

In transverse section, the spinal cord features:

- a **central canal** lined by ependymal cells;
- **gray matter** (butterfly-shaped profile) surrounding the central canal; and
- **white matter** surrounding the gray matter; also notice,
- **spinal roots** and **meninges** external to the spinal cord.

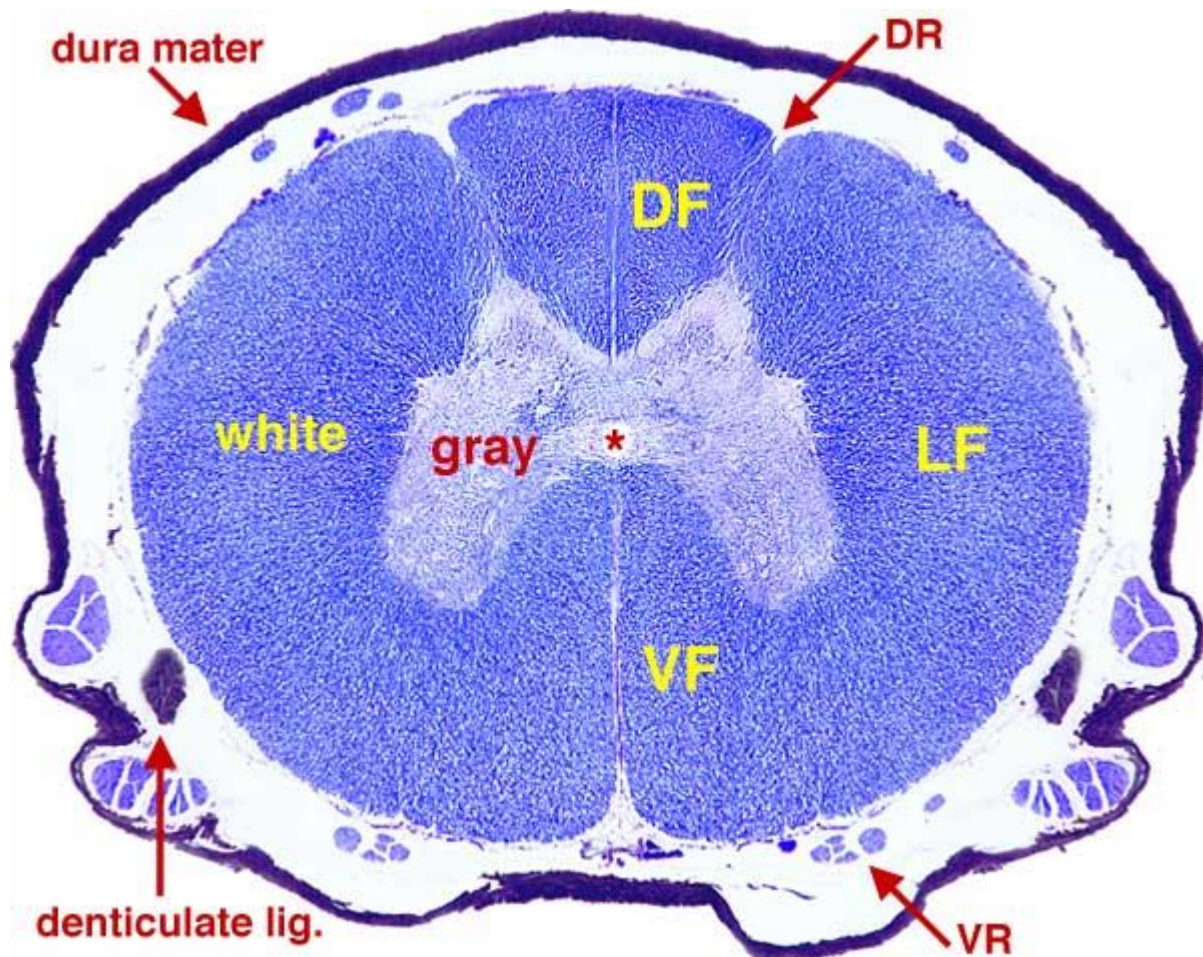


Fig. 1. Canine spinal cord segment T-6. At low power, identify H-shaped **gray matter** surrounding the **central canal** (asterisk). The dorsal and ventral projections of gray matter are called "horns". Notice that ventral horns are broader than dorsal horns (particularly in segments that innervate limbs) and that this thoracic segment has small lateral horns. **White matter** (DF/LF/VF) is exterior to gray matter and spinal roots (DR/VR) and meninges (dura mater & denticulate lig.) are external to the spinal cord.

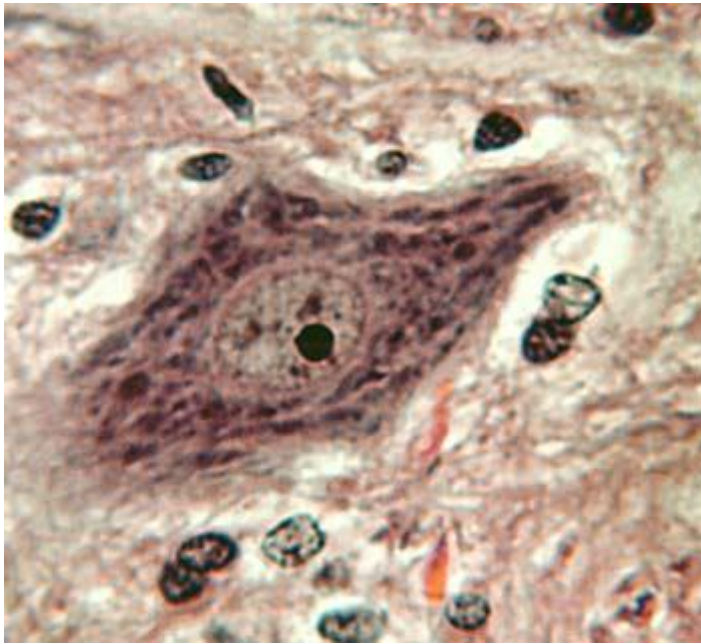


Fig. 14. H&E stained spinal gray matter exhibits a variety of perikarya belonging to neurons and glial cells. Examine ventral horn gray matter at high power to find perikarya of the large **motor neurons** that innervate skeletal muscle. These **multipolar neurons** have a **leptochromatic nucleus**, a **prominent nucleolus**, and distinct clumps of **Nissl substance (RER)** in the cytoplasm of the cell body and proximal dendrites.

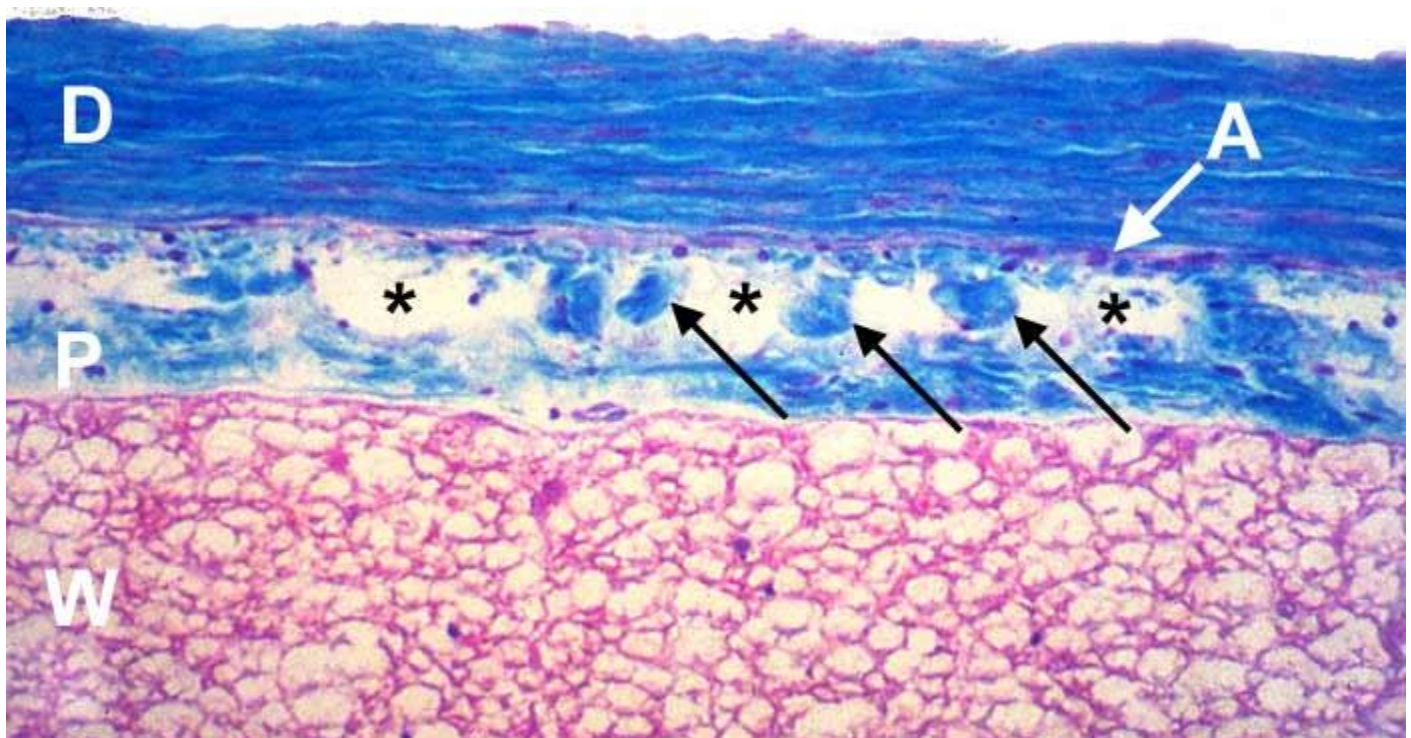
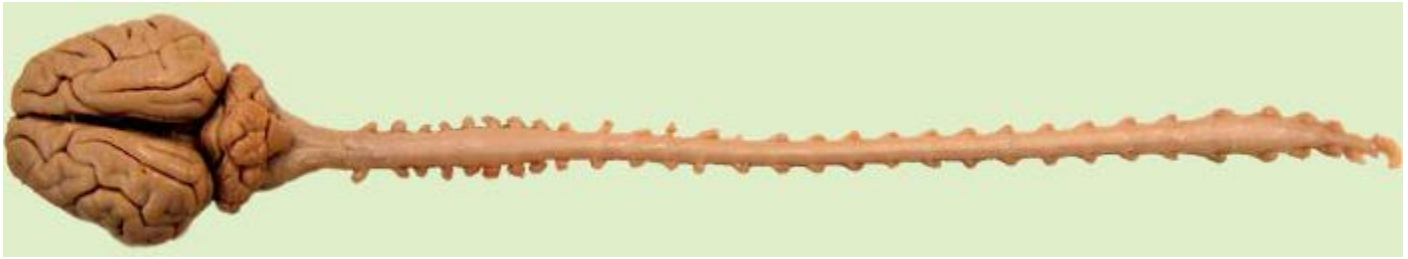
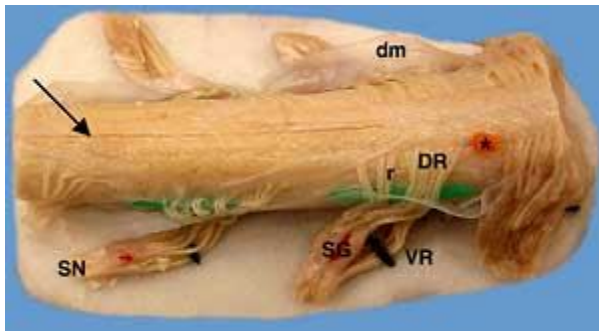


Fig. 15. Meninges are connective tissue layers surrounding the brain, the spinal cord, and the roots of peripheral nerves. The **pia mater** (P) is a delicate connective tissue layer attached directly to the white matter of the spinal cord. The **dura mater** (D) is a thick connective tissue layer. It is the most superficial of the three meningeal layers. The **arachnoid** (arachnoid membrane) is attached to the deep surface of the dura mater (A). Arachnoid trabeculae (arrows) extend from the arachnoid to the pia mater. The **subarachnoid space** (asterisks), between the arachnoid and pia mater, is lined by flat fibrocytes and contains cerebrospinal fluid.

Spinal Cord Gross Anatomy



The **spinal cord** is a long cylinder of nervous tissue with subtle cervical and lumbar (lumbosacral) enlargements. The enlarged segments contribute to the brachial and lumbosacral plexuses. In the above image, showing a brain and spinal cord from a neonatal pig, the spinal cord and spinal roots are enveloped by dura mater.



The spinal cord is divided into **spinal cord segments**. Each segment gives rise to paired spinal nerves. Dorsal and ventral **spinal roots** arise as a series of rootlets. A **spinal ganglion** is present distally on each dorsal root. The canine spinal cord has 8 cervical, 13 thoracic, 7 lumbar, 3 sacral and 5 caudal segments. The following table compares species.

Spinal cord segments in different species (for reference purposes):

Dog: 8 cervical; 13 thoracic; 7 lumbar; 3 sacral; & 5 caudal = 36 total

Cat: 8 cervical; 13 thoracic; 7 lumbar; 3 sacral; & 5 caudal = 36 total

Bovine: 8 cervical; 13 thoracic; 6 lumbar; 5 sacral; & 5 caudal = 37 total

Horse: 8 cervical; 18 thoracic; 6 lumbar; 5 sacral; & 5 caudal = 42 total

Swine: 8 cervical; 15/14 thoracic; 6/7 lumbar; 4 sacral; & 5 caudal = 38 total

Human: 8 cervical; 12 thoracic; 5 lumbar; 5 sacral; & 1 coccygeal = 31 total

The spinal cord and spinal roots are enveloped by meninges and housed within the vertebral canal. The **epidural space**, situated between the wall of the vertebral canal and the spinal dura mater, contains a variable amount of fat. Within **dura mater**, the spinal cord is suspended by bilateral **denticulate ligaments** and surrounded by **subarachnoid space** filled with **cerebrospinal fluid**. Dorsal and ventral spinal roots unite to form spinal nerves which exit the vertebral canal at intervertebral foramina. An intervertebral foramen is formed by adjacent vertebrae and by the intervertebral disc joining the vertebrae.

As a result of differential growth of the spinal cord and vertebral column, most **spinal cord segments** are positioned cranial to their nominally corresponding vertebrae. However, spinal segment length is variable along the spinal cord in our domestic mammals. Segments become progressively shorter from the C3 to T2. Then they elongate so that segments at the thoracolumbar junction are within nominally corresponding vertebrae. Thereafter, segments progressively shorten until the cord terminates in a **terminal filament** of glia. (The term "conus medullaris" refers to the cone-shaped cord region between the lumbosacral enlargement and the glial filament.)

Since spinal nerves exit the vertebral canal at nominally corresponding intervertebral foramina, **spinal roots** must elongate when spinal cord segments are displaced cranially. The term **cauda equina** (horse tail) refers to caudally streaming spinal roots running to intervertebral foramina in the sacrum and tail. Damage to the cauda equina affects pelvic viscera and the tail. Cauda equina epidural anesthesia (putting anesthetic into the epidural space to block conduction in spinal roots) is a common obstetrical procedure in cattle.

Because vertebrae can be palpated and visualized in ordinary radiographs, unlike spinal segments, it is clinically useful to know locations of spinal cord segments relative to vertebrae. Typically (for most dogs) the cervical enlargement is centered at the C6-7 intervertebral disc; spinal segments of the thoracolumbar junction are within nominally corresponding vertebrae; the sacral segments are within vertebra L5; and the functional spinal cord terminates at the L6-7 vertebral junction. (Termination is about one vertebra further caudally in small dogs, less than 7 kg.)

Segments—Vertebrae Relationships

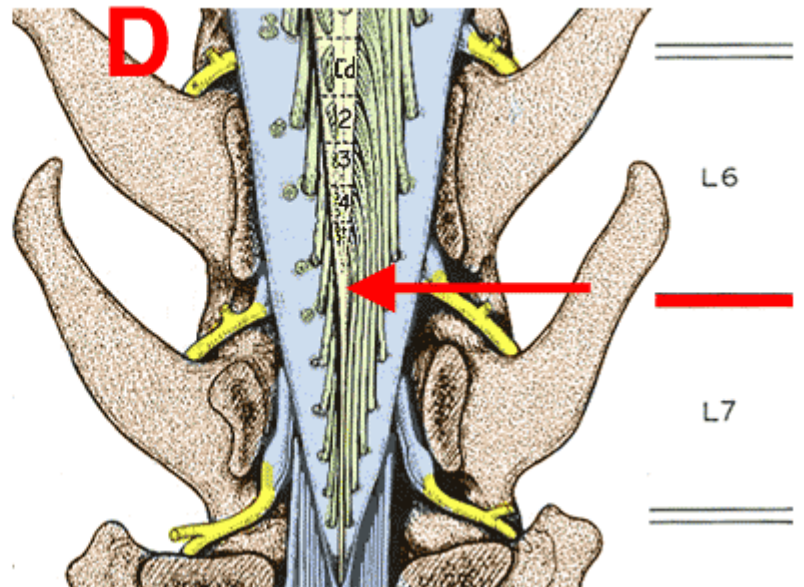
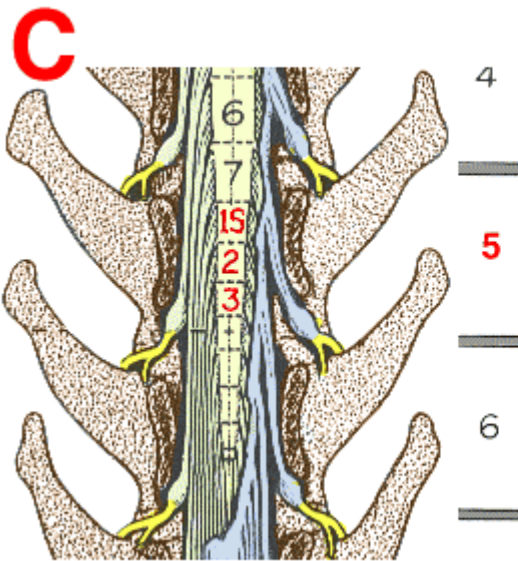
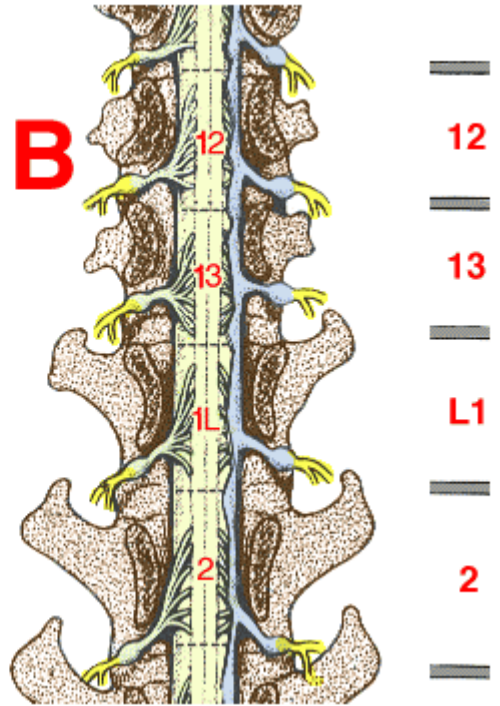
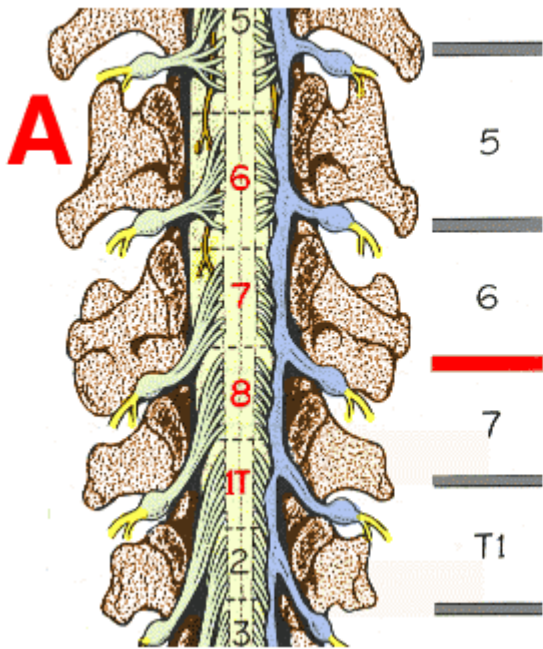
It is clinically useful to know the approximate locations of **spinal cord segments** relative to palpable, radiographically visible vertebrae. One learning strategy is to remember the following four relationships and then interpolate other position relationships as necessary. (The illustrated relationships are the most common for medium and large dogs (\pm half vertebra). In small dogs the position is one vertebra caudal to that shown.)

A. The cervical enlargement (brachial plexus segments) are centered at the C6-C7 intervertebral disc.

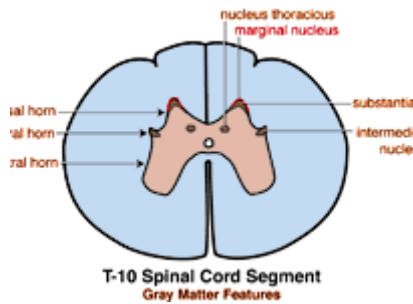
B. At the thoraco-lumbar junction, segments are positioned within nominally corresponding vertebrae.

C. The three sacral segments are located within the L5 vertebra.

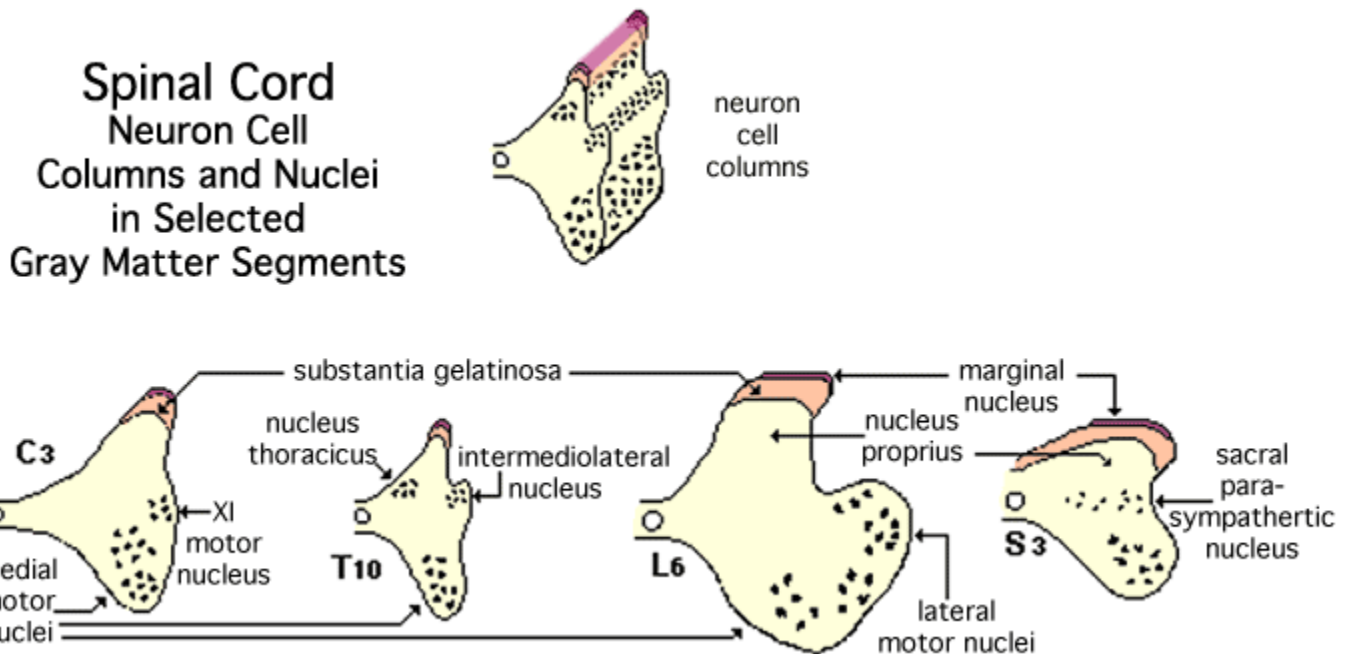
D. The spinal cord terminates at the L6-L7 intervertebral disc.



Spinal Cord Gray Matter



Spinal gray matter is butterfly-shaped. It extends from the **ependymal cells** lining the **central canal** to the surrounding white matter. Spinal gray matter is divided bilaterally into **dorsal horn**, **intermediate substance**, and **ventral horn**. At thoracolumbar levels, intermediate substance features a **lateral horn**. Intermediate substance lacks precise boundaries; in general, it is around the central canal and between dorsal and ventral horns.

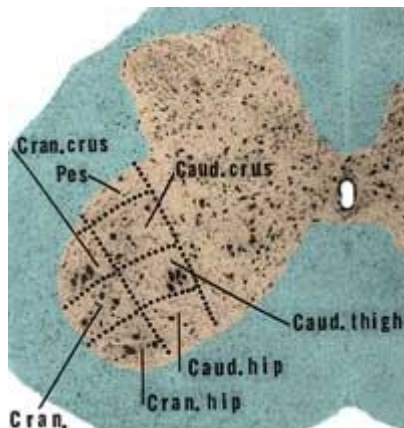


Spinal neurons within the gray matter are either efferent neurons (axons enter ventral roots), projection neurons (axons join white matter tracts), or interneurons (axons remain within gray matter). The gray matter "horns" are actually profiles of gray columns. Columns of neuron cell bodies, when transected, appear as clusters of neuron cell body profiles within gray matter. The cell body clusters are called

nuclei. Some nuclei (columns of cell bodies) are present throughout the spinal cord, other nuclei have more restricted segmental distributions.



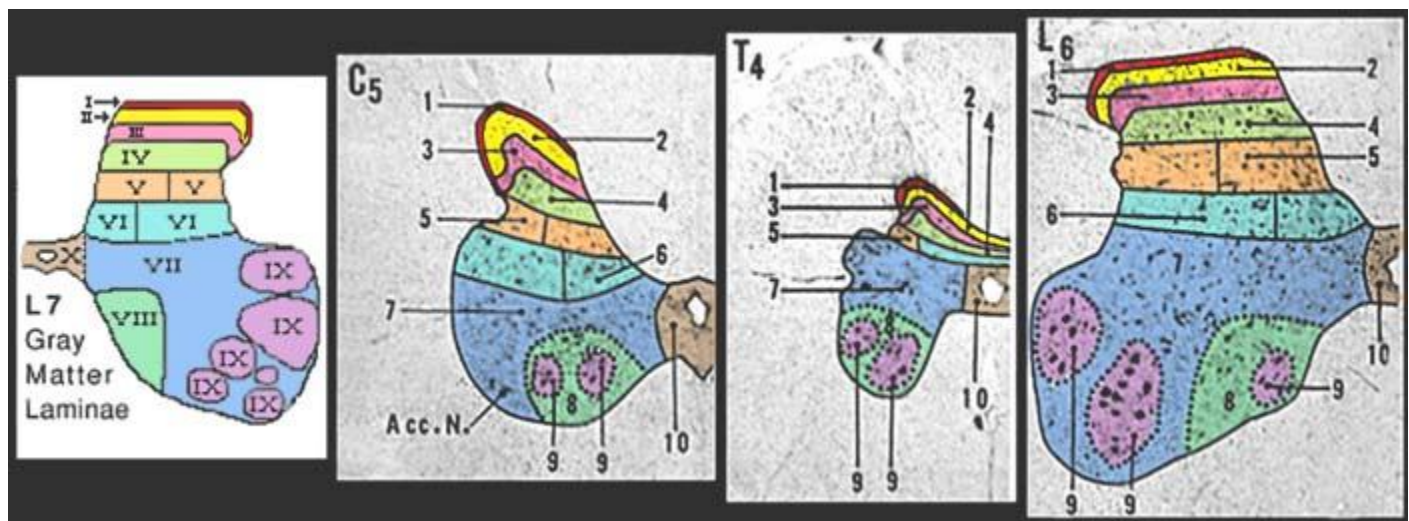
The dorsal horn surface is capped by a **marginal nucleus** (lamina I) which is thin and not distinct in transverse sections. A population of small neurons forms a very distinctive **substantia gelatinosa** (lamina II). The remainder of the dorsal horn may be considered **nucleus proprius**. The **nucleus thoracicus**, located medially in the base of the dorsal horn, is present in thoracolumbar segments; axons from the nucleus form the dorsal spinocerebellar tract (Note: nucleus thoracicus projection neurons are large but sparse and not evident in some sections).



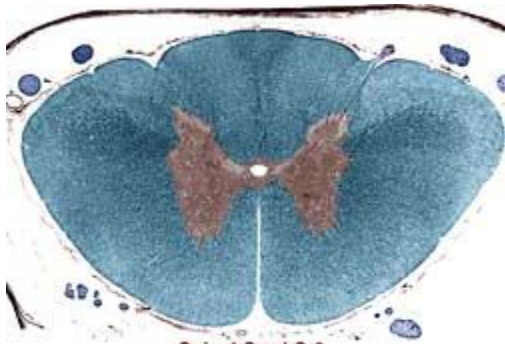
In the intermediate substance, one nucleus is found only in thoracic and cranial lumbar segments of the spinal cord. The **intermediolateral nucleus**, which forms a lateral horn, is composed of sympathetic preganglionic neurons.

The ventral horn contains somatic efferent motor neurons. **Medial motor nuclei** innervate muscles of the trunk and are found in all spinal segments. Lateral collections of motor neurons, which innervate limb muscle, are seen in segments of the cervical and lumbosacral enlargements. Motor nuclei are somatotopically arranged.

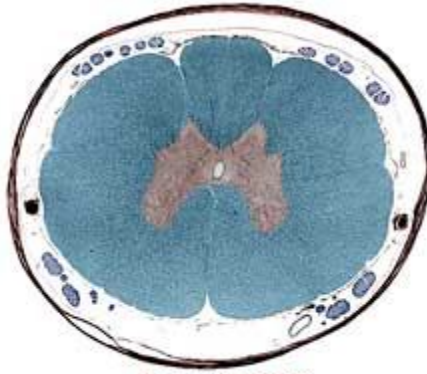
Much of the spinal gray matter is outside of recognizable nuclei. An alternative method of categorizing gray matter involves defining spinal laminae (below), as opposed to nuclei. Laminae offer the advantage of including all regions of gray matter. The disadvantage of laminae is that, unlike nuclei, laminar boundaries are not evident in normal sections.



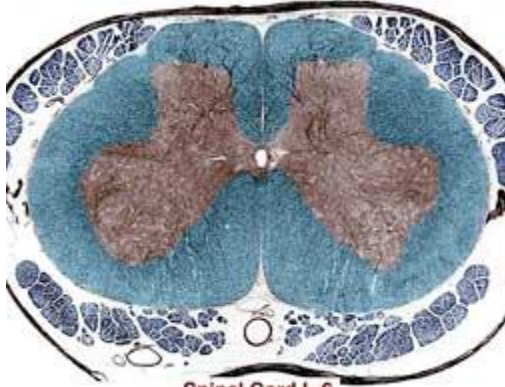
Below are links for viewing spinal gray matter in better quality sections.



Spinal Cord C-3

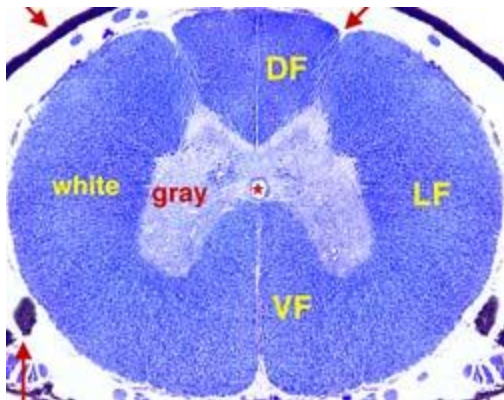


Spinal Cord T-6

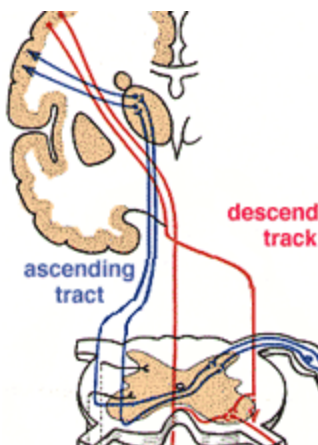


Spinal Cord L-6

Spinal Cord White Matter

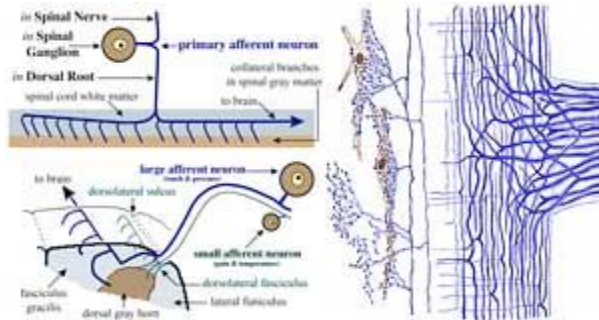


In each half of the spinal cord, white matter is divided into three major bundles, called funiculi. The dorsolateral sulcus marks the division between **dorsal funiculus** and **lateral funiculus**. The boundary between lateral funiculus and **ventral funiculus** is arbitrarily set where the most lateral bundle of ventral root fibers passes transversely through the white matter. Right and left ventral funiculi are connected by a **ventral white commissure**, located along the midline ventral to gray matter and dorsal to the ventral median fissure.

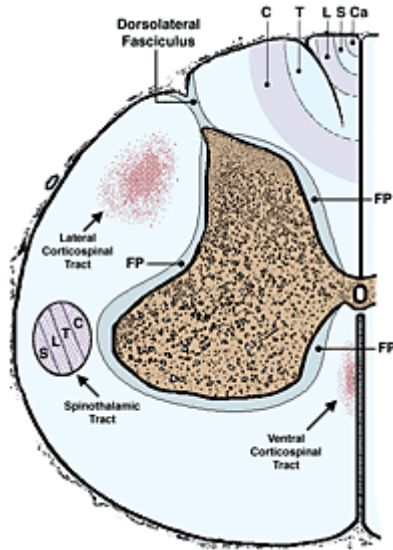


Spinal **white matter** consists of nerve fibers entering from dorsal roots; nerve fibers exiting to ventral roots; and millions of longitudinally oriented fibers organized into **spinal tracts** (some tracts are called fasciculi). Ascending spinal

tracts convey information cranially from spinal cord projection neurons to the brain. Descending spinal tracts convey information caudally from brain neurons to the spinal cord. Although spinal tracts are anatomically nondescript (all fibers look alike); functionally, each tract is distinct since its fibers go to, or come from, a particular location in the brain and they signal a particular type of information. Some tract fibers arise and terminate entirely within the spinal cord and do not reach the brain. They are located deep, next to gray matter, and collectively they are called **fasciculus proprius**.



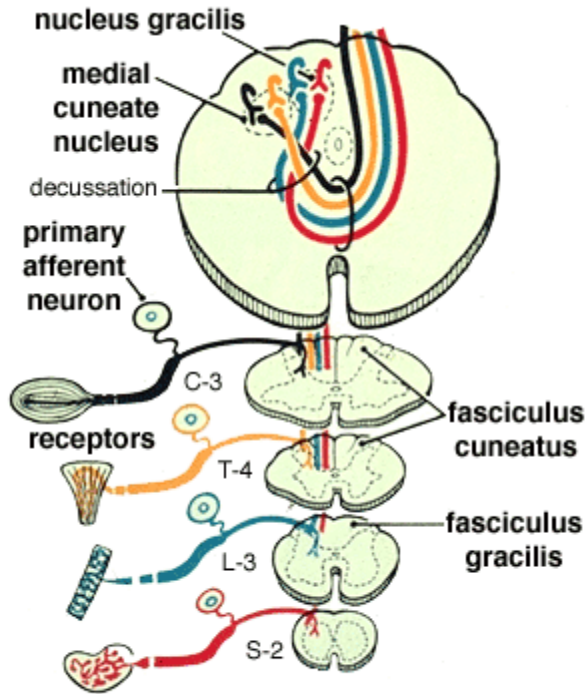
As **dorsal rootlet nerve fibers** enter the spinal cord, they bifurcate into cranially and caudally directed branches. These primary branches give off collateral branches that arc in a transverse plane and enter the dorsal horn gray matter. Thinly myelinated and nonmyelinated fibers (pain & temperature fibers) collect laterally as the dorsal rootlet enters the cord. Their cranial and caudal branches form the **dorsolateral fasciculus**. Thick myelinated fibers (touch & kinesthesia) gather medially in the dorsal funiculus as the dorsal rootlet enters the cord. Their cranial branches continue on to the brain. Such cranial branches form **fasciculus gracilis** (from the caudal half of the body) and **fasciculus cuneatus** (from the cranial half of the body).



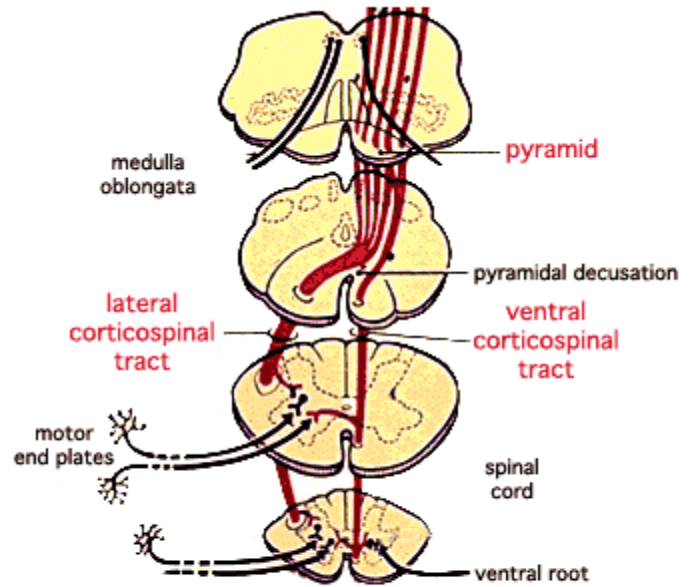
Within a tract, fibers are organized such that the shortest ones are closest to gray matter; thus, fibers to the cervical region are deeper than those to the sacral region. In the dorsal funiculus, ascending branches of myelinated touch & kinesthesia fibers are regionally organized (Ca, S, L, T, & C). Those from the caudal half of the body constitute **fasciculus gracilis**. Those from the cranial half of the body form **fasciculus cuneatus**. The shortest tract fibers form **fasciculus proprius** (FP), immediately adjacent to gray matter. Lateral and ventral corticospinal tracts are depicted so as to illustrate that tracts consist of a dense core surrounded by a zone of decreasing fiber density.

Spinal Pathways

All **spinal pathways** involve a sequence of neurons. Excitability is transmitted from one neuron to the next in the sequence. Pathways are either ascending (carrying information from receptors to the brain) or descending (conveying information from the brain to spinal cord neurons). Below, parts of a touch & kinesthesia **ascending pathway** and a corticospinal **descending pathway** are diagrammed.



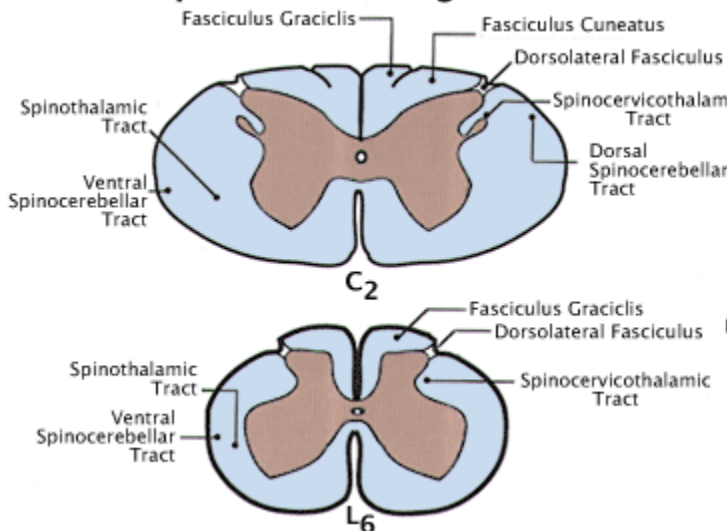
Ascending Pathway



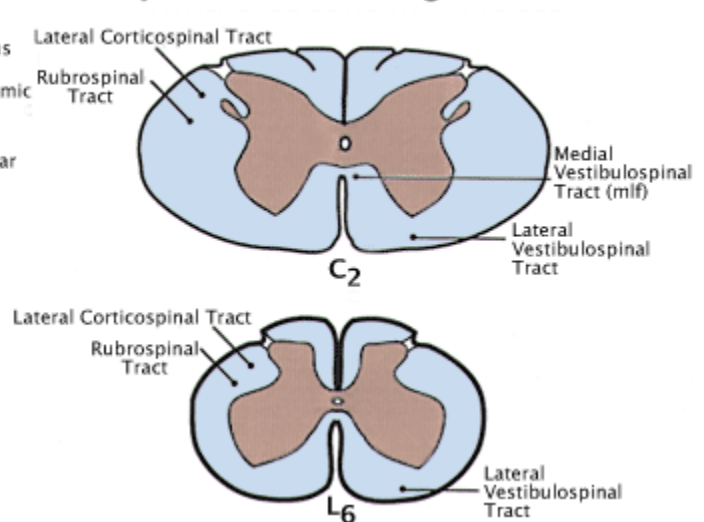
Descending Pathway

The initial neuron in an **ascending spinal pathway** is always a *primary afferent neuron* having a unipolar cell body in a spinal ganglion and receptors at the peripheral end of its axon (above left). The central end of its axon synapses on projection neurons within the spinal cord (or brain). In conscious pathways, projection neurons terminate in the contralateral thalamus, synapsing on a thalamic neuron that projects to the cerebral cortex.

Spinal Ascending Tracts

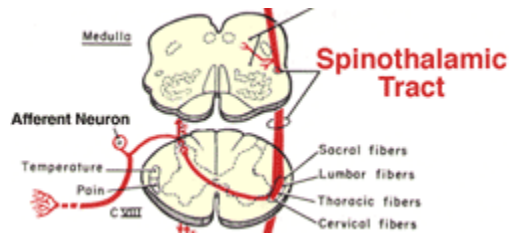


Spinal Descending Tracts

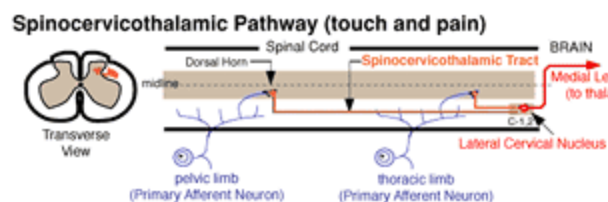


The above illustration shows approximate locations in spinal white matter of selective **ascending tracts** (left) and **descending tracts** (right). Tracts that decussate in the spinal cord are shown on the left side. Tracts that remain ipsilateral are shown on the right side. Cervical and lumbar levels of the spinal cord have different combinations of tracts because not all tracts run the whole length of the spinal cord. Descending tracts will be discussed later in the course.

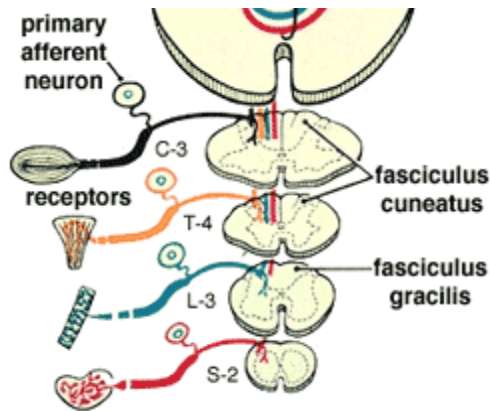
Selected Ascending Pathways



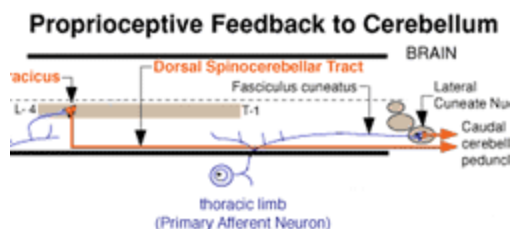
Pain and Temperature Ascending Pathway. These receptors are mainly free nerve endings. Axons of the primary afferent neurons are nonmyelinated (C-fibers) or thin myelinated axons (A-delta fibers) that bifurcate in the **dorsolateral fasciculus**. Projection neurons are located throughout the dorsal horn but they are concentrated in the **marginal nucleus** and **nucleus proprius**. Axons of the projection neurons decussate and ascend in the **spinothalamic tract** to reach the contralateral thalamus. Thalamic projection neurons send axons through the internal capsule to the somesthetic area of the cerebral cortex.



In carnivores, the **spinothalamic pathway** is an important pain pathway. The pathway is unusual because it has two spinal projection neurons (and four instead of the usual three neurons for conscious pathways). The first projection neuron runs from the dorsal horn to the ipsilateral **lateral cervical nucleus** (located only in segments C1 & 2). The axon of the second projection neuron, arising in the lateral cervical nucleus, decussates and runs to the contralateral thalamus. Thalamic neurons project to the somesthetic area of the cerebral cortex.



Touch and Kinesthesia Ascending Pathway. The pathway begins with encapsulated mechanoreceptors associated with primary afferent neurons featuring myelinated axons and large unipolar cell bodies. The axons bifurcate in the dorsal funiculus and ascend in **fasciculus gracilis** (pelvic limb and trunk) or **fasciculus cuneatus** (thoracic limb and neck) to, synapse in, respectively, **nucleus gracilis** or **medial cuneate nucleus** in the brainstem. From these nuclei, axons of projection neurons decussate (cross) and run in the medial lemniscus to the contralateral thalamus. Thalamic projection neurons send axons through the internal capsule to the somesthetic area of the cerebral cortex.



Subconscious Spinocerebellar Pathways. Subconscious pathways typically are ipsilateral (uncrossed) and involve only two neurons (primary afferent & projection neurons). In the case of spinocerebellar pathways, which you will study later in this course, receptors are mainly encapsulated proprioceptors associated with large myelinated axons, since the information is generally urgent. Pelvic and thoracic limb spinocerebellar pathways differ. Primary afferent neurons from the pelvic limb synapse on the **nucleus thoracicus**, which gives rise to the **dorsal spinocerebellar tract**. For the thoracic limb, cranial branches of primary afferent neurons run in the **fasciculus cuneatus** and synapse in the **lateral cuneate nucleus**. Axons of projection neurons from both limbs run in the caudal cerebellar peduncle to reach the cerebellum.