Motor system-Motor Functions of the Spinal Cord-

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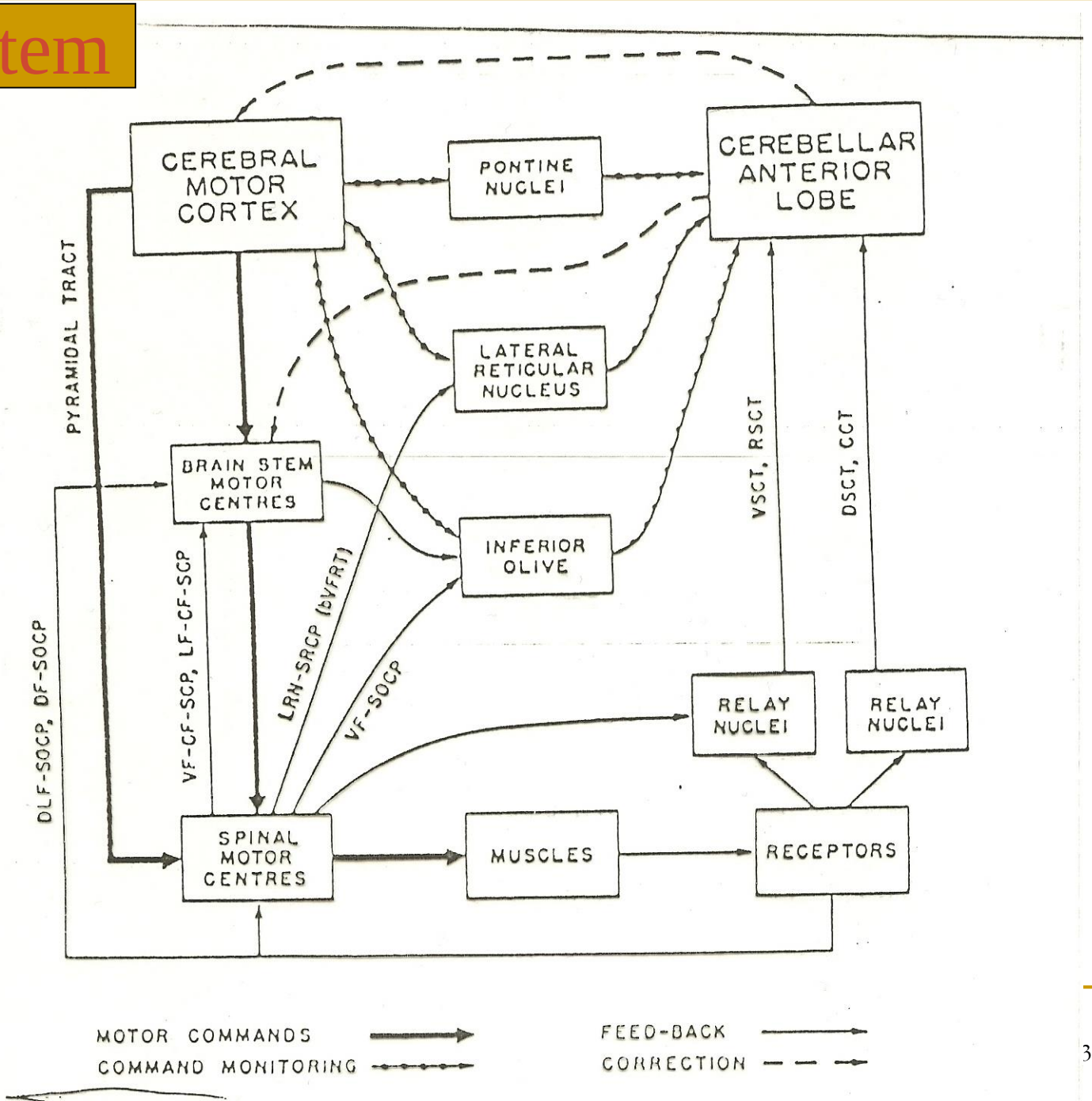
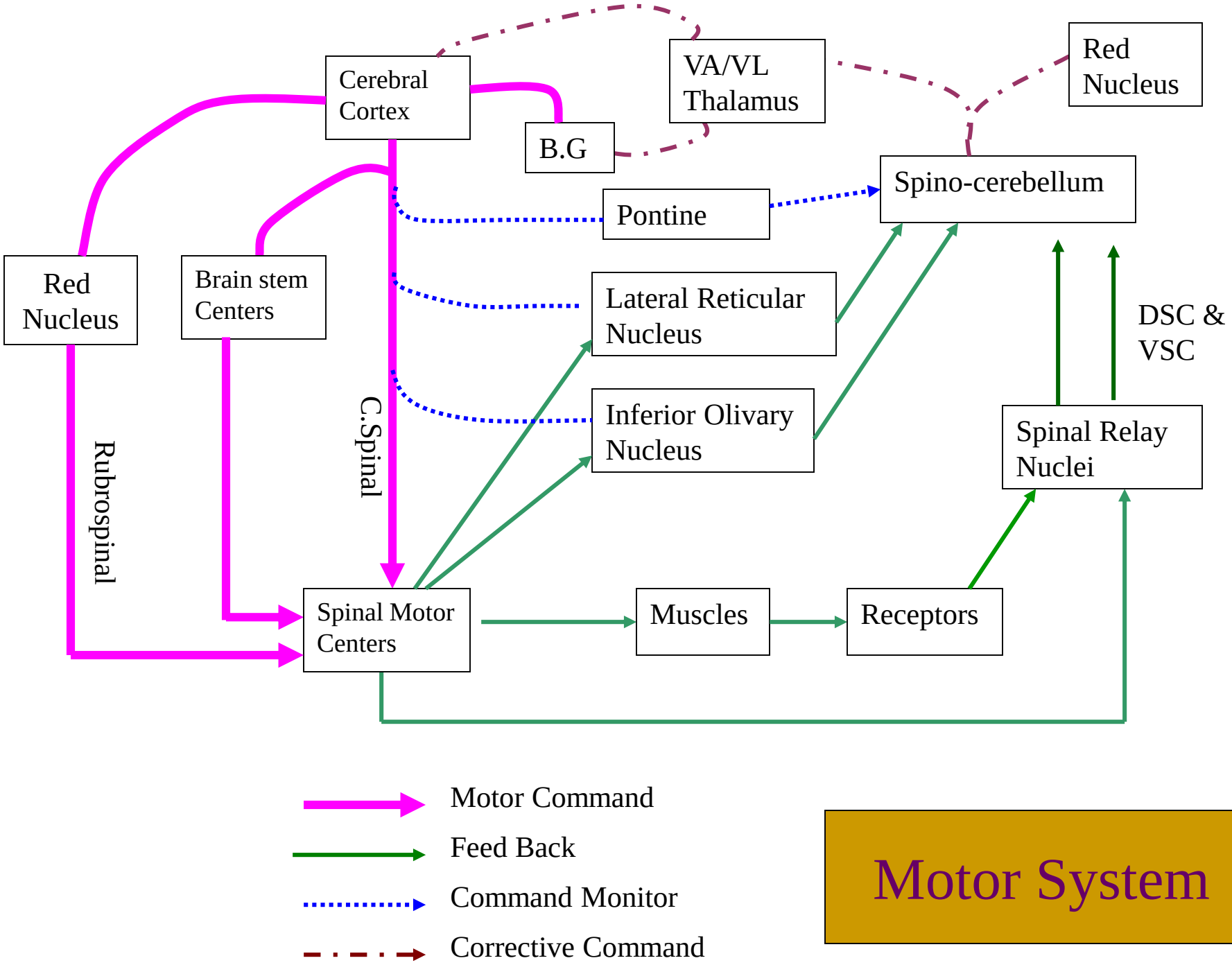
Objectives

- 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

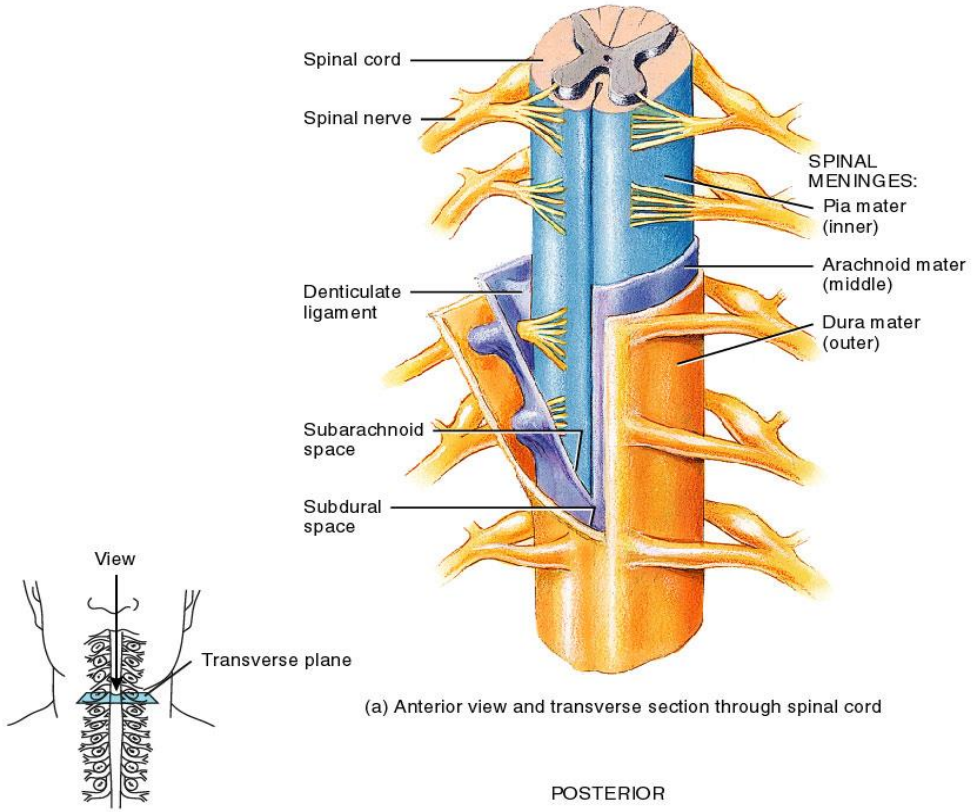
Motor System



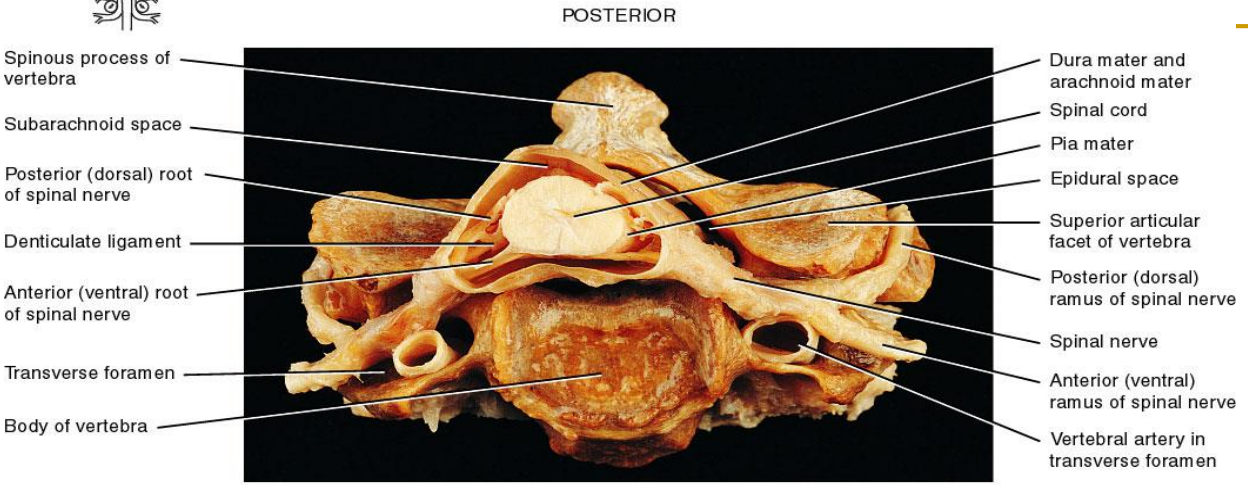

Cerebral Cortex
VA/VL Thalamus
Red Nucleus
B.G
Spino-cerebellum
Pontine
Red Nucleus
Brain stem Centers
Lateral Reticular Nucleus
DSC & VSC
Inferior Olivary Nucleus
Spinal Relay Nuclei
C.Spinal
Rubrospinal
Spinal Motor Centers
Muscles
Receptors
Motor Command
Feed Back
Command Monitor
Corrective Command
Motor System

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

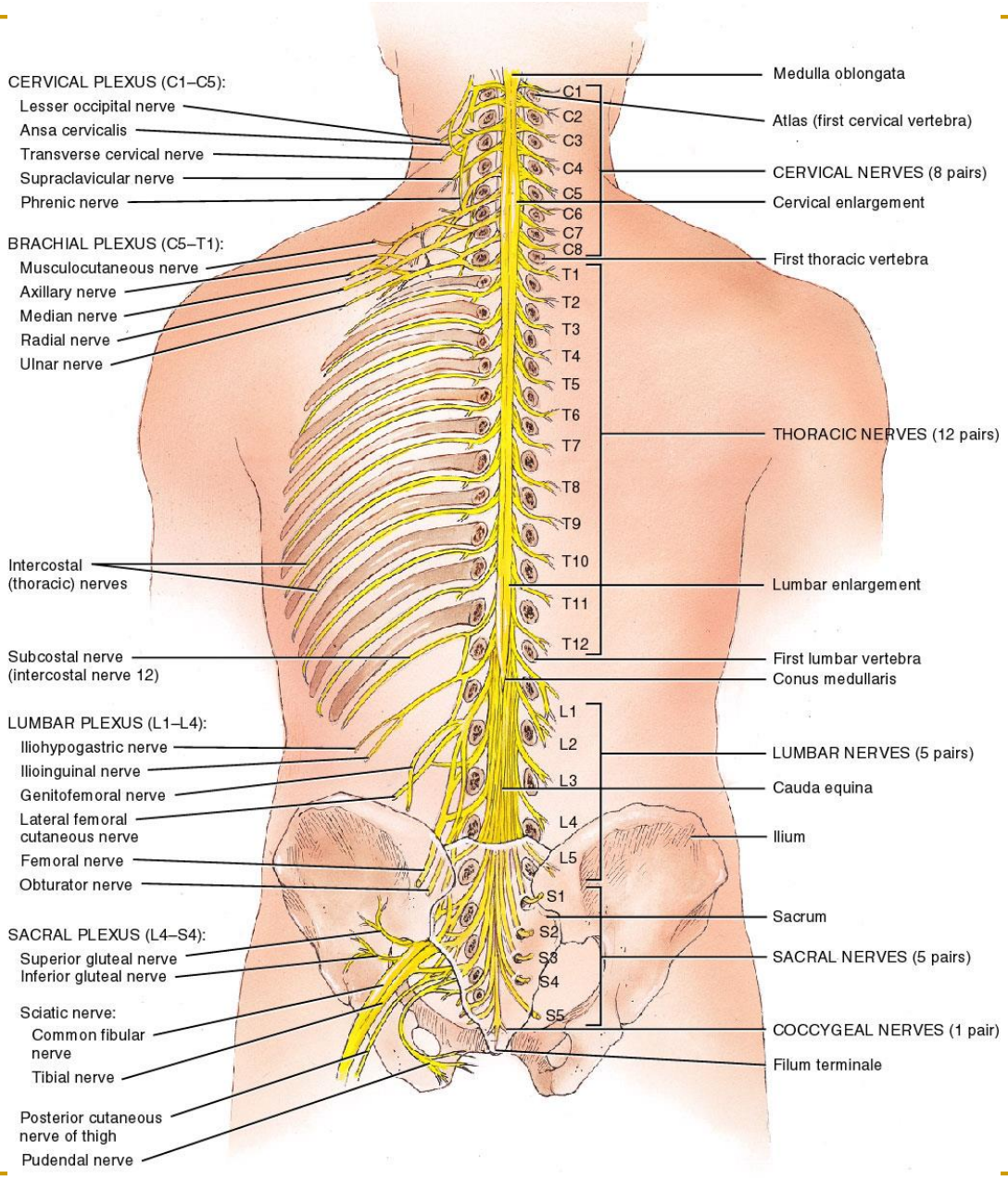


(a) Anterior view and transverse section through spinal cord



(b) Transverse section of the spinal cord within a cervical vertebra

13.01



Posterior view of entire spinal cord and portions of spinal nerves

13.02

Internal Anatomy of Spinal Cord

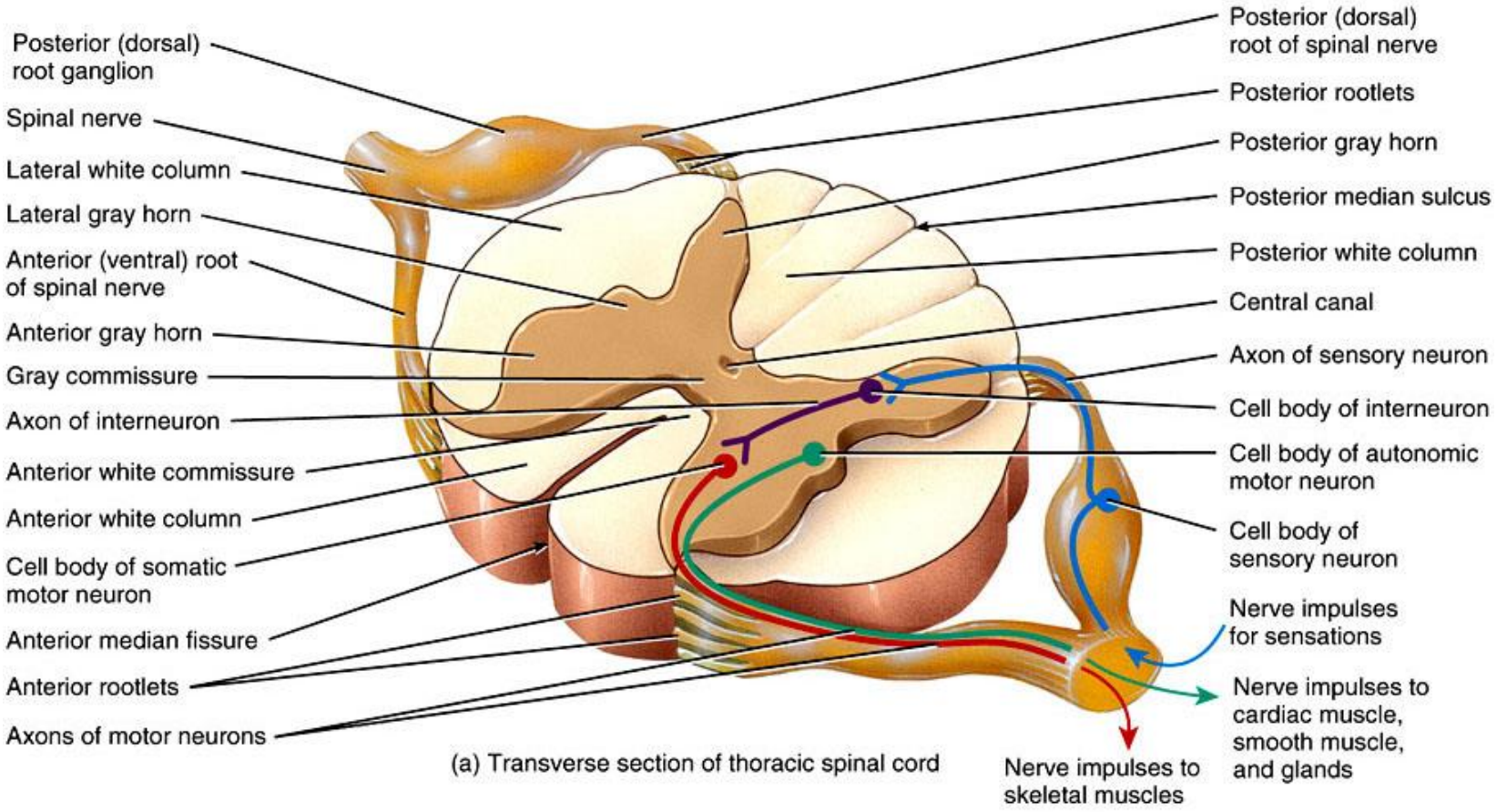
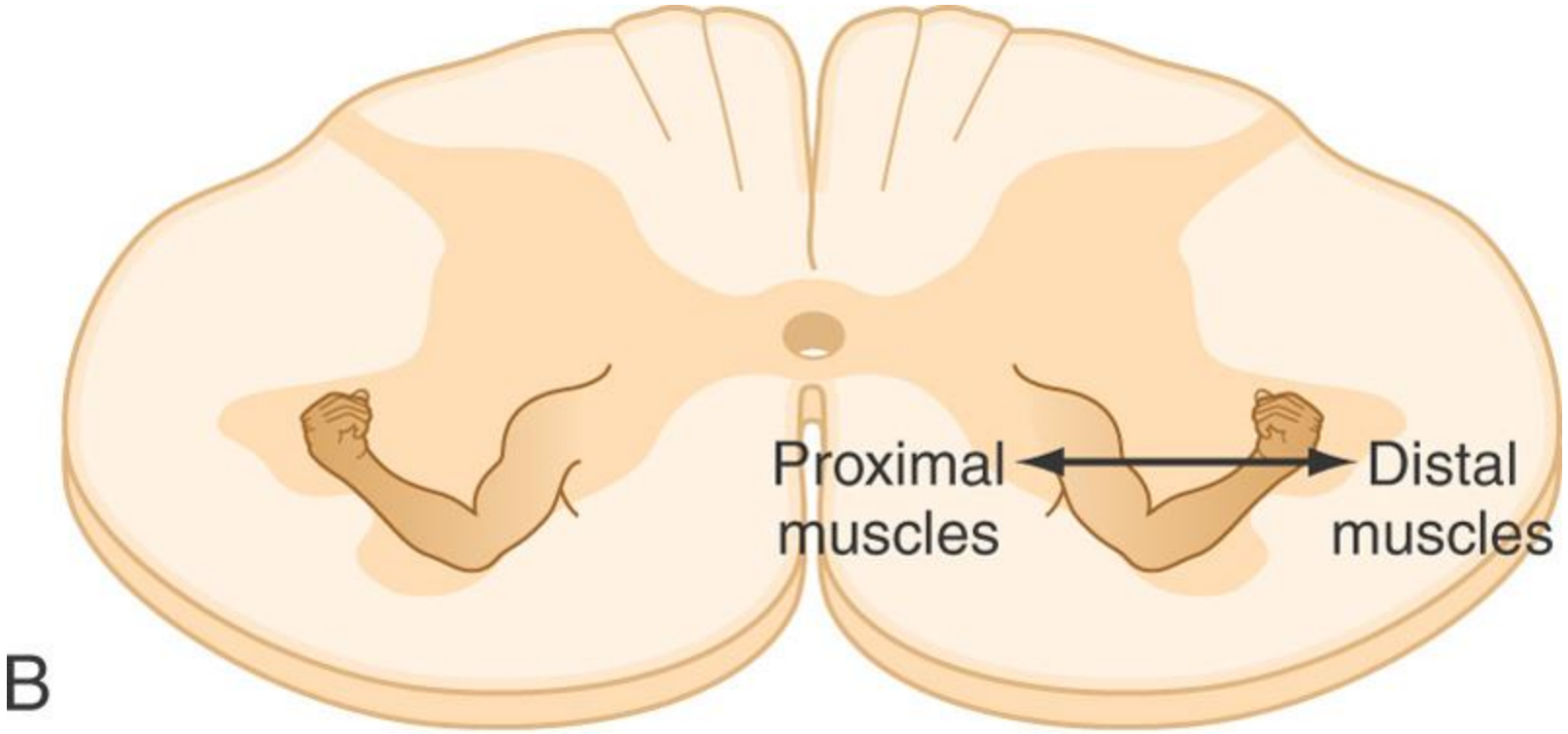
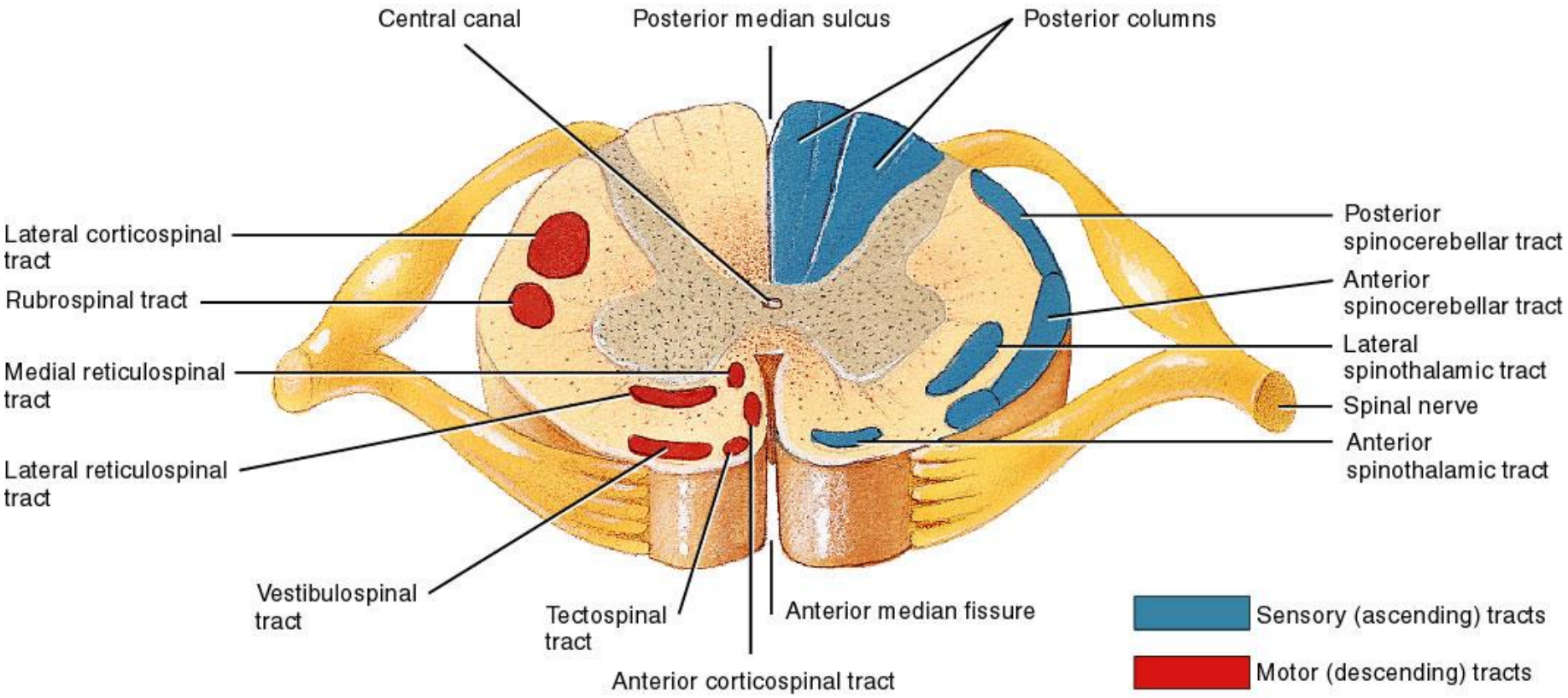


Figure 13.03 Tortora - PAP 12/e



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


Central canal
Posterior median sulcus
Posterior columns
Lateral corticospinal tract
Rubrospinal tract
Medial reticulospinal tract
Lateral reticulospinal tract
Vestibulospinal tract
Tectospinal tract
Anterior median fissure
Anterior corticospinal tract
Posterior spinocerebellar tract
Anterior spinocerebellar tract
Lateral spinothalamic tract
Spinal nerve
Anterior spinothalamic tract
Sensory (ascending) tracts
Motor (descending) tracts

13.04

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

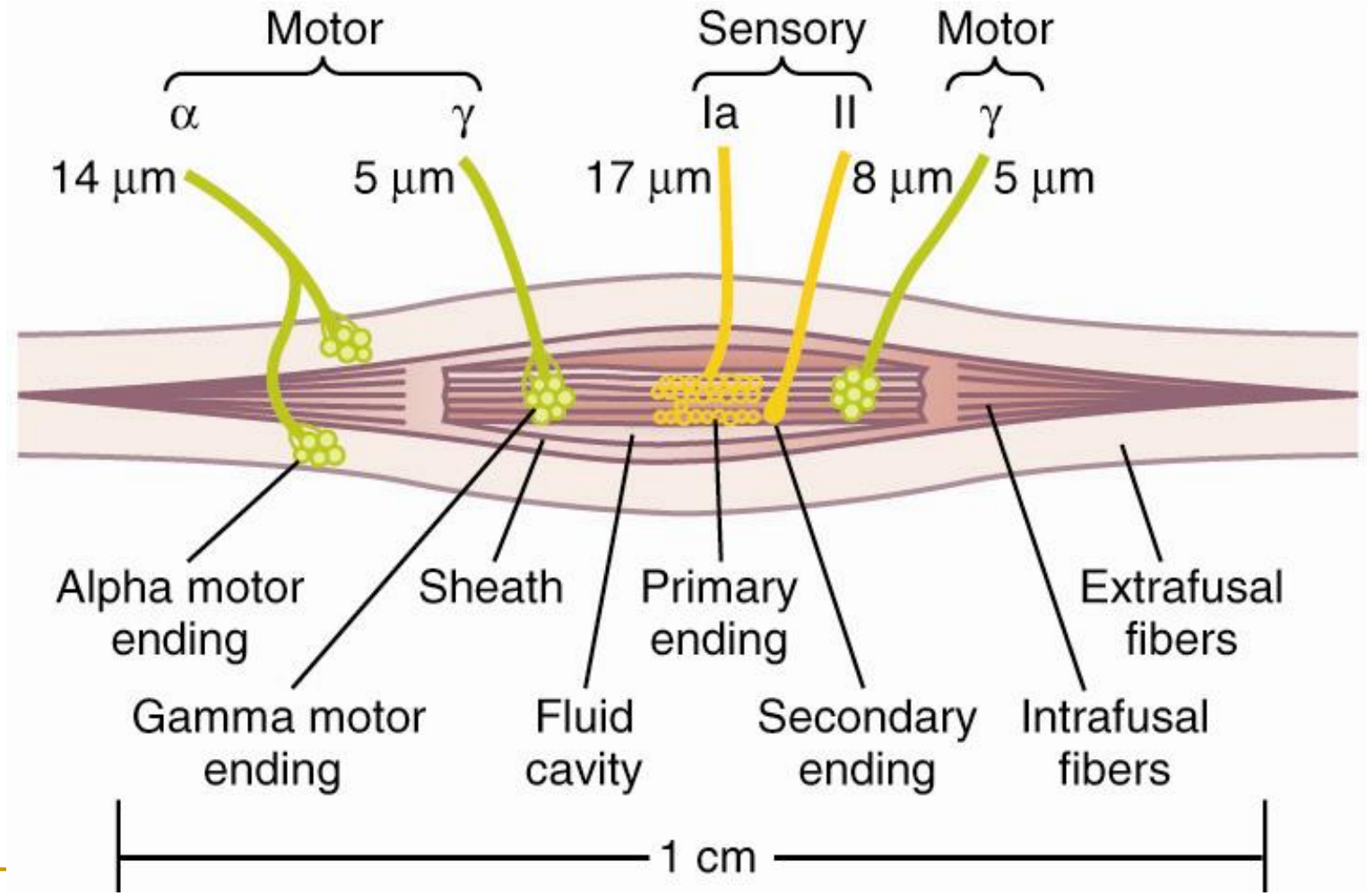
- Alpha motor neurons
  - give rise to large type A alpha fibers (~14 microns).
  - stimulation can excite 3 - 100 ***extrafusal*** muscle fibers collectively called a motor unit
- Gamma motor neurons
  - give rise to smaller type A gamma fibers (~5 microns)
  - stimulation excites ***intrafusal fibers***,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

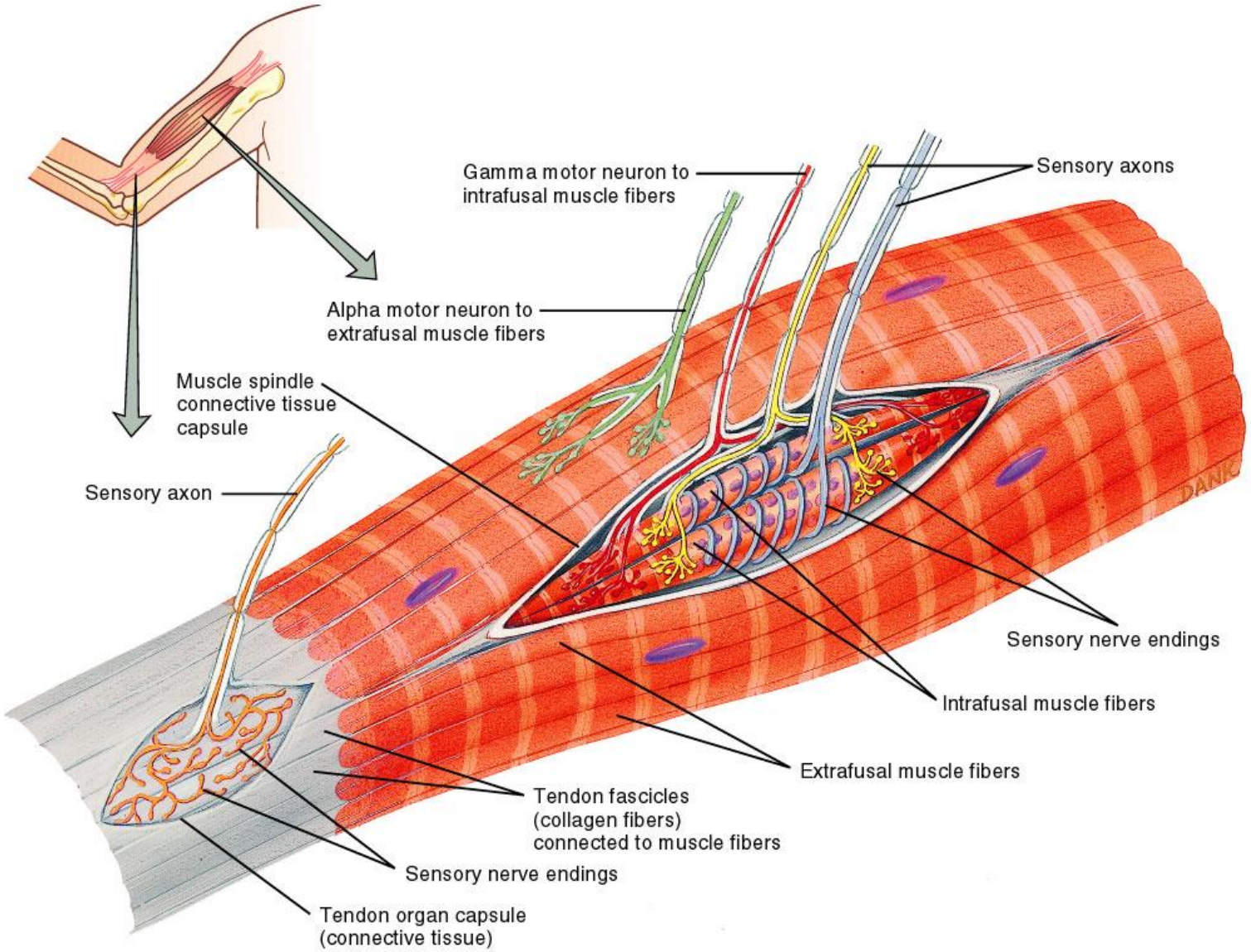
Interneurons and Propriospinal Fibers

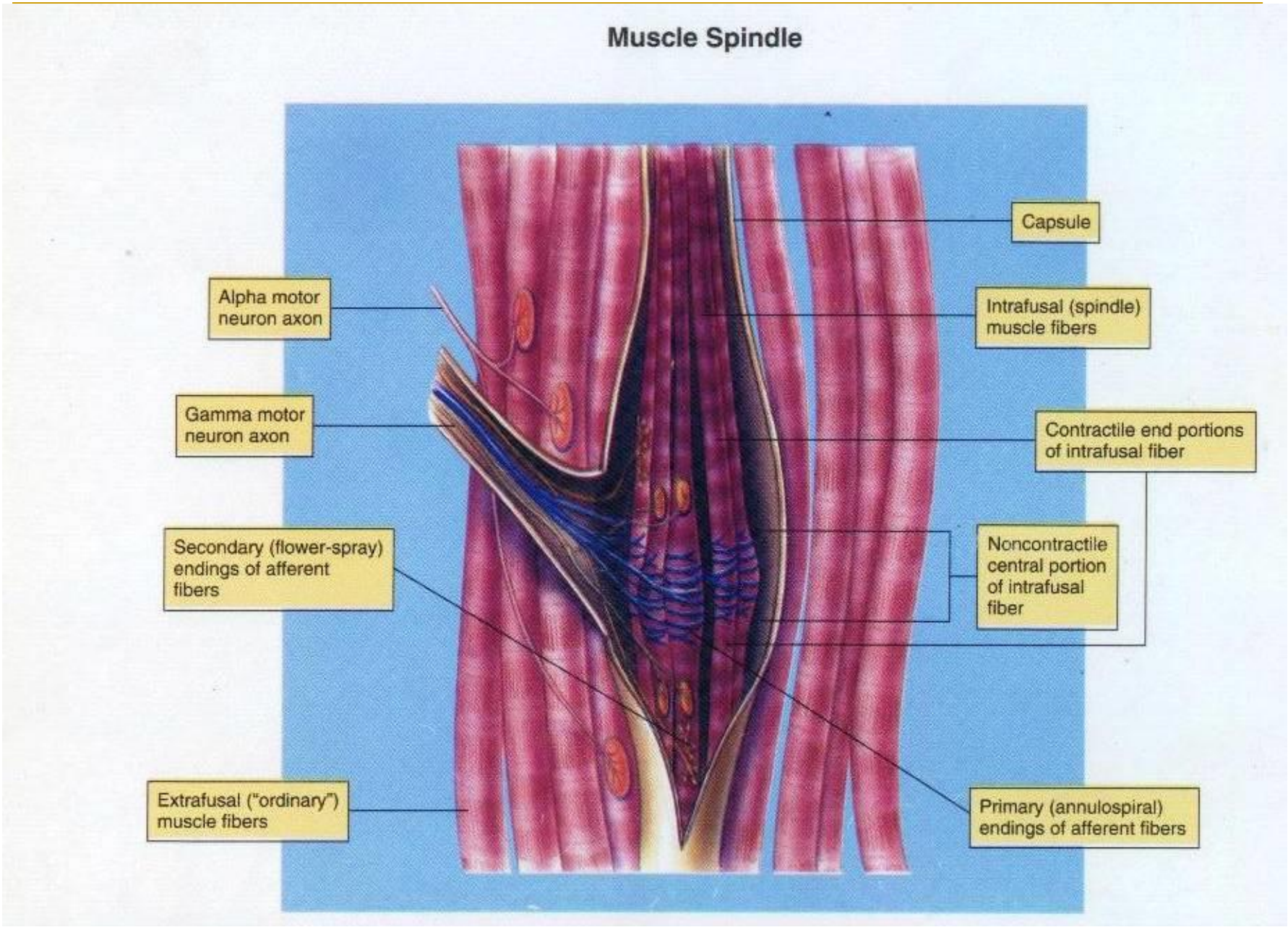
- Interneurons
  - 30 times as many as anterior motor neurons
  - small and very excitable
  - comprise the neural circuitry for the motor reflexes
- Propriospinal fibers
  - travel up and down the cord for 1 - 2 segments
  - provide pathways for multisegmental reflexes

Sensory Receptors of the Muscle

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


Motor
Sensory
Motor
α
γ
Ia
II
γ
14 μm
5 μm
17 μm
8 μm
5 μm
Alpha motor ending
Sheath
Primary ending
Extrafusal fibers
Gamma motor ending
Fluid cavity
Secondary ending
Intrafusal fibers
1 cm


Gamma motor neuron to intrafusal muscle fibers
Sensory axons
Alpha motor neuron to extrafusal muscle fibers
Muscle spindle connective tissue capsule
Sensory axon
Sensory nerve endings
Intrafusal muscle fibers
Extrafusal muscle fibers
Tendon fascicles (collagen fibers) connected to muscle fibers
Sensory nerve endings
Tendon organ capsule (connective tissue)


Muscle Spindle
Capsule
Alpha motor neuron axon
Intrafusal (spindle) muscle fibers
Gamma motor neuron axon
Contractile end portions of intrafusal fiber
Secondary (flower-spray) endings of afferent fibers
Noncontractile central portion of intrafusal fiber
Extrafusal ("ordinary") muscle fibers
Primary (annulospiral) endings of afferent fibers

Sensory fibers of muscle spindle

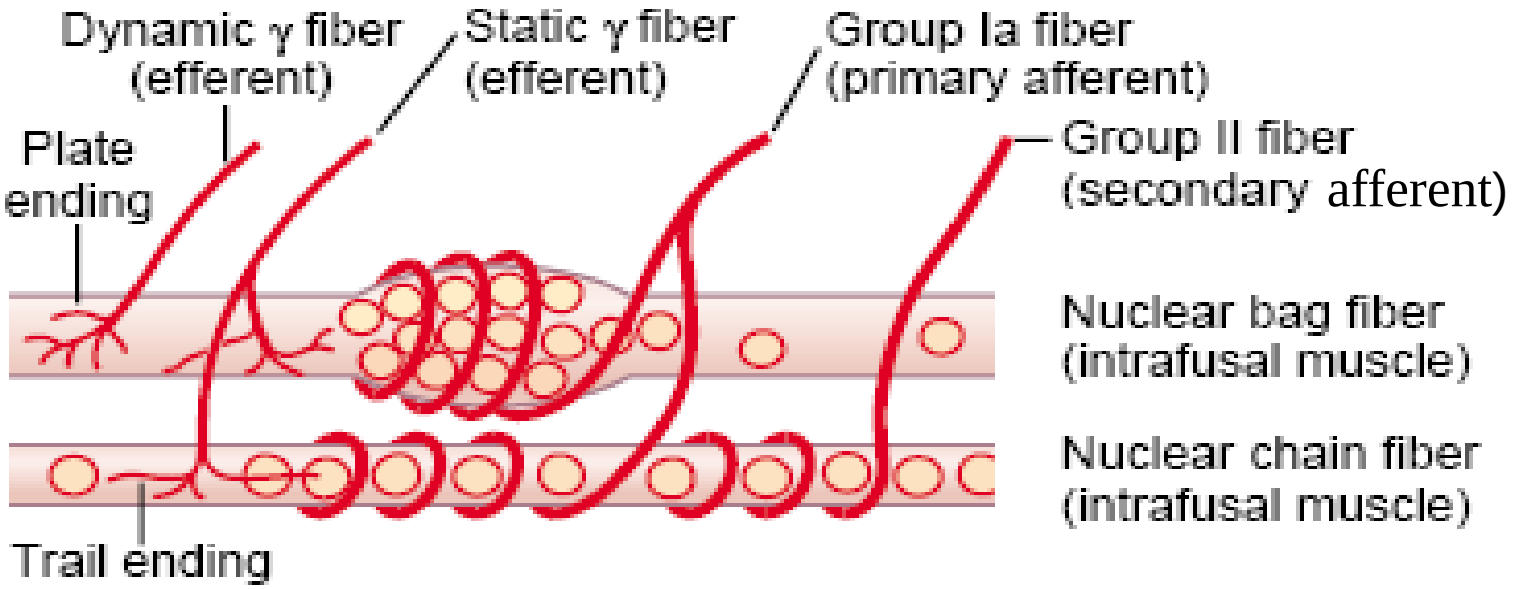


Figure 54–3

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.

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.

Smoothening effect of muscle spindle

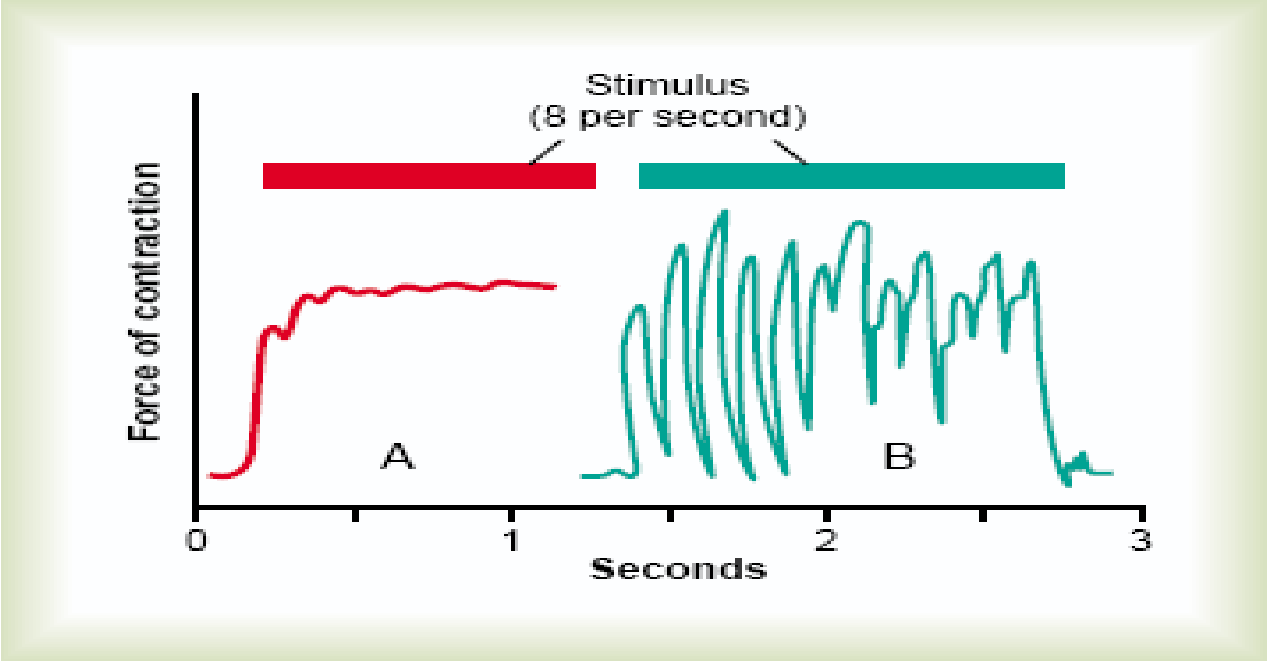
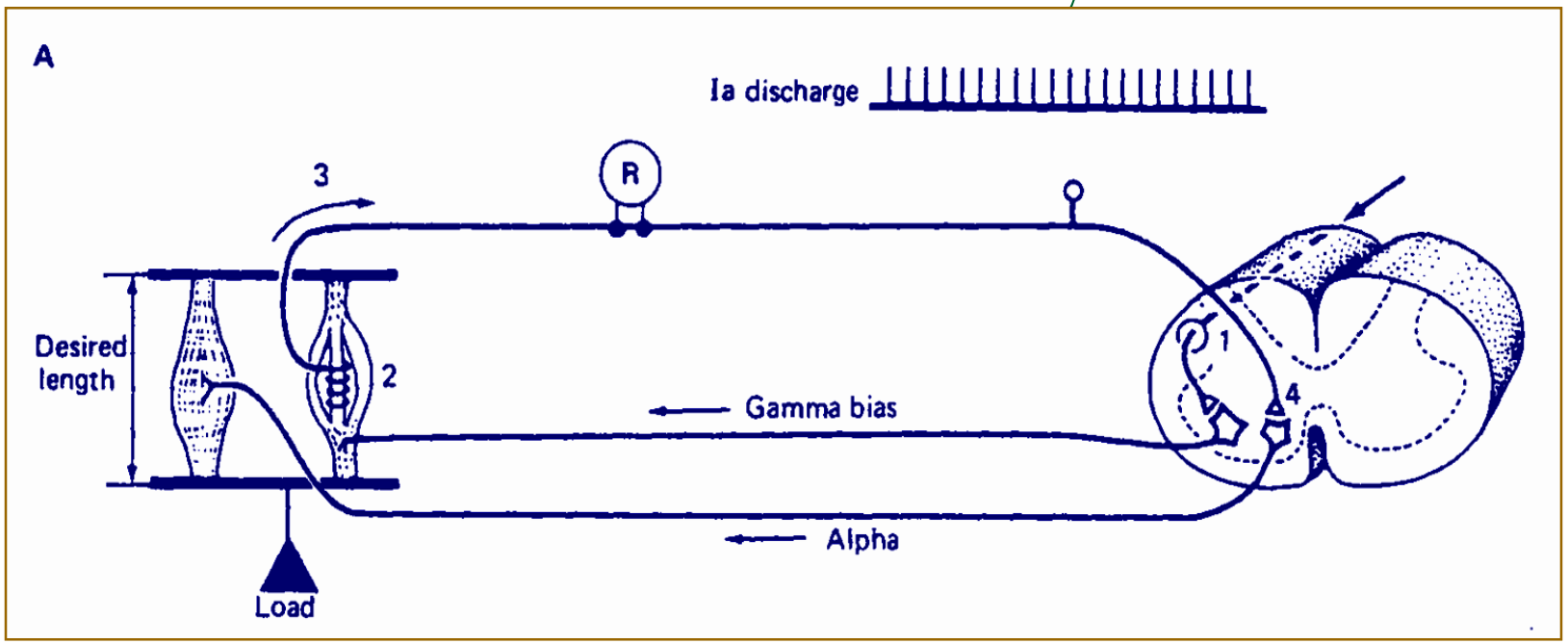


Figure 54–5

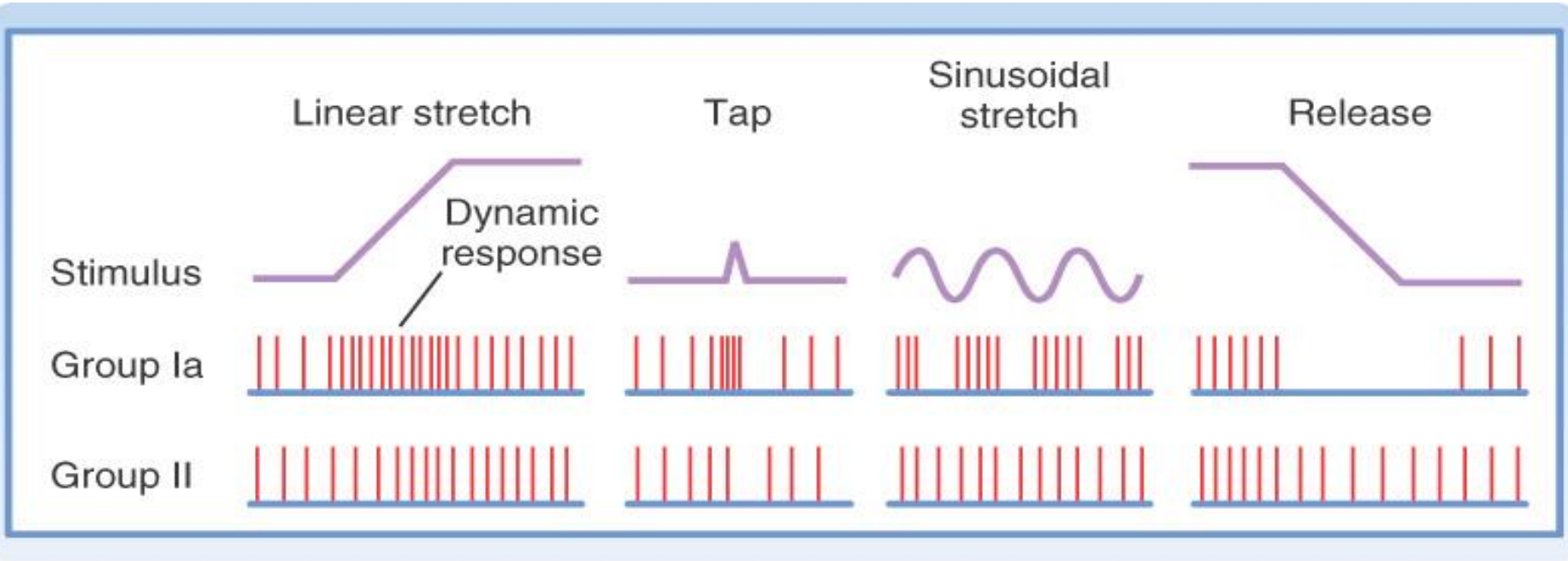
Muscle contraction caused by a spinal cord signal under two conditions: curve A, in a normal muscle, and curve B, in a muscle whose muscle spindles were denervated by section of the posterior roots of the cord 82 days previously. Note the smoothing effect of the muscle spindle reflex in curve A. (Modified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

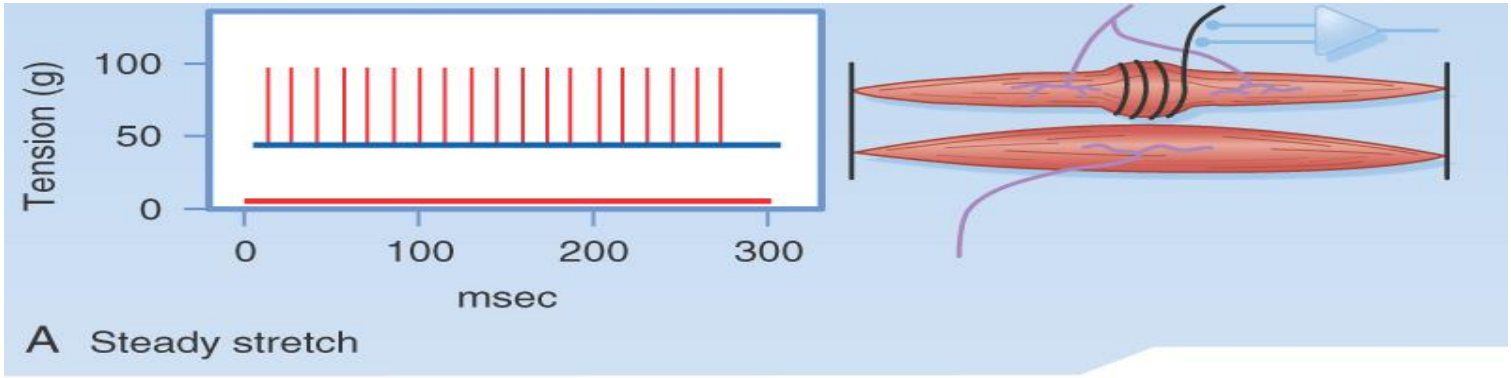
Function of the Gamma System



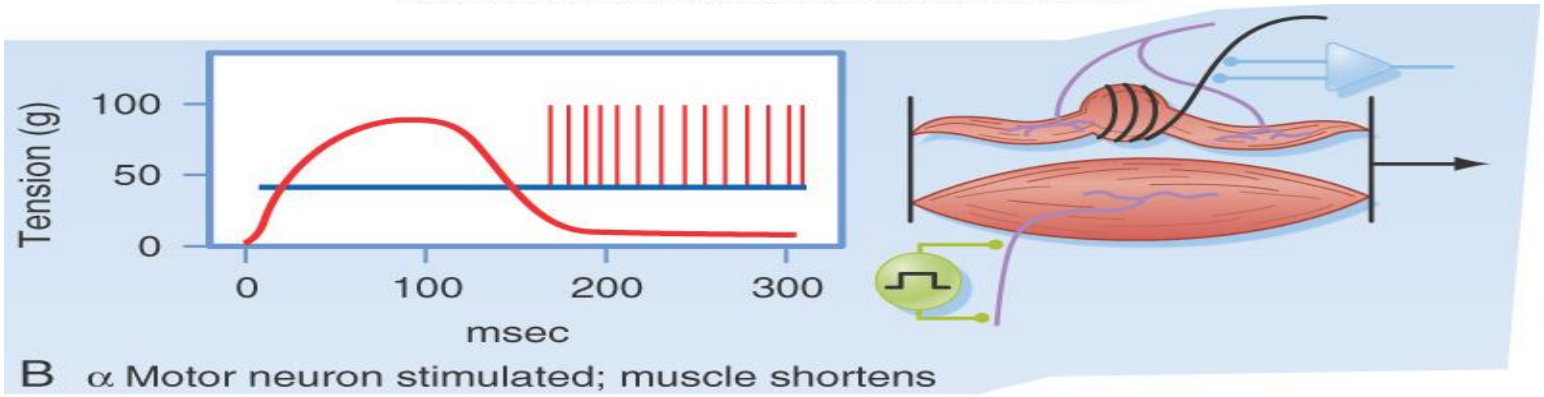
- Spindle is normally tonically active as a result of input from higher brain centers. Alpha-gamma co-activation helps maintain muscle contraction
- Controls the intensity of the stretch reflex.

- Performs a damping function by adjusting sensitivity.

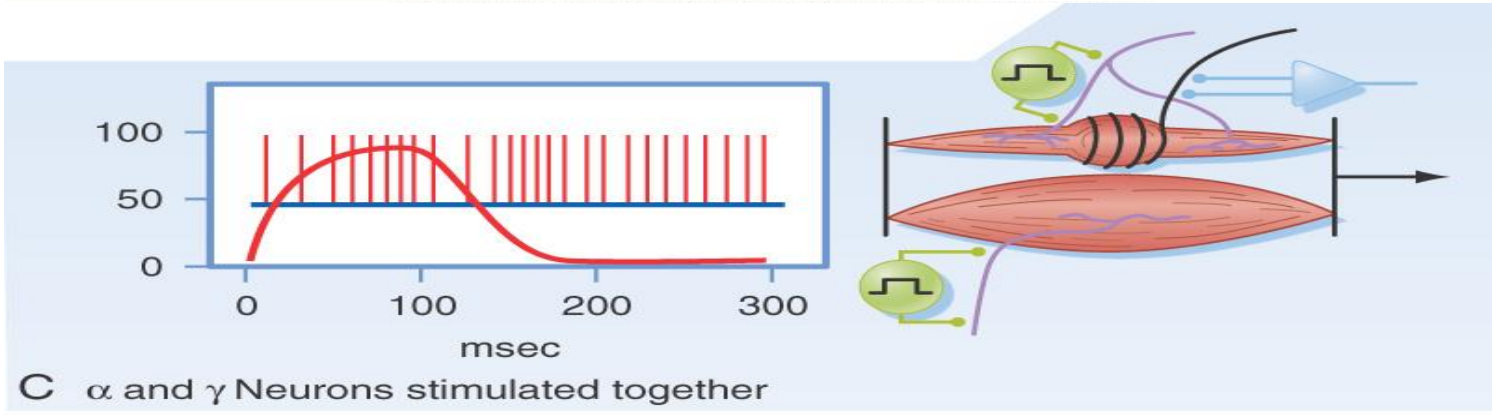




A Steady stretch



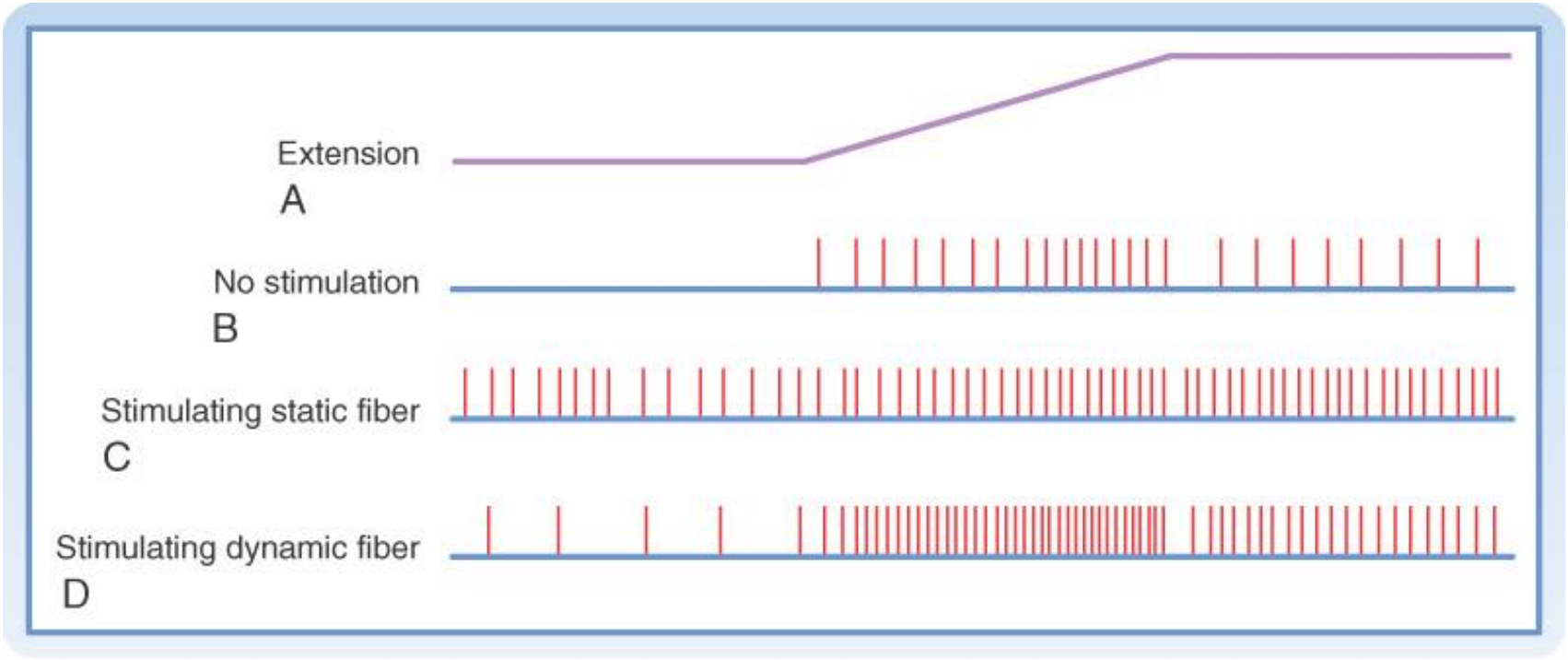
B α Motor neuron stimulated; muscle shortens



C α and γ 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 Physio174:109, 1964.)

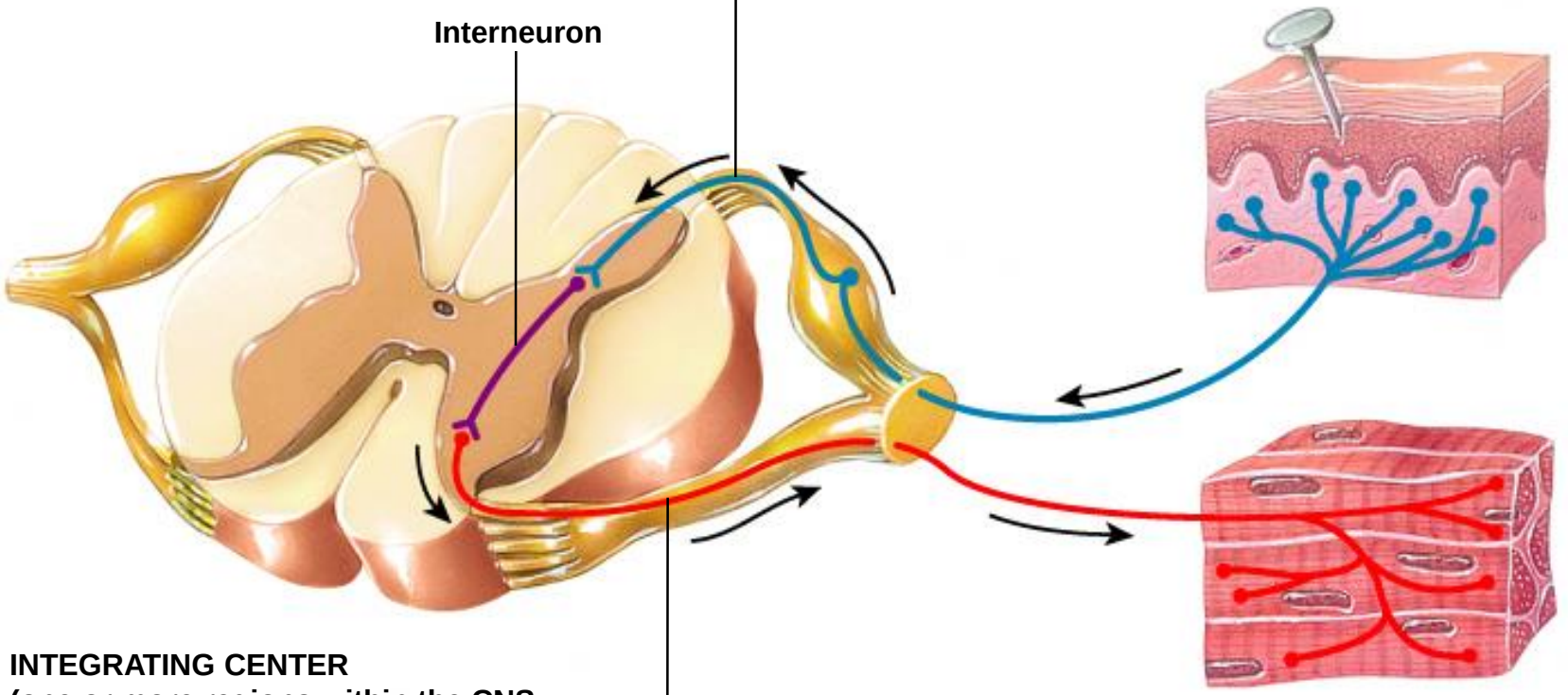
Control of the Gamma Motor System (Fusimotor System)

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

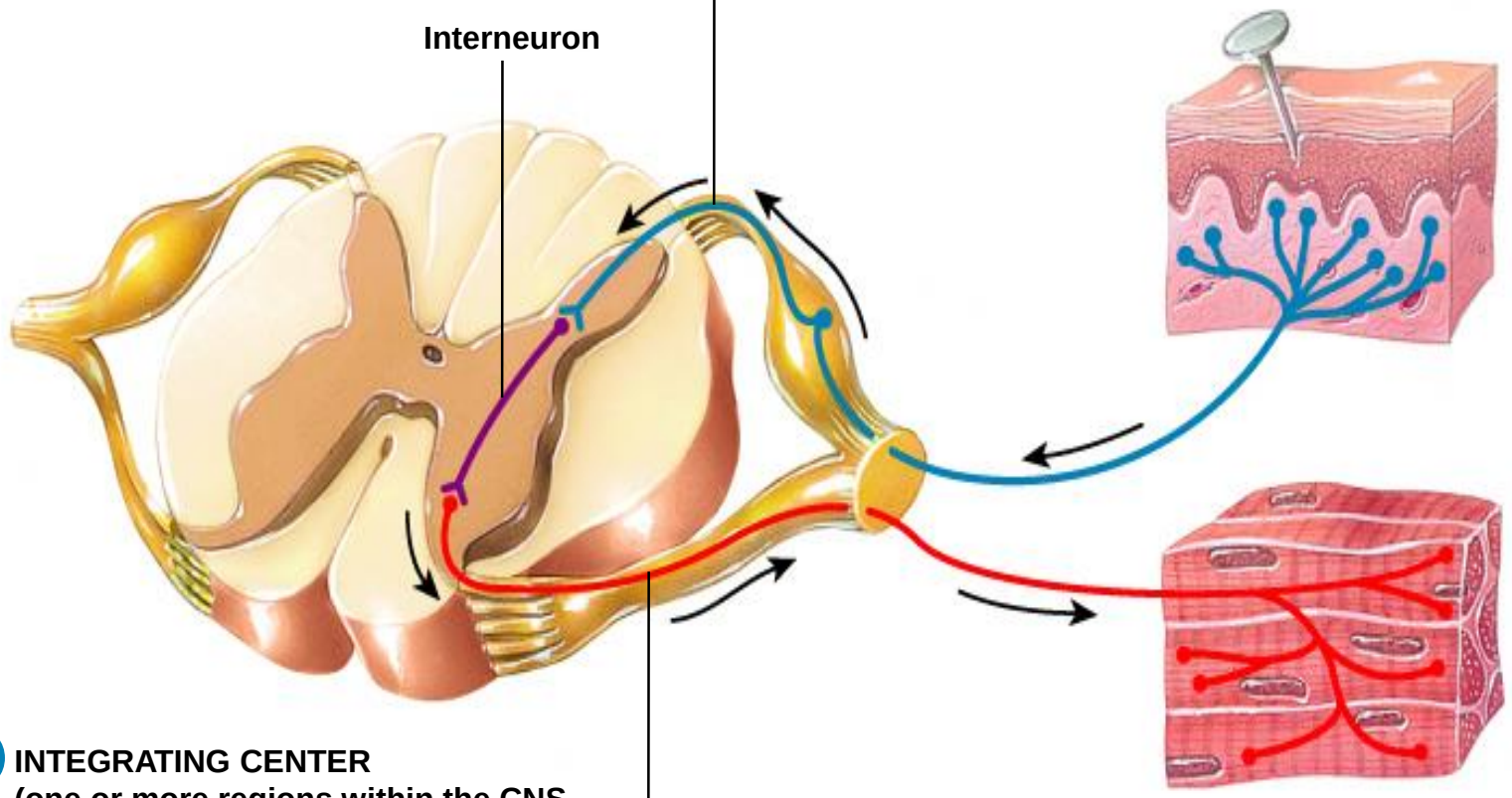
Clinical Application of the Stretch Reflex

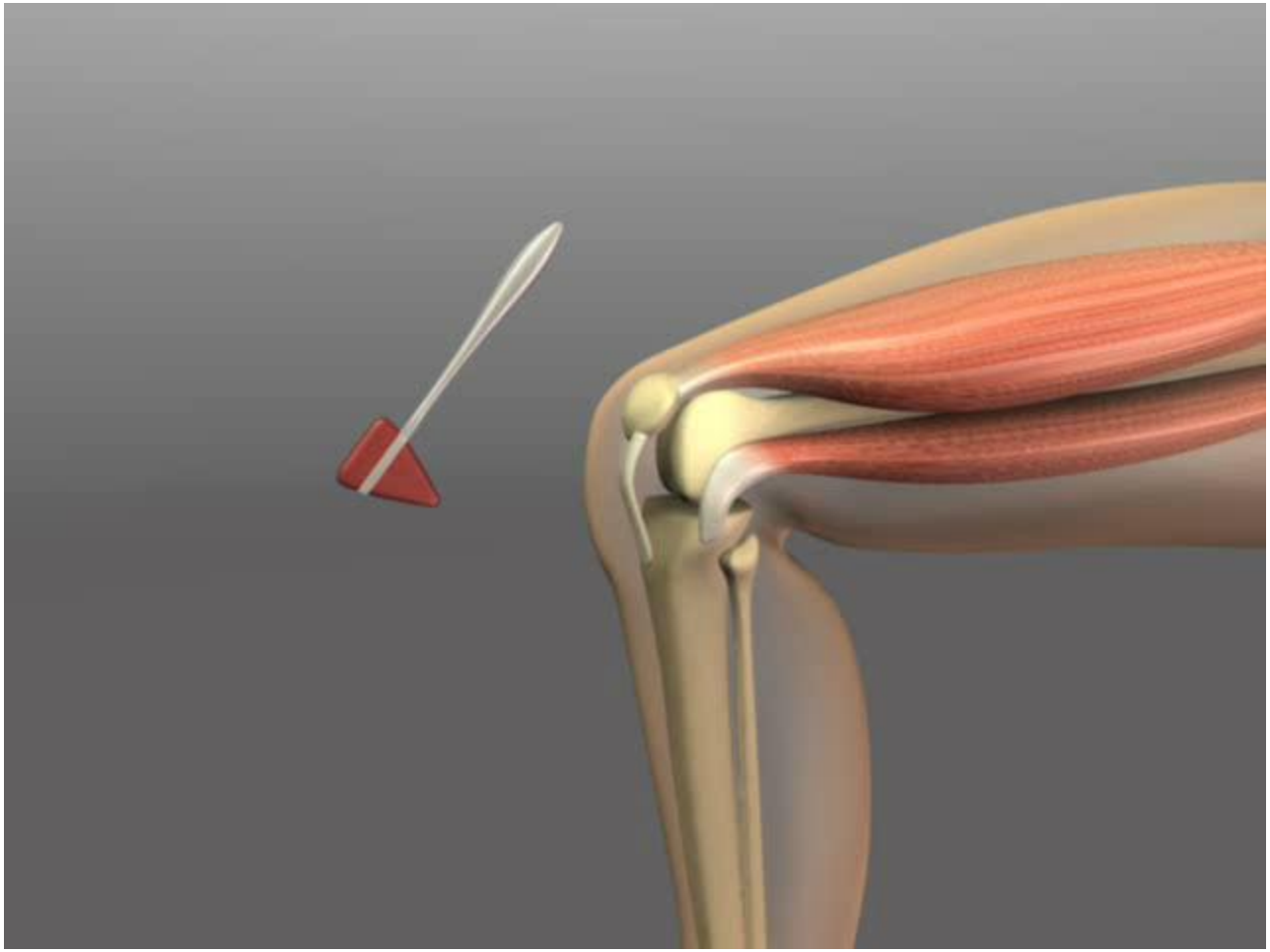
- Knee jerk reflex
  - striking the patellar tendon with a hammer stretches the quadriceps muscle.
  - this initiates a stretch reflex which shortens the muscle and causes the knee to move forward.
- Can be done with almost any muscle.
- Index of the facilitation of the gamma efferents.
- Cortical lesions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

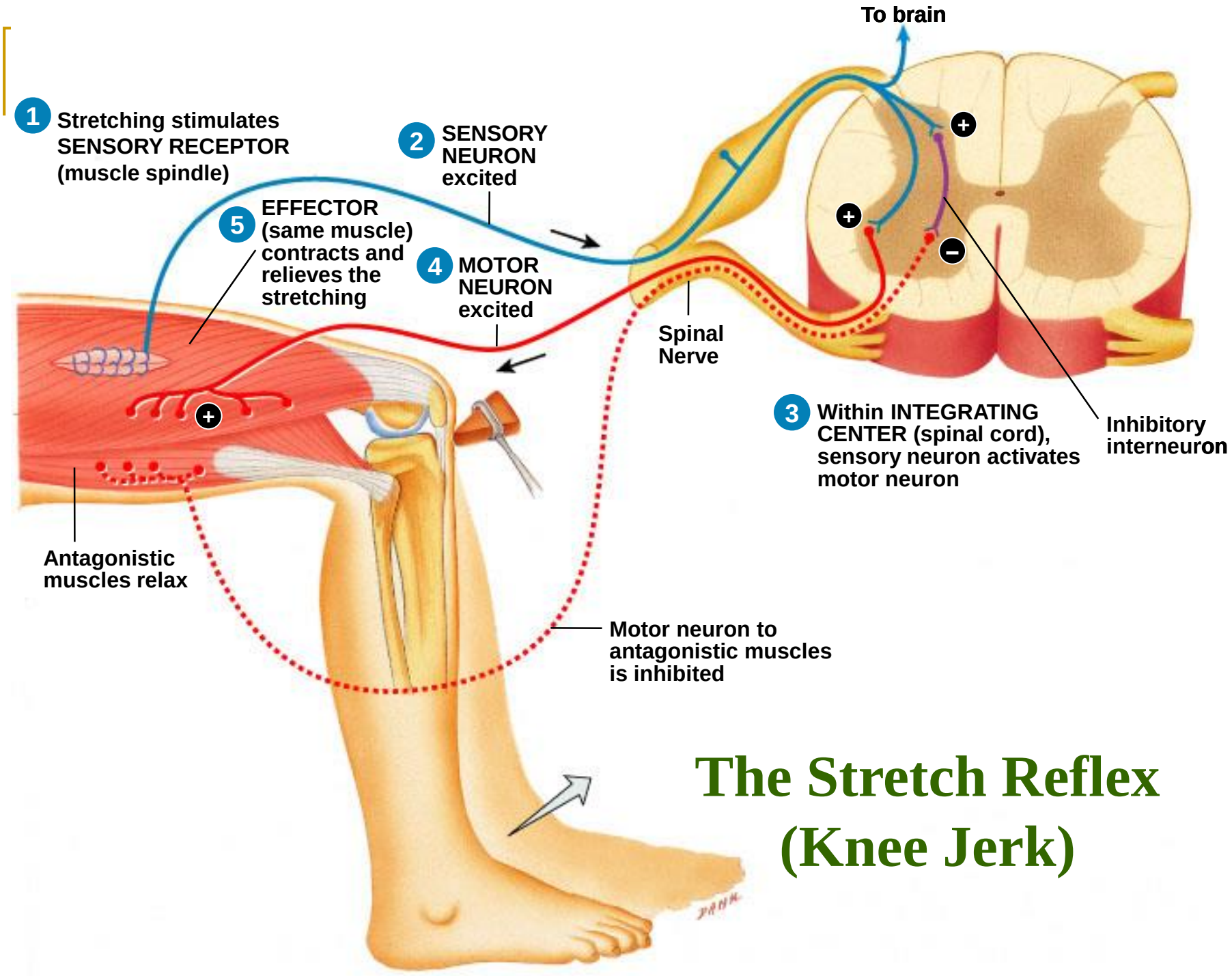
Reflex Arc


2 SENSORY NEURON
(axon conducts impulses from receptor to integrating center)
1 SENSORY RECEPTOR
(responds to a stimulus by producing a generator or receptor potential)
Interneuron
3 INTEGRATING CENTER
(one or more regions within the CNS that relay impulses from sensory to motor neurons)
4 MOTOR NEURON
(axon conducts impulses from integrating center to effector)
5 EFFECTOR
(muscle or gland that responds to motor nerve impulses)

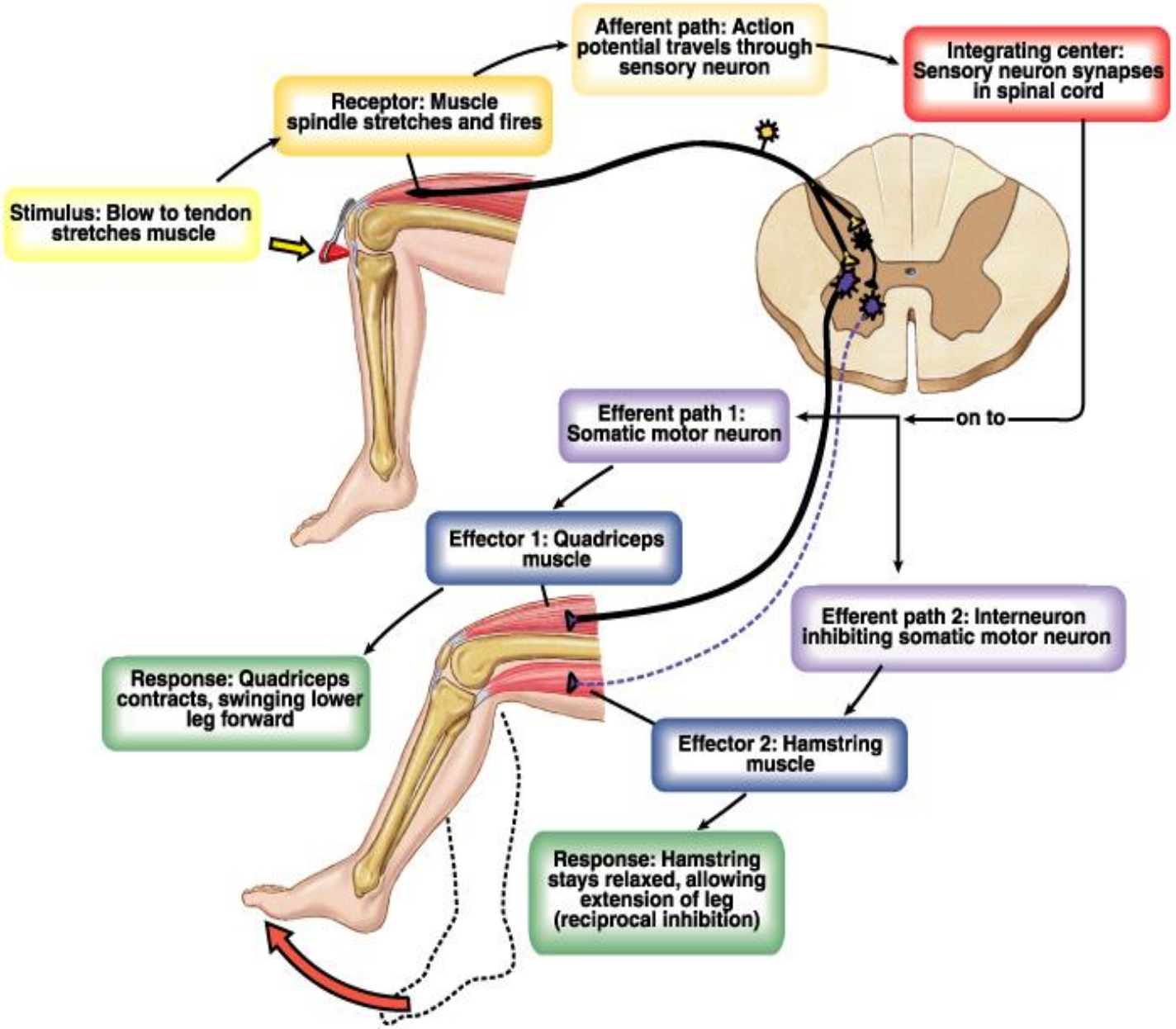
Reflex Arc


2 SENSORY NEURON
(axon conducts impulses from receptor to integrating center)
1 SENSORY RECEPTOR
(responds to a stimulus by producing a generator or receptor potential)
Interneuron
3 INTEGRATING CENTER
(one or more regions within the CNS that relay impulses from sensory to motor neurons)
4 MOTOR NEURON
(axon conducts impulses from integrating center to effector)
5 EFFECTOR
(muscle or gland that responds to motor nerve impulses)



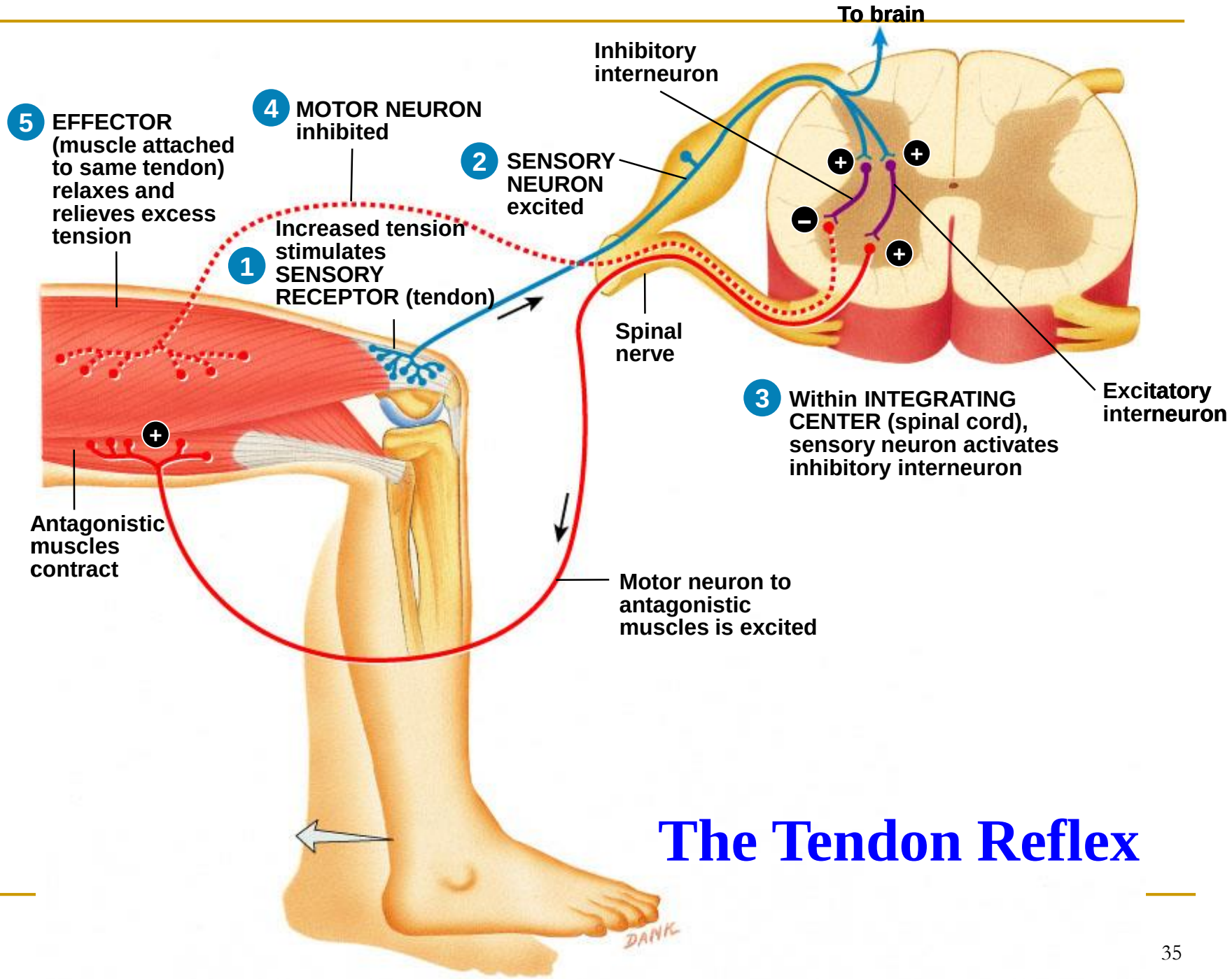


The Stretch Reflex (Knee Jerk)


Afferent path: Action potential travels through sensory neuron
Integrating center: Sensory neuron synapses in spinal cord
Receptor: Muscle spindle stretches and fires
Stimulus: Blow to tendon stretches muscle
Efferent path 1: Somatic motor neuron
on to
Effector 1: Quadriceps muscle
Efferent path 2: Interneuron inhibiting somatic motor neuron
Response: Quadriceps contracts, swinging lower leg forward
Effector 2: Hamstring muscle
Response: Hamstring stays relaxed, allowing extension of leg (reciprocal inhibition)

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)

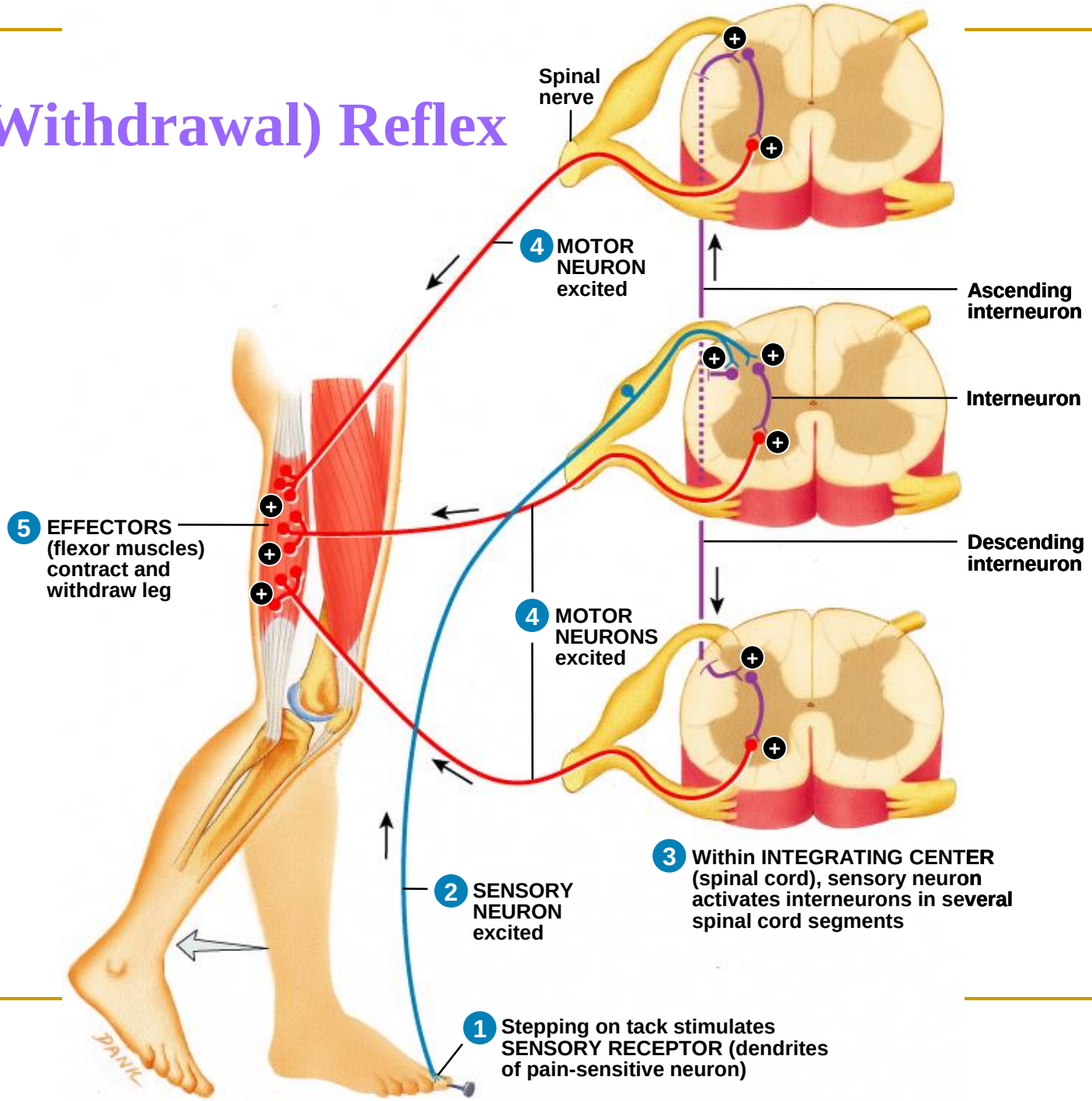


The Tendon Reflex

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)

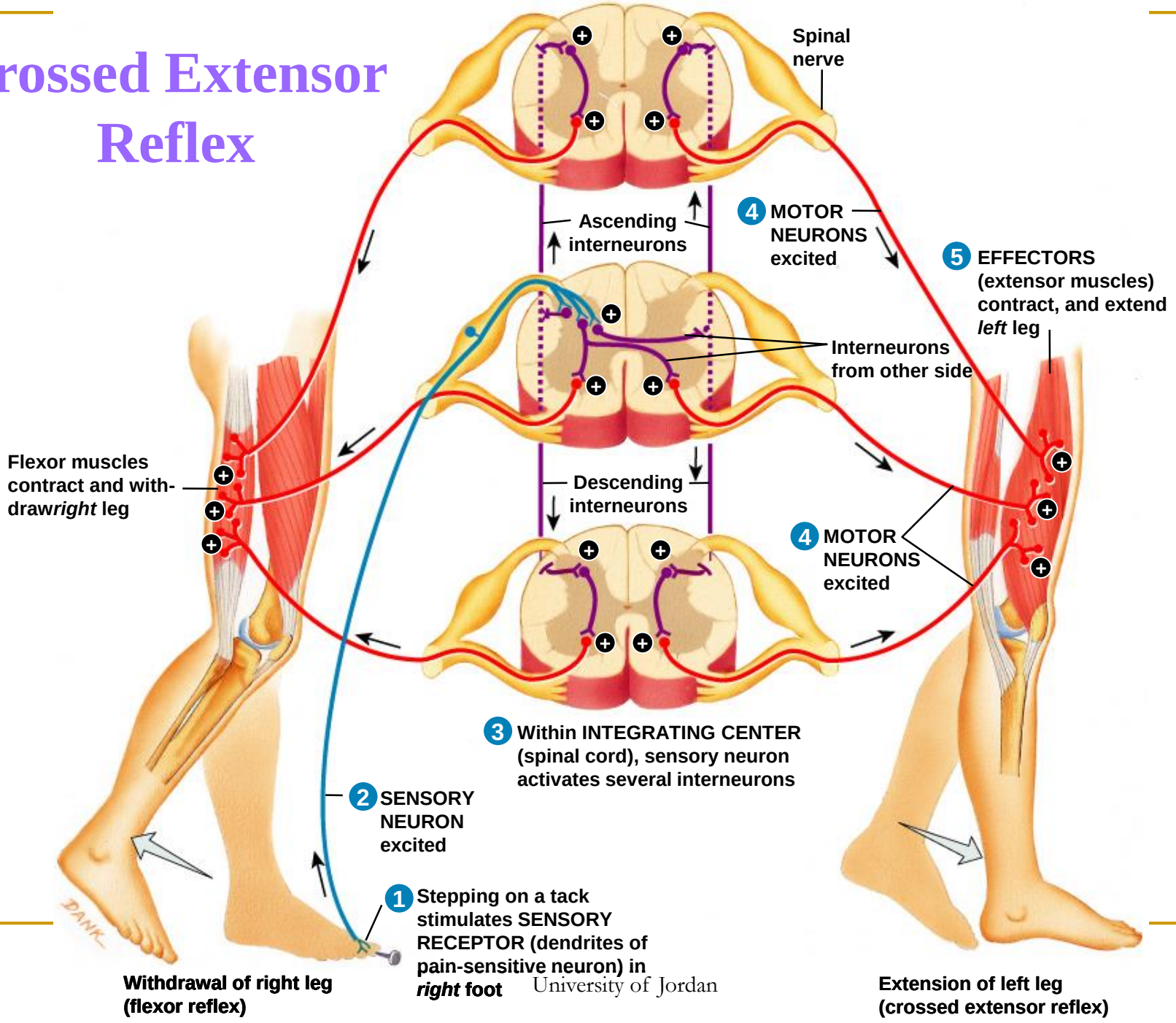
Flexor (Withdrawal) Reflex

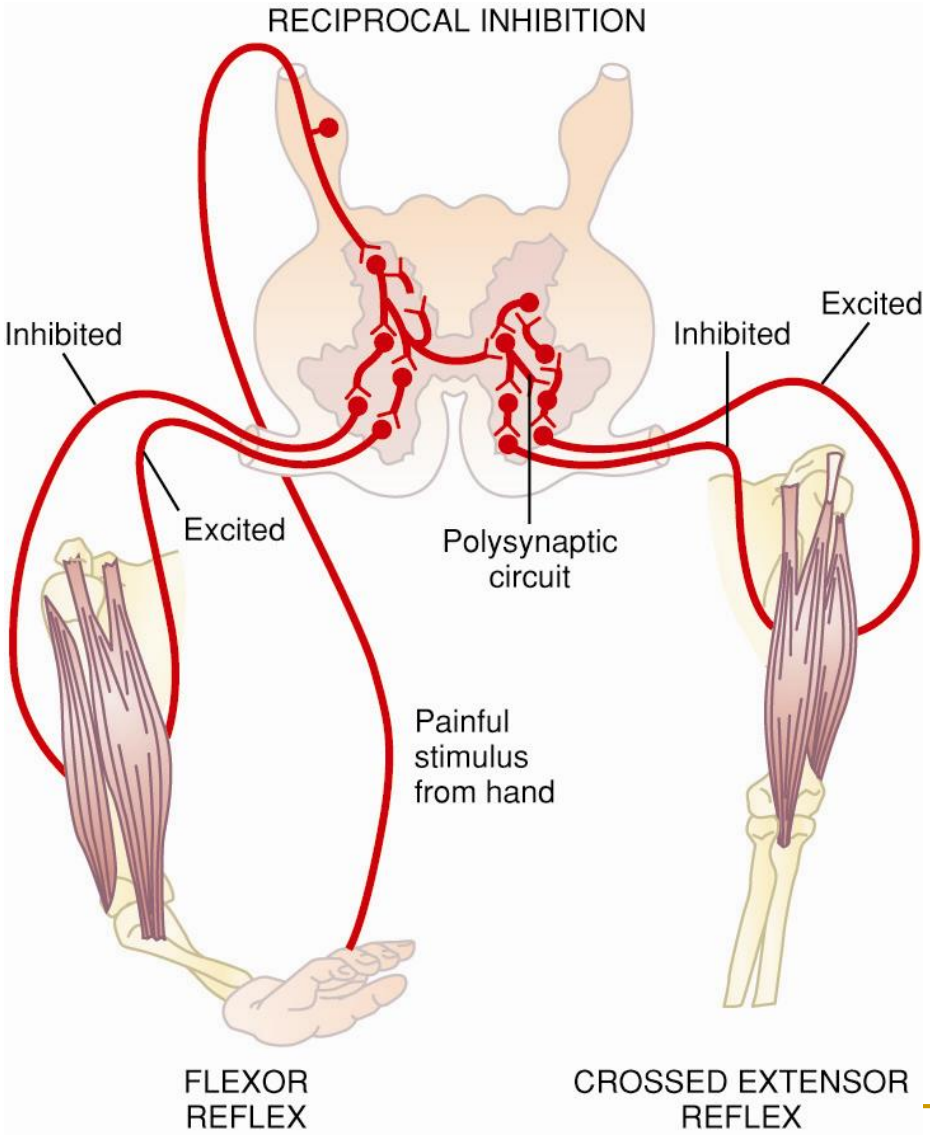


Flexor (Withdrawal) Reflex

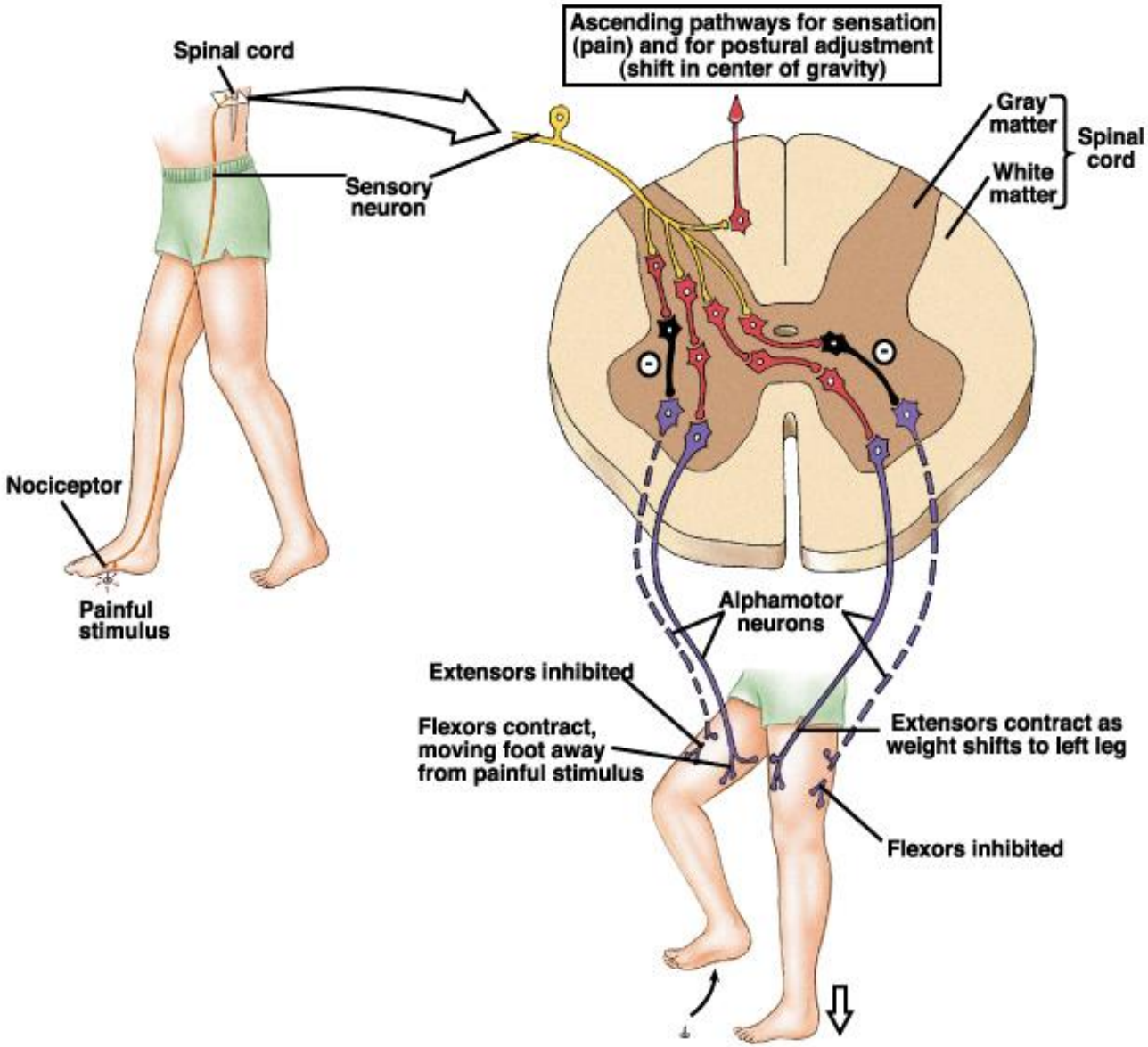
- Polysynaptic reflex
- Ipsilateral.
- Stepping on a tack (stimulus) → nerve impulse → activation of the interneuron → activation of the motor neuron →muscle contraction →withdrawal of the leg (excitatory reflex)
- There is reciprocal inhibition (i.e inhibition of antagonist group of muscles on the same side)

Crossed Extensor Reflex





Neuronal Circuits for Withdrawal and Crossed Extensor Reflex

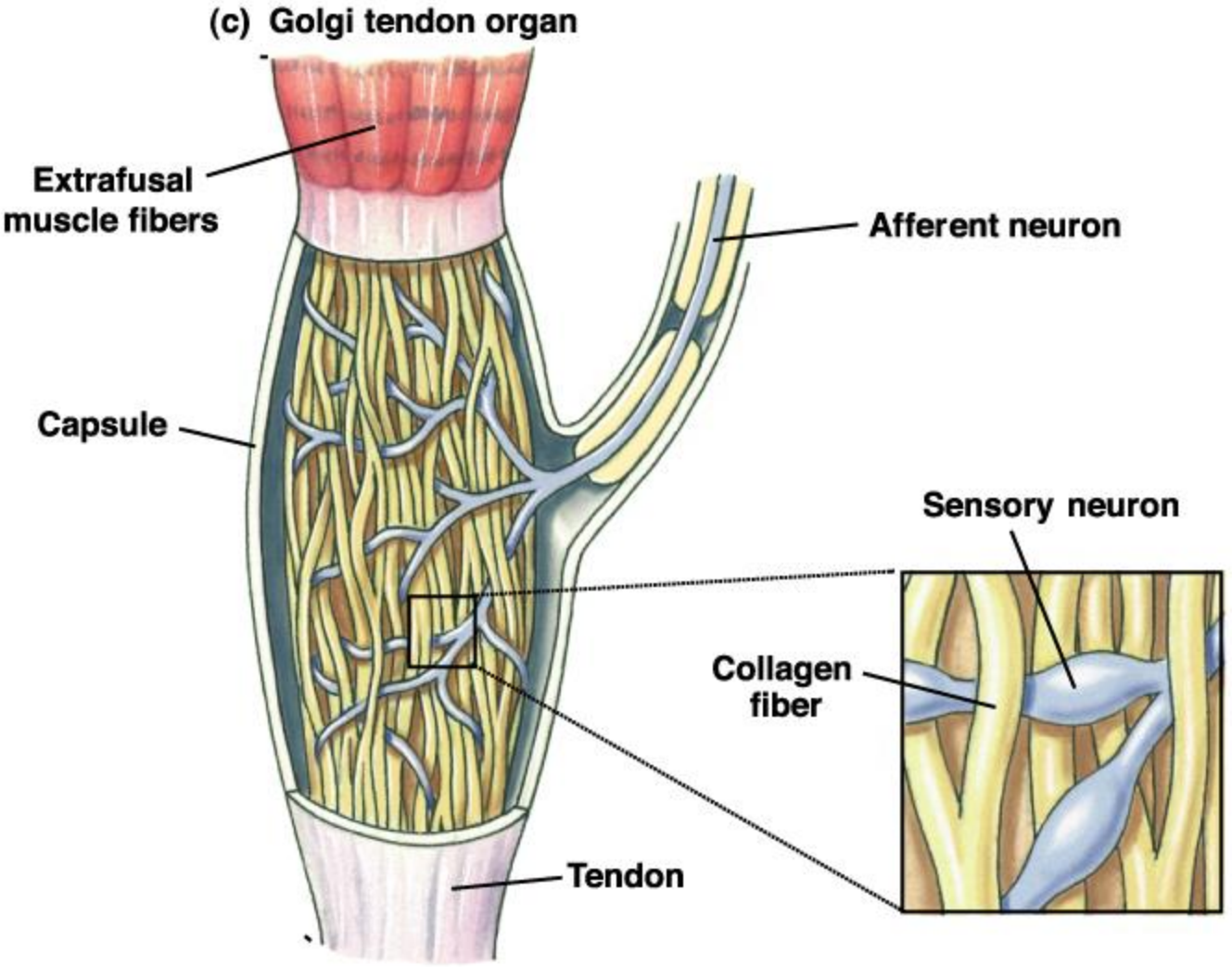

Ascending pathways for sensation (pain) and for postural adjustment (shift in center of gravity)
Spinal cord
Sensory neuron
Gray matter
White matter
Spinal cord
Nociceptor
Painful stimulus
Alphamotor neurons
Extensors inhibited
Flexors contract, moving foot away from painful stimulus
Extensors contract as weight shifts to left leg
Flexors inhibited

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)

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.


(c) Golgi tendon organ
Extrafusal muscle fibers
Afferent neuron
Capsule
Sensory neuron
Collagen fiber
Tendon

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

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.

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, of overactivity
  - reflex contraction increases painful stimulus and causes more muscle contraction

Myograms of flexor and crossed extensor reflexes

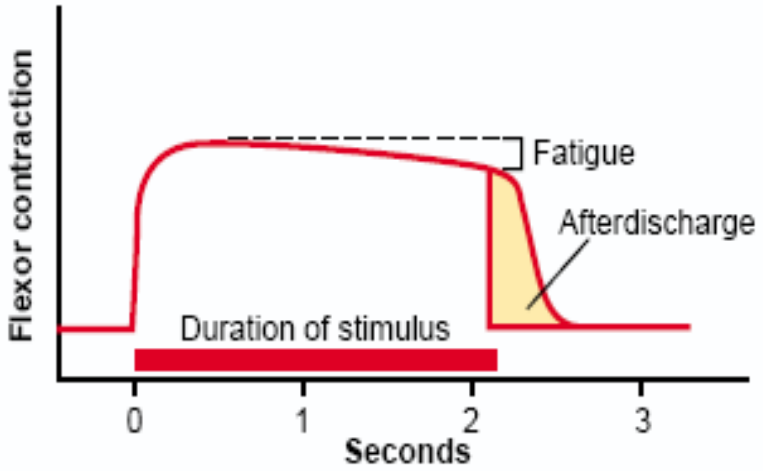


Figure 54–9

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

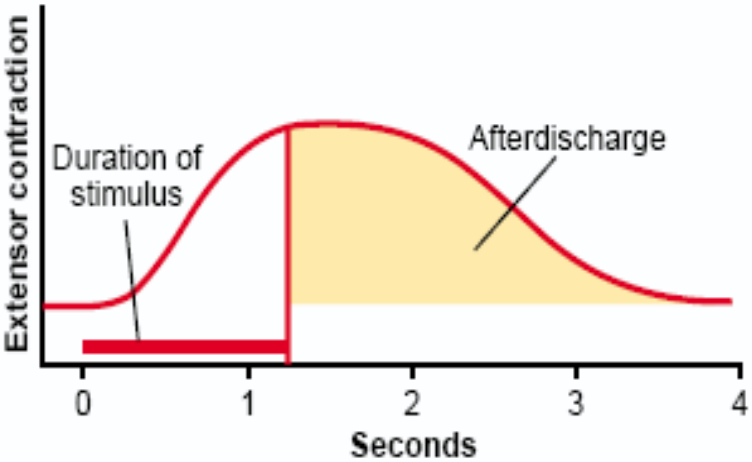


Figure 54–10

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

Thank You