Medical Education

Anatomy and Structure of the Spinal Cord and Spinal Cord Injuries

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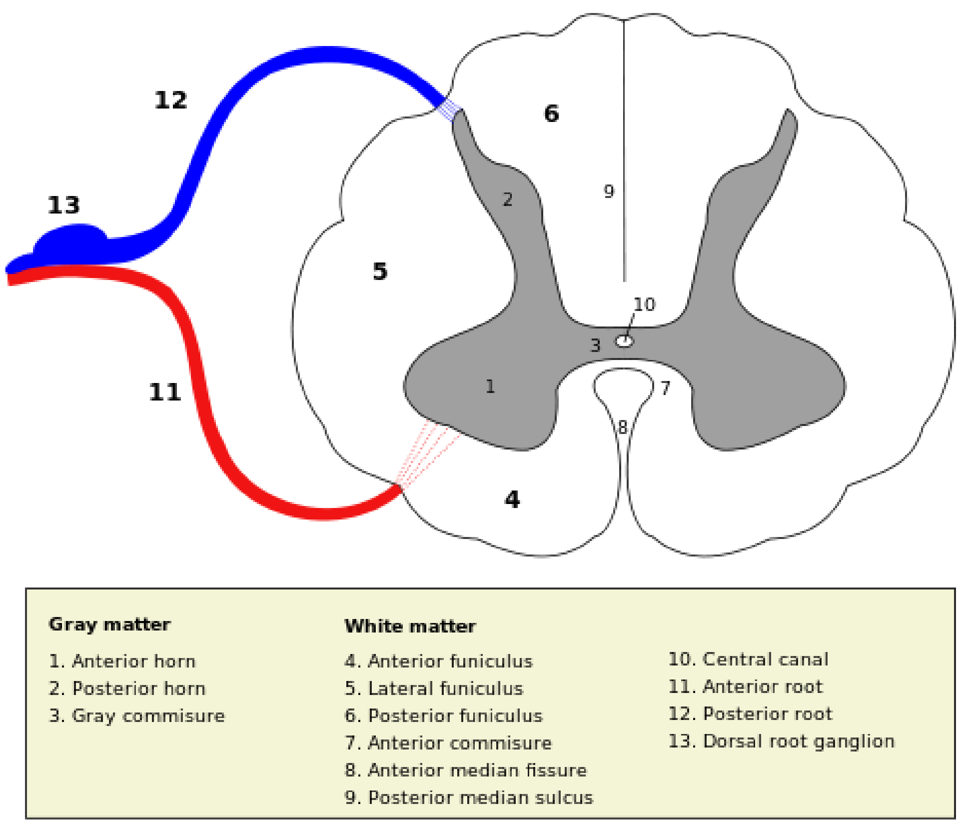
The spinal cord (medulla spinalis) is part of the central nervous system and connects the body to the brain. On the posterior side of the spinal cord, sensory information from the skin, skeletal musculature, joints, and intestines flows in from the afferent nerves via the dorsal root of the spinal nerves. On the frontal side, in turn, spinal nerve roots exit as efferences and deliver information to the peripheral nervous system—the skeletal musculature, intestines, etc. This article provides an overview of the structure and function of this fascinating organ, and of certain spinal cord injuries.



Location and Structure

As part of the central nervous system, the spinal cord (**medulla spinalis**) is held in place by ligaments and is well protected in the spinal canal of the vertebral column. It begins at the foramen magnum, at the base of the skull (**medulla oblongata**).

Along the spine are 2 spindle-shaped enlargements (**cervical and lumbar enlargements**) that deal with motor input and output innervation to and from the limbs. The lower end of the spinal cord is conical-shaped and tapered and is thus known as the **conus medullaris or medullary cone**. Surrounding the spinal cord and projecting downward is a slim connecting filament where the spinal cord ends (**filum terminale**).

Connective tissue surrounds and protects the entire spinal cord, creating epidural space that is filled with fatty adipose tissue, a network of venous plexuses, and blood vessels. In this way, the outermost layer protects the sensitive spinal cord from damage.

As well, the spinal cord has 2 thin grooves that run along its entire length. The 1st groove, **anterior median fissure,** runs along the front ventral side, and the 2nd groove, **posterior median sulcus,** runs on the back dorsal side. Both symmetrically “split” the spinal cord into a left and a right half.

The spinal cord is divided lengthwise into 31–33 segments. In each segment of both sides of the spinal cord, dorsal sensory nerve roots enter and ventrolateral roots exit, combining to form spinal nerves on the right and the left sides. These spinal nerves emerge from openings in the intervertebral foramen between 2 spinal vertebrae.

Given that, in newborn babies, the spinal canal and the spinal cord still have the same length, the spinal nerves exit the vertebral column at the same level as their intervertebral foramina. As the human body develops, the vertebral column grows faster than the spinal cord, which means that the spinal nerves must travel much longer to exit the vertebral column. This leads to the development of the so-called horse’s tail (**cauda equina**), which is a dense collection of downward-extending spinal nerves.

In adults, above the level of the first lumbar segment, spinal nerves only run in a downward, or caudal, fashion. The length of the cord is estimated to be about 45 cm in males and 43 cm in females.

Spinal cord segments

The spinal cord itself is not visibly segmented; the division into segments is only for topographical and functional classification. Every segment is a cross-section of the spinal cord with its corresponding pair of incoming sensory and outgoing motor spinal nerves.

Segments are referred to in relation to the vertebrae: 8 cervical segments forming the cervical nerves (since the first cervical spinal nerve exits above the first cervical vertebra), 12 thoracic segments making up the thoracic nerves, 5 lumbar segments collectively referred to as the lumbar nerves, 5 sacral segments forming the sacral nerves, and 1 to 3 coccygeal segments.

Spinal nerves

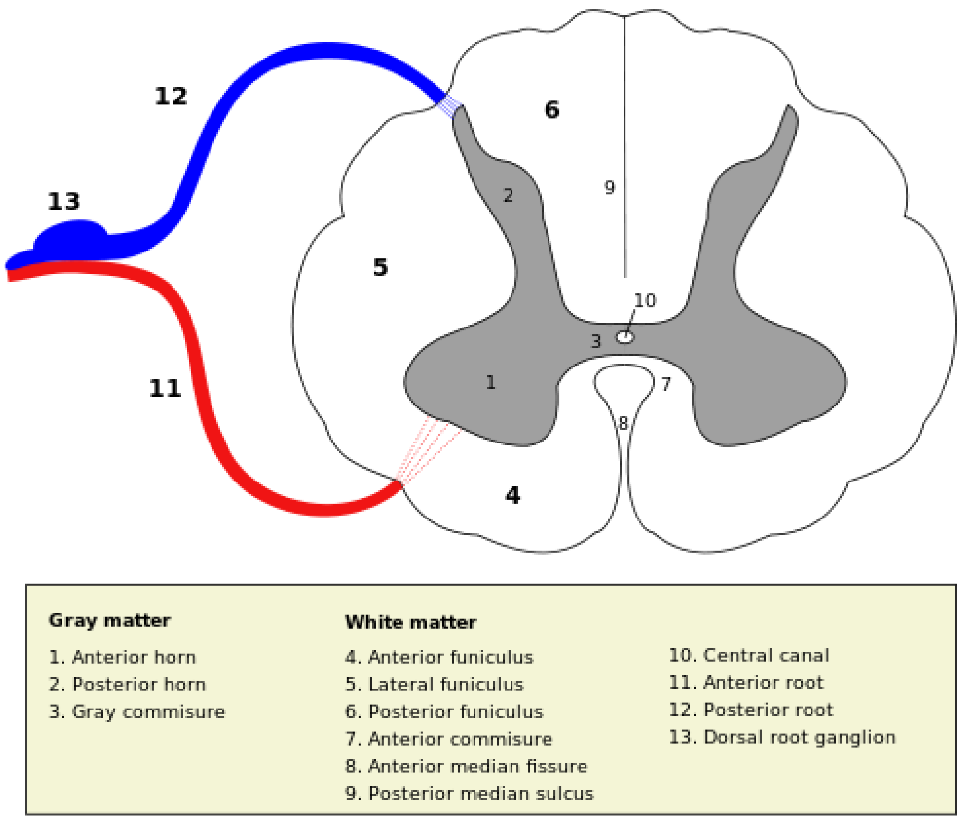
The border between the central and peripheral nervous systems is found at the transition between each spinal segment in the frontal and rear side roots. From there, the spinal roots become part of the peripheral nervous system. Thirty-one spinal nerves emerge from the spinal column through the intervertebral foramen opening between adjacent vertebrae. Each spinal nerve pair corresponds to a spinal cord segment (see table below).

Number of cervicales	8 pairs	C1– C8	The 1st spinal nerve pair emerges between the occipital bone and the atlas.

Number of thoracales	12 pairs	T1–T12	The 1st thoracic nerve pair emerges between T1 and T2.
Number of lumbales	5 pairs	L1–L5	The 1st lumbar pair emerges between L1 and L2.
Number of sacrales	5 pairs	S1–S5	The 1st sacral nerve pair emerges between S1 and S2.
Number of coccygei	1–3 pairs, partly rudimentary		The 1st nerve pair emerges between the 1st and 2nd coccygeal vertebrae.

Spinal cord cross-section

A cross-section of the spinal cord reveals gray, butterfly-shaped matter surrounded by neuronal white matter. The spinal cord has a different appearance depending on the height of the cross-section. It is largest around the cervical and lumbar regions, since a high number of neuron conduits dealing with motor information to the limbs are located there.



Spinal cord gray matter (substantia grisea)

Spinal cord gray matter consists of neuronal cell bodies (**somata**) and glial cells resembling a butterfly when seen from a cross-section. This butterfly shape has a symmetric construction where both halves of the gray matter are connected by the **gray commissure**, the central region of which surrounds the **central canal** and contains cerebrospinal fluid.

Both halves of the spinal cord possess a so-called dorsal horn, a ventral horn, and, between segments C8 and L1, an additional lateral horn. In its 3-dimensional longitudinal perspective, 3 columns develop: the **dorsal column, ventral column, and lateral column.**

During the embryonic stage, the dorsal horn develops from the **alar plate**. It contains the sensory neurons of the afference system. The ventral horn derives from the basal plate and contains motor nerve cells (**motor neurones**), the nerve fibers of which affect the axial muscles. Postganglionic neurons of the sympathetic are located in the lateral horn.

Image: “Layers and nuclei in the gray matter of the spinal cord” by Polarlys. License: CC BY 2.5

The structure of gray matter

Two different systems are used to describe the function of cells within the gray matter.

First system: Rexed laminae

Gray matter is sorted into 10 different layers according to the size and thickness of the nerve cells:

- **Dorsal horn: laminae I–V/VI**
- Ventral horn: lamina VII and VIII, which contains lamina IX (built from the nuclei of motoneurons).
- Gray commissure: lamina X

Second system: separating gray matter into layers and nuclei (the sorting of nerve cells according to their functional association) using their Latin notations.

Some laminae possess particular nuclei:

- Lamina I: zona marginalis
- Lamina II: substantia gelatinosa Rolandi
- Lamina III, IV: nucleus proprius
- Lamina VII: substantia intermedia lateralis (aona intermedia)

The motor neurons in the ventral horn are ordered according to the groups of nuclei outlined in the table below.

Medial nucleus groups of the ventral horn	Lateral nucleus groups of the dorsal horn	Central nucleus groups of the ventral horn cervical cord
Dorsomedialis	Dorsolateralis	Phrenicus
Ventromedialis	Ventrolateralis	Accessorius
	Retrodorsolateralis	

In this way, the ventral horn is described as having a **somatosensory organization.**

The cervical medulla, for example, has the following somatosensory organization:

Nucleus groups	Medial nucleus groups of the ventral horn	Lateral nucleus groups of the ventral horn		
		Ventrolateralis	**Dorsolateralis**	**Retrodorsolateralis**
Function	Neck and back musculature	Shoulder	Lower arm	Little finger
	Intercostal muscles	Upper arm	Hand	
	Abdominal musculature			

Somatosensory organization does not correlate with the level of the spinal cord; rather, cells for the shoulder girdle are found on the furthest cranial and descend caudally from the upper arm to the lower arm and hand.

Cells for the extensor musculature are arranged in the ventral area of the ventral horn, while the cells for flexor muscles are located in the dorsal area.

The spinal cord proprioceptive apparatus (propriospinal system)

The spinal cord propriospinal system is an internal system for the transmission of information. It is made up of a collection of ascending and descending nerve cells that originate in the spinal cord itself. These nerve fibers either extend the length of several spinal segments, run inside a single segment connecting different levels of the spinal cord, or cross over each other. The propriospinal system lays the foundations for the monosynaptic and polysynaptic reflexes.

Propriospinal system cell types

- **Association cells:** connect flat-lying nerve cells on different spinal segments via the **ipsilateral proper fasciculi**
- **Commissural cells:** connect contralateral lying cells of the same segment through the **anterior white commissure**
- **Relay cells (interneurons):** connect ipsilateral lying cells of the same segment (e.g., **Renshaw cells**, which are inhibitory interneurons)

Renshaw cell inhibition is a backward recurrent inhibition created by a negative feedback mechanism. Renshaw cells are activated by alpha motor neurons when they receive excitatory collateral from the alpha neuron’s axon, resulting in the inhibition of their own actions. This mechanism prevents unwanted muscular oscillatory movements from occurring.

A trip to the clinic: Tetanus infection

Infection with the bacterium ***Clostridium tetani*** causes a build-up of toxins in the spinal cord that damages the inhibitory neurons of the muscle nerve cells, resulting in hyperactive incoming alpha motor neurons. This leads to severe tonic-clonic muscle contractions.

Spinal cord white matter (substantia alba)

Spinal cord white matter is composed of ascending and descending nerve fibers; these strands (**funiculi**), bundles (**fasciculi**), and tracts (**tractus**) connect areas of gray matter together with **glial cells** and, as a whole, form the supporting tissue of the nervous system. White matter can be divided into the following strands:

- **Posterior funiculus** (found between the posterolateral and posterior median sulcus, above all ascending fibers)
- **Lateral funiculus**(found between the exit of the anterior nerve roots and the posterolateral sulcus)

- **Anterior funiculus** (found between the anterior median fissure and the lateral anterior nerve roots)

The last 2 strands also make up part of the ventral funiculus.

White matter ascending tracts

Ventral funiculus tracts	Dorsal funiculus tracts	Spinocerebellar projection tracts
Lateral spinothalamic tract	Fasciculus gracilis	Posterior spinocerebellar tract
Anterior spinothalamic tract	Fasciculus cuneatus	Anterior spinocerebellar tract
Spinotectal tract		

White matter descending tracts

Pyramidal tract = tractus corticospinalis	Extrapyramidal tracks	Vegetative tracts
Lateral corticospinal tract	Vestibulospinal tract	Parependymal tract on both sides of the central canal
Anterior corticospinal tract	Medial and lateral reticulospinal tract from the arch	The vegetative tracts rarely build closed bundles.
	Lateral reticulospinal tract out of the medulla oblongata	
	Tegmentospinal tract	

Fasciculi proprii latch directly onto the gray matter of the spinal cord proprioceptive apparatus.

The Reflex Arc

A reflex is an involuntary response to a stimulus. Afferent nerve fibers transmit their excitation directly to the motor neuron cells of the anterior horn which, through their efferent nerves, control the musculature. This reaction takes place on the level of the spinal cord and is known as a simple reflex. The underlying neural circuit is referred to as the reflex arc.

In this way, a reflex can occur quickly without the delay of routing signals through the brain, since afferent sensory neurons synapse directly in the spinal cord instead. As such, the afferent signals reach the spinal cord either by passing directly to a single motor neuron, creating a single chemical response (**monosynaptic reflex),** or via the connection of 1 or more interneurons that connect sensory-afferent signals with motor-efferent signals (**polysynaptic reflex**).

Monosynaptic reflex

Monosynaptic reflexes have only 1 synapse between the receptor and effector, i.e., between outgoing motor response and incoming sensory.

The patellar reflex is an example of a monosynaptic reflex. A blow to the patellar ligament causes the quadriceps muscle to extend. Receptors produce a signal that travels back to the spinal cord and stretches the muscle spindle in the quadriceps femoris muscle. The sensory afferents send the signals to the dorsal horn, which synapse only once in the anterior horn at segments L2–L4; the efferent fibers then send an impulse to the lumbar plexus, which is isolated in the femoral nerve, and then send it back to the muscle to cause its contraction.

The purpose of testing this reflex lies in testing not its strength, but rather what its consistency is over time.

Polysynaptic reflex

Polysynaptic reflexes have multiple synapses between receptor and effector. Electrical impulses are transferred from a sensory neuron to a motor neuron via at least 1 interneuron.

Polysynaptic withdrawal reflex

For example, the withdrawal reflex is a protective reflex. **Nociceptors** trigger a sensory impulse in the nerves, causing an excitation that travels to various levels of the spinal cord. The sensory neuron then synapses with interneurons that connect to motor neurons. Some of these send motor impulses to the flexors to allow withdrawal.

Examples include:

- **Cremasteric reflex**
- Abdominal reflex
- Blink reflex

Spinal Cord Blood Supply

Supply of blood via arteries

The 3 main arteries that supply the spinal cord come from the **vertebral arteries:**

- **Anterior spinal artery:** The vessel is found in the anterior median fissure, has a caudal flow, and ends at the sulcus of the sulco-commissural artery.
- **Posterior spinal arteries:** These 2 supply arteries run adjacent to the entrance of the dorsal root and branch out within the spinal cord.

Additionally, the posterior **intercostal** arteries in the thorax region and the lumbar arteries in the lumbar region (both outlets of the aorta) release branches to supply the thoracic spine and the lumbar spine. The large branhces in the intumescentia lumbalis area is called the artery of **Adamkiewicz.**

The spinal cord is surrounded by a vasocorona (vascular ring) where the anterior and posterior spinal arteries anatomose. These branches form the vasocorona penetrate and supply the white matter.

Spinal cord vein drainage

Vein drainage works via the anterior spinal vein and both posterior spinal veins. The efferent veins drain into the epidural venous plexus.

The Spinal Meninges

The connective tissue of the spinal meninges comprises membranes that envelop the entire spinal cord in order to protect and nourish it. Above the foramen magnum, they continue as brain meninges.

Dura mater meninges

Dura mater is highly sensitive to pain and is the outermost layer of the protective membrane. It forms a so-called thecal sac made from an outer and inner dural fold. The outermost layer of the spinal canal is the superficial or periosteal layer. Between the folds is where the epidural and peridural space is located; it contains the venous plexus and fatty tissues. The dural sac works as soft padding for the spinal cord and is used as protection during spinal movements.

Epidural anesthesia

The administration of a local anesthetic into the epidural space (PDA) is often used for pain relief during labor, or, in the form of an epidural catheter, for the treatment of chronic pain.

Soft meninges = arachnoid mater (arachnoid mater) and pia mater spinalis

The arachnoid mater lies between the 2 other meninges, the dura mater and the **pia mater,** which are separated by **subarachnoid space** in which **cerebrospinal fluid** flows and ends with the conus medullaris. Dura mater and arachnoid mater fill the spinal canal caudally.

Puncture Sites for Liquid Extraction

Cerebrospinal fluid is a transparent fluid that is largely composed of the interstitial fluid of other tissues. It contains little protein and some lymphocytes. An infection of the central nervous system changes the appearance of the cerebrospinal fluid so that it is possible to diagnose certain conditions by examining it.

Lumbar puncture

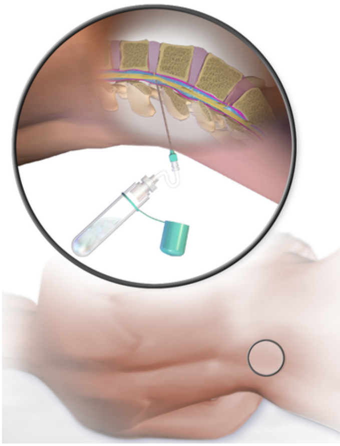


Image: “Lumbar puncture” by Bruce Blaus. License: CC BY 3.0

A lumbar puncture is an extraction of cerebrospinal liquid from the subarachnoid space; this liquid is used for diagnostic purposes. The puncture point is located around the cauda equina between the lumbar vertebrae LIII and LIV, and LIV and LV, as there is less risk of damage to the spinal cord in these spaces. The front and back roots of cauda equina soften the penetration of the needle.

Cisternal puncture

The puncture point for this fluid-extraction procedure is in the midline located below the external occipital protuberance where the needle enters into the cisterna magna.

Cerebrospinal fluid is taken from the **cisterna cerebellomedullary**. A cisternal puncture is sometimes carried out on small children because, in a child’s body, the spinal cord is much more caudal, so a lumbar puncture is often not appropriate. However, due to the risk of injury by the needle entering the medulla, this is a very rare procedure.

Spinal Cord Injuries

Meningocele and myelomeningocele = “split spine”

Spina bifida is a birth defect wherein the closing of the backbone and membranes around the spinal cord is not completed before birth.

During embryonic development, the closure of the **neural tube** and spine is incomplete, causing the meninges to be forced into the gaps between the vertebrae (meningocele). In some cases, the unused portion of the spinal column allows the spinal cord to protrude through an opening (myelomeningocele). The most common location for this spinal defect is the lower back; however, rare cases involving the middle back as well as the neck have been seen in recent years.

Only in so-called **spina bifida occulta** does the spinal cord membrane remain intact. The outer part of some of the vertebrae is not completely closed, but splits in the vertebrae are so small that the spinal cord does not protrude. The skin at the site may have a bit of hair growing from it, or a dimple or birthmark.

The treatment of spina bifida involves neurosurgical closure and subsequent therapies to maintain the closure’s integrity. Whether the operation is successful depends on the level of the defect. As with all spinal cord defects and injuries, the higher the defect on the spine, the less favorable the prognosis.

The causes of this condition are believed to be both genetic and environmental. Lack of adequate folate during pregnancy also plays a major role.

Problems associated with this defect include challenges in bladder control, poor walking abilities, and learning disabilities.

Spinal cord injury

- **Complete spinal cord injury**: the complete dysfunction of an individual spinal segment
- **Incomplete spinal cord injury:** the partial loss of function of the spinal cord at a certain spinal level

The symptom complex includes paralysis, sensory disturbances, and disruption of vegetative functions. Depending on where the injury occurs, **paraplegia** (total paralysis of the legs) or **quadriplegia** (total paralysis of both arms and legs) may also occur.

Spinal cord injuries are usually the result of traumatic accidents. However, inflammation (e.g., poliomyelitis and multiple sclerosis), tumors, and disc herniation can also cause a spinal cord injury.

Note: Every spinal cord injury should be treated as a neurological emergency.

Spinal disc herniation (prolapse nuclei pulposi) = lumbar disc herniation (BSP)

Disk herniation is caused either by trauma or the degeneration of the intervertebral disc, the contents of which (nucleus pulposus) get pressed against the spinal cord, resulting in the rupture of the membrane.

A distinction is made between:

- **Prolapsed disk** (a complete prolapse of the nucleus pulposus through damaged annulus fibrosis); and
- **Protruded disc** (an incomplete protrusion or herniation, whereby the nucleus pulposus bulges into the spinal canal, although the fibrous ring of the disc still remains intact or is only slightly torn)

Spinal cord infection (myelitis)

Myelitis is a rare disorder with mostly immunological and allergic causes. The inflammation can be spread out over the entire spinal cord or occur in a narrow region (**disseminated myelitis**). Inflammation may damage the myelin and axon causing sensory loss or paralysis. **There are a number of different types of myelitis.**

Parainfectious myelitis

Spinal cord inflammation can be caused by infectious diseases such as measles, mumps, and rubella.

Poliomyelitis (infantile paralysis)

Poliomyelitis is an infectious disease caused by the poliovirus, which produces a viral infection in the gray matter, leading to muscle paralysis, muscle weakness, or death. The Standing Committee on Vaccination (STIKO) at the Robert Koch Institute, therefore, recommends vaccination for polio after the 2nd month of a baby's life.

Tetanus

The toxin of tetanus pathogen, known as ***C. tetani*,** damages the inhibitory synapses of the central nervous system (CNS). The uninhibited motoneurons lead to convulsions and skeletal muscle spasms and the following symptoms: **risus sardonicus**, **opisthotonus,** and **tonic and clonic seizures**. Tetanus infection has a high mortality rate and, if left untreated, inevitably leads to death. STIKO recommends a primary vaccination after an infant's 2nd month of life.

Transverse myelitis

Transverse myelitis refers to an inflammation of the spinal cord. The inflammation damages nerve fibers so extensively that they lose their myelin coating, leading to decreased electrical conductivity in the nervous system (caused by, for example, endocarditis or septicemia).

Meningococcal myelitis

Meningitis can spread directly to the spinal cord due to its topographical proximity.

Multiple sclerosis

Commonly referred to encephalomyelitis, in this condition the nerve sheaths in the brain and the spine are damaged. This can result in a variety of physical as well as mental disorders.

Common symptoms of myelitis

The following pathogens are responsible for this disorder:

- Bacterial: Bacteria that cause tuberculosis can in rare cases cause myelitis.
- Viral: Viral infections can directly cause acute myelitis, as in polio. Viruses such as HIV that affect immunity can cause chronic myelitis.
- Fungal: In some cases, fungal infections can cause myelitis by affecting the bone, which puts pressure on the spinal cord.
- Autoimmune conditions: In some cases, autoimmune disorders can cause the body to attack the nerve cells, which can lead to myelitis.
- Parasites: Parasites that infect the body can sometimes affect the spine, causing myelitis.

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Notes