Organization of the Spinal Cord and Peripheral Nervous System
Objectives

1. Describe the relationships between the spinal cord, spinal nerves and vertebral column.

2. Describe and identify the major structures of the spinal cord (cervical and lumbar enlargements, cauda equina, conus medullaris).

3. Describe the average level for the termination of the spinal cord.

4. Describe the level at which a lumbar puncture can be performed.

5. Describe the relationships of the meninges to the spinal cord, spinal nerve roots and vertebral column.

6. Define and identify spinal cord gray and white matter.

7. Explain and identify the differences between the 4 major spinal cord levels.

8. State or identify the location and function of spinal cord nuclei and tracts.

9. Explain peripheral and central overlap as these terms apply to somatic fibers.

10. Describe the general location of sensory dermatome regions of the body served by spinal nerves.

Organization of the Spinal Cord and Peripheral Nervous System
Outline

I. General Relationships
   - A. Gray and White Matter
   - B. Meninges
   - C. Rootlets
   - D. Sulci and Fissures
   - E. Funiculi

II. Variations in morphology at different levels: Cervical to Sacral
   - A. Gray matter in nuclear groups
   - B. White matter and tracts
   - C. Enlargements: Cervical and Lumbosacral
   - D. Spinal Accessory nerve: Cranial Nerve 11 with a spinal origin

III. Nuclei of spinal cord gray matter
   - A. Variations at different cord levels
   - B. Ventral (Anterior) horn motor groups
   - C. Dorsal (Posterior) horn sensory groups
   - D. Basic function

IV. Neuronal Circuits - General
   - A. Variety of inputs to ventral horn lower motor neurons
     1. Upper Motor Neurons
     2. Interneurons
     3. Sensory Neurons
   - B. Sites of Input
   - C. Divergence of sensory inputs to multiple cord segments/levels
   - D. Sensory endings for sensory input to cord
     1. Touch and Pressure: Ruffini, Meissner's and Pacinian corpuscles
     2. Touch and Pressure: Merkels discs, peritrichial endings
     3. Pain: Free nerve endings in epidermis (C fibers)

V. Functional localization in gray matter
   - A. Motor neuron groups (nuclei) – somatotopic localization pattern
   - B. Alpha and gamma motor neurons

VI. Interconnections of cord segments for spinal reflexes
   - A. Propriospinal connections
   - B. Fasciculus proprius

VII. Overlap of primary sensory neuron terminals
   - A. Peripheral overlap at dermatomes
   - B. Central overlap in spinal cord segments

Organization of the Spinal Cord and Peripheral Nervous System B. Puder, Ph.D.

I. General Information

- Conduit between the body and brain
- **Relays sensory information** from the body and viscera and **motor output** to muscles

The Spinal Cord is involved in 4 functions:

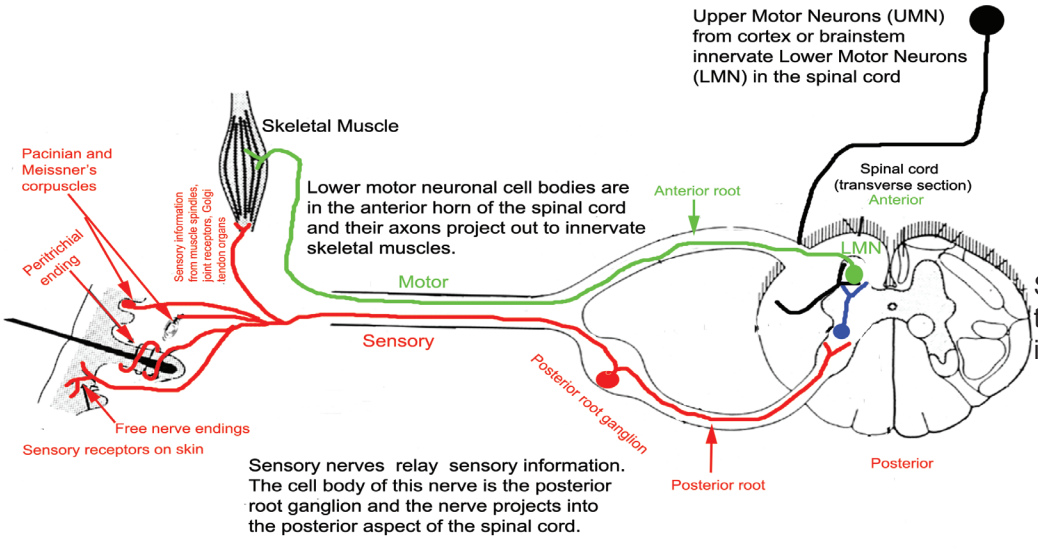
1. **Receives** primary **sensory input** from receptors in skin, skeletal muscles and tendons (**somatosensory fibers**) and from receptors in the thoracic, abdominal, and pelvic viscera (**viscerosensory fibers**).

2. The Spinal Cord contains **somatic motor neurons** that innervate **skeletal muscles** and **visceral motor neurons** which after synapsing in peripheral ganglion, influence **smooth** and **cardiac muscle** and **glandular epithelium**.

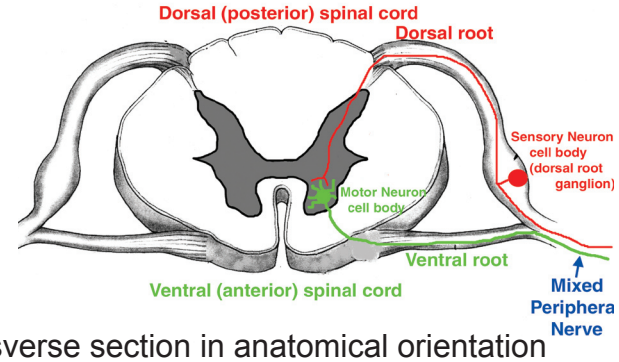
Clinical Aspect: Poliomyelitis is a disease which results in **damage to somatic motor neurons**.

3. Spinal Reflex
   - Involves somatosensory fibers interneuron motor neuron

4. Spinal Cord contains descending fibers that originate in cerebral cortex and brainstem that influence the activity of motor and sensory neurons.



Spinal cord transverse section in clinical orientation



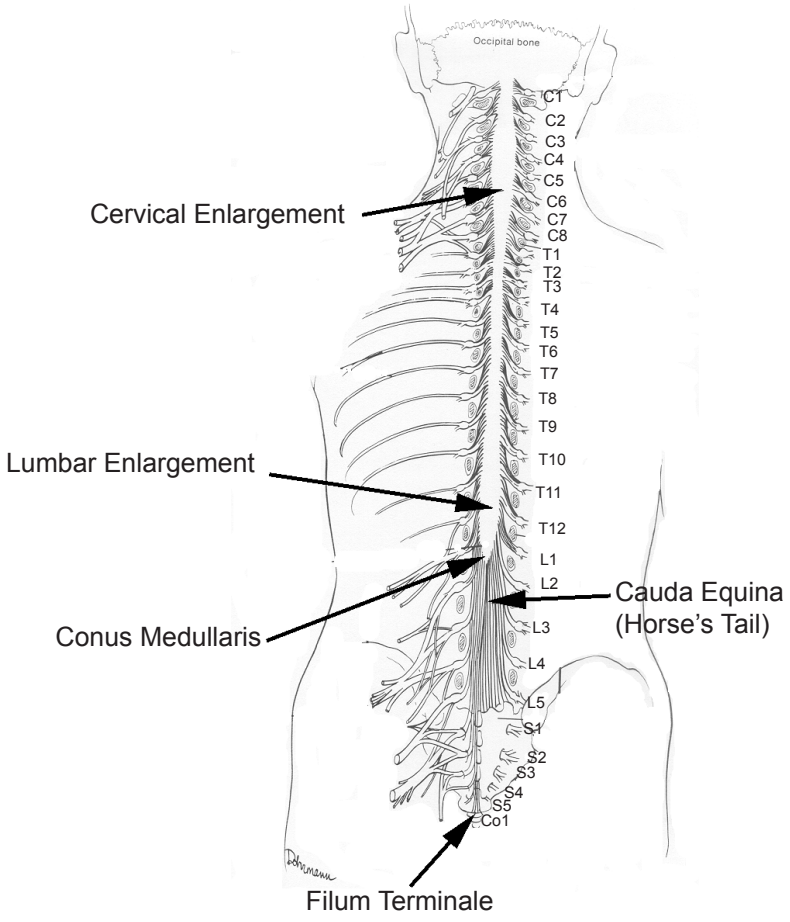
Spinal cord transverse section in anatomical orientation

II. Spinal Cord - Gross Anatomy

- Spinal Cord extends from the foramen magnum to the L1/L2 vertebrae.
- Contains 31 segments along with 31 spinal nerves
  The segments include:

  8 Cervical
  12 Thoracic
  5 Lumbar
  5 Sacral
  1 Coccygeal

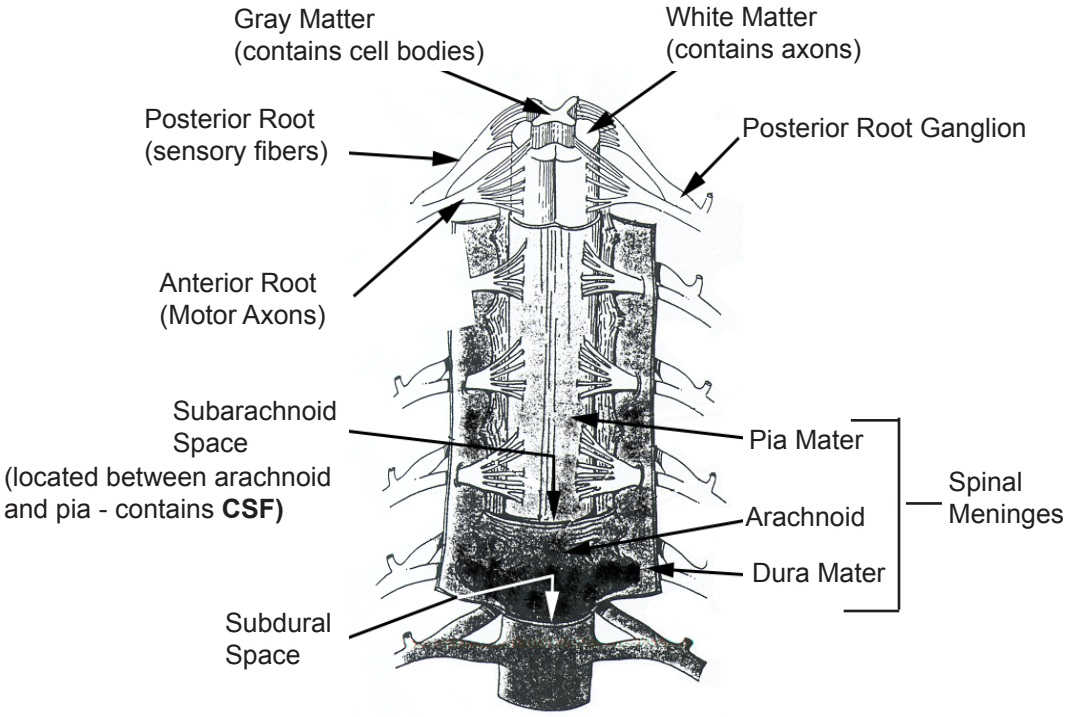
- The spinal nerves are mixed nerves containing sensory, motor, and autonomic nerves.
- Several spinal nerves will join together to form a peripheral nerve.
- There are 8 cervical spinal nerves but only 7 cervical vertebrae, so all the cervical spinal nerves are rostral to the vertebrae, while all the spinal nerves starting from thoracic and descending caudally are caudal to their respective vertebrae.
- There are **2 major enlargements** on the spinal cord:
  1. **Cervical** Enlargement located at segments C4-T1
  2. **Lumbar** enlargement located at segments L1-S2
- The **most caudal point** of the spinal cord is the **conus medullaris**
- The **spinal nerves of L1-Co1** comprise the **cauda equina** (Horse's Tail)



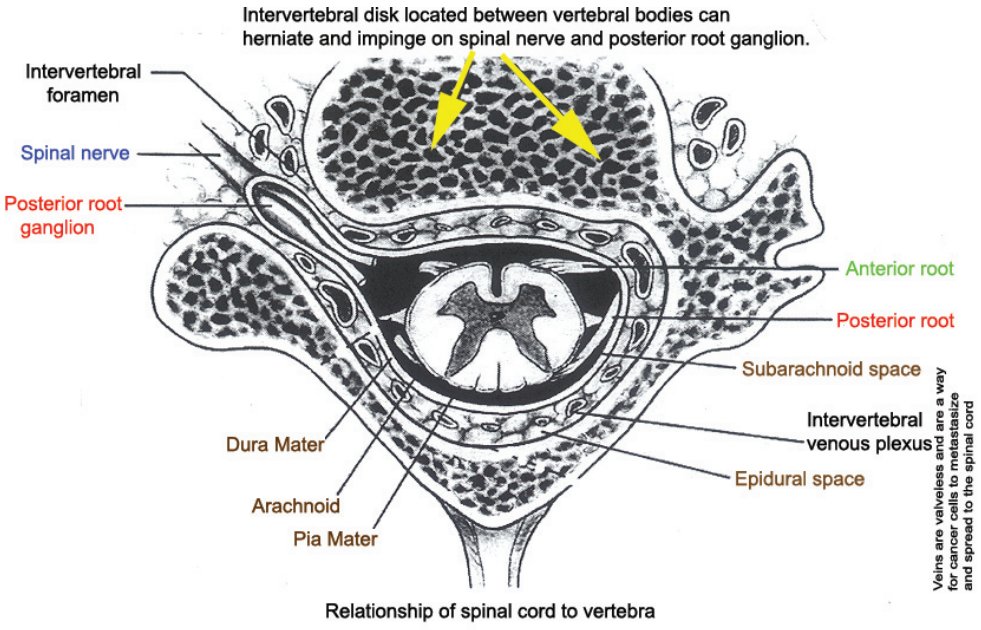
Posterior view of spinal cord and spinal nerves

III. Spinal Meninges

- The dural sac encloses the spinal cord.
- The meninges are attached cranially to the foramen magnum.
- The closed caudal end is anchored to the coccyx by the filum terminale externum. (The filum terminale internum extends from the conus medullaris to the dural sac and the filum terminale externum extends from the dura to the coccyx.
- Denticulate ligaments make up the lateral attachments of spinal cord to the dura.
- Same as around the brain, the dura mater is the outermost layer, with the arachnoid mater more inward, and the pia the innermost layer against the spinal cord. The subarachnoid space is filled with CSF and a lumbar cistern is located at vertebral levels L2 - S2.



Longitudinal and Anterior view of the spinal cord with meningeal layers



Cross section of spinal cord, meninges, and vertebral column

IV. Relationships of Spinal Cord, Vertebrae, Meninges, and Cisterns

A. The Lumbar Cistern

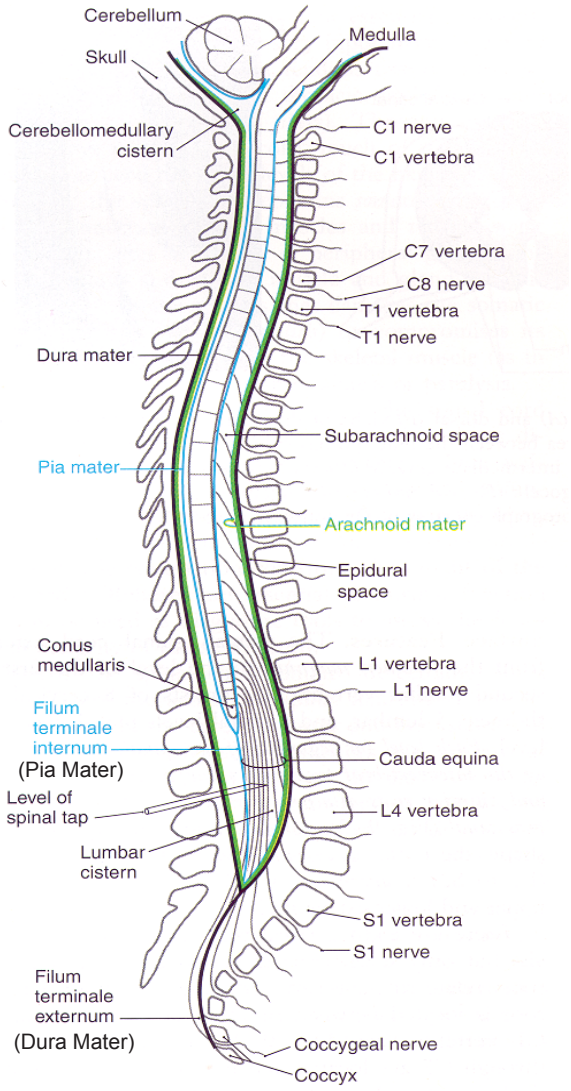
The **enlarged part** of the **spinal subarachnoid space** is the **lumbar cistern.**

The Lumbar Cistern contains the **roots** of **spinal cord segments L1 - Co1** (which is the **cauda equina**).

It is in the area of **VERTEBRAL levels L2 -S2**.

Remember that the end of the **spinal cord (Co1) coincides with VERTEBRAL level L1/L2,** and the
Dural Sac (which contains the cauda equina) **ends** at **VERTEBRAL level S2.**

Posterior



Anterior

Sagittal view of spinal cord and partial vertebrae

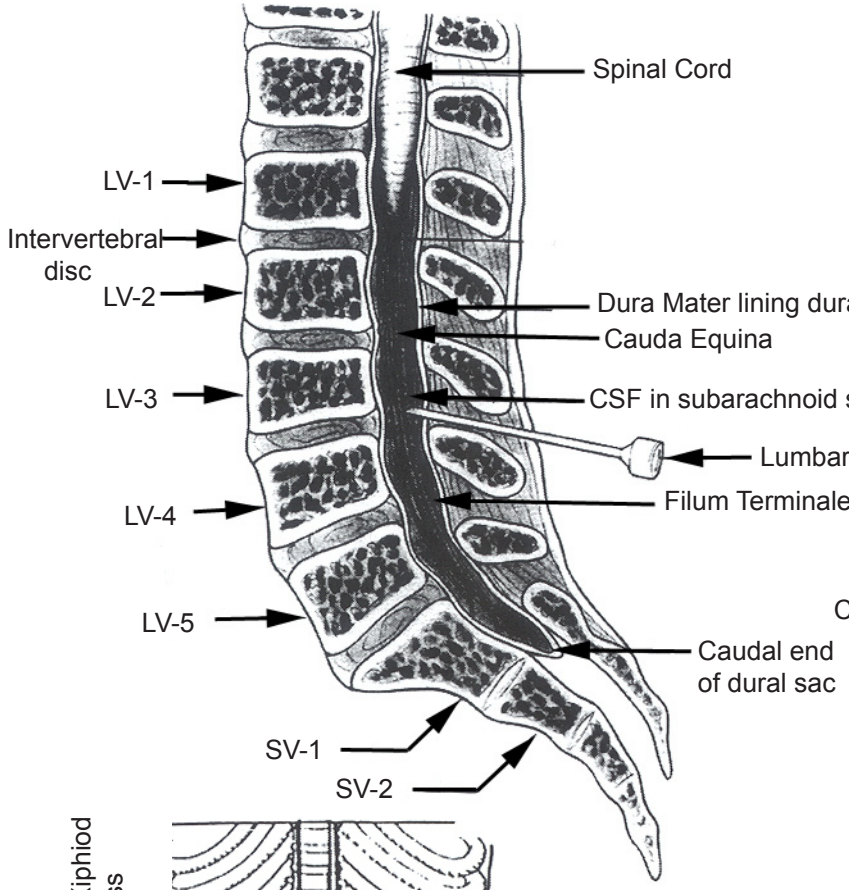
Adapted from: Fundamental Neuroscience, D.E. Haines, 2002

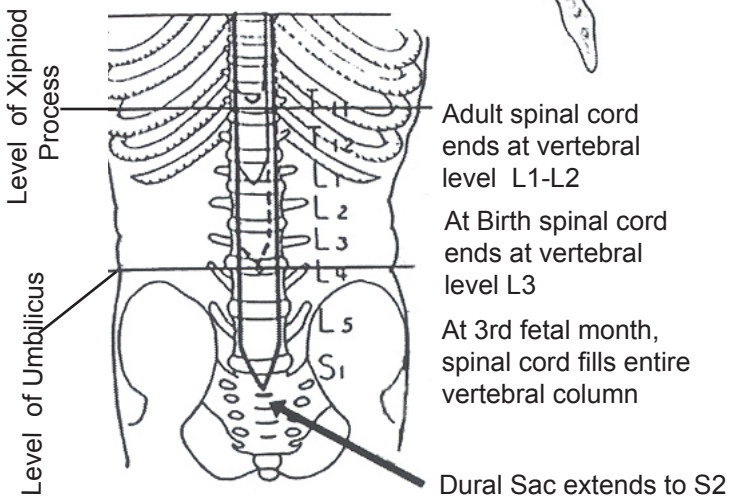
Clinical Aspects: A **lumbar puncture** is performed to obtain a CSF sample from **vertebral level L3/L4** or L4/L5.

Anesthetics can be placed in the **subarachnoid space (spinal block)**, or **CSF withdrawn (spinal tap)** for clinical chemistry.

The **subdural space** is only a **potential space** under normal conditions, however, **bleeding** can occur here and create a **subdural hematoma**.

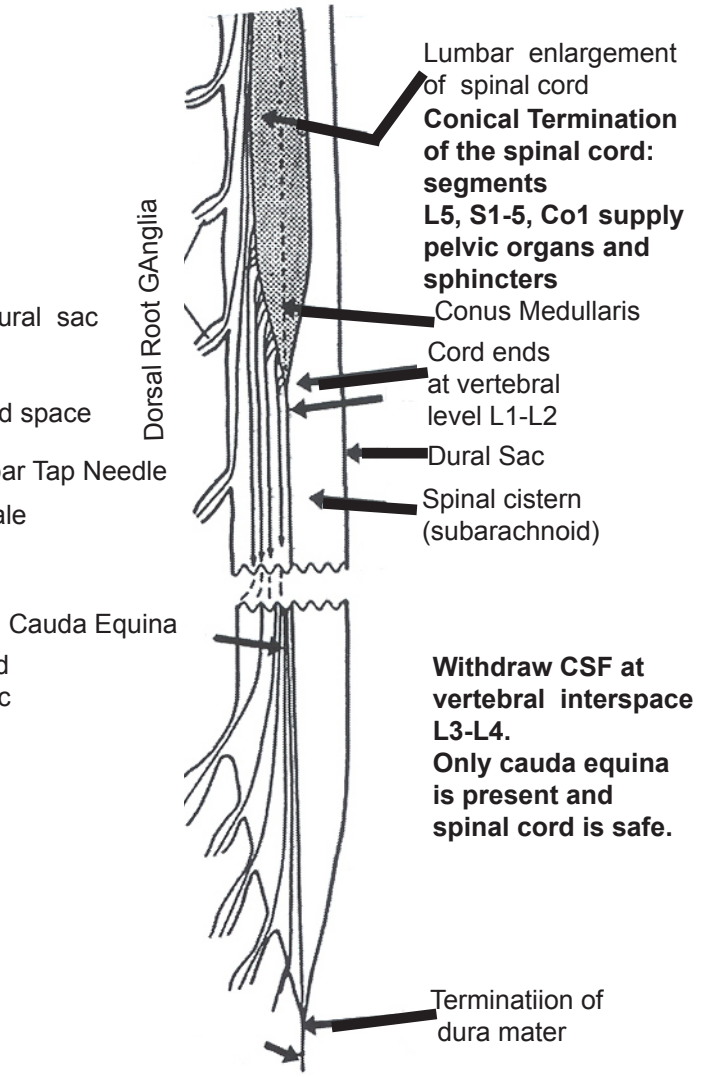
Relationship of spinal cord and cauda equina to vertebra durning spinal tap to remove CSF





Changing Levels of the spinal cord during growth and development

Relationships of caudal spinal cord, cauda equina, dural sac, and conus medullaris



Filum terminale externum attaches to sacrum and coccyx

Reproduced from Basic Clinical Neuroanatomy by P.A. Young and P.H. Young, Williams & Wilkins

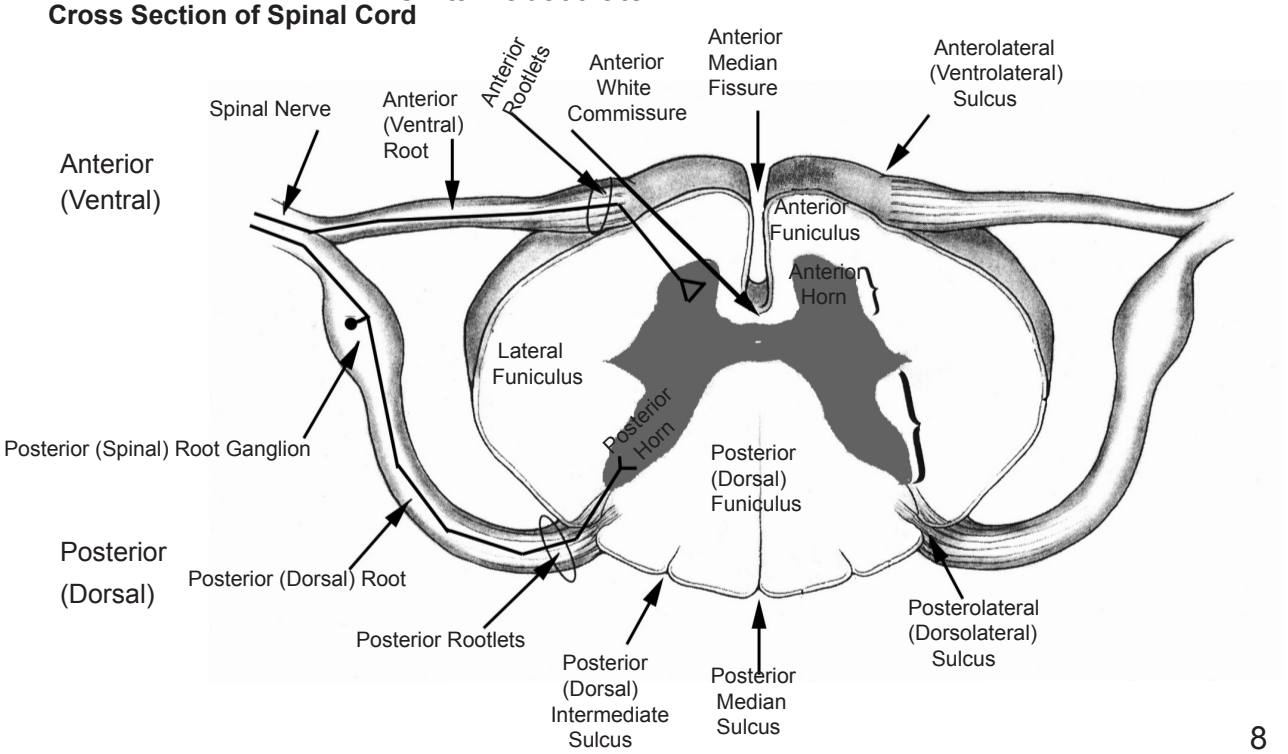
V. Spinal Cord in cross section

- The spinal cord contains an outer white matter (axons) and an inner gray matter (cell bodies) and a central canal.

The white matter

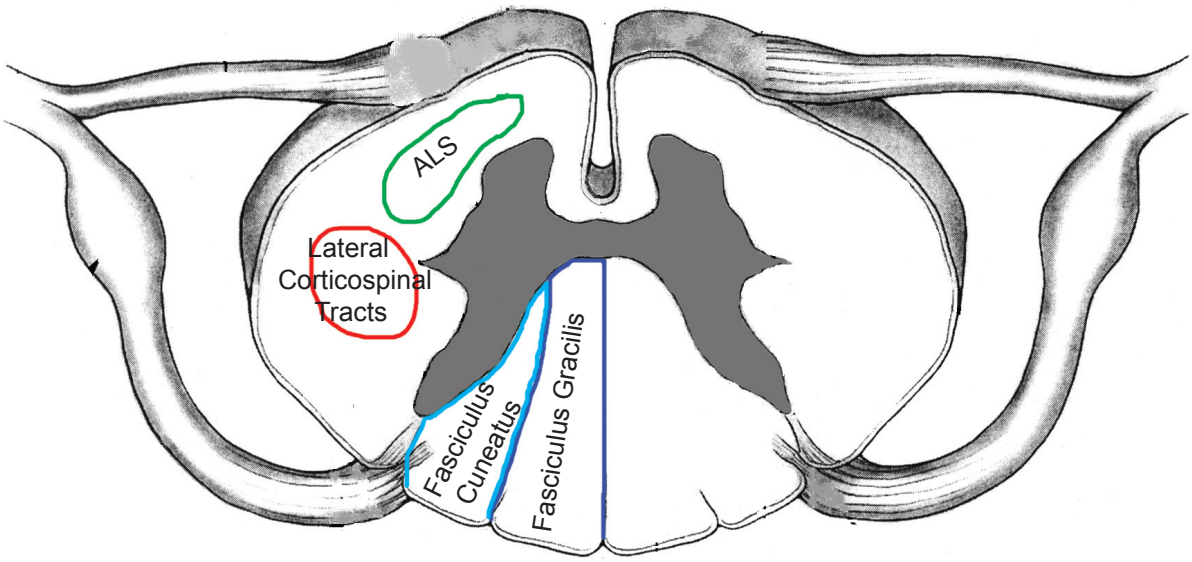
- Consists mainly of Funiculi (funiculus = singular form).
- There are **3 pairs of funicul**i:
  1. **Posterior** (dorsal) funiculi
  2. **Lateral** funiculi
  3. **Anterior** (ventral) funiculi
     - The funiculi contain ascending and descending axons to and from higher centers which are grouped into smaller tracts and fasciculi (fasciculus = singular).
- The posterior (dorsal) median sulcus splits the spinal cord into 2 halves.
- The **posterolateral (dorsolateral) sulcus** is the **entry point** of **sensory fibers**.
- The anterolateral (ventrolateral) sulcus is an exit point for anterior fibers (it is not as distinct as the posterolateral sulcus).
- The **Posterior (dorsal) intermediate sulcus** is only present at spinal cord **levels T6 and higher**. It **divides each funiculus** into 2 **fasciculi**.
- The **anterior (ventral) median fissure** contains sulcal branches of the **anterior spinal artery** and **divides the cord** in half.
- The **anterior (ventral) white commissure** is an area just **ventral to** the **gray area** (ventral to the crossbar in the gray "H"). This is an area where **axons cross** from one side to another in a pathway that we'll talk about later.

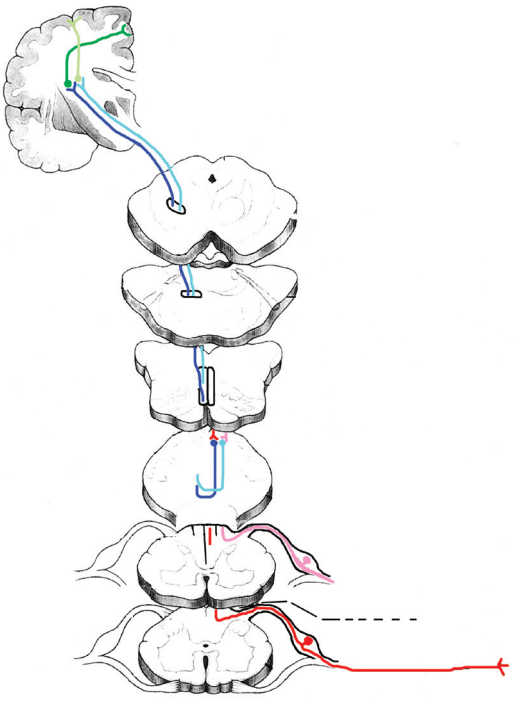
Cross Section of Spinal Cord



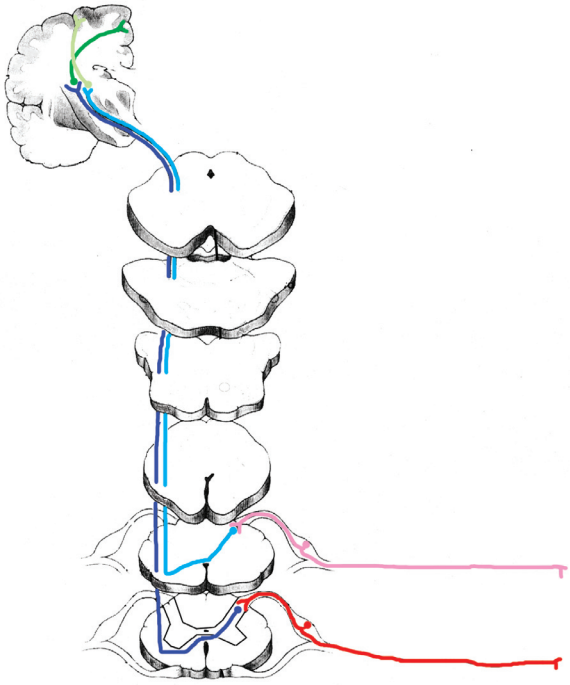
VI. Spinal cord white matter - tracts

- The white matter contains tracts (groups of axons) that are part of specific sensory and motor pathways.
- The **fasciculus gracilis** and **cuneatus** are part of a sensory pathway relaying touch, vibratory sense from the lower and upper extremities respectively.This pathway is called the **Posterior columns/Medial Lemniscus Pathway.**
- The **lateral corticospinal tract** is a descending pathway that is involved in motor movement.
- The **anterolateral system** is a bunch of axons relaying pain and temperature information from the body to the cortex.

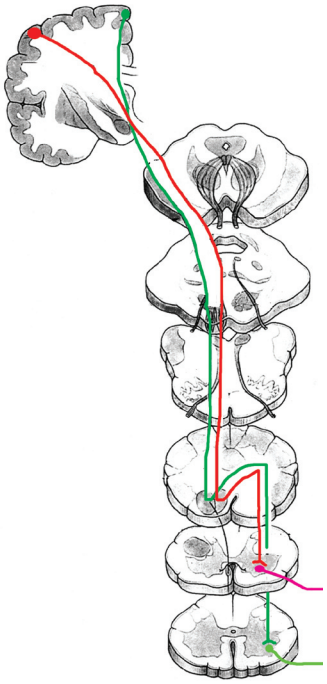




Posterior columns/Medial Lemniscus Pathway



Anterolateral System



Descending Voluntary Motor Pathway

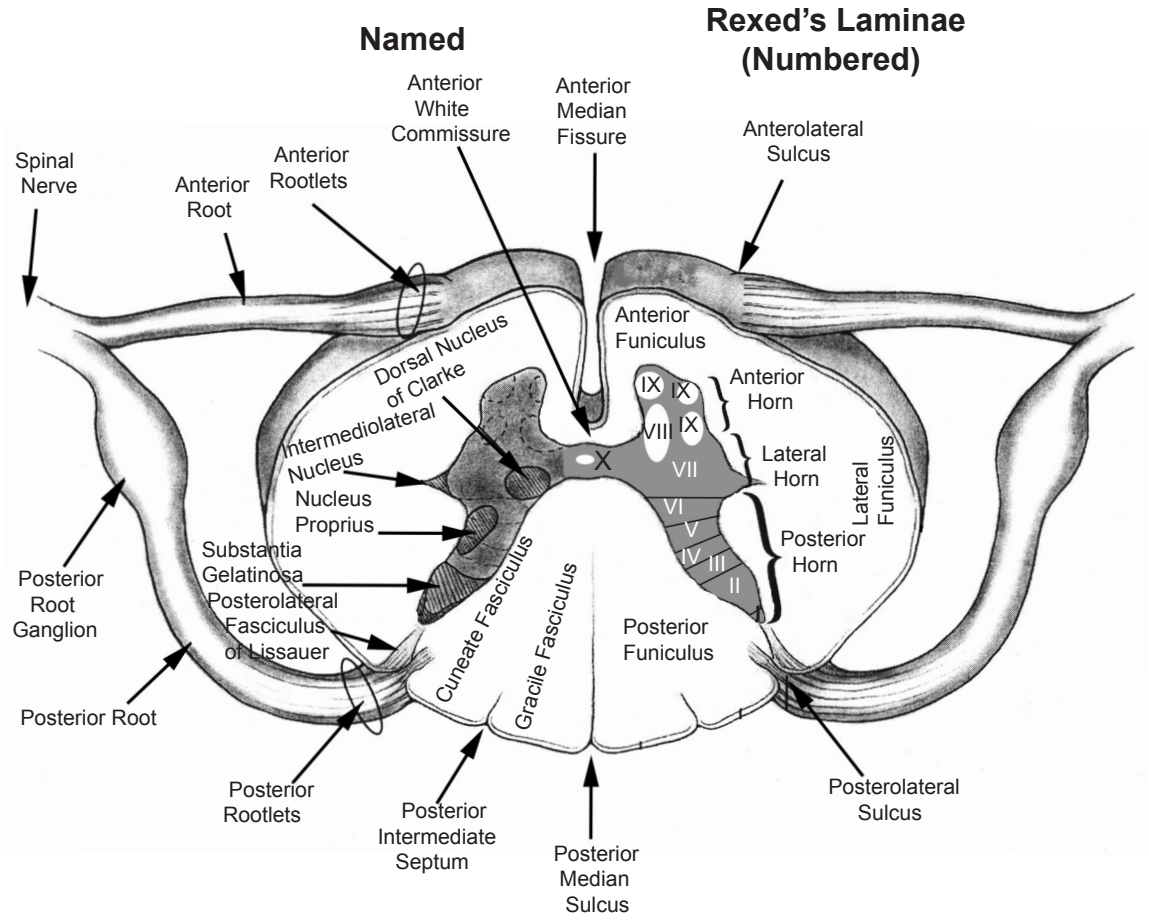
Note: Bottom 3 images of pathways have spinal cord and brainstem sections oriented with posterior aspect towards top of the page and anterior towards bottom of the page.

VII. The gray matter

- Is “H” shaped and contains neuronal cell bodies, dendrites, and glial cells.
- Consists of **2 major parts:**
    1. **Posterior (Dorsal) horn** = Mainly sensory (receives incoming **sensory information** and relays it.)
    2. **Anterior (Ventral) Horn** = Mainly **motor** (sends out information from the spinal cord.
- Divided into **10 laminae** (Rexed’s laminae) that correspond to the size, shape, and distribution of neurons.

The **gray matter** has also been given **names**, some of which correspond to Rexed’s lamina:

Rexed’s Lamina I = **Posteromarginal Nucleus**
Rexed’s Lamina II = **Substantia Gelatinosa**
Rexed’s Lamina III & IV = **Nucleus Proprius (Proper Sensory Nucleus)**
Rexed’s Lamina VII = (At thoracic levels) **Dorsal Nucleus of Clarke & IML**
Rexed’s Lamina VIII & IX = **Motor Neurons**



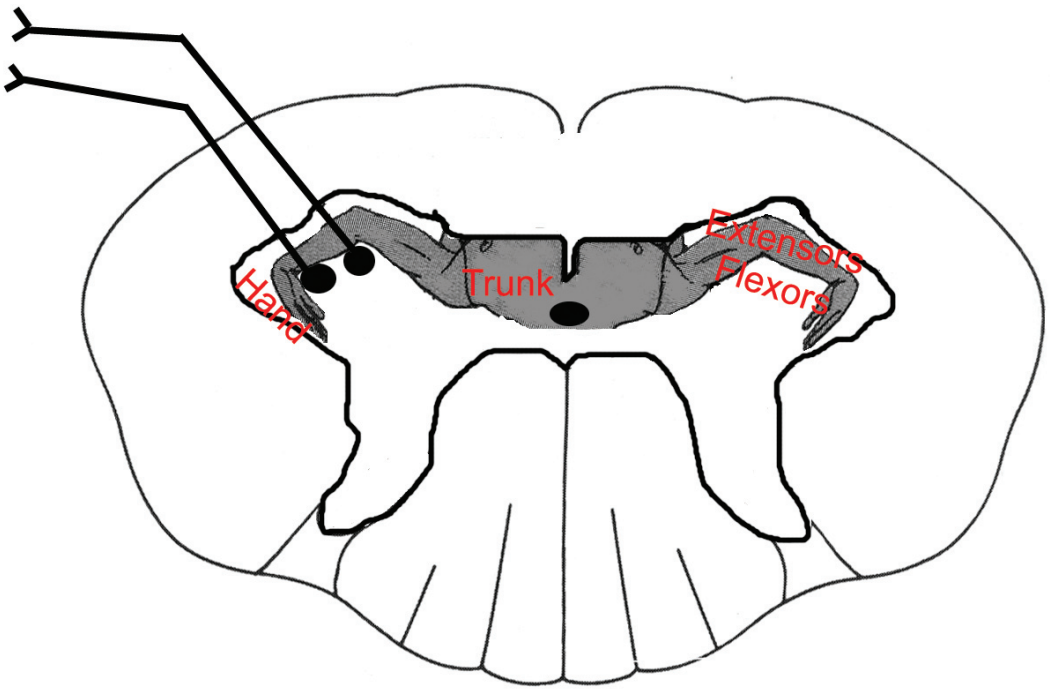
Cross (transverse)section of spinal cord depicting the named areas of gray matter on the left and Rexed’s numbered laminae on the right.

VIII. Functional Localization in the Gray Matter - Somatotopic Pattern

Certain neurons innervate certain muscle groups. This becomes important when considering lesions because discrete muscle groups may be lost and thus give rise to specific deficits, eg. loss of flexors in arm.

There exists a **somatotopic localization pattern** in the anterior portion of spinal cord gray matter for innervating muscles.

Neurons innervating **trunk** muscles are most **medial**.
Neurons innervating **hand** muscles are most **lateral**.
Neurons innervating **flexor** muscles are most **posterior**.
Neurons innervating **extensor** muscles are most **anterior**.



There are **2 main types of motor neurons in the ventral horn:**
(These are called **lower motor neurons -LMN** and we will talk about that later).

1. **Alpha** motor neurons - larger neurons, heavily myelinated (so fast conducting) that innervate working muscle and cause flexion or extension.
2. **Gamma** motor neurons - smaller neurons, moderately myelinated (so conduction is not as fast) that innervate small, striated muscle involved in tone.

Review from Neurohistology Lecture:
Remember that the **junction** between these n**eurons and the muscle** is called the **neuromuscular junction** and the **neurotransmitter** released is **ACH** which **binds to nicotinic ACH receptors** located on the muscle cell membrane.

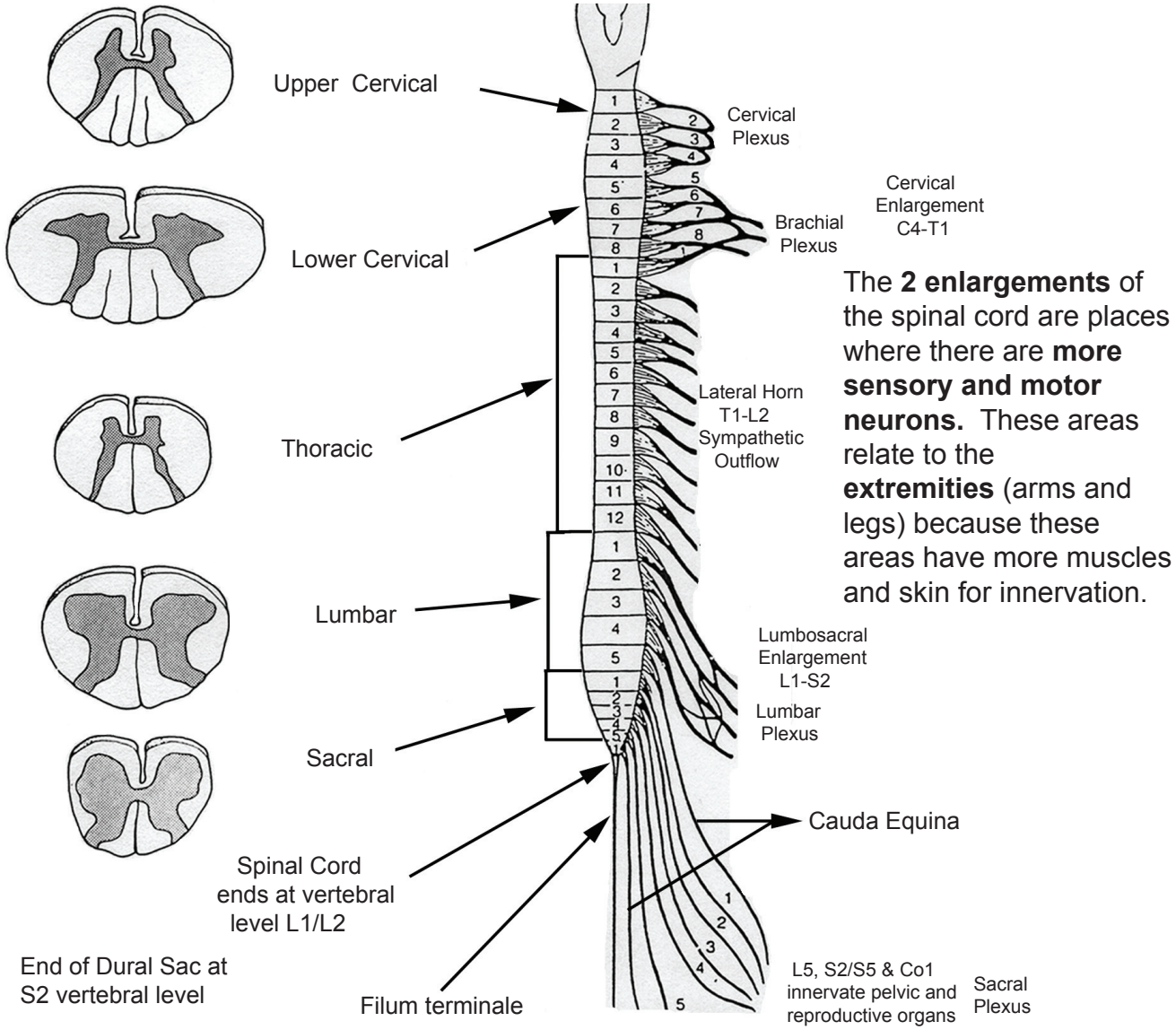
What disease attacks the nicotinic ACH receptors at the neuromuscular junction? (Answer upsidedown at bottom of page.)

Myasthenia Gravis

IX. Variations in Spinal Cord Anatomy

- The **pattern of gray and white matter vary** at certain levels of the spinal cord, as well as the **overall size and shape**.

The **ratio of gray:white matter changes** as we progress down the cord.
At **cervical levels** there is **less gray matter compared to white matter**, but in the **sacral level** there is **more gray matter as compared to white matter.**



The **2 enlargements** of the spinal cord are places where there are **more sensory and motor neurons.** These areas relate to the **extremities** (arms and legs) because these areas have more muscles and skin for innervation.

Clinical Aspect (review): If the spinal cord ends at vertebral level L1 and the dural sac continues to vertebral level S2, between which two vertebral interspaces could you safely insert a needle? Why would you want to insert a needle in this space anyway? (Answers upside down at bottom of page.)

Between L3/L4 vertebrae or L4/L5 vertebrae.A spinal tap is performed to withdraw CSF for bacteriologic and chemical examinations or to insert anesthetics or drugs.

Variations between spinal cord regions

Cervical Level

-**Oval** shape
-Larger
-**Large** amount of **white matter**
-Contains **both gracile and cuneate fasciculi**
-**Large anterior and posterior horns** at levels C4-C8

Thoracic Level

-Round shape
-Posterior and anterior horns are small
-Contains both gracile and cuneate fasciculi in upper thoracic, but **ONLY gracile fasciclus in lower thoracic levels**
-Contains the **Dorsal Nucleus of Clarke**
-Contains **lateral horns (Intermediolateral nucleus -IML)**

Lumbar Level

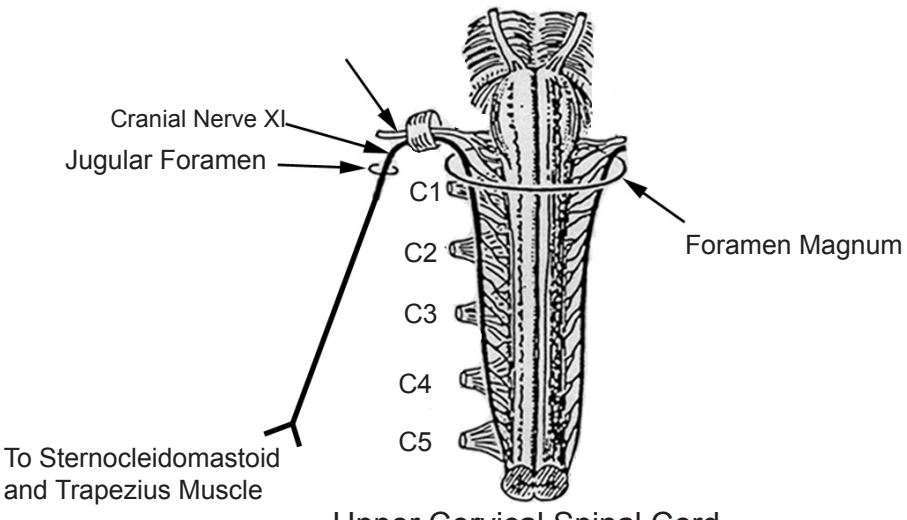
-Round Shape
-**Large anterior and posterior horns**
-Nucleus of Clarke at L1/L2

Sacral Level

-Round and small
-**Primarily gray** matter
-S2, S3, S4 levels contain the **SPN (sacral parasympathetic nucleus)**

Special Spinal Nerve -Cranial Nerve XI (Spinal Accessory Nerve)

Cranial Nerve XI begins in **cervical spinal cord** levels and **projects its axons up** through the **Foramen Magnum** and then **back out the Jugular Foramen** to **innervate** the **Sterno-cleidomastiod** and **Trapezius** muscle.

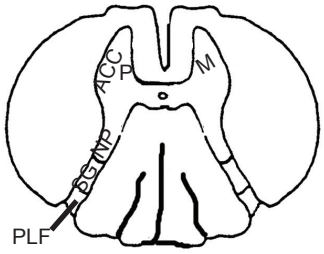


Upper Cervical Spinal Cord

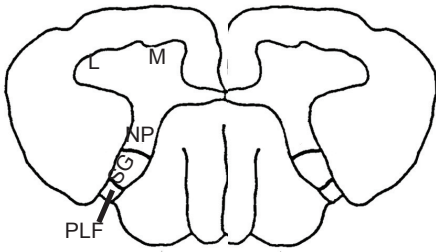
X. Nuclei of Spinal Cord Gray Matter

- The **gray matter** of the spinal cord is **organized into groups** of neurons that have a **common function** and a **common destination** of their axons.
- These **groups of neuronal cell bodies** are called **nuclei**.
- The nuclear groups can extend over several segments of the spinal cord.
- The nuclear groups are named based on location and histologic appearance.

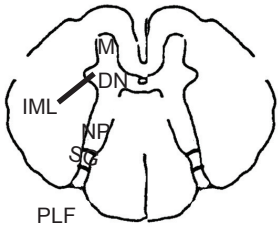
C4



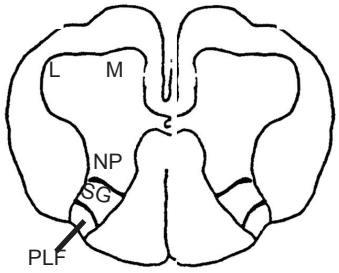
C8



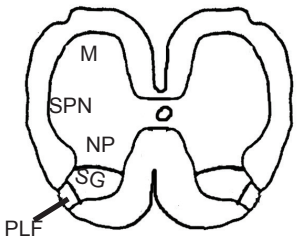
T4



L3



S2



Nuclei and Tracts found throughout the cord

PLF = Posterolateral Fasciculus (Of Lissauer) -these are actually ascending and descending collaterals of primary sensory axons (so not a nucleus, but a tract).

SG = Substantia gelatinosa -receives sensory input, mainly nociception, and are projection neurons.

NP = Nucleus Proprius -sensory input, mainly touch, and are projection neurons.

M = Medial motor nucleus - skeletal muscles of the ipsilateral neck and trunk.

Nuclei found only at certain levels of the cord

L = Lateral motor nucleus - skeletal muscle of the upper of lower ipsilateral extremity. C4 - T1 and L1 - S2.

DN = Dorsal Nucleus of Clarke - reflex proprioception, dorsal spinocerebellar tract. T1-L2.

IML = Intermediolateral nucleus - sympathetic preganglionic neurons. Lateral horn, T1-L2.

SPN = Sacral parasympathetic nucleus - parasympathetic preganglionic neurons for pelvic viscera. S2,S3,S4.

P = Phrenic motor nucleus - skeletal muscle of ipsilateral half of the diaphragm, mostly at C3,C4,C5.

ACC = Spinal accessory nucleus - innervates the skeletal muscles of the ipsilateral sternocleidomastoid and trapezius muscles.

XI. Branching of Primary Afferent Nerve Fibers as they enter the Spinal Cord

Afferent nerve fibers branch into **ascending** and **descending collaterals**. This is important because:

1. **Spinal Reflexes spread to multiple levels**
2. **Muscles are innervated by multiple segments of the spinal cord**

For Example: Activation of a pain fiber in 1 dermatome (segment of skin) may have to activate neurons in several spinal cord segments in order to produce an effective motor response. (Biceps muscle is innervated by motor neurons in spinal cord segments C5 and C6).

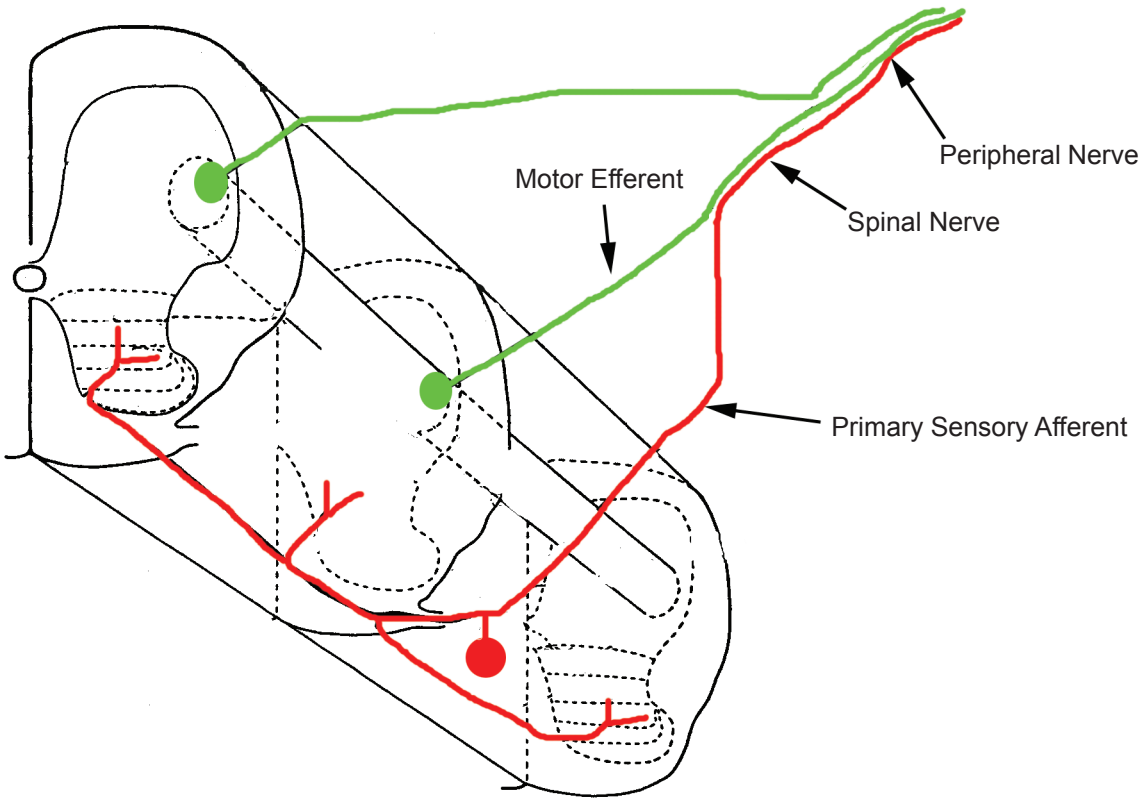
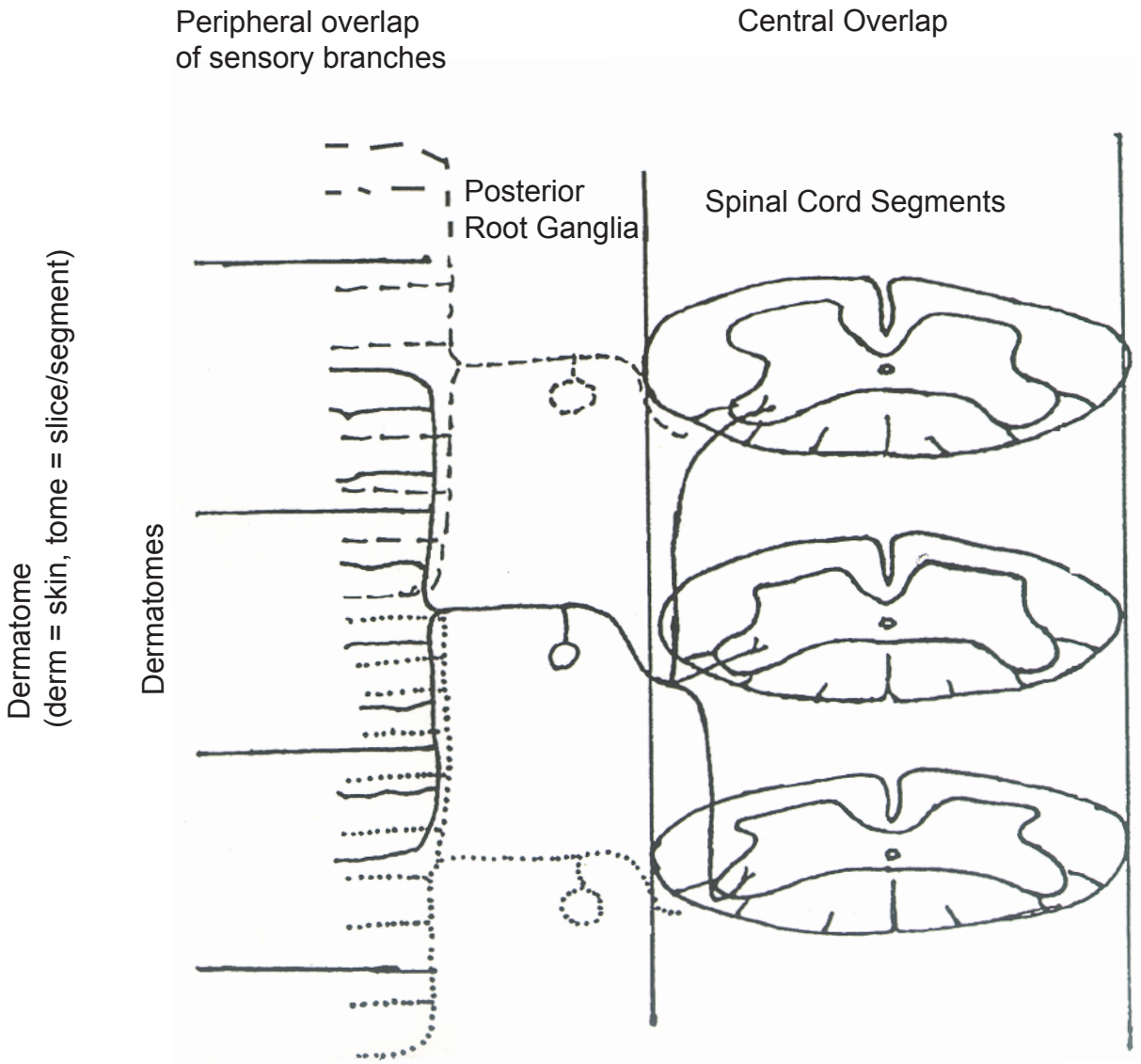


Illustration showing how a single primary afferent neuron is distributed within the spinal cord. The entering axon bifurcates into a long ascending and descending branch. Each long branch gives off several short penetrating branches that divide extensively, sending terminal branches among the dendrites of the neurons with which they eventually contact via synapses.

This **Branching Concept** is **important** in order to understand muscular reflexes - especially during the **neurologic exam.** For example: If a patient can **raise his/her right arm on command, and with proper strength,** then you **know** that spinal cord segments **C4-C6 are intact on the right side.**

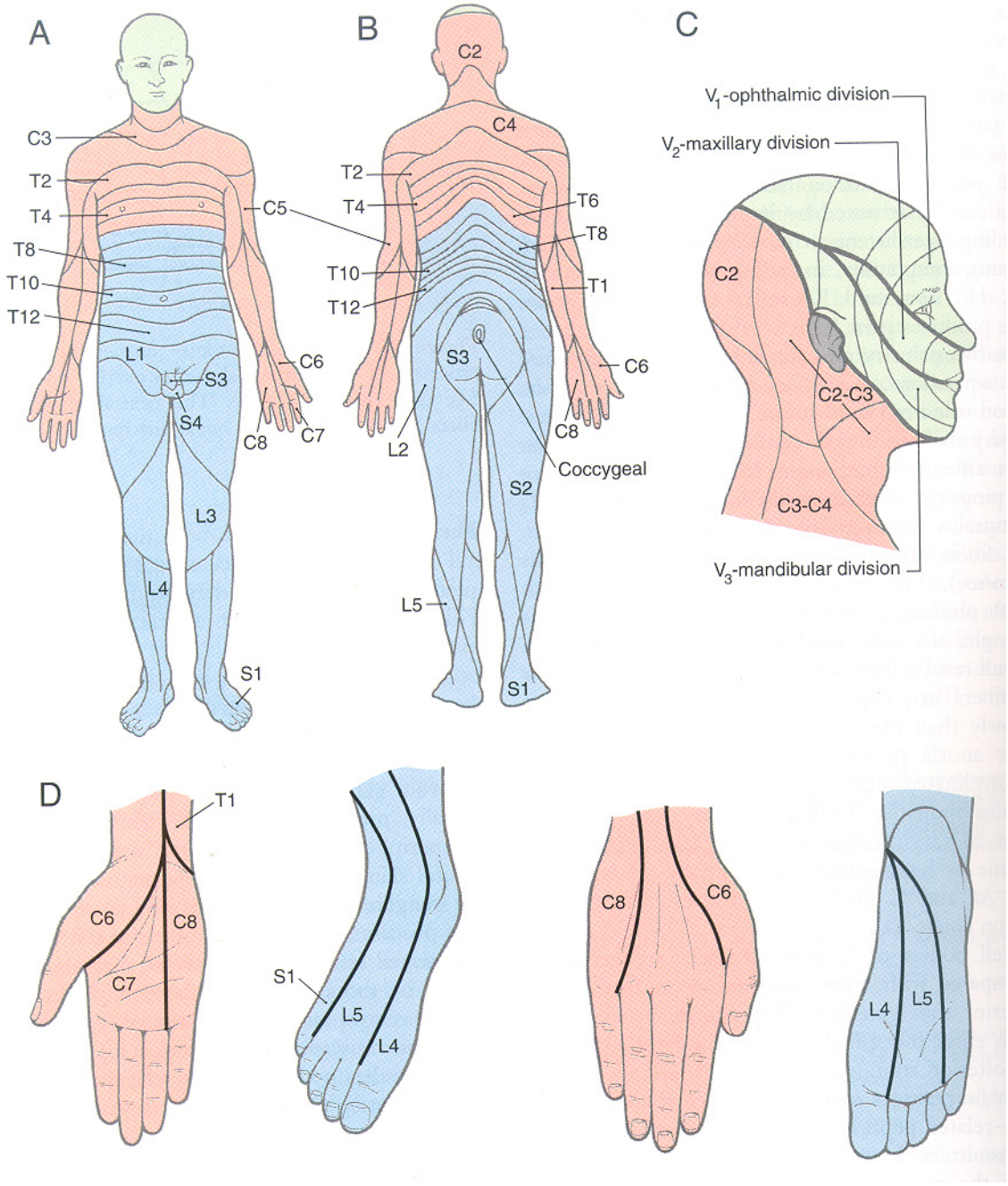
XII. Overlap of Primary Sensory Neuron Terminals in the Spinal Cord and Dermatomes



As discussed on the previous page, there is a **branching of central fibers of sensory neurons** and these branches extend to adjacent spinal cord segments. This creates **central overlap** of sensory nerve fibers.
There is also **branching of the peripheral fibers** in the skin. Some of these branching fibers extend to adjacent dermatomes. Thus there is **peripheral overlap** of sensory nerve fibers.

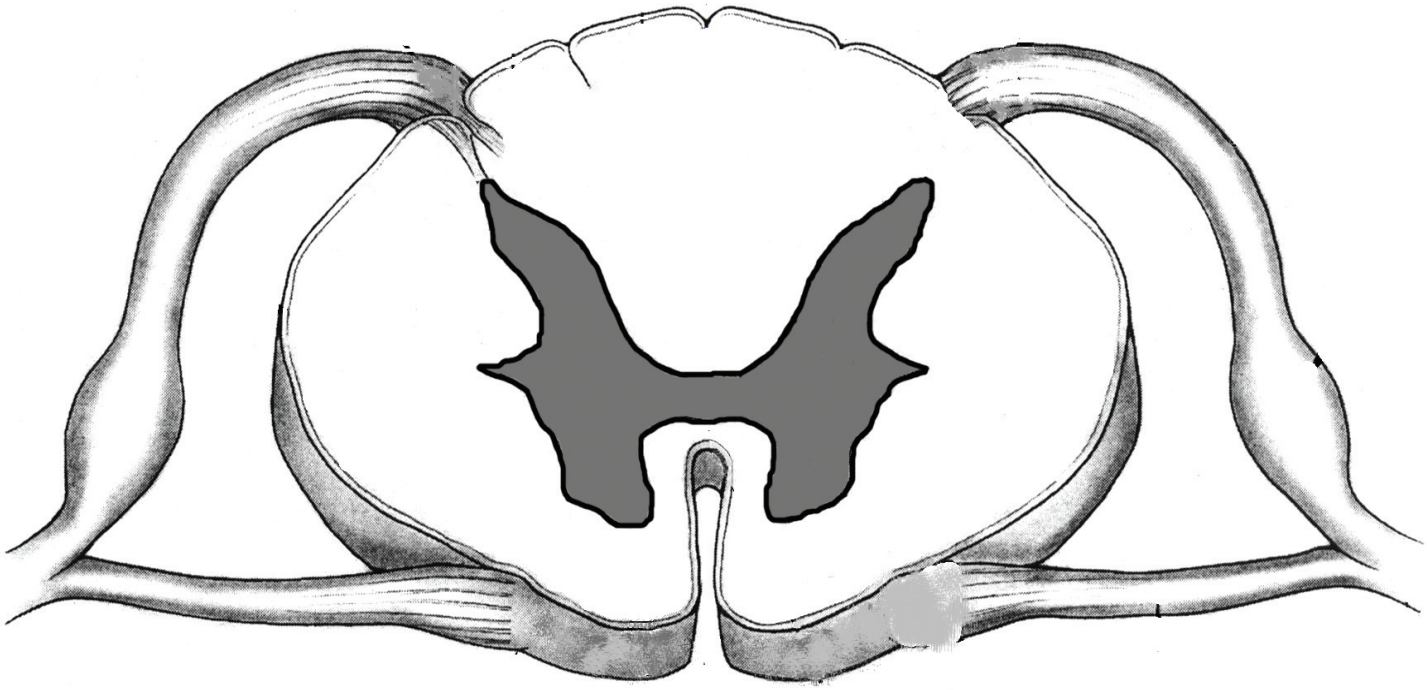
SO...If you destroy 1 spinal nerve, you will not see a cutaneous sensory loss. Due to the central and peripheral overlap of spinal nerve branches, one must **lose** at least **3 adjacent spinal nerves** to create **anesthesia in 1 dermatome.**
If you loose **2 adjacent spinal nerves**, you may see a sensory change (in the skin, it may be **hypoesthetic**).
If you destroy **1 or 2 ventral roots** of spinal nerves (motor fibers), you would expect to see some **motor deficiencies**, such as **weakness**, but not necessarily paralysis since many muscles are supplied by many spinal nerves and spinal cord segments.

Dermatomes are very important!! Learn, Love, and Embrace them!!

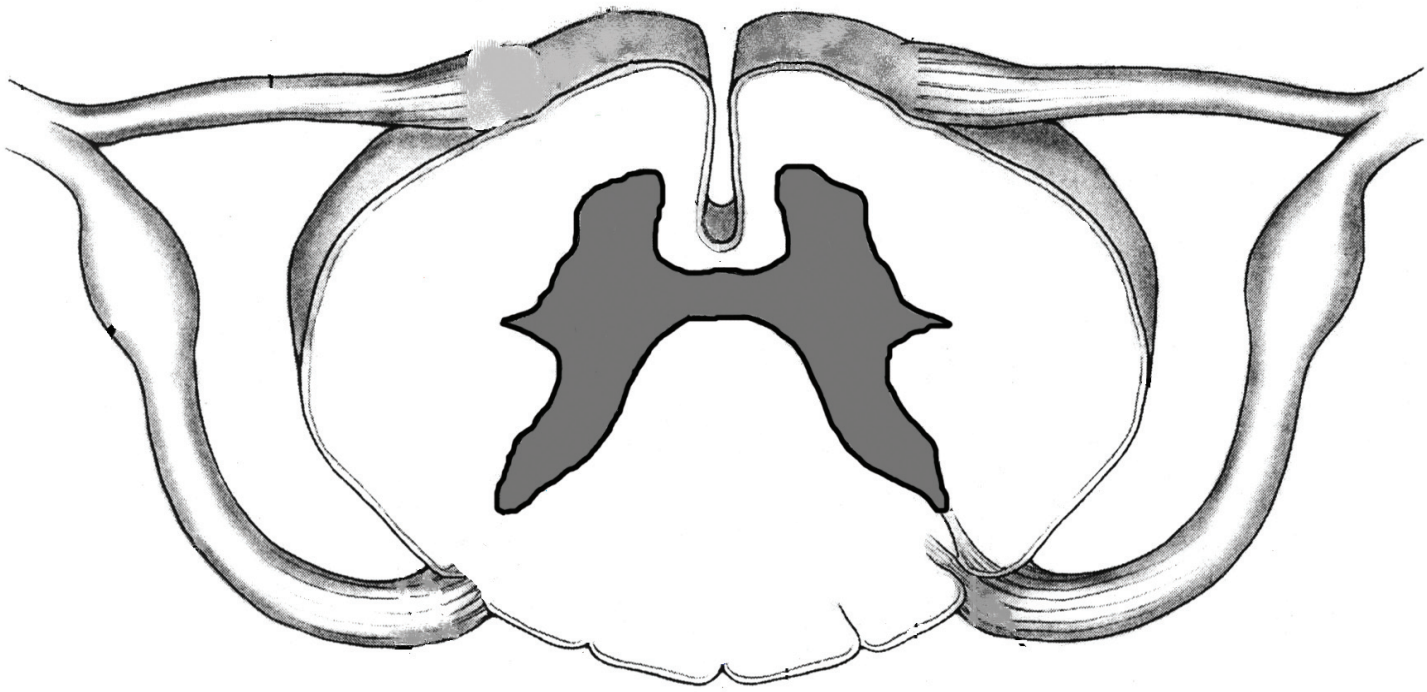


Adapted from Fundamental Neuroscience, D.E. Haines, 2002

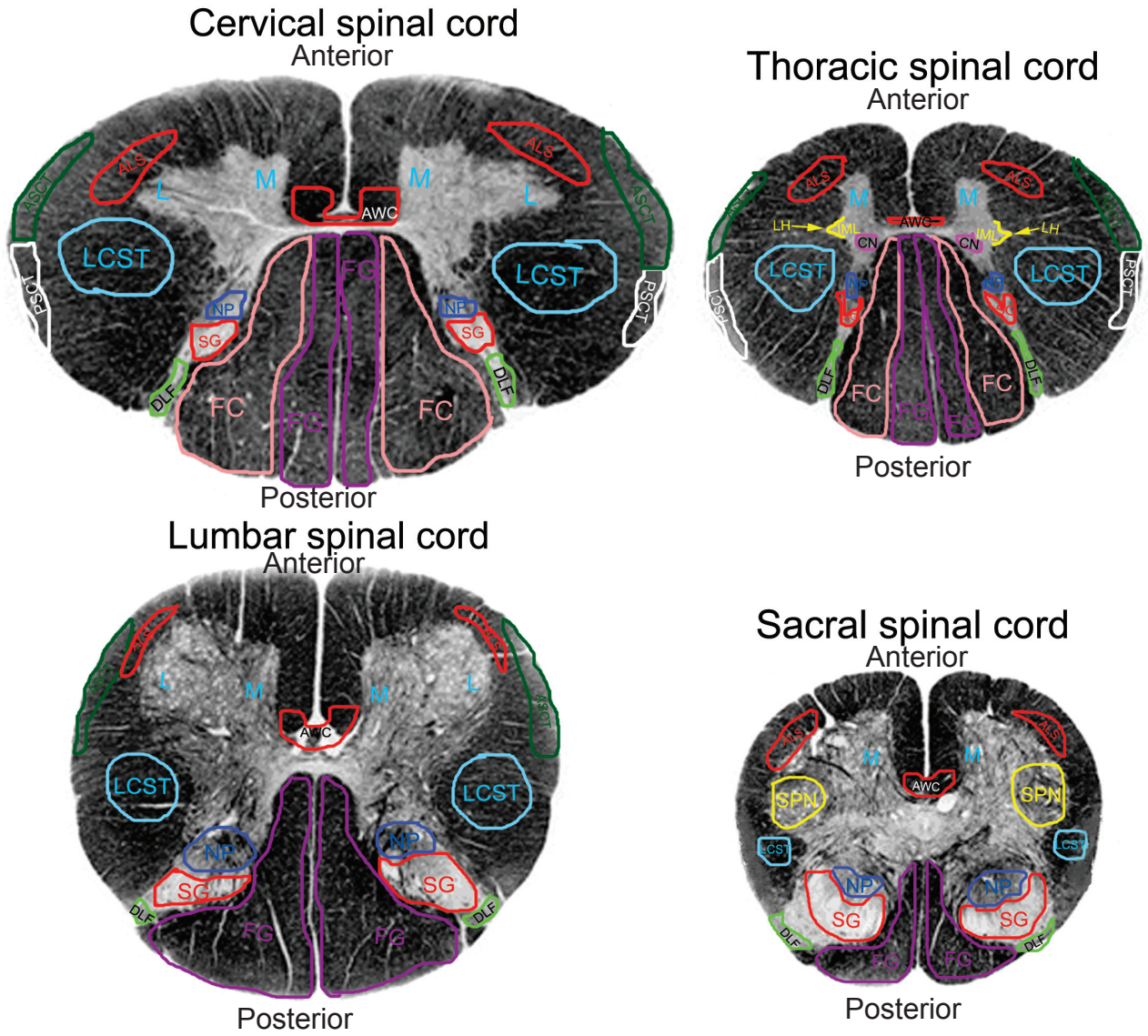
Transverse section of spinal cord in “anatomically taught” orientation



Transverse section of spinal cord in “clinical” orientation



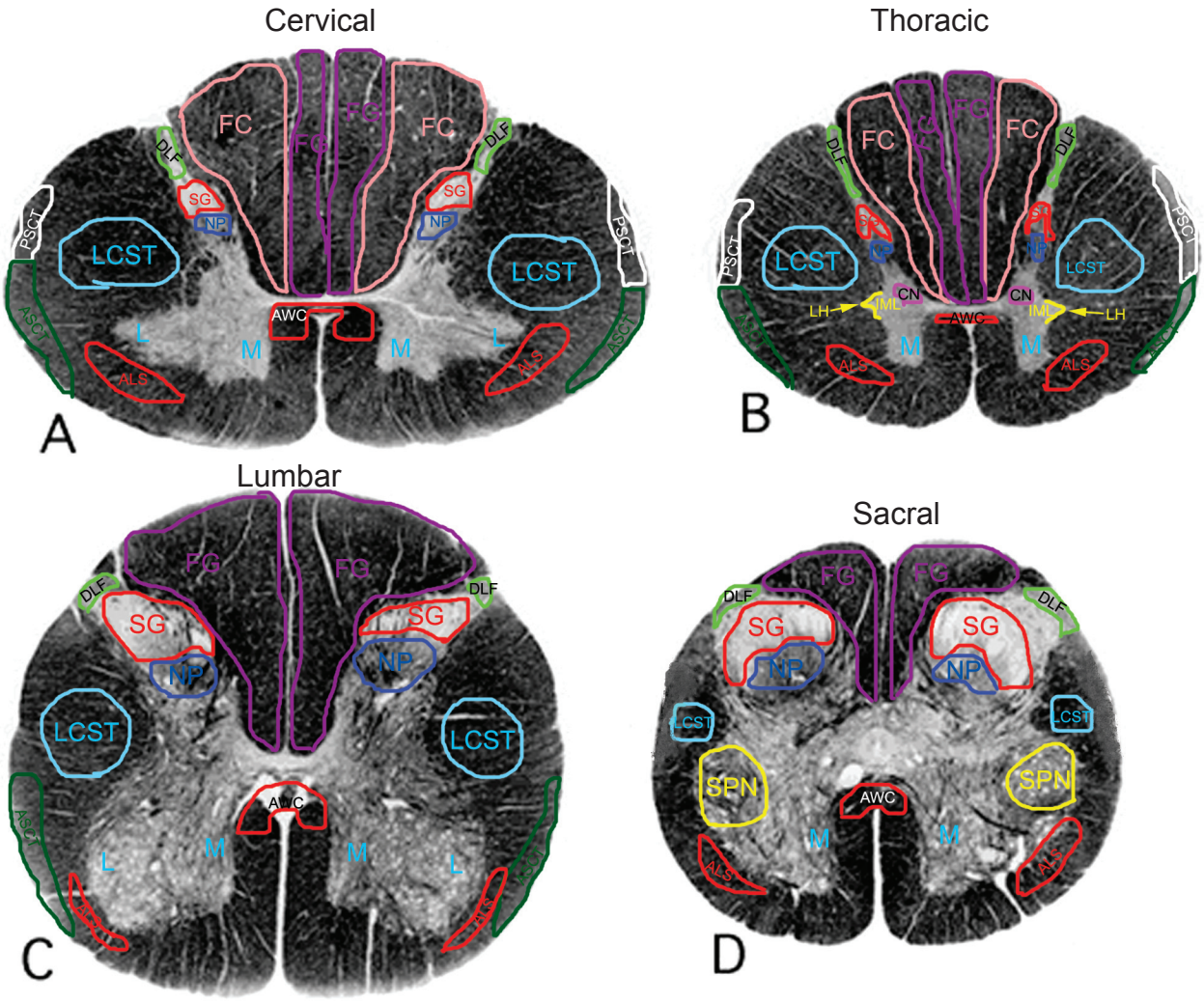
Spinal Cord Transverse Sections in Clinical Orientation



Transverse sections of spinal cord in clinical orientation

ALS = Anterolateral system (ascending pathway carrying pain and temperature info)
ASCT = Anterior spinocerebellar tract (haven't talked about yet - ascending axons going to cerebellum)
AWC = Anterior white commissure (axons crossing to contralateral spinal cord carrying pain and temp
CN = Clarke's nucleus
FC = Fasciculus cuneatus (ascending axons carrying tactile, vibratory info from the upper extremity)
FG = Fasciculus Gracilus (ascending axons carrying tactile, vibratory info from the lower extremity)
IML = Intermediolateral nucleus (preganglionic sympathetic cell bodies)
LH = Lateral Horns (lateral protrusions that contain the IML)
L = Lateral lower motor neuronal cell bodies in the ventral (anterior) horn
LCST = Lateral corticospinal tracts (descending pathway containing axons of upper motor neurons)
M = Medial lower motor neuronal cell bodies in the ventral (anterior) horn
NP = Nucleus Proprious (sensory cell bodies in the dorsal horn)
PLF = Posterolateral Fasciculus (sensory fibers entering spinal cord)
PSCT = Posterior spinocerebellar tracts (axons going from spinal cord to cerebellum)
SG = Substantia Gelatinosa (cell bodies relaying pain and temp info to higher brain centers)
SPN = Sacral parasympathetic nucleus (preganglionic parasympathetic cell bodies)

Spinal Cord Transverse Sections in Anatomical Orientation



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