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The Spinal Cord

SPINAL CORD GROSS ORGANIZATION

General Features

1. The spinal cord is the CNS in the trunk. It lies inside the vertebral canal. It is connected to the body by 31 pairs of ***spinal nerves*** (Fig. 1).
2. ***Dermatomes*** are areas of the skin innervated by particular spinal nerves (Fig. 2)
3. In the adult, the spinal cord ends between the 1st two lumbar vertebrae (vertebrae L1 & L2) (Fig. 1).
4. ***Conus medullaris*** *is* the end of spinal cord and is anchored to the dura by the ***filum terminale (***a connective tissue thread) which continues through the dura to become the ***coccygeal ligament,*** which inserts on the coccyx bone.

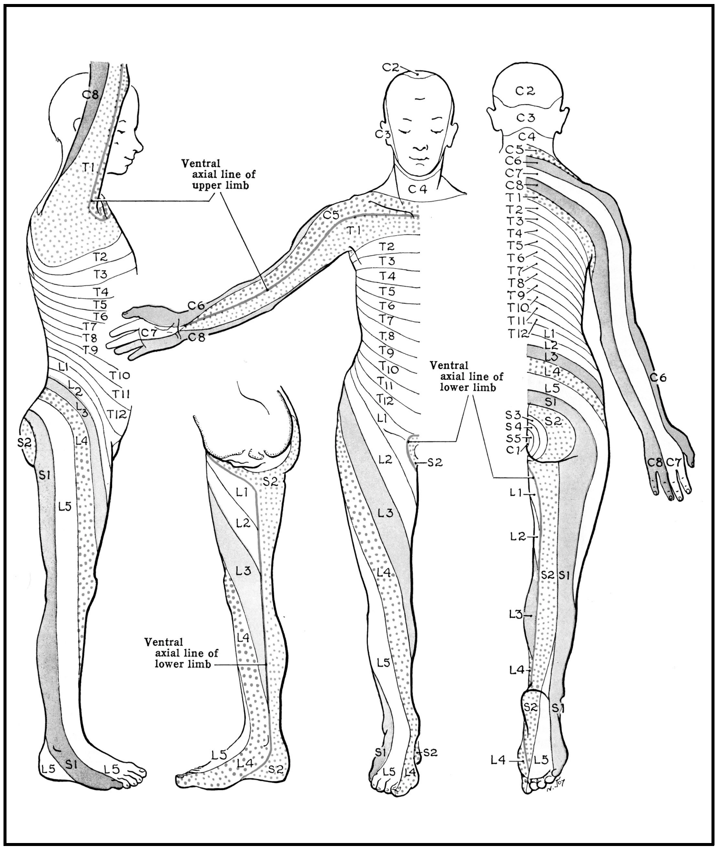


Figure 2

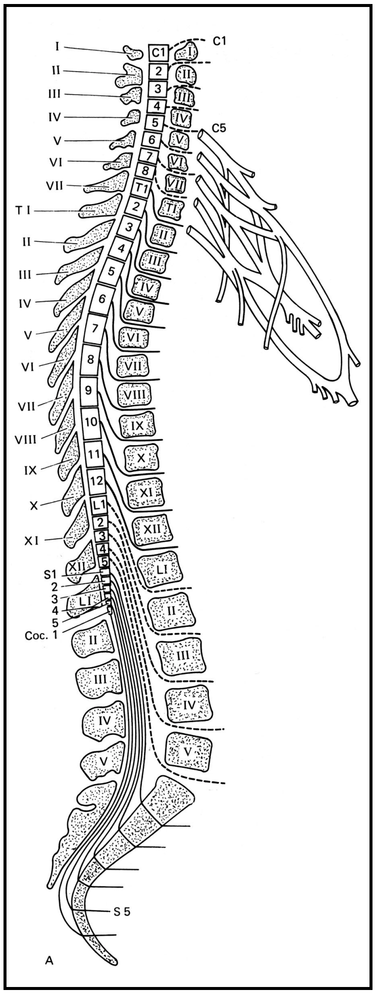


Figure 1

5. Spinal nerves travel caudally in the vertebral canal to exit between each of the lower vertebrae. Since the cord is shorter than the vertebral canal in the adult, the ***cauda equina*** is formed by the spinal nerves caudal to the conus medullaris before they exit the lower vertebra (Fig. 1).
6. ***Meninges*** envelop the whole spinal cord, including the

cauda equina. These are the same as those that cover the brain: 1) ***dura,*** *outside layer; 2)* ***arachnoid membrane***, middle layer; 3) ***pia mater***, inner layer apposed to the neural tissue (Fig. 3).

7. ***Ventral root*****s**, exit the ventral (anterior) surface and are motor in function (Fig. 3).
8. ***Dorsal root*****s**, exit the dorsal (posterior) surface and are sensory in function (Fig. 3).
9. ***Dorsal root ganglion*** **(*DRG*)** contains the cell bodies of ***primary sensory neurons*** that travel in the dorsal root (Fig. 3).
10. The internal structure of the spinal cord can be described in terms of a shell of white matter (myelinated axons) surrounding a core of gray matter (cell bodies, dendrites, axons forming synapses (Fig. 3).

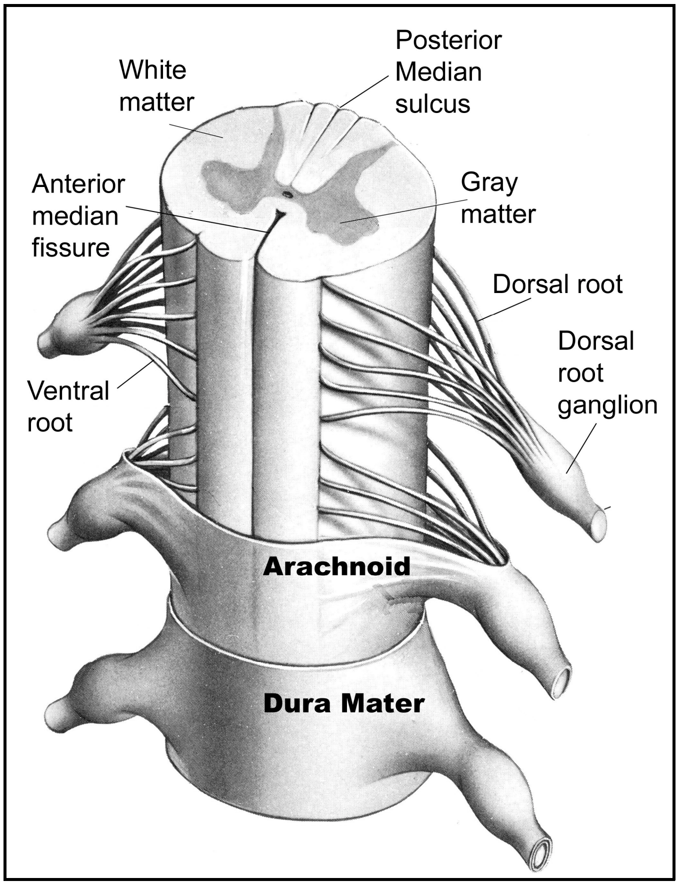


Figure 3

GRAY MATTER

When the spinal cord is cut transversely, the spinal gray matter (Fig. 3) appears H-shaped and can be divided into horns. The ***dorsal horn*** (Fig. 4) is usually the more elongate and closely approaches the dorsolateral surface of the spinal cord. The ***ventral horn*** is more rounded or boot-shaped, never approaching the spinal surface. The ***gray commissure*** connects the left and right portions of the gray matter.

1. Dorsal horn of the spinal cord is sensory in function. The basic anatomy is directly related to developmental origin of the cells:
Sensory = dorsal part = alar plate derivative.

Sensory structures include the entire posterior gray matter of the dorsal horn:(1-3 in Fig. 4)

The dorsal horn is divided into a head (caput), neck (cervix), and broad base (Fig. 5). The head contains the ***marginal zone*** (1, Fig. 4) and the ***substantia gelatinosa*** (2, Fig. 4). The neck, ventral to the substantia gelatinosa, is the ***proper sensory nucleus (nucleus proprius)*** (3, Fig. 4), which is the main sensory nucleus of the dorsal horn. The base (Fig. 5) really belongs to the ***intermediate gray***, an area which includes the dorsal part of the ventral horn.

2. Ventral horn of the spinal cord is motor in function. (8, 9, Figs. 4-5)

Motor = ventral part = basal plate derivative.

3. Intermediate gray of spinal cord in intermediate in function. (4, Fig. 4-5)

It includes mostly interneurons. It is at the border of alar and basal plates = level of central canal. Special nuclei are particularly prominent in the intermediate gray of the thoracic spinal cord. These are:

a. **The intermediolateral nucleus.** See below.

b. **Nucleus dorsalis of Clarke** (Clarke's column, 5, Fig. 4). This nucleus lies near the dorso-medial border of the intermediate gray matter and spans spinal levels T1-L2. The cells are secondary neurons, which receive collaterals of 1a primary afferents from spindles in the muscles of the trunk and the hind limb. Neurons in Clarke's nucleus send their axons into the *dorsal spino-cerebellar tract.*

FIGURE 5-5 (From Peele, 1977)
Diagram of a spinal cord segment (low cervical) showing lamination of the posterior funiculi and principal nuclear divisions of the anterior and posterior gray columns. *S, L, D,* and *C,* representations, respectively, of sacral, lumbar, dorsal (thoracic), and cervical cord segments in the posterior funiculi; *FC,* fasciculus cuneatus; *FG,* fasciculus gracilis. *FIF,* fasciculus interfascicularis: 1, posteromarginal nucleus; 2, substantia gelatinosa; 3, proper sensory nucleus; 4, reticular nucleus; 5, dorsal nucleus (of Clarke); 6, posterior commissural nucleus; 7, anterior commissural nucleus; 8, medial motor cell columns; 9, lateral and dorsolateral motor cell columns; 10, intermediomedial nucleus; 11, dorsolateral (Lissauer's) fasciculus.

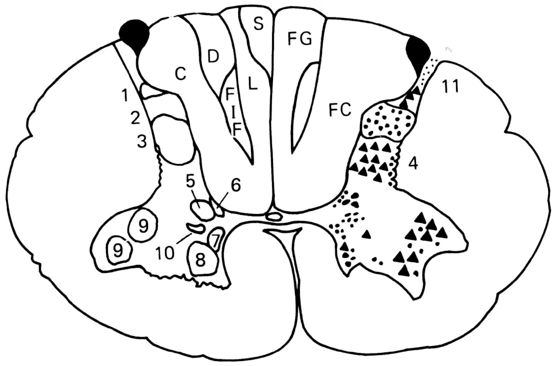


Figure 4

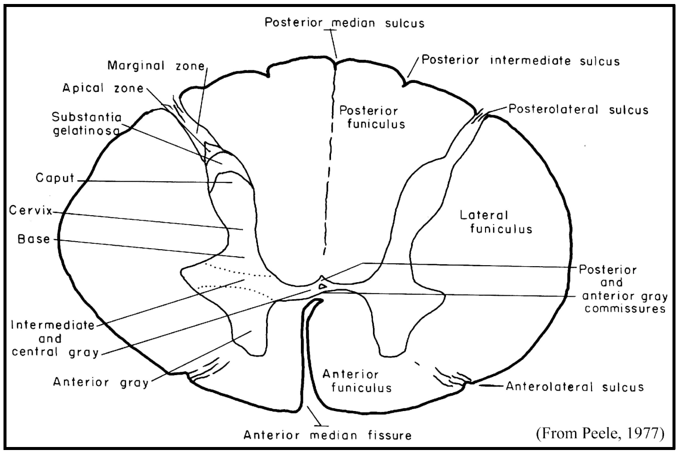
WHITE MATTER

The white matter surrounds the gray matter and is divided into three regions (Fig. 5):

1. Dorsal columns (posterior funiculus, Fig. 5) - Contains the fasiculus gracilis and fasiculus cuneatus.

2. Lateral columns (lateral funiculus, Fig. 5) - Contains the lateral corticospinal tract

3. Ventral columns (ventral funiculus, Fig. 5)- Contains a large number of ascending and descending tracts.



(From Peele, 1977)

Figure 5

ORGANIZATION OF THE DORSAL/SENSORY PART OF SPINAL CORD

Cell Types

1. Projection neurons -- Send information to brain.

2. Interneurons -- Local circuits within dorsal part of spinal cord.

Inputs

Dorsal root - The dorsal root fibers carry information into the CNS from the periphery. Some information goes to the ventral part and to the motor neurons. Other information is more directed towards the brain. The cell body of the primary sensory neuron lies in the dorsal root ganglion. The distal end of its peripheral axon is associated with a sensory receptor. Its central axon projects through the dorsal root to enter the spinal cord in the dorsal funiculus, medial to the dorsal horn. Here it bifurcates into an ascending and a descending branch. Each branch extends through the spinal segment in which the afferent fiber entered the dorsal funiculus, and it extends through one or more levels.

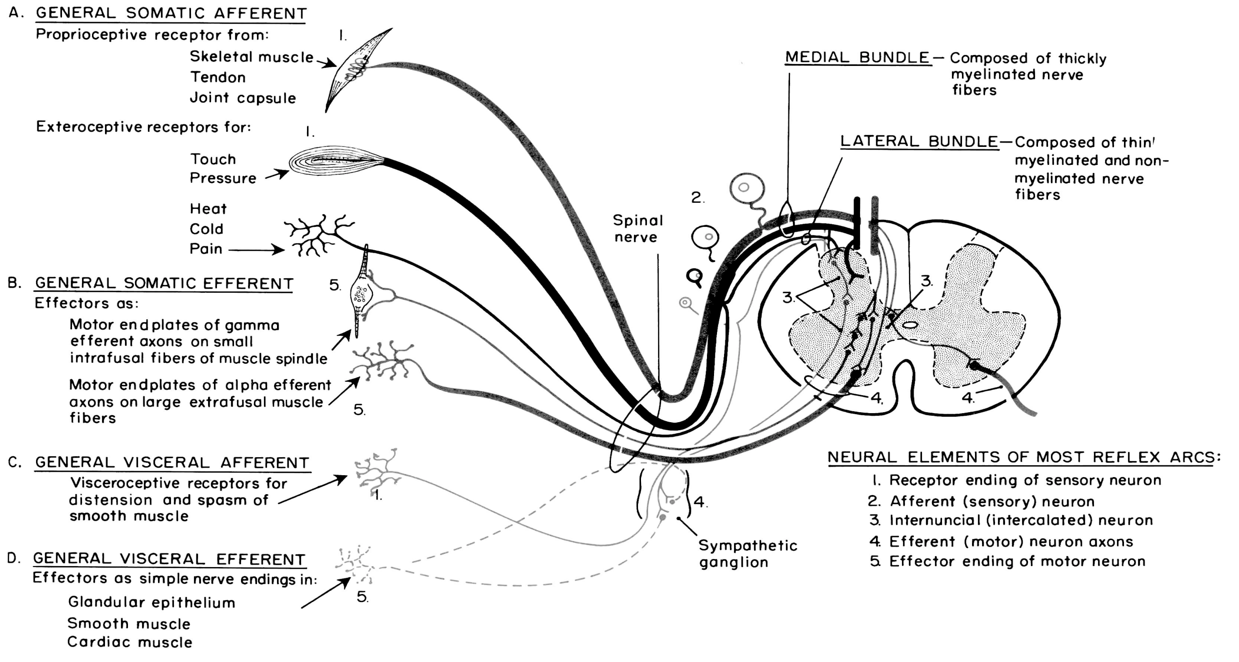


Figure 3.20. Diagram of functional components of a thoracic spinal nerve and the arrangement of dorsal root fibers as they enter the spinal cord via medial and lateral bundles. Muscle afferent and efferent fibers are indicated in *red*. Visceral afferent and efferent fibers are shown in *blue*. An afferent fiber from a Pacinian corpuscle (*black*) and a thin pain fiber (*black*) also are shown. Numbers in the diagram correspond to neural elements that form reflex arcs. (From Carpenter and Sutin, *Human Neuroanatomy*, 1983; courtesy of Williams & Wilkins.)

Figure 6

Receptors associated with muscles use the largest dorsal root fibers Ia, Ib (General somatic afferents) (Fig. 6)

stretch - muscle spindle;
Golgi tendon organ

Types of sensory information associated with skin and deep receptors use medium and small sized dorsal root fibers (General somatic afferents) (Fig. 6)

tactile - touch, free nerve endings, hair follicles
vibration - enclosed endings

deep pressure - free
pain - thermal; nociceptor;
proprioceptive (position) - joint.

General visceral afferents:) (Fig. 6)

Sensory receptors in the viscera, especially smooth muscle and wall of alimentary canal.

The finest fibers, which convey information about pain and temperature, are unmyelinated. They enter the dorsal funiculus most laterally of all the primary afferents and they bifurcate there to form ascending and descending branches. Because the fibers are not myelinated, they appear as a pale band in the lateral part of the dorsal funiculus, just above the marginal zone. This part of the dorsal funiculus is called ***Lissauer's tract*** or ***the dorsolateral funiculus of Lissauer***. The collaterals of these branches cross into the marginal zone and the substantia gelatinosa.

Outputs

Ascending sensory

a. dorsal column system - primary afferents continue to medulla without synapse in spinal cord (Fig. 7).
b. spino-thalamic system - projection neurons in dorsal horn send axons to thalamus (Fig. 7)
c. spino-reticular system - projection neurons (Fig. 7)

Ascending sensory-motor

a. Spinocerebellar tract - from Clarke’s nucleus (and other intermediate gray areas) to cerebellum (Fig. 7)
b. Cuneocerebellar tract - primary afferents from muscle spindles and golgi tendon organs to medulla (Fig. 7).

ORGANIZATION OF THE MOTOR/VENTRAL PART OF SPINAL CORD

Cell types:

1. Motor neurons.

Large ***α-motor neurons*** that innervate skeletal muscles (Figs. 4,6).

Smaller ***γ-motor neurons*** which innervate the contractile portions of muscle spindles (intrafusal muscle) (Figs. 4,6).

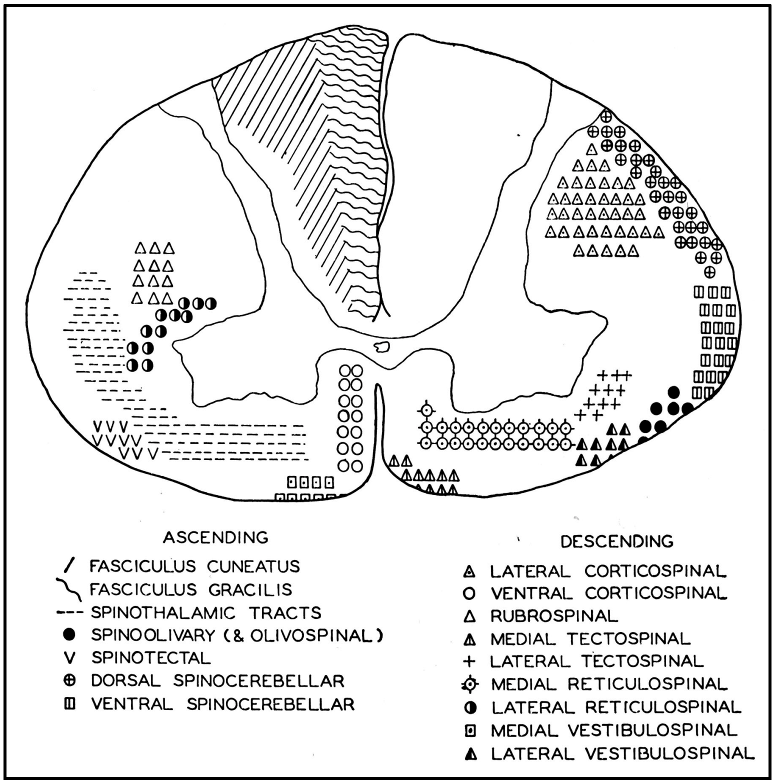


Figure 7

2. Propriospinal neurons
Interconnect levels of spinal cord. These are essential for coordination between segments.

3. Interneurons (Fig. 6)
Make local connections between other neurons and the motor neurons. Interneurons are essential for most reflexes and are also intermediaries for inputs from the brain.

Inputs:
1. Primary afferents from the dorsal root.
2. Propriospinal inputs from other levels of cord
3. Descending inputs from brain.

Outputs
1. Skeletal motor system. Motor neurons innervate skeletal muscle.

Each motor neuron nucleus innervates a particular muscle. In the cervical (C5-C8) and lumbar enlargements (L3-S3), there are distinct motor nuclei, innervating each of the many muscles of the limbs. In those regions the ventral horn is enlarged (Fig. 8).

Motor neurons, propriospinal, and interneurons in the ventral horn are grouped into nuclei. Each nucleus is a long, cigar-shaped structure which extends through at least one and typically several spinal levels. Each group includes the motor neurons of a particular muscle in the periphery and, therefore, each group is considered a motor neuron ***nucleus*** (***a collection of neuronal cell bodies in the CNS***). In a motor neuron nucleus that spans several levels, each motor neuron sends its axon out of the spinal cord through the nearest ventral rootlet.

In the cervical (C5-C8) and lumbar enlargements (L3-S3), there are distinct motor nuclei, innervating each of the many muscles of the limbs. They protrude from the ventral horn ventrolaterally and provide the characteristic shape of these enlargements (Fig. 8). By contrast, in thoracic segments, there are few motor neuron nuclei, just those innervating the relatively few axial (trunk) muscles. Here, the spinal cord is not humped, but tubular (Fig. 8).

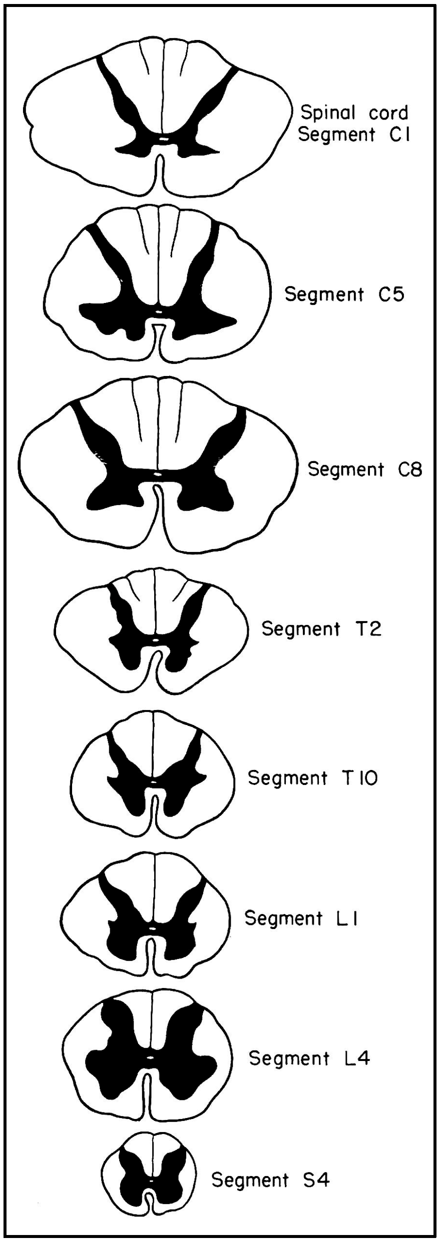


Figure 8

The location of the motor neuron nucleus that controls each muscle can also be mapped in transverse sections of the spinal cord. This mapping illustrates ***somatotopic organization***. This means that areas of the body are represented topographically by particular areas of the CNS.

Distal muscles of the extremities are represented **laterally** in the ventral horn, while **proximal limb muscles and the axial muscles** are represented more **medially** (Fig. 9)**.**

Extensors are represented **superficially** in the ventral horn by cell groups along its outer edge, while **flexors** are represented by **deeper nuclei** (Fig. 9).

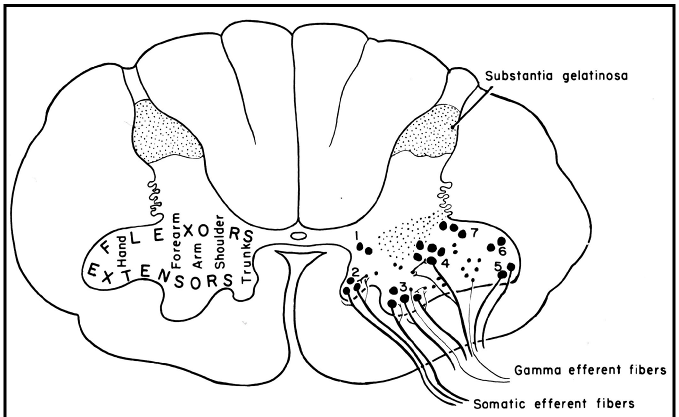


Figure 3.18. Diagram of motor nuclei in anterior gray horn of a lower cervical spinal segment. On the *left* the general location of anterior horn cells innervating the muscle groups of the upper extremity are shown. Groups of motor nuclei indicated on the *right* are *1*, posteromedial; *2*, anteromedial; *3*, anterior; *4*, central; *5*, anterolateral; 6, posterolateral; *7*, retroposterolateral. Smaller anterior horn cells (gamma neurons) supply the intrafusal muscle fibers of neuromuscular spindle (Fig. 3.23). Note the collaterals from somatic efferent axons that return to gray matter and synapse on small medially placed "Renshaw cells." Smaller cells represented as dots in the intermediate gray (lamina VII) indicate the area of the internuncial neurons. (From Carpenter and Sutin, *Human Neuroanatomy*, 1983; courtesy of Williams & Wilkins.)

`Figure 9`

2. Autonomic sympathetic motor system.

The intermediolateral nucleus (intermediolateral cell column) contains preganglionic neurons that innervate postganglionic neurons in the ***sympathetic ganglia***. This nucleus lies at the lateral border of the intermediate gray matter and typically spans spinal levels T1-L2, occasionally including levels C8 and L3 (Fig. 8).

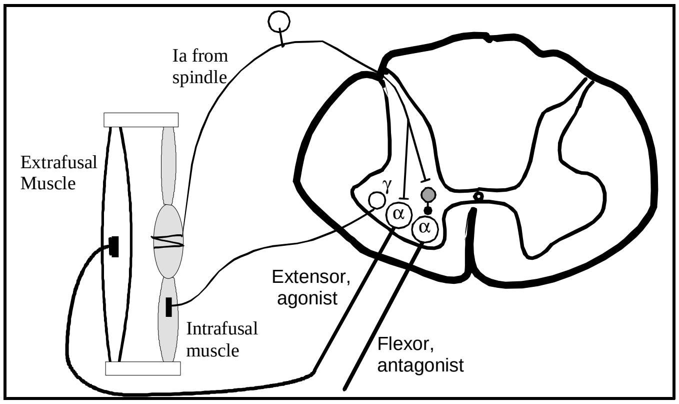
Parasympathetic preganglionic neurons are located in the sacral spinal cord. These neurons are in the intermediate gray but do not form a distinct nucleus that we can identify easily. Parasympathetic neurons terminate on postganglionic neurons located at the organ innervated.

3. ***Interneurons*** scattered throughout the ventral horn participate in reflexes.

REFLEXES – SOME EXAMPLES OF HOW NEURONS IN SPINAL CORD MAKE USEFUL NEURAL CIRCUITS

Stretch *(myotatic)* Reflex (Fig. 10)

Stretch reflex - muscle stretch causes agonist muscles to contract. Monosynaptic, 0.5-0.9 ms latency.



`Figure 10`

Stretch of the extrafusal fibers in the muscle spindle cause Ia dorsal root fibers to fire. The central axon bifurcates on entering the dorsal funiculus of the spinal cord and distributes collaterals over the entire rostro-caudal extent of the motor neuron nucleus that innervates the muscle from which the 1a afferent came. Action potentials invade each of the collaterals of the primary afferent fiber. Each collateral forms monosynaptic contacts with alpha-motor neurons. Activation of the motor neuron then causes the muscle (that was stretched) to contract.

Cutaneous Reflex

Cutaneous reflex - flexion of limb to avoid painful/nociceptive stimulus; opposite limb extends to support body. It illustrates divergence of the primary afferents and role of interneurons of different types.

1. In the ipsilateral limb: the flexors contract (+) and the extensors are inhibited (-).

2. Simultaneously, in the contralateral limb: - flexors; + extensors

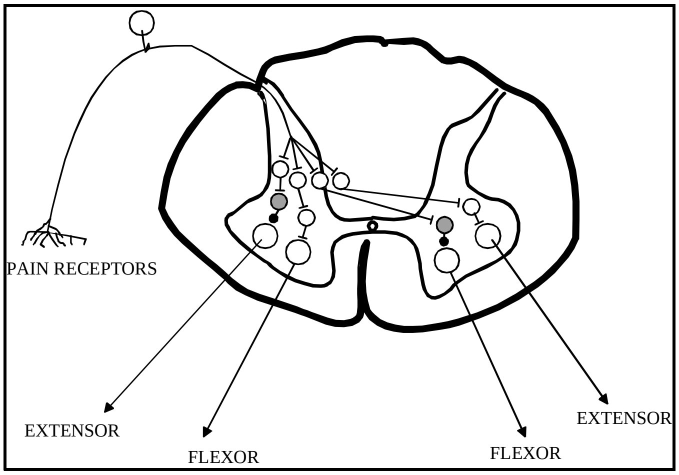


Figure 11

Interneurons That Coordinate Reflexes

1. ***Excitatory interneurons*** (Fig. 11) use glutamate as transmitter. May receive inputs from dorsal root afferents, descending afferents from the brain, or from other neurons in the spinal cord. Example of *feed-forward excitation.*

A. Crossed – synapse on the opposite side of the spinal cord. Axons pass through the white commissure (Fig. 11).
B. Uncrossed – synapse on the same side of the spinal cord (Fig. 11).

2. ***Inhibitory interneurons*** – Inhibit motor neurons. Inputs are from dorsal root afferents, descending afferents from the brain, or from other neurons in the spinal cord. Example of feed-forward inhibition (Fig. 11).

3. ***Renshaw cell*** (Fig. 12) – A specialized interneuron that is activated by the axon of a motor neuron and then it inhibits the same motor neuron. Example of *feedback inhibition*.

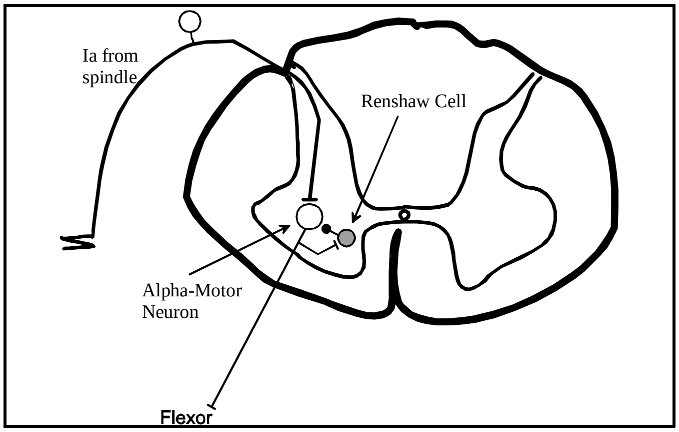


Figure 12

LONG PATHWAYS IN THE WHITE MATTER OF THE SPINAL CORD

Long pathways connect the spinal cord to the brain. Ascending pathways send sensory information to the brain. Descending pathways carry motor control information from the brain to the spinal cord in order to control the activity of motor neurons or autonomic neurons (sympathetic or parasympathetic). See Figure 7. These will be the topics of several more lectures.