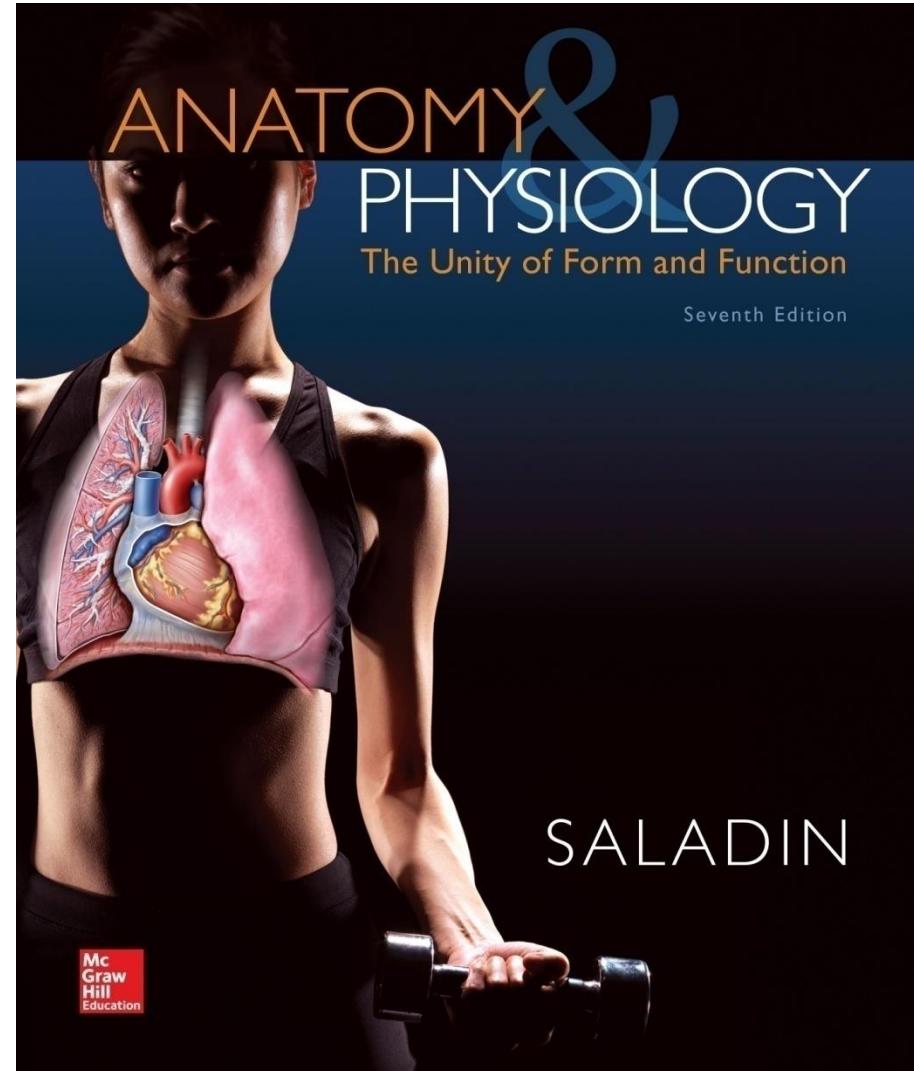


Chapter 13

Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.



Introduction

- **Thousands of Americans are paralyzed by spinal cord injury every year**
- **The spinal cord is the “information highway” that connects the brain with the lower body**
- **In this chapter we will study the spinal cord and spinal nerves**

The Spinal Cord

- **Expected Learning Outcomes**
 - State the three principal functions of the spinal cord.
 - Describe its gross and microscopic structure.
 - Trace the pathways followed by nerve signals traveling up and down the spinal cord.

Functions of the Spinal Cord

- **Conduction**—nerve fibers conduct sensory and motor information up and down the spinal cord
- **Neural integration**—spinal neurons receive input from multiple sources, integrate it, and execute appropriate output (e.g., bladder control)
- **Locomotion**—spinal cord contains central pattern generators: groups of neurons that coordinate repetitive sequences of contractions for walking
- **Reflexes**—involuntary responses to stimuli that are vital to posture, coordination and protection

Surface Anatomy

- **Spinal cord**—cylinder of nervous tissue that arises from the brainstem at the foramen magnum of the skull
 - Occupies the **upper two-thirds of vertebral canal**
 - Inferior margin **ends at L1** or slightly beyond
 - Averages 1.8 cm thick and 45 cm long
 - Gives rise to **31 pairs of spinal nerves**
 - **Segment:** part of the spinal cord supplied by each pair of spinal nerves

Surface Anatomy

- **Longitudinal grooves on anterior and posterior sides**
 - Anterior median fissure and posterior median sulcus
- Spinal cord divided into the **cervical, thoracic, lumbar, and sacral regions**
- **Two areas of the cord are thicker than elsewhere**
 - Cervical enlargement—nerves to upper limb
 - Lumbar enlargement—nerves to pelvic region and lower limbs
- **Medullary cone (conus medullaris):** cord tapers to a point inferior to lumbar enlargement
- **Cauda equina:** bundle of nerve roots that occupy the vertebral canal from L2 to S5

Surface Anatomy

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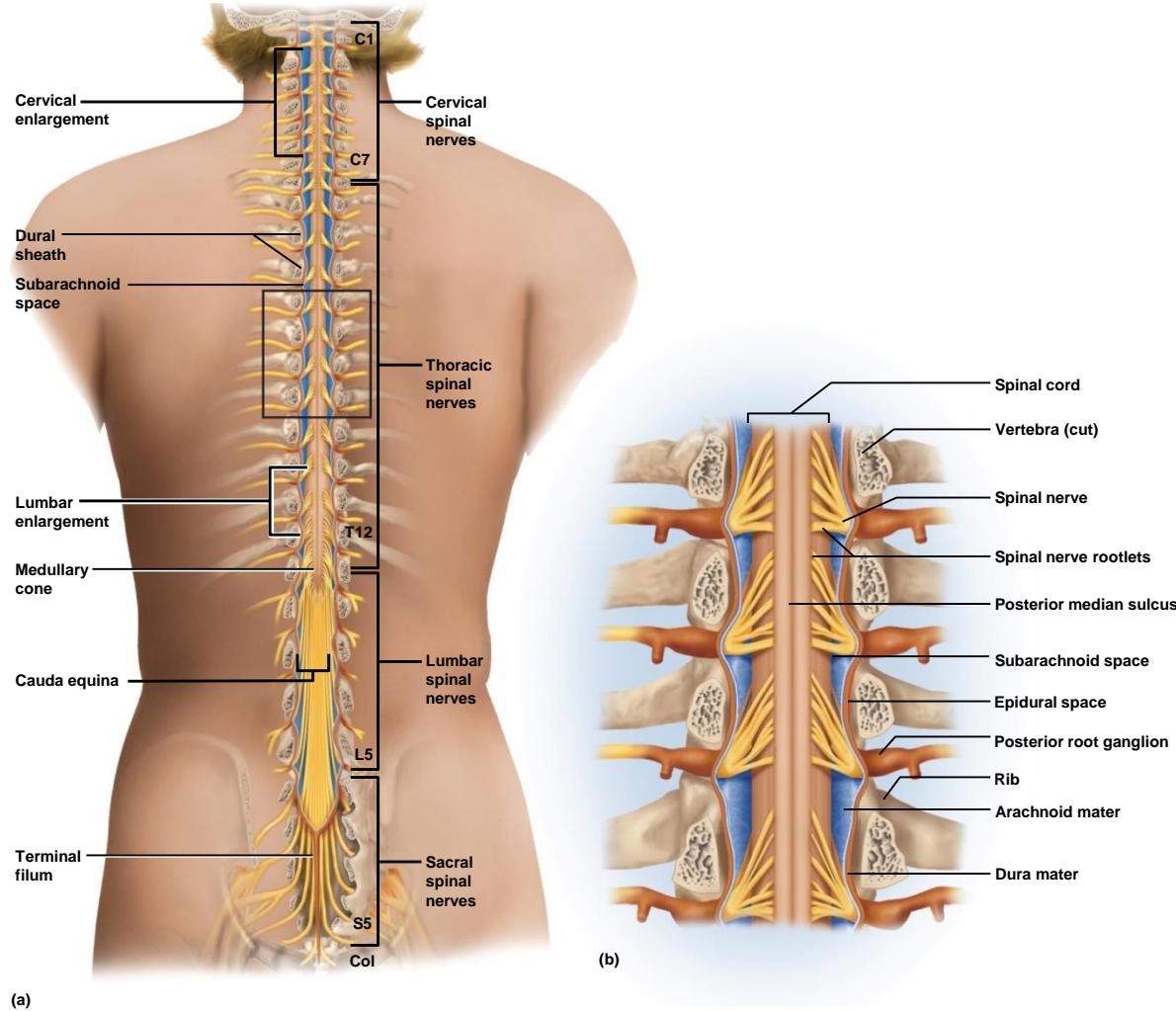


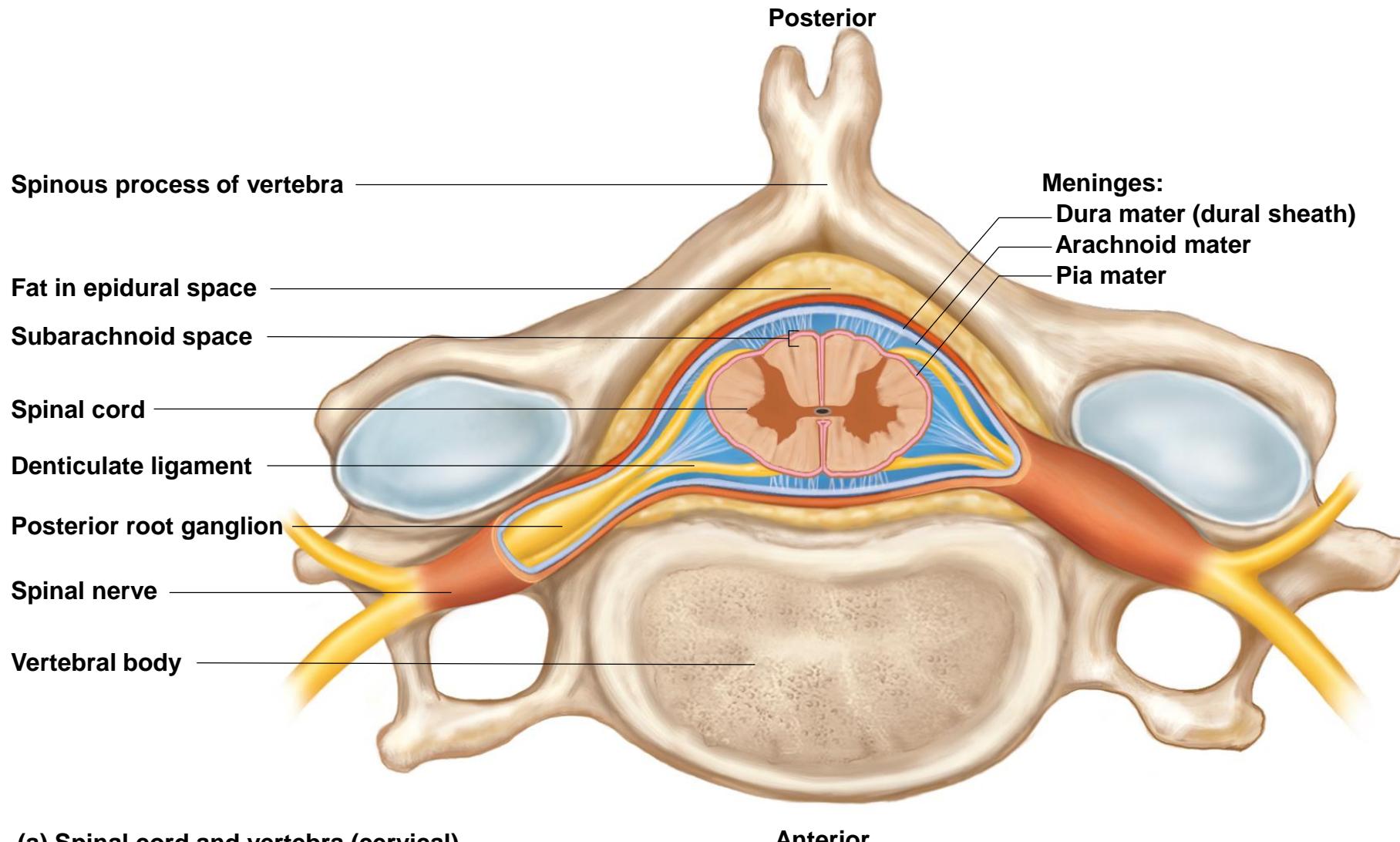
Figure 13.1

Meninges of the Spinal Cord

- **Meninges**—three fibrous membranes that enclose the brain and spinal cord
 - They separate soft tissue of central nervous system from bones of cranium and vertebral canal
 - From superficial to deep: **dura mater**, **arachnoid mater**, and **pia mater**
 - **Dural sheath** surrounds spinal cord and is separated from vertebrae by **epidural space**
 - Arachnoid membrane adheres to dura and is separated from pia by fibers spanning the **subarachnoid space** that is filled with cerebrospinal fluid (CSF)
 - Lumbar puncture (spinal tap) takes sample of CSF
 - Pia is delicate membrane that follows contours of spinal cord and continues inferiorly as a fibrous **terminal filum** that fuses with dura to form **coccygeal ligament**

Meninges of the Spinal Cord

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(a) Spinal cord and vertebra (cervical)

Figure 13.2a

Spina Bifida

- **Spina bifida**—congenital defect in which one or more vertebrae fail to form a complete vertebral arch for enclosure of the spinal cord
 - In 1 baby out of 1,000
 - Common in lumbosacral region
 - Most serious form: **spina bifida cystica**
- **Folic acid** (a B vitamin now added to flour) is part of a healthy diet for all women of childbearing age – it reduces risk of spina bifida
 - Defect occurs during the first 4 weeks of development, so folic acid supplements for mothers must begin 3 months before conception

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Figure 13.3

Cross-Sectional Anatomy

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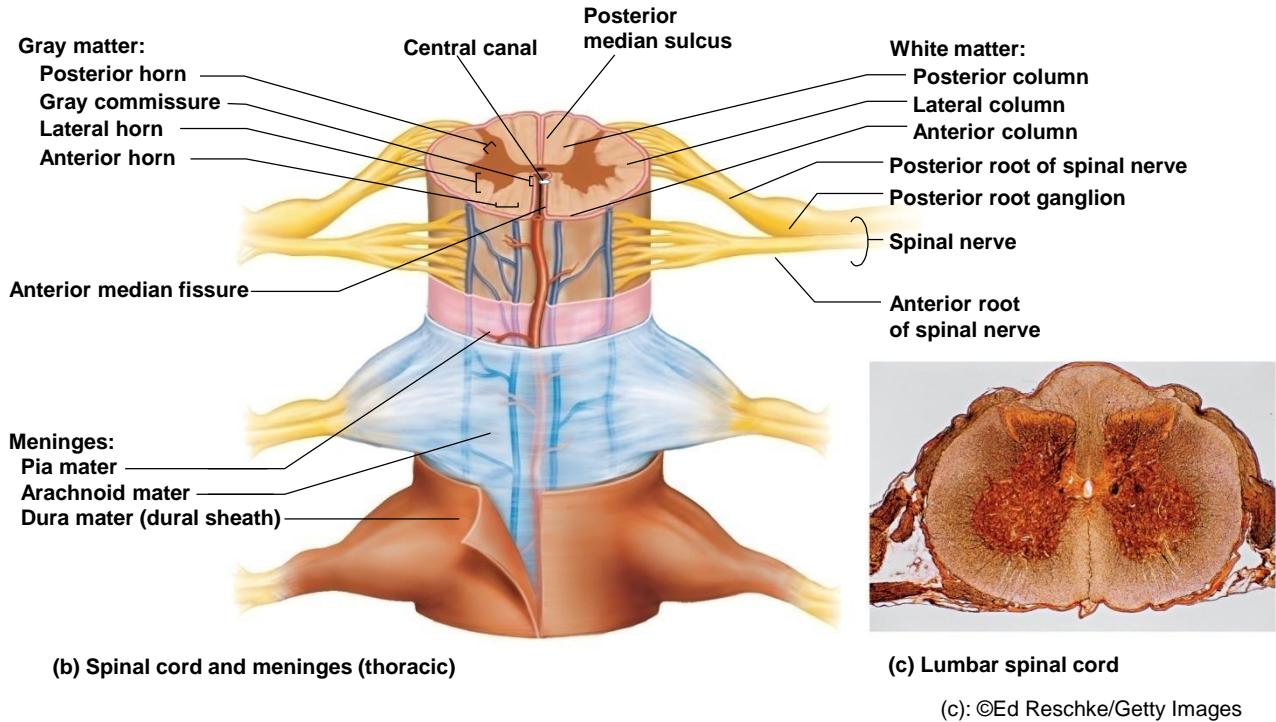


Figure 13.2b,c

- **Central area of gray matter shaped like a butterfly and surrounded by white matter in three columns**
- **Gray matter**—neuron cell bodies with little myelin
 - Site of information processing, synaptic integration
- **White matter**—abundantly myelinated axons
 - Carry signals from one part of the CNS to another

Gray Matter

- Spinal cord has a central core of gray matter that looks butterfly- or H-shaped in cross section
 - Pair of **posterior (dorsal) horns**
 - **Posterior (dorsal) root** of spinal nerve carries only sensory fibers
 - Pair of thicker **anterior (ventral) horns**
 - **Anterior (ventral) root** of spinal nerve carries only motor fibers
 - **Gray commissure** connects right and left sides
 - Has central canal lined with ependymal cells and filled with CSF
 - **Lateral horn:** visible from T2 through L1
 - Contains neurons of sympathetic nervous system

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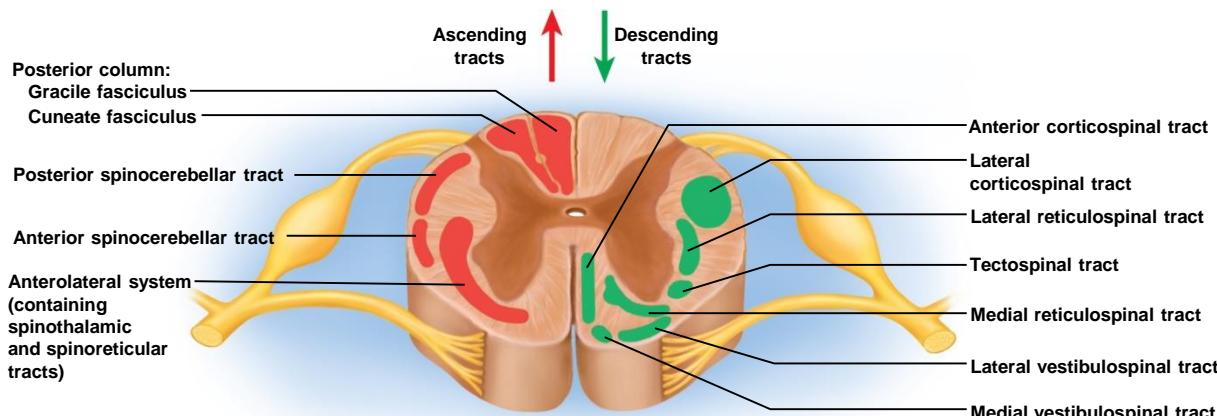


Figure 13.4

White Matter

- White matter of the spinal cord surrounds the gray matter
- Consists of bundles of axons that course up and down the cord providing communication between different levels of the CNS
- Columns or funiculi—three pairs of these white matter bundles
 - Posterior (dorsal), lateral, and anterior (ventral) columns on each side
- Tracts or fasciculi—subdivisions of each column

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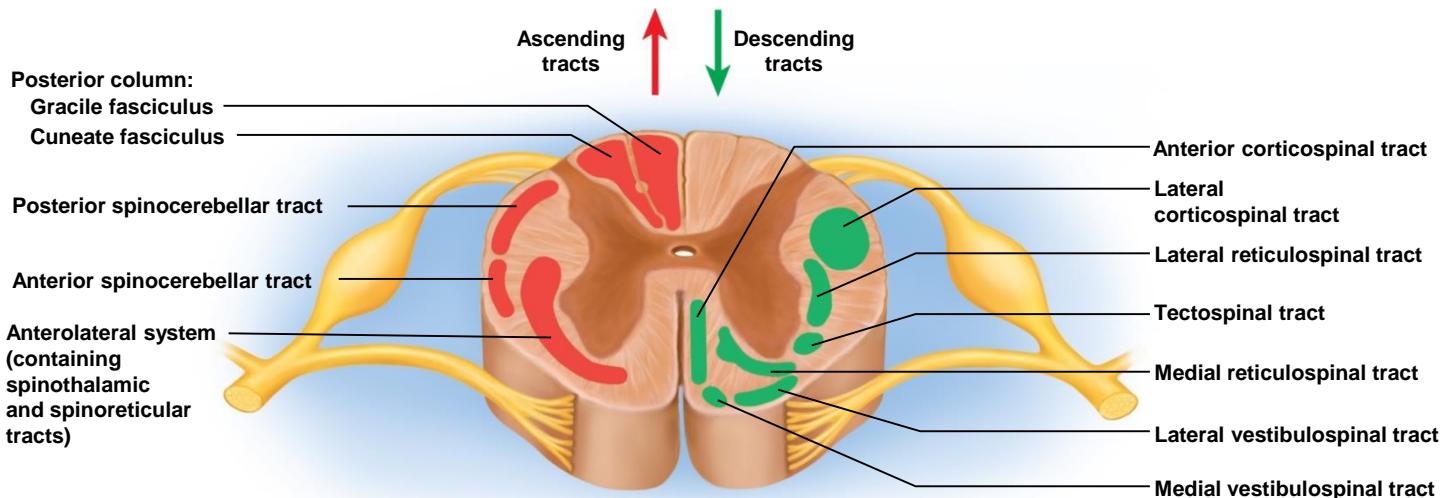


Figure 13.4

Spinal Tracts

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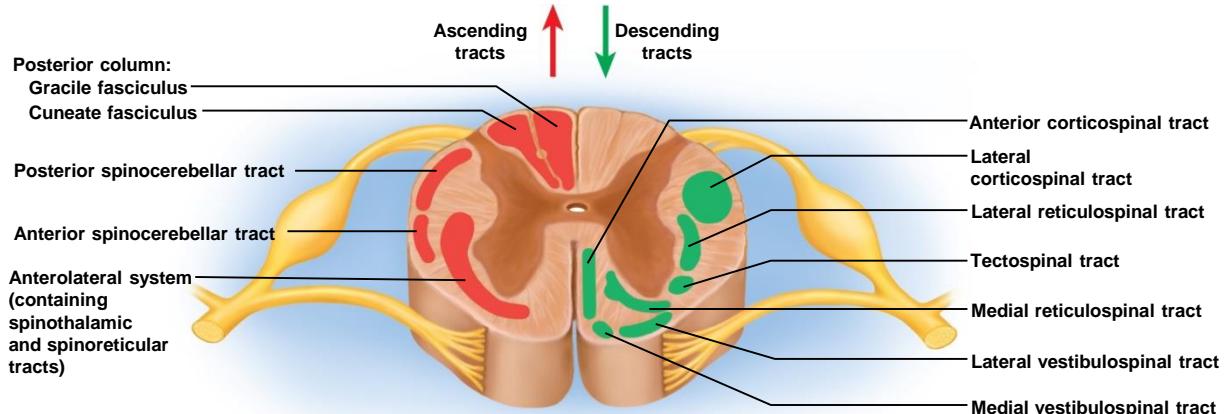


Figure 13.4

- **Fibers in a given tract have similar origin, destination and function**
- **Ascending tracts**—carry sensory information up
- **Descending tracts**—carry motor information down
- **Decussation**—crossing of the midline that occurs in many tracts so that brain senses and controls contralateral side of body
- **Contralateral**—when the origin and destination of a tract are on opposite sides of the body
- **Ipsilateral**—when the origin and destination of a tract are on the same side of the body; does not decussate

Ascending Tracts

- Ascending tracts carry sensory signals **up the spinal cord**
- **Sensory signals travel across three neurons from origin (receptors) to destinations in the sensory areas of the brain**
 - **First-order neurons:** detect stimulus and transmit signal to spinal cord or brainstem
 - **Second-order neurons:** continues to the thalamus at the upper end of the brainstem
 - **Third-order neurons:** carries the signal the rest of the way to the sensory region of the cerebral cortex

Ascending Tracts

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- **Gracile fasciculus**
- **Cuneate fasciculus**
- **Spinothalamic tract**
- **Spinoreticular tract**
- **Posterior (dorsal) and anterior (ventral) spinocerebellar tracts**

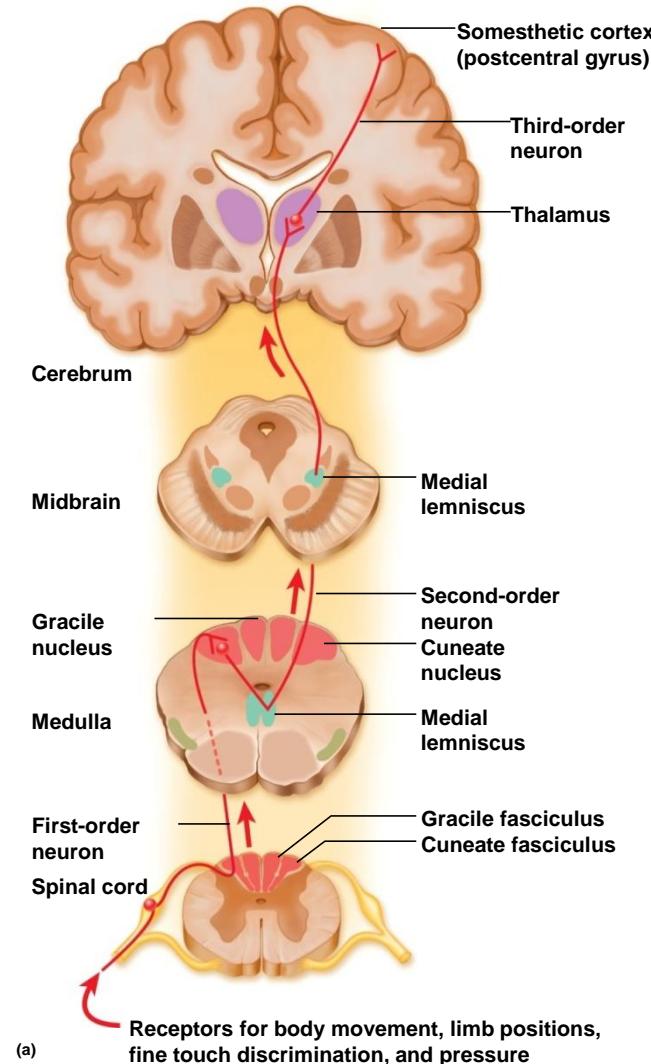


Figure 13.5a

Gracile Fasciculus

- **Gracile fasciculus carries signals from midthoracic and lower parts of body**
- **Below T6, it composes the entire posterior column**
 - At T6 and above, it is accompanied by cuneate fasciculus
- **Consists of first-order nerve fibers traveling up the ipsilateral side of the spinal cord**
- **Terminates at gracile nucleus of medulla oblongata**
- **Carries signals for vibration, visceral pain, deep and discriminative touch, and proprioception from lower limbs and lower trunk**
- **Proprioception**—nonvisual sense of the position and movements of the body

Cuneate Fasciculus

- At T6 and above, cuneate fasciculus occupies lateral portion of posterior column (pushes gracile fasciculus medially)
- It contains first order neurons carrying the same type of sensory signals as the gracile fasciculus
 - Its signals are from upper limb and chest
- Fibers end in cuneate nucleus of ipsilateral medulla oblongata
- Second order neurons of gracile and cuneate nuclei decussate and form the medial lemniscus—a tract leading to thalamus
- Third-order neurons go from thalamus to cerebral cortex, carrying signals to cerebral hemisphere
 - Due to crossing of 2nd order neurons, the left hemisphere processes stimuli from right side of body, and vice versa

Spinothalamic Tract

- **Spinothalamic tract is part of the anterolateral system that passes up the anterior and lateral columns of the spinal cord**
- **It carries signals for pain, pressure, temperature, light touch, tickle, and itch**
- **The tract is made up of axons of second-order neurons**
 - First-order neurons end in posterior horn of spinal cord
 - Second-order neurons start in posterior horn, then decussate and form the spinothalamic tract
 - Third-order neurons continue from there to cerebral cortex
- **Due to cross of second-order neurons, signals are sent to cerebral hemisphere that is contralateral to site of stimulus**

Spinoreticular Tract

- **Spinoreticular tract travels up anterolateral system**
- **Carries pain signals resulting from tissue injury**
- **It is made up of axons of second-order neurons**
 - First-order neurons enter posterior horn and immediately synapse with second-order neurons
 - Second-order neurons decussate to opposite anterolateral system
 - Ascend the cord and end in **reticular formation**: loosely organized core of gray matter in the medulla and pons
 - Third-order neurons continue from the pons to the thalamus
 - Fourth-order neurons complete the path to the cerebral cortex

Spinocerebellar Tracts

- **Anterior and posterior spinocerebellar tracts travel through lateral column**
- **Carry proprioceptive signals from limbs and trunk up to the cerebellum**
- **They are made up of axons of second-order neurons**
 - First-order neurons originate in the muscles and tendons and end in posterior horn of the spinal cord
 - Second-order nerves ascend spinocerebellar tracts and end in cerebellum providing it with feedback needed to coordinate movements
 - Posterior spinocerebellar tract stays ipsilateral
 - Anterior spinocerebellar tracts cross over and travel up contralateral side, but cross back to end in ipsilateral cerebellum

Descending Tracts

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- **Descending tracts**—carry motor signals down brainstem and spinal cord
- **Involve two motor neurons**
 - **Upper motor neuron** originates in cerebral cortex or brainstem and terminates on a lower motor neuron
 - **Lower motor neuron** soma is in brainstem or spinal cord
 - **Axon of lower motor neuron** leads to muscle or other target organ

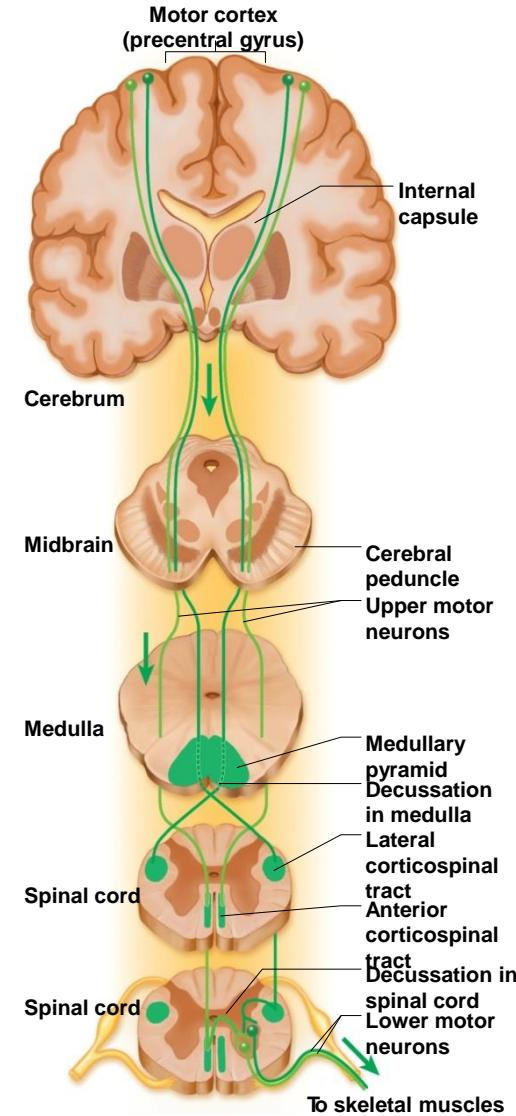


Figure 13.6

Corticospinal Tracts

- **Corticospinal tracts carry signals from cerebral cortex for precise, finely coordinated movements**
- **Pyramids**—ridges on anterior surface of medulla oblongata formed from fibers of this system
- Most fibers decussate in lower medulla forming the **lateral corticospinal tract** on contralateral side of spinal cord
- Some fibers form the **anterior (ventral) corticospinal tract** that descends in the ipsilateral side of spinal cord and decussates inferiorly (like lateral tract, they ultimately control contralateral muscles)

Descending Tracts

- **Tectospinal tract**—begins in midbrain region (**tectum**)
 - Crosses to contralateral side of midbrain
 - Reflex turning of head in response to sights and sounds
- **Lateral and medial reticulospinal tracts**
 - Originate in the **reticular formation** of brainstem
 - Control muscles of upper and lower limbs, especially those for posture and balance
 - Contain **descending analgesic pathways**
 - Reduce the transmission of pain signals to brain
- **Lateral and medial vestibulospinal tracts**
 - Begin in brainstem **vestibular nuclei**
 - Receive impulses for balance from inner ear
 - Control extensor muscles of limbs for balance control

The Spinal Nerves

- **Expected Learning Outcomes**
 - Describe the anatomy of nerves and ganglia in general.
 - Describe the attachments of a spinal nerve to the spinal cord.
 - Trace the branches of a spinal nerve distal to its attachment.
 - Name the five plexuses of spinal nerves and describe their general anatomy.
 - Name some major nerves that arise from each plexus.
 - Explain the relationship of dermatomes to the spinal nerves.

General Anatomy of Nerves and Ganglia

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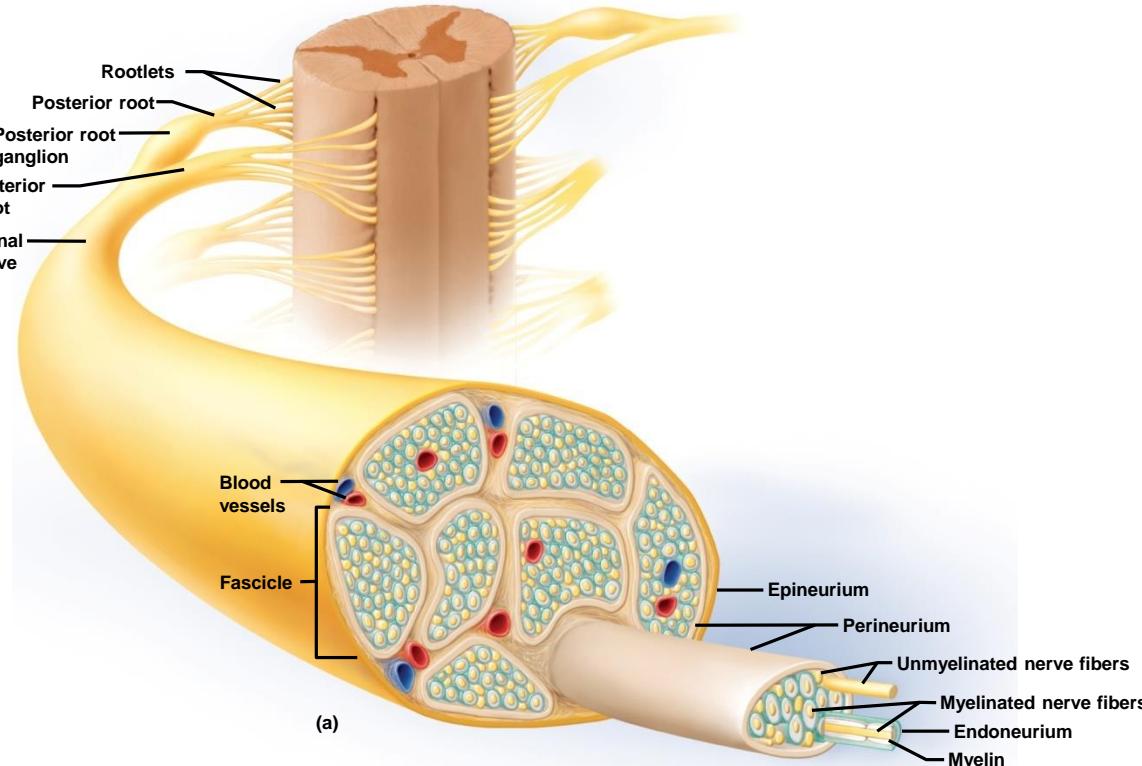


Figure 13.8a

General Anatomy of Nerves and Ganglia

- Spinal cord communicates with the rest of the body by way of **spinal nerves**
- **Nerve**—a cord-like organ composed of numerous nerve fibers (axons) bound together by connective tissue
 - **Mixed nerves** contain both afferent (sensory) and efferent (motor) fibers

General Anatomy of Nerves and Ganglia

- Nerve fibers of peripheral nervous system are surrounded by **Schwann cells** forming **neurilemma** and **myelin sheath** around the axon
- **Endoneurium**—loose connective tissue external to neurilemma
- **Perineurium**—layers of overlapping squamous cells that wrap **fascicles**: bundles of nerve fibers
- **Epineurium**—dense irregular connective tissue that wraps entire nerve
- **Blood vessels penetrate connective tissue coverings**
 - Provide plentiful blood supply

Poliomyelitis and ALS

- Both diseases cause destruction of motor neurons leading to skeletal muscle atrophy from lack of innervation
- Poliomyelitis
 - Caused by the poliovirus
 - Destroys motor neurons in brainstem and anterior horn of spinal cord
 - Signs of polio include muscle pain, weakness, and loss of some reflexes
 - Followed by paralysis, muscular atrophy, and respiratory arrest
 - Virus spreads by fecal contamination of water

Poliomyelitis and ALS

- **Amyotrophic lateral sclerosis (ALS) or Lou Gehrig disease**
 - Destruction of motor neurons and muscular atrophy
 - Also **sclerosis (scarring)** of lateral regions of the spinal cord
 - Astrocytes fail to reabsorb the neurotransmitter glutamate from the tissue fluid
 - Accumulates to toxic levels
 - Early signs: muscular weakness; difficulty speaking, swallowing, and using hands
 - Sensory and intellectual functions remain unaffected

General Anatomy of Nerves and Ganglia

- **Sensory (afferent) nerves**
 - Carry signals from sensory receptors to the CNS
- **Motor (efferent) nerves**
 - Carry signals from CNS to muscles and glands
- **Mixed nerves**
 - Consists of both afferent and efferent fibers
- **Both sensory and motor fibers can also be described as:**
 - **Somatic or visceral**
 - **General or special**

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TABLE 13.2		The Classification of Nerve Fibers
Class	Description	
Afferent fibers	Carry sensory signals from receptors to the CNS	
Efferent fibers	Carry motor signals from the CNS to effectors	
Somatic fibers	Innervate skin, skeletal muscles, bones, and joints	
Visceral fibers	Innervate blood vessels, glands, and viscera	
General fibers	Innervate widespread organs such as muscles, skin, glands, viscera, and blood vessels	
Special fibers	Innervate more localized organs in the head, including the eyes, ears, olfactory and taste receptors, and muscles of chewing, swallowing, and facial expression	

General Anatomy of Nerves and Ganglia

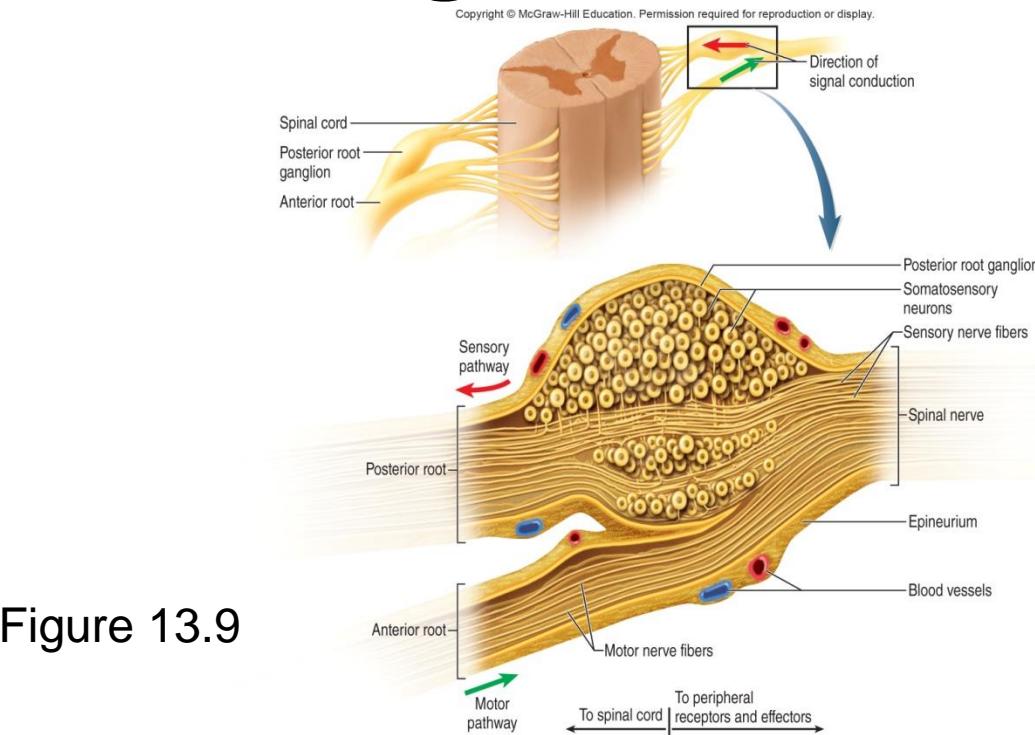


Figure 13.9

- **Ganglion**—cluster of neurosomas outside the CNS
 - Enveloped in an endoneurium continuous with that of the nerve
- **Among neurosomas are bundles of nerve fibers leading into and out of the ganglion**
- **Posterior root ganglion associated with spinal nerves**

Spinal Nerves

- **31 pairs** of spinal nerves (mixed nerves)
 - **8 cervical** (C1–C8)
 - First cervical nerve exits between skull and atlas
 - Others exit at **intervertebral foramina**
 - **12 thoracic** (T1–T12)
 - **5 lumbar** (L1–L5)
 - **5 sacral** (S1–S5)
 - **1 coccygeal** (Co1)

Spinal Nerves

- **Each spinal nerve is formed from two roots (proximal branches)**
 - **Posterior (dorsal) root** is sensory input to spinal cord
 - **Posterior (dorsal) root ganglion**—contains the somas of sensory neurons carrying signals to the spinal cord
 - Six to eight **rootlets** enter posterior horn of cord
 - **Anterior (ventral) root** is motor output out of spinal cord
 - Six to eight **rootlets** leave spinal cord and converge to form anterior root
 - **Cauda equina:** formed from roots arising from L2 to Co1

Spinal Nerves

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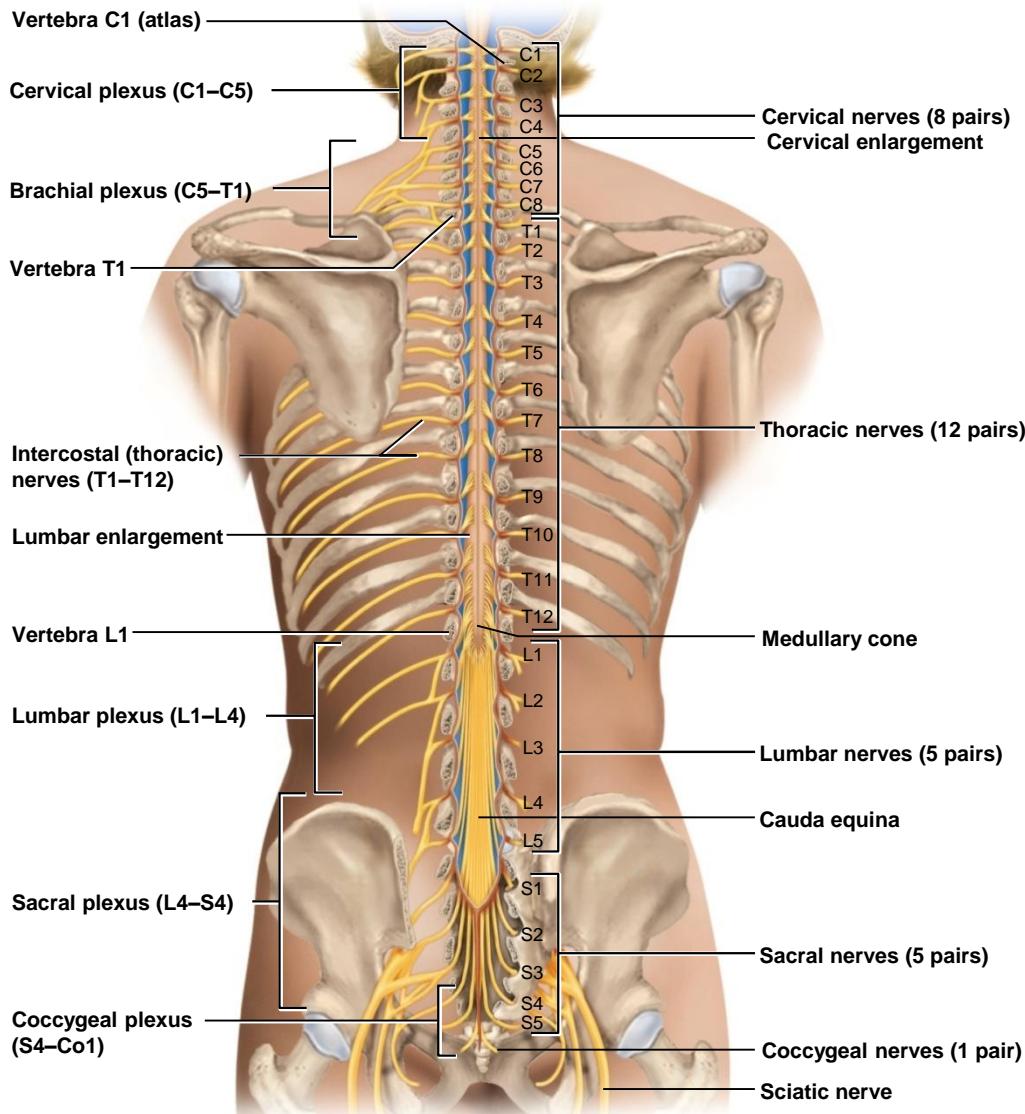


Figure 13.10

Spinal Nerves

- Beyond the vertebra, the nerve divides into **distal branches**:
 - **Anterior ramus**:
 - In thoracic region, it gives rise to intercostal nerve
 - In other regions, anterior rami form plexuses
 - **Posterior ramus**: innervates the muscles and joints in that region of the spine and the skin of the back
 - **Meningeal branch**: reenters the vertebral canal and innervates the meninges, vertebrae, and spinal ligaments

Spinal Nerves

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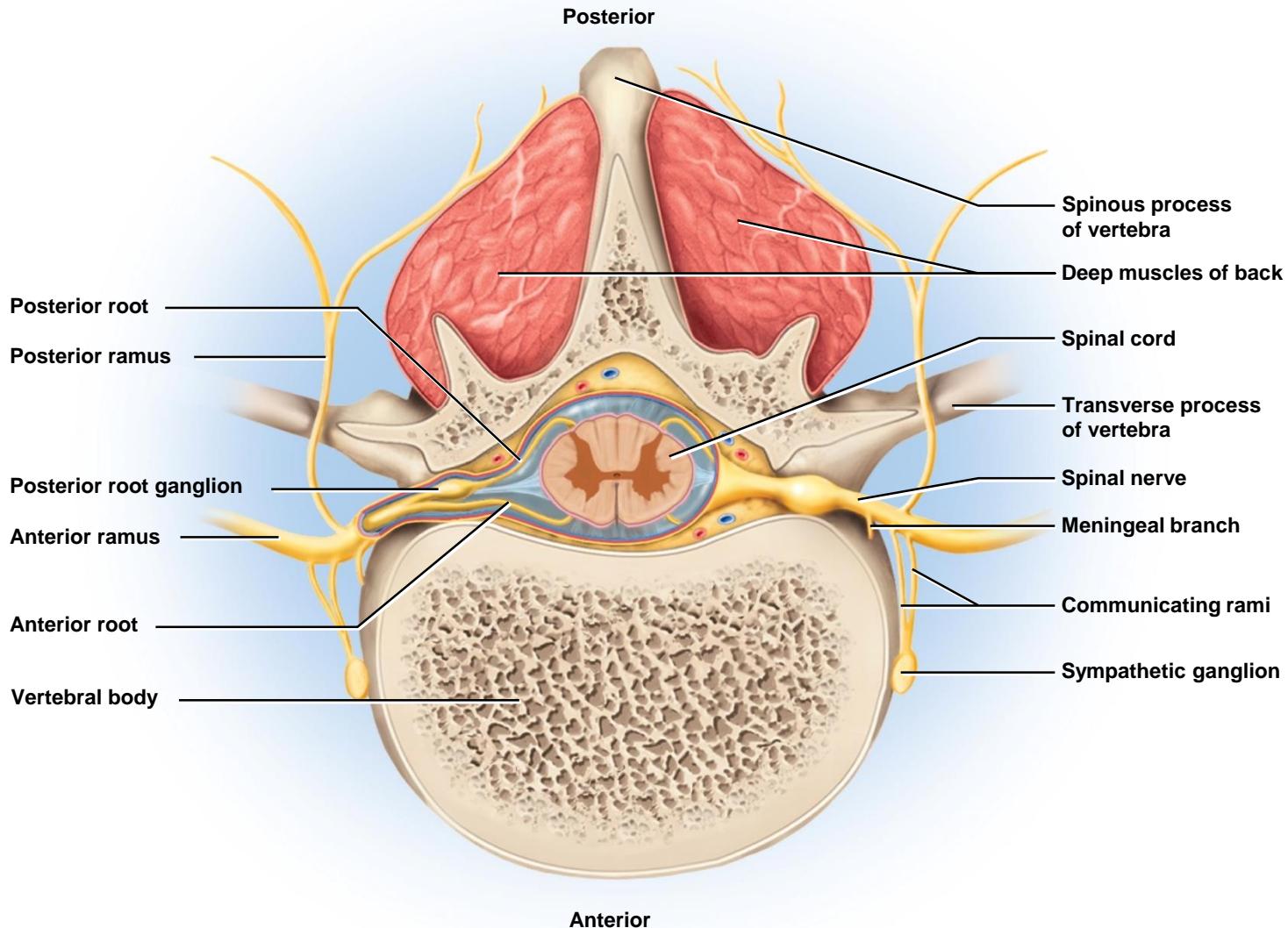
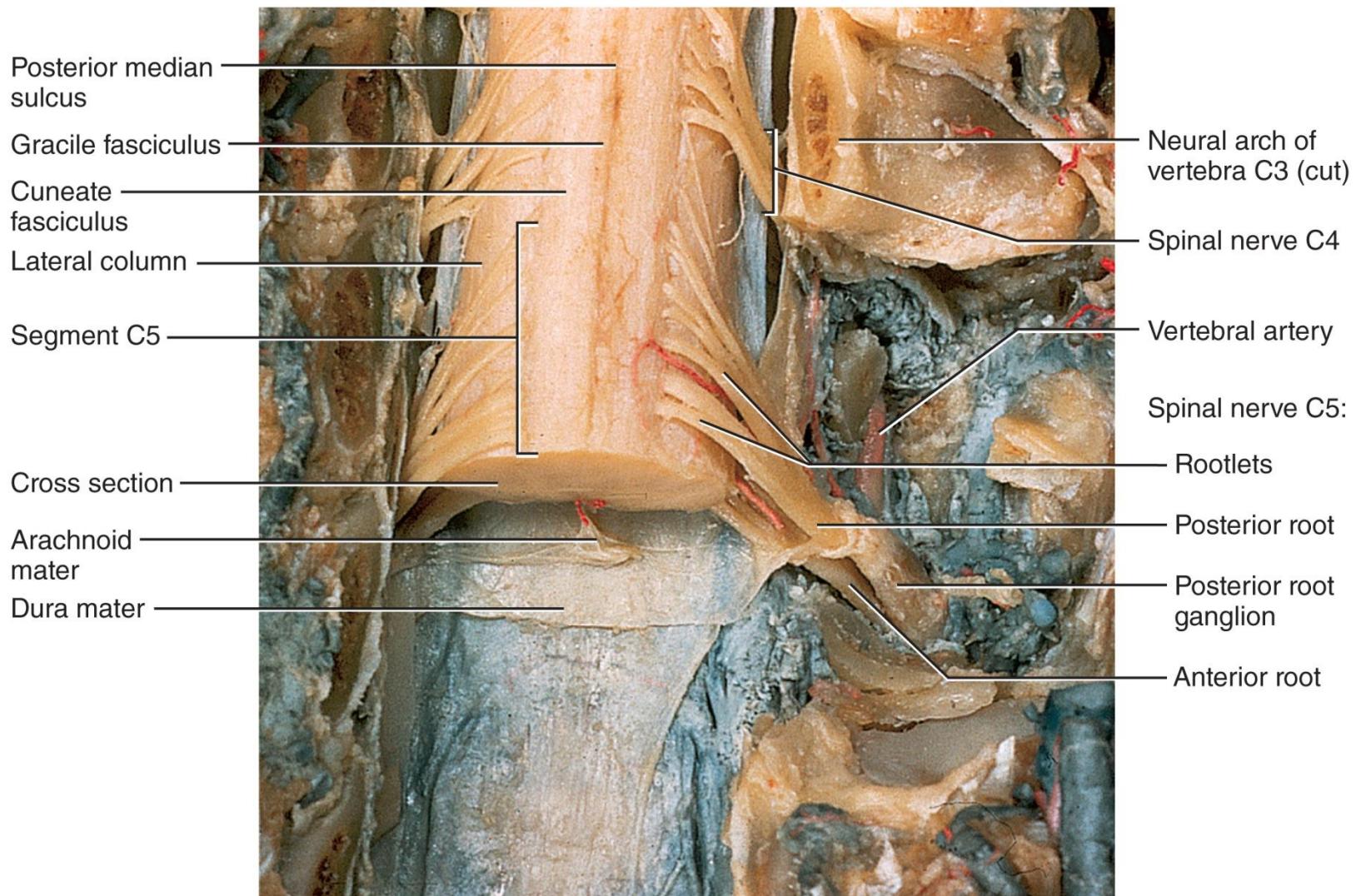


Figure 13.11

Spinal Nerves

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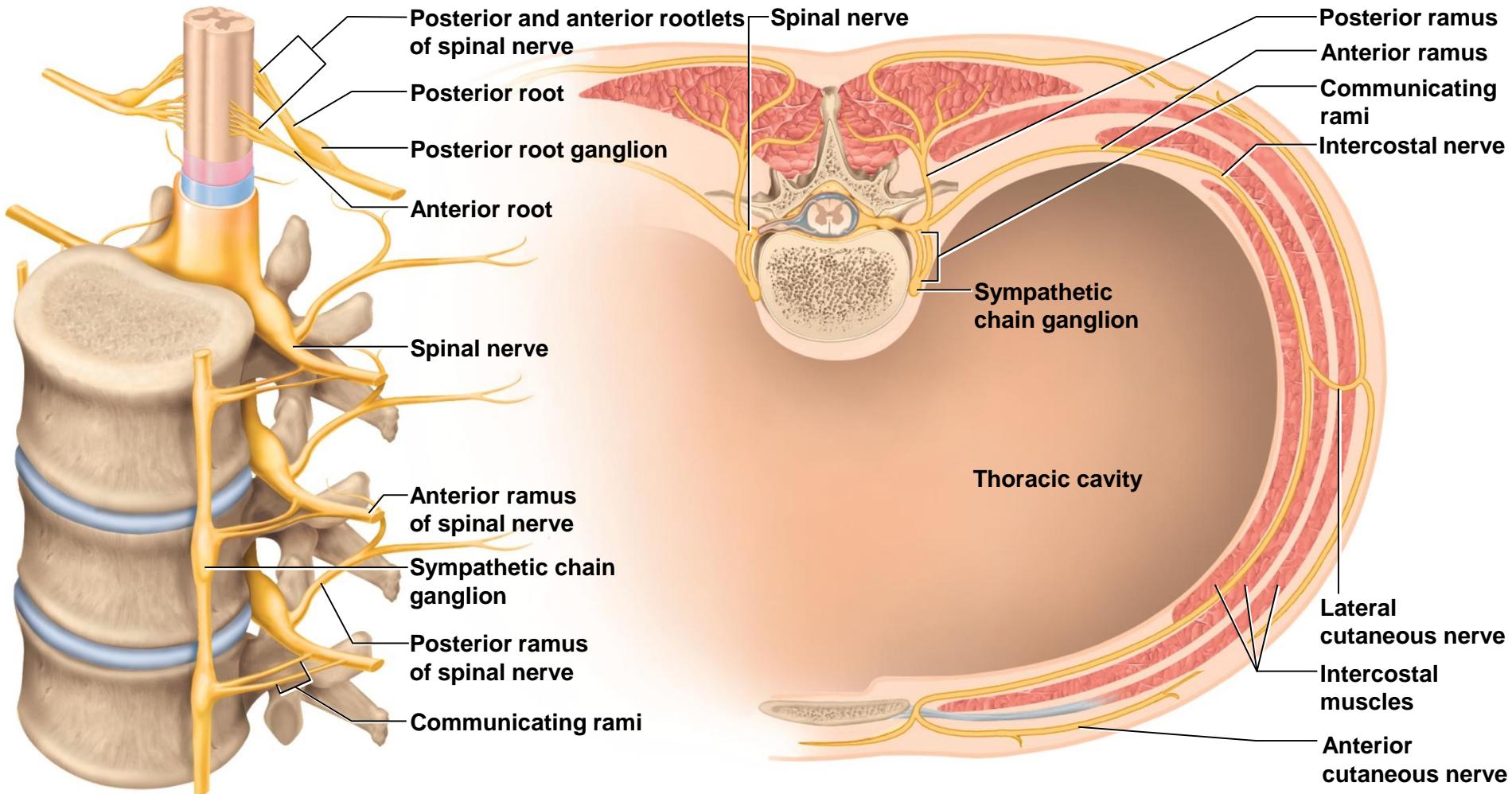


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Figure 13.12

Rami of the Spinal Nerves

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(a) Anterolateral view

(b) Cross section

Figure 13.13

Nerve Plexuses

- **Anterior rami branch and anastomose repeatedly to form five nerve plexuses**
 - **Cervical plexus** in the neck, C1 to C5
 - Supplies neck and **phrenic nerve** to the diaphragm
 - **Brachial plexus** near the shoulder, C5 to T1
 - Supplies upper limb and some of shoulder and neck
 - Median nerve—carpal tunnel syndrome
 - **Lumbar plexus** in the lower back, L1 to L4
 - Supplies abdominal wall, anterior thigh, and genitalia
 - **Sacral plexus** in the pelvis, L4, L5, and S1 to S4
 - Supplies remainder of lower trunk and lower limb
 - **Coccygeal plexus**, S4, S5, and Co1

Nerve Plexuses

- **Somatosensory function**—carry sensory signals from bones, joints, muscles, and skin
 - **Proprioception:** brain receives information about body position and movements from nerve endings in muscles, tendons, and joints
- **Motor function**—primarily to stimulate muscle contraction

Shingles

- **Chickenpox**—common disease of early childhood
 - Caused by **varicella-zoster virus**
 - Produces itchy rash that clears up without complications
- **Virus remains for life in the posterior root ganglia**
 - Kept in check by the immune system
- **Shingles (herpes zoster)**—localized disease caused by the virus traveling down the sensory nerves by fast axonal transport when immune system is compromised
 - Common after age 50
 - Painful trail of skin discoloration and fluid-filled vesicles along path of nerve
 - Usually in chest and waist on one side of the body
 - Pain and itching
 - Childhood chickenpox vaccinations reduce the risk of shingles later in life

The Cervical Plexus

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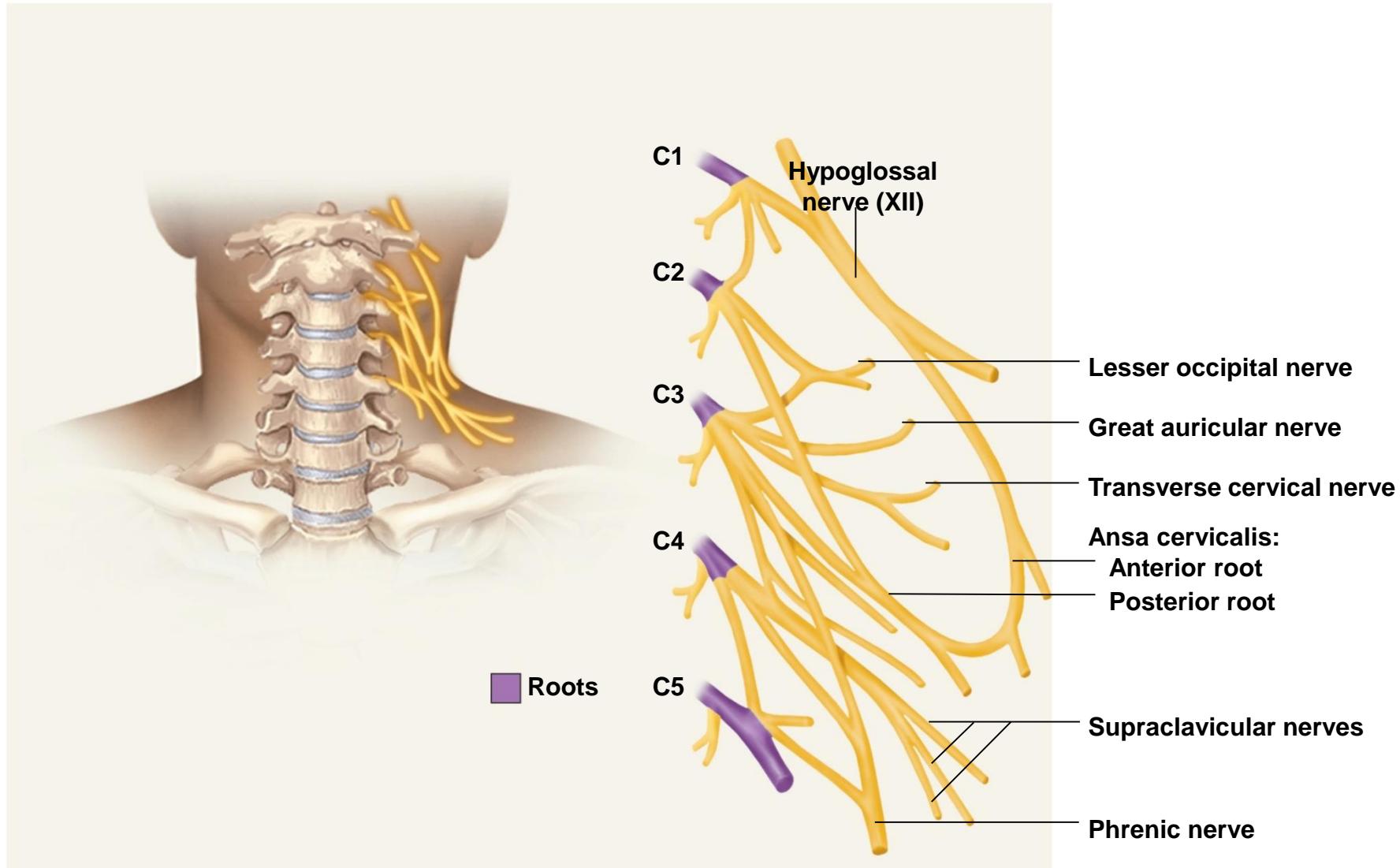


Figure 13.14

The Brachial Plexus

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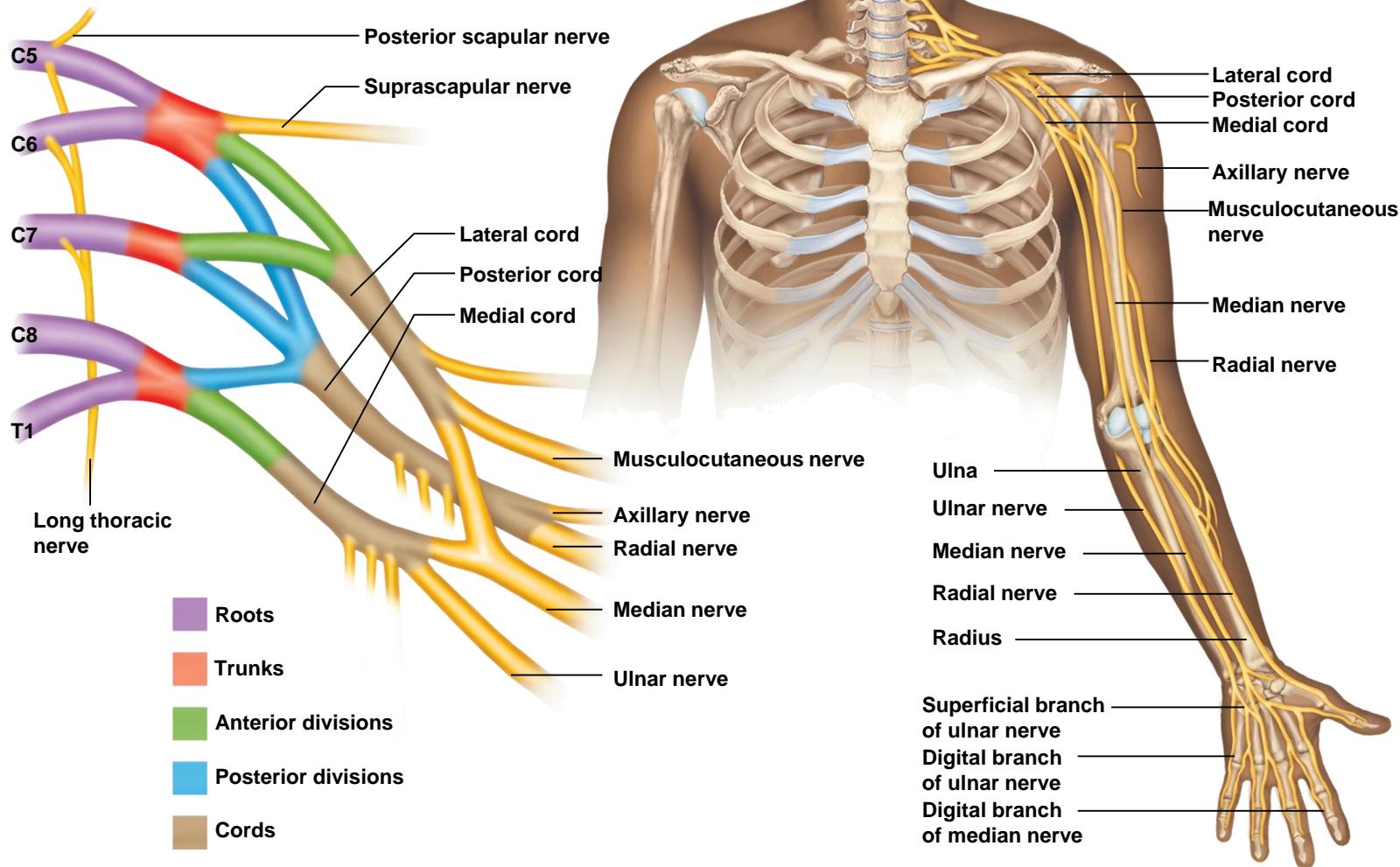
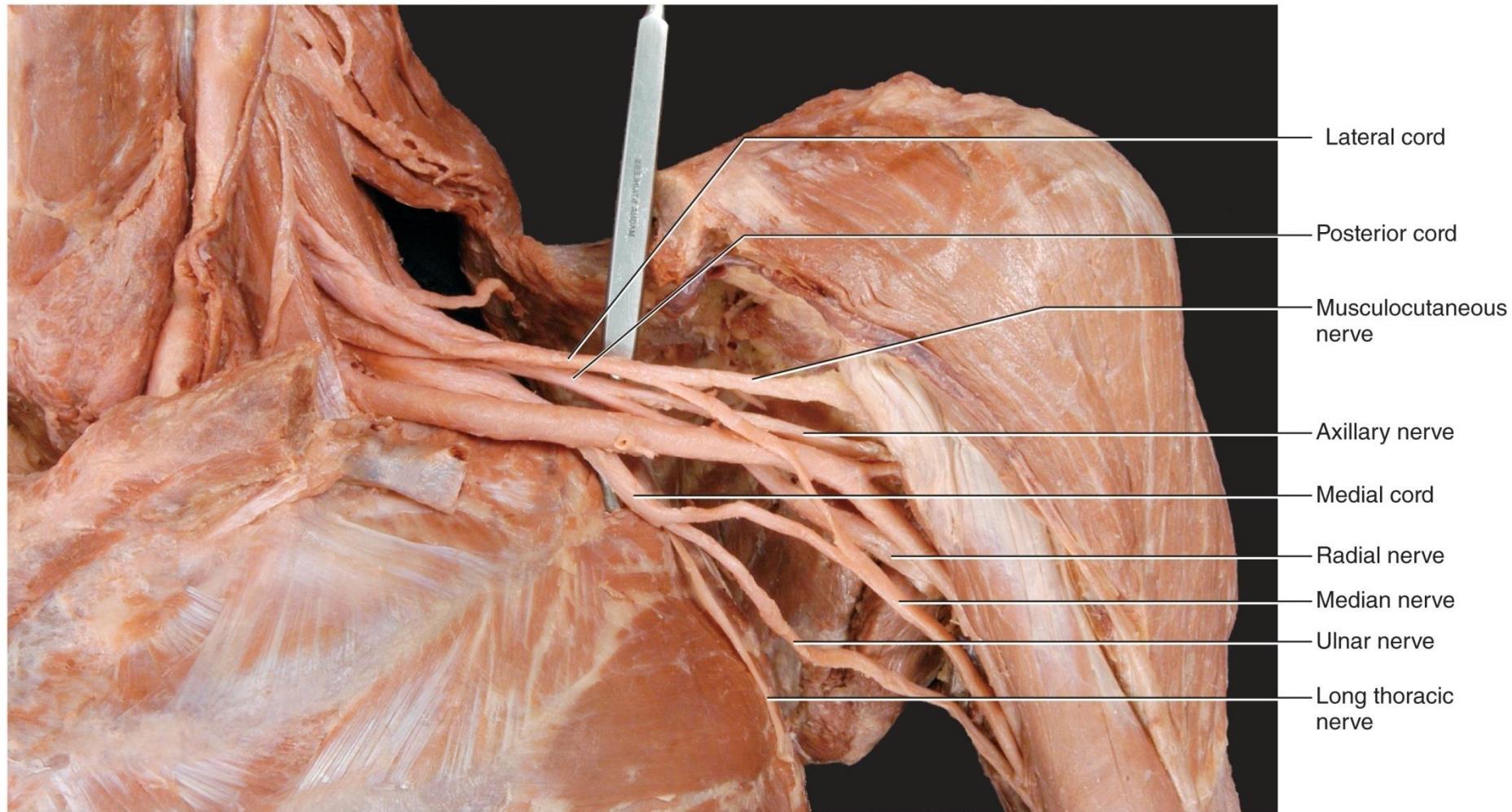


Figure 13.15

The Brachial Plexus

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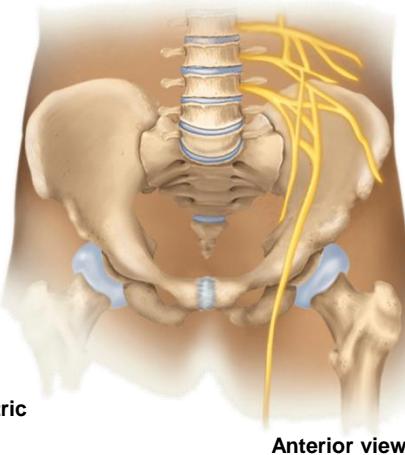
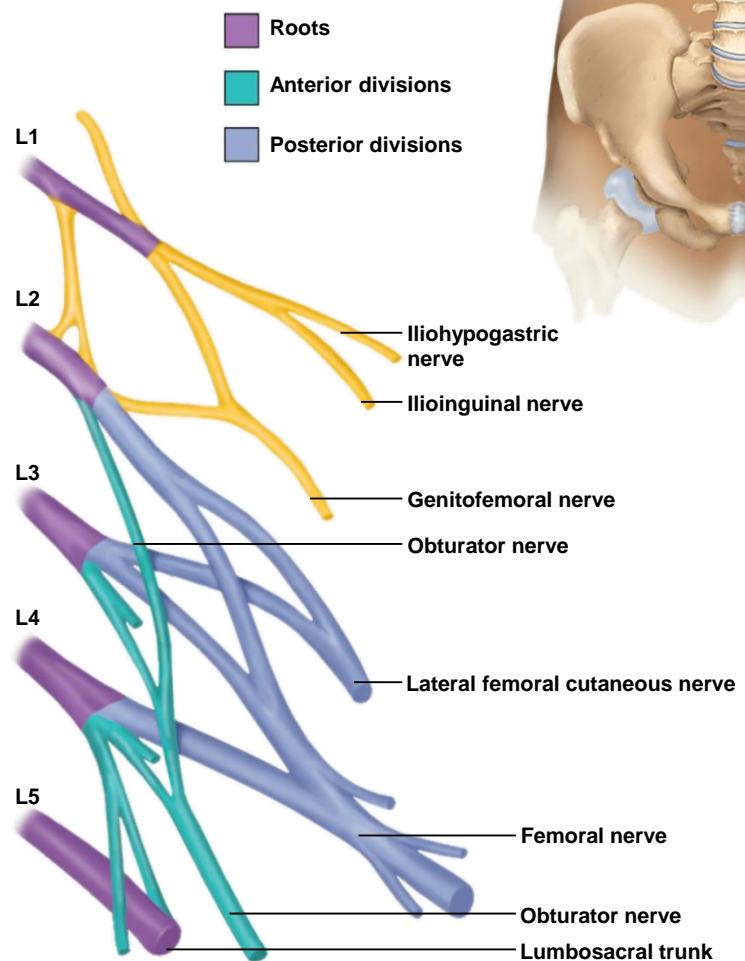


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Figure 13.16

The Lumbar Plexus

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From lumbar plexus
From sacral plexus

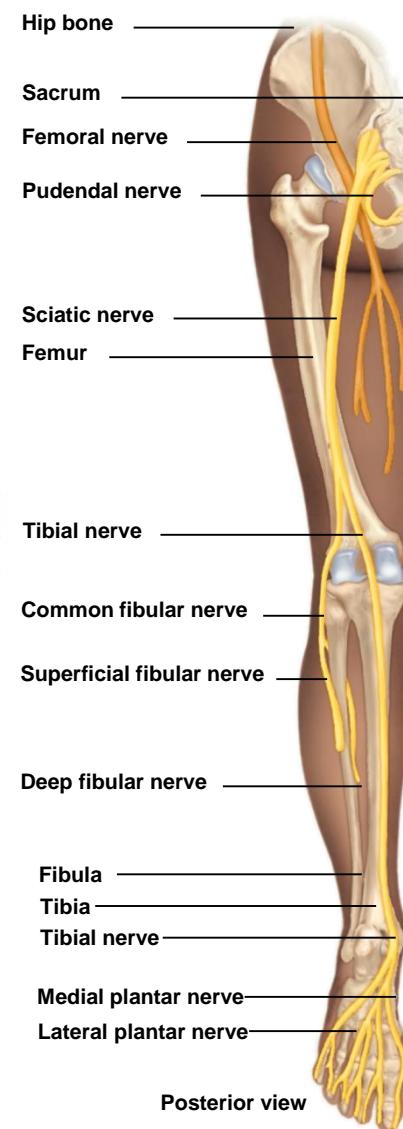


Figure 13.17

The Sacral and Coccygeal Plexuses

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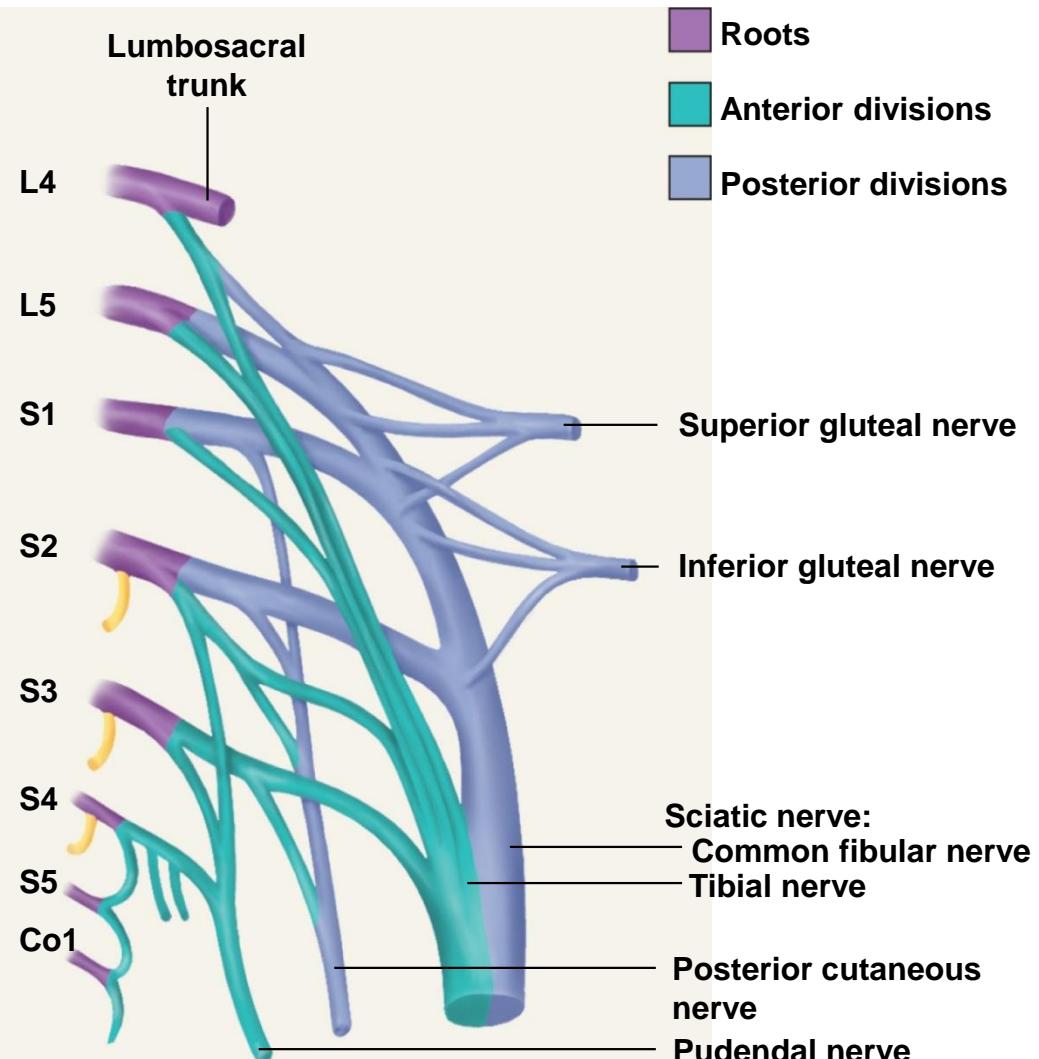
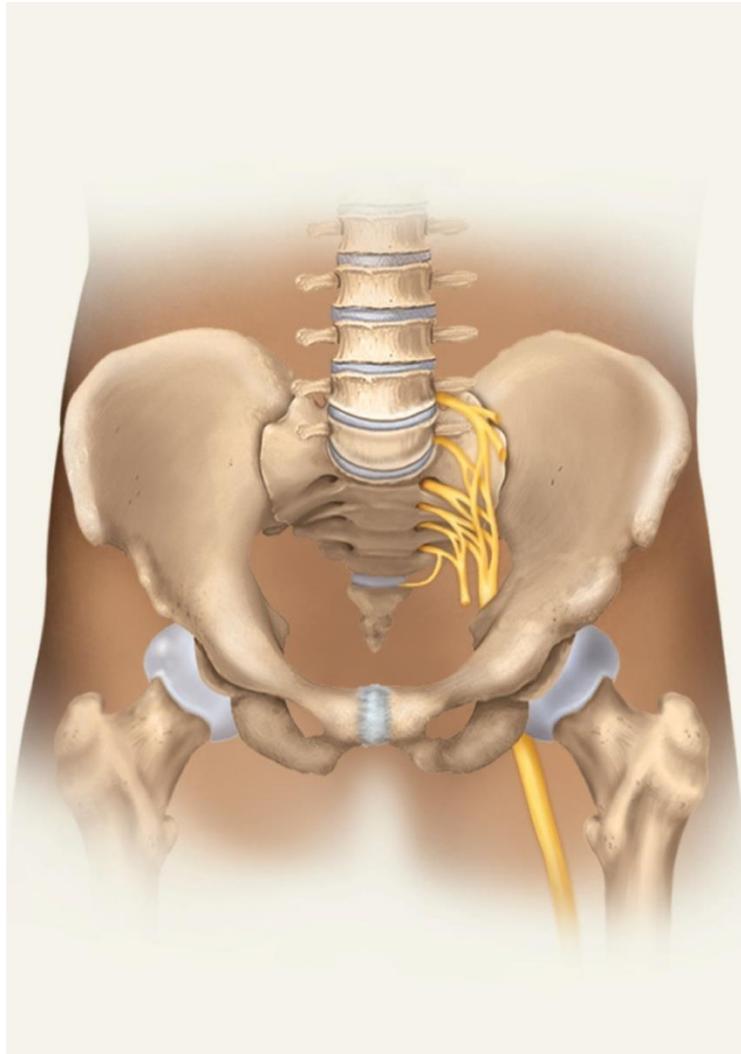


Figure 13.18

Nerve Injuries

- **Radial nerve injury**
 - Passes through axilla
 - **Crutch paralysis**
 - **Wrist drop**
- **Sciatic nerve injury**
 - **Sciatica:** sharp pain that travels from gluteal region along the posterior side of the thigh and leg to ankle
 - 90% of cases result from herniated intervertebral disc or osteoporosis of lower spine

Cutaneous Innervation and Dermatomes

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- **Dermatome**—a specific area of skin that conveys sensory input to a spinal nerve
- **Dermatome map**—a diagram of the cutaneous regions innervated by each spinal nerve
- **Dermatomes overlap their edges as much as 50%**
 - Necessary to anesthetize three successive spinal nerves to produce a total loss of sensation in one dermatome

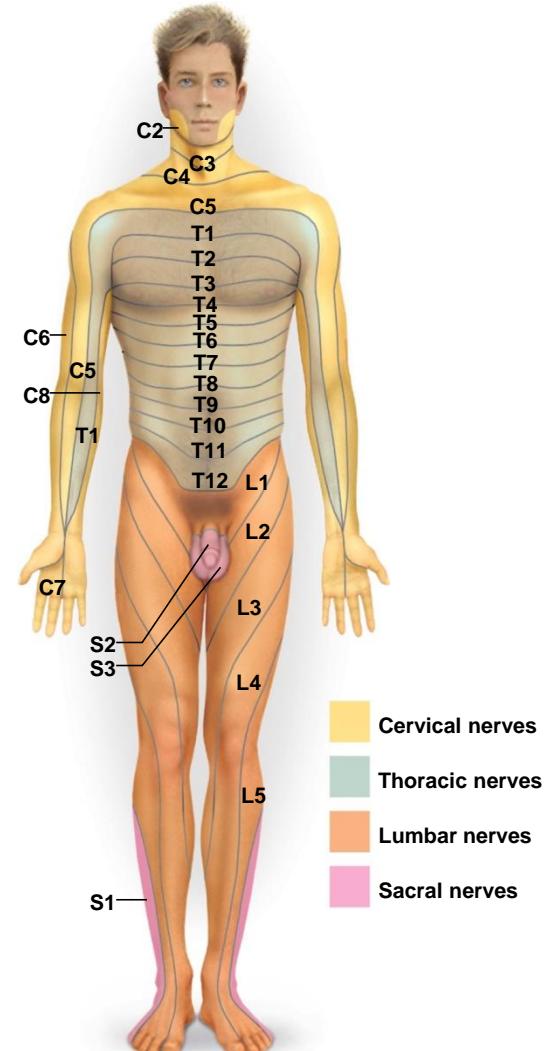


Figure 13.19

Somatic Reflexes

- **Expected Learning Outcomes**
 - Define *reflex* and explain how reflexes differ from other motor actions.
 - Describe the general components of a typical reflex arc.
 - Explain how the basic types of somatic reflexes function.

The Nature of Reflexes

- **Reflexes**—quick, involuntary, stereotyped reactions of glands or muscle to stimulation
 - Reflexes **require stimulation**
 - Not spontaneous actions, but responses to sensory input
 - Reflexes are **quick**
 - Involve few, if any, interneurons and minimum synaptic delay
 - Reflexes are **involuntary**
 - Occur without intent and are difficult to suppress
 - Reflexes are **stereotyped**
 - Occur essentially the same way every time

The Nature of Reflexes

- **Reflexes** include glandular secretion and contraction of all three types of muscle
- **Somatic reflexes**—reflexes involving the somatic nervous system innervating skeletal muscle

The Nature of Reflexes

- **Pathway of a somatic reflex arc**
 - **Somatic receptors**
 - In skin, muscles, or tendons
 - **Afferent nerve fibers**
 - Carry information from receptors to posterior horn of spinal cord or to the brainstem
 - **Integrating center**
 - A point of synaptic contact between neurons in gray matter of cord or brainstem
 - Determines whether efferent neurons issue signal to muscles
 - **Efferent nerve fibers**
 - Carry motor impulses to muscles
 - **Effectors**
 - The muscles that carry out the response

The Nature of Reflexes

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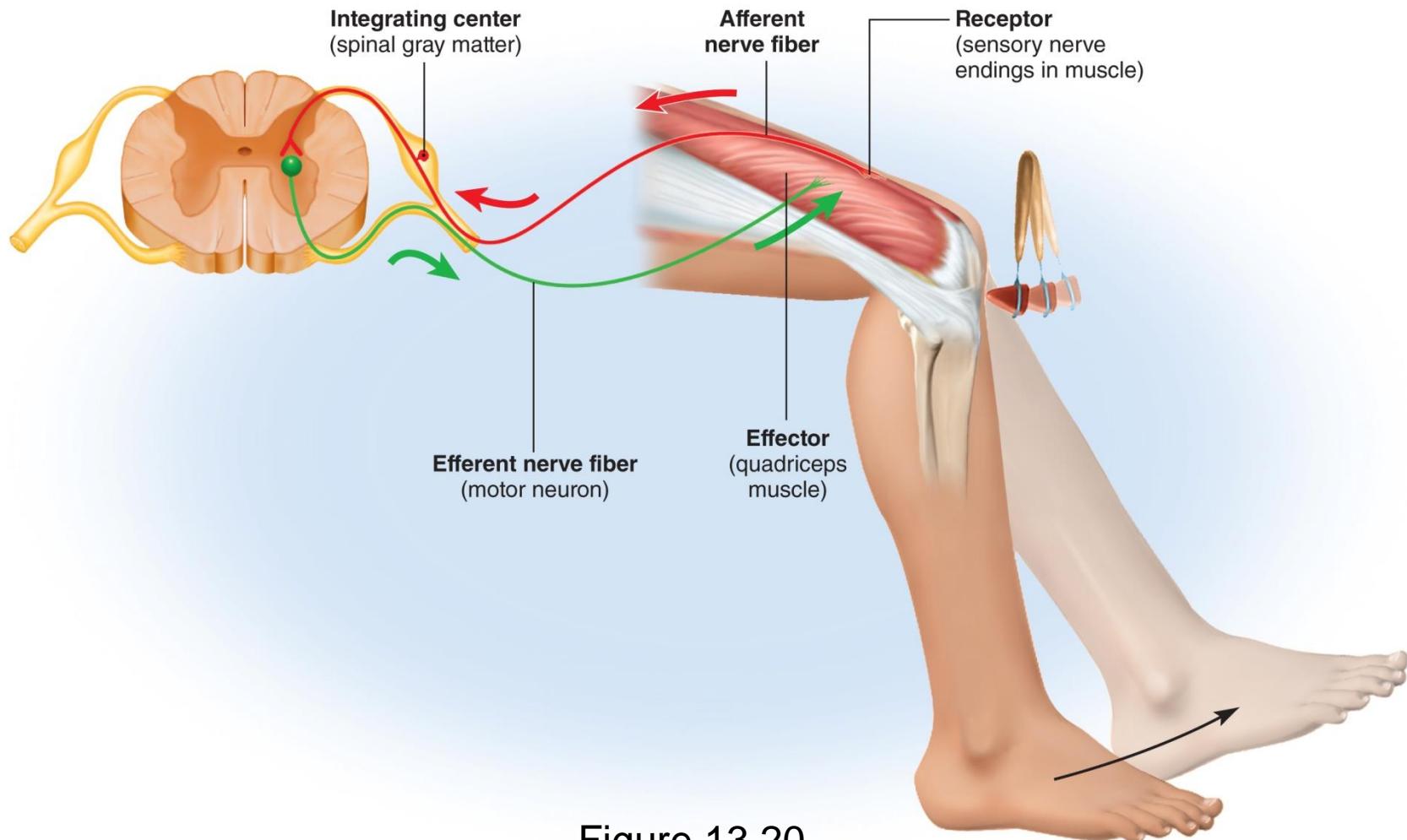


Figure 13.20

The Muscle Spindle

- **Muscle spindle**—stretch receptors embedded in skeletal muscles
- **Proprioceptors**—specialized sense organs to monitor position and movement of body parts
- **Muscle spindles inform the brain of muscle length and body movement**
- **Enables brain to send motor commands back to the muscles that control coordinated movement, corrective reflexes, muscle tone, and posture**

The Muscle Spindle

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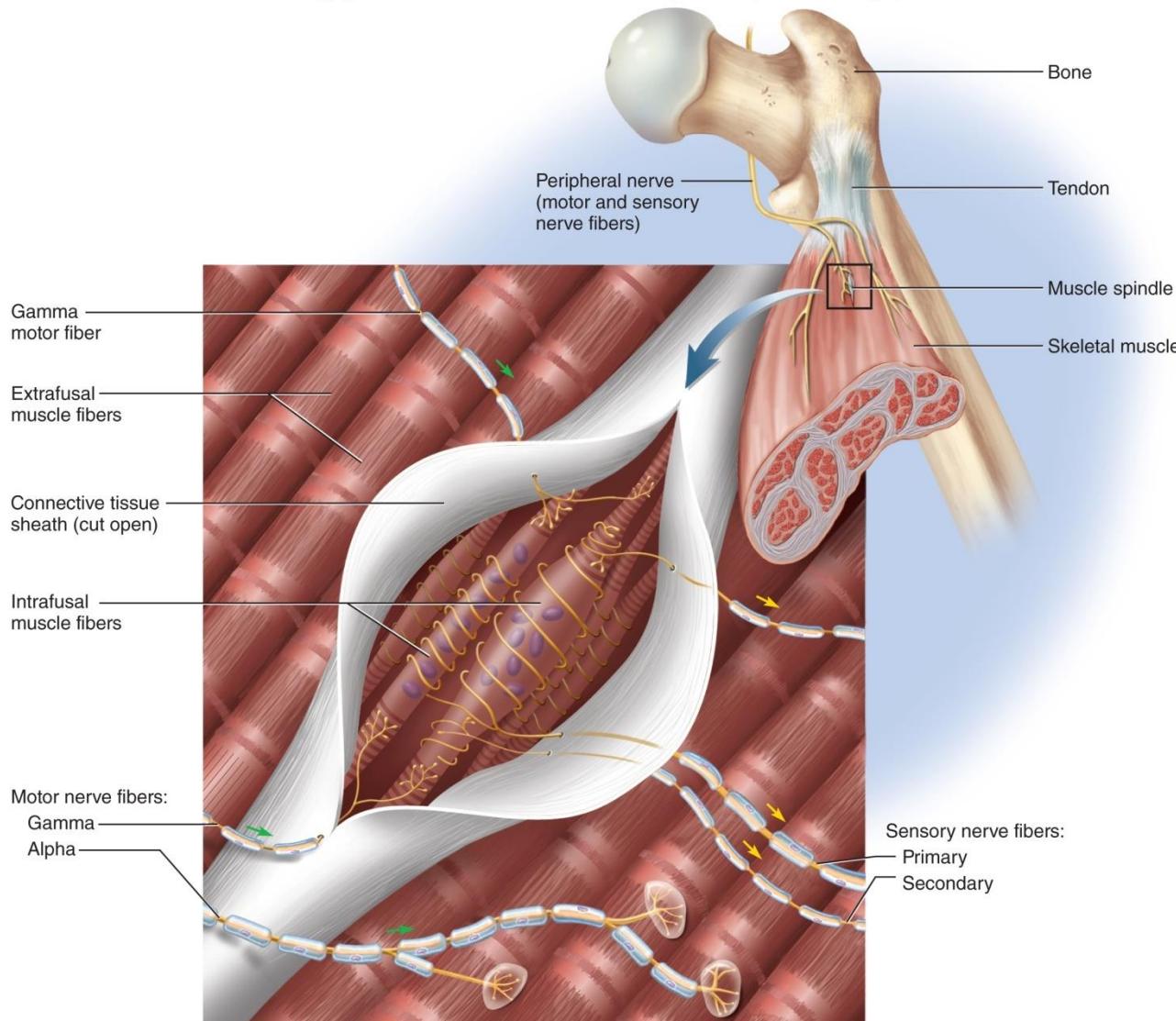


Figure 13.21

The Muscle Spindle

- A spindle contains 7 or 8 **intrafusal muscle fibers** within it
 - Rest of the muscle's fibers (those generating force for movement) are extrafusal fibers
- **Nerve fibers** in muscle spindle
 - A **gamma motor neuron** innervates the ends of an intrafusal fiber and keeps it taut
 - (As opposed to alpha motor neurons that contact extrafusal fibers)
 - The midportion of the intrafusal fiber contains sensory nerve fibers
 - **Primary afferent fibers** – monitor fiber length and speed of length changes
 - **Secondary afferent fibers** – monitor length only
- **Example of spindle function: help you to keep upright when standing on a boat**

The Stretch Reflex

- **Stretch (myotatic) reflex**—when a muscle is stretched, it “fights back” and contracts
- **Helps maintain equilibrium and posture**
 - Head starts to tip forward as you fall asleep
 - Muscles contract to raise the head
- **Stabilize joints by balancing tension in extensors and flexors, smoothing muscle actions**
- **Stretch reflex is mediated primarily by the brain, but its spinal component can be more pronounced if muscle is suddenly stretched by a tendon tap (knee jerk)**

The Stretch Reflex

- **Knee-jerk (patellar) reflex** is a monosynaptic reflex
 - One synapse between the afferent and efferent neurons
- **Testing somatic reflexes helps diagnose many diseases**
- **Reciprocal inhibition**—reflex phenomenon that prevents muscles from working against each other by inhibiting antagonist when agonist is excited

Patellar Tendon Reflex

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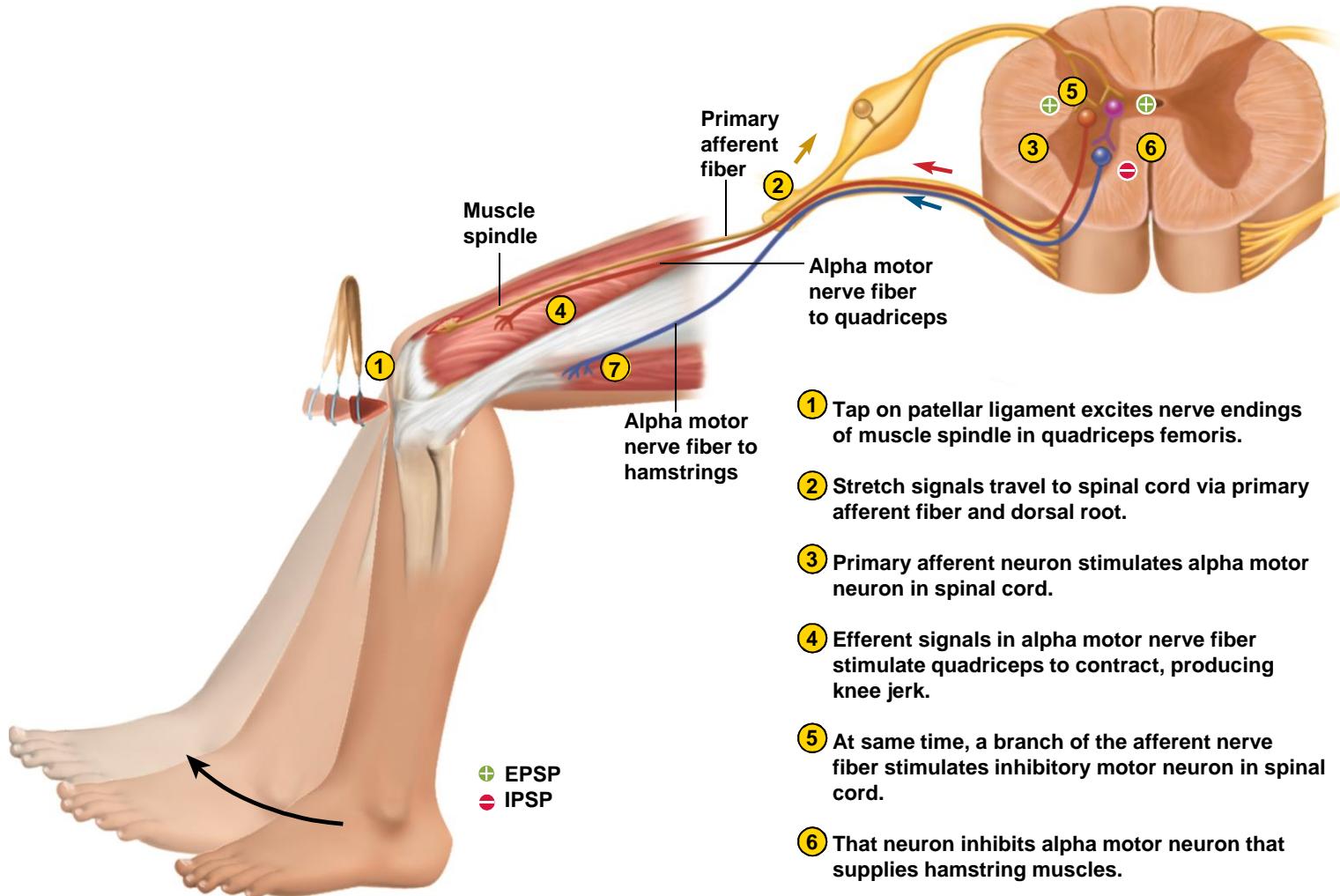
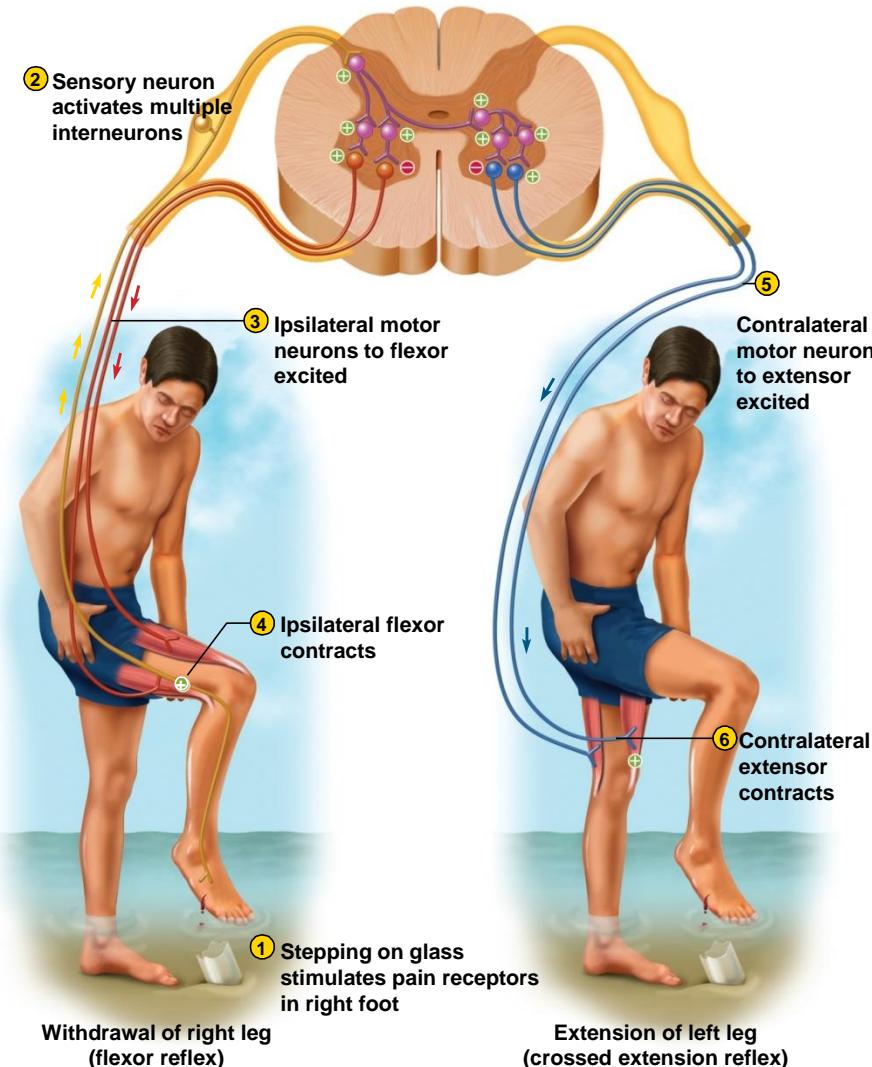


Figure 13.22

- ① Tap on patellar ligament excites nerve endings of muscle spindle in quadriceps femoris.
- ② Stretch signals travel to spinal cord via primary afferent fiber and dorsal root.
- ③ Primary afferent neuron stimulates alpha motor neuron in spinal cord.
- ④ Efferent signals in alpha motor nerve fiber stimulate quadriceps to contract, producing knee jerk.
- ⑤ At same time, a branch of the afferent nerve fiber stimulates inhibitory motor neuron in spinal cord.
- ⑥ That neuron inhibits alpha motor neuron that supplies hamstring muscles.
- ⑦ Hamstring contraction is inhibited so hamstrings (knee flexors) do not antagonize quadriceps (knee extensor).

The Flexor (Withdrawal) Reflex

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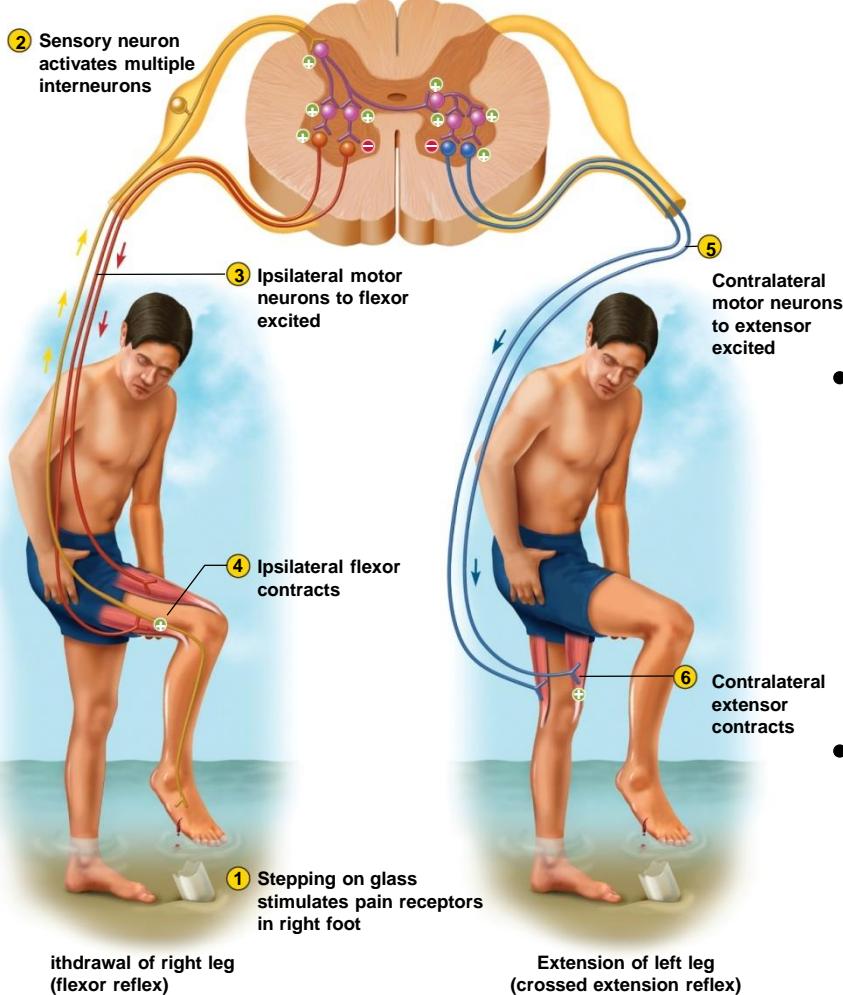


- **Flexor reflex**—the quick contraction of flexor muscles resulting in the withdrawal of a limb from an injurious stimulus
- Triggers contraction of the flexors and relaxation of the extensors in that limb
- **Polysynaptic reflex arc**—pathway in which signals travel over many synapses on their way to the muscle

Figure 13.23

The Crossed Extension Reflex

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- **Crossed extension reflex**—contraction of extensor muscles in limb opposite of the one that is withdrawn
 - Maintains balance by extending other leg
- Flexor reflex uses an **ipsilateral reflex arc**, (stimulus and response on same side) whereas crossed extension reflex uses a **contralateral reflex arc** (input and output are on opposite sides)
- **Intersegmental reflex**—one in which the input and output occur at different levels (segments) of the spinal cord
 - Pain in foot causes contraction of abdominal muscles

Figure 13.23

The Tendon Reflex

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- **Tendon organs**— proprioceptors in a tendon near its junction with a muscle
 - Golgi tendon organ: 1 mm long, nerve fibers entwined in collagen fibers of the tendon
- **Tendon reflex**—in response to excessive tension on the tendon
 - Inhibits muscle from contracting strongly
 - Moderates muscle contraction before it tears a tendon or pulls it loose from the muscle or bone

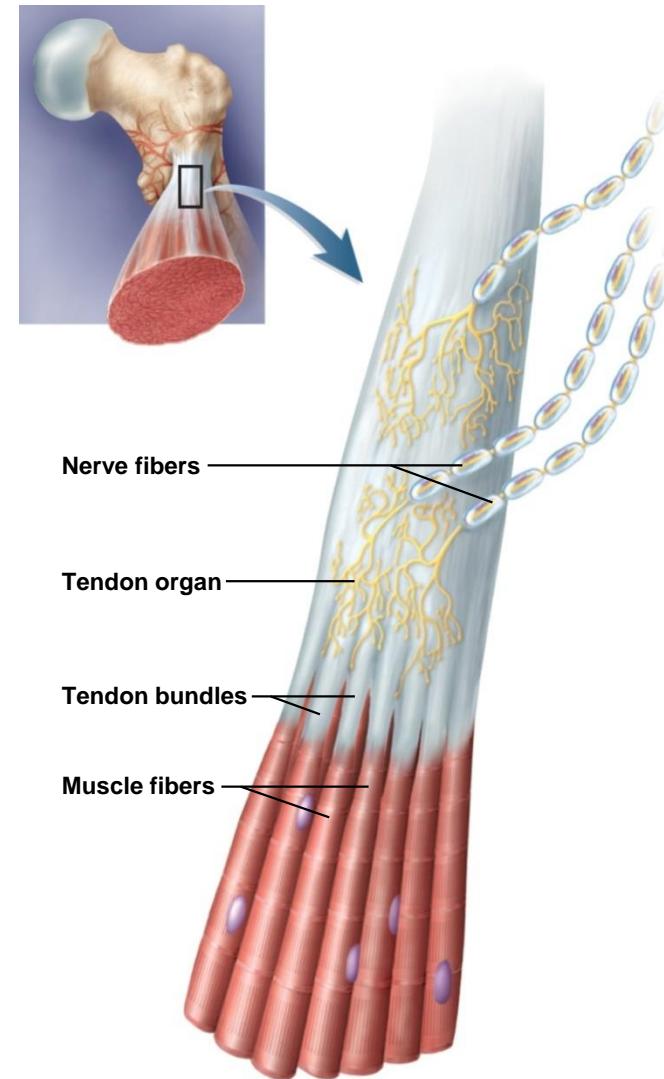


Figure 13.24

Spinal Cord Trauma

- **In United States, 10,000 to 12,000 people paralyzed each year by spinal cord trauma**
 - Usually by vertebral fractures
 - Highest risk group: males 16 to 30 years old
- **55% occur in automobile or motorcycle accidents**

Spinal Cord Trauma

(Continued)

- **Complete transection**—complete severance of cord
 - Immediate loss of motor control below level of injury
 - Above C4 poses the threat of respiratory failure
 - Spinal shock
 - **Paralysis**
 - **Paraplegia**—paralysis of both lower limbs
 - **Quadriplegia**—paralysis of all four limbs
 - **Hemiplegia**—paralysis on one side of the body
 - **Paresis**—partial paralysis or weakness of the limbs