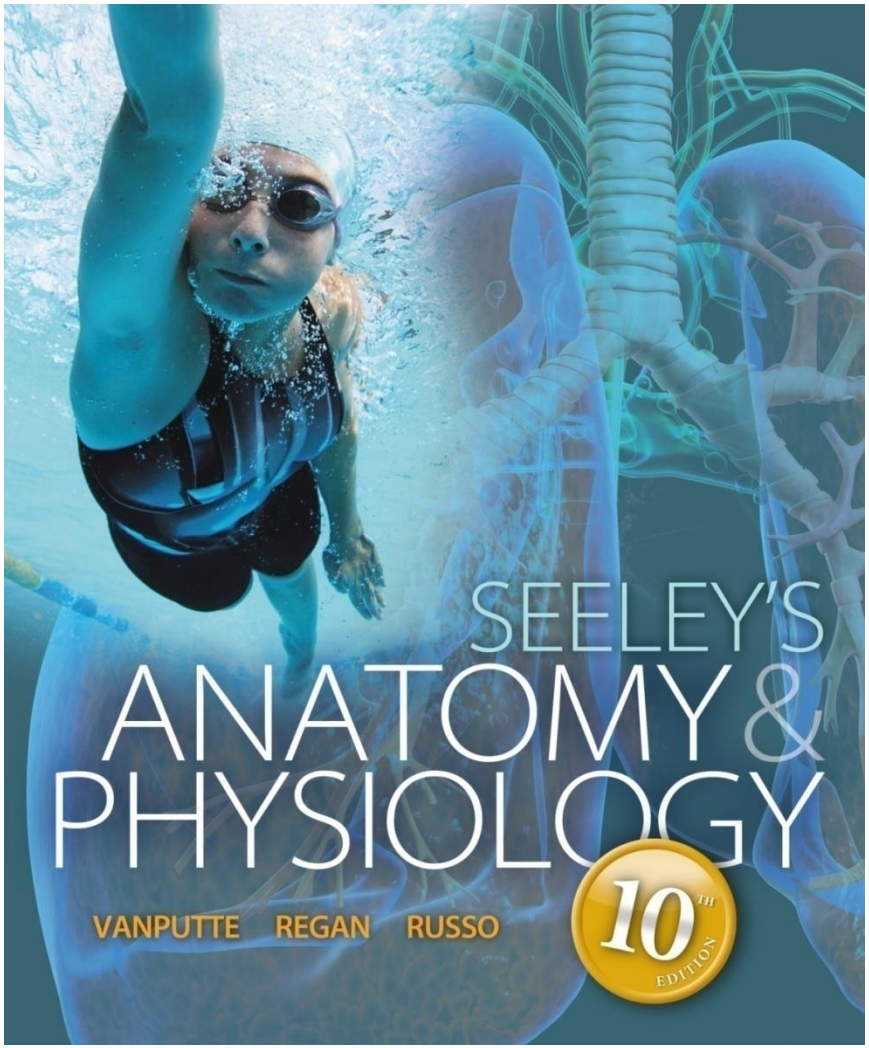
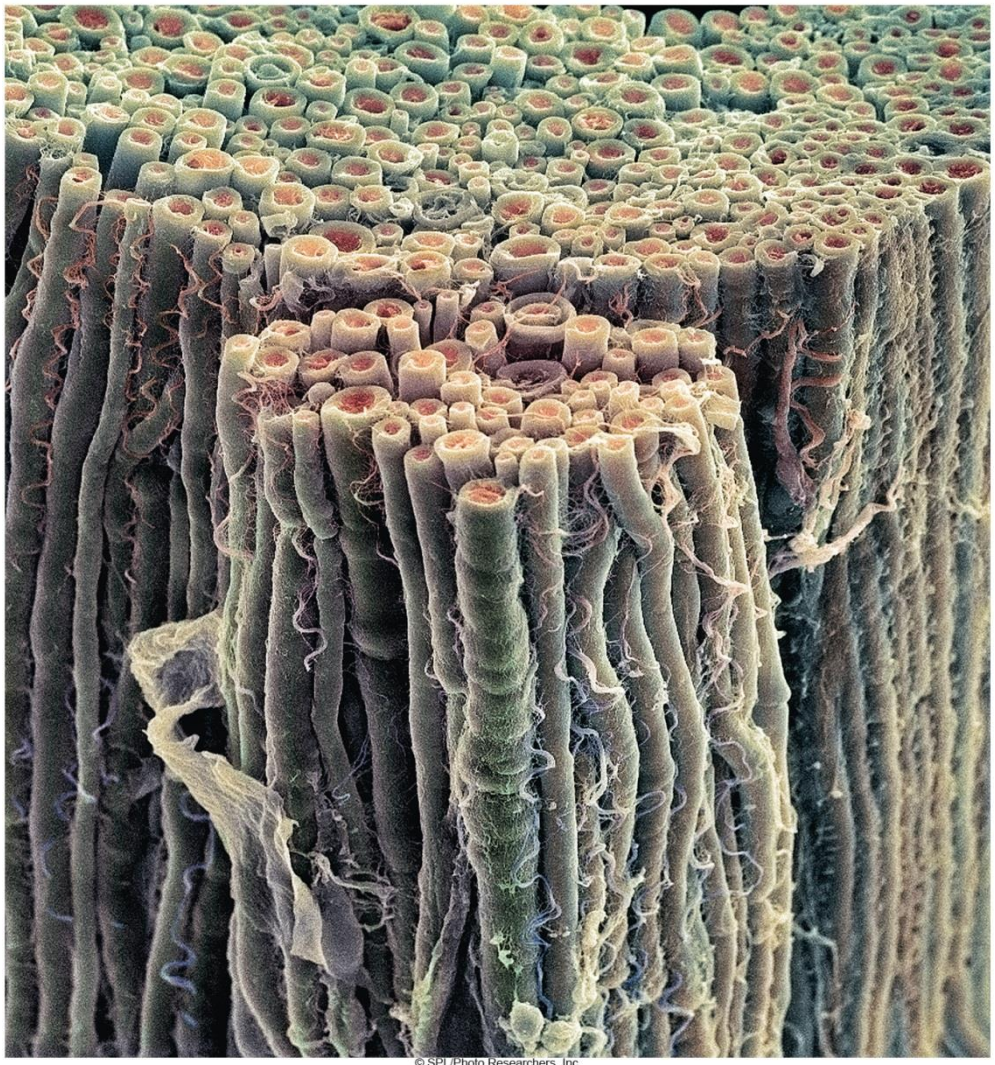


Chapter 12

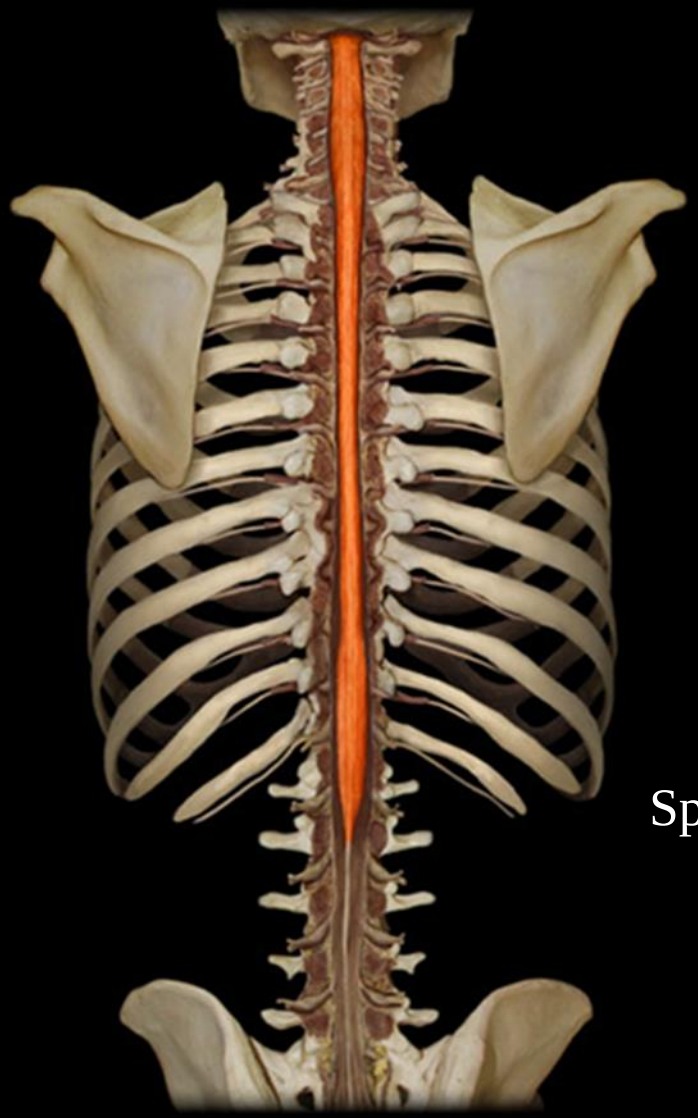
APR Enhanced Lecture Slides

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

Chapter 12
Spinal Cord and Spinal Nerves



Spinal Cord and Spinal Nerves

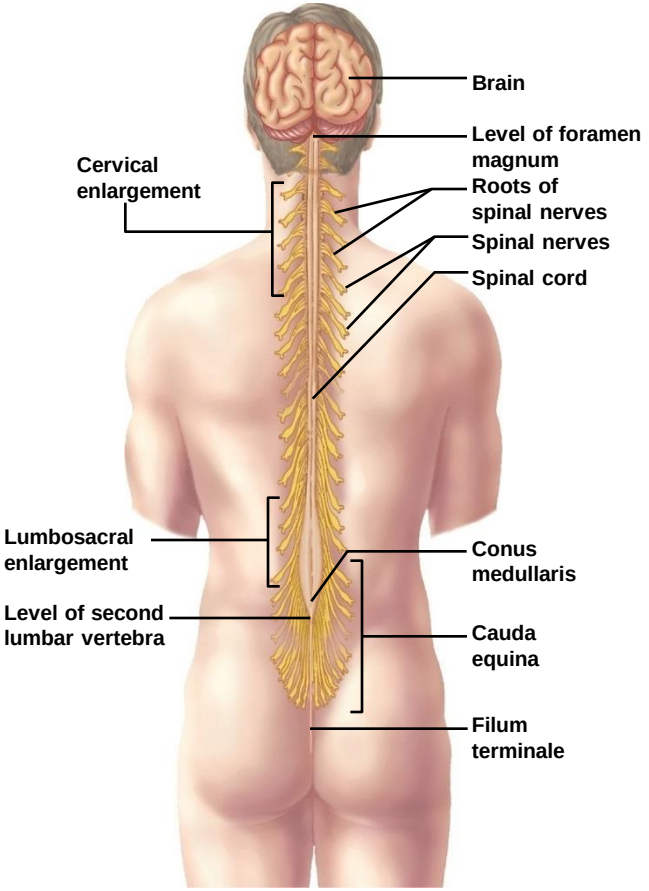


Spinal cord

Spinal Nerves
31 pairs

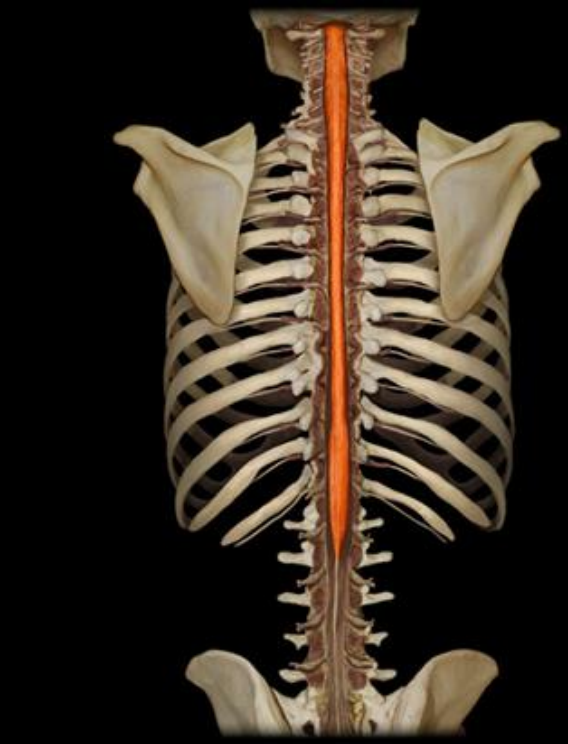
12.1 Spinal Cord

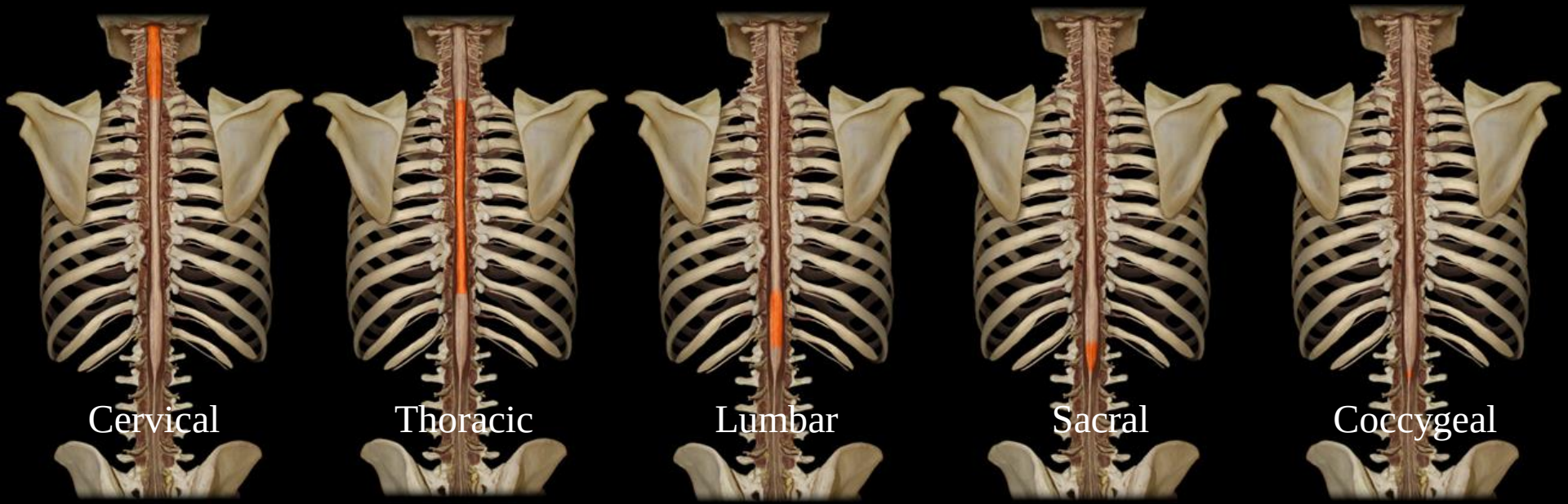
- Extends from foramen magnum to second lumbar vertebra
- Segmented
  - Cervical
  - Thoracic
  - Lumbar
  - Sacral
- Gives rise to 31 pairs of spinal nerves
- Not uniform in diameter throughout length
  - **Cervical enlargement**: supplies upper limbs
  - **Lumbar enlargement**: supplies lower limbs
- Conus medullaris: tapered inferior end.
- Cauda equina: origins of spinal nerves extending inferiorly from lumbosacral enlargement and conus medullaris.



Posterior view

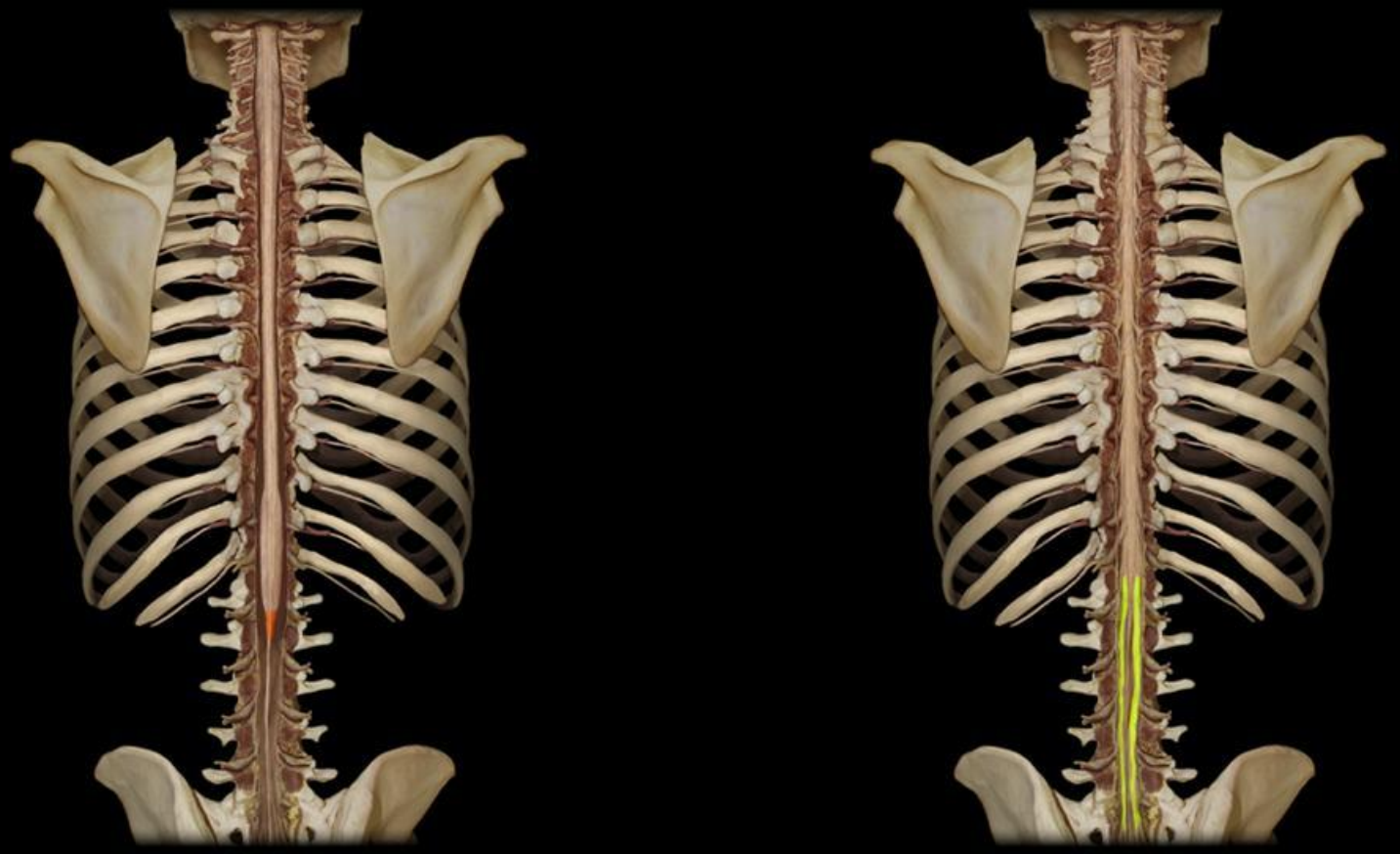
Spinal Cord Regions



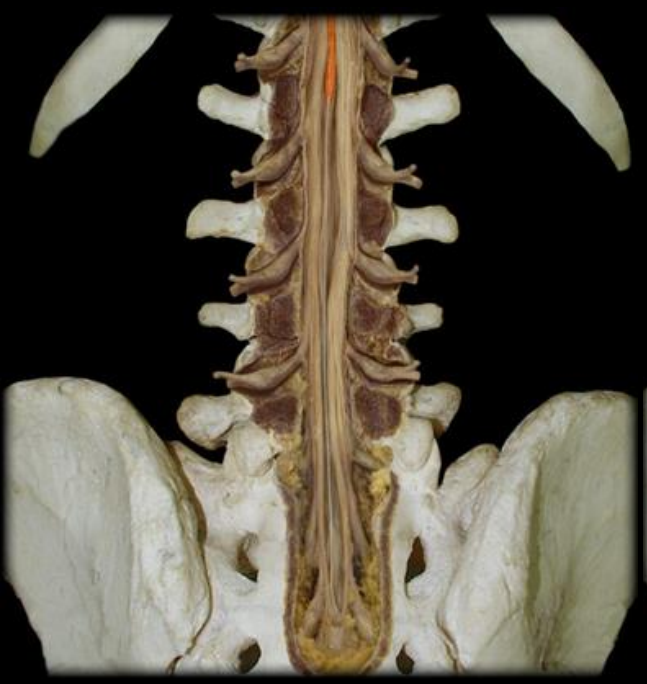


Cervical & Lumbosacral Enlargements

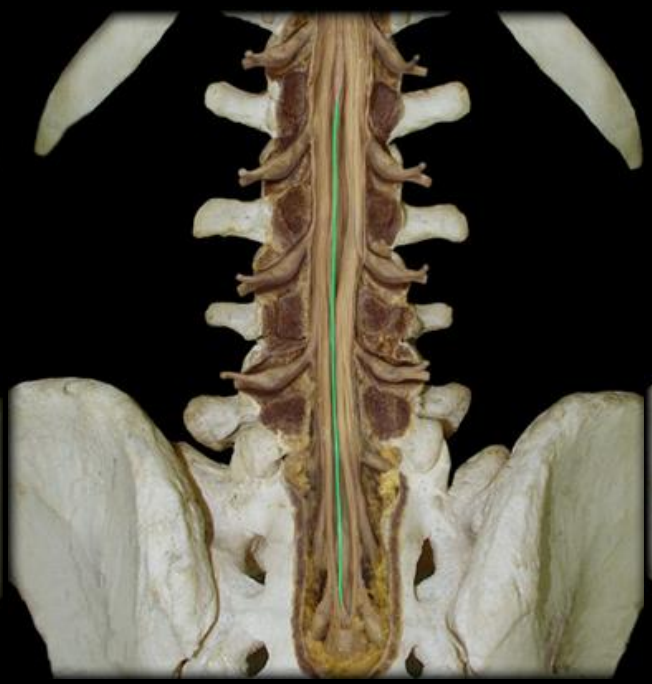
Medullary Cone & Cauda Equina



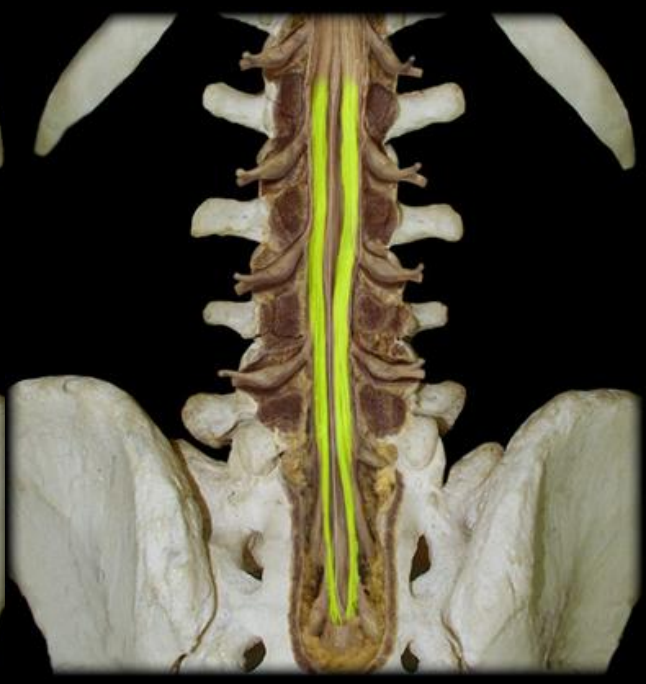
Spinal Cord



Conus medullaris



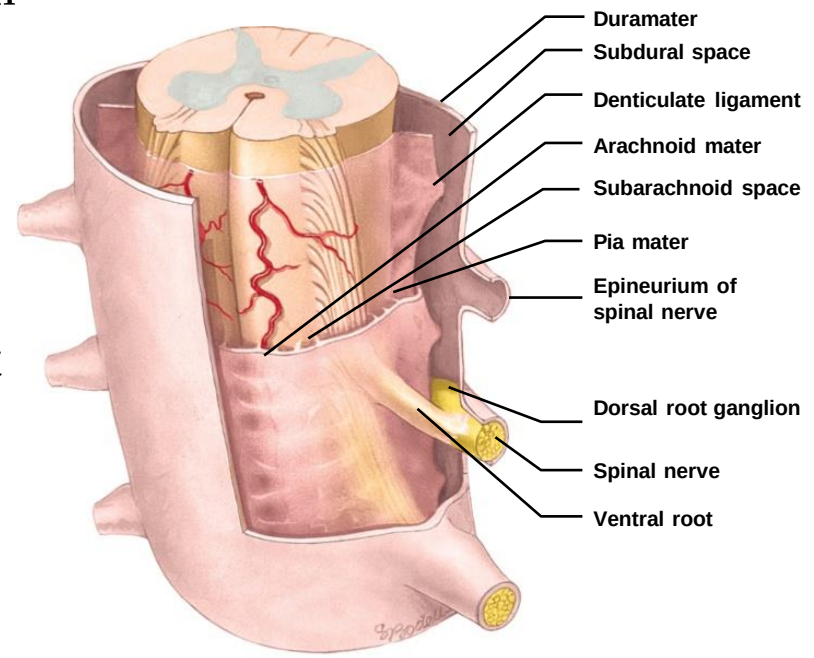
Filum terminale



Cauda equina

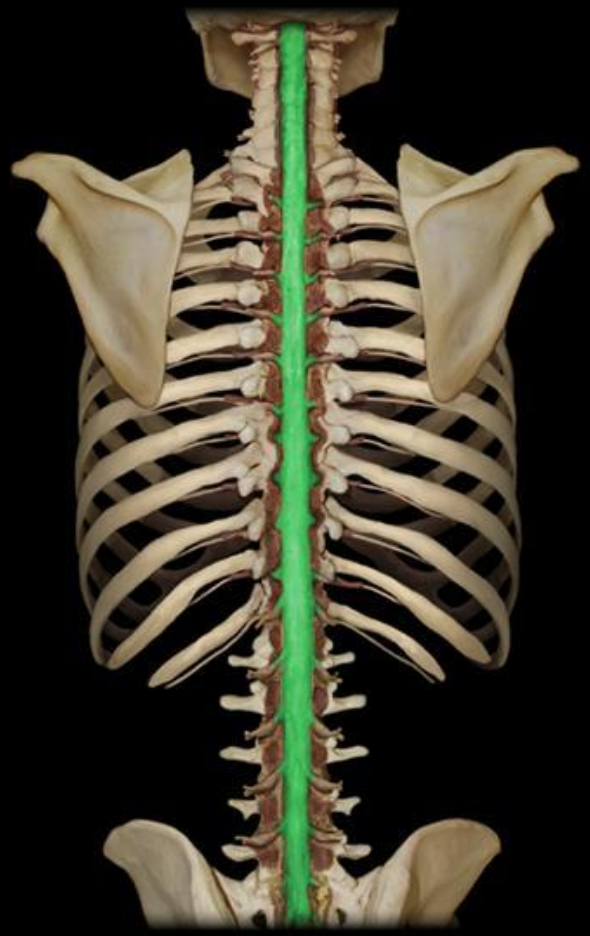
Meninges of the Spinal Cord

- Connective tissue membranes surrounding spinal cord and brain
  - **Dura mater**: continuous with epineurium of the spinal nerves
  - **Arachnoid mater**: thin and wispy
  - **Pia mater**: bound tightly to surface of brain and spinal cord. Forms the **filum terminale**, which anchors spinal cord to coccyx and the denticulate ligaments that attach the spinal cord to the dura mater
- Spaces
  - **Epidural**: anesthesia injected. Contains blood vessels, areolar connective tissue and fat.
  - **Subdural**: serous fluid
  - **Subarachnoid**: CSF and blood vessels within web-like strands of arachnoid tissue

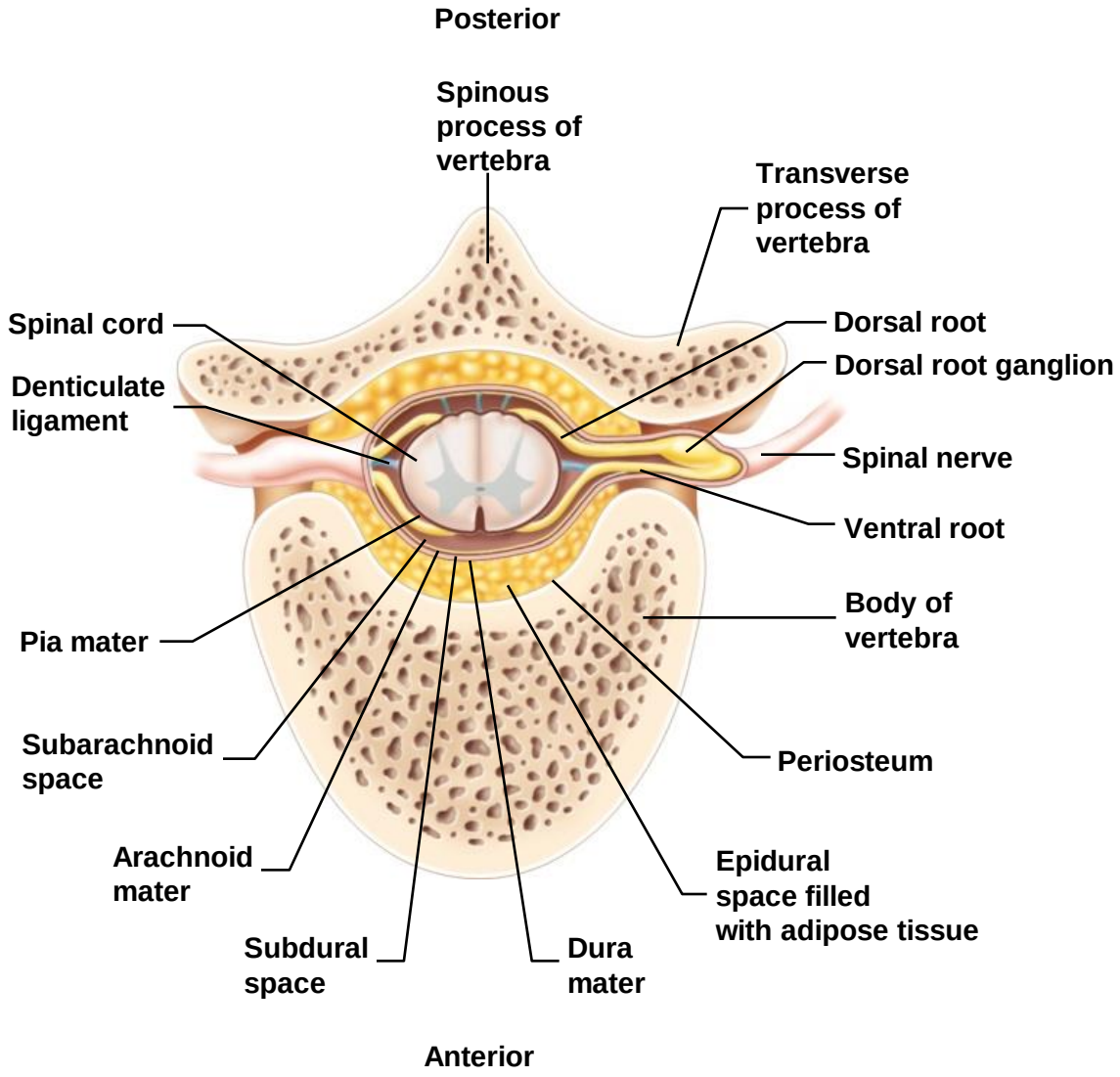


(a) Anterolateral view

Meninges of Spinal Cord

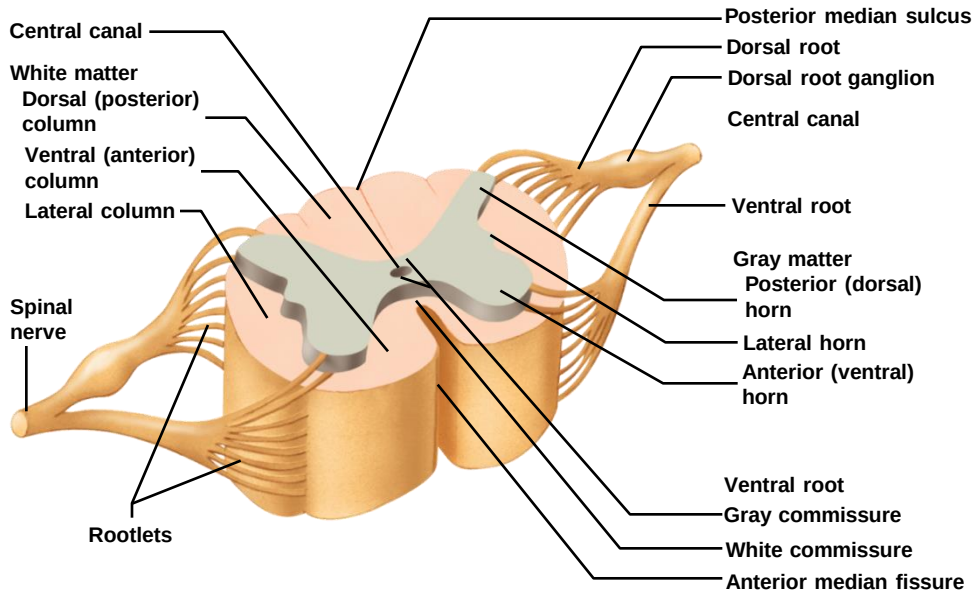


Meninges of the Spinal Cord

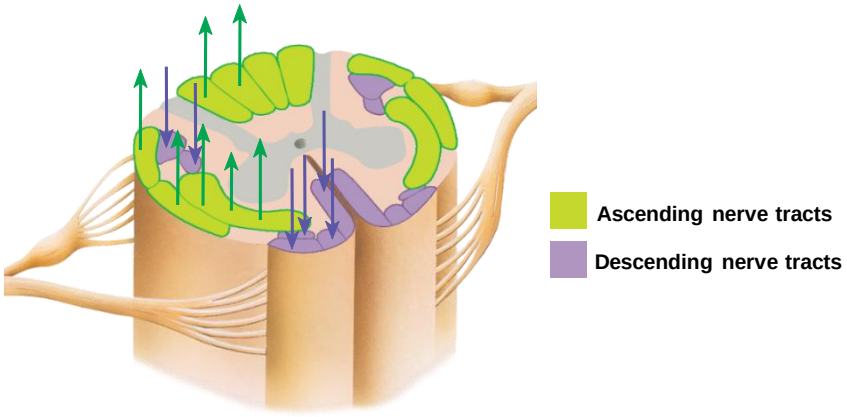


(b) Superior view

Cross Section of Spinal Cord



(a) Anterolateral view



(c) Anterolateral view

Spinal Cord

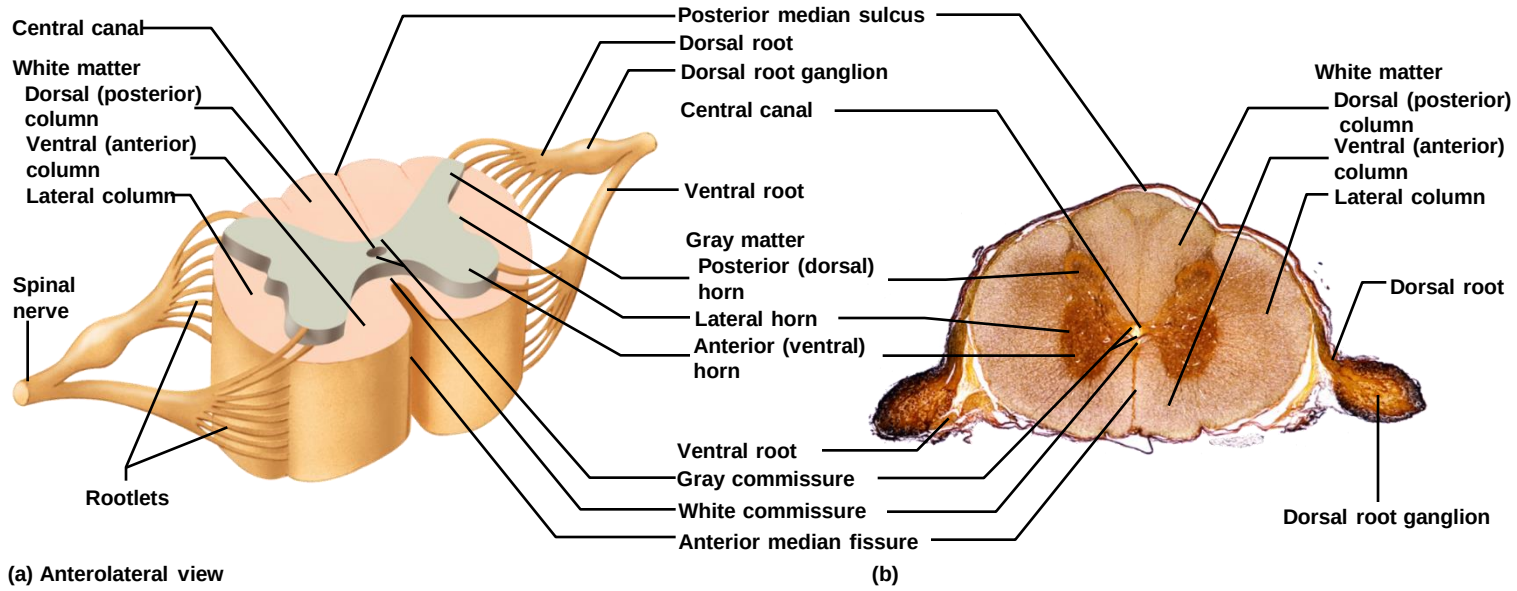
Gray matter

White matter

Cross Section of Spinal Cord

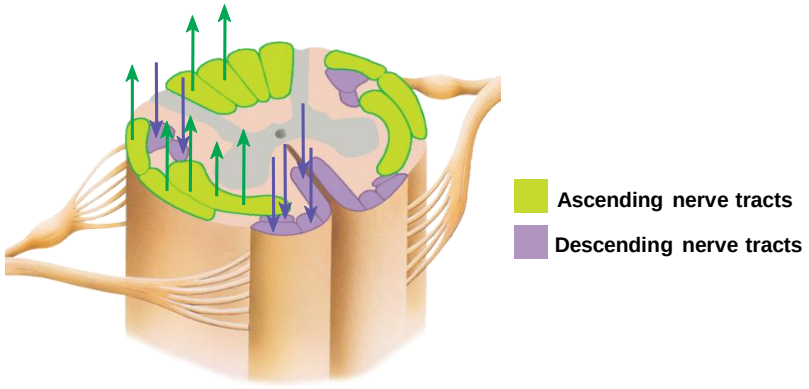
- **Anterior median fissure** and **posterior median sulcus**: deep clefts partially separating left and right halves
- White matter: myelinated axons forming tracts
  - Three columns (funiculi): ventral, dorsal, lateral
    - Each of these divided into tracts (fasciculi; pathways)
- Gray matter: neuron, cell, cell bodies, dendrites, axons
  - **Horns**
    - Posterior (dorsal)
    - Anterior (ventral)
    - Lateral (associated with ANS)

Cross Section of Spinal Cord



(a) Anterolateral view

(b)

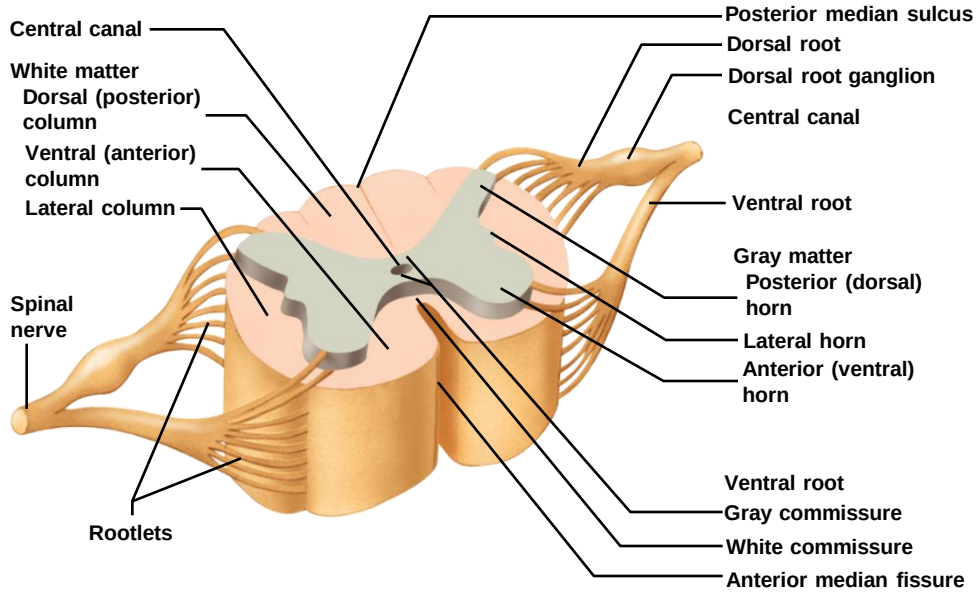


(c) Anterolateral view

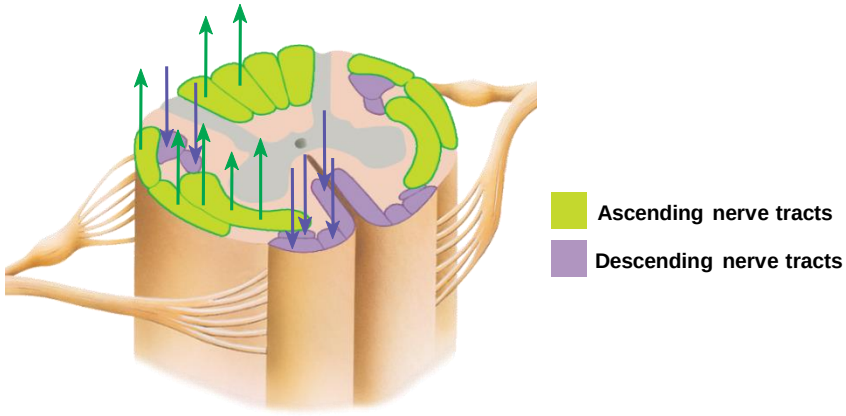
b: © Ed Reschke/Peter Arnold, Inc./Getty Images

Cross Section of Spinal Cord

- **Commissures**: connections between left and right halves
  - Gray with central canal in the center
  - White
- **Roots**: spinal nerves arise as rootlets then combine to form roots
  - Dorsal (posterior) root has a ganglion
  - Ventral (anterior)
  - Two roots merge laterally and form the spinal nerve



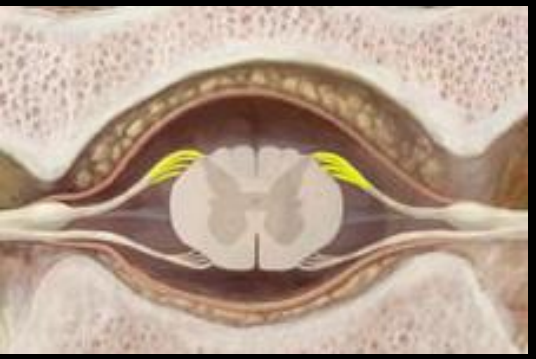
(a) Anterolateral view



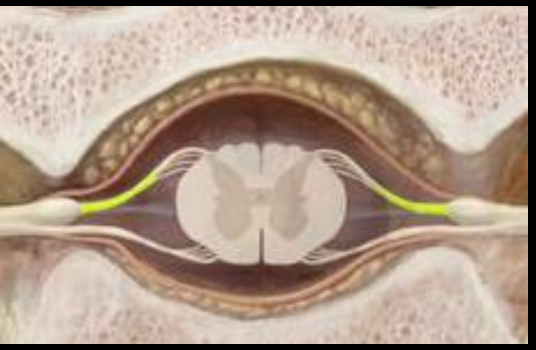
(c) Anterolateral view

Spinal Nerve

Dorsal rootlets

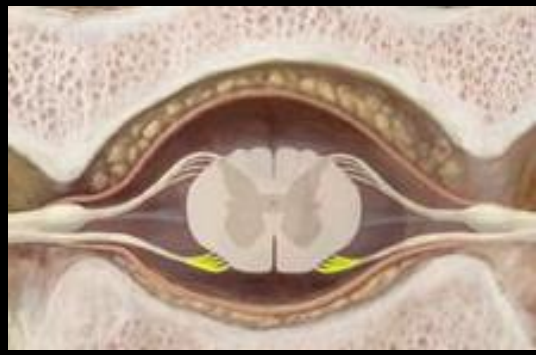


Dorsal root

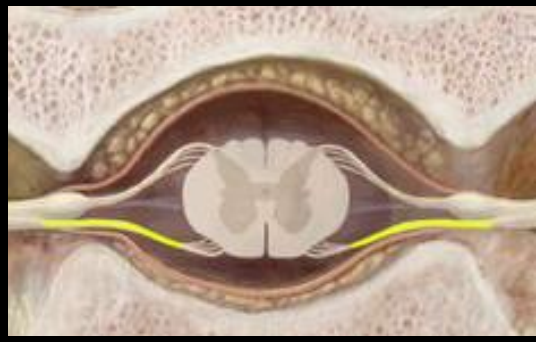


Dorsal root gangion

Ventral rootlets



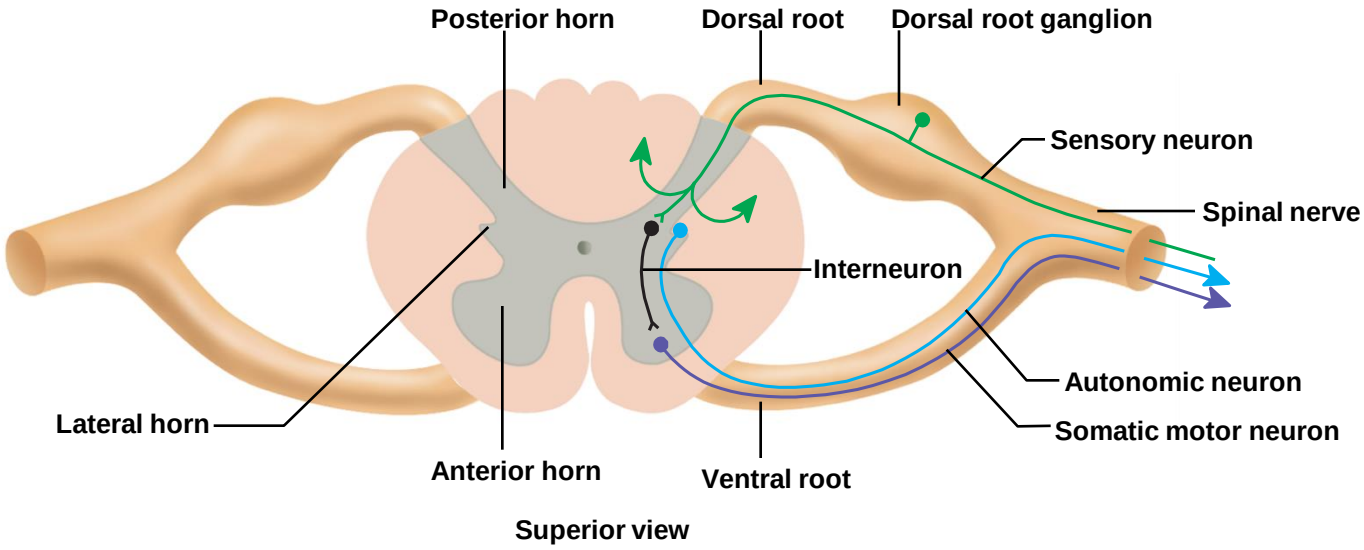
Ventral root



Spinal nerve

Organization of Neurons in the Spinal Cord and Spinal Nerves

- **Dorsal root ganglion**: collections of cell bodies of unipolar sensory neurons forming dorsal roots.

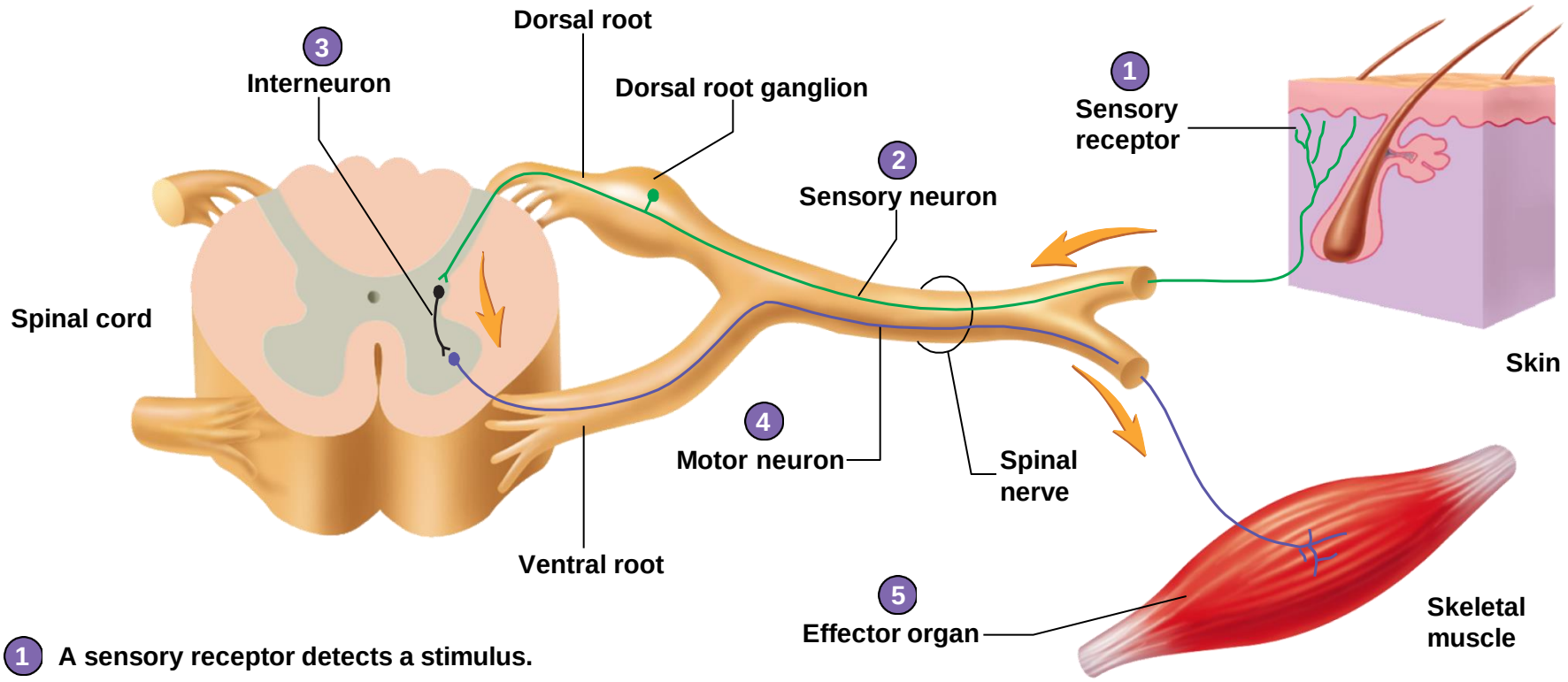


- Motor neuron cell bodies are in anterior and lateral horns of spinal cord gray matter.
  - Multipolar somatic motor neurons in anterior (motor) horn
  - Autonomic neurons in lateral horn
- Axons of motor neurons form ventral roots and pass into spinal nerves

12.2 Reflexes

- Basic functional unit of nervous system and simplest portion capable of receiving a stimulus and producing a response
- Automatic response to a stimulus that occurs without conscious thought. Homeostatic.
- Components
  - Action potentials produced in **sensory receptors** transmitted to
  - **Sensory neuron**. To-**Interneurons**. To-**Motor neuron**. To-
  - **Effector organ** which responds with a **reflex**

Reflex Arc



1. A sensory receptor detects a stimulus.
2. A sensory neuron conducts action potentials through the nerve and dorsal root to the spinal cord.
3. In the spinal cord, the sensory neuron synapses with an interneuron. (An interneuron is not involved in a monosynaptic reflex arc.)
4. The interneuron synapses with a motor neuron.
5. A motor neuron axon conducts action potentials through the ventral root and spinal nerve to an effector organ.

Variety of Reflexes

- Some integrated within spinal cord; some within brain
- Some involve excitatory neurons yielding a response; some involve inhibitory neurons that prevent an action
- Higher brain centers can influence, suppress, or exaggerate reflex responses

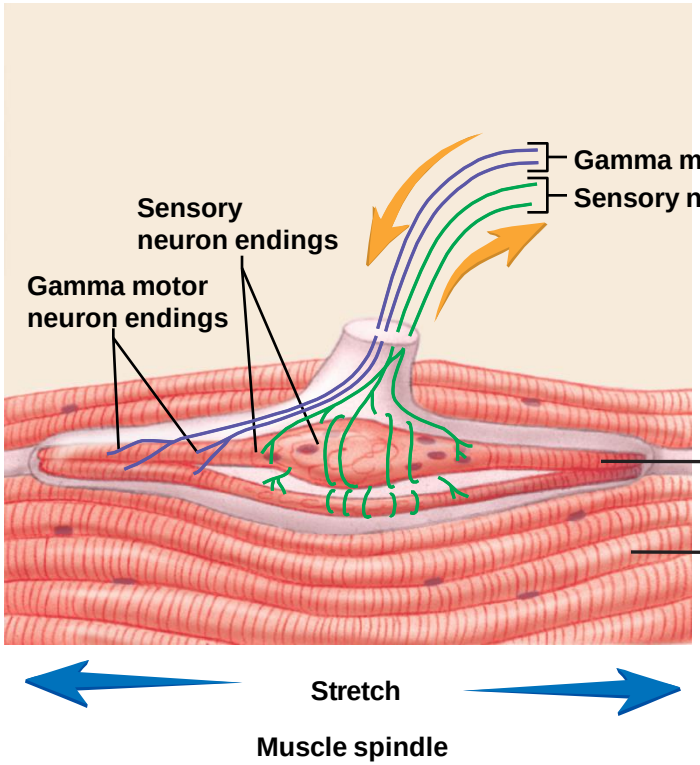
Stretch Reflex

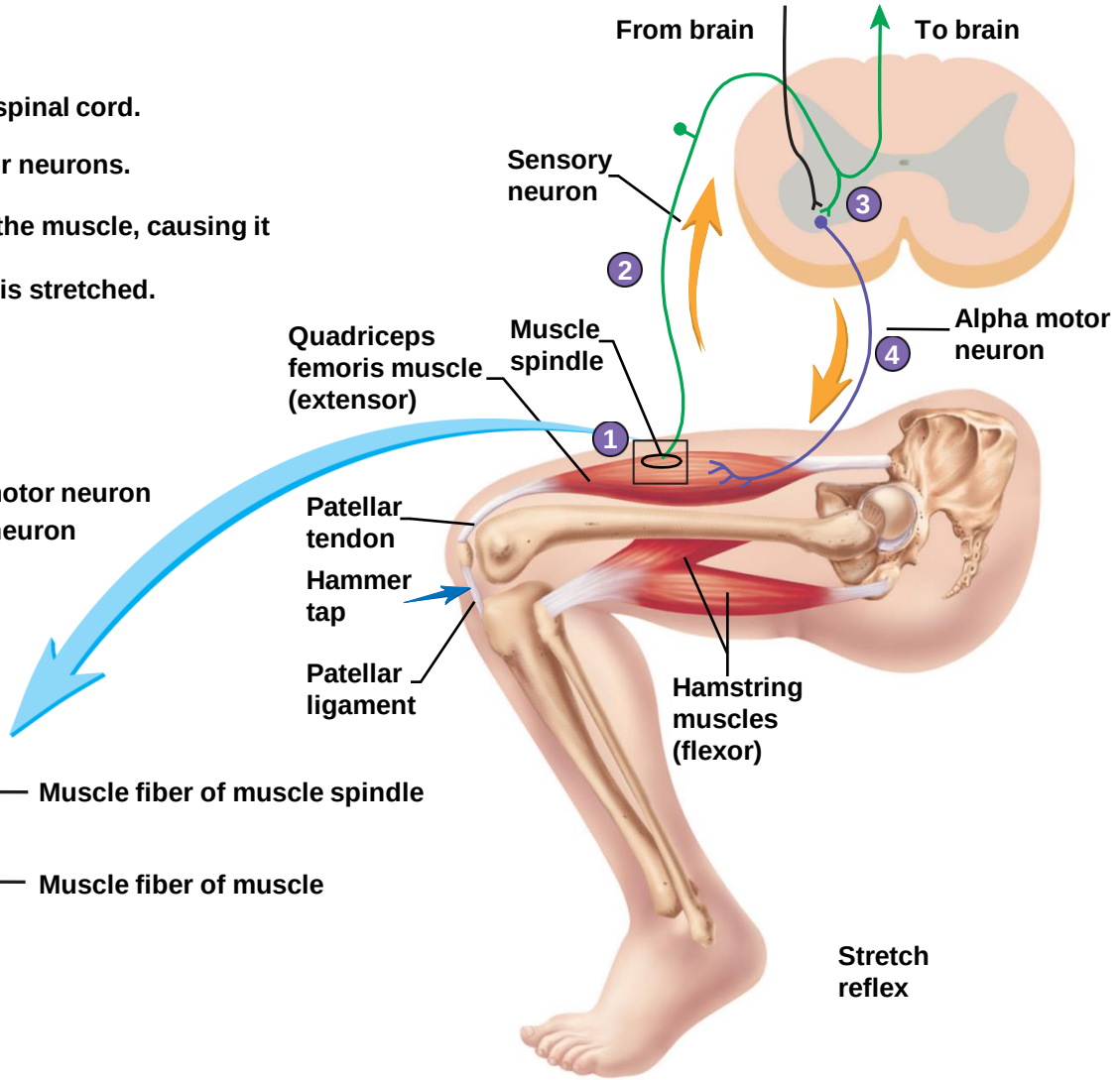
- Muscles contract in response to a stretching force applied to them. Unique because no interneuron.
- Muscle spindle: specialized muscle cells that respond to stretch.
- Innervated by specific motor neurons: gamma motor neurons (small diameter neurons). Control sensitivity of muscle spindle.
- Sensory neurons innervate the noncontractile centers of the muscle spindle cells.
- These sensory neurons synapse with motor neurons of the spinal cord called alpha motor neurons which in turn innervate the muscle in which the muscle spindle is embedded.

Stretch Reflex

Sudden stretch of a muscle results in:

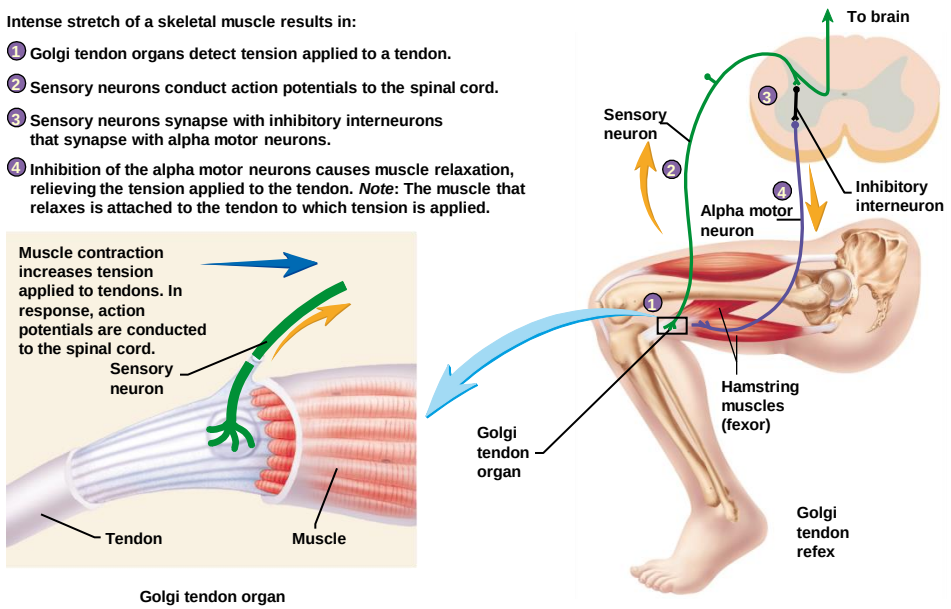
1. **Muscle spindles detect stretch of the muscle.**
2. **Sensory neurons conduct action potentials to the spinal cord.**
3. **Sensory neurons synapse directly with alpha motor neurons.**
4. **Alpha motor neurons conduct action potentials to the muscle, causing it to contract and resist being stretched.**
   Note: **The muscle that contracts is the muscle that is stretched.**





Golgi Tendon Reflex

- Prevents contracting muscles from applying excessive tension to tendons
- **Golgi tendon organ**. Encapsulated nerve endings that have at their ends numerous terminal branches with small swellings associated with bundles of collagen fibers in tendon. Located in tendon near muscle
- Prevent damage to tendons that could be caused by excessive tension
- Produces sudden relaxation of the muscles
  - Example: weight lifter suddenly drops heavy weight. Sudden movements of "clean and jerk" put so much tension on tendons like Achilles, they could break.



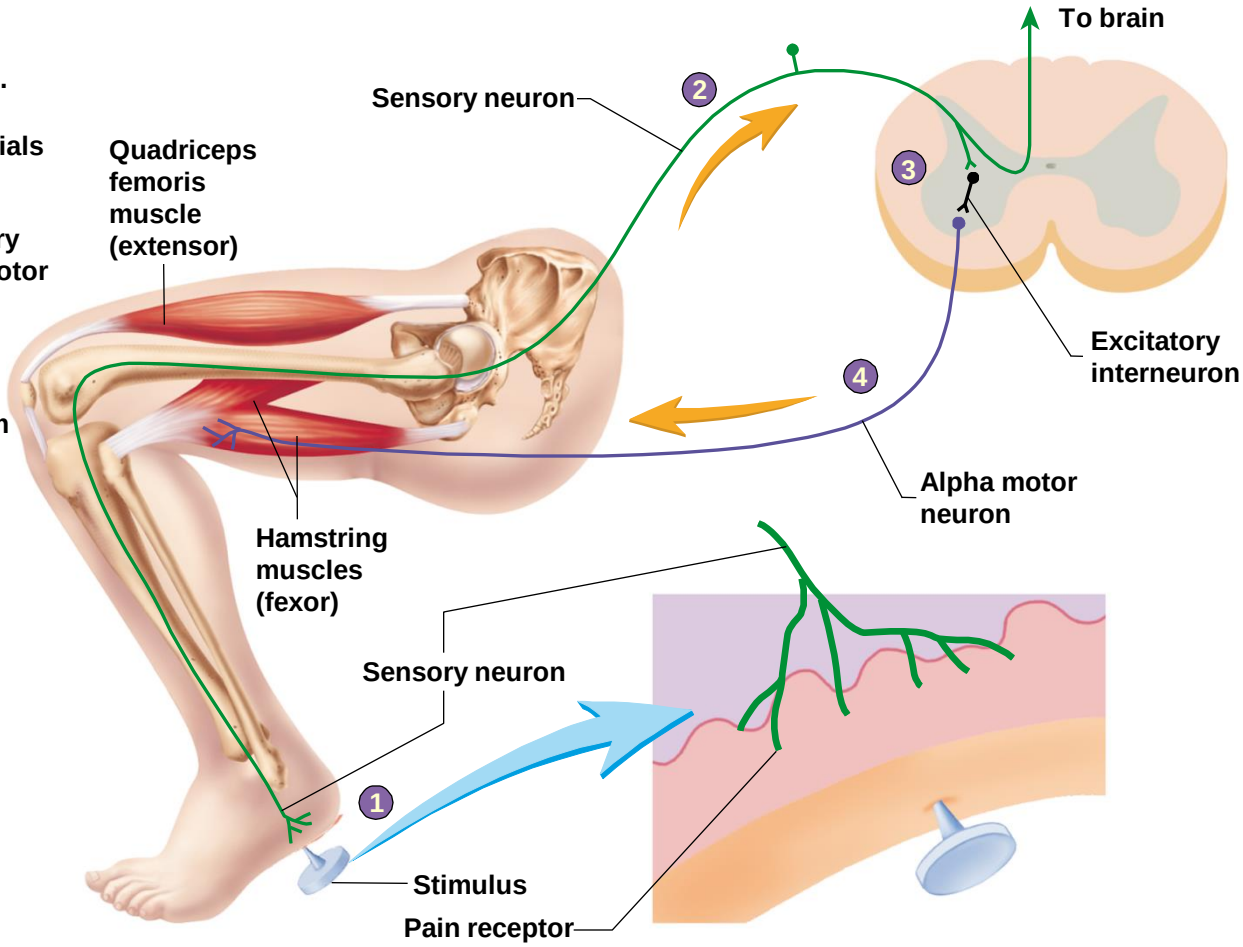
Withdrawal Reflex

- Function is to remove a body limb or other part from a painful stimulus.
- **Reciprocal innervation**: causes relaxation of extensor muscle when flexor muscle contracts.
  - Also involved in stretch reflex.
- **Crossed extensor reflex**: when a withdrawal reflex is initiated in one lower limb, the crossed extensor reflex causes extension of opposite lower limb.

Withdrawal Reflex

Stimulation of pain receptors results in:

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.**

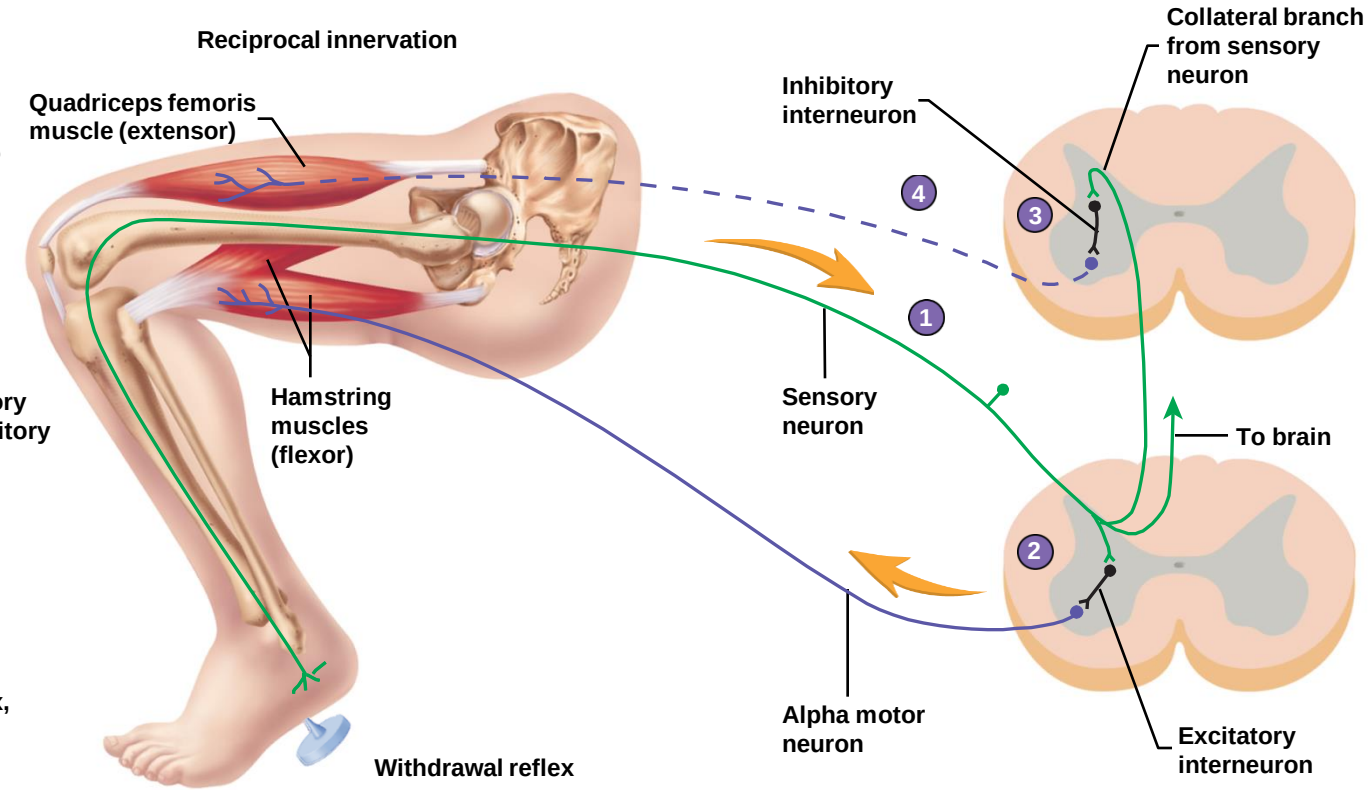


Withdrawal reflex

Withdrawal Reflex with Reciprocal Innervation

Reciprocal innervation

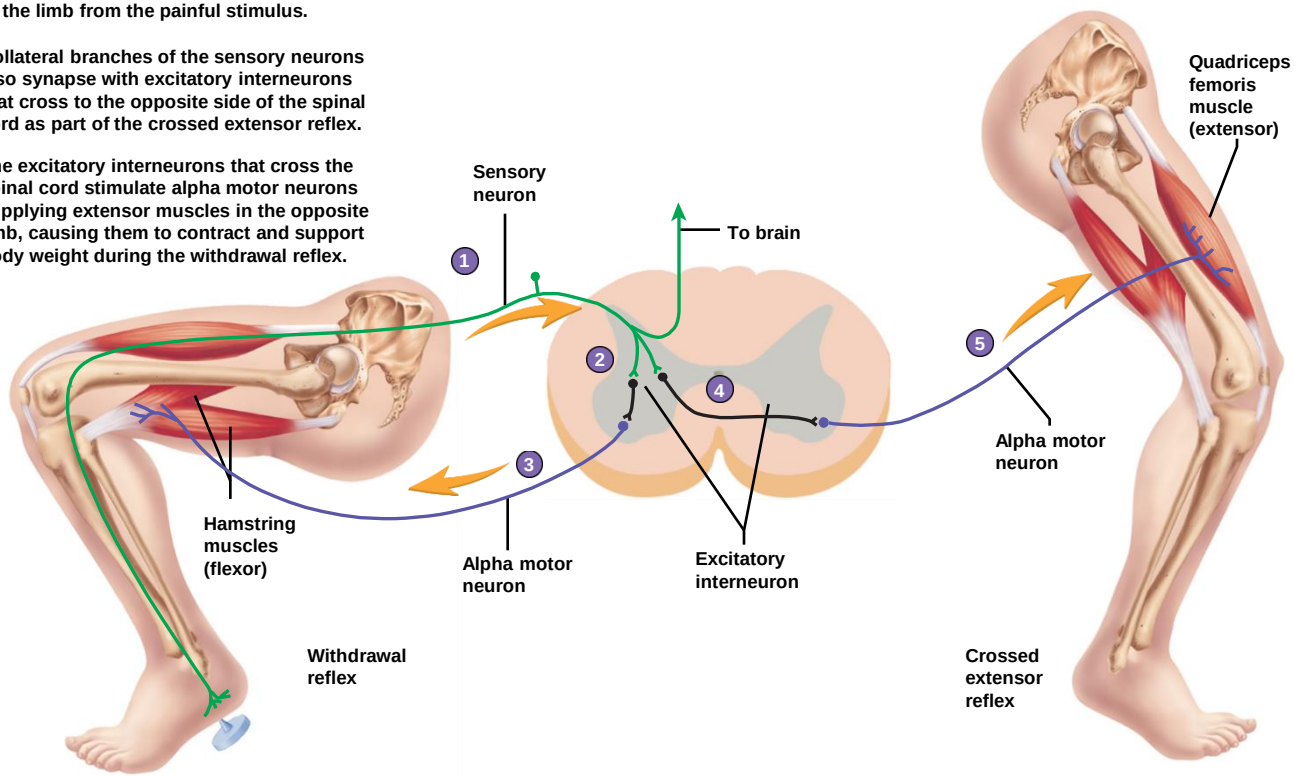
1. During the withdrawal reflex, sensory neurons conduct action potentials from pain receptors to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex.
3. Collateral branches of the sensory neurons also synapse with inhibitory interneurons that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



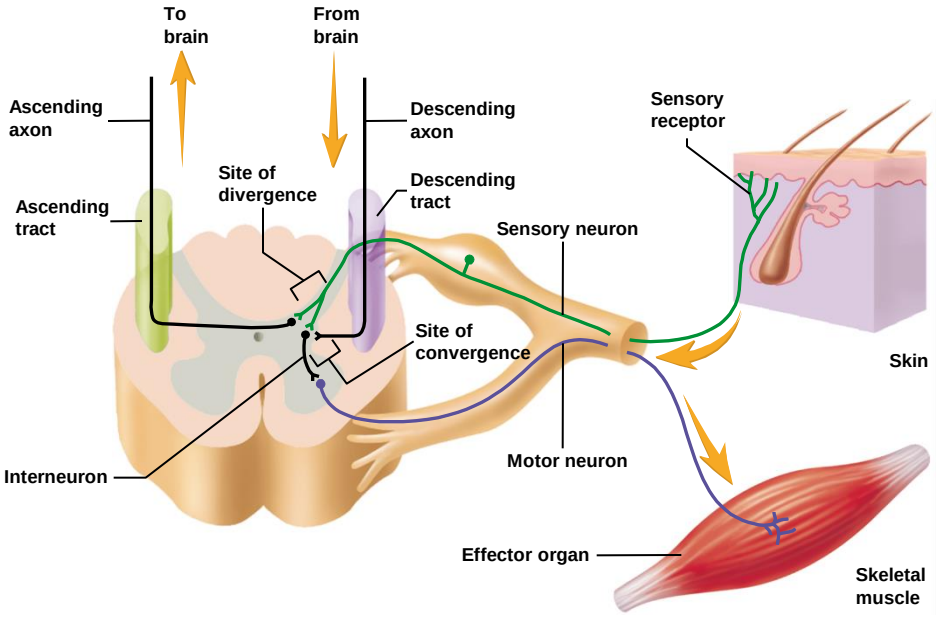
Withdrawal Reflex with Crossed Extensor Reflex

Crossed extensor reflex

1. During the withdrawal reflex, sensory neurons from pain receptors conduct action potentials to the spinal cord.
2. Sensory neurons synapse with excitatory interneurons that are part of the withdrawal reflex.
3. The excitatory interneurons that are part of the withdrawal reflex stimulate alpha motor neurons that innervate flexor muscles, causing withdrawal of the limb from the painful stimulus.
4. Collateral branches of the sensory neurons also synapse with excitatory interneurons that cross to the opposite side of the spinal cord as part of the crossed extensor reflex.
5. The excitatory interneurons that cross the spinal cord stimulate alpha motor neurons supplying extensor muscles in the opposite limb, causing them to contract and support body weight during the withdrawal reflex.



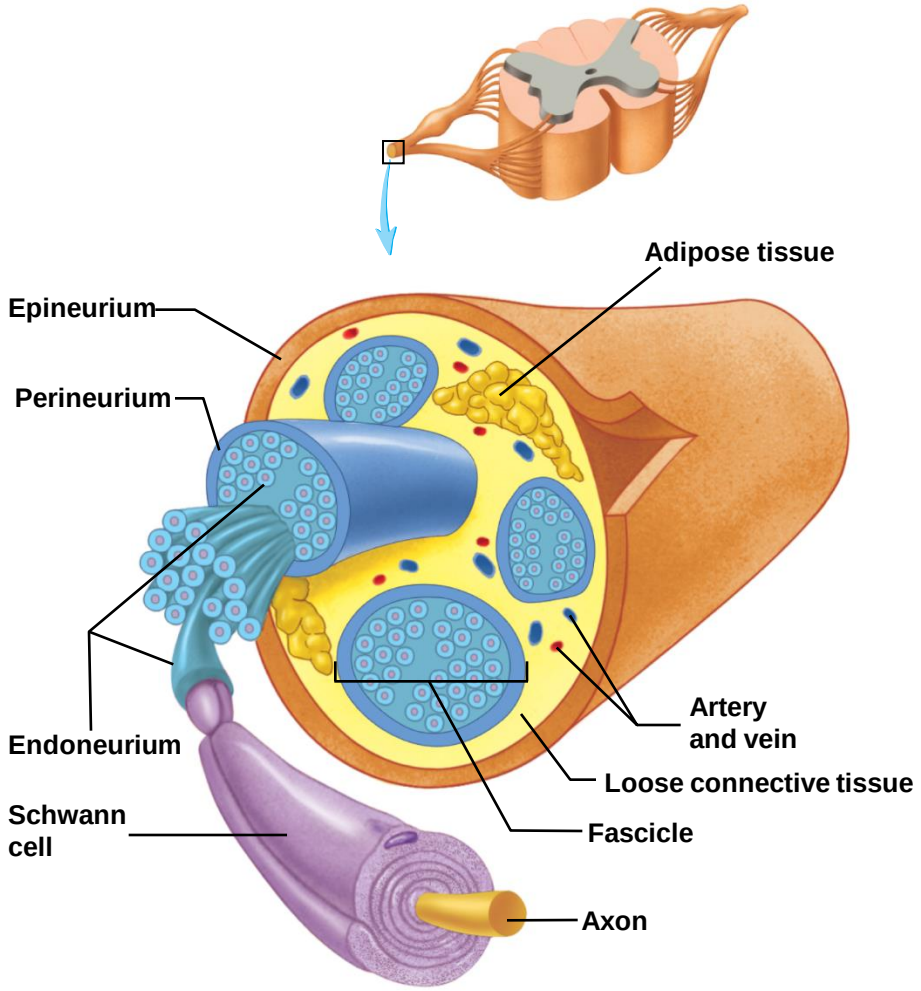
Interactions with Spinal Cord Reflexes



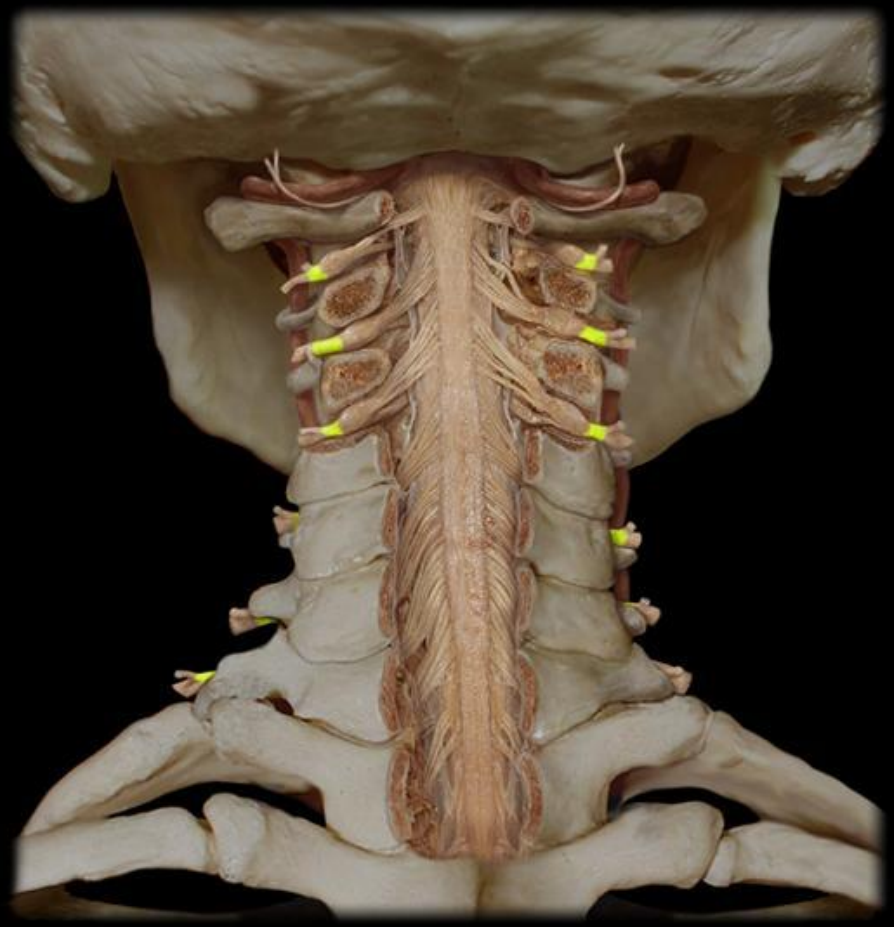
- Sensory information goes to brain; e.g., pain.
- Descending tracts from brain carry info to reflexes.
- Neurotransmitters produce either EPSPs or IPSPs modifying the reflex.

12.3 Spinal Nerves

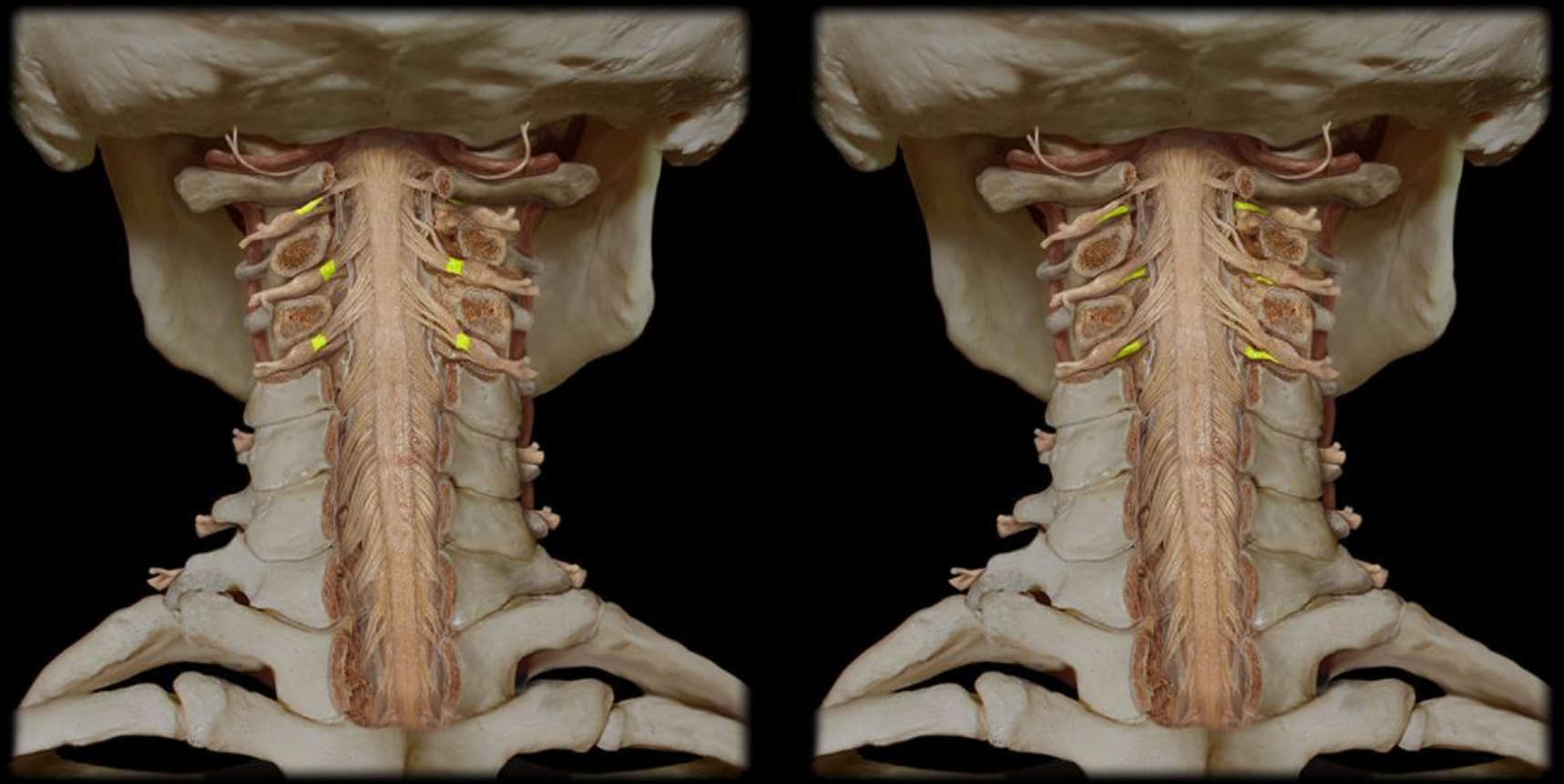
- Consist of
  - Axon bundles
  - Schwann cells
  - Connective tissue
    - **Endoneurium**: surrounds individual neurons
    - **Perineurium**: surrounds axon groups to form fascicles
    - **Epineurium**: surrounds the entire nerve



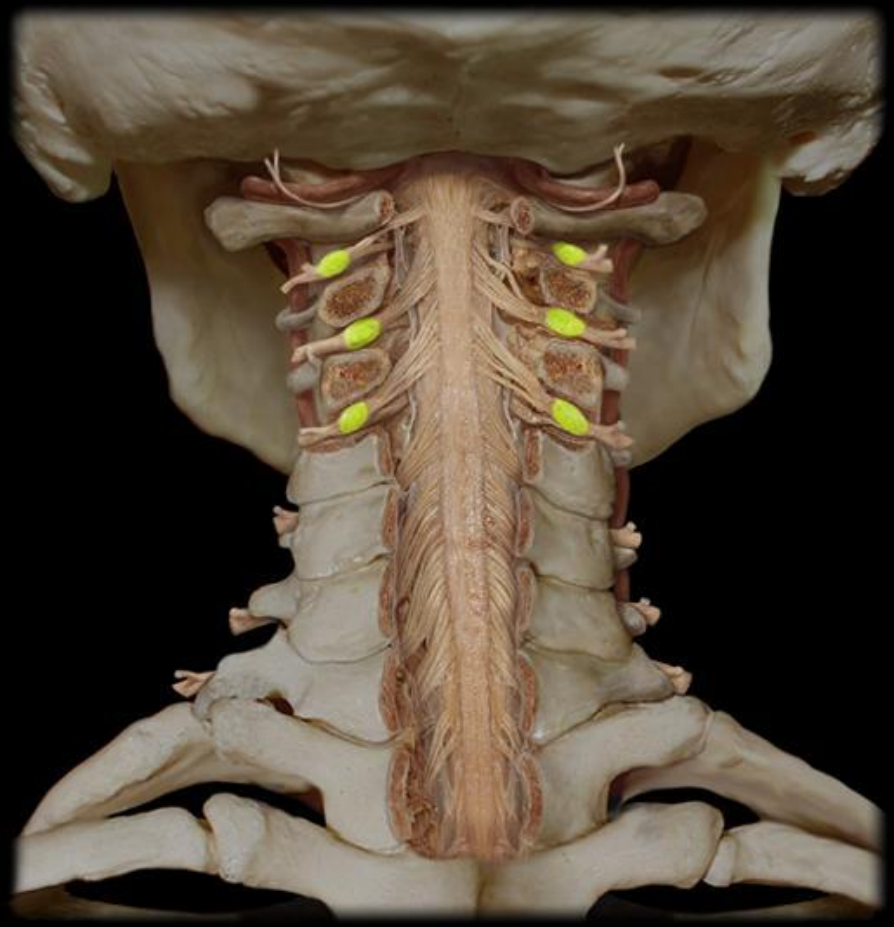
31 Pair of Spinal Nerves



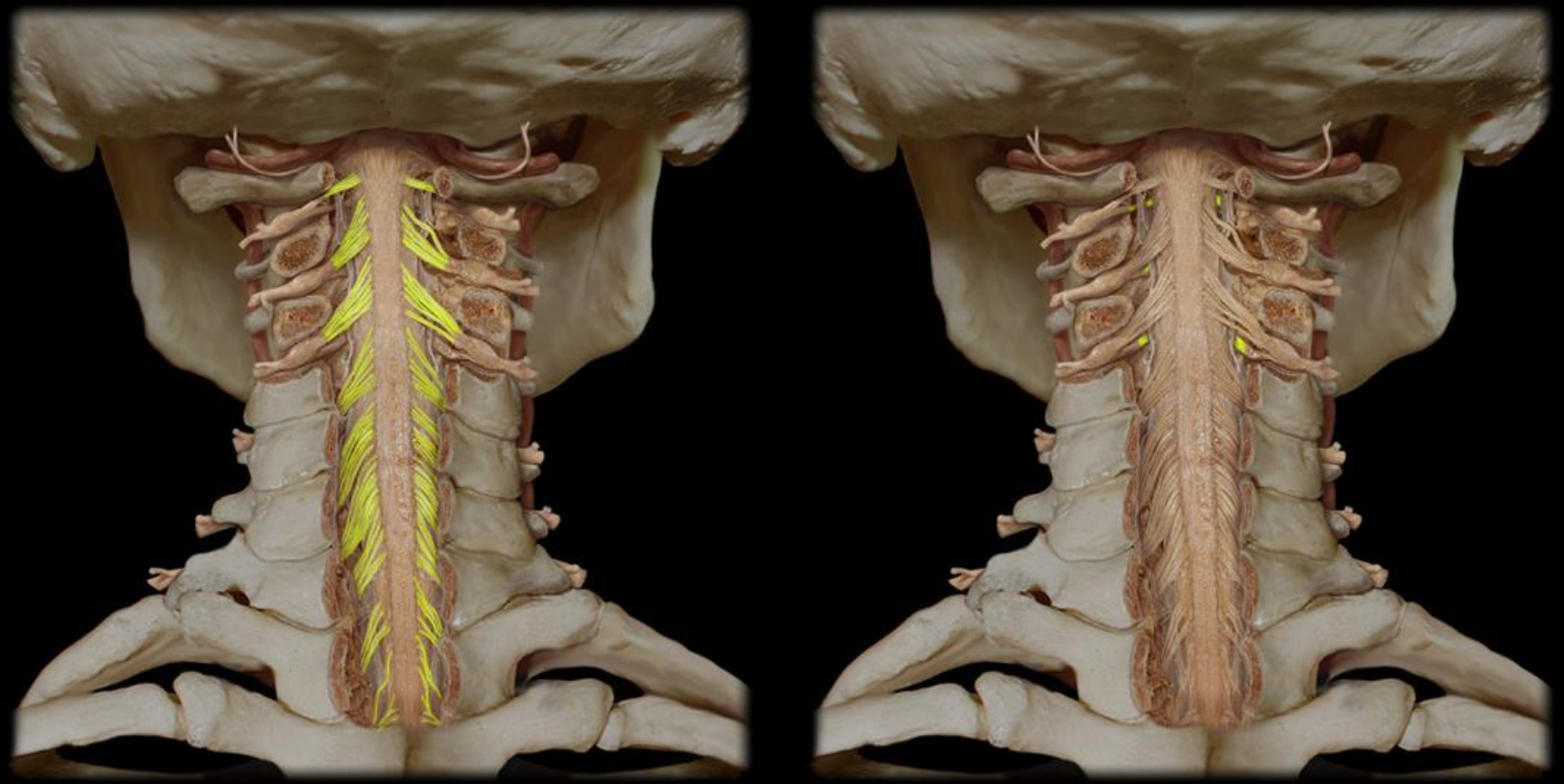
Posterior (Dorsal) & Anterior (Ventral) Roots

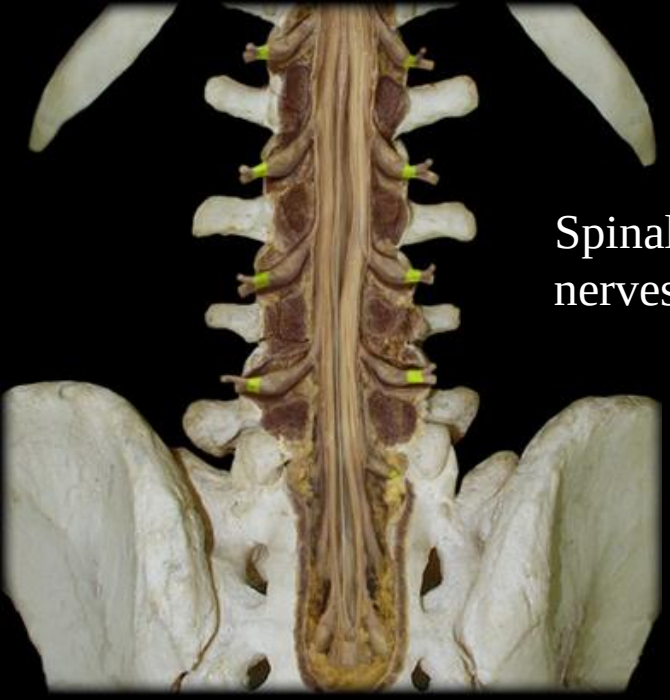


Posterior (Dorsal) Root Ganglia

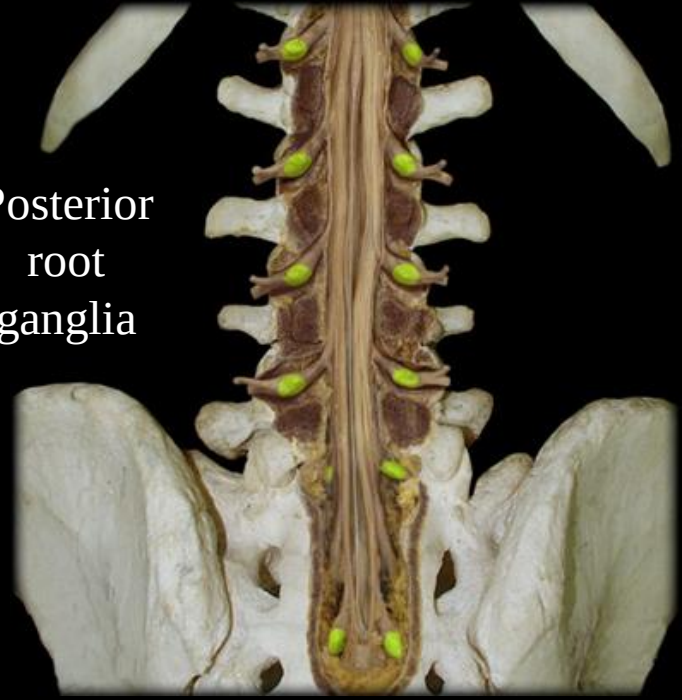


Posterior (Dorsal) and Anterior (Ventral) Rootlets

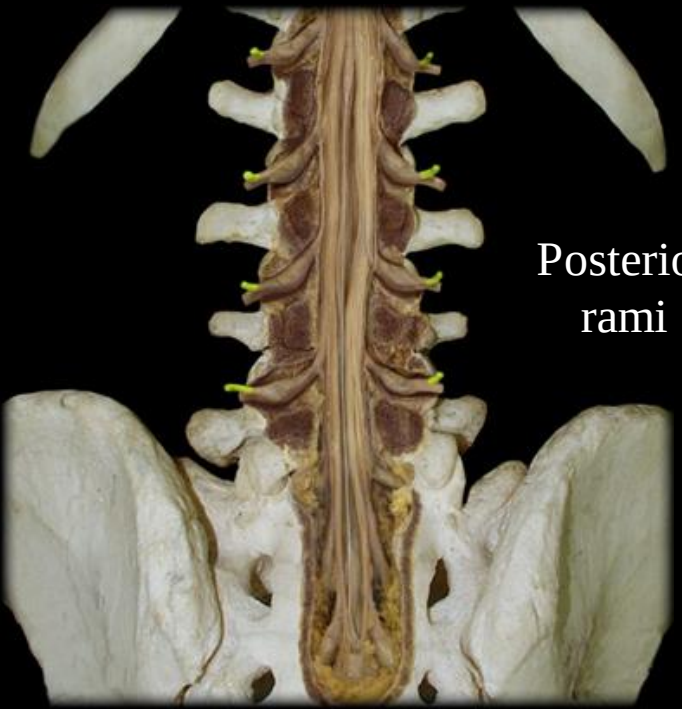




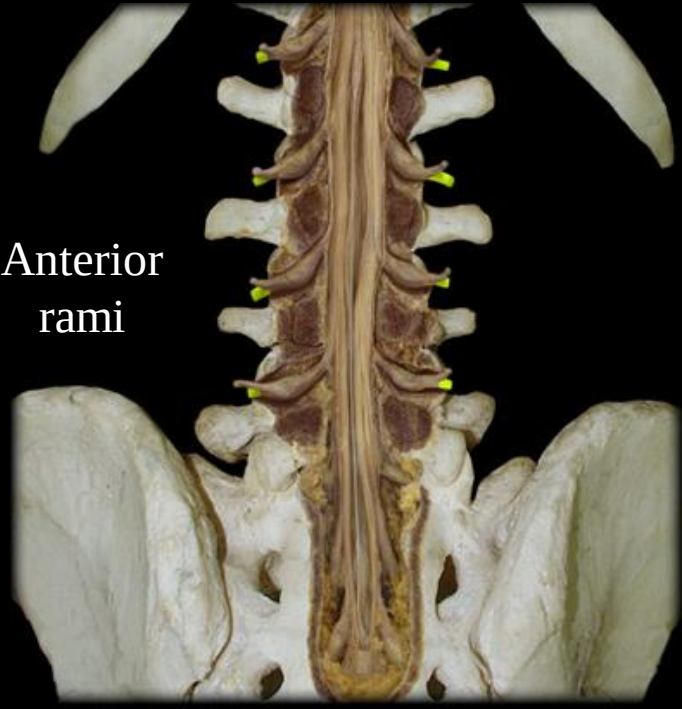
Spinal nerves



Posterior root ganglia



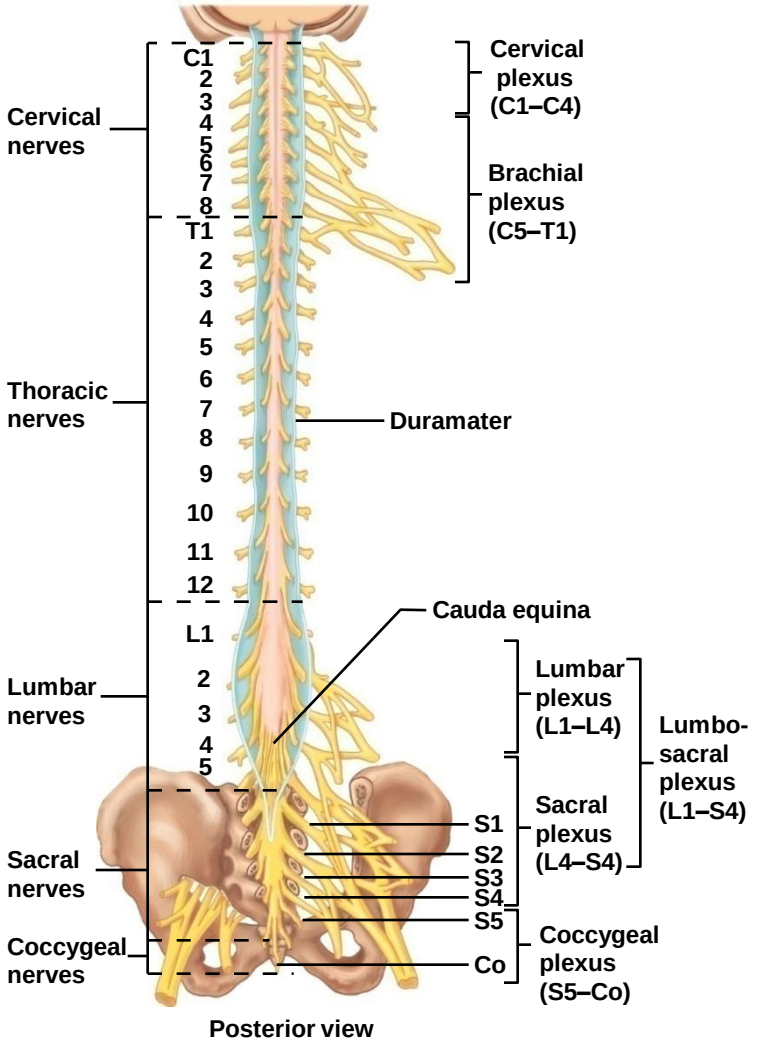
Posterior rami



Anterior rami

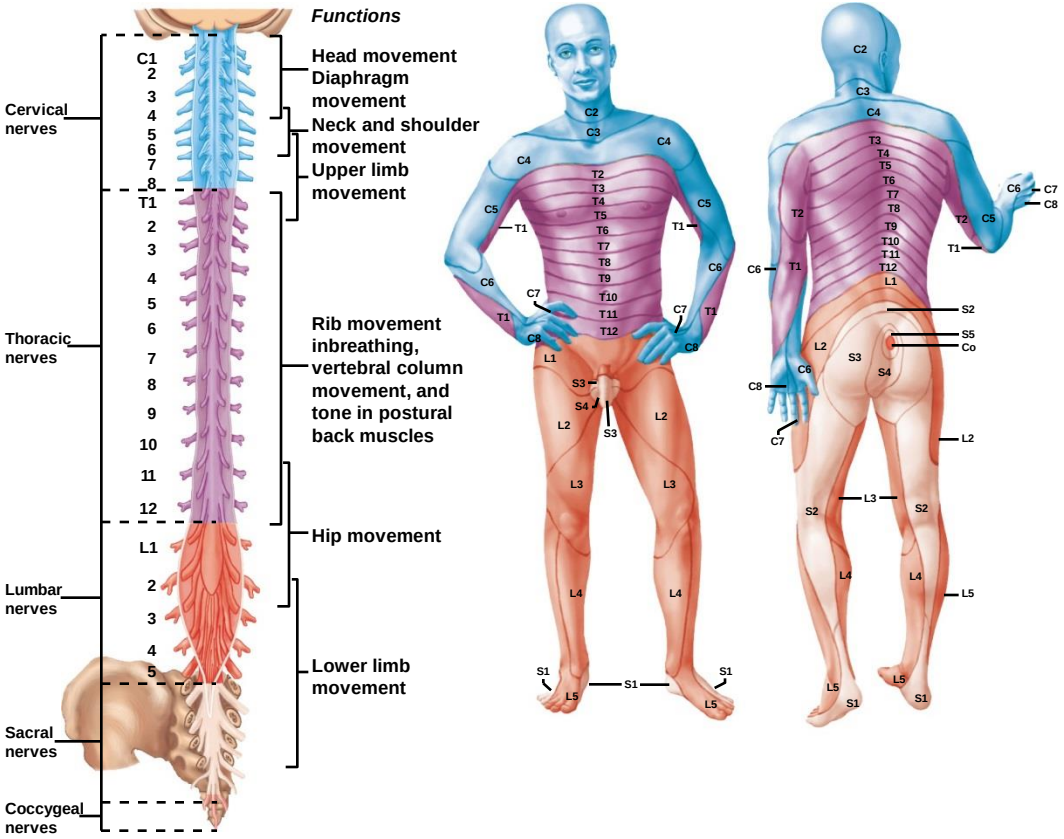
Organization of Spinal Nerves

- Thirty-one pairs of spinal nerves
- First pair exit vertebral column between skull and atlas
- Last four pair exit via the sacral foramina
- Others exit through intervertebral foramina
- Eight pair cervical, twelve pair thoracic, five pair lumbar, five pair sacral, one pair coccygeal



Dermatomal Map

- Spinal nerves indicated by capital letter and number
- **Dermatomal map**: skin area supplied with sensory innervation by spinal nerves



Branches of Spinal Nerves

•**Dorsal Ramus**: innervate deep muscles of the trunk responsible for movements of the vertebral column and the C.T. and skin near the midline of the back.

•**Ventral Ramus**: what they innervate depends upon which part of the spinal cord is considered.

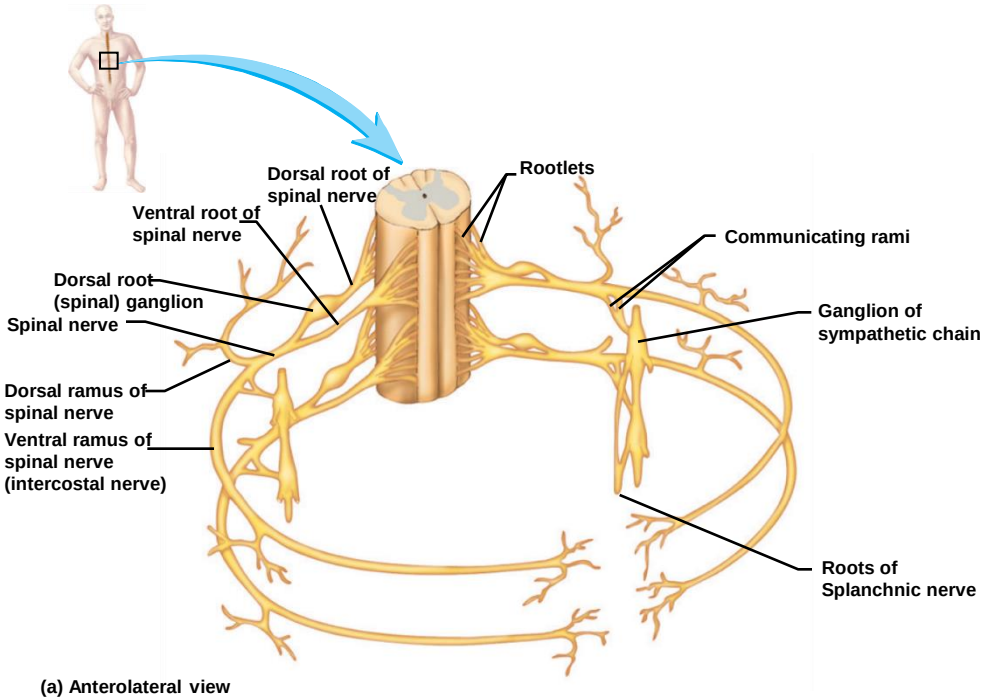
–Thoracic region: form **intercostal nerves** that innervate the intercostal muscles and the skin over the thorax

–Remaining spinal nerve ventral rami (**roots** of the plexus): form five plexuses (intermingling of nerves).

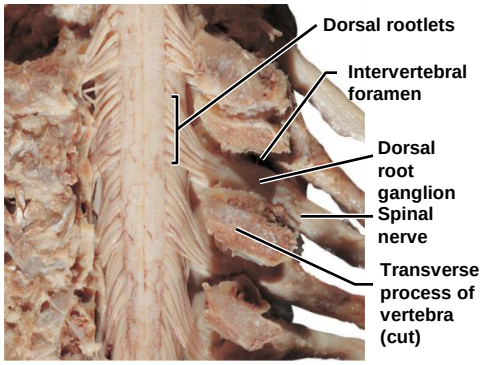
- Ventral rami of C1-C4= **cervical plexus**
- Ventral rami of C5-T1= **brachial plexus**
- Ventral rami of L1-L4= **lumbar plexus**
- Ventral rami of L4-S4= **sacral plexus**
- Ventral rami of S4 and S5= **coccygeal plexus**

- **Communicating Rami**: communicate with sympathetic chain of ganglia.

Branches of Spinal Nerves



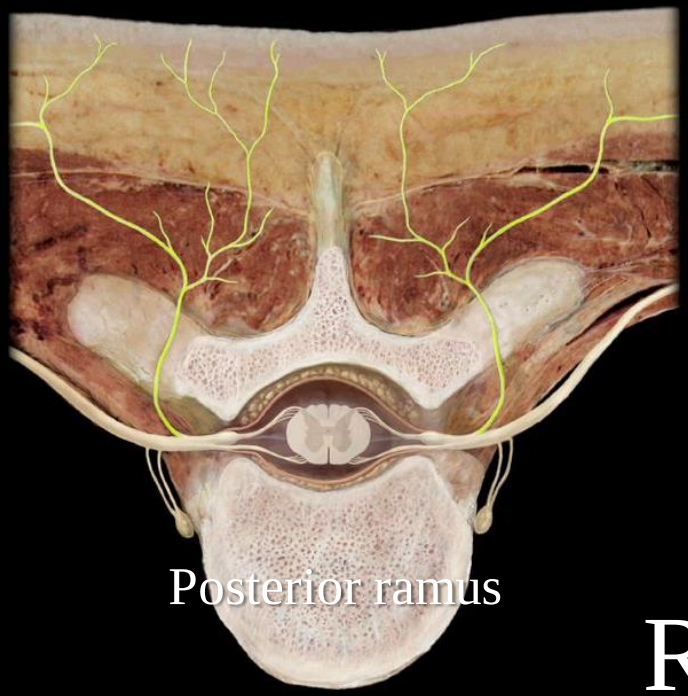
(a) Anterolateral view

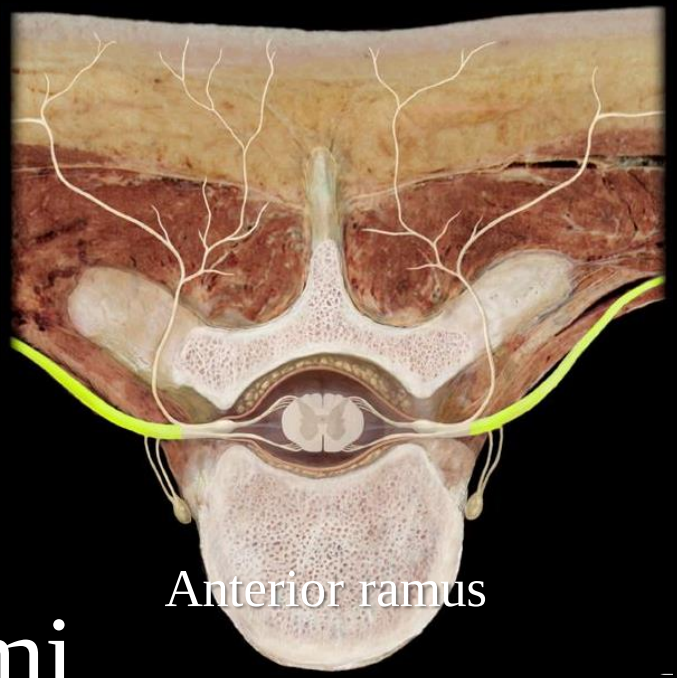


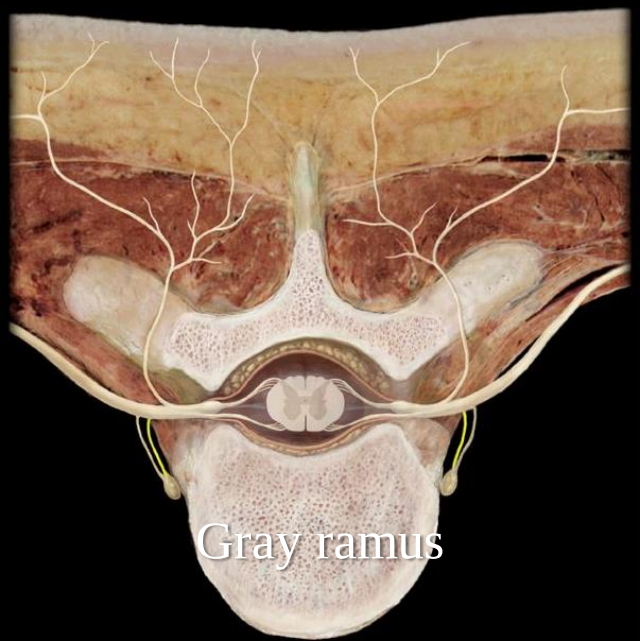
(b) Posterior view

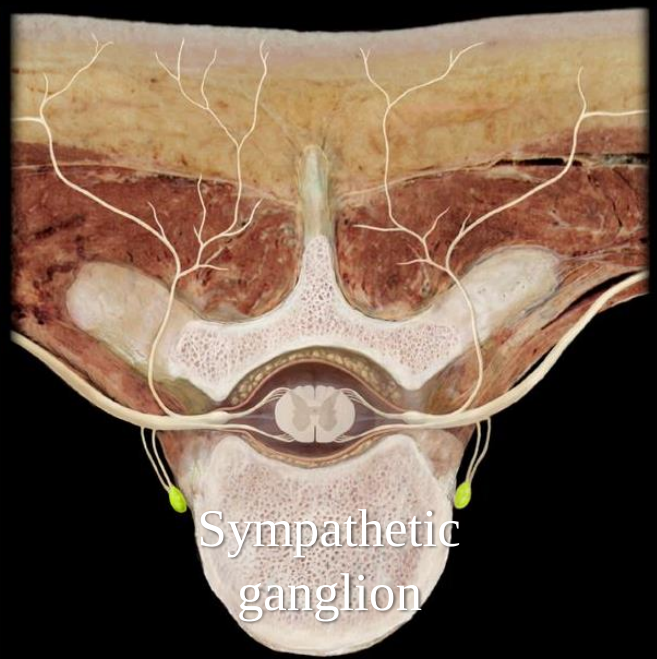
b: © McGraw-Hill Higher Education, Inc./Rebecca Gray, photographer/Don Kincaid, dissections

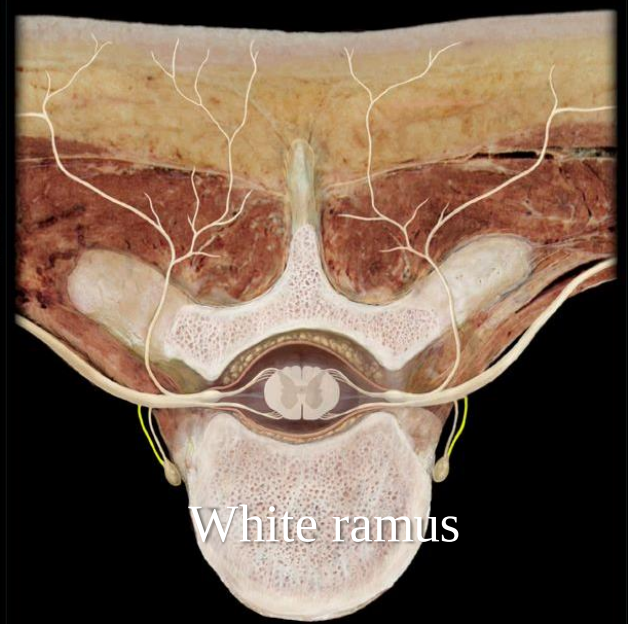
Rami


Posterior ramus

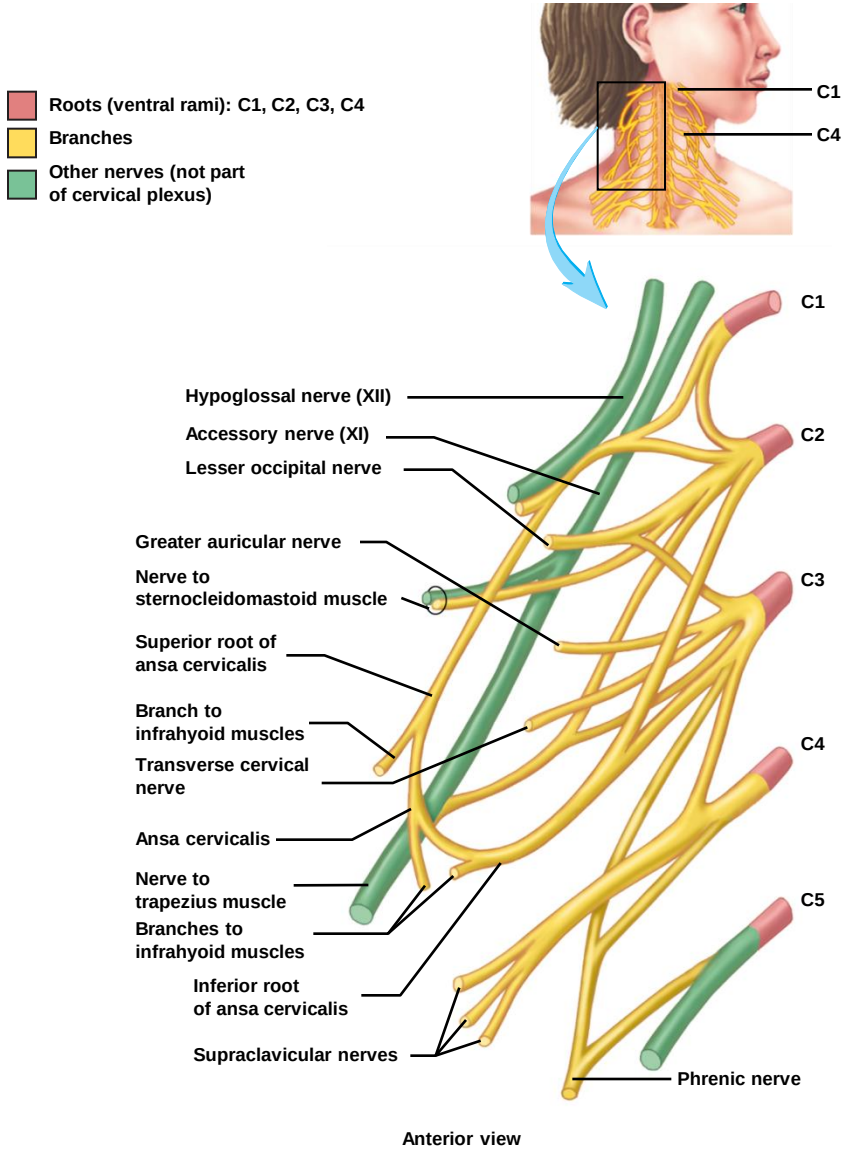

Anterior ramus


Gray ramus


Sympathetic ganglion

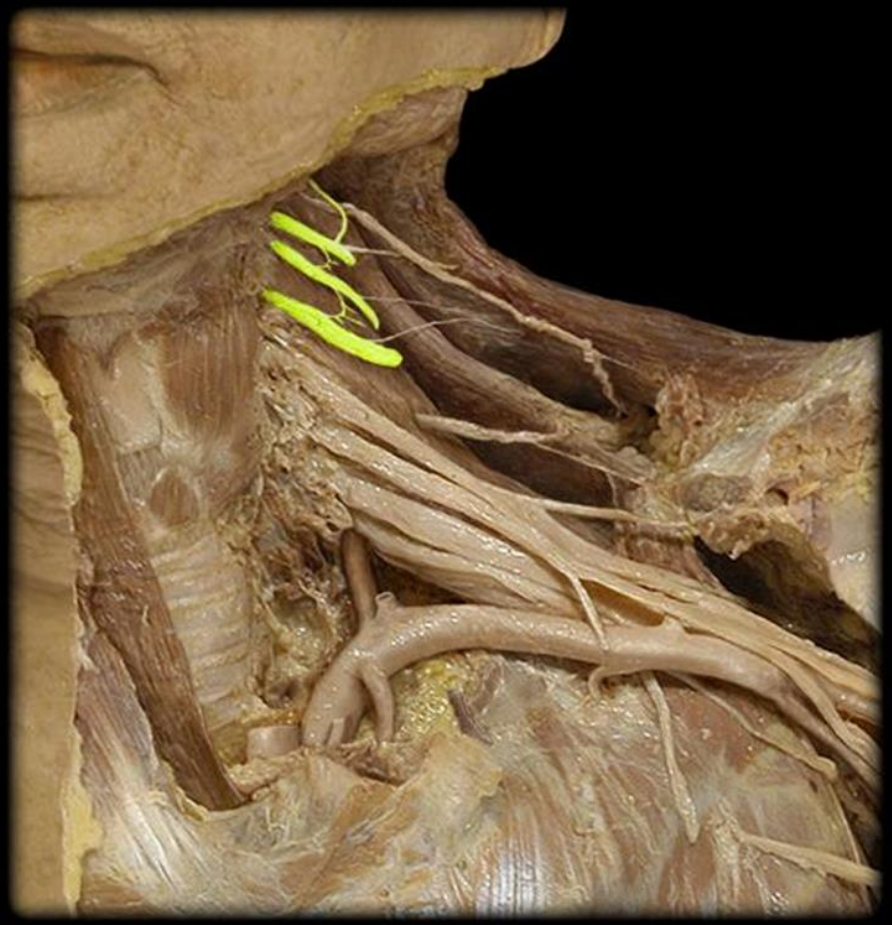

White ramus

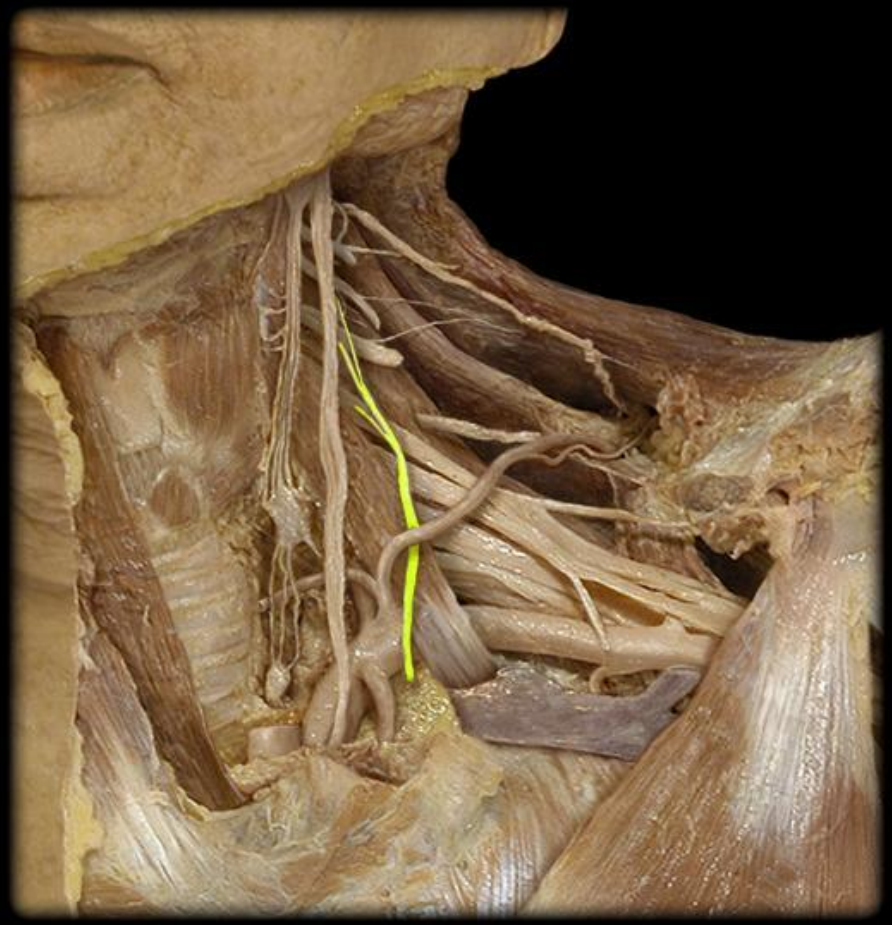
Cervical Plexus



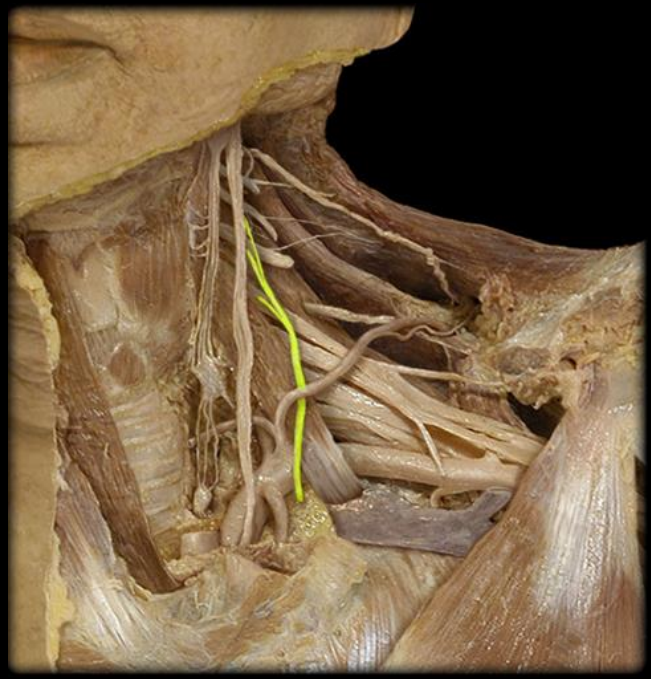
- C1-C4
- Innervates superficial neck structures, skin of neck, posterior portion of head
- Ansa cervicalis: loop between C1 and C3
- Phrenic nerve
  - From C3-C5 (cervical and brachial plexuses)
  - Innervate diaphragm

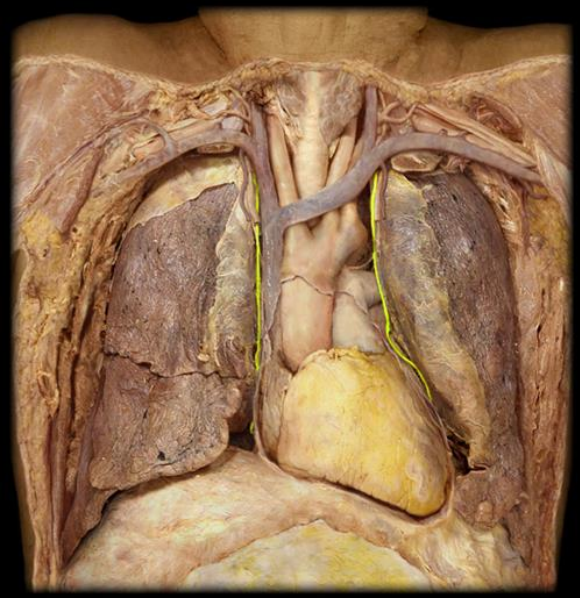
Cervical Plexus – Phrenic Nerve



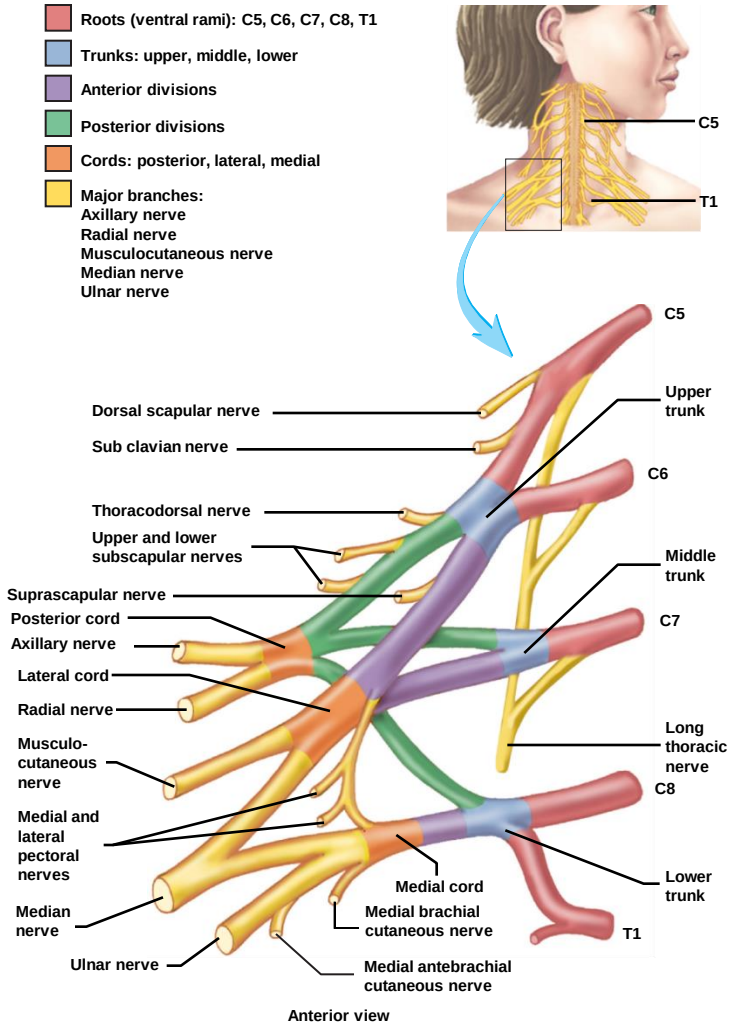


Phrenic Nerve



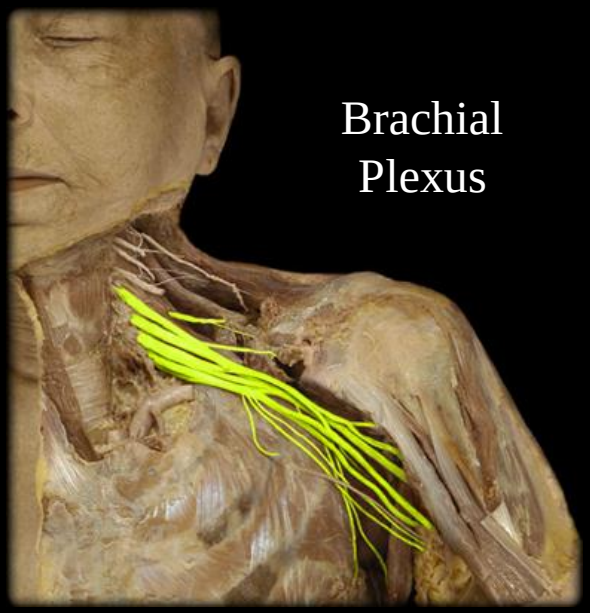


Brachial Plexus

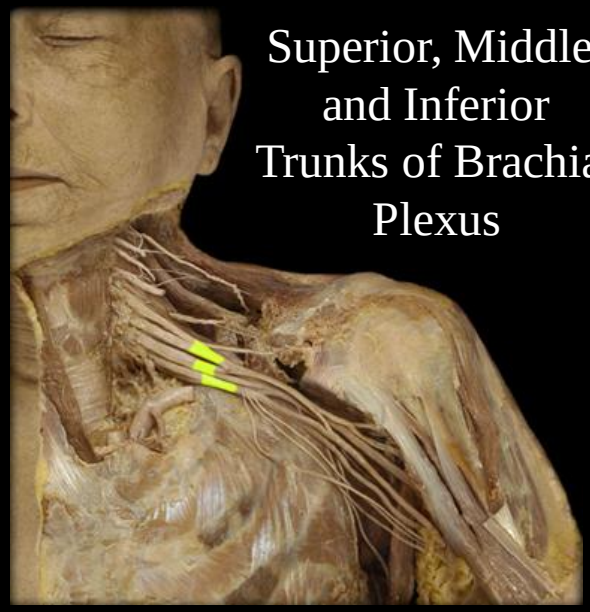


- C4 from cervical plus C5-T1
- Five ventral rami form three **trunks** that separate into six **divisions** then form **cords** that give rise to:
- **Branches/nerves**
  - **Axillary**
  - **Radial**
  - **Musculocutaneous**
  - **Ulnar**
  - **Median**
  - Smaller nerves such as pectoral, long thoracic, thoracodorsal, subscapular, suprascapular

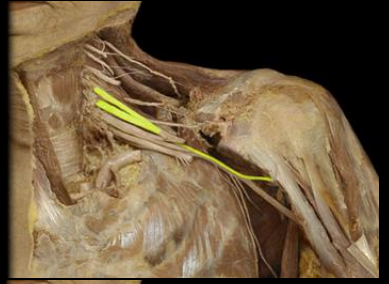
Brachial Plexus



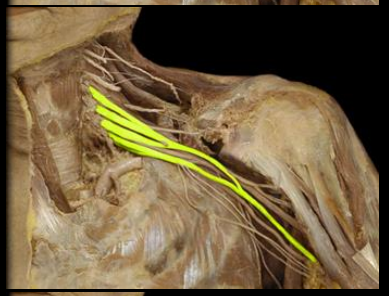
Brachial Plexus



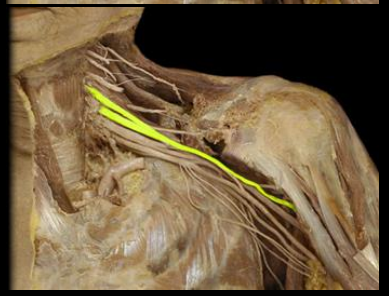
Superior, Middle, and Inferior Trunks of Brachial Plexus



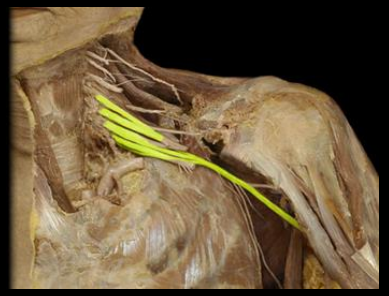
Axillary n.



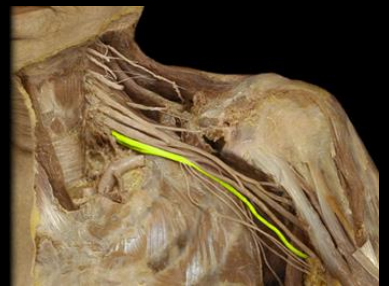
Median n.



Musculocutaneous n.



Radial n.



Ulnar n.

Axillary Nerve

Axillary Nerve

Origin

Posterior cord of brachial plexus, C5–C6

Movements/Muscles Innervated

Laterally rotates arm

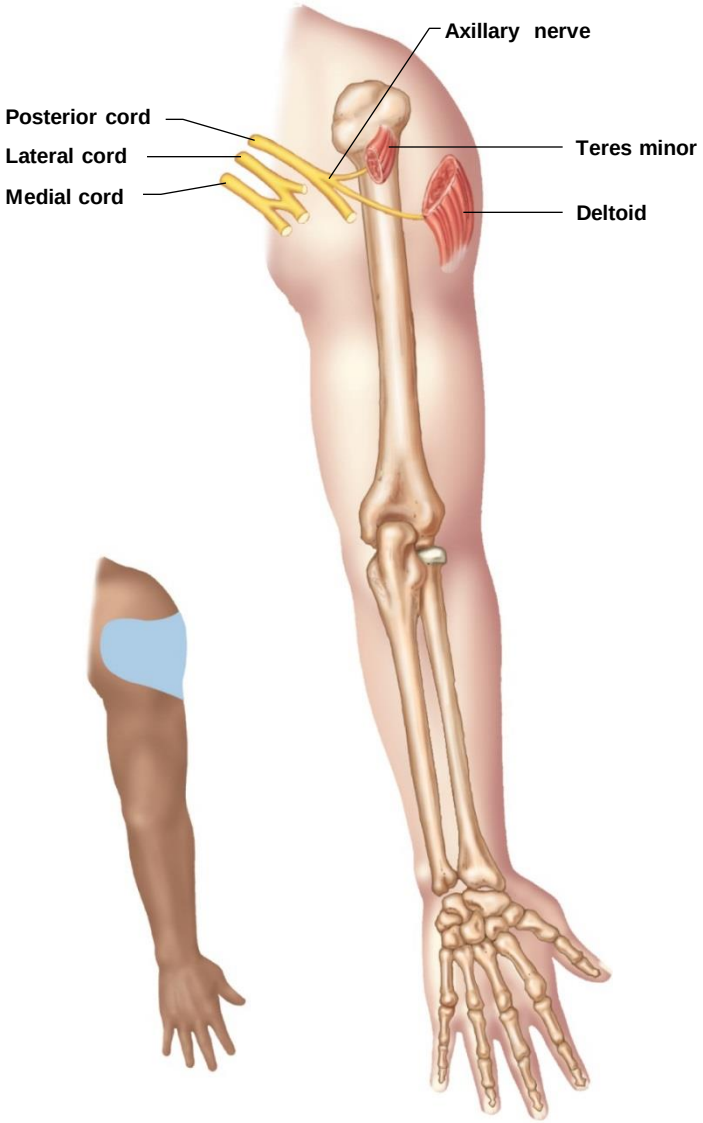
- *Teres minor*

Abducts arm

- *Deltoid*

Cutaneous (Sensory) Innervation

Inferior lateral shoulder



Posterior views

Axillary Nerve

Radial Nerve

Radial Nerve

Origin

Posterior cord of brachial plexus, C5–T1

Movements/Muscles Innervated

Extends elbow
- *Triceps brachii*
- *Anconeus*

Flexes elbow
- *Brachialis (part; sensory only)*
- *Brachioradialis*

Extends and abducts wrist
- *Extensor carpi radialis longus*
- *Extensor carpi radialis brevis*

Supinates forearm and hand
- *Supinator*

Extends fingers
- *Extensor digitorum*
- *Extensor digiti minimi*
- *Extensor indicis*

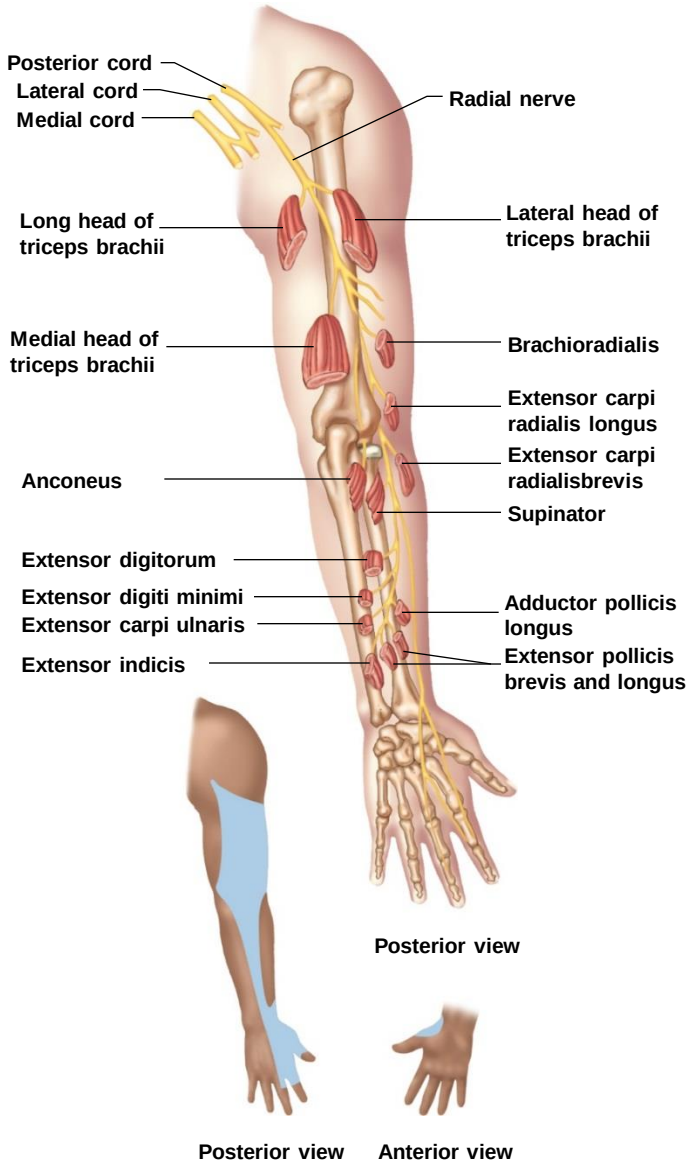
Extends and adducts wrist
- *Extensor carpi ulnaris*

Abducts thumb
- *Abductor pollicis longus*

Extends thumb
- *Extensor pollicis longus*
- *Extensor pollicis brevis*

Cutaneous (Sensory) Innervation

Posterior surface of arm and forearm, lateral two-thirds of dorsum of hand



Radial Nerve

Musculocutaneous Nerve

Musculocutaneous Nerve

Origin

Lateral cord of brachial plexus, C5–C7

Movements/Muscles Innervated

Flexes shoulder

- *Biceps brachii*
- *Coracobrachialis*

Flexes elbow and supinates forearm and hand

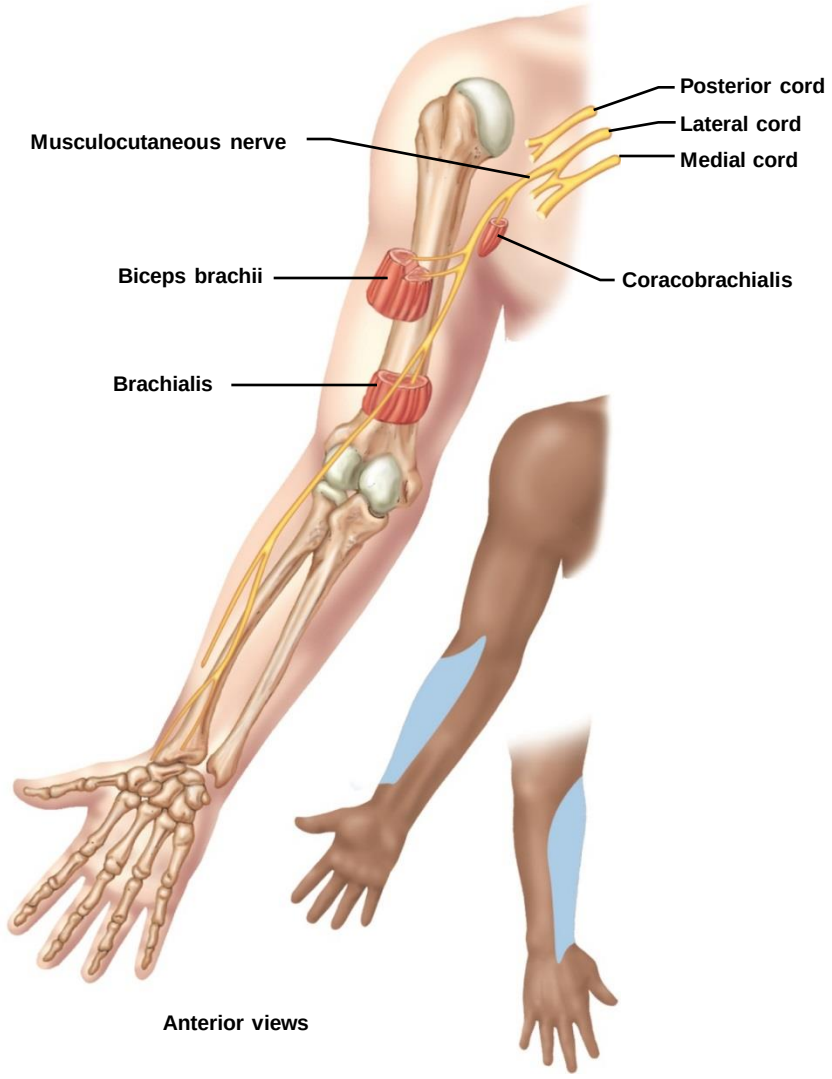
- *Biceps brachii*

Flexes elbow

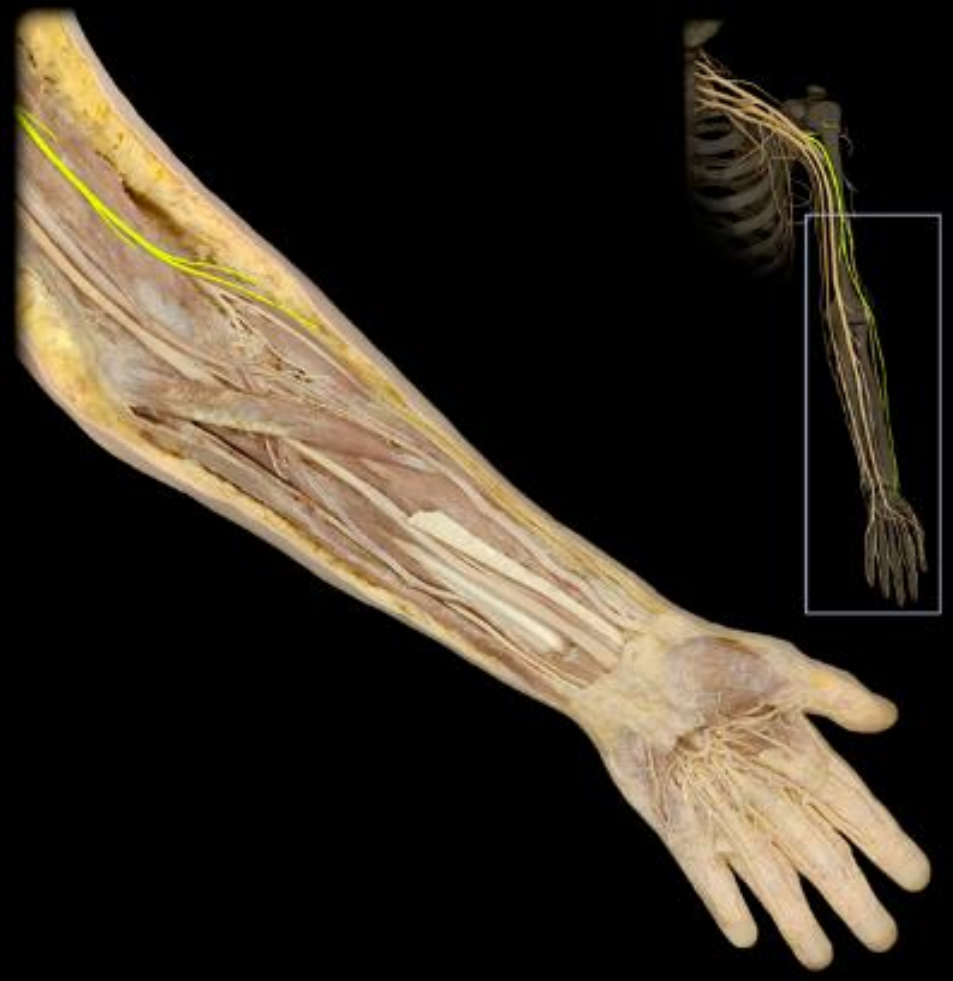
- *Brachialis (also small amount of innervation from radial nerve)*

Cutaneous (Sensory) Innervation

Lateral surface of forearm



Musculocutaneous Nerve



Ulnar Nerve

Ulnar Nerve

Origin

Medial cord of brachial plexus, C8–T1

Movements/Muscles Innervated

Flexes and adducts wrist
- *Flexor carpi ulnaris*

Flexes fingers
- *Part of the flexor digitorum profundus controlling the distal phalanges of little and ring fingers*

Adducts thumb
- *Adductor pollicis*

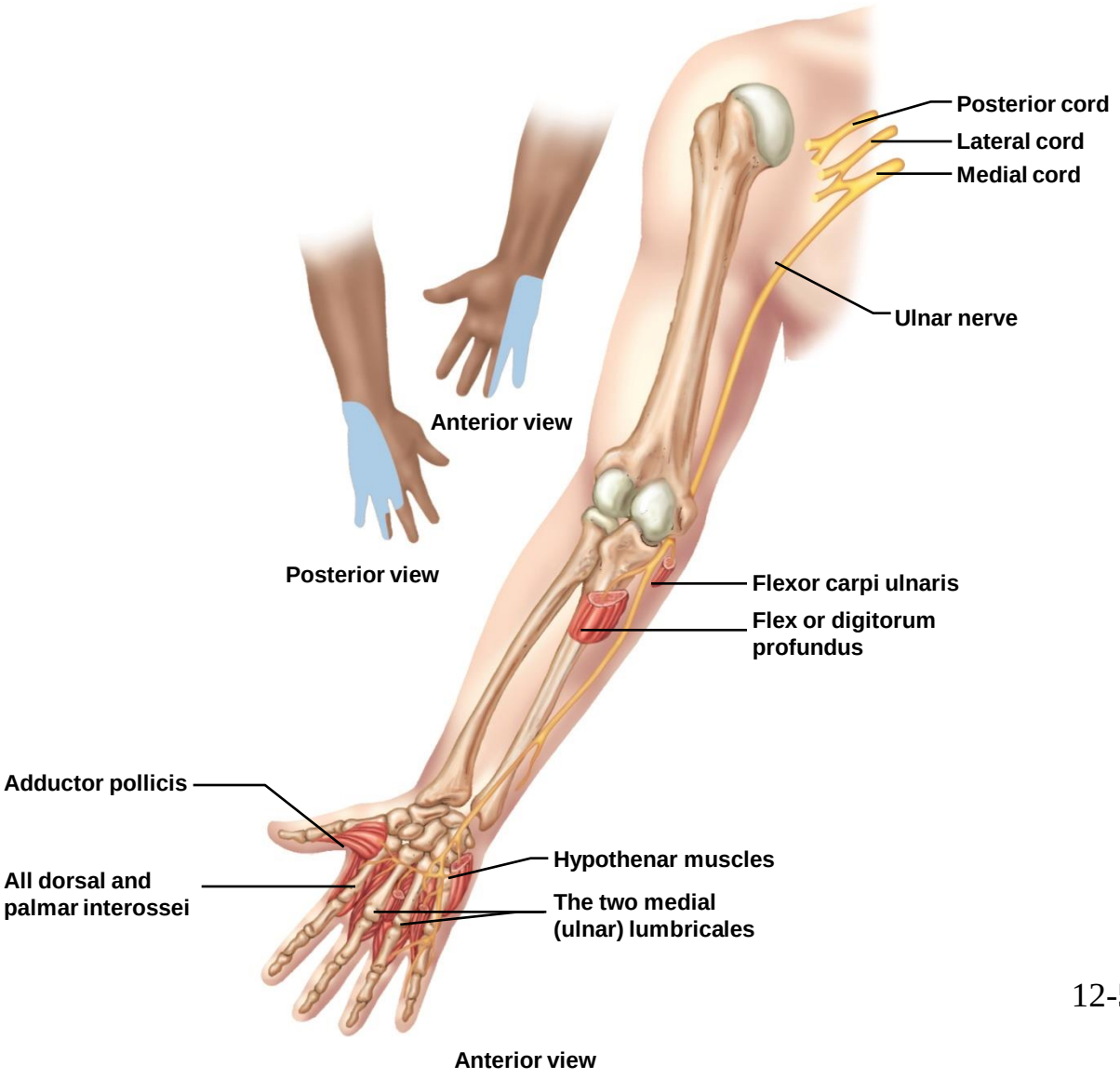
Controls hypothenar muscles
- *Flexor digiti minimi brevis*
- *Abductor digiti minimi*
- *Opponens digiti minimi*

Flexes metacarpophalangeal joints and extends interphalangeal joints
- *Two medial (ulnar) lumbricales*

Abducts and adducts fingers
- *Interossei*

Cutaneous (Sensory) Innervation

Medial third of hand, little finger, and medial half of ring finger



Ulnar Nerve

Median Nerve

Median Nerve

Origin

Medial and lateral cords of brachial plexus, C5–T1

Movements/Muscles Innervated

Pronates forearm and hand
- *Pronator teres*
- *Pronator quadratus*

Flexes and abducts wrist
- *Flexor carpiradialis*

Flexes wrist
- *Palmaris longus*

Flexes fingers
- *Part of flexor digitorum profundus controlling the distal phalanx of the middle and index fingers*
- *Flexor digitorum superficialis*

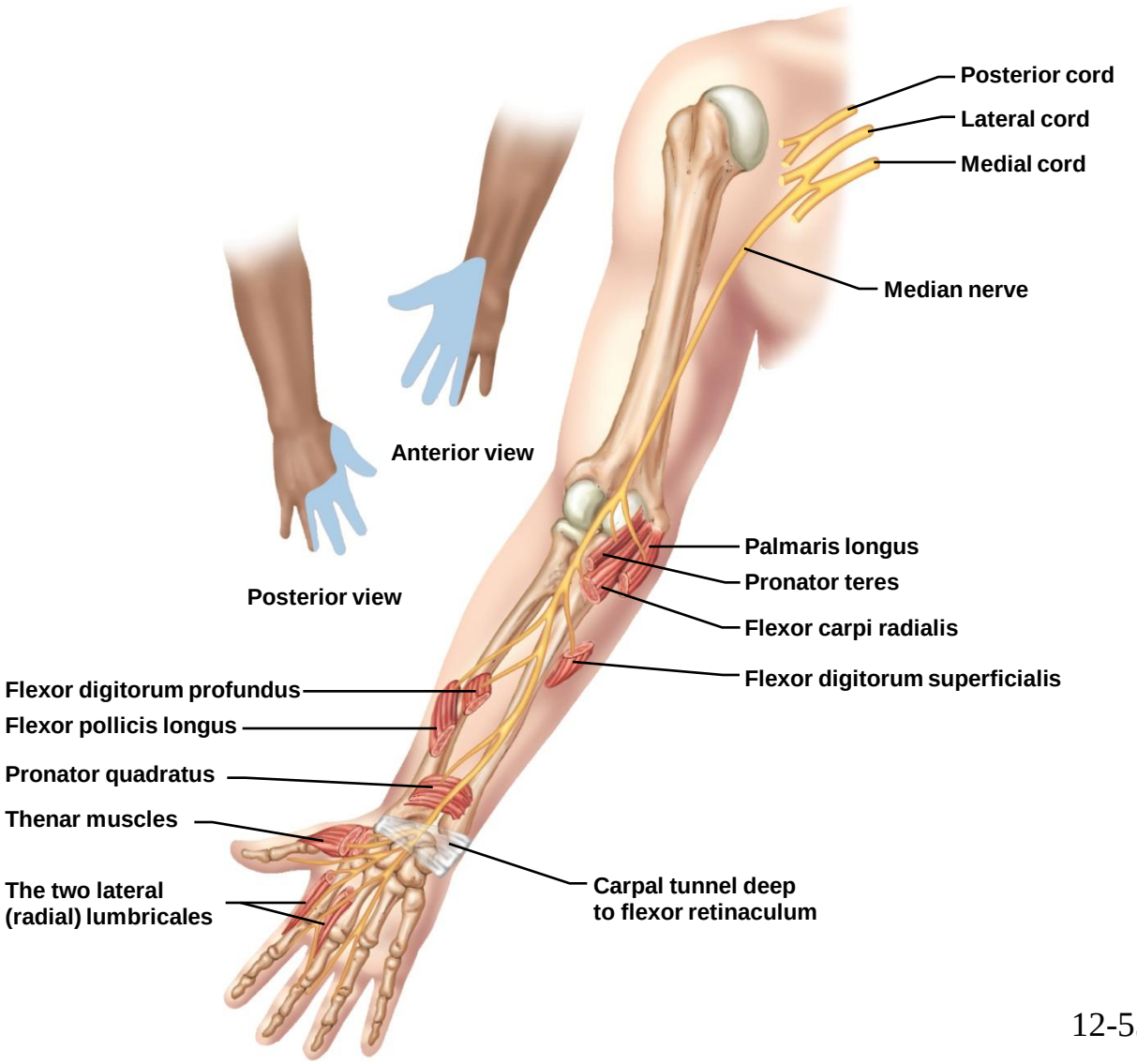
Controls thumb muscle
- *Flexor pollicis longus*

Controls thenar muscles
- *Abductor pollicis brevis*
- *Opponens pollicis*
- *Flexor pollicis brevis*

Flexes metacarpophalangeal joints and extends interphalangeal joints
- *Two lateral (radial) lumbricales*

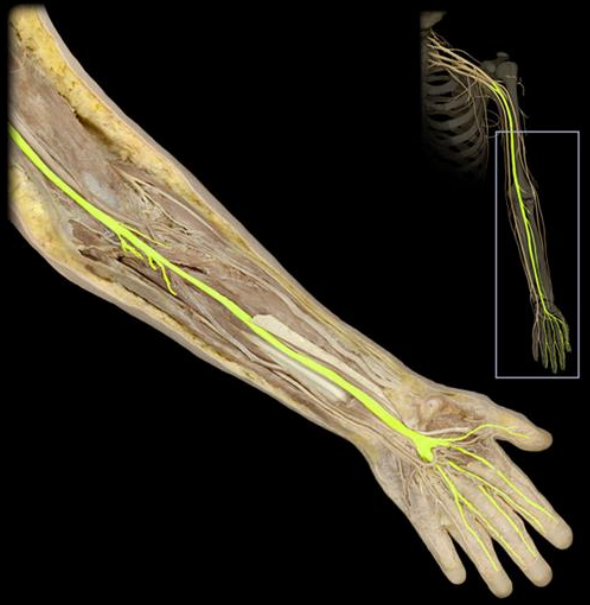
Cutaneous (Sensory) Innervation

Lateral two-thirds of palm of hand, thumb, index and middle fingers, and the lateral half of ring finger and dorsal tips of the same fingers



Anterior view

Brachial Plexus - Median Nerve

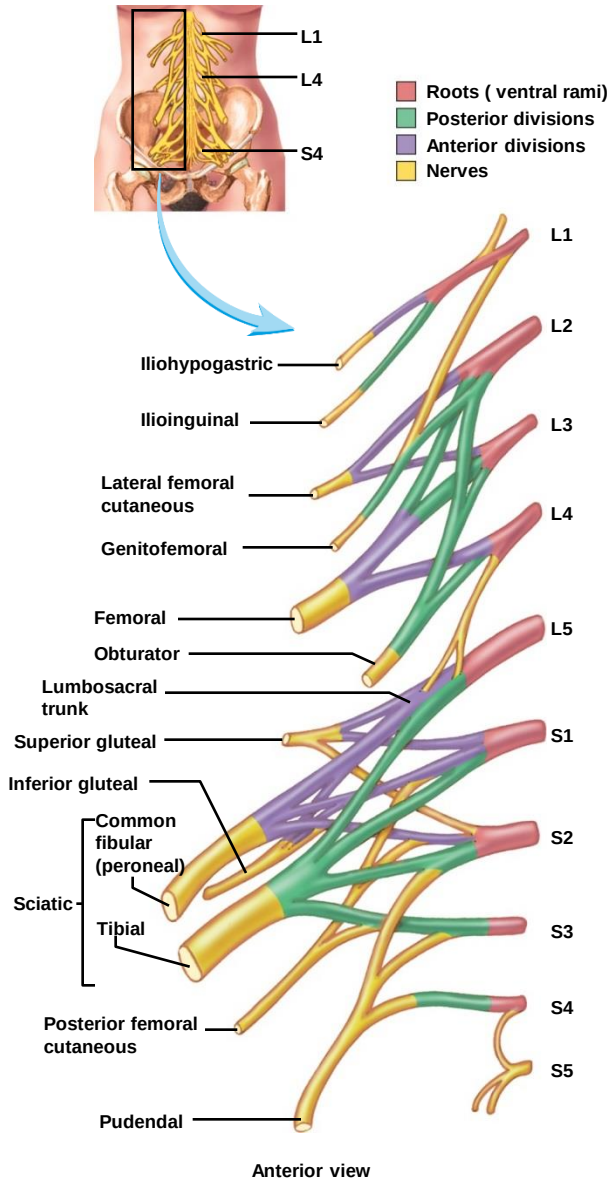


Other Nerves of the Brachial Plexus

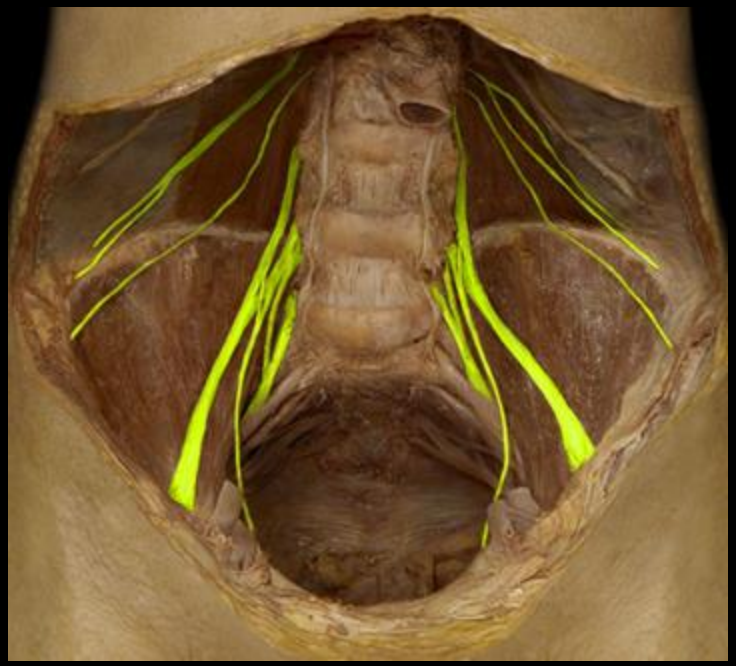
- Small nerves that innervate muscles acting on scapula and arm
  - Pectoral
  - Long thoracic
  - Thoracodorsal
  - Subscapular
  - Suprascapular
- Innervate the skin of the medial arm and forearm

Lumbar and Sacral Plexuses

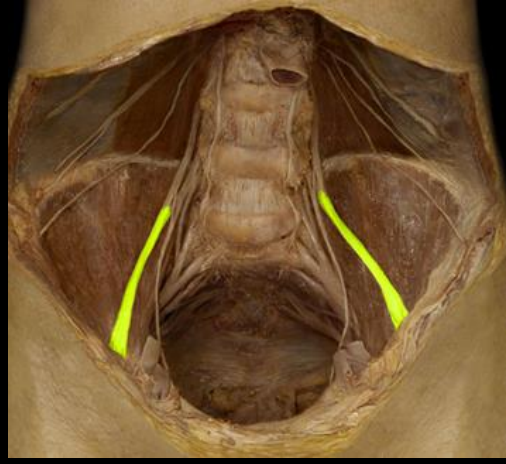
- Lumbar plexus: ventral rami of L1-L4
- Sacral plexus: ventral rami of L4-S4
- Usually considered together because of their close relationship
- Four major nerves exit and enter lower limb
  - Obturator
  - Femoral
  - Tibial
  - Common fibular (peroneal)



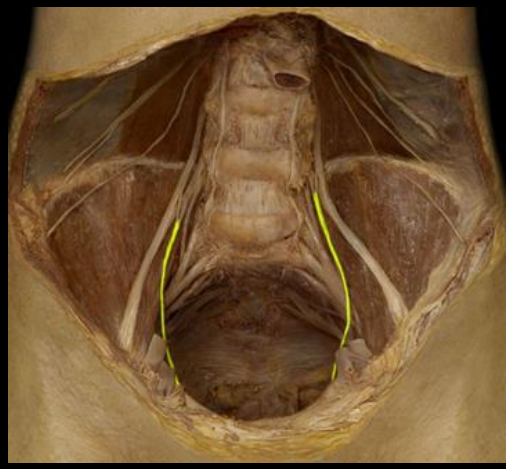
Lumbar Plexus



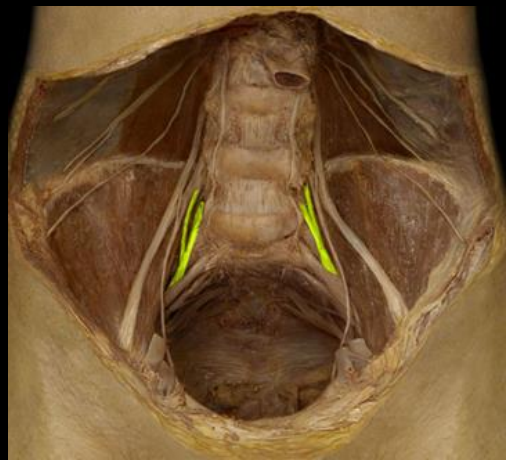
Femoral n.



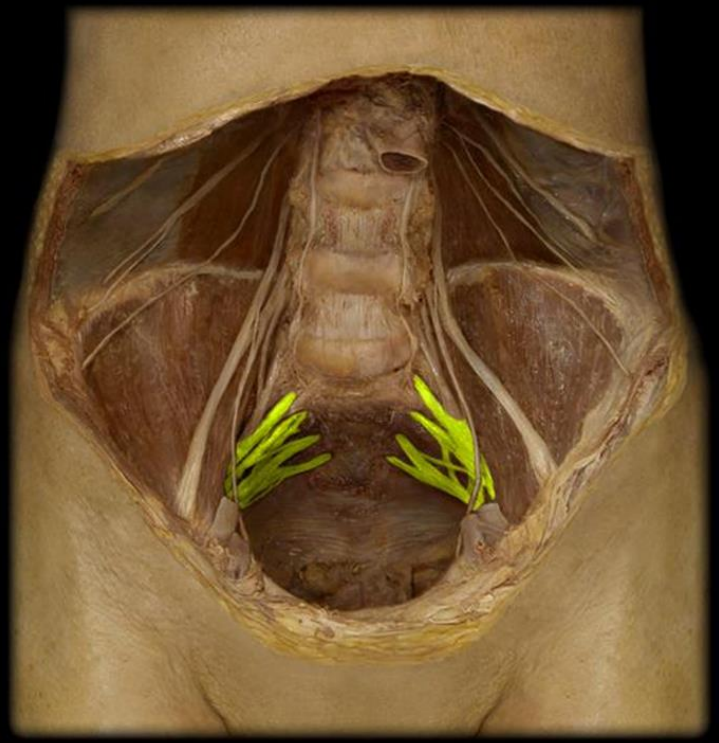
Obturator n.



Lumbosacral trunk



Sacral Plexus



Sciatic n.

Tibial n.

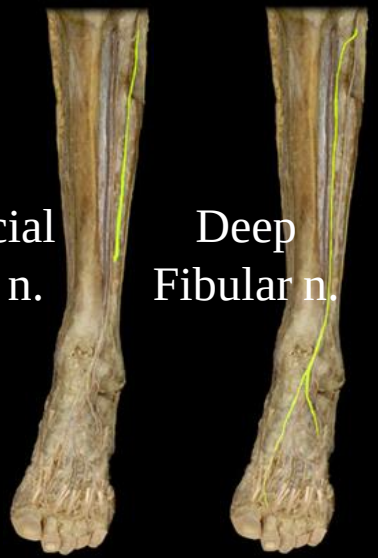
Common Fibular n.

Tibial n.

Fibular n.

Superficial Fibular n.

Deep Fibular n.



Obturator Nerve

Obturator Nerve

Origin

Lumbosacral plexus, L2–L4

Movements/Muscles Innervated

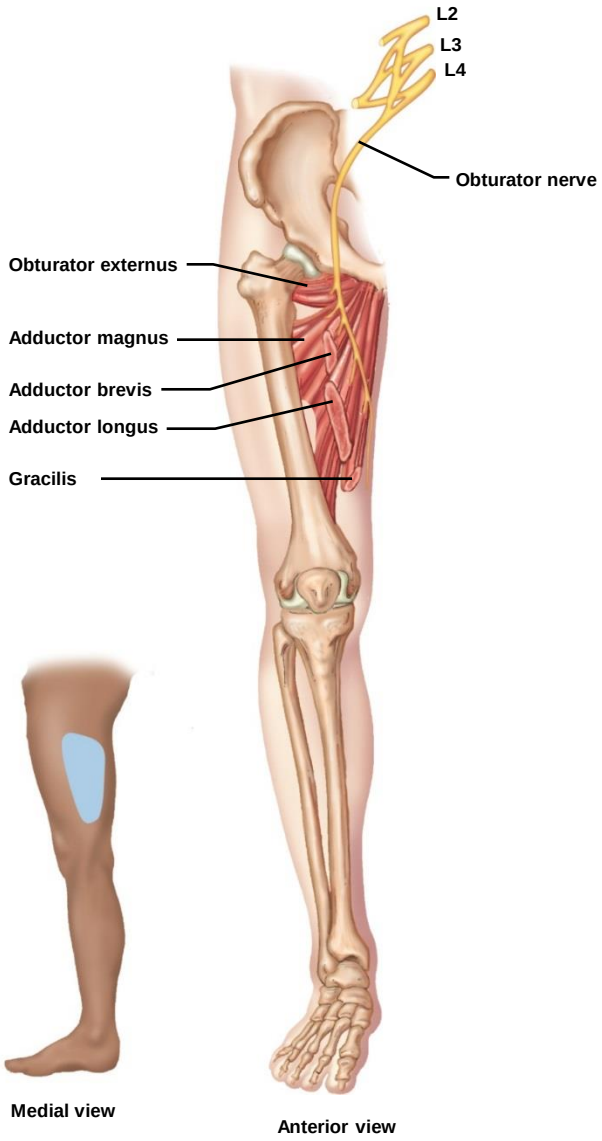
Rotates thigh laterally
- *Obturator externus*

Adducts thigh
- *Adductor magnus (adductor part)*
- *Adductor longus*
- *Adductor brevis*

Adducts thigh and flexes knee
- *Gracilis*

Cutaneous (Sensory) Innervation

Superior medial side of thigh



Obturator Nerve

Femoral Nerve

Femoral Nerve

Origin

Lumbosacral plexus, L2–L4

Movements/Muscles Innervated

Flexes hip
- *Psoas major*
- *Iliacus*
- *Pectineus*

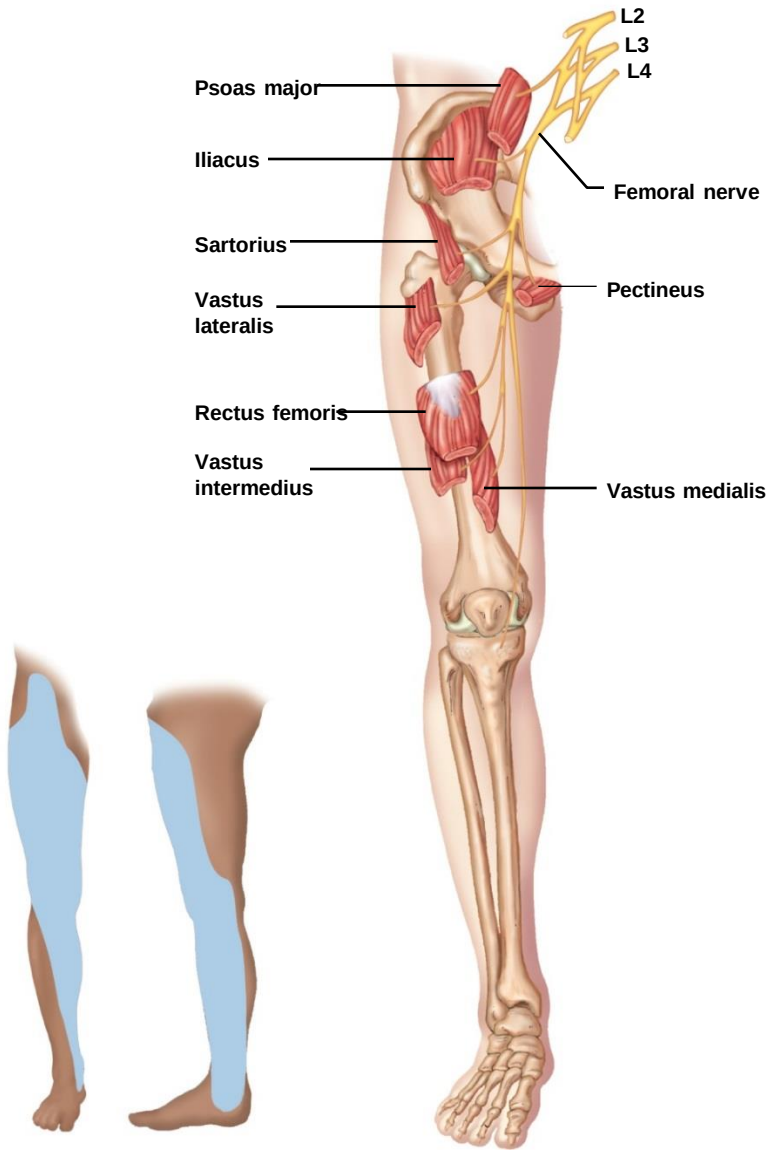
Flexes hip and flexes knee
- *Sartorius*

Extends knee
- *Vastus lateralis*
- *Vastus intermedius*
- *Vastus medialis*

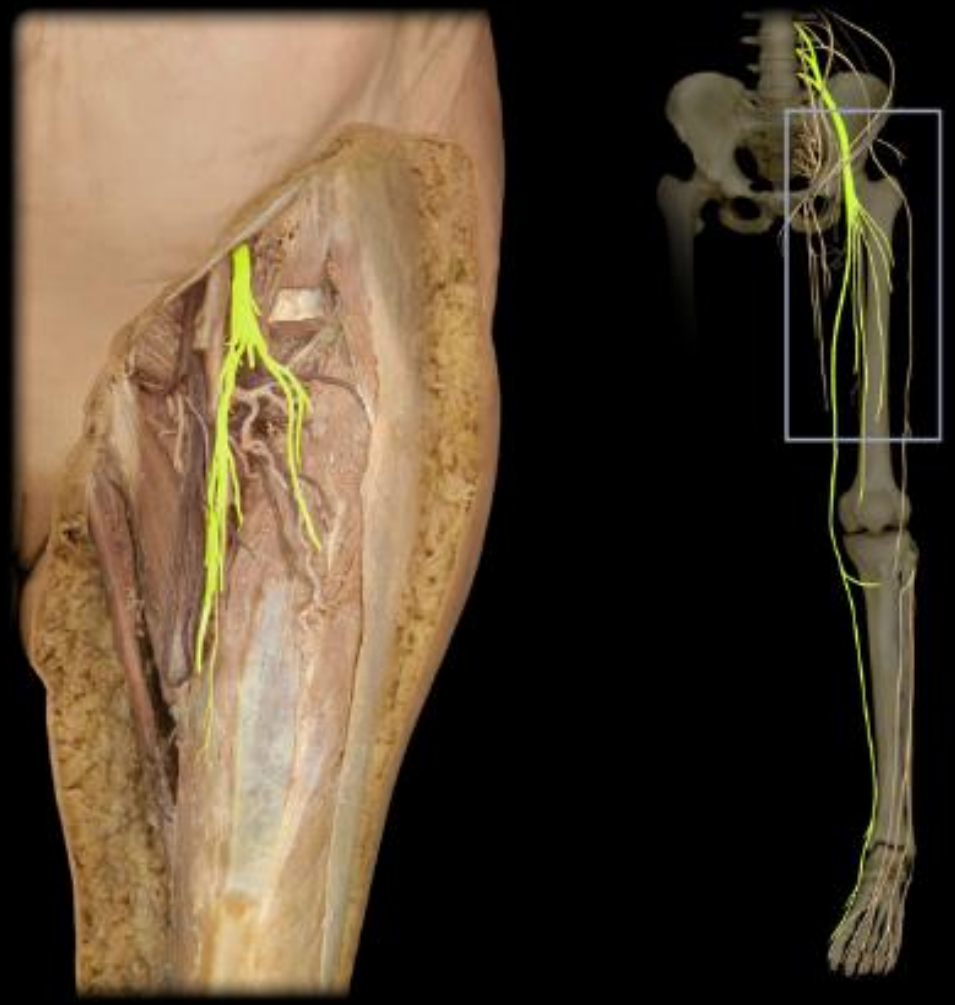
Extends knee and flexes hip
- *Rectus femoris*

Cutaneous (Sensory) Innervation

Anterior and lateral branches supply the anterior and lateral thigh; saphenous branch supplies the medial leg and foot



Femoral Nerve



Tibial and Common Fibular Nerves

- The two nerves together referred to as the **sciatic** (**ischiadic**) nerve

Sciatic Nerve

Tibial Nerve

Tibial Nerve

Origin
Lumbosacral plexus, L4–S3

Movements/Muscles Innervated
Extends hip and flexes knee
- *Biceps femoris (long head)*
- *Semitendinosus*
- *Semimembranosus*

Extends hip and adducts thigh
- *Adductor magnus (hamstring part)*

Plantar flexes foot
- *Plantaris*
- *Gastrocnemius*
- *Soleus*
- *Tibialis posterior*

Flexes knee
- *Popliteus*

Flexes toes
- *Flexor digitorum longus*
- *Flexor hallucis longus*

Cutaneous (Sensory) Innervation
None

Medial and Lateral Plantar Nerves

Origin
Tibial nerve

Movements/Muscles Innervated
Flex and adduct toes
- *Plantar muscles of foot*

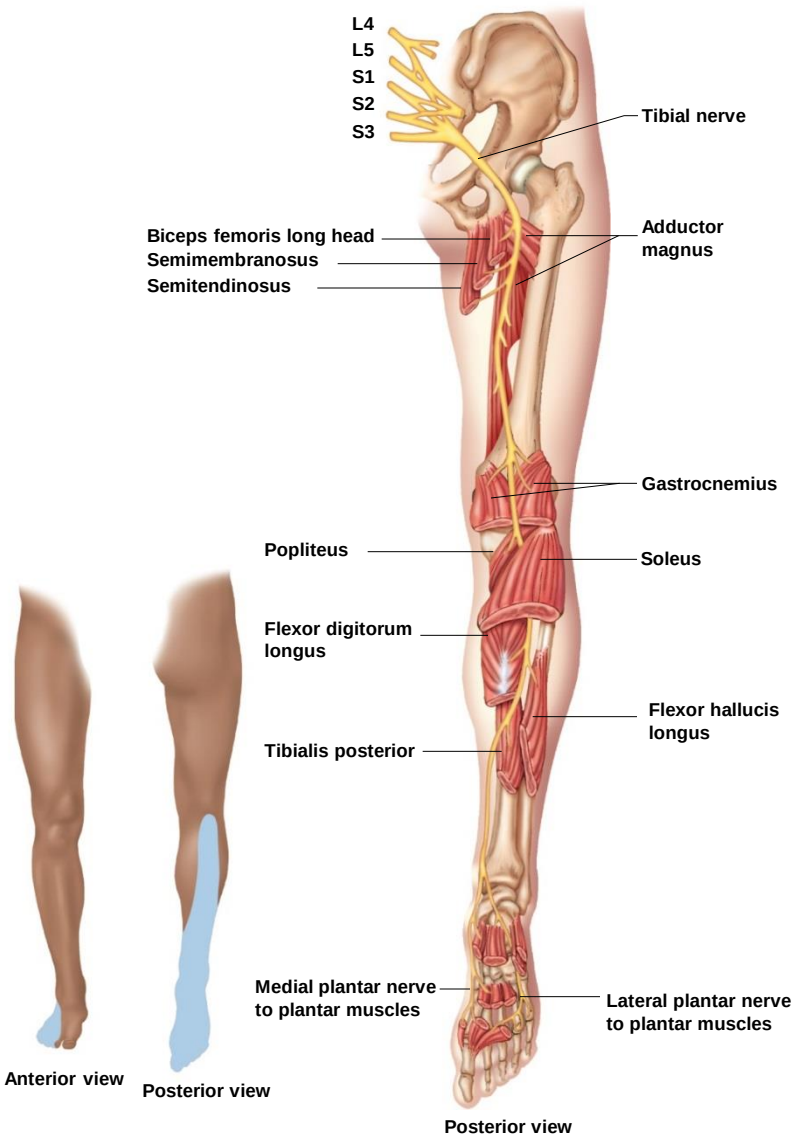
Cutaneous (Sensory) Innervation
Sole of foot

Sural Nerve (Not Shown)

Origin
Tibial nerve

Movements/Muscles Innervated
None

Cutaneous (Sensory) Innervation
Lateral and posterior one-third of leg and lateral side of foot



Tibial Nerve

Common Fibular (Peroneal) Nerve

Common Fibular (Peroneal) Nerve

Origin

Lumbosacral plexus, L4–S2

Movements/Muscles Innervated

Extends hip and flexes knee

- *Biceps femoris (short head)*

Cutaneous (Sensory) Innervation

Lateral surface of knee

Deep Fibular (Peroneal) Nerve

Origin

Common fibular (peroneal) nerve

Movements/Muscles Innervated

Dorsiflexes foot

- *Tibialis anterior*
- *Fibularis tertius*

Extends toes

- *Extensor digitorum longus*
- *Extensor hallucis longus*
- *Extensor digitorum brevis*

Cutaneous (Sensory) Innervation

Great and second toe

Superficial Fibular (Peroneal) Nerve

Origin

Common fibular (peroneal) nerve

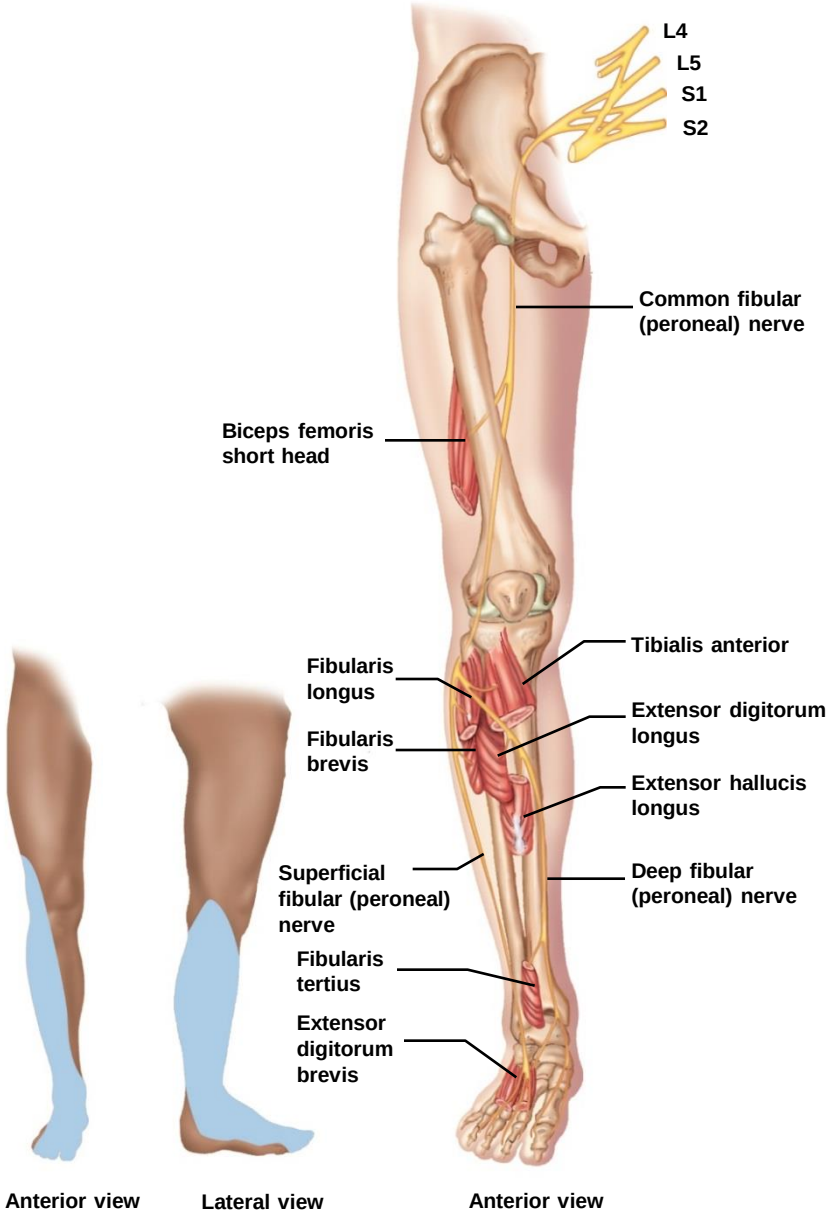
Movements/Muscles Innervated

Plantar flexes and everts foot

- *Fibularis longus*
- *Fibularis brevis*

Cutaneous (Sensory) Innervation

Dorsal anterior third of leg and dorsum of foot



Common Fibular Nerve

Other Lumbosacral Plexus Nerves

- Nerves that innervate the skin of the suprapubic area, external genitalia, superior medial thigh, posterior thigh
  - **Gluteal nerves**
  - **Pudendal nerve**
  - **Iliohypogastric nerve**
  - **Ilioingual nerve**
  - **Genitofemoral nerve**
  - **Cutaneous femoral**

Coccygeal Plexus

- S5; **coccygeal nerve**
- Muscles of pelvic floor
- Sensory information from skin over coccyx