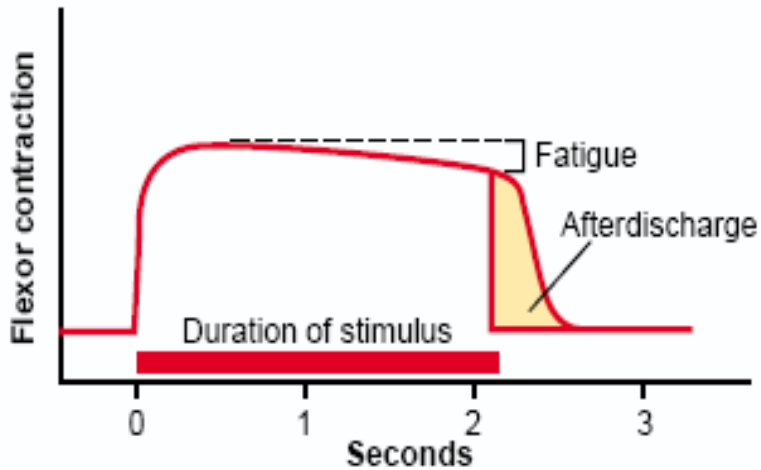


Figure 54-9

Myogram of the flexor reflex showing rapid onset of the reflex, an interval of fatigue, and, finally, afterdischarge after the input stimulus is over.

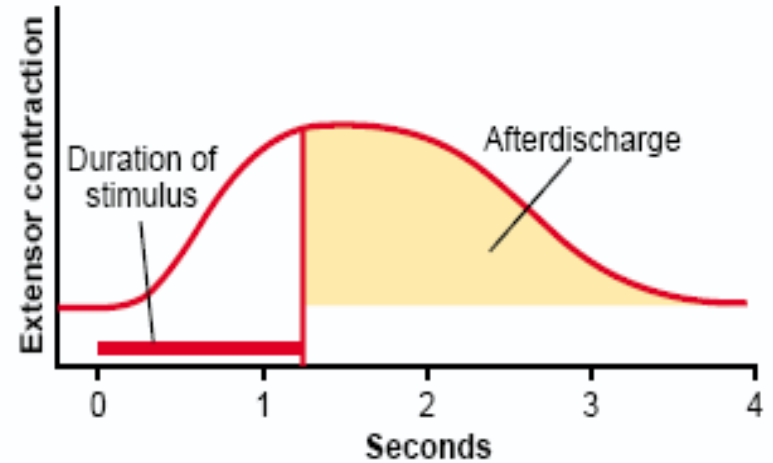


Figure 54-10

Myogram of a crossed extensor reflex showing slow onset but prolonged afterdischarge.

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# Spinal Shock

- Definition: Immediate temporary loss of total power and reflexes below the level of injury.
- Usually recover after 24-48 hours.
- Trauma causes a concussion injury to the spinal cord
- Reflexes in the spinal cord below the level of injury are lost (Areflexia)
- The shock in spinal shock does not refer to circulatory collapse

# Phases of spinal shock

Phase	Time	Physical Exam Findings	Underlying Physiological Event
1	0-1 days	Areflexia	Loss of descending facilitation
2	1-3 days	Initial reflex return	Denervation susceptibility
3	1-4 weeks	Hyperreflexia	Axon-supported synapse growth
4	1-12 months	Hyperreflexia, spasticity	Soma-supported synapse growth

# Phase 1:

- ❑ Complete loss of all reflexes below the level of spinal cord injury
- ❑ Spinal cord concussion caused the neurons involved in various reflex arcs and the neural input from the brain become hyperpolarized and unresponsive

# Phase 2:

- ❑ The reason reflexes return is the hypersensitivity of reflex muscles following denervation; more receptors are expressed and therefore are easier to stimulate

# Phase 3 and 4

- ❑ Characterized by hyperreflexia
- ❑ Neurons below the injury attempt to re-establish the synapses

## Spinal shock Vs. Neurogenic shock

	Spinal shock	Neurogenic shock
Definition		
BP	Hypotension	Hypotension
Pulse	Bradycardia	Bradycardia
Motor	Flaccid paralysis	Variable
Mechanism	Peripheral neurons become unresponsive to brain stimuli	Disruption of autonomic pathways causes loss of sympathetic pathways and vasodilation

# Thank You

