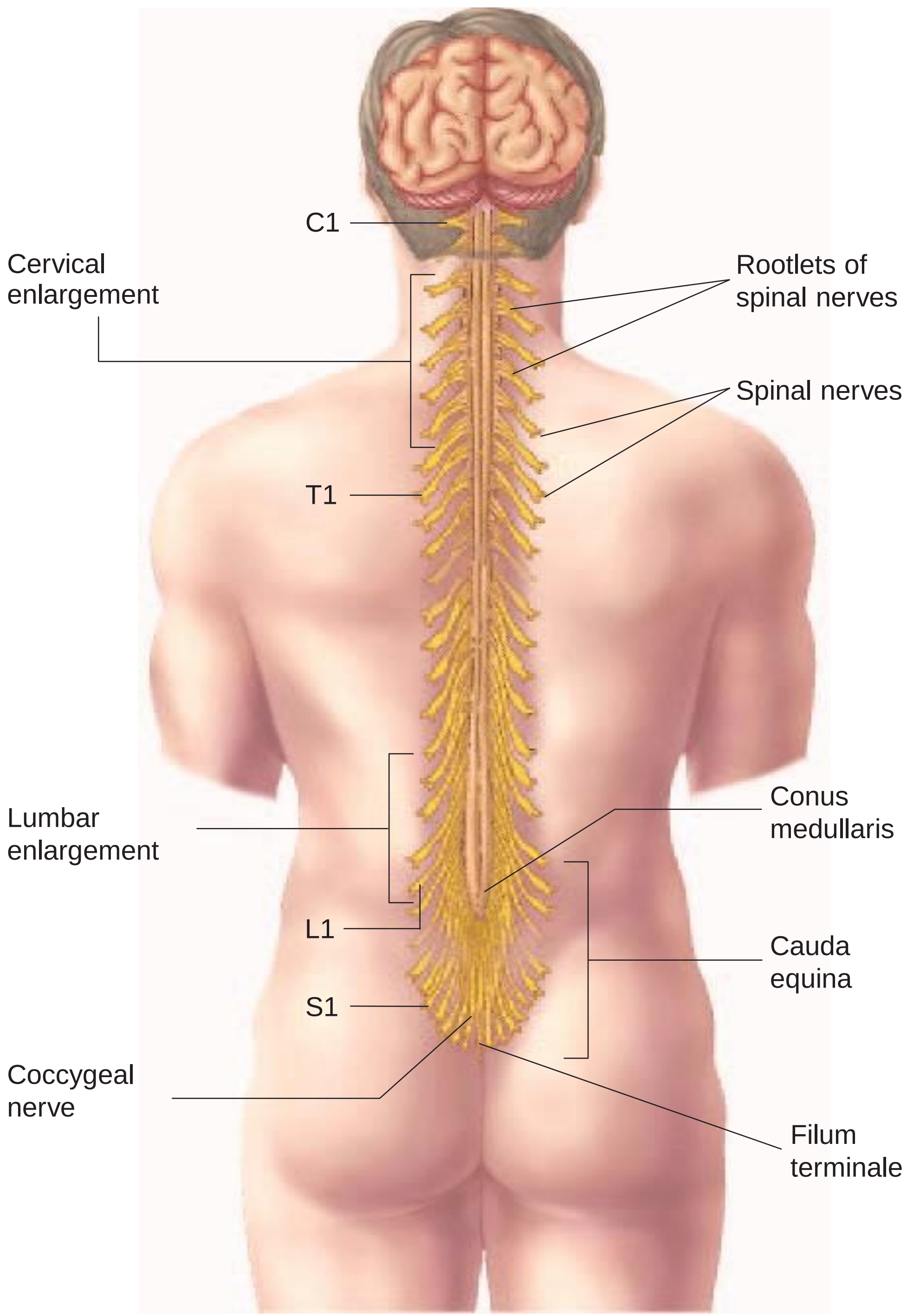
SPINAL CORD AND SPINAL REFLEXES

SPINAL CORD

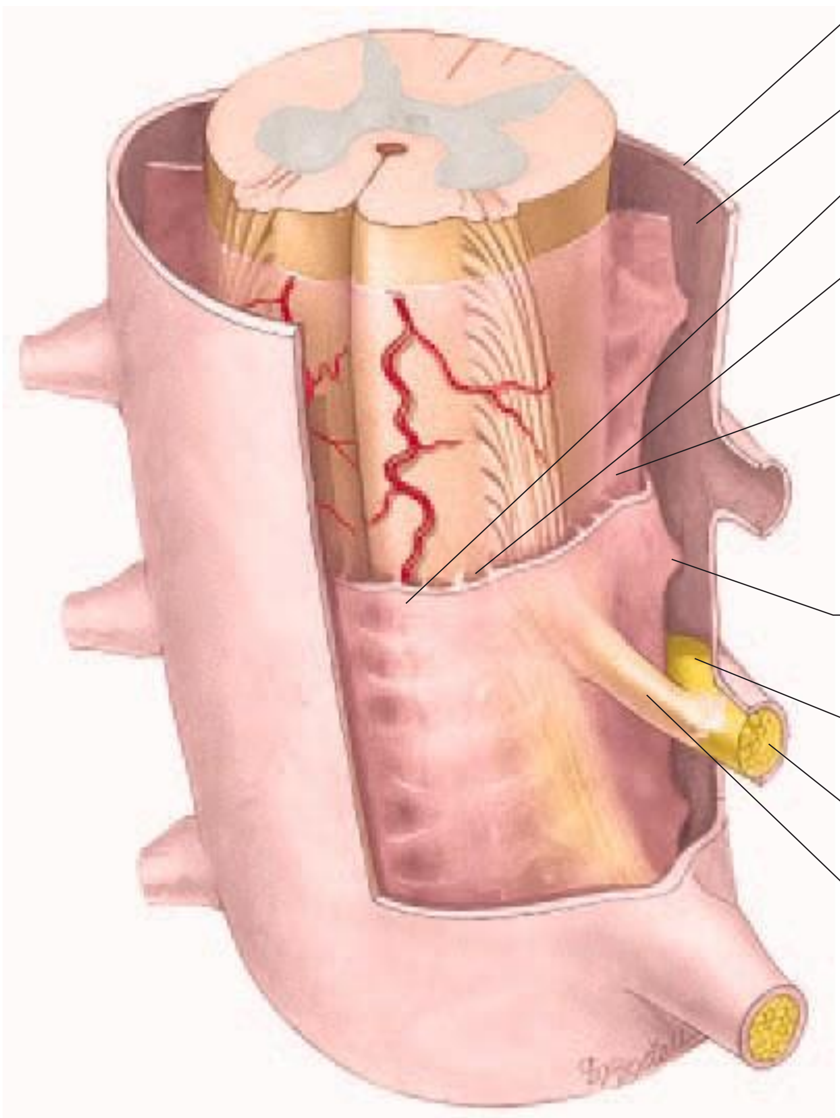
The spinal cord is extremely important to the overall function of the nervous system. It is the communication link between the brain and the peripheral nervous system inferior to the head; it integrates incoming information and produces responses through reflex mechanisms.

GENERAL STRUCTURE



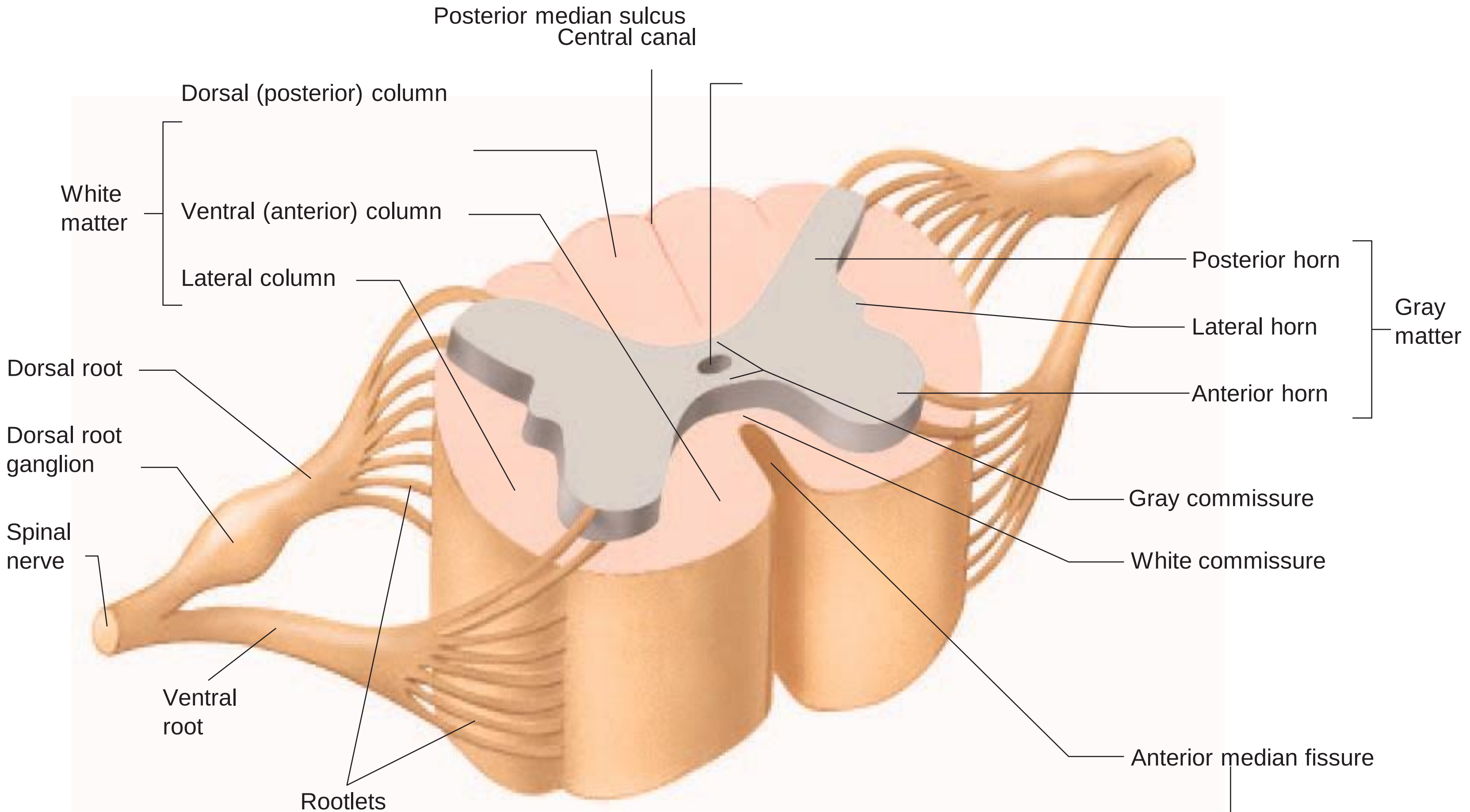
- The spinal cord is composed of cervical, thoracic, lumbar, and sacral segments, named according to the portion of the vertebral column from which their nerves enter and exit. The spinal cord gives rise to 31 pairs of spinal nerves, which exit the vertebral column through the intervertebral foramina. The nerves from the lower segments descend some distance in the vertebral canal before they exit.
- The spinal cord is not uniform in diameter throughout its length. It's larger in diameter at its superior end, and it gradually decreases in diameter toward its inferior end. Two enlargements occur where nerves supplying the upper and lower limbs enter and leave the cord. The cervical enlargement in the inferior cervical region corresponds to the location where axons that supply the upper limbs enter and leave the cord. The lumbar enlargement in the inferior thoracic and superior lumbar regions is the site where the axons supplying the lower limbs enter or leave the cord.
- The nerves supplying the lower limbs and other inferior structures of the body arise from the second lumbar to the fifth sacral nerves. They exit the lumbar enlargement, course inferiorly through the vertebral canal, and exit through the intervertebral foramina from the second lumbar to the fifth sacral vertebrae.

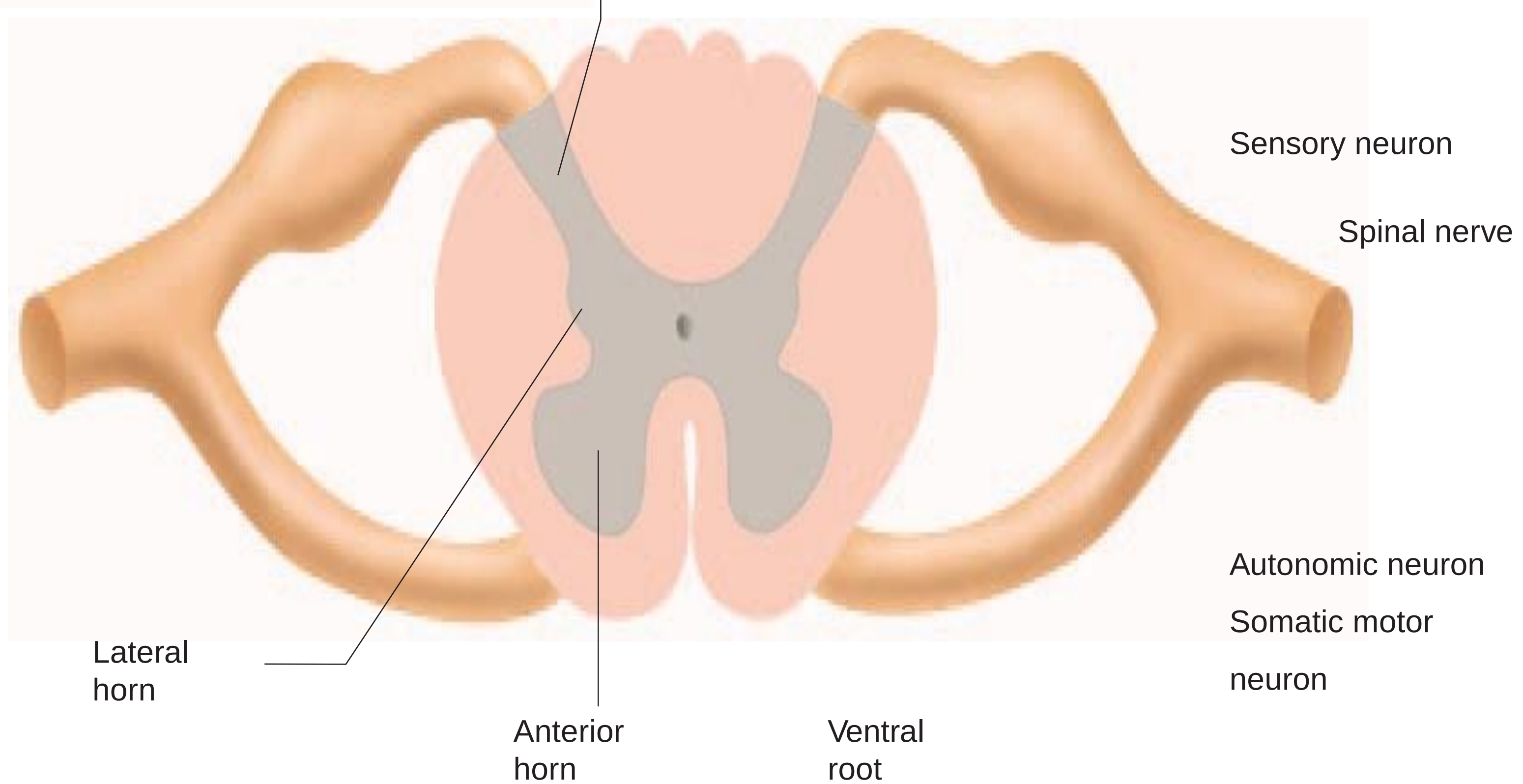
MENINGEAL MEMBRANES SURROUNDING THE SPINAL CORD



- The spinal cord and brain are surrounded by connective tissue membranes called meninges. The most superficial and thickest membrane is the dura mater. The dura mater surrounds the spinal cord and is continuous with the epineurium of the spinal nerves. The dura mater around the spinal cord is separated from the periosteum of the vertebral canal by the epidural space. This is a true space around the spinal cord that contains blood vessels, areolar connective tissue, and fat. Epidural anesthesia of the spinal nerves is induced by injecting anesthetics into this space.
- The next meningeal membrane is a very thin, wispy arachnoid mater. The space between this membrane and the dura mater is the subdural space and contains only a very small amount of serous fluid.
- The third meningeal layer, the pia mater is bound very tightly to the surface of the brain and spinal cord.

CROSS SECTION OF THE SPINAL CORD

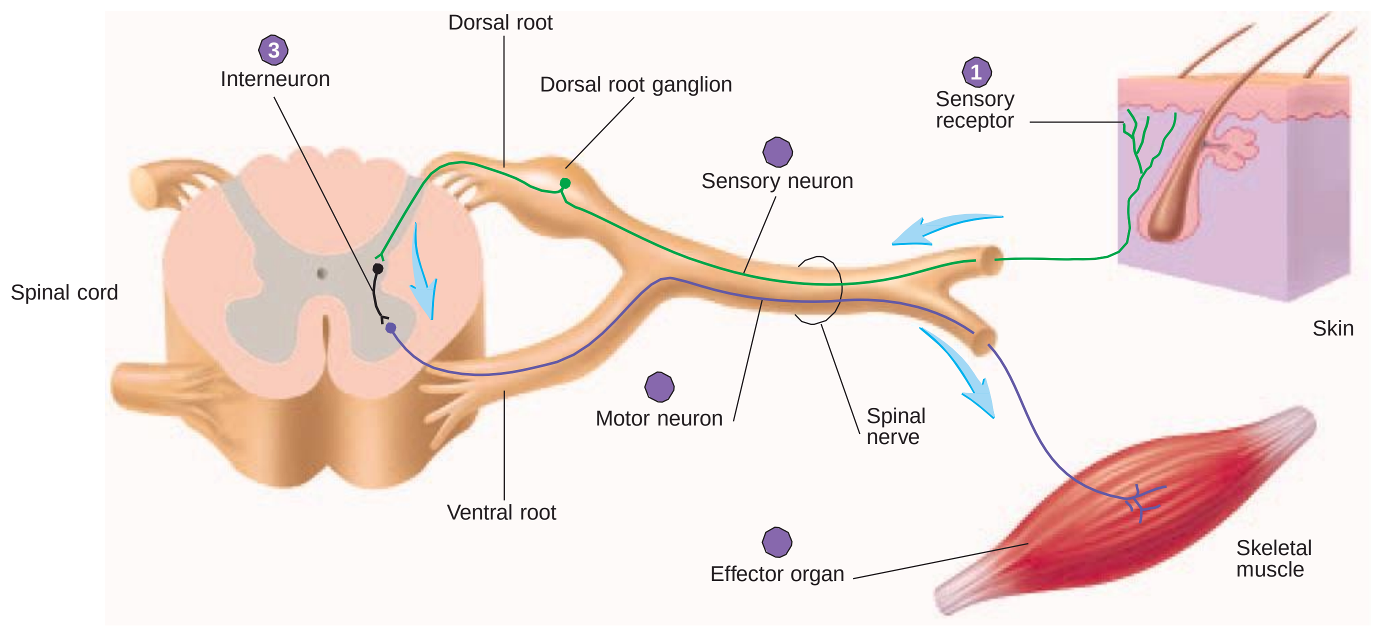




STRUCTURE OF THE SPINAL CORD

- A cross section of the spinal cord reveals that the cord consists of a peripheral white portion and a central gray portion. The white matter consists of myelinated axons forming nerve tracts, and the gray matter consists of neuron cell bodies, dendrites, and axons.
- The white matter in each half of the spinal cord is organized into three columns, or funiculi, called the ventral (anterior), dorsal (posterior), and lateral columns. Each column is subdivided into nerve tracts or fasciculi; also referred to as pathways. Individual axons ascending to the brain or descending from the brain are usually grouped together within the nerve tracts. Axons within a given nerve tract carry basically the same type of information, although they may overlap to some extent. For example, one ascending nerve tract carries action potentials related to pain and temperature sensations, whereas another functions to carry action potentials related to light touch.
- The central gray matter is organized into horns. Each half of the central gray matter of the spinal cord consists of a relatively thin posterior (dorsal) horn and a larger anterior (ventral) horn. Small lateral horns exist in levels of the cord associated with the autonomic nervous system.
- The two halves of the spinal cord are connected by gray and white commissures. The white and gray commissures contain axons that cross from one side of the spinal cord to the other.
- Spinal nerves arise from numerous rootlets along the dorsal and ventral surfaces of the spinal cord. About six to eight of these rootlets combine to form each ventral root on the ventral side of the spinal cord, and another six to eight form each dorsal root on the dorsal side of the cord at each segment.
- The ventral and dorsal roots join one another just lateral to the spinal cord to form a spinal nerve. Each dorsal root contains a ganglion, called the dorsal root, or spinal, ganglion.

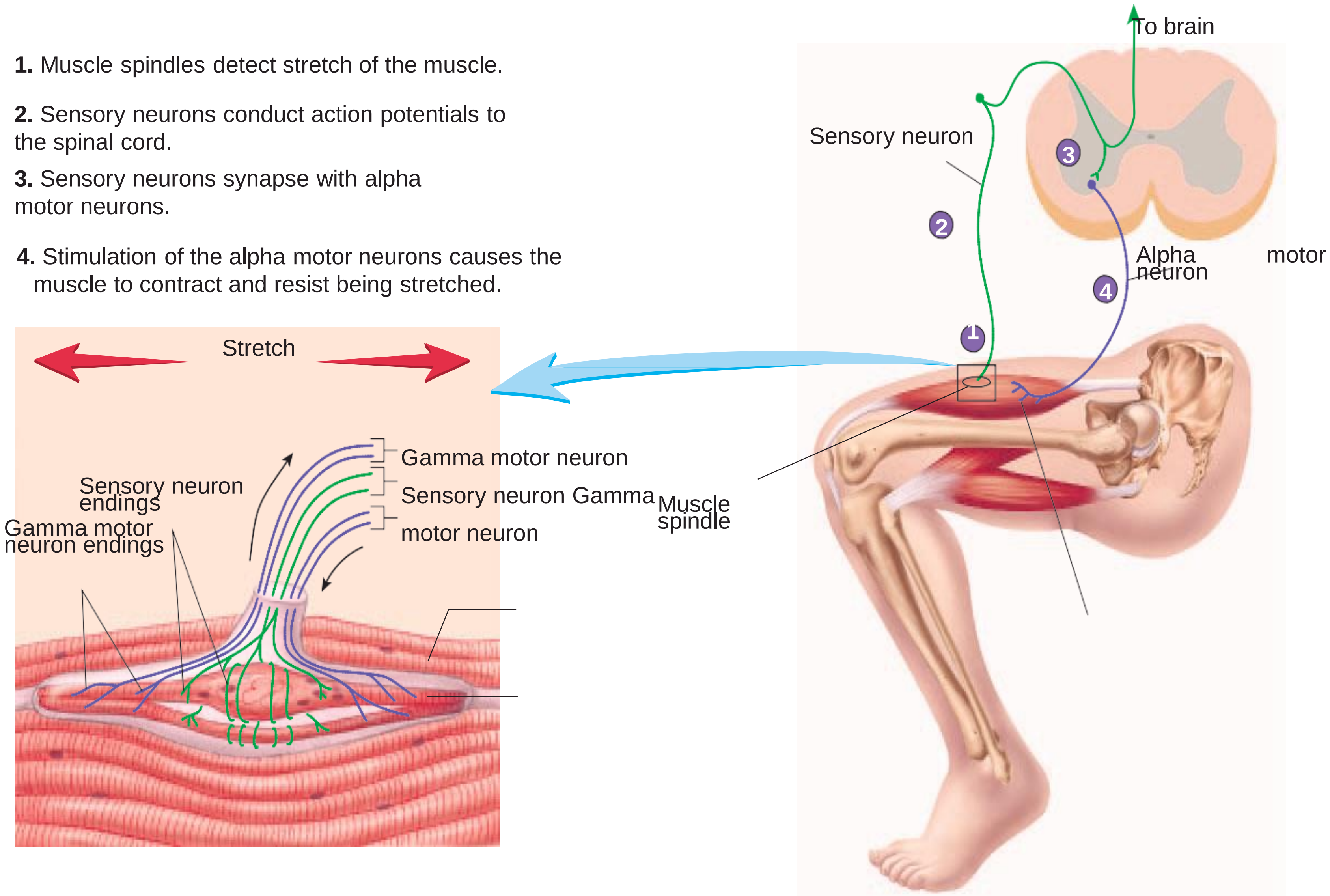
SPINAL REFLEXES



List the components and characteristics of a reflex.
The basic structural unit of the nervous system is the neuron. The reflex arc is the basic functional unit of the nervous system and is the smallest, simplest portion capable of receiving a stimulus and producing a response. The reflex arc has five basic components:
(1) a sensory receptor, (2) a sensory neuron, (3) an interneuron, (4) a motor neuron, and (5) an effector organ.

- Action potentials initiated in sensory receptors are transmitted along the axons of sensory neurons to the CNS, where the axons usually synapse with interneurons. Interneurons synapse with motor neurons, which send axons out of the spinal cord and through the PNS to muscles or glands, where the action potentials of the motor neurons cause effector organs to respond. The response produced by the reflex arc is called a reflex. It's an automatic response to a stimulus that occurs without conscious thought.
- Reflexes are, in general, homeostatic. Some function to remove the body from painful stimuli that would cause tissue damage, and others function to keep the body from suddenly falling or moving because of external forces. A number of reflexes are responsible for maintaining relatively constant blood pressure, blood carbon dioxide levels, and water intake.
- Individual reflexes vary in their complexity. Some involve simple neuronal pathways and few or even no interneurons, whereas others involve complex pathways and integrative centers. Many are integrated within the spinal cord, and others are integrated within the brain. Some reflexes involve excitatory neurons and result in a response, such as when a muscle contracts. Other reflexes involve inhibitory neurons and result in inhibition of a response, such as when a muscle relaxes. In addition, higher brain centers influence reflexes by either suppressing or exaggerating them. Major spinal cord reflexes include the stretch reflex, the **Golgi tendon reflex**, the **withdrawal reflex**, and the **crossed extensor reflex**.

STRETCH REFLEX



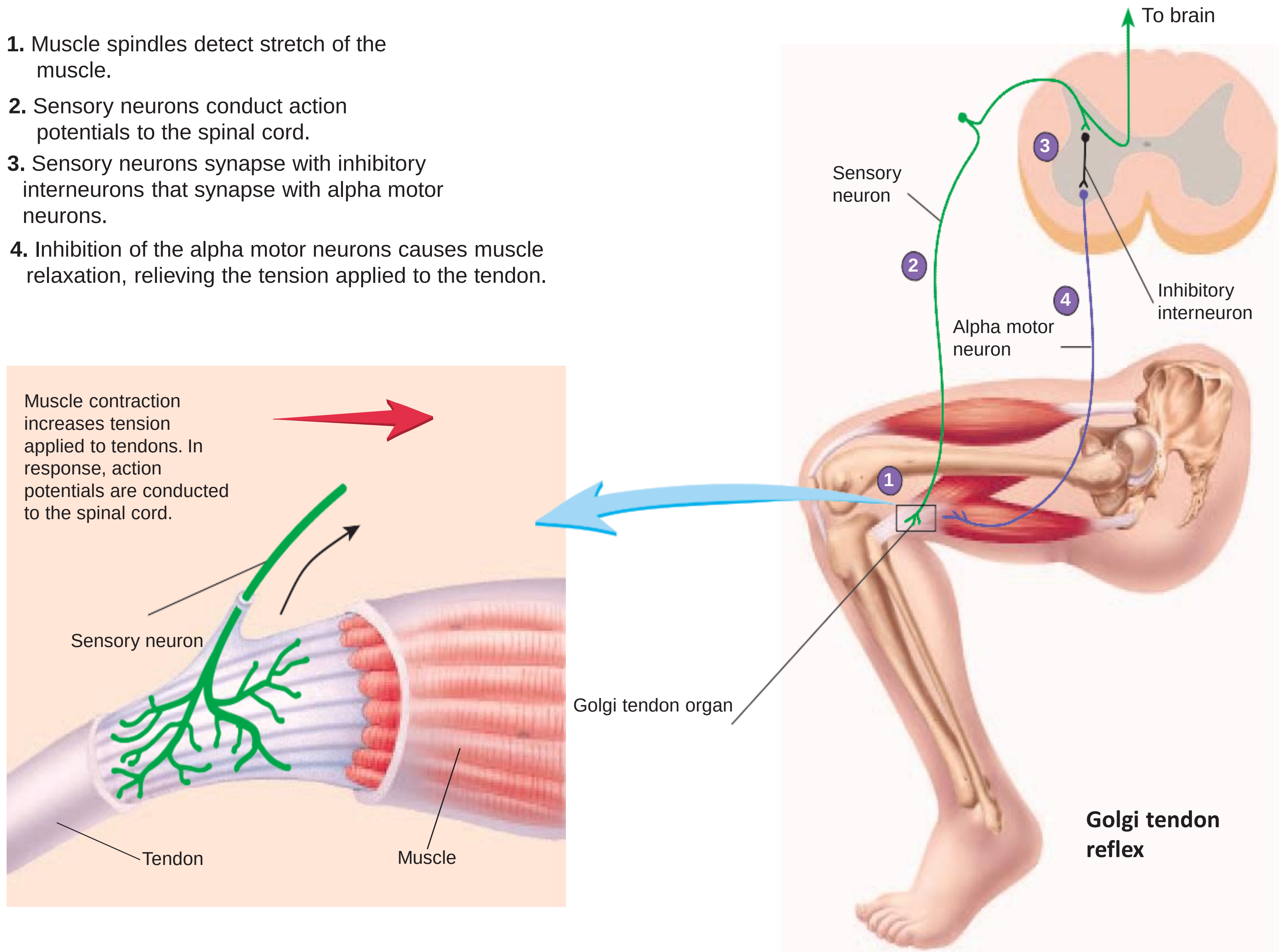
- The simplest reflex is the stretch reflex, a reflex in which muscles contract in response to a stretching force applied to them.
- The sensory receptor of this reflex is the muscle spindle, which consists of 3 to 10 small, specialized skeletal muscle cells. The cells are contractile only at their ends and are innervated by specific motor neurons called gamma motor neurons.
- The gamma motor neurons are small diameter axons originating from the spinal cord and controlling contraction of the ends of the muscle spindle cells.

- Sensory neurons innervate the noncontractile centers of the muscle spindle cells. Axons of these sensory neurons synapse directly with motor neurons in the spinal cord called alpha motor neurons (the term alpha refers to motor neurons with large diameter axons), which in turn innervate the muscle in which the muscle spindle is embedded. The stretch reflex is unique because there is no interneuron between the sensory and motor neurons.
- Stretching a muscle also stretches muscle spindles located among the muscle fibers. The stretch stimulates the sensory neurons that innervate the center of each of the muscle spindles. The increased frequency of action potentials in the sensory neurons stimulates the alpha motor neurons in the spinal cord. The alpha motor neurons transmit action potentials to skeletal muscle, causing a rapid contraction of the stretched muscle, which opposes the stretch of the muscle.
- The postural muscles demonstrate the adaptive nature of this reflex. If a person is standing upright and then bends slightly to one side, the postural muscles associated with the vertebral column on the other side are stretched. As a result, stretch reflexes are initiated in those muscles, which cause them to con- tract and reestablish normal posture.

Knee-Jerk Reflex

The knee-jerk reflex, or patellar reflex, is a classic example of the stretch reflex. Clinicians use this reflex to determine whether the higher CNS centers that normally influence this reflex are functional. When the patellar ligament is tapped, the tendons and muscles of the quadriceps femoris muscle group are stretched. The muscle spindle fibers within these muscles are also stretched, and the stretch reflex is activated. Consequently, contraction of the muscles extends the leg, thus producing the characteristic knee-jerk response. When the stretch reflex is greatly exaggerated, it indicates that the neurons within the brain that innervate the gamma motor neurons and enhance the stretch reflex are overly active. On the other hand, if the neurons that innervate the gamma motor neurons are depressed, the stretch reflex can be suppressed or absent. Absence of the stretch reflex may indicate that the reflex pathway is not intact.

GOLGI TENDON REFLEX



- The Golgi tendon reflex prevents contracting muscles from applying excessive tension to tendons.
- Golgi tendon organs are encapsulated nerve endings that have at their ends numerous terminal branches with small swellings associated with bundles of collagen fibers in tendons.
- The Golgi tendon organs are located within tendons near the muscle tendon junction. As a muscle contracts, the attached tendons are stretched, resulting in increased tension in the tendon.
- The increased tension stimulates action potentials in the sensory neurons from the Golgi tendon organs. Golgi tendon organs have a high threshold and are sensitive only to intense stretch.

- The sensory neurons of the Golgi tendon organs pass through the dorsal root to the spinal cord and enter the posterior gray matter, where they branch and synapse with inhibitory interneurons. The interneurons synapse with alpha motor neurons that innervate the muscle to which the Golgi tendon organ is attached.
- When a great amount of tension is applied to the tendon, the sensory neurons of the Golgi tendon organs are stimulated. The sensory neurons stimulate the interneurons to release inhibitory neurotransmitters which inhibit the alpha motor neurons of the associated muscle and causes it to relax. This reflex protects muscles and tendons from damage caused by excessive tension.
- The sudden relaxation of the muscle reduces the tension applied to the muscle and tendons. A weight lifter who suddenly drops a heavy weight after straining to lift it does so, in part, because of the effect of the Golgi tendon reflex.

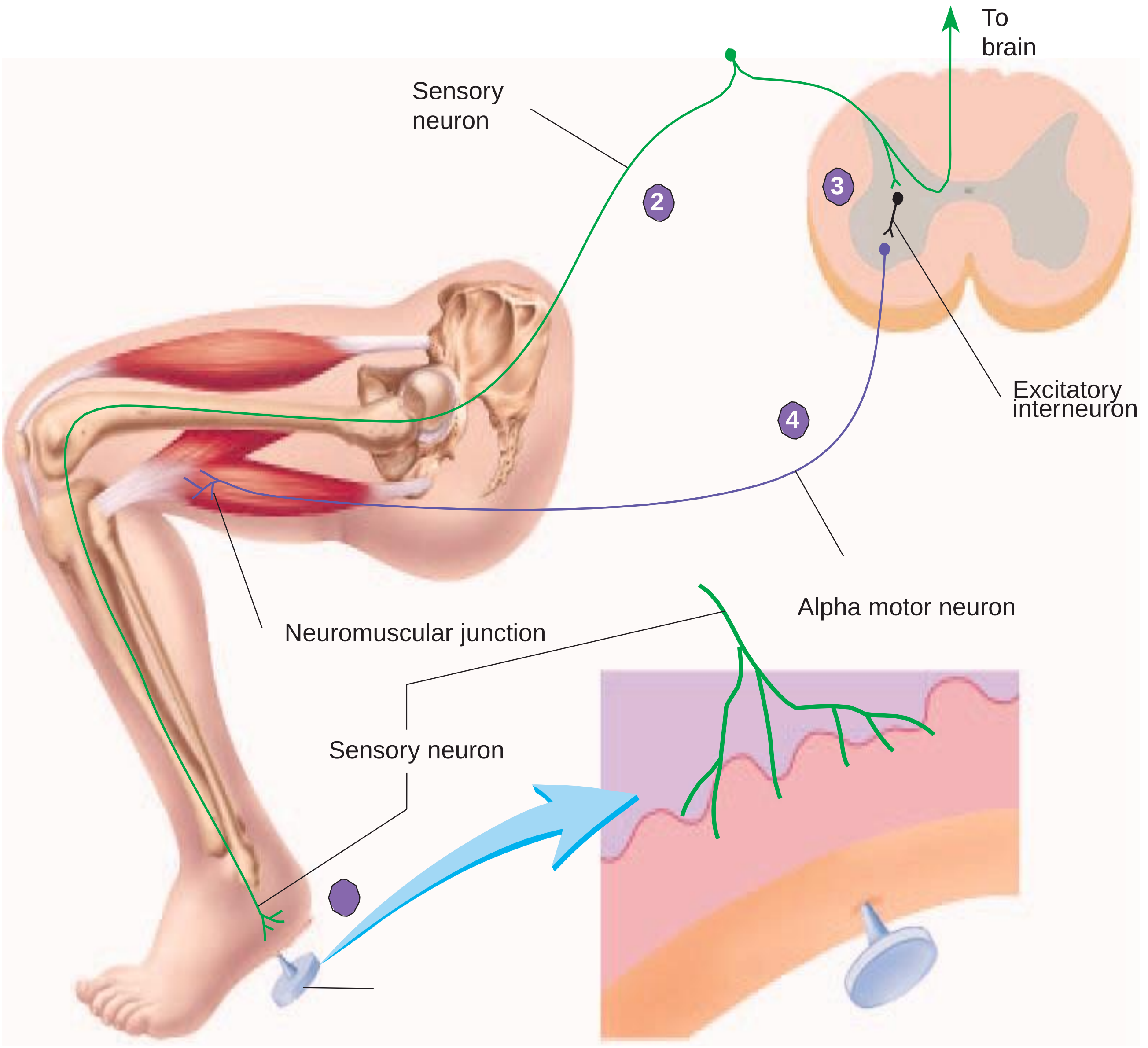
WITHDRAWAL REFLEX

1. Pain receptors detect a painful stimulus.

2. Sensory neurons conduct action potentials to the spinal cord.

3. Sensory neurons synapse with excitatory interneurons that synapse with alpha motor neurons.

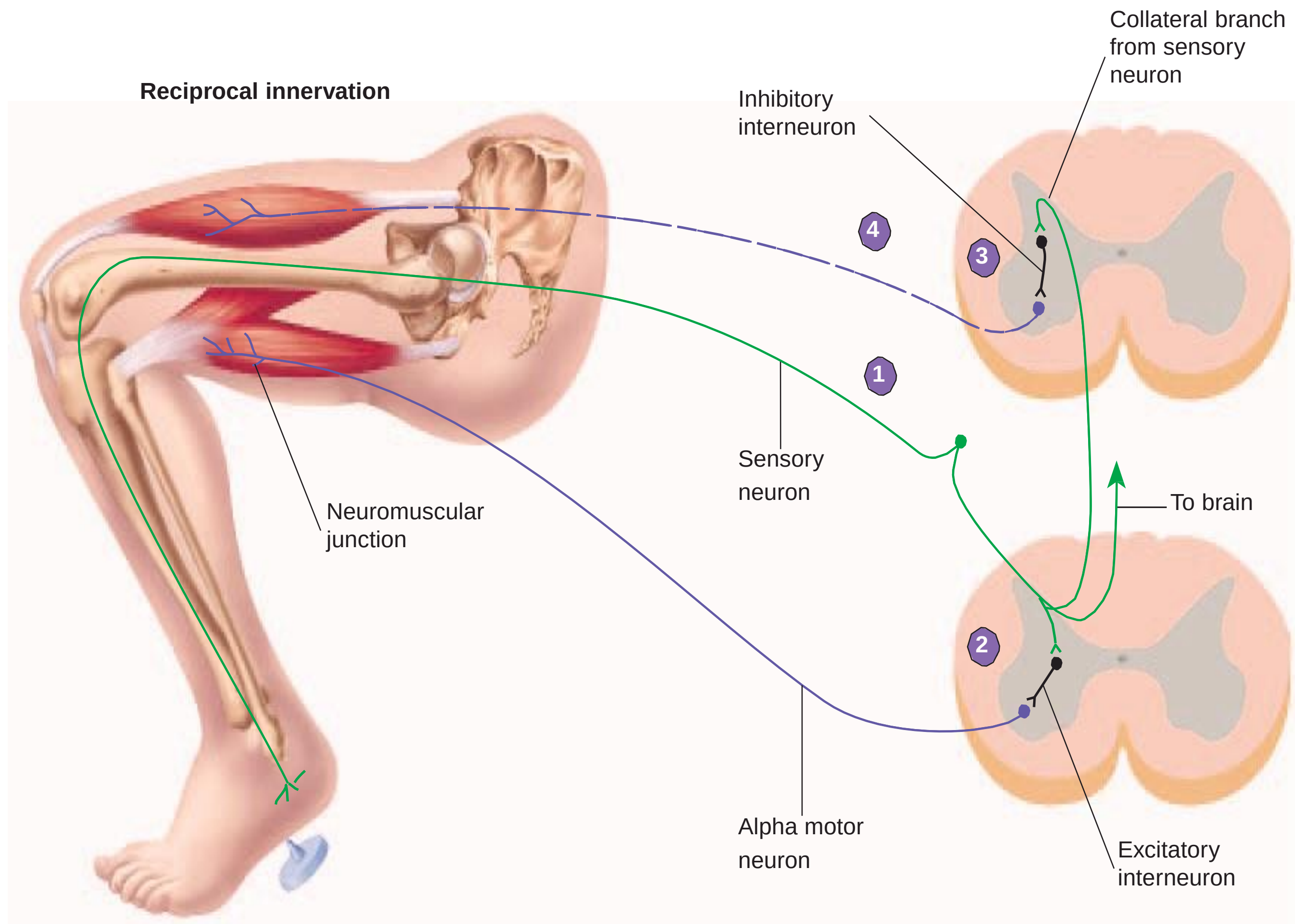
4. Excitation of the alpha motor neurons results in contraction of the flexor muscles and withdrawal of the limb from the painful stimulus.



The function of the withdrawal, or flexor, reflex is to remove a limb or other body part from a painful stimulus. The sensory receptors are pain receptors. Action potentials from painful stimuli are conducted by sensory neurons through the dorsal root to the spinal cord, where they synapse with excitatory interneurons, which in turn synapse with alpha motor neurons. The alpha motor neurons stimulate muscles, usually flexor muscles, that remove the limb from the source of the painful stimulus. Collateral branches of the sensory neurons synapse with ascending fibers to the brain, providing conscious awareness of the painful stimuli.

RECIPROCAL INNERVATION

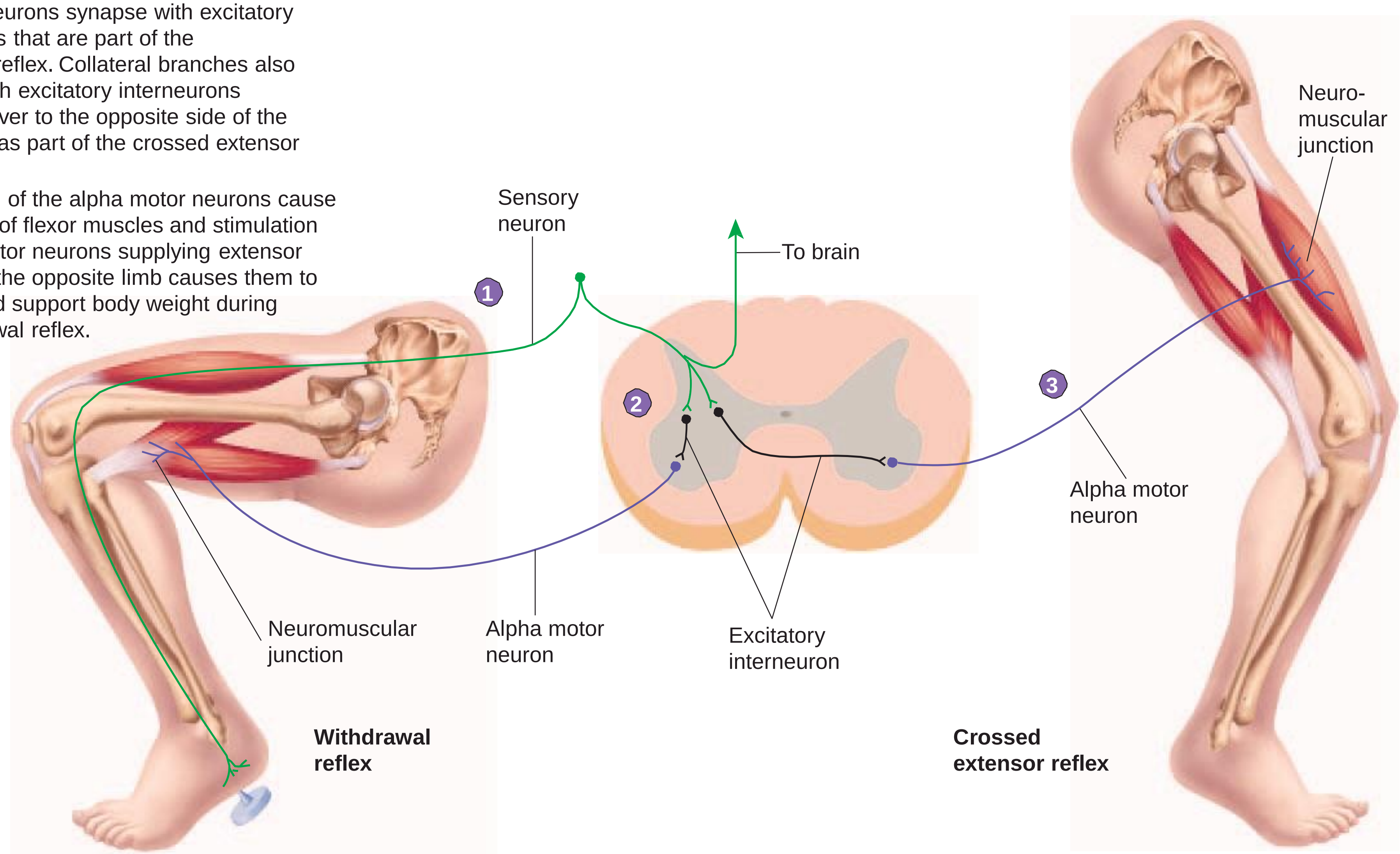
1. During the withdrawal reflex, sensory neurons conduct action potentials to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex.
3. Collateral branches also synapse with inhibitory interneurons that are part of reciprocal innervation.
4. Inhibition of the alpha motor neurons supplying the extensor muscles causes them to relax and not oppose the flexor muscles of the withdrawal reflex.



- Reciprocal innervation is associated with the withdrawal reflex and reinforces its efficiency. Collateral axons of sensory neurons that carry action potentials from pain receptors synapse with inhibitory interneurons in the dorsal horn of the spinal cord, which synapse with and inhibit alpha motor neurons of extensor (antagonist) muscles.
- When the withdrawal reflex is initiated, flexor muscles contract, and reciprocal innervation causes relaxation of the extensor muscles. This reduces the resistance to movement that the extensor muscles would otherwise generate.
- Reciprocal innervation is also involved in the stretch reflex. When the stretch reflex causes a muscle to contract, reciprocal innervation causes opposing muscles to relax. In the patellar reflex, for example, the quadriceps femoris muscle contracts and the hamstring muscles relax.

CROSSED EXTENSOR REFLEX

1. During the withdrawal reflex, sensory neurons conduct action potentials to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex. Collateral branches also synapse with excitatory interneurons that cross over to the opposite side of the spinal cord as part of the crossed extensor reflex.
3. Stimulation of the alpha motor neurons cause contraction of flexor muscles and stimulation of alpha motor neurons supplying extensor muscles in the opposite limb causes them to contract and support body weight during the withdrawal reflex.



- The crossed extensor reflex is another reflex associated with the withdrawal reflex. Interneurons that stimulate alpha motor neurons, resulting in withdrawal of a limb, have collateral axons that extend through the white commissure to the opposite side of the spinal cord and synapse with alpha motor neurons that innervate extensor muscles in the opposite side of the body.
- When a withdrawal reflex is initiated in one lower limb, the crossed extensor reflex causes extension of the opposite lower limb.

REVIEW QUESTIONS

- Describe the cervical and lumbar enlargements of the spinal cord and the cauda equina. How many pairs of spinal nerves exit the spinal cord?
- Name the meninges surrounding the spinal cord. What is found within the epidural, subdural, and subarachnoid spaces?
- How is the spinal cord held within the vertebral canal?
- Explain the arrangement of white matter in the spinal cord. What are commissures?
- Describe the spinal cord gray matter. Where are sensory, somatic motor, and autonomic neuron cell bodies located in the gray matter?
- Where do dorsal and ventral roots exit the spinal cord? What kinds of axons are in the dorsal and ventral roots and in the spinal nerves?
- Contrast and give the functions of a stretch reflex and a Golgi tendon reflex. Describe the sensory receptors for each.
- Describe the operation of gamma motor neurons. What do they accomplish?
- What is a withdrawal reflex? How do reciprocal innervation and the crossed extensor reflex assist the withdrawal reflex?