

13

The Spinal Cord, Spinal Nerves, and Spinal Reflexes

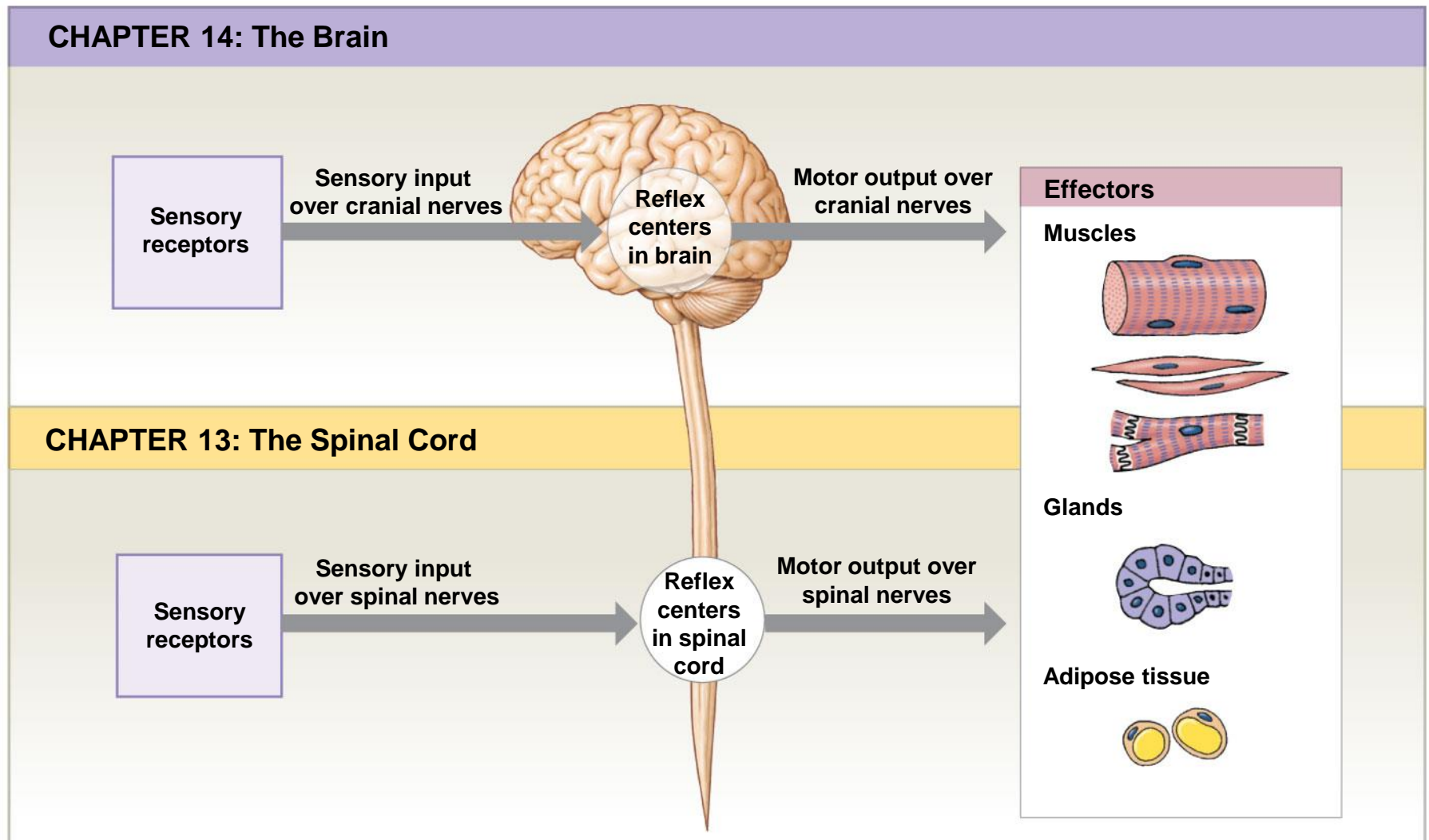
*PowerPoint® Lecture Presentations prepared by
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An Introduction to the Spinal Cord, Spinal Nerves, and Spinal Reflexes

- Spinal Reflexes
 - Rapid, automatic nerve responses triggered by specific stimuli
 - Controlled by spinal cord alone, not the brain

Figure 13-1 An Overview of Chapters 13 and 14



13-2 Spinal Cord

- Gross Anatomy of the Spinal Cord
 - About 18 inches (45 cm) long
 - 1/2 inch (14 mm) wide
 - Ends between vertebrae L₁ and L₂
 - Bilateral symmetry
 - Grooves divide the spinal cord into left and right
 - **Posterior median sulcus** – on posterior side
 - **Anterior median fissure** – deeper groove on anterior side

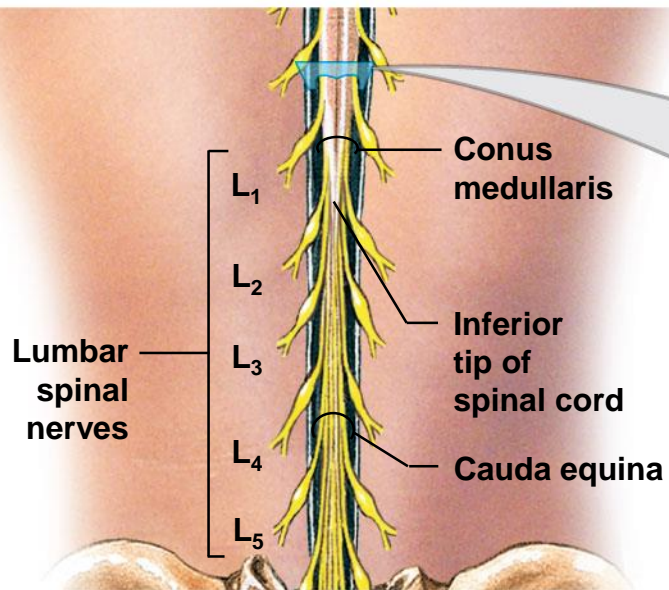
13-2 Spinal Cord

- **Enlargements of the Spinal Cord**
 - Caused by:
 - Amount of gray matter in segment
 - Involvement with sensory and motor nerves of limbs
 - **Cervical enlargement**
 - Nerves of shoulders and upper limbs
 - **Lumbar enlargement**
 - Nerves of pelvis and lower limbs

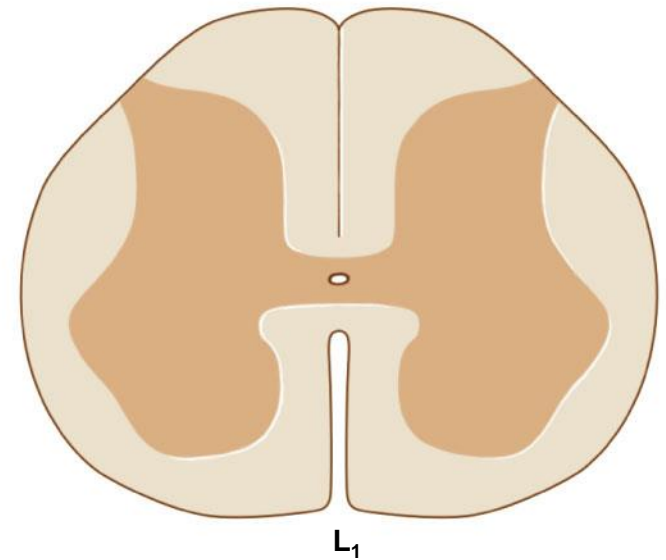
13-2 Spinal Cord

- Gross Anatomy of the Spinal Cord
 - The distal end
 - **Conus medullaris**
 - Thin, conical spinal cord below lumbar enlargement
 - **Cauda equina**
 - Nerve roots extending below conus medullaris

Figure 13-2 Gross Anatomy of the Adult Spinal Cord



a



b

Figure 13-2 Gross Anatomy of the Adult Spinal Cord

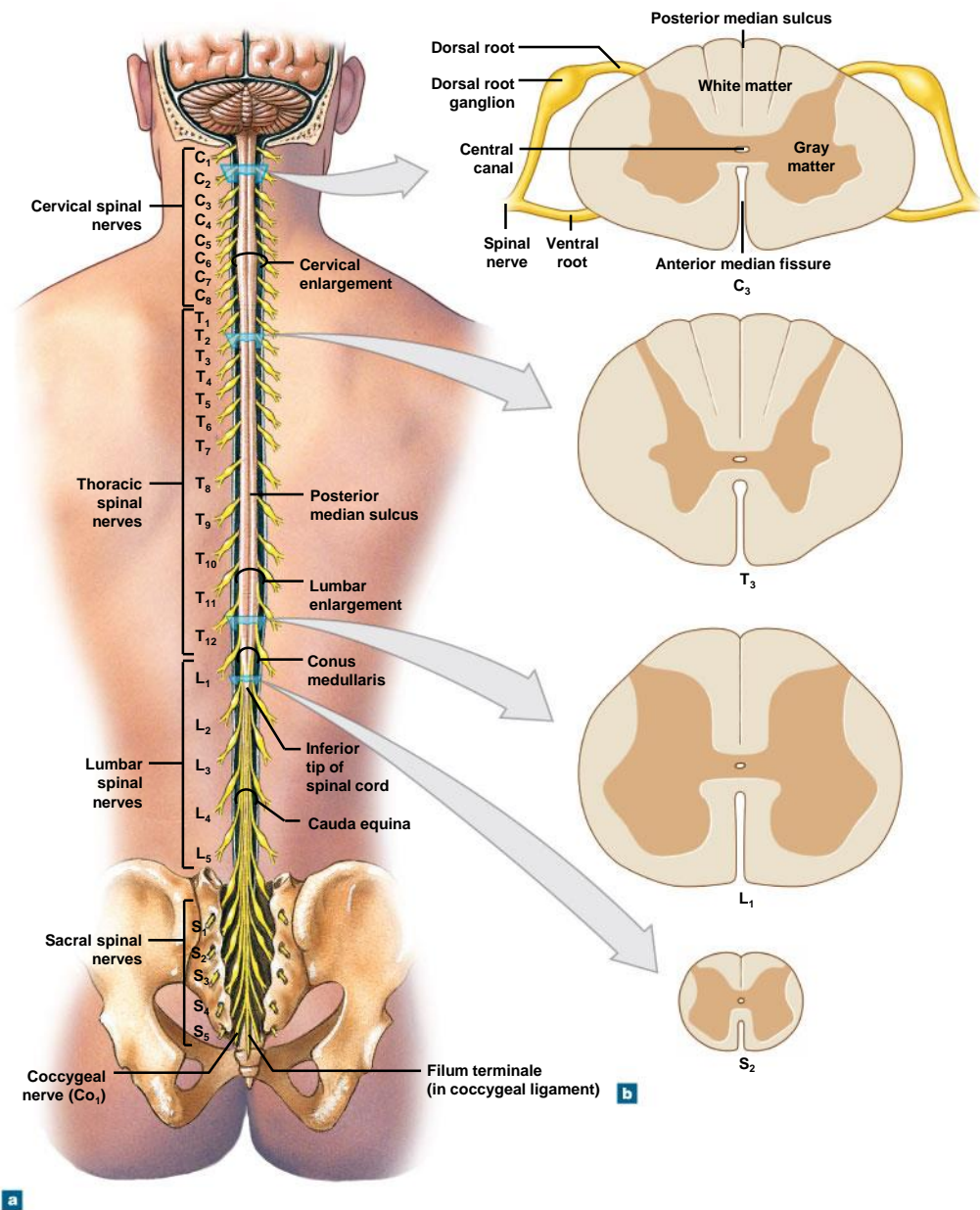
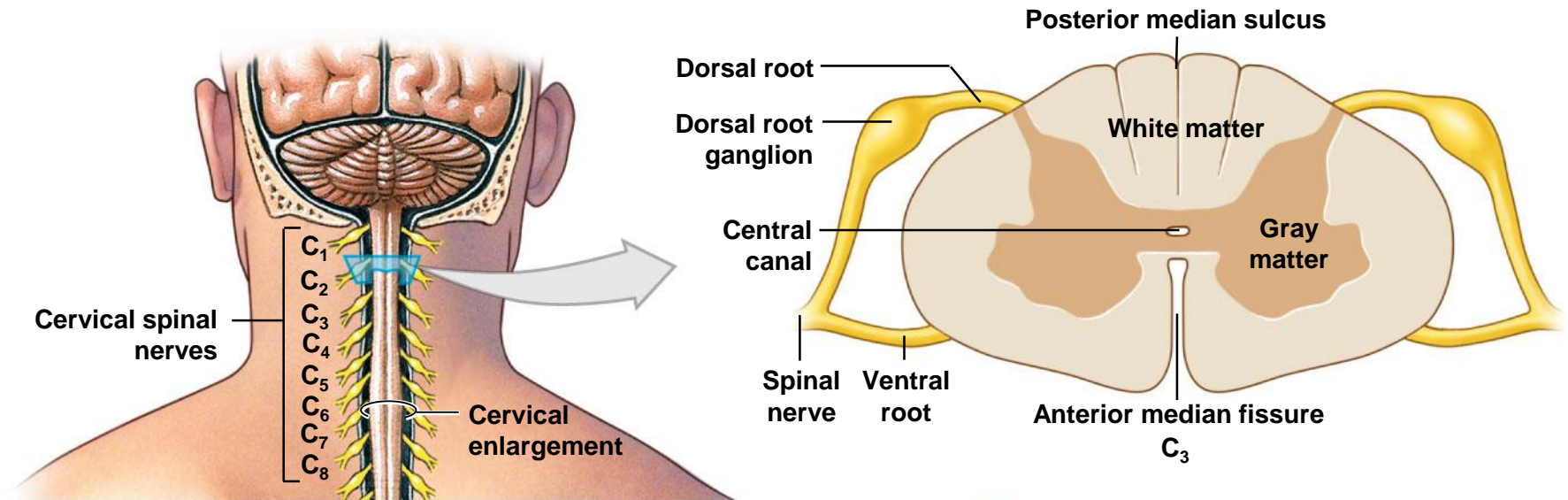


Figure 13-2 Gross Anatomy of the Adult Spinal Cord



a The superficial anatomy and orientation of the adult spinal cord. The numbers to the left identify the spinal nerves and indicate where the nerve roots leave the vertebral canal. The spinal cord extends from the brain only to the level of vertebrae L₁–L₂; the spinal segments found at representative locations are indicated in the cross sections.

b Inferior views of cross sections through representative segments of the spinal cord, showing the arrangement of gray matter and white matter.

Figure 13-2 Gross Anatomy of the Adult Spinal Cord

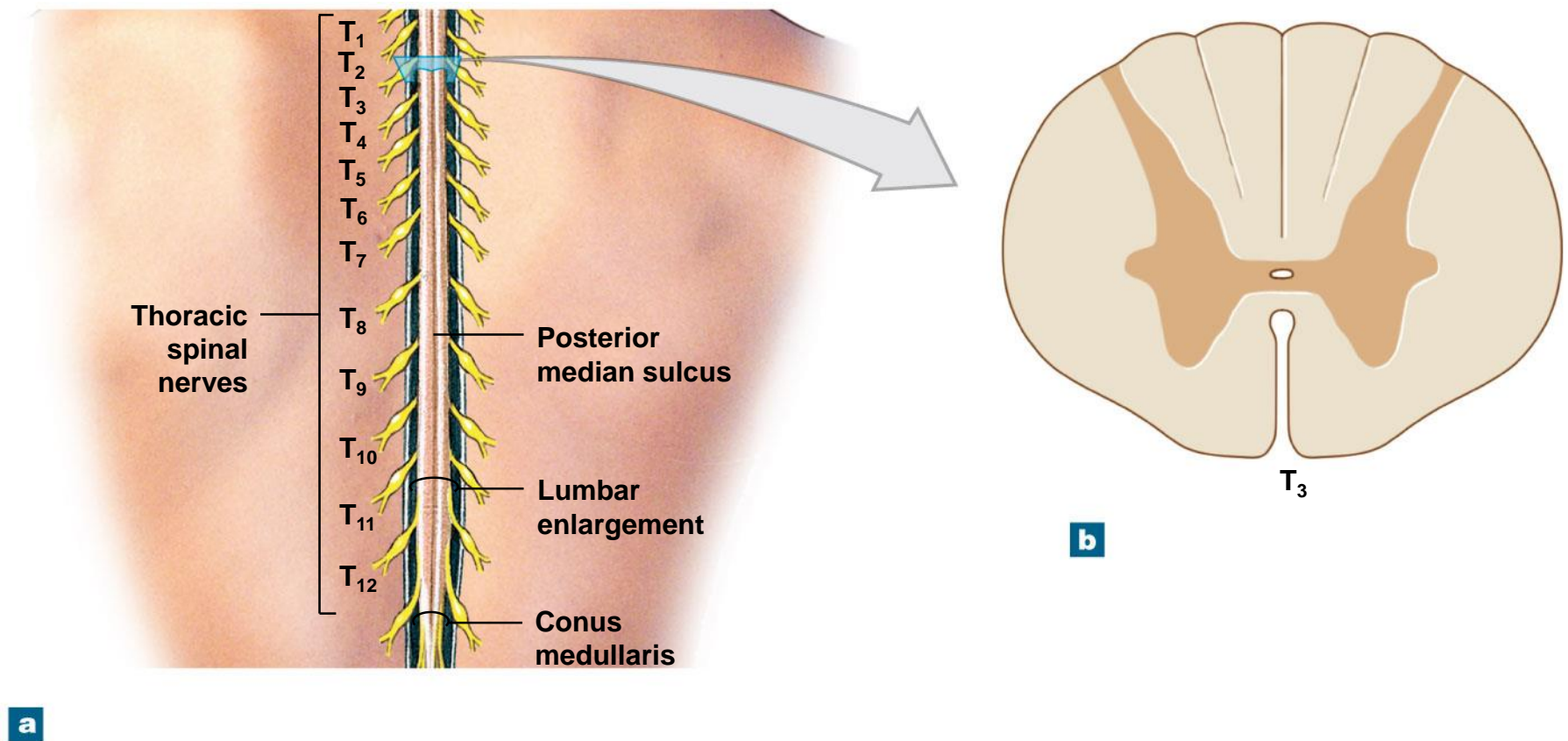
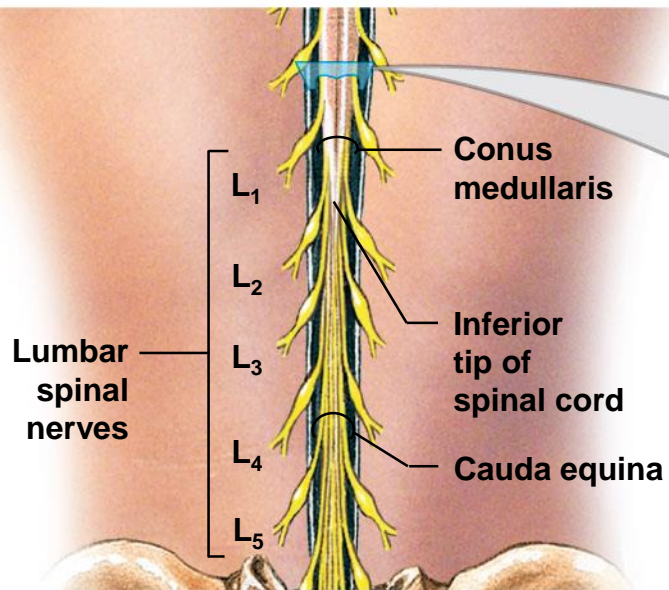
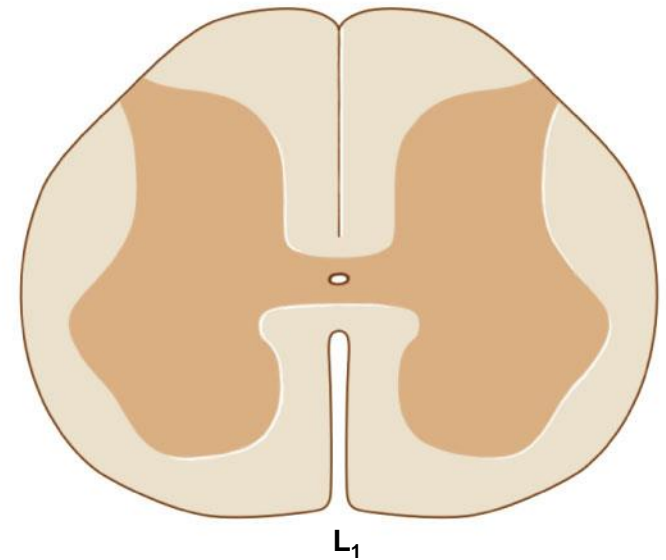


Figure 13-2 Gross Anatomy of the Adult Spinal Cord

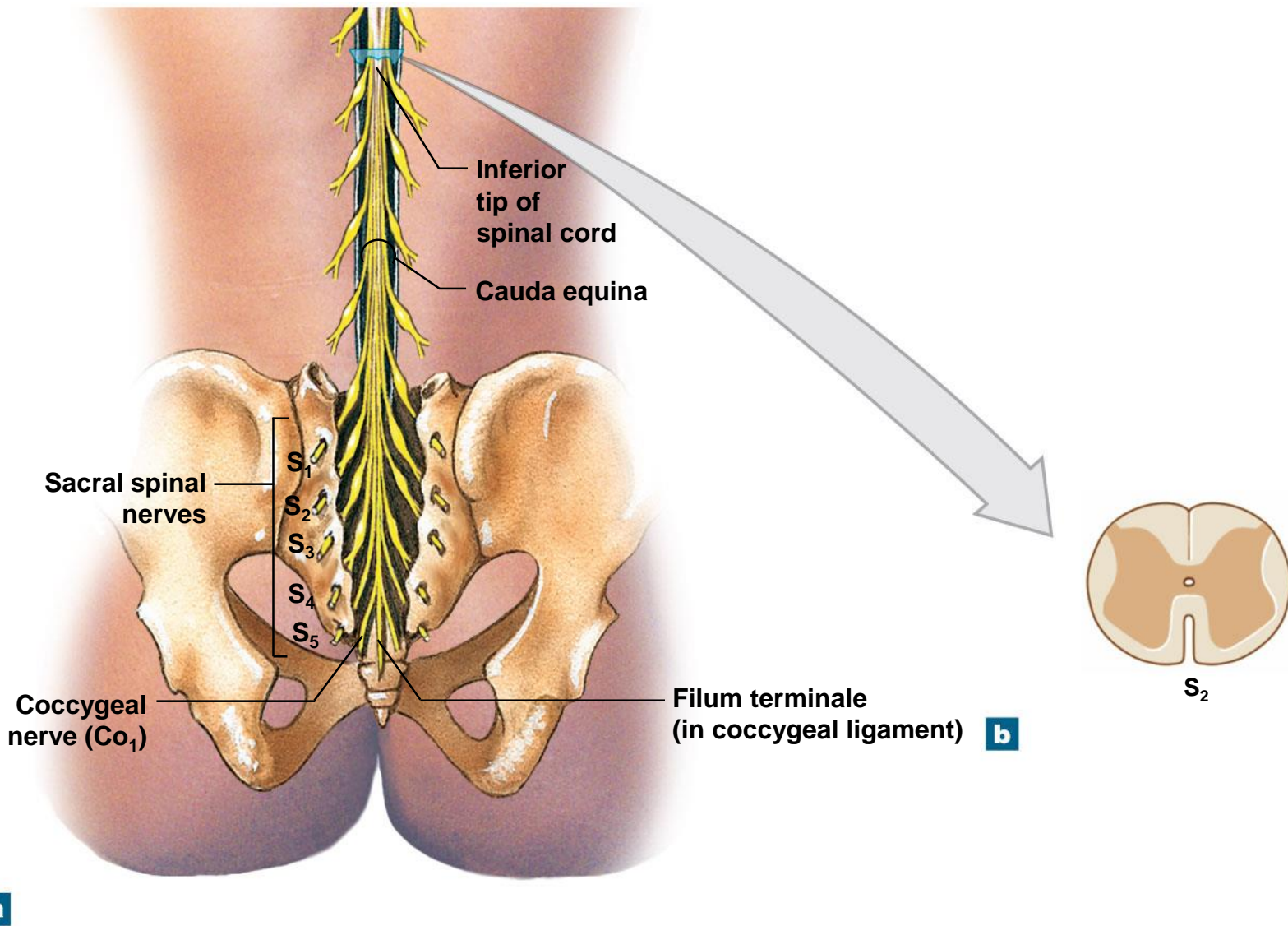


a



b

Figure 13-2 Gross Anatomy of the Adult Spinal Cord



13-2 Spinal Cord

- 31 Spinal Cord Segments
 - Based on vertebrae where spinal nerves originate
 - Positions of spinal segment and vertebrae change with age
 - Cervical nerves
 - Are named for inferior vertebra
 - All other nerves
 - Are named for superior vertebra

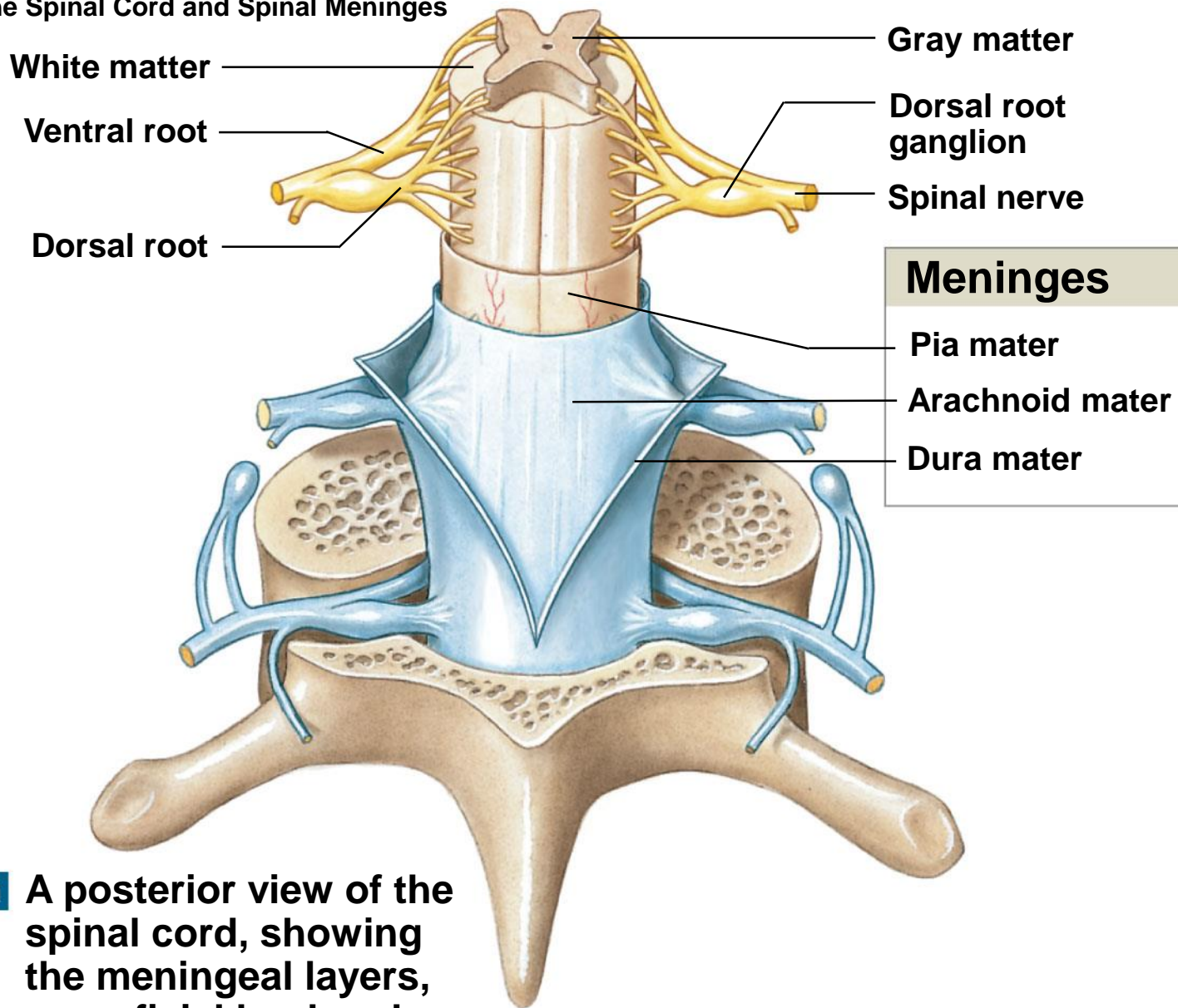
13-2 Spinal Cord

- **Roots**
 - Two branches of spinal nerves
 - 1. Ventral root**
 - Contains axons of motor neurons
 - 2. Dorsal root**
 - Contains axons of sensory neurons
 - **Dorsal root ganglia**
 - Contain cell bodies of sensory neurons

13-2 Spinal Cord

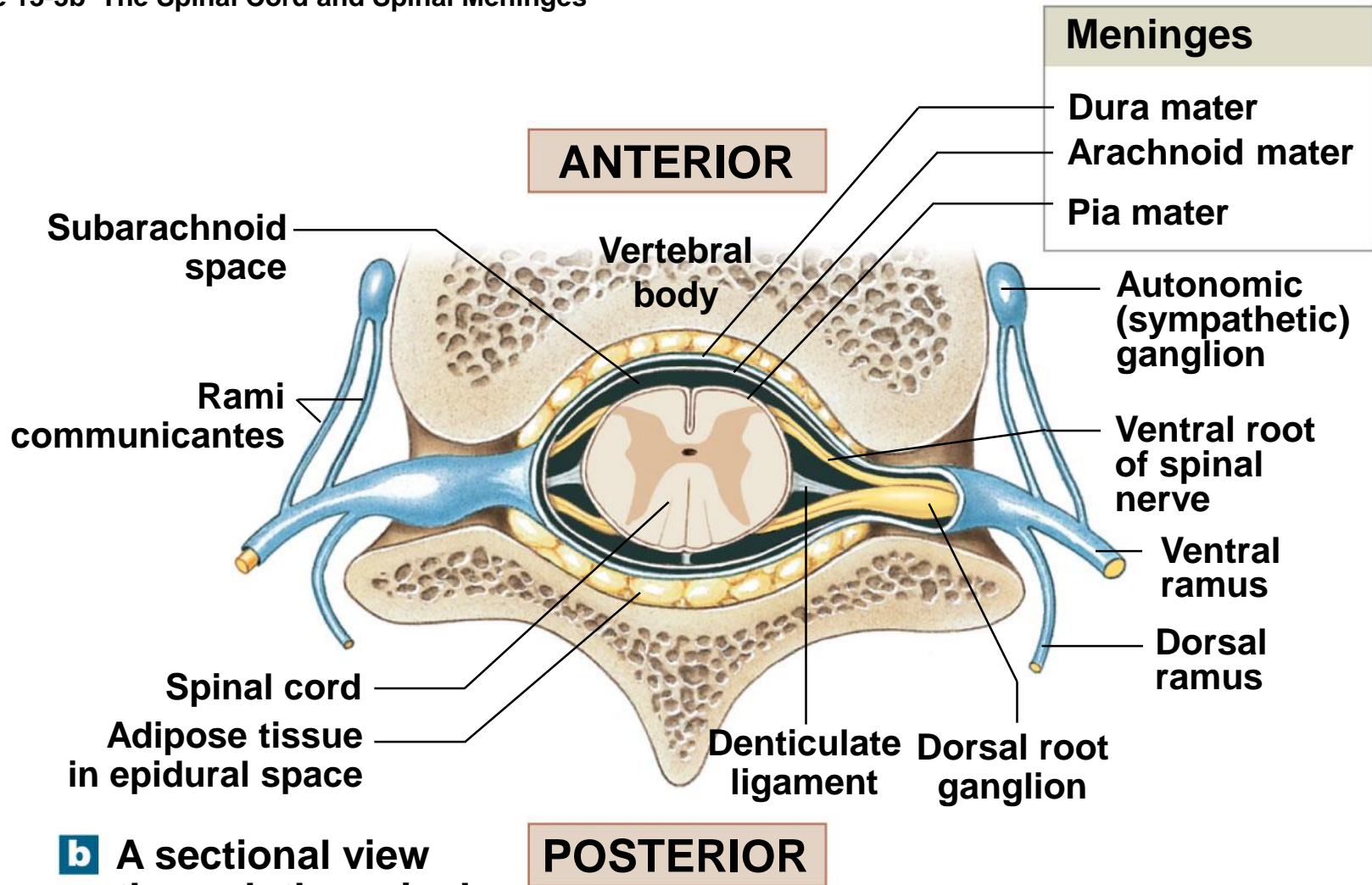
- The **Spinal Nerve**
 - Each side of spine
 - Dorsal and ventral roots join
 - To form a spinal nerve
 - **Mixed Nerves**
 - Carry both afferent (sensory) and efferent (motor) fibers

Figure 13-3a The Spinal Cord and Spinal Meninges



a A posterior view of the spinal cord, showing the meningeal layers, superficial landmarks, and distribution of gray matter and white matter

Figure 13-3b The Spinal Cord and Spinal Meninges



b A sectional view through the spinal cord and meninges, showing the peripheral distribution of spinal nerves

13-2 Spinal Cord

- **The Spinal Meninges**
 - Specialized membranes isolate spinal cord from surroundings
 - Functions of the spinal meninges include:
 - Protecting spinal cord
 - Carrying blood supply
 - Continuous with **cranial meninges**
- **Meningitis**
 - Viral or bacterial infection of meninges

13-2 Spinal Cord

- The Three Meningeal Layers
 - 1. Dura mater**
 - Outer layer of spinal cord
 - 2. Arachnoid mater**
 - Middle meningeal layer
 - 3. Pia mater**
 - Inner meningeal layer

13-2 Spinal Cord

- The **Dura Mater**
 - Tough and fibrous
 - Cranially
 - Fuses with periosteum of occipital bone
 - Is continuous with cranial dura mater
 - Caudally
 - Tapers to dense cord of collagen fibers

13-2 Spinal Cord

- The **Dura Mater**
 - The **Epidural Space**
 - Between spinal dura mater and walls of vertebral canal
 - Contains loose connective and adipose tissue
 - Anesthetic injection site

13-2 Spinal Cord

- The **Arachnoid Mater**
 - Middle meningeal layer
 - Arachnoid membrane
 - Simple squamous epithelia
 - Covers arachnoid mater

13-2 Spinal Cord

- The Interlayer Spaces of Arachnoid Mater
 - **Subarachnoid space**
 - Between arachnoid mater and pia mater
 - Contains collagen/elastin fiber network (arachnoid trabeculae)
 - Filled with **cerebrospinal fluid (CSF)**

13-2 Spinal Cord

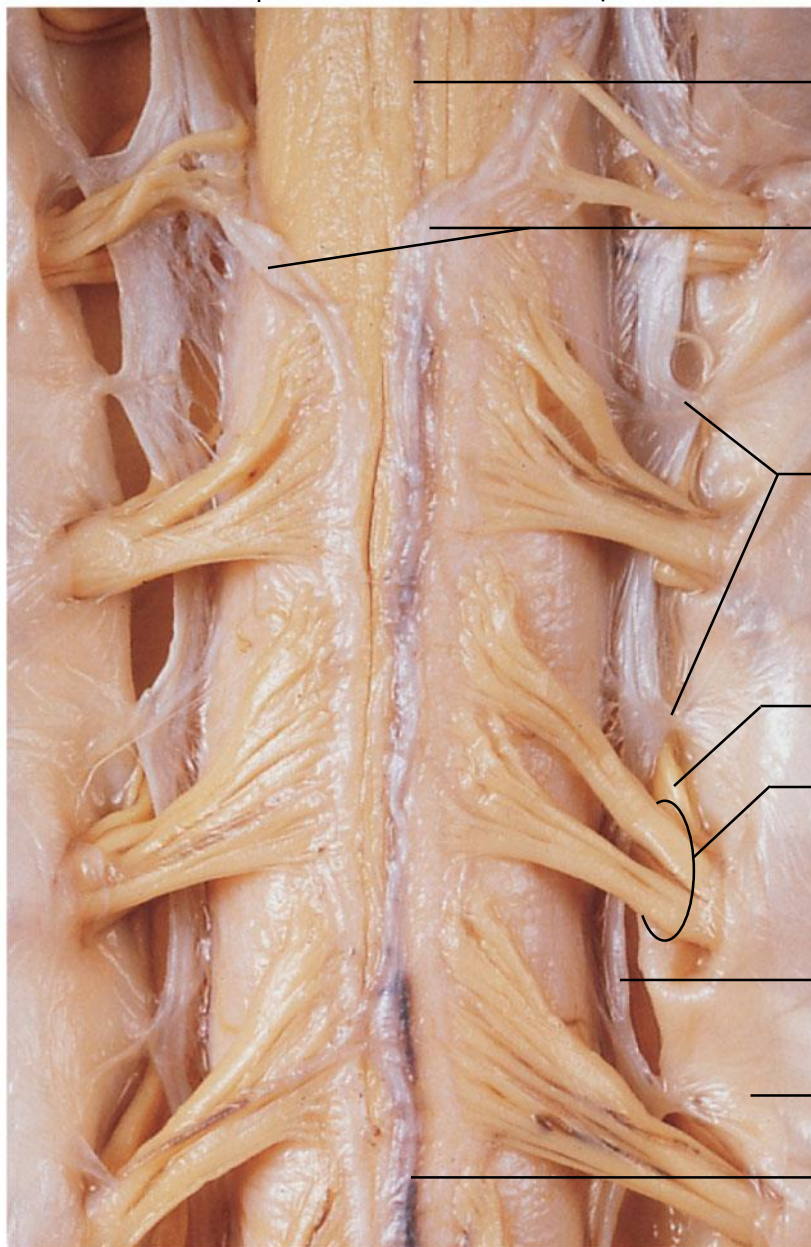
- **The Pia Mater**
 - Is the innermost meningeal layer
 - Is a mesh of collagen and elastic fibers
 - Is bound to underlying neural tissue

13-2 Spinal Cord

- Blood vessels
 - Along surface of spinal pia mater
 - Within subarachnoid space

Figure 13-4 The Spinal Cord and Associated Structures

Spinal cord



Anterior median fissure

Pia mater

**Denticulate
ligaments**

Dorsal root

**Ventral root, formed by
several "rootlets" from
one cervical segment**

**Arachnoid mater
(reflected)**

Dura mater (reflected)

Spinal blood vessel

13-3 Gray Matter and White Matter

- Sectional Anatomy of the Spinal Cord
 - **White matter**
 - Is superficial
 - Contains myelinated and unmyelinated axons
 - **Gray matter**
 - Surrounds **central canal** of spinal cord
 - Contains neuron cell bodies, neuroglia, unmyelinated axons
 - Has projections (gray **horns**)

13-3 Gray Matter and White Matter

- Organization of Gray Matter
 - The gray horns
 - **Posterior gray horns** contain somatic and visceral sensory nuclei
 - **Anterior gray horns** contain somatic motor nuclei
 - **Lateral gray horns** are in thoracic and lumbar segments; contain visceral motor nuclei
 - **Gray commissures**
 - Axons that cross from one side of cord to the other before reaching gray matter

13-3 Gray Matter and White Matter

- Organization of Gray Matter
 - The cell bodies of neurons form functional groups called **nuclei**
 - **Sensory nuclei**
 - Dorsal (posterior)
 - Connect to peripheral receptors
 - **Motor nuclei**
 - Ventral (anterior)
 - Connect to peripheral effectors

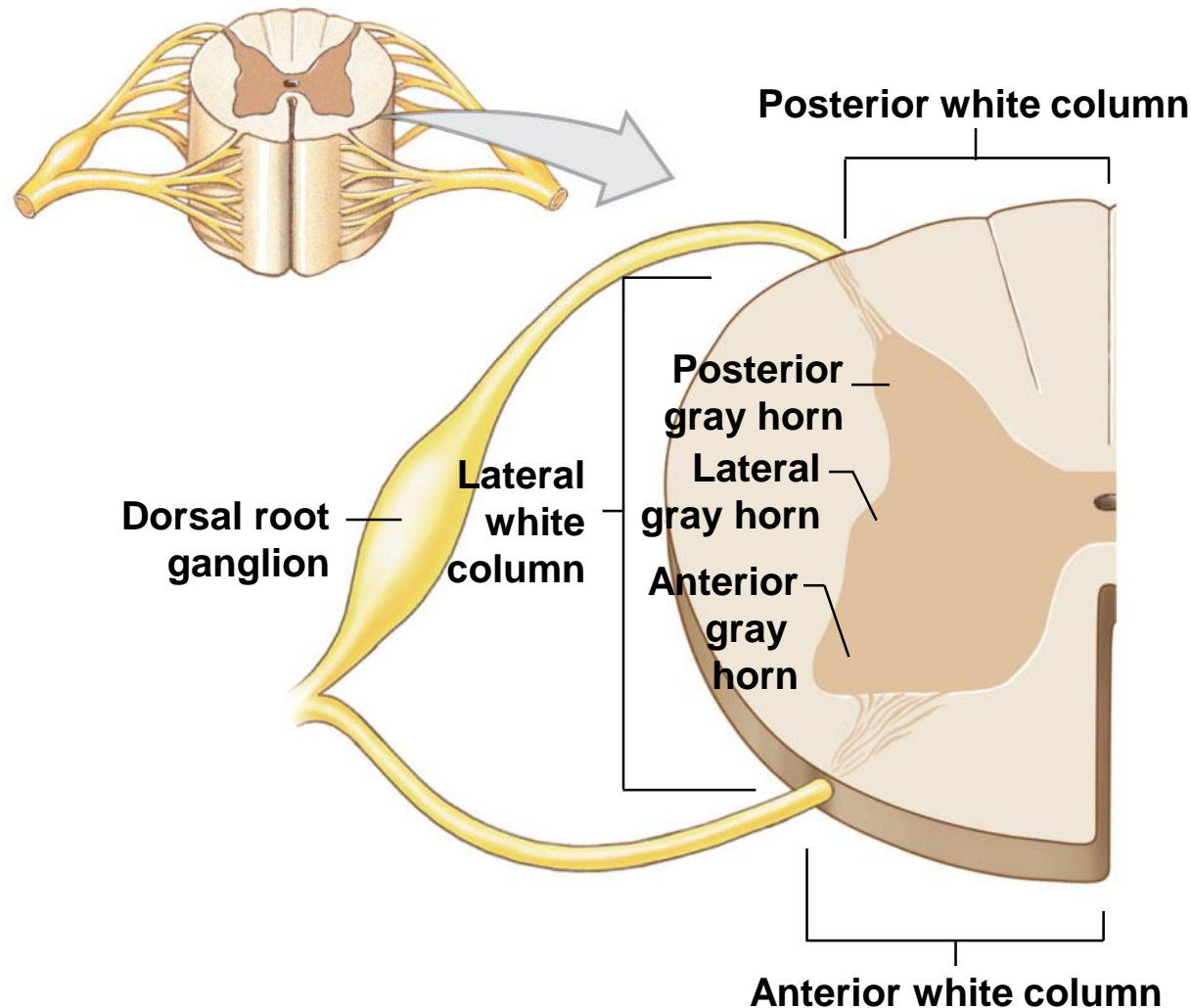
13-3 Gray Matter and White Matter

- Organization of White Matter
 - **Posterior white columns** lie between posterior gray horns and posterior median sulcus
 - **Anterior white columns** lie between anterior gray horns and anterior median fissure
 - **Anterior white commissure** area where axons cross from one side of spinal cord to the other
 - **Lateral white columns** located on each side of spinal cord between anterior and posterior columns

13-3 Gray Matter and White Matter

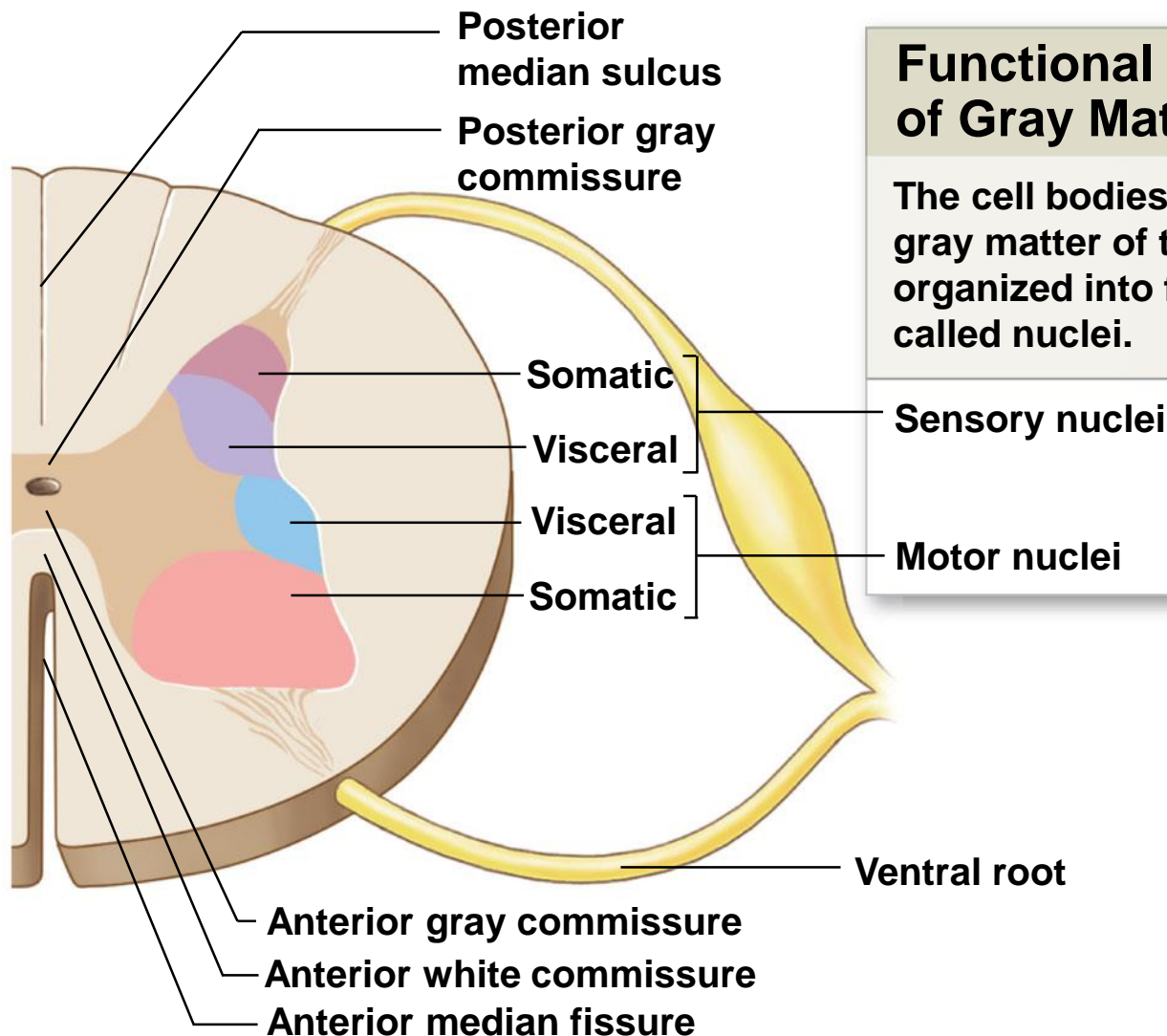
- Organization of White Matter
 - **Tracts** or *fasciculi*
 - In white columns
 - Bundles of axons
 - Relay same information in same direction
 - **Ascending tracts**
 - Carry information to brain
 - **Descending tracts**
 - Carry motor commands to spinal cord

Figure 13-5a The Sectional Organization of the Spinal Cord



- a** The left half of this sectional view shows important anatomical landmarks, including the three columns of white matter. The right half indicates the functional organization of the nuclei in the anterior, lateral, and posterior gray horns.

Figure 13-5a The Sectional Organization of the Spinal Cord



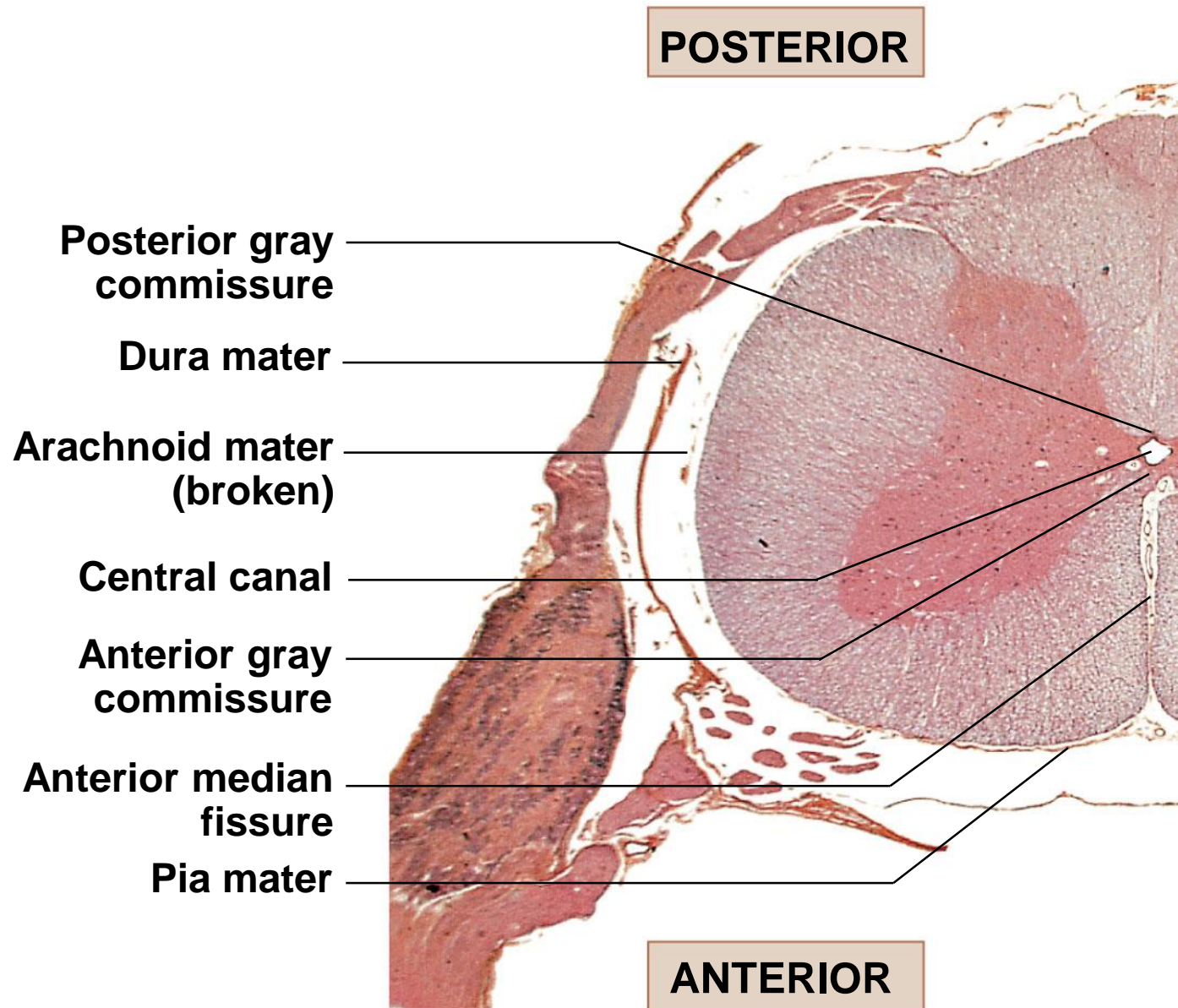
Functional Organization of Gray Matter

The cell bodies of neurons in the gray matter of the spinal cord are organized into functional groups called nuclei.

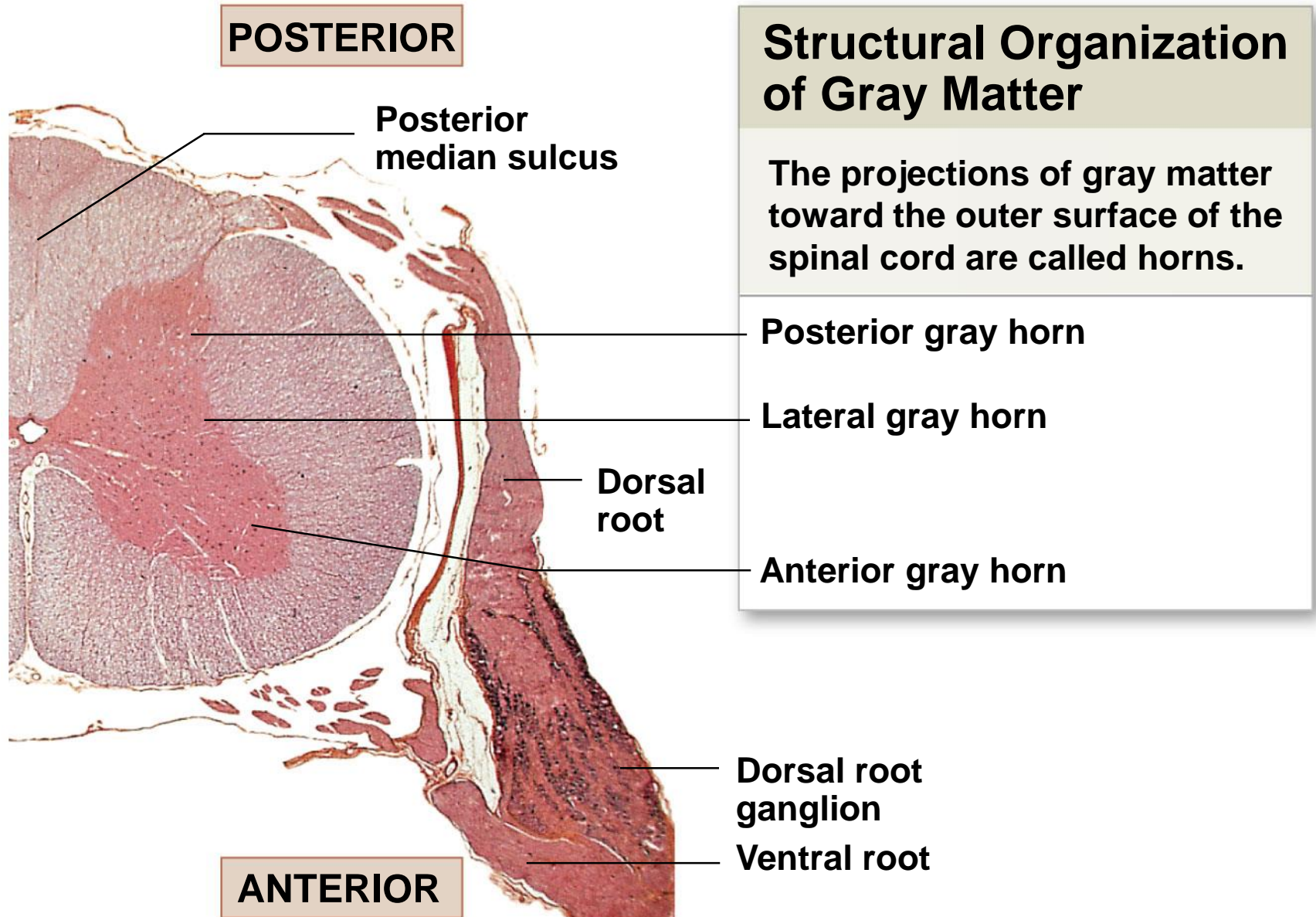
Sensory nuclei

Motor nuclei

a The left half of this sectional view shows important anatomical landmarks, including the three columns of white matter. The right half indicates the functional organization of the nuclei in the anterior, lateral, and posterior gray horns.



b A micrograph of a section through the spinal cord, showing major landmarks in and surrounding the cord.



b A micrograph of a section through the spinal cord, showing major landmarks in and surrounding the cord.

13-3 Gray Matter and White Matter

- Spinal Cord Summary
 - Spinal cord has a narrow **central canal**
 - Surrounded by gray matter
 - Containing sensory and motor nuclei
 - Sensory nuclei are dorsal
 - Motor nuclei are ventral

13-3 Gray Matter and White Matter

- Spinal Cord Summary
 - Gray matter
 - Is covered by a thick layer of white matter
 - White matter
 - Consists of ascending and descending axons
 - Organized in columns
 - Contains axon bundles with specific functions
 - Spinal cord is so highly organized
 - It is possible to predict results of injuries to specific areas

13-4 Spinal Nerves and Plexuses

- Anatomy of Spinal Nerves
 - Every spinal cord segment
 - Is connected to a pair of spinal nerves
 - Every spinal nerve
 - Is surrounded by three connective tissue layers
 - That support structures and contain blood vessels

13-4 Spinal Nerves and Plexuses

- Three Connective Tissue Layers of Spinal Nerves

1. **Epineurium**

- Outer layer
- Dense network of collagen fibers

2. **Perineurium**

- Middle layer
- Divides nerve into *fascicles* (axon bundles)

3. **Endoneurium**

- Inner layer
- Surrounds individual axons

Figure 13-6 A Peripheral Nerve

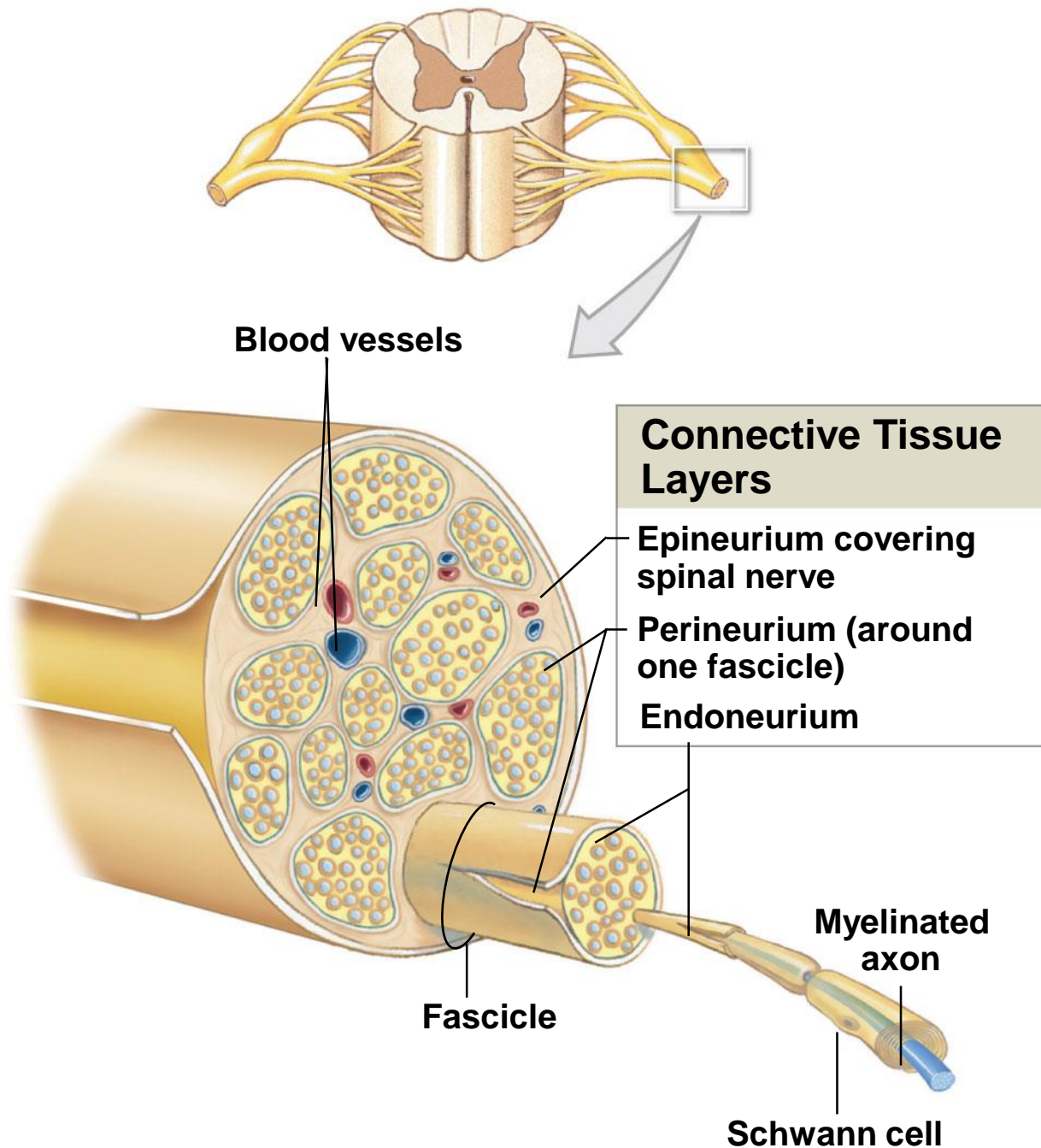
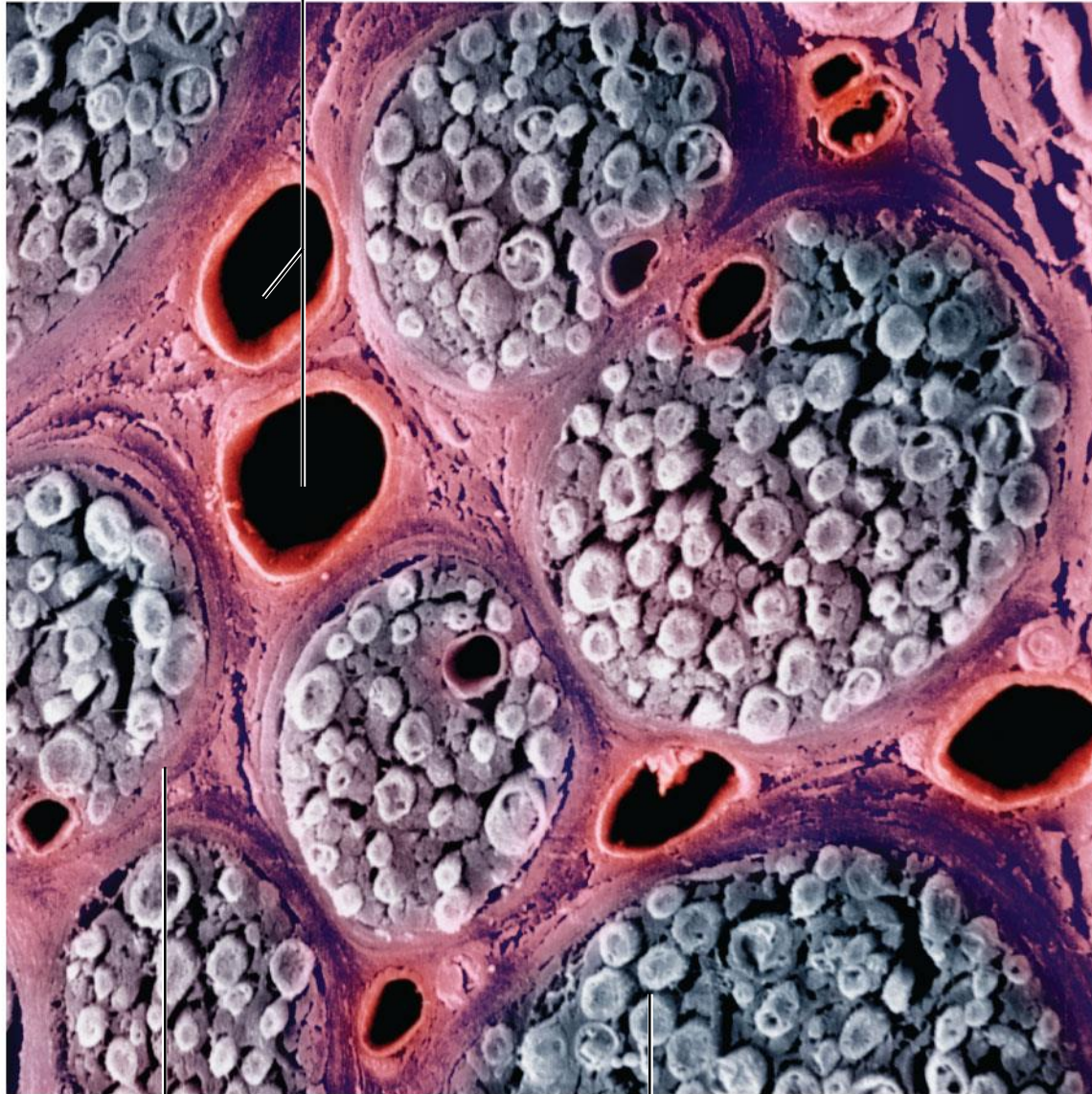


Figure 13-6 A Peripheral Nerve

Blood vessels



**Perineurium
(around one fascicle)**

Endoneurium

13-4 Spinal Nerves and Plexuses

- Peripheral Nerves
 - Interconnecting branches of spinal nerves
 - Surrounded by connective tissue sheaths

13-4 Spinal Nerves and Plexuses

- Peripheral Distribution of Spinal Nerves
 - Spinal nerves
 - Form lateral to intervertebral foramen
 - Where dorsal and ventral roots unite
 - Then branch and form pathways to destination

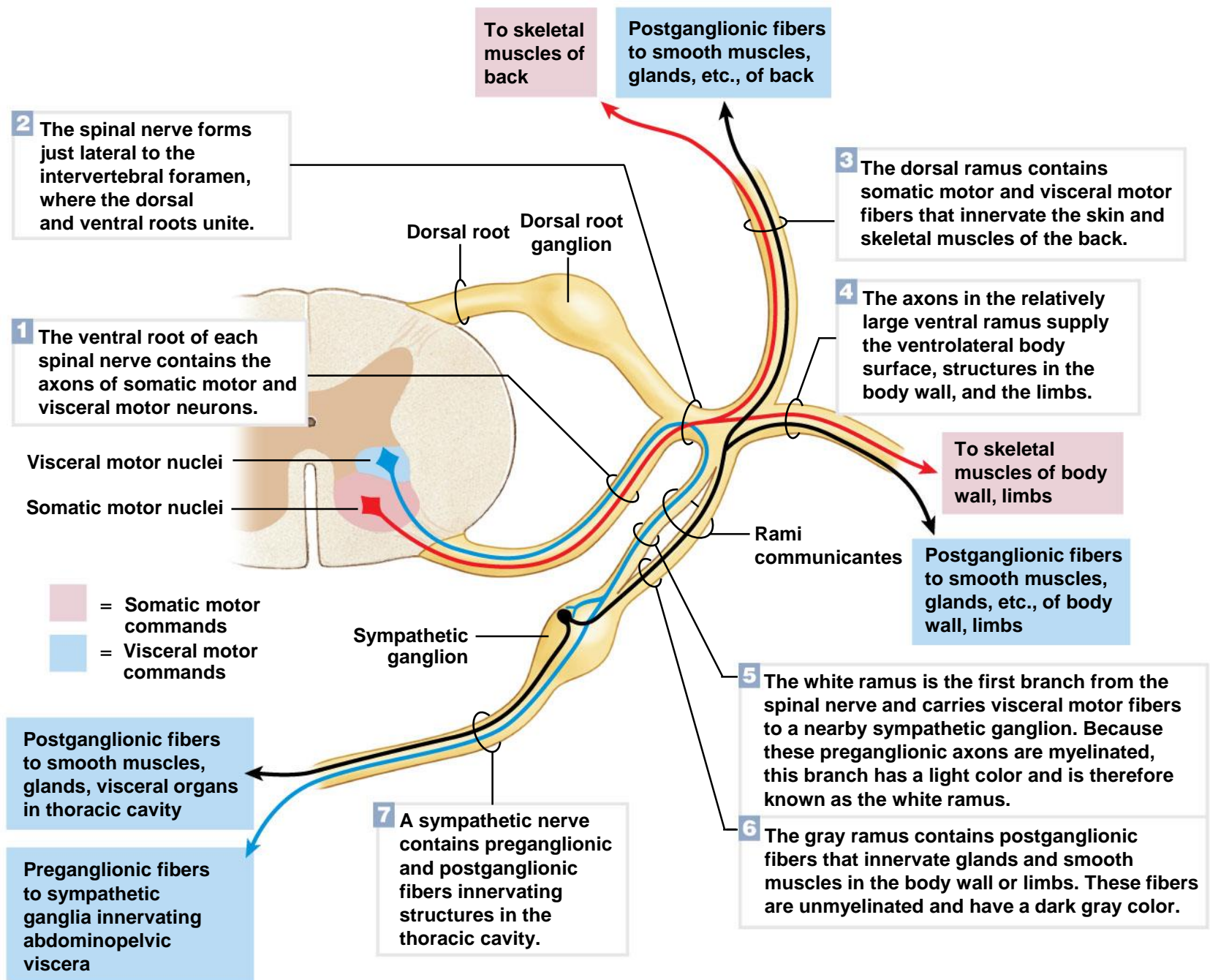
13-4 Spinal Nerves and Plexuses

- Peripheral Distribution of Spinal Nerves
 - Motor nerves
 - The first branch
 - White ramus
 - Carries visceral motor fibers to sympathetic ganglion of autonomic nervous system
 - Gray ramus
 - Unmyelinated nerves
 - Return from sympathetic ganglion to rejoin spinal nerve

13-4 Spinal Nerves and Plexuses

- Peripheral Distribution of Spinal Nerves
 - Motor nerves
 - Dorsal and ventral rami
 - Dorsal ramus
 - Contains somatic and visceral motor fibers
 - Innervates the back
 - Ventral ramus
 - Larger branch
 - Innervates ventrolateral structures and limbs

Figure 13-7 Peripheral Distribution of Spinal Nerves



13-4 Spinal Nerves and Plexuses

- Peripheral Distribution of Spinal Nerves
 - Sensory nerves
 - In addition to motor impulses
 - Dorsal, ventral, and white rami also carry sensory information
 - **Dermatomes**
 - Bilateral region of skin
 - Monitored by specific pair of spinal nerves

Figure 13-7 Peripheral Distribution of Spinal Nerves

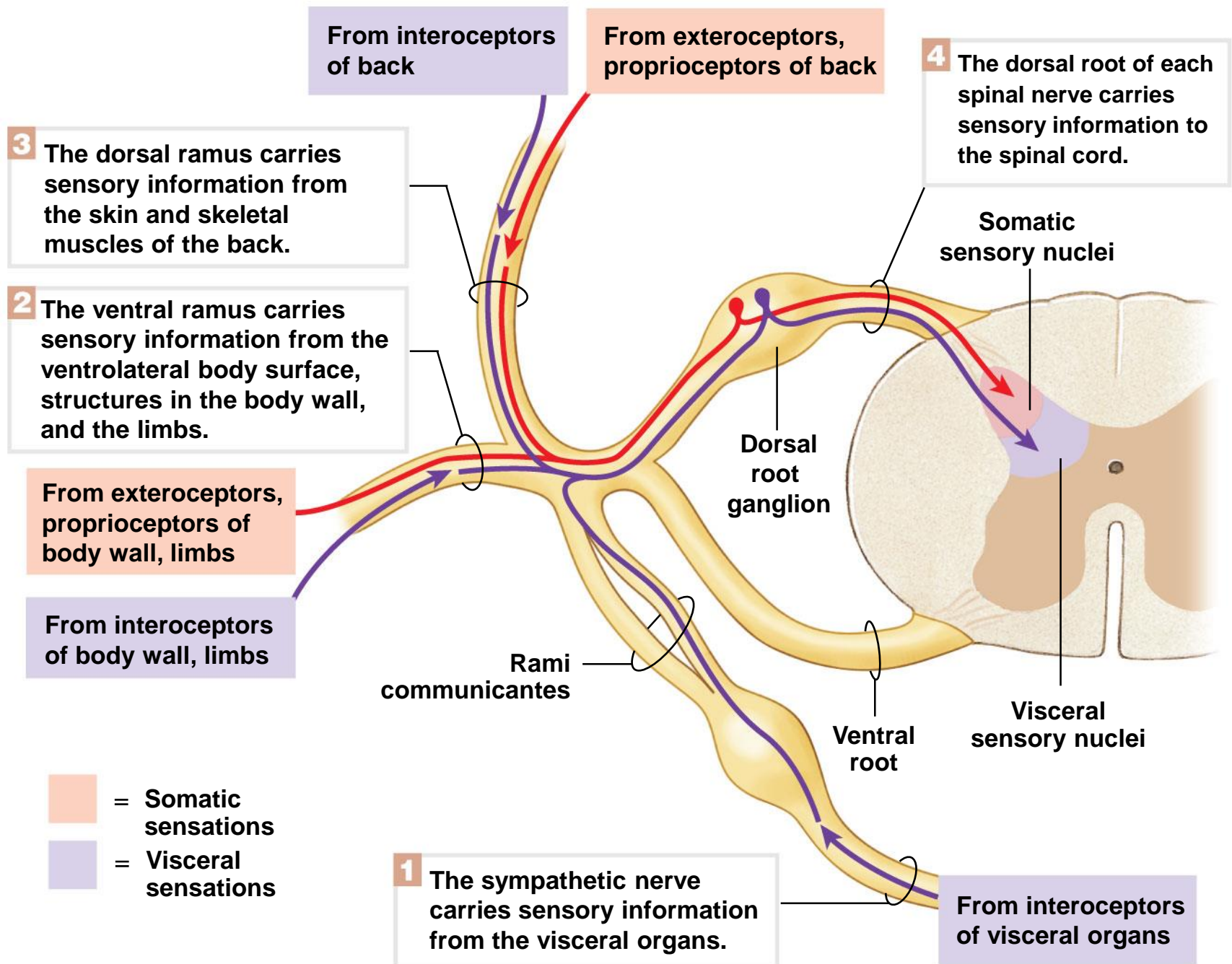


Figure 13-8 Dermatomes

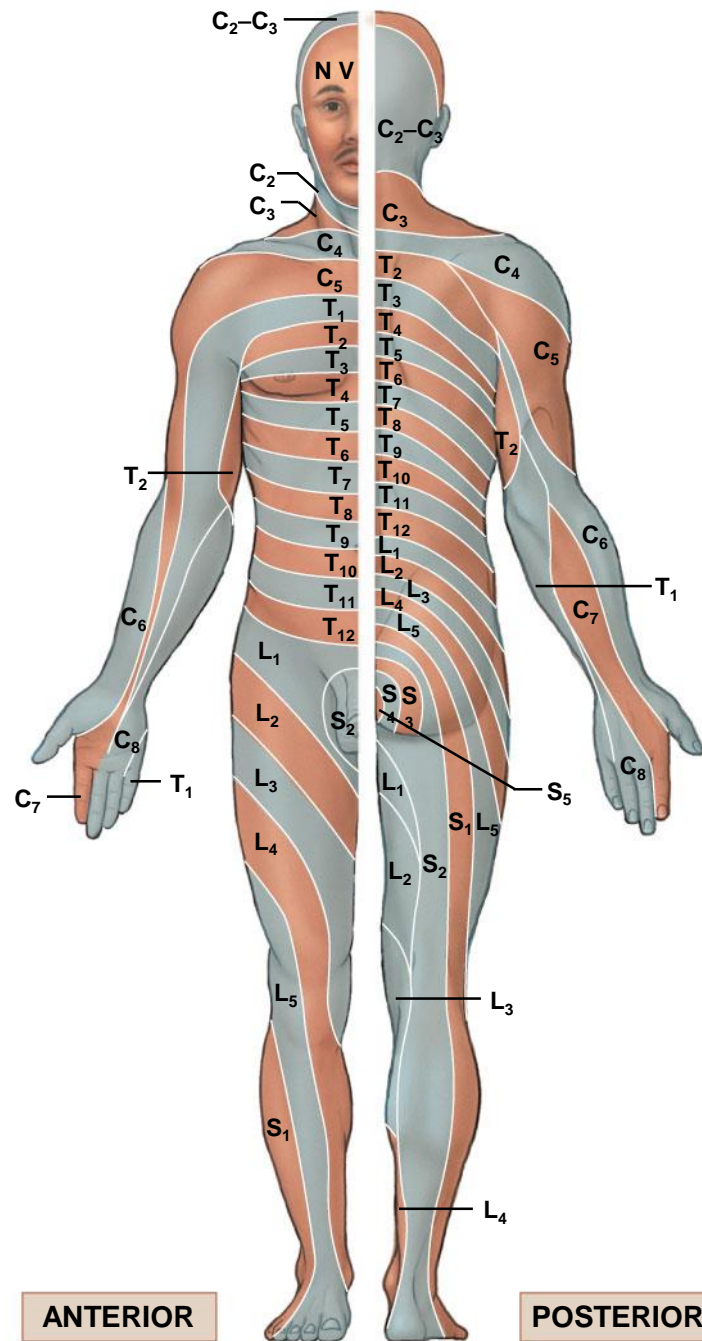


Figure 13-9 Shingles



13-4 Spinal Nerves and Plexuses

- **Nerve Plexuses**

- Complex, interwoven networks of nerve fibers
- Formed from blended fibers of ventral rami of adjacent spinal nerves
- Control skeletal muscles of the neck and limbs

13-4 Spinal Nerves and Plexuses

- The Four Major Plexuses of Ventral Rami
 1. **Cervical plexus**
 2. **Brachial plexus**
 3. **Lumbar plexus**
 4. **Sacral plexus**

Figure 13-10 Peripheral Nerves and Nerve Plexuses

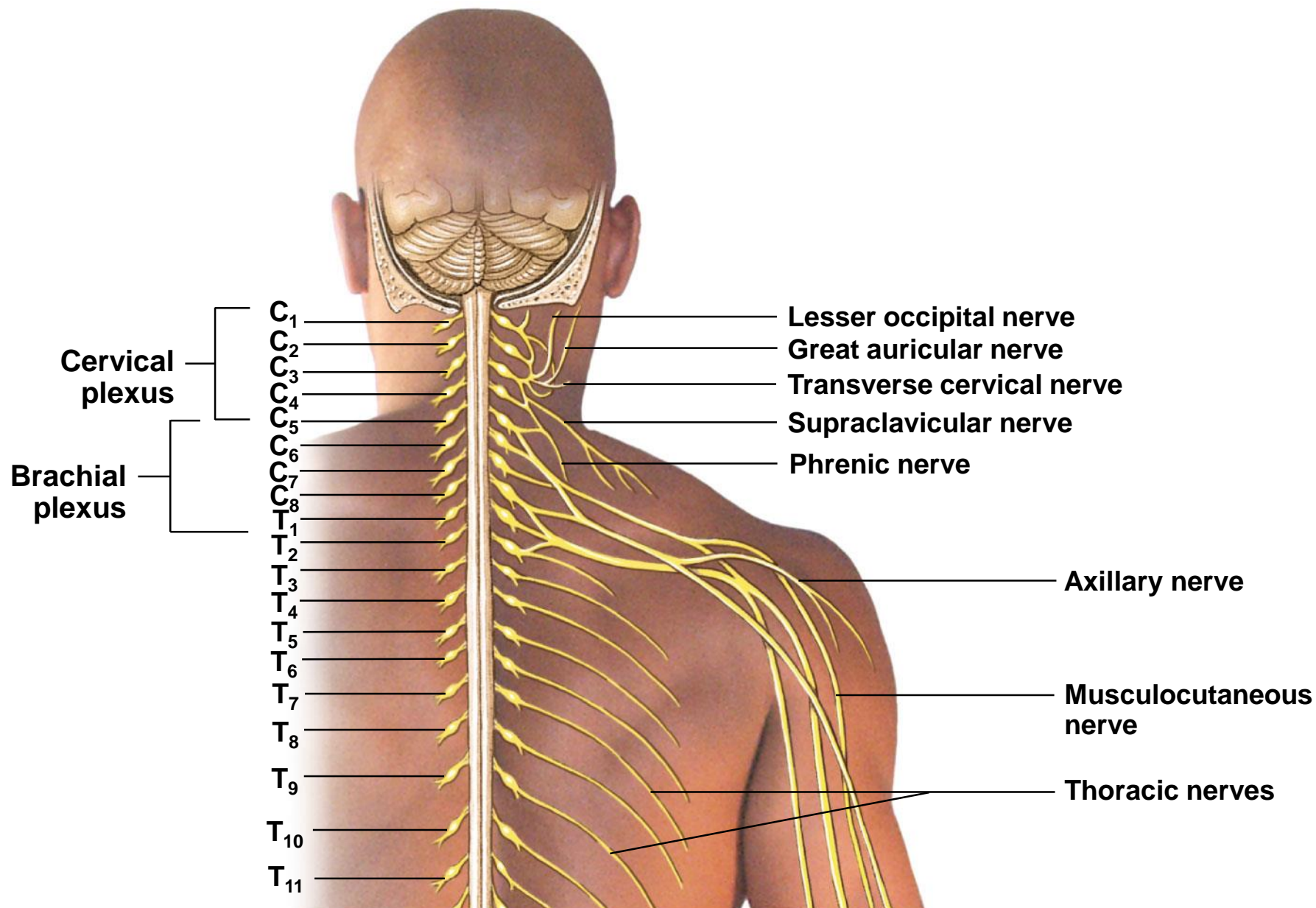
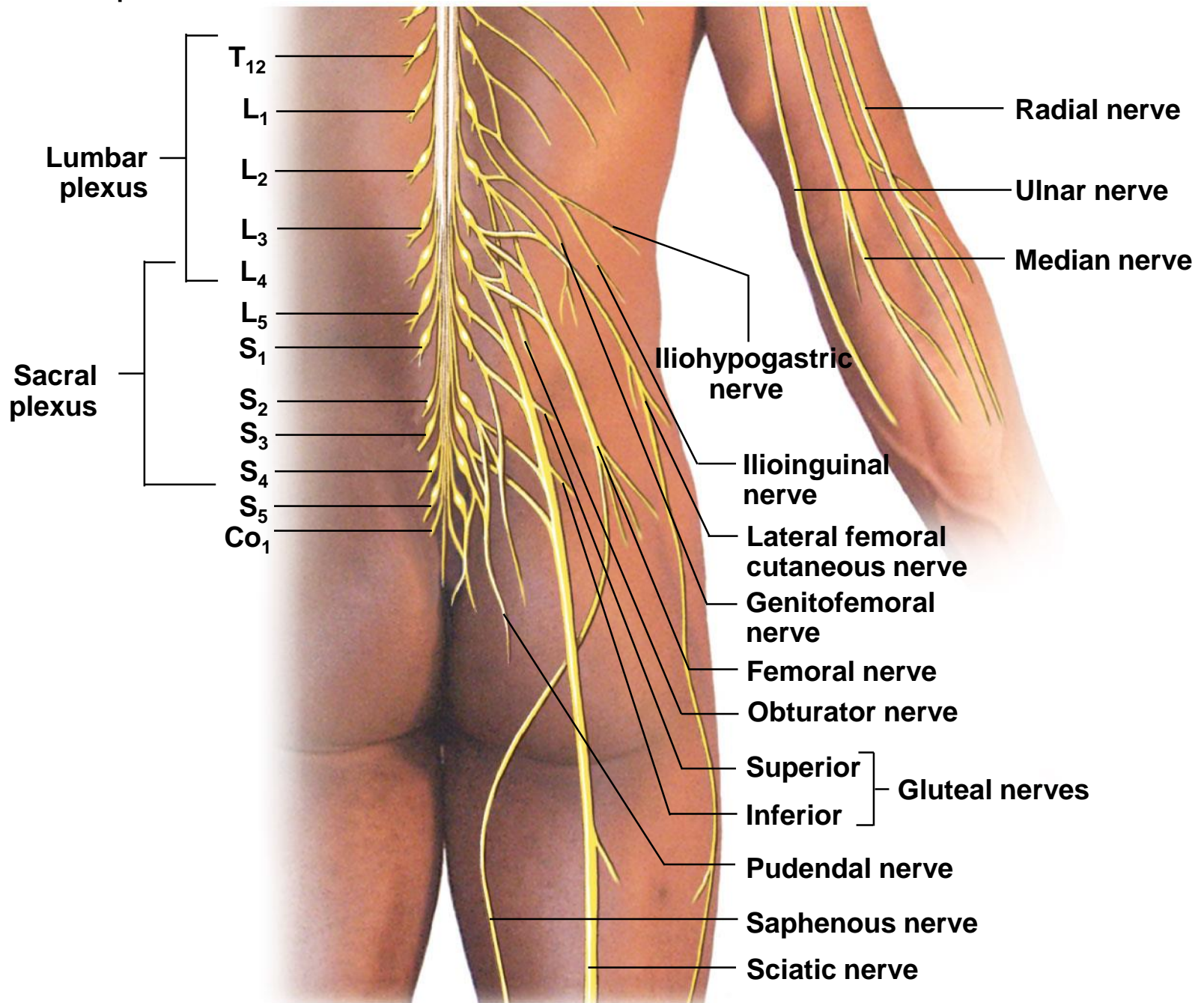


Figure 13-10 Peripheral Nerves and Nerve Plexuses



13-4 Spinal Nerves and Plexuses

- The **Cervical Plexus**
 - Innervates neck, thoracic cavity, diaphragmatic muscles
 - Major nerve
 - **Phrenic nerve** (controls diaphragm)

Figure 13-11 The Cervical Plexus

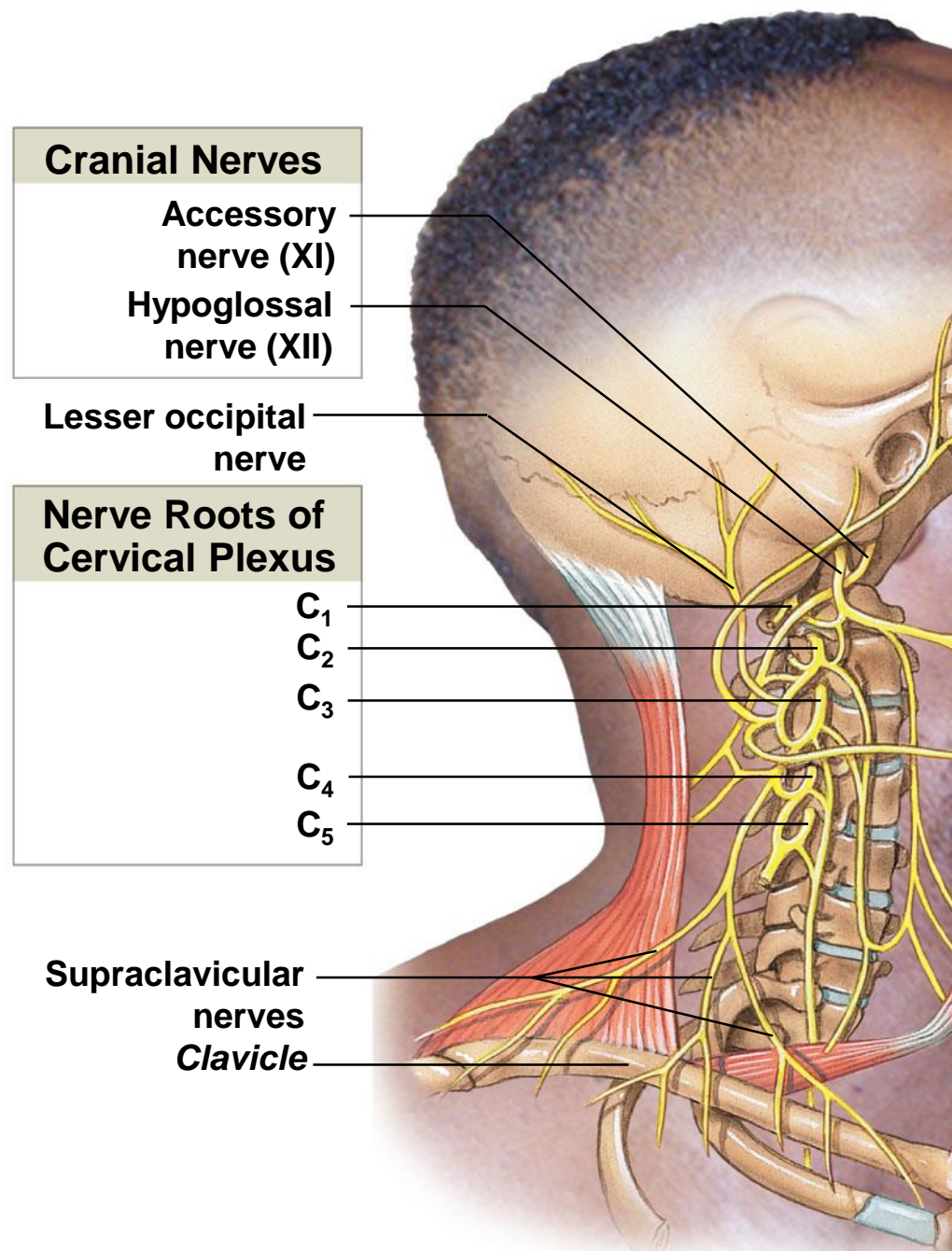
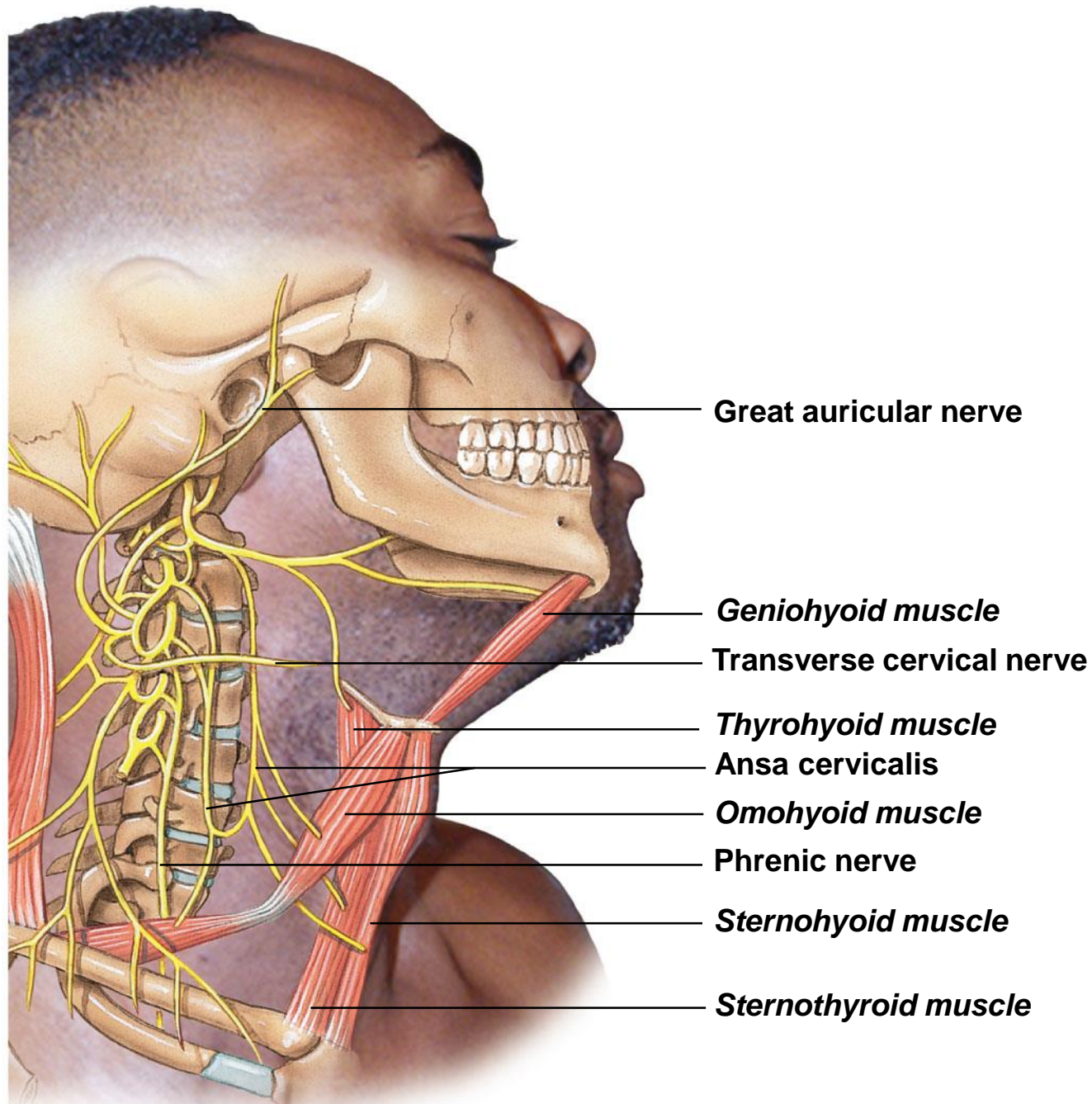


Figure 13-11 The Cervical Plexus



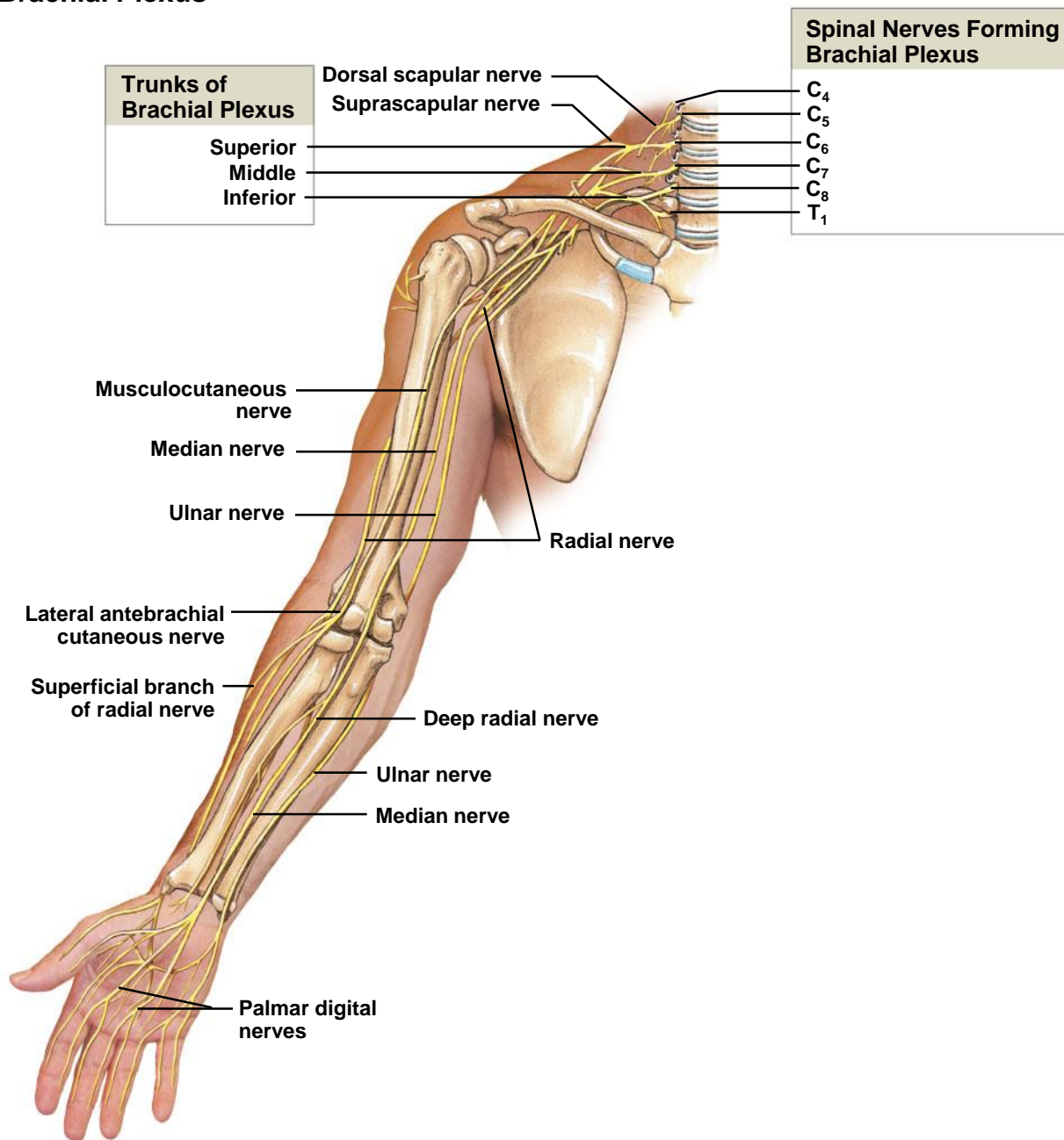
13-4 Spinal Nerves and Plexuses

- The **Brachial Plexus**
 - Innervates pectoral girdle and upper limbs

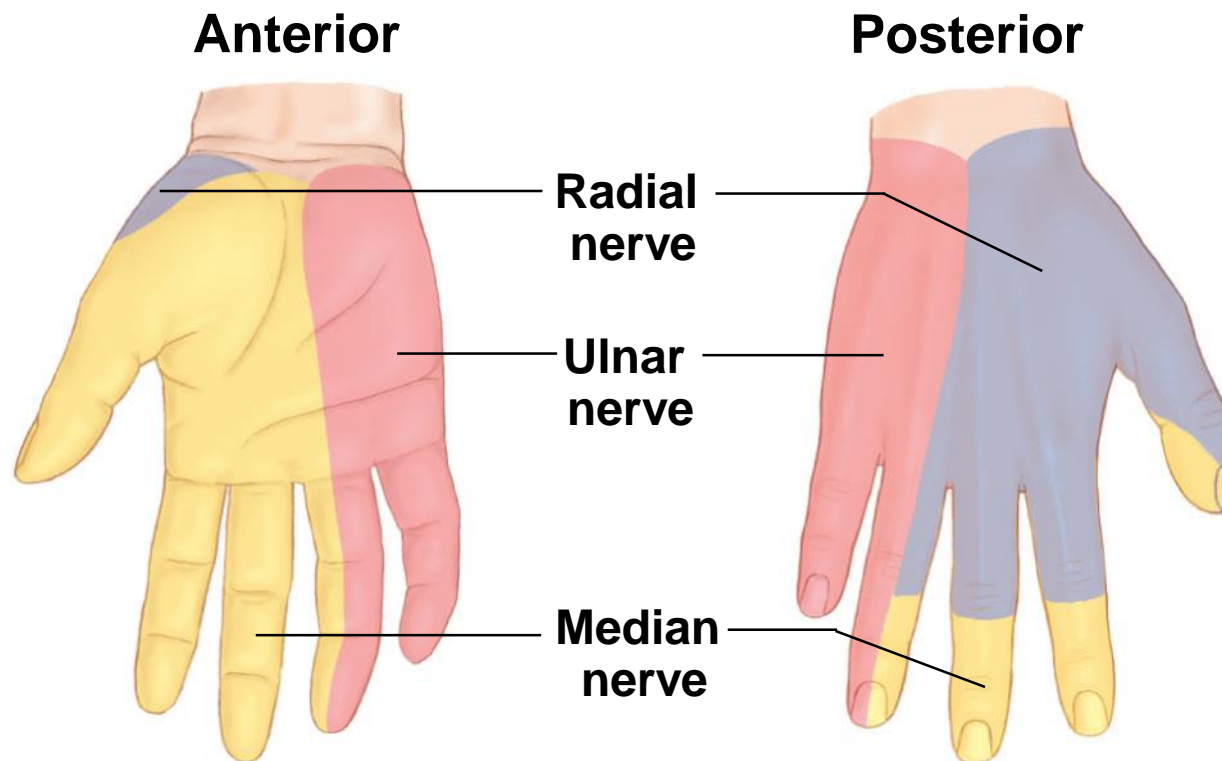
13-4 Spinal Nerves and Plexuses

- The Brachial Plexus
 - Major nerves
 - **Musculocutaneous nerve** (lateral cord)
 - **Median nerve** (lateral and medial cords)
 - **Ulnar nerve** (medial cord)
 - **Axillary nerve** (posterior cord)
 - **Radial nerve** (posterior cord)

Figure 13-12a The Brachial Plexus



a Major nerves originating at the right brachial plexus, anterior view



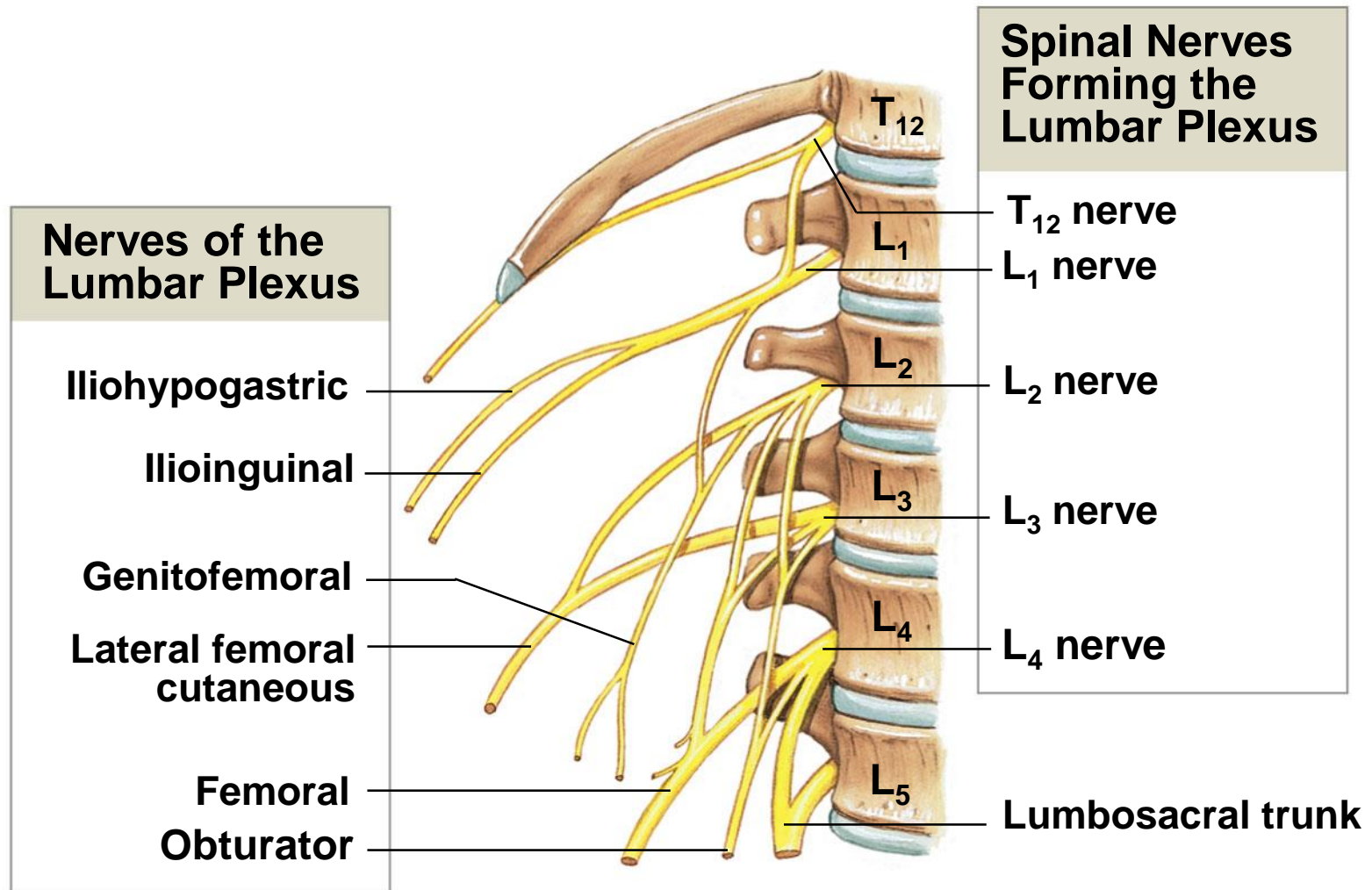
b Areas of the hands serviced by nerves of the right brachial plexus

13-4 Spinal Nerves and Plexuses

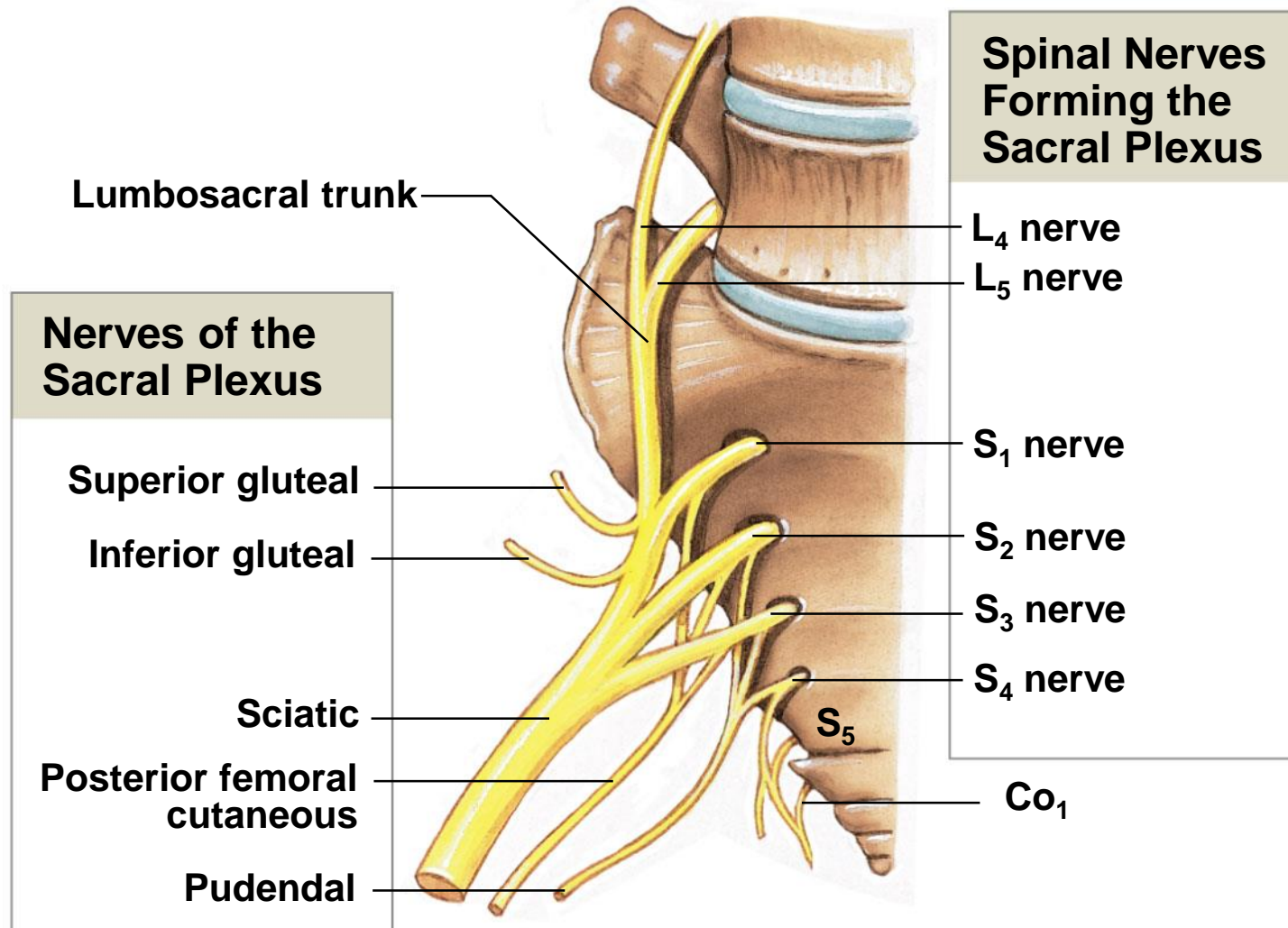
- **The Lumbar Plexus**
 - Major nerve
 - **Femoral nerve**

13-4 Spinal Nerves and Plexuses

- The **Sacral Plexus**
 - Major nerves
 - **Sciatic nerve**
 - Two branches of the sciatic nerve
 1. **Fibular nerve**
 2. **Tibial nerve**

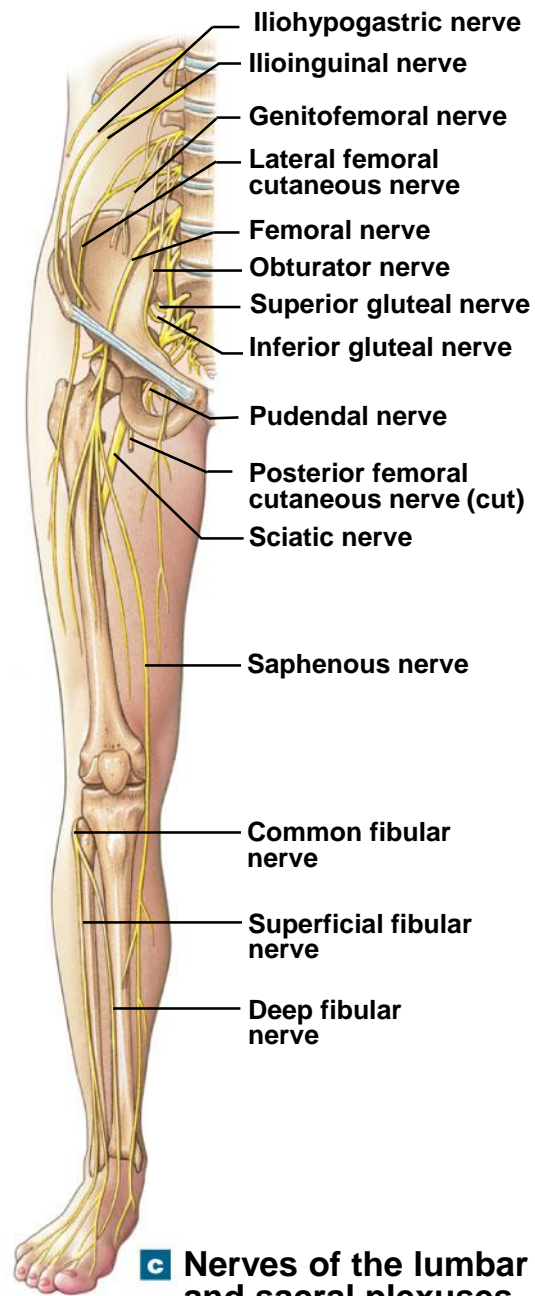


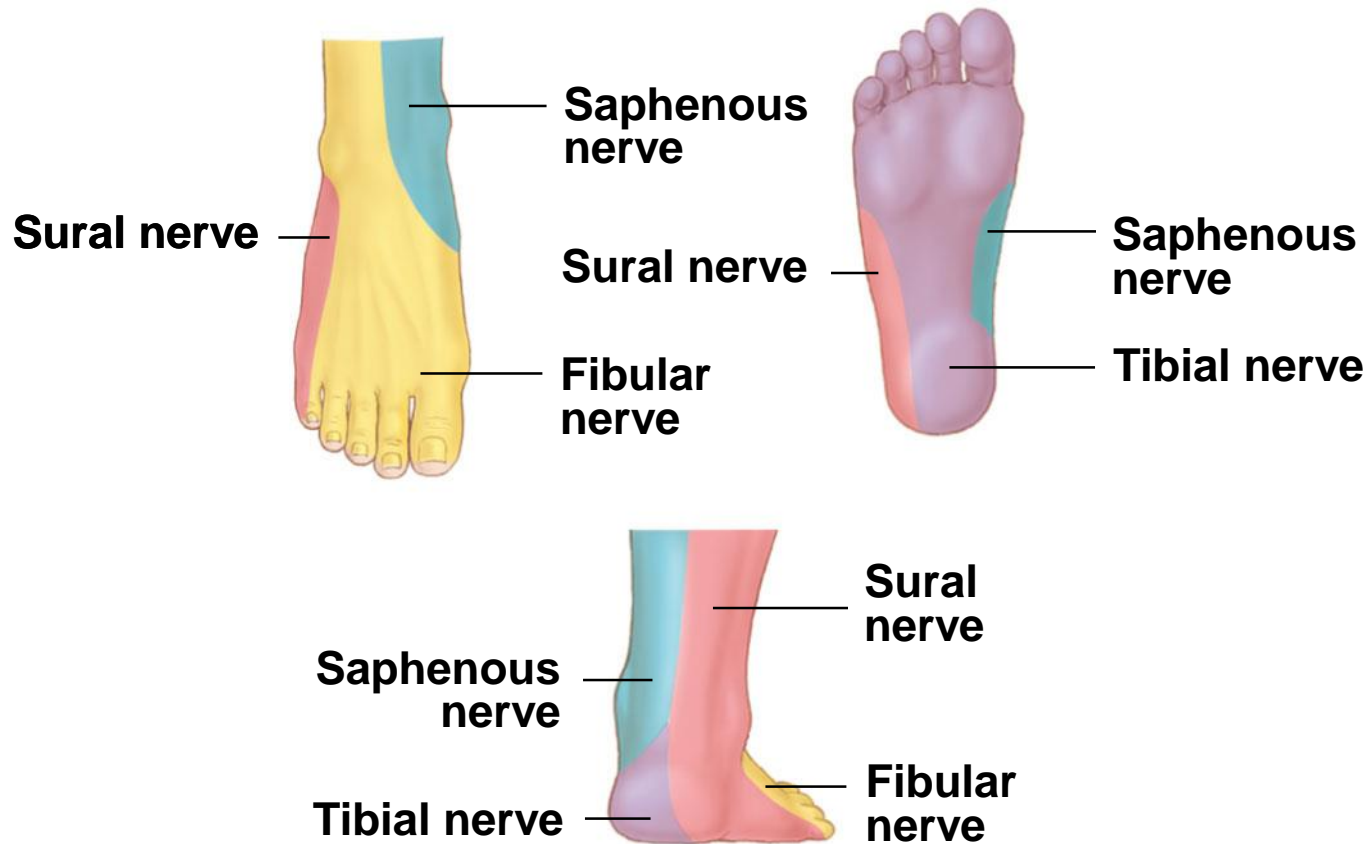
a Lumbar plexus, anterior view



b Sacral plexus, anterior view

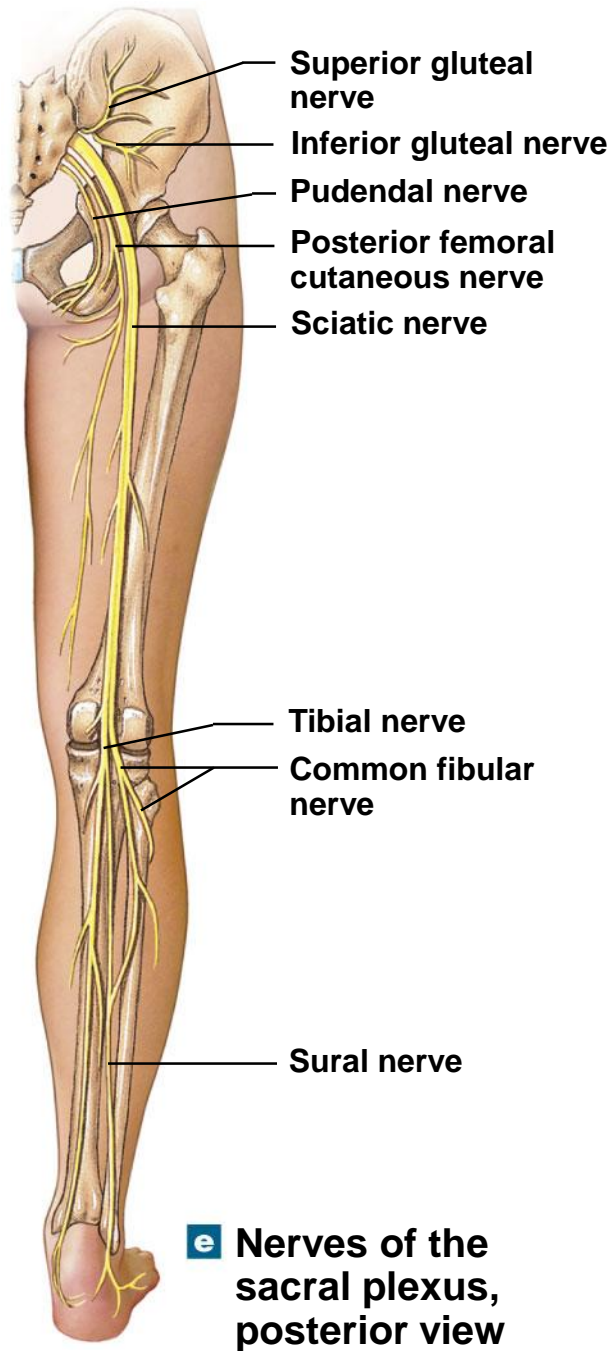
Figure 13-13c The Lumbar and Sacral Plexuses





d Cutaneous distribution of the nerves in the foot and ankle

Figure 13-13e The Lumbar and Sacral Plexuses



13-5 Neuronal Pools

- Functional Organization of Neurons
 - Sensory neurons
 - About 10 million
 - Deliver information to CNS
 - Motor neurons
 - About 1/2 million
 - Deliver commands to peripheral effectors
 - Interneurons
 - About 20 billion
 - Interpret, plan, and coordinate signals in and out

13-5 Neuronal Pools

Five Patterns of *Neural Circuits* in Neuronal Pools

1. Divergence

- Spreads stimulation to many neurons or neuronal pools in CNS

2. Convergence

- Brings input from many sources to single neuron

3. Serial processing

- Moves information in single line

13-5 Neuronal Pools

- Five Patterns of Neural Circuits in Neuronal Pools

4. Parallel processing

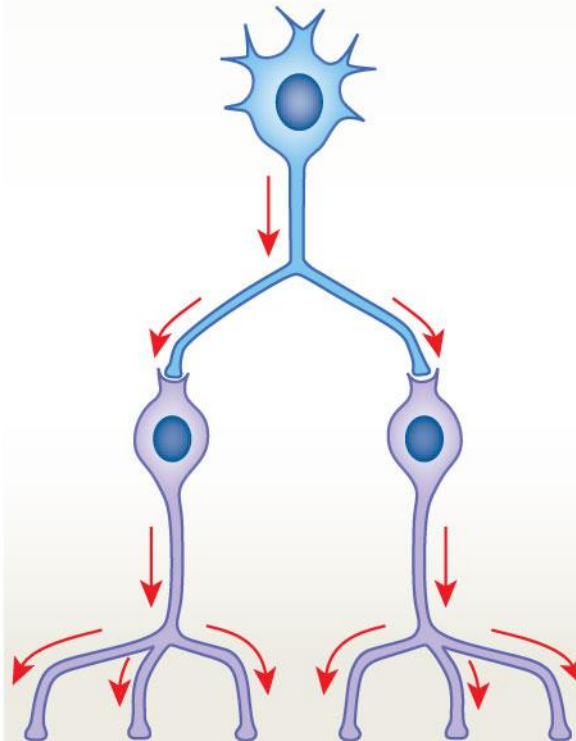
- Moves same information along several paths simultaneously

5. Reverberation

- Positive feedback mechanism
- Functions until inhibited

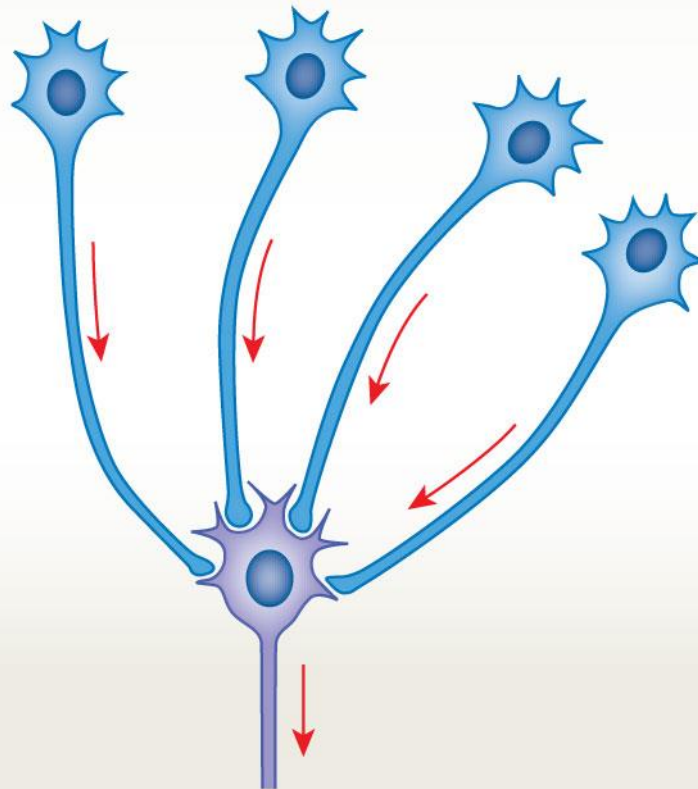
a Divergence

A mechanism for spreading stimulation to multiple neurons or neuronal pools in the CNS



b Convergence

A mechanism for providing input to a single neuron from multiple sources





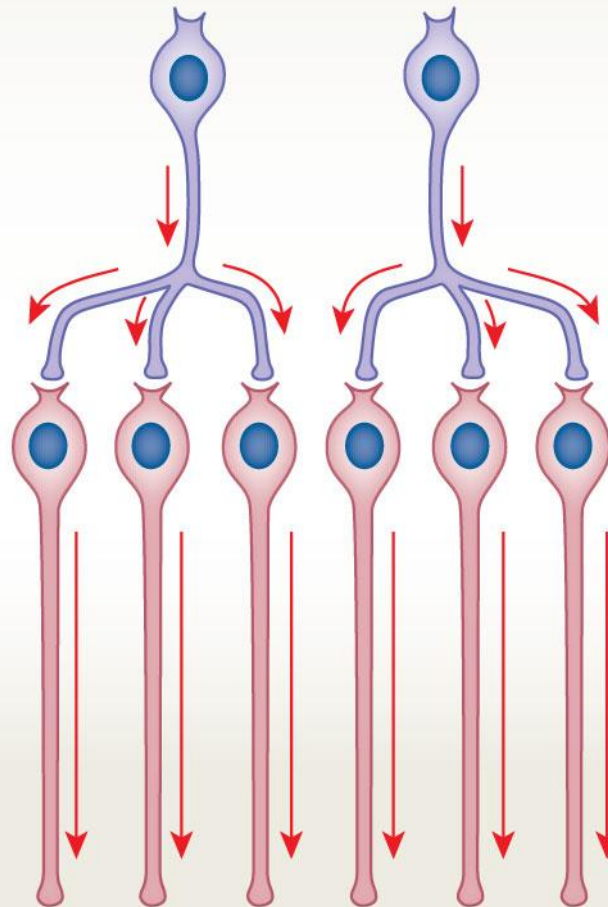
Serial processing

A mechanism in which neurons or pools work sequentially



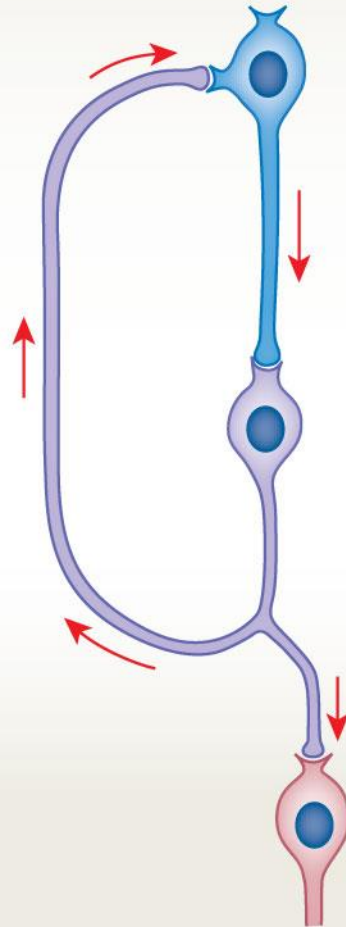
d Parallel processing

A mechanism in which neurons or pools process the same information simultaneously



Reverberation

A positive feedback mechanism



13-6 Reflexes

- **Reflexes**
 - Automatic responses coordinated within spinal cord
 - Through interconnected sensory neurons, motor neurons, and interneurons
 - Produce simple and complex reflexes

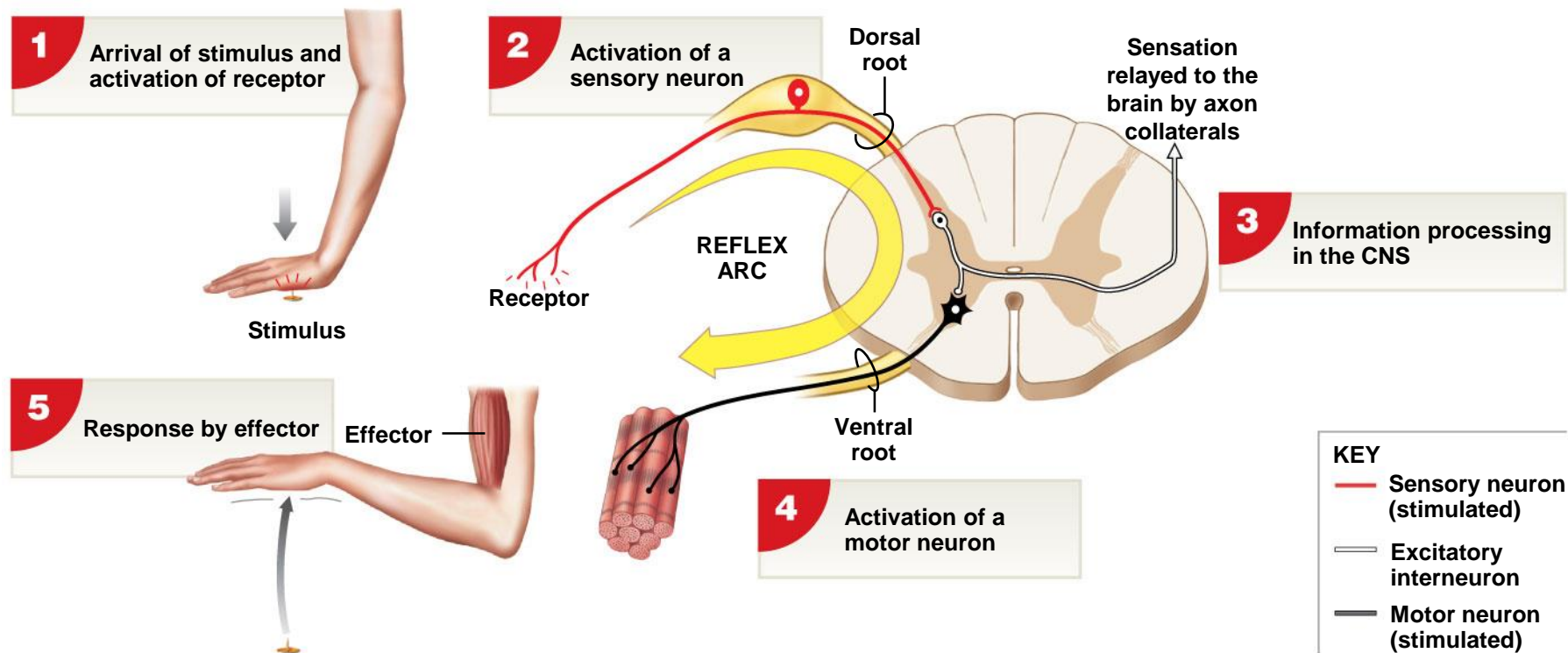
13-6 Reflexes

- *Neural Reflexes*
 - Rapid, automatic responses to specific stimuli
 - Basic building blocks of neural function
 - One neural reflex produces one motor response
 - **Reflex arc**
 - The wiring of a single reflex
 - Beginning at *receptor*
 - Ending at peripheral *effector*
 - Generally opposes original stimulus (negative feedback)

13-6 Reflexes

- Five Steps in a Neural Reflex
 - ***Step 1: Arrival of stimulus, activation of receptor***
 - Physical or chemical changes
 - ***Step 2: Activation of sensory neuron***
 - ***Step 3: Information processing by postsynaptic cell***
 - Triggered by neurotransmitters
 - ***Step 4: Activation of motor neuron***
 - Action potential
 - ***Step 5: Response of peripheral effector***
 - Triggered by neurotransmitters

Figure 13-15 Events in a Neural Reflex



13-6 Reflexes

- Four Classifications of Reflexes
 1. By early development
 2. By type of motor response
 3. By complexity of neural circuit
 4. By site of information processing

13-6 Reflexes

- Development of Reflexes
 - **Innate reflexes**
 - Basic neural reflexes
 - Formed before birth
 - **Acquired reflexes**
 - Rapid, automatic
 - Learned motor patterns

13-6 Reflexes

- Motor Response
 - Nature of resulting motor response
 - **Somatic reflexes**
 - Involuntary control of nervous system
 - Superficial reflexes of skin, mucous membranes
 - Stretch or deep tendon reflexes (e.g., *patellar*, or “*knee-jerk*,” *reflex*)
 - **Visceral reflexes** (*autonomic reflexes*)
 - Control systems other than muscular system

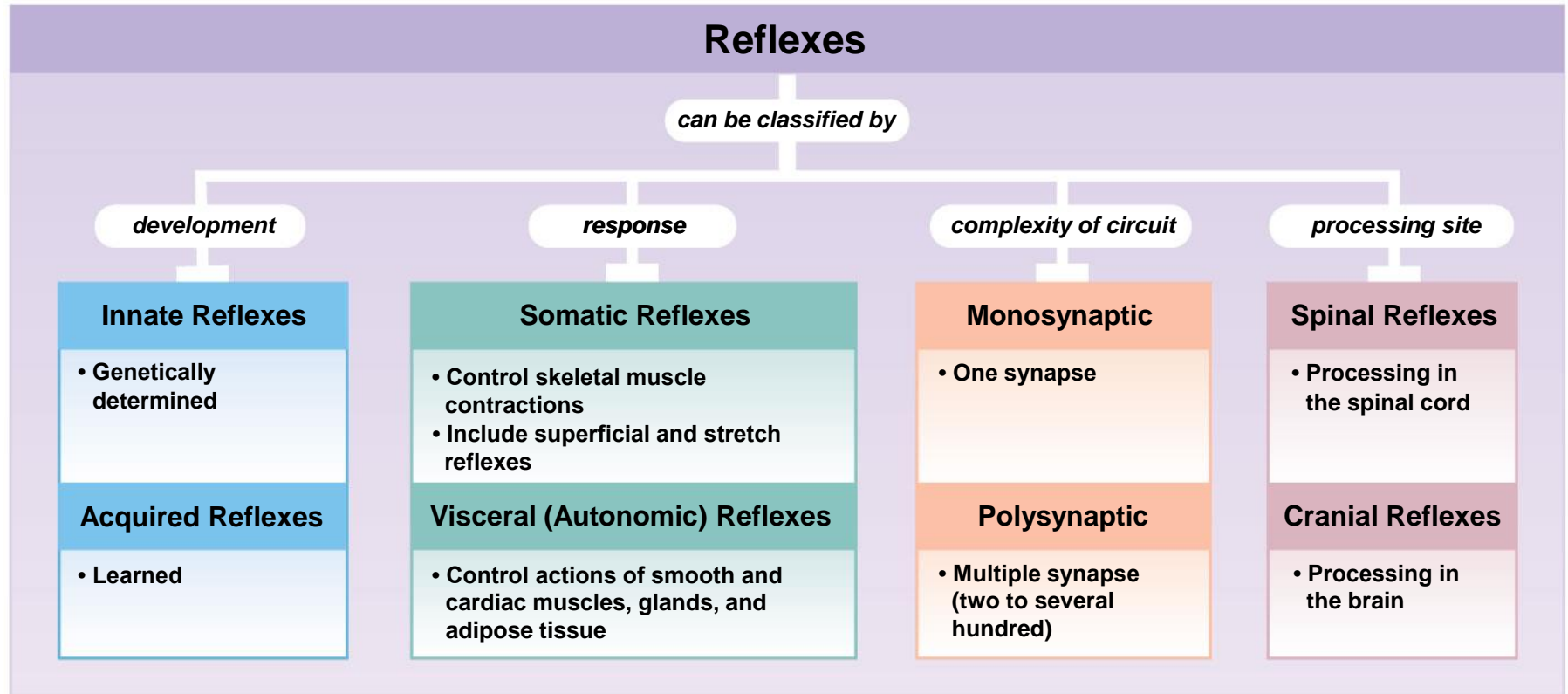
13-6 Reflexes

- Complexity of Neural Circuit
 - **Monosynaptic reflex**
 - Sensory neuron synapses directly onto motor neuron
 - **Polysynaptic reflex**
 - At least one interneuron between sensory neuron and motor neuron

13-6 Reflexes

- Site of Information Processing
 - **Spinal reflexes**
 - Occur in spinal cord
 - **Cranial reflexes**
 - Occur in brain

Figure 13-16 The Classification of Reflexes



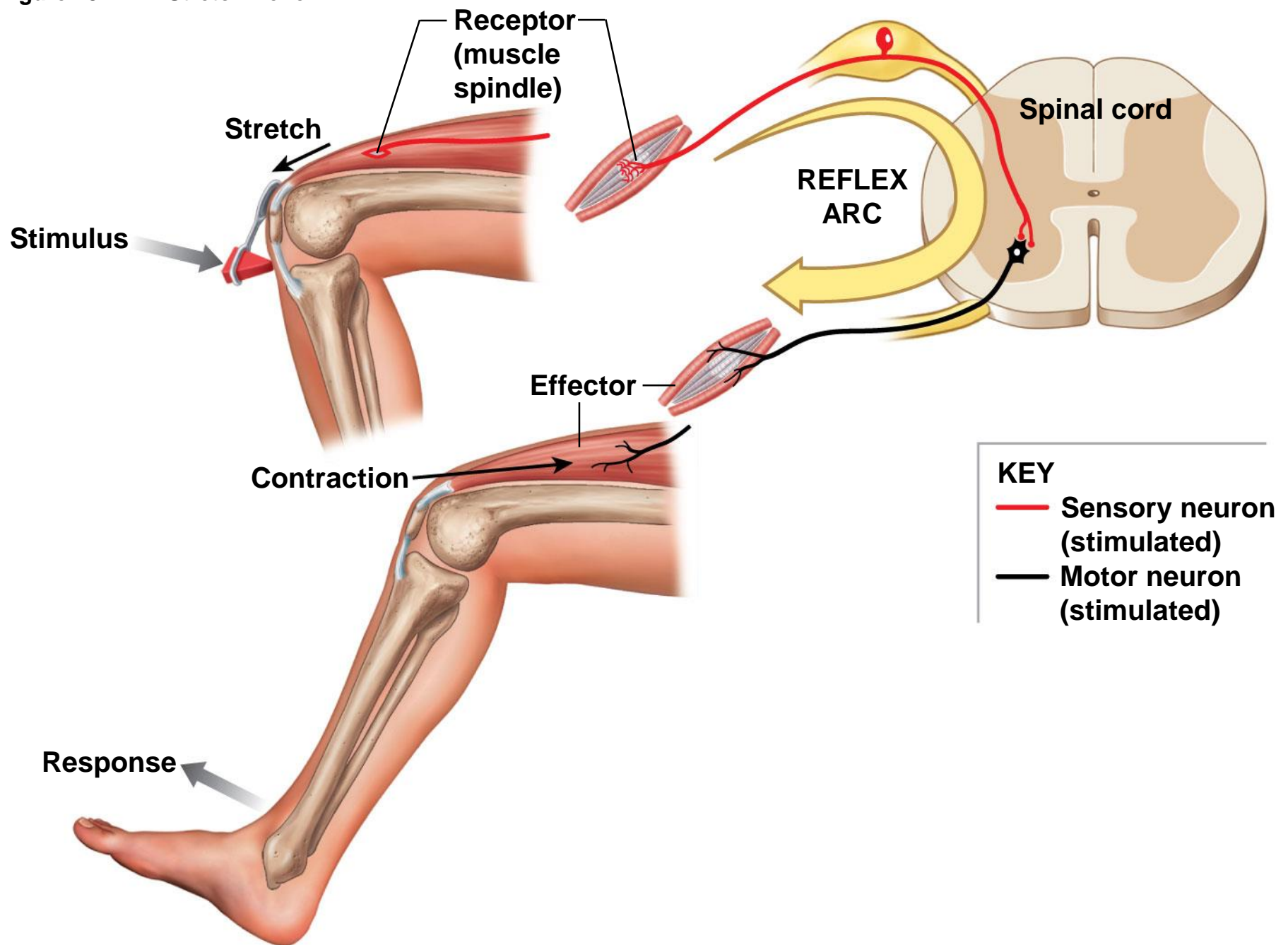
13-7 Spinal Reflexes

- Spinal Reflexes
 - Range in increasing order of complexity
 - Monosynaptic reflexes
 - Polysynaptic reflexes
 - **Intersegmental reflex arcs**
 - Many segments interact
 - Produce highly variable motor response

13-7 Spinal Reflexes

- Monosynaptic Reflexes
 - A **stretch reflex**
 - Have least delay between sensory input and motor output
 - For example, stretch reflex (such as **patellar reflex**)
 - Completed in 20–40 msec
 - Receptor is muscle spindle

Figure 13-17 A Stretch Reflex



13-7 Spinal Reflexes

- **Postural reflexes**
 - Stretch reflexes
 - Maintain normal upright posture
 - Stretched muscle responds by contracting
 - Automatically maintain balance

13-7 Spinal Reflexes

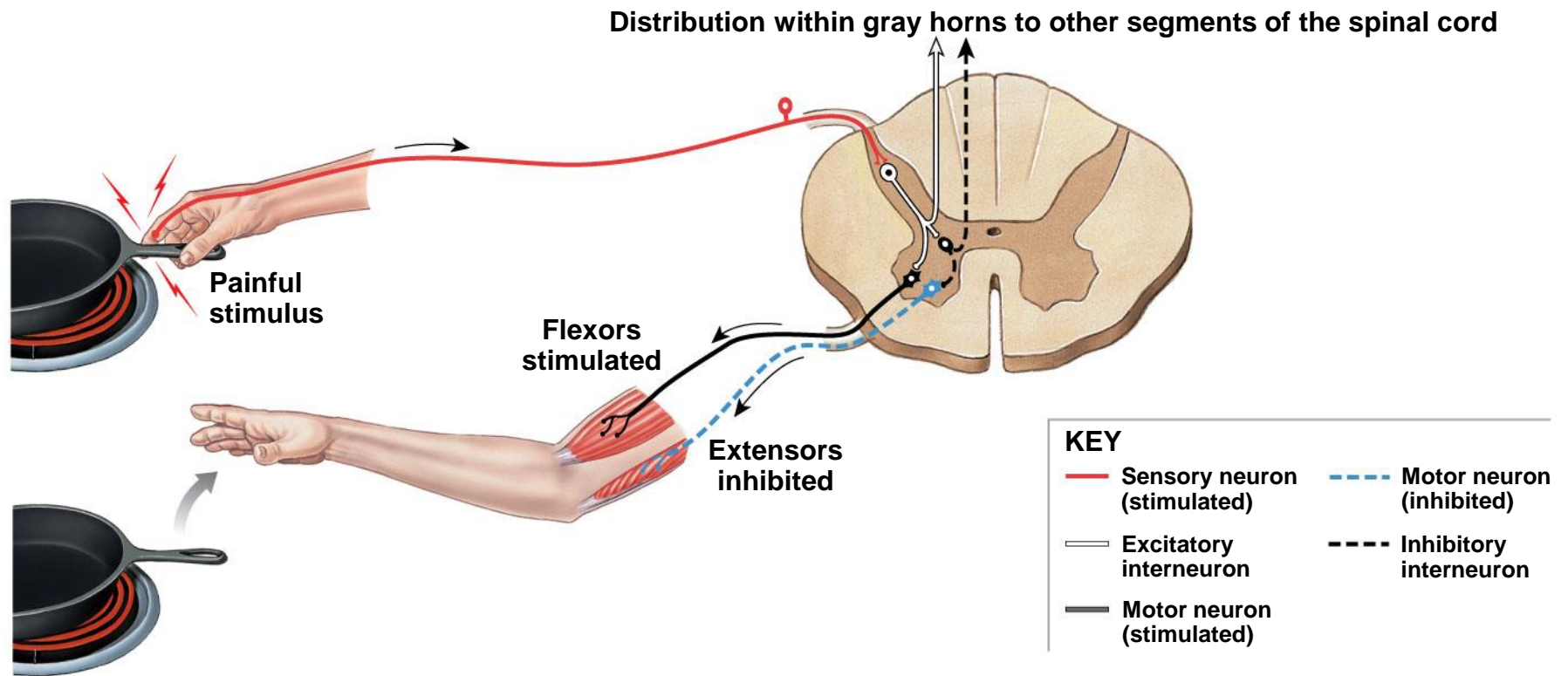
- Polysynaptic Reflexes
 - More complicated than monosynaptic reflexes
 - Interneurons control more than one muscle group
 - Produce either excitatory or inhibitory effects

13-7 Spinal Reflexes

- **Withdrawal Reflexes**

- Move body part away from stimulus (pain or pressure)
 - For example, **flexor reflex**
 - Pulls hand away from hot stove
- Strength and extent of response
 - Depend on intensity and location of stimulus

Figure 13-19 A Flexor Reflex



13-7 Spinal Reflexes

- **Reciprocal Inhibition**

- For flexor reflex to work
 - The stretch reflex of antagonistic (extensor) muscle must be inhibited (reciprocal inhibition) by interneurons in spinal cord

13-8 The Brain Can Alter Spinal Reflexes

- Integration and Control of Spinal Reflexes
 - Reflex behaviors are automatic
 - But processing centers in brain can facilitate or inhibit reflex motor patterns based in spinal cord