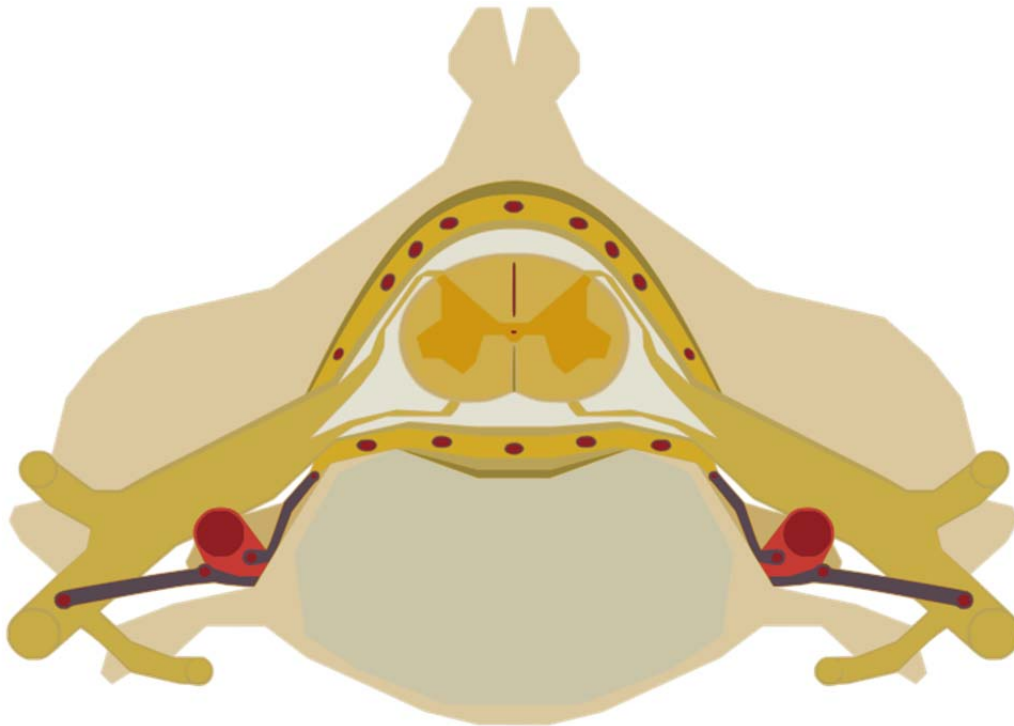


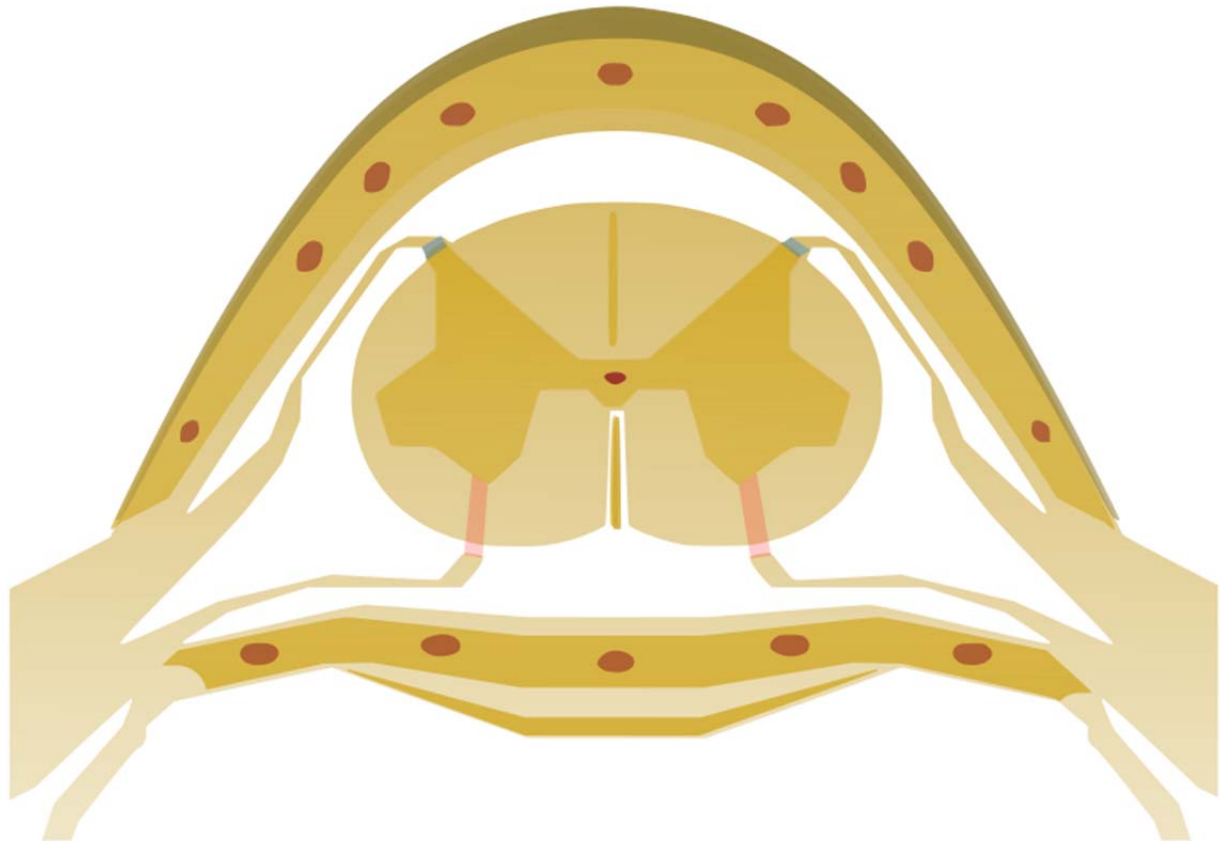
## Spinal Cord

The spinal cord is a long, thin, tubular bundle of nervous tissue and support cells that extends from the brain (the medulla oblongata specifically). The brain and spinal cord together make up the central nervous system. The spinal cord begins at the occipital bone and extends down to the space between the first and second lumbar vertebrae; it does not extend the entire length of the vertebral column. It is around 45 cm (18 in) in men and around 43 cm (17 in) long in women. Also, the spinal cord has a varying width, ranging from 1/2 inch thick in the cervical and lumbar regions to 1/4 inch thick in the thoracic area. The enclosing bony vertebral column protects the relatively shorter spinal cord. The spinal cord functions primarily in the transmission of neural signals between the brain and the rest of the body but also contains neural circuits that can independently control numerous reflexes and central pattern generators. The spinal cord has three major functions: A. Serve as a conduit for motor information, which travels down the spinal cord. B. Serve as a conduit for sensory information, which travels up the spinal cord. C. Serve as a center for coordinating certain reflexes.

## Structure



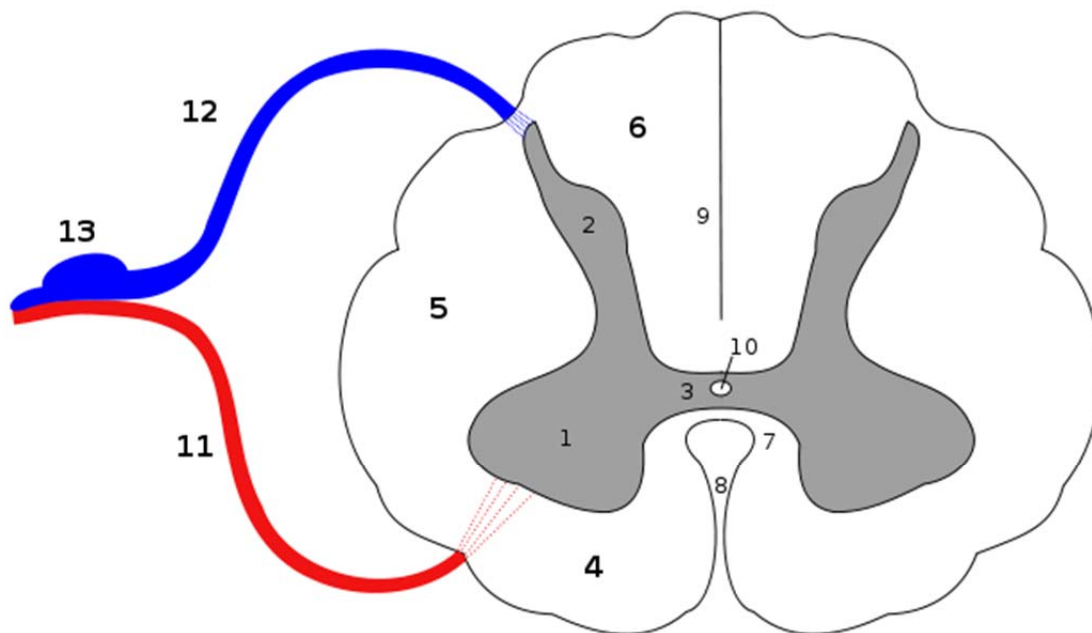
The spinal cord is the main pathway for information connecting the brain and peripheral nervous system. The length of the spinal cord is much shorter than the length of the bony spinal column. The human spinal cord extends from the foramen magnum and continues through to the conus medullaris near the second lumbar vertebra, terminating in a fibrous extension known as the filum terminale.



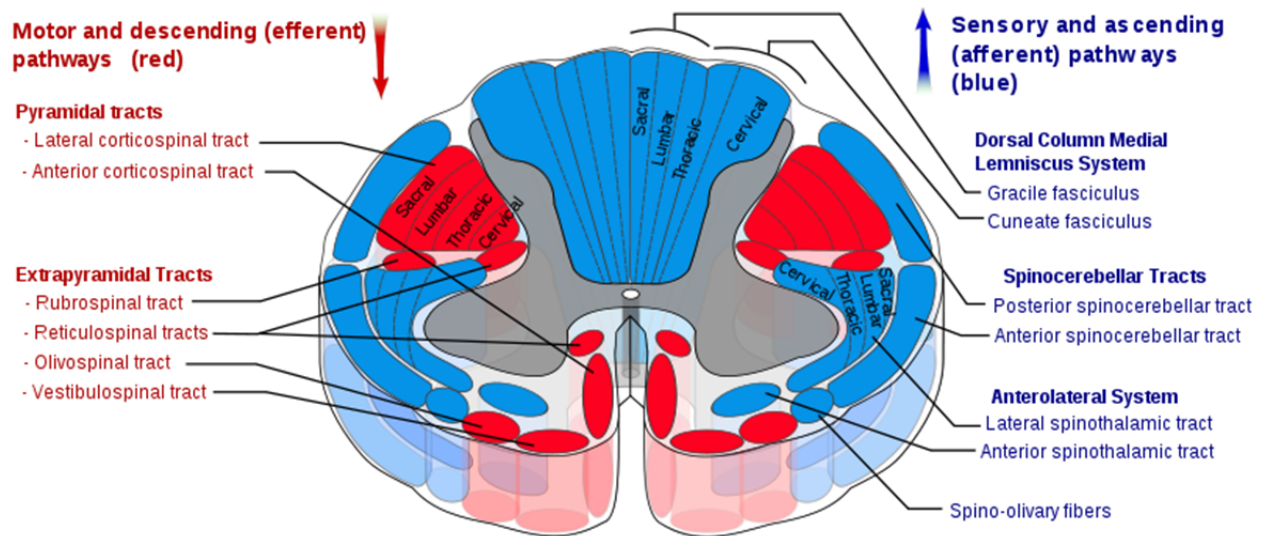
It is about 45 cm (18 in) long in men and around 43 cm (17 in) in women, ovoid-shaped, and is enlarged in the cervical and lumbar regions. The cervical enlargement, located from C3 to T2 spinal segments, is where sensory input comes from and motor output goes to the arms. The lumbar enlargement, located between L1 and S3 spinal segments, handles sensory input and motor output coming from and going to the legs.

The spinal cord is protected by three layers of tissue, called spinal meninges, that surround the canal. The dura mater is the outermost layer, and it forms a tough protective coating. Between the dura mater and the surrounding bone of the vertebrae is a space called the epidural space. The epidural space is filled with adipose tissue, and it contains a network of

blood vessels. The arachnoid mater is the middle protective layer. Its name comes from the fact that the tissue has a spiderweb-like appearance. The space between the arachnoid and the underlying pia mater is called the subarachnoid space. The subarachnoid space contains cerebrospinal fluid (CSF). The medical procedure known as a lumbar puncture (or spinal tap) involves use of a needle to withdraw cerebrospinal fluid from the subarachnoid space, usually from the lumbar region of the spine. The pia mater is the innermost protective layer. It is very delicate and it is tightly associated with the surface of the spinal cord. The cord is stabilized within the dura mater by the connecting denticulate ligaments, which extend from the enveloping pia mater laterally between the dorsal and ventral roots. The dural sac ends at the vertebral level of the second sacral vertebra.



Gray matter	White matter	
1. Anterior horn	4. Anterior funiculus	10. Central canal
2. Posterior horn	5. Lateral funiculus	11. Anterior root
3. Gray commissure	6. Posterior funiculus	12. Posterior root
	7. Anterior commissure	13. Dorsal root ganglion
	8. Anterior median fissure	
	9. Posterior median sulcus	

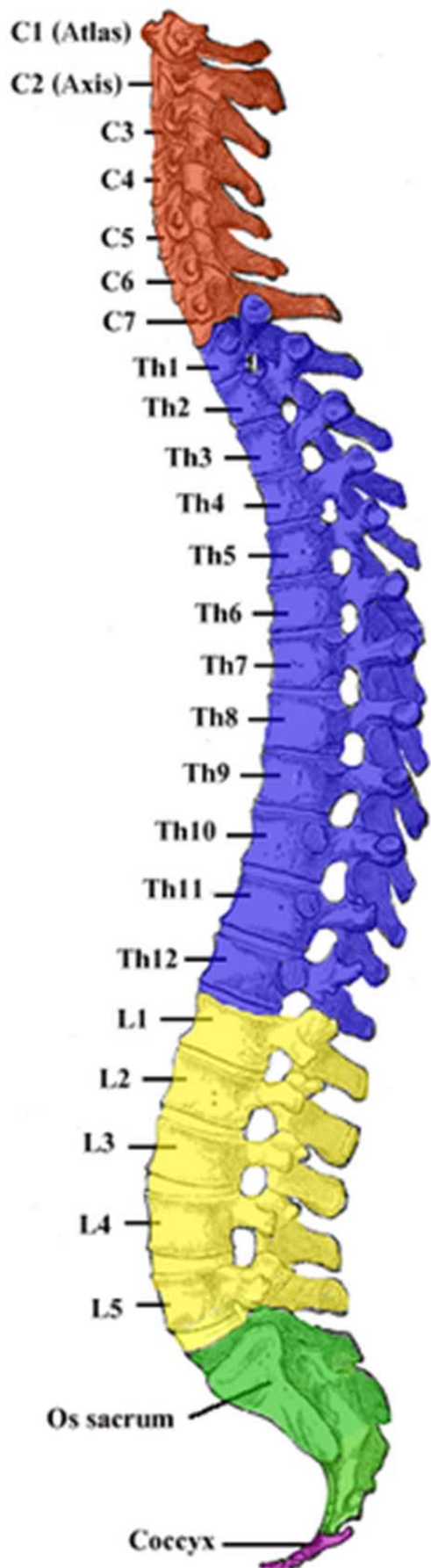


In cross-section, the peripheral region of the cord contains neuronal white matter tracts containing sensory and motor neurons. Internal to this peripheral region is the gray, butterfly-shaped central region made up of nerve cell bodies. This central region surrounds the central canal, which is an anatomic extension of the spaces in the brain known as the ventricles and, like the ventricles, contains cerebrospinal fluid.

The spinal cord has a shape that is compressed dorso-ventrally, giving it an elliptical shape. The cord has grooves in the dorsal and ventral sides. The posterior median sulcus is the groove in the dorsal side, and the anterior median fissure is the groove in the ventral side.

### [Spinal cord segments](#)

The human spinal cord is divided into 31 different segments. At every segment, right and left pairs of spinal nerves (mixed; sensory and motor) form. Six to eight motor nerve rootlets branch out of right and left ventro lateral sulci in a very orderly manner. Nerve rootlets combine to form nerve roots. Likewise, sensory nerve rootlets form off right and left dorsal lateral sulci and form sensory nerve roots. The ventral (motor) and dorsal (sensory) roots combine to form spinal nerves (mixed; motor and sensory), one on each side of the spinal cord. Spinal nerves, with the exception of C1 and C2, form inside intervertebral foramen (IVF). Note that at each spinal segment, the border between the central and peripheral nervous system can be observed. Rootlets are a part of the peripheral nervous system.



<b>Segmental Spinal Cord Level and Function</b>	
<b>Level</b>	<b>Function</b>
C1-C6	Neck flexors
C1-T1	Neck extensors
C3,C4,C5	Supply diaphragm (mostly C4)
C5,C6	Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); C6 externally rotates the arm (supinates)
C6,C7	Extends elbow and wrist (triceps and wrist extensors); pronates wrist
C7,T1	Flexes wrist
C7,T1	Supply small muscles of the hand
T1-T6	Intercostals and trunk above the waist
T7-L1	Abdominal muscles
L1,L2,L3,L4	Thigh flexion
L2,L3,L4	Thigh adduction
L4,L5, S1	Thigh abduction
L5,S1, S2	Extension of leg at the hip (gluteus maximus)
L2,L3,L4	Extension of leg at the knee (quadriceps femoris)
L4,L5,S1,S2	Flexion of leg at the knee (hamstrings)
L4,L5,S1	Dorsiflexion of foot (tibialis anterior)
L4,L5,S1	Extension of toes
L5,S1,S2	Plantar <u>flexion</u> of foot
L5,S1,S2	Flexion of toes

In the upper part of the vertebral column, spinal nerves exit directly from the spinal cord, whereas in the lower part of the vertebral column nerves pass further down the column before exiting. The terminal portion of the spinal cord is called the conus medullaris. The dura mater continues as an extension called the filum terminale, which anchors the spinal cord to the coccyx. The cauda equina (“horse’s tail”) is the name for the collection of nerves in the vertebral column that continue to travel through the

vertebral column below the conus medullaris. The cauda equina forms as a result of the fact that the spinal cord stops growing in length at about age four, even though the vertebral column continues to lengthen until adulthood. This results in the fact that sacral spinal nerves actually originate in the upper lumbar region. The spinal cord can be anatomically divided into 31 spinal segments based on the origins of the spinal nerves.

Each segment of the spinal cord is associated with a pair of ganglia, called dorsal root ganglia, which are situated just outside of the spinal cord. These ganglia contain cell bodies of sensory neurons. Axons of these sensory neurons travel into the spinal cord via the dorsal roots.

Ventral roots consist of axons from motor neurons, which bring information to the periphery from cell bodies within the CNS. Dorsal roots and ventral roots come together and exit the intervertebral foramina as they become spinal nerves.

The gray matter, in the center of the cord, is shaped like a butterfly and consists of cell bodies of interneurons and motor neurons. It also consists of neuroglia cells and unmyelinated axons. Projections of the gray matter (the "wings") are called horns. Together, the gray horns and the gray commissure form the "gray H."

The white matter is located outside of the gray matter and consists almost totally of myelinated motor and sensory axons. "Columns" of white matter carry information either up or down the spinal cord.

Within the CNS, nerve cell bodies are generally organized into functional clusters, called nuclei. Axons within the CNS are grouped into tracts.

There are 33 spinal cord nerve segments in a human spinal cord:

8 cervical segments forming 8 pairs of cervical nerves (C1 spinal nerves exit spinal column between occiput and C1 vertebra; C2 nerves exit between posterior arch of C1 vertebra and lamina of C2 vertebra; C3-C8 spinal nerves through IVF above corresponding cervical vertebra, with the exception of C8 pair which exit via IVF between C7 and T1 vertebra)

12 thoracic segments forming 12 pairs of thoracic nerves (exit spinal column through IVF below corresponding vertebra T1-T12)

5 lumbar segments forming 5 pairs of lumbar nerves (exit spinal column through IVF, below corresponding vertebra L1-L5)

5 sacral segments forming 5 pairs of sacral nerves (exit spinal column through IVF, below corresponding vertebra S1-S5)

3 coccygeal segments joined up becoming a single segment forming 1 pair of coccygeal nerves (exit spinal column through the sacral hiatus).

Because the vertebral column grows longer than the spinal cord, spinal cord segments do not correspond to vertebral segments in adults, especially in the lower spinal cord. In the fetus, vertebral segments do correspond with spinal cord segments. In the adult, however, the spinal cord ends around the L1/L2 vertebral level, forming a structure known as the conus medullaris. For example, lumbar and sacral spinal cord segments are found between vertebral levels T9 and L2.

Although the spinal cord cell bodies end around the L1/L2 vertebral level, the spinal nerves for each segment exit at the level of the corresponding vertebra. For the nerves of the lower spinal cord, this means that they exit the vertebral column much lower (more caudally) than their roots. As these nerves travel from their respective roots to their point of exit from the vertebral column, the nerves of the lower spinal segments form a bundle called the cauda equina.

### Spinal cord

There are two regions where the spinal cord enlarges:

Cervical enlargement - corresponds roughly to the brachial plexus nerves, which innervate the upper limb. It includes spinal cord segments from about C4 to T1. The vertebral levels of the enlargement are roughly the same (C4 to T1).

Lumbosacral enlargement - corresponds to the lumbosacral plexus nerves, which innervate the lower limb. It comprises the spinal cord segments from L2 to S3 and is found about the vertebral levels of T9 to T12.

### Embryology

The spinal cord is made from part of the neural tube during development. As the neural tube begins to develop, the notochord begins to secrete a factor known as Sonic hedgehog or SHH. As a result, the floor plate then also begins to secrete SHH, and this will induce the basal plate to develop motor neurons. Meanwhile, the overlying ectoderm secretes bone

morphogenetic protein (BMP). This induces the roof plate to begin to secrete BMP, which will induce the alar plate to develop sensory neurons. The alar plate and the basal plate are separated by the sulcus limitans.

Additionally, the floor plate also secretes netrins. The netrins act as chemoattractants to decussation of pain and temperature sensory neurons in the alar plate across the anterior white commissure, where they then ascend towards the thalamus.

Lastly, it is important to note that the past studies of Viktor Hamburger and Rita Levi-Montalcini in the chick embryo have been further proven by more recent studies which demonstrated that the elimination of neuronal cells by programmed cell death (PCD) is necessary for the correct assembly of the nervous system.

Overall, spontaneous embryonic activity has been shown to play a role in neuron and muscle development but is probably not involved in the initial formation of connections between spinal neurons.

### Blood supply

The spinal cord is supplied with blood by three arteries that run along its length starting in the brain, and many arteries that approach it through the sides of the spinal column. The three longitudinal arteries are called the anterior spinal artery, and the right and left posterior spinal arteries. These travel in the subarachnoid space and send branches into the spinal cord. They form anastomoses (connections) via the anterior and posterior segmental medullary arteries, which enter the spinal cord at various points along its length. The actual blood flow caudally through these arteries, derived from the posterior cerebral circulation, is inadequate to maintain the spinal cord beyond the cervical segments.

The major contribution to the arterial blood supply of the spinal cord below the cervical region comes from the radially arranged posterior and anterior radicular arteries, which run into the spinal cord alongside the dorsal and ventral nerve roots, but with one exception do not connect directly with any of the three longitudinal arteries. These intercostal and lumbar radicular arteries arise from the aorta, provide major anastomoses and supplement the blood flow to the spinal cord. In humans the largest of the anterior radicular arteries is known as the artery of Adamkiewicz, or anterior radicularis magna (ARM) artery, which usually arises between L1 and L2, but can arise anywhere from T9 to L5. Impaired blood flow through

these critical radicular arteries, especially during surgical procedures that involve abrupt disruption of blood flow through the aorta for example during aortic aneurysm repair, can result in spinal cord infarction and paraplegia.

### Somatosensory organization

Somatosensory organization is divided into the dorsal column-medial lemniscus tract (the touch/proprioception/vibration sensory pathway) and the anterolateral system, or ALS (the pain/temperature sensory pathway). Both sensory pathways use three different neurons to get information from sensory receptors at the periphery to the cerebral cortex. These neurons are designated primary, secondary and tertiary sensory neurons. In both pathways, primary sensory neuron cell bodies are found in the dorsal root ganglia, and their central axons project into the spinal cord.

In the dorsal column-medial lemniscus tract, a primary neuron's axon enters the spinal cord and then enters the dorsal column. If the primary axon enters below spinal level T6, the axon travels in the fasciculus gracilis, the medial part of the column. If the axon enters above level T6, then it travels in the fasciculus cuneatus, which is lateral to the fasciculus gracilis. Either way, the primary axon ascends to the lower medulla, where it leaves its fasciculus and synapses with a secondary neuron in one of the dorsal column nuclei: either the nucleus gracilis or the nucleus cuneatus, depending on the pathway it took. At this point, the secondary axon leaves its nucleus and passes anteriorly and medially. The collection of secondary axons that do this are known as internal arcuate fibers. The internal arcuate fibers decussate and continue ascending as the contralateral medial lemniscus. Secondary axons from the medial lemniscus finally terminate in the ventral posterolateral nucleus (VPL) of the thalamus, where they synapse with tertiary neurons. From there, tertiary neurons ascend via the posterior limb of the internal capsule and end in the primary sensory cortex.

The anterolateral system works somewhat differently. Its primary neurons enter the spinal cord and then ascend one to two levels before synapsing in the substantia gelatinosa. The tract that ascends before synapsing is known as Lissauer's tract. After synapsing, secondary axons decussate and ascend in the anterior lateral portion of the spinal cord as the spinothalamic tract. This tract ascends all the way to the VPL, where it synapses on tertiary neurons. Tertiary neuronal axons then travel to the primary sensory cortex via the posterior limb of the internal capsule.

It should be noted that some of the "pain fibers" in the ALS deviate from their pathway towards the VPL. In one such deviation, axons travel towards the reticular formation in the midbrain. The reticular formation then projects to a number of places including the hippocampus (to create memories about the pain), the centromedian nucleus (to cause diffuse, non-specific pain) and various parts of the cortex. Additionally, some ALS axons project to the periaqueductal gray in the pons, and the axons forming the periaqueductal gray then project to the nucleus raphe magnus, which projects back down to where the pain signal is coming from and inhibits it. This helps control the sensation of pain to some degree.

### Motor organization

The corticospinal tract serves as the motor pathway for upper motor neuronal signals coming from the cerebral cortex and from primitive brainstem motor nuclei.

Cortical upper motor neurons originate from Brodmann areas 1, 2, 3, 4, and 6 and then descend in the posterior limb of the internal capsule, through the crus cerebri, down through the pons, and to the medullary pyramids, where about 90% of the axons cross to the contralateral side at the decussation of the pyramids. They then descend as the lateral corticospinal tract. These axons synapse with lower motor neurons in the ventral horns of all levels of the spinal cord. The remaining 10% of axons descend on the ipsilateral side as the ventral corticospinal tract. These axons also synapse with lower motor neurons in the ventral horns. Most of them will cross to the contralateral side of the cord (via the anterior white commissure) right before synapsing.

The midbrain nuclei include four motor tracts that send upper motor neuronal axons down the spinal cord to lower motor neurons. These are the rubrospinal tract, the vestibulospinal tract, the tectospinal tract and the reticulospinal tract. The rubrospinal tract descends with the lateral corticospinal tract, and the remaining three descend with the anterior corticospinal tract.

The function of lower motor neurons can be divided into two different groups: the lateral corticospinal tract and the anterior cortical spinal tract. The lateral tract contains upper motor neuronal axons which synapse on dorsal lateral (DL) lower motor neurons. The DL neurons are involved in distal limb control. Therefore, these DL neurons are found specifically only in the cervical and lumbosacral enlargements within the spinal cord.

There is no decussation in the lateral corticospinal tract after the decussation at the medullary pyramids.

The proprioception of the lower limbs differs from the upper limbs & upper trunk. There is a 4 neuron pathway for lower limbs proprioception. This pathway initially follows the dorsal spino-cerebellar pathway. It is arranged as follows: proprioceptive receptors of lower limb -> peripheral process -> dorsal root ganglion -> central process -> clarks column -> 2nd order neuron -> medulla oblongata (nucleus z of broadal) -> 3rd order neuron -> VPL of thalamus -> 4th order neuron -> posterior limb of internal capsule -> corona radiata -> sensory area of cerebrum.

The anterior corticospinal tract descends ipsilaterally in the anterior column, where the axons emerge and either synapse on lower ventromedial (VM) motor neurons in the ventral horn ipsilaterally or decussate at the anterior white commissure where they synapse on VM lower motor neurons contralaterally. The tectospinal, vestibulospinal and reticulospinal descend ipsilaterally in the anterior column but do not synapse across the anterior white commissure. Rather, they only synapse on VM lower motor neurons ipsilaterally. The VM lower motor neurons control the large, postural muscles of the axial skeleton. These lower motor neurons, unlike those of the DL, are located in the ventral horn all the way throughout the spinal cord.

### [Spinocerebellar tracts](#)

Proprioceptive information in the body travels up the spinal cord via three tracts. Below L2, the proprioceptive information travels up the spinal cord in the ventral spinocerebellar tract. Also known as the anterior spinocerebellar tract, sensory receptors take in the information and travel into the spinal cord. The cell bodies of these primary neurons are located in the dorsal root ganglia. In the spinal cord, the axons synapse and the secondary neuronal axons decussates and then travel up to the superior cerebellar peduncle where they decussate again. From here, the information is brought to deep nuclei of the cerebellum including the fastigial and interposed nuclei.

From the levels of L2 to T1, proprioceptive information enters the spinal cord and ascends ipsilaterally, where it synapses in Clarke's nucleus. The secondary neuronal axons continue to ascend ipsilaterally and then pass into the cerebellum via the inferior cerebellar peduncle. This tract is known as the dorsal spinocerebellar tract.

From above T1, proprioceptive primary axons enter the spinal cord and ascend ipsilaterally until reaching the accessory cuneate nucleus, where they synapse. The secondary axons pass into the cerebellum via the inferior cerebellar peduncle where again, these axons synapse on cerebellar deep nuclei. This tract is known as the cuneocerebellar tract.

Motor information travels from the brain down the spinal cord via descending spinal cord tracts. Descending tracts involve two neurons: the upper motor neuron (UMN) and lower motor neuron (LMN).[4] A nerve signal travels down the upper motor neuron until it synapses with the lower motor neuron in the spinal cord. Then, the lower motor neuron conducts the nerve signal to the spinal root where efferent nerve fibers carry the motor signal toward the target muscle. The descending tracts are composed of white matter. There are several descending tracts serving different functions. The corticospinal tracts (lateral and anterior) are responsible for coordinated limb movements.

## Injury

Spinal cord injuries can be caused by trauma to the spinal column (stretching, bruising, applying pressure, severing, laceration, etc.). The vertebral bones or intervertebral disks can shatter, causing the spinal cord to be punctured by a sharp fragment of bone. Usually, victims of spinal cord injuries will suffer loss of feeling in certain parts of their body. In milder cases, a victim might only suffer loss of hand or foot function. More severe injuries may result in paraplegia, tetraplegia (also known as quadriplegia), or full body paralysis below the site of injury to the spinal cord.

Damage to upper motor neuron axons in the spinal cord results in a characteristic pattern of ipsilateral deficits. These include hyperreflexia, hypertonia and muscle weakness. Lower motor neuronal damage results in its own characteristic pattern of deficits. Rather than an entire side of deficits, there is a pattern relating to the myotome affected by the damage. Additionally, lower motor neurons are characterized by muscle weakness, hypotonia, hyporeflexia and muscle atrophy.

Spinal shock and neurogenic shock can occur from a spinal injury. Spinal shock is usually temporary, lasting only for 24–48 hours, and is a temporary absence of sensory and motor functions. Neurogenic shock lasts for weeks and can lead to a loss of muscle tone due to disuse of the muscles below the injured site.

The two areas of the spinal cord most commonly injured are the cervical spine (C1-C7) and the lumbar spine (L1-L5). (The notation C1, C7, L1, L5 refer to the location of a specific vertebra in either the cervical, thoracic, or lumbar region of the spine.)

### [Spinal cord genomic map](#)

The Allen Institute for Brain Science, on July 16, 2008, launched the online "Allen Spinal Cord Atlas" (backed by Paul Allen). Its first release included 4000 sets of digital images, showing spatial expression patterns for various genes. When complete, it is planned to map 20,000 genes in adult and juvenile mouse spinal cords. The spinal cord atlas is organized like the Allen Institute's earlier atlas of the mouse brain.

## [Spinal Cord Anatomy](#)

### [Spinal Cord Overview](#)

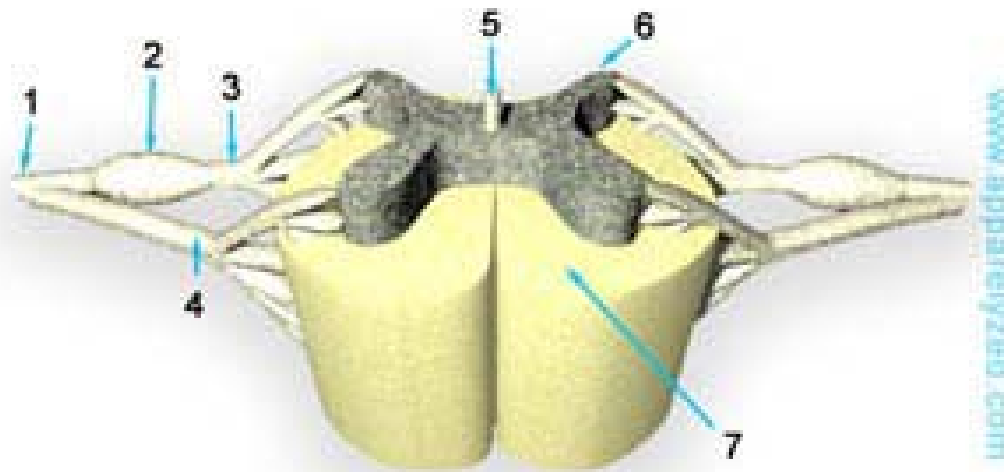


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- |                         |                 |
|-------------------------|-----------------|
| 1 Spinal Nerve          | 5 Central Canal |
| 2 Dorsal Root Ganglion  | 6 Grey Matter   |
| 3 Dorsal Root (Sensory) | 7 White Matter  |
| 4 Ventral Root          |                 |

**(Motor)**

The Spinal Cord is connected to the brain and is about the diameter of a human finger. From the brain the spinal cord descends down the middle of the back and is surrounded and protected by the bony vertebral column. The spinal cord is surrounded by a clear fluid called Cerebral Spinal Fluid (CSF), that acts as a cushion to protect the delicate nerve tissues against damage from banging against the inside of the vertebrae.

The anatomy of the spinal cord itself, consists of millions of nerve fibres which transmit electrical information to and from the limbs, trunk and organs of the body, back to and from the brain. The nerves which exit the spinal cord in the upper section, the neck, control breathing and the arms. The nerves which exit the spinal cord in the mid and lower section of the back, control the trunk and legs, as well as bladder, bowel and sexual function.

The nerves which carry information from the brain to muscles are called Motor Neurones. The nerves which carry information from the body back to the brain are called Sensory Neurones. Sensory Neurones carry information to the brain about skin temperature, touch, pain and joint position.

The brain and spinal cord are referred to as the Central Nervous System, whilst the nerves connecting the spinal cord to the body are referred to as the Peripheral Nervous System.

### **Ascending and Descending Spinal Tracts**

The nerves within the spinal cord are grouped together in different bundles called Ascending and Descending tracts.

Ascending tracts within the spinal cord carry sensory information from the body, upwards to the brain, such as touch, skin temperature, pain and joint position.

Descending tracts within the spinal cord carry information from the brain downwards to initiate movement and control body functions.

## Spinal Nerves

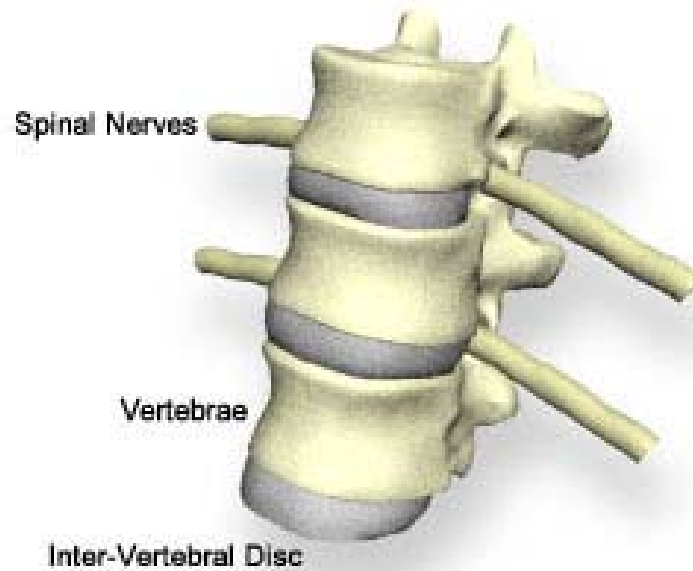


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Nerves called the spinal nerves or nerve roots, branch off the spinal cord and pass out through a hole in each of the vertebrae called the Foramen. These nerves carry information from the spinal cord to the rest of the body, and from the body back up to the brain.

There are four main groups of spinal nerves, which exit different levels of the spinal cord.

These are in descending order down the vertebral column:

**Cervical Nerves "C"** : (nerves in the neck) supply movement and feeling to the arms, neck and upper trunk. Also control breathing.

**Thoracic Nerves "T"** : (nerves in the upper back) supply the trunk and abdomen.

**Lumbar Nerves "L" and Sacral Nerves "S"** : (nerves in the lower back) supply the legs, the bladder, bowel and sexual organs.

## Spinal Cord Level Numbering System

The spinal nerves carry information to and from different levels (segments) in the spinal cord. Both the nerves and the segments in the

spinal cord are numbered in a similar way to the vertebrae. The point at which the spinal cord ends is called the conus medullaris, and is the terminal end of the spinal cord. It occurs near lumbar nerves L1 and L2. After the spinal cord terminates, the spinal nerves continue as a bundle of nerves called the cauda equina. The upper end of the conus medullaris is usually not well defined.

There are 31 pairs of spinal nerves which branch off from the spinal cord. In the cervical region of the spinal cord, the spinal nerves exit above the vertebrae. A change occurs with the C7 vertebra however, where the C8 spinal nerve exits the vertebra below the C7 vertebra. Therefore, there is an 8th cervical spinal nerve even though there is no 8th cervical vertebra. From the 1st thoracic vertebra downwards, all spinal nerves exit below their equivalent numbered vertebrae.

The spinal nerves which leave the spinal cord are numbered according to the vertebra at which they exit the spinal column. So, the spinal nerve T4, exits the spinal column through the foramen in the 4th thoracic vertebra. The spinal nerve L5 leaves the spinal cord from the conus medullaris, and travels along the cauda equina until it exits the 5th lumbar vertebra.

The level of the spinal cord segments do not relate exactly to the level of the vertebral bodies i.e. damage to the bone at a particular level e.g. L5 vertebrae does not necessarily mean damage to the spinal cord at the same spinal nerve level.

## Spinal Cord Nerve Levels

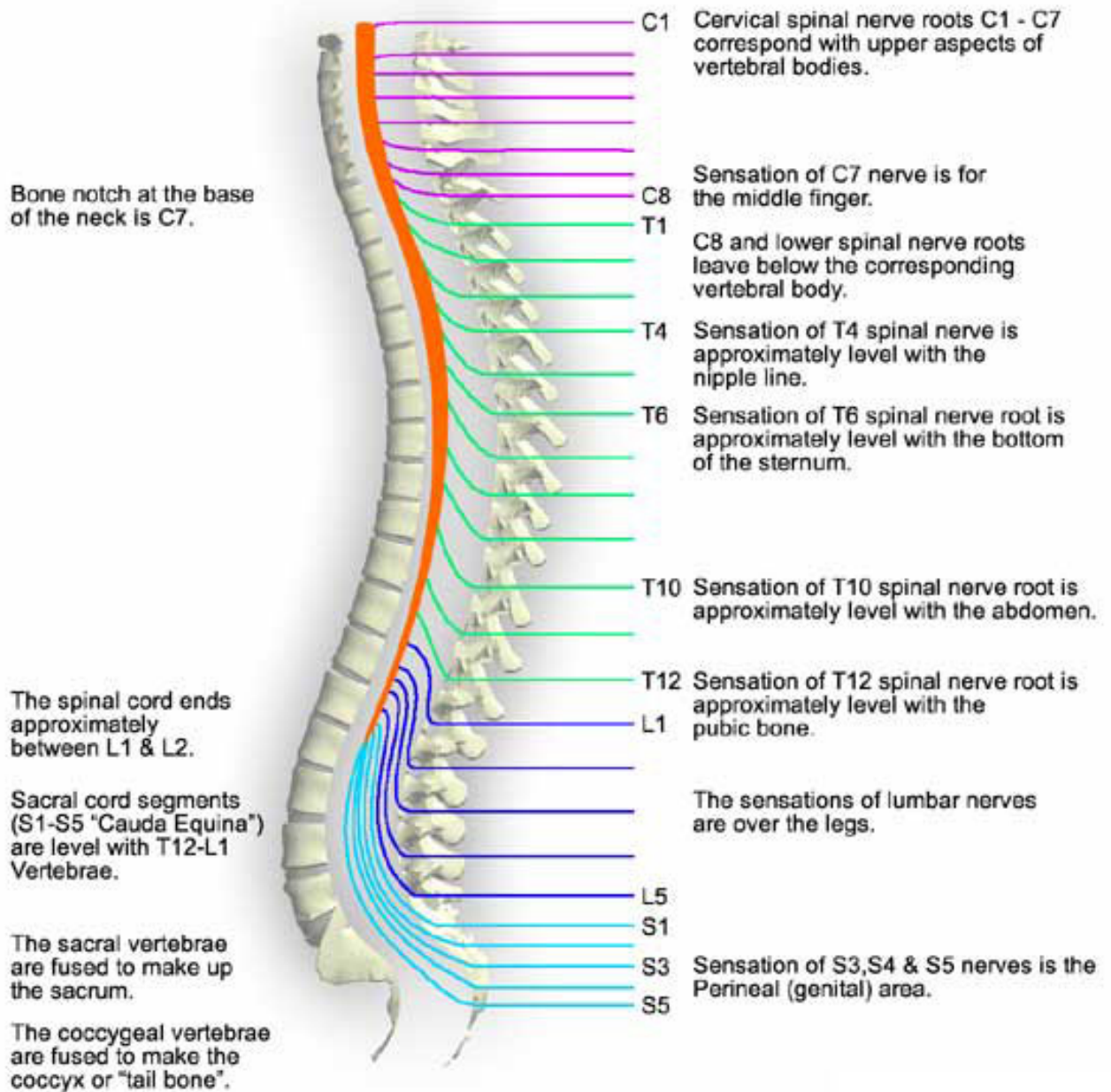


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Diagram Showing The Relationship Between Spinal Nerve Roots and Vertebrae