Anatomy and Structure of the Spinal Cord and Spinal Cord Injuries

The spinal cord (medulla spinalis) is part of the central nervous system, while simultaneously connecting 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 - to the skeletal musculature and the intestines, and so forth. The following article will provide you with a first impression of the structure and function of this fascinating organ.

Location and Structure of the Spinal Cord

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 starts at
the foramen magnum at the base of the skull (medulla oblongata).

Along the course of the spine are two spindle-shaped enlargements (intumescentia cervicalis and intumescentia lumbalis) 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. Surrounding the spinal cord and projecting downwards is a slim connecting filament where the spinal cord ends (filum terminale).

Connective tissue surrounds and protects the entire spinal cord creating epidural space which 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.

Furthermore, the spinal cord has two thin grooves which run along its entire length. The first groove fissura mediana ventralis runs along the front ventral side, and the second groove sulcus medianus dorsalis runs on the back dorsal side. In a manner of speaking, both symmetrically “split” the spinal cord into a left and a right half.

The spinal cord is divided lengthways 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 side. These spinal nerves emerge from openings in the intervertebral foramen between two 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 Horses 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 the 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 1-3 coccygeal segments.

**Spinal nerves**

The border between the central and peripheral nervous system is found at the transition between each spinal segment in the frontal and rear side roots. From then on, the spinal roots become part of the peripheral nervous system. 31 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.
Nn. cervicales  8 pairs of cervical nerves  C1 - C8  The first spinal nerve pair emerges between the occipital bone and the atlas

Nn. thoracales  12 pairs of thoracic nerves  T1 - T12  The first thoracic nerve pair emerges between T1 and T2

Nn. lumbales  5 pairs of lumbar nerves  L1 - L5  The first lumbar pair emerges between L1 and L2

Nn. sacrales  5 pairs of sacral nerves  S1 - S5  The first sacral nerve pair emerges between S1 and S2

Nn. coccygei  1 - 3 coccygeal nerve pairs, partly rudimentary  The first nerve pair emerges between the first and second coccygeal vertebrae.

Spinal cord cross-section

When seen from a cross-section, the spinal cord reveals grey, butterfly-shaped matter surrounded by neuronal white matter.

The spinal cord has a different appearance, depending on the height of the cross-section. The cross-section 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 grey matter (substantia grisea)

Spinal cord grey matter consists of neuronal cell bodies (somata) and glial cells which look like a “butterfly” when seen from a cross-section.

This butterfly-shape has a symmetric construction where both halves of the grey matter are connected by the commissura grisea whose central region surrounds the canalis centralis and contains cerebrospinal fluid.

Both halves of the spinal cord possess a so-called dorsal horn (cornu dorsale), a ventral horn (cornu ventrale), and, between segments C8-L1, an additional lateral horn (cornu laterale). In its three-dimensional longitudinal perspective, three columns develop: columna dorsalis, columna ventralis and columna lateralis.

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) whose nerve fibres affect the axial muscles. Postganglionic neurons of the sympathetic are located in the lateral horn.

The structure of grey matter

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

1st system: Rexed laminae

Grey 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).
- Grey commissure: Lamina X

2nd system: separating grey 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 = Zona intermedia

The motor neurones in the ventral horn are ordered according to the following groups of nuclei:

<table>
<thead>
<tr>
<th>Medial nucleus groups of the ventral horn</th>
<th>Lateral nucleus groups of the dorsal horn</th>
<th>Central nucleus groups of the ventral horn cervical cord</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ncl. dorsomedialis</td>
<td>Ncl. dorsolateralis</td>
<td>Ncl. phrenicus</td>
</tr>
</tbody>
</table>
In this way, the ventral horn is described as having a **somatosensory organization**.

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

<table>
<thead>
<tr>
<th>Nucleus groups of the ventral horn</th>
<th>Lateral nucleus groups of the ventral horn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ncl. ventromedialis</td>
<td>Ncl. ventrolateralis</td>
</tr>
<tr>
<td>Ncl. accessorius</td>
<td>Ncl. retrodorsolateralis</td>
</tr>
<tr>
<td>Neck and back musculature</td>
<td>Shoulder</td>
</tr>
<tr>
<td>Intercostal muscles</td>
<td>Lower arm</td>
</tr>
<tr>
<td>Abdominal musculature</td>
<td>Little finger</td>
</tr>
<tr>
<td></td>
<td>Upper arm</td>
</tr>
<tr>
<td></td>
<td>Hand</td>
</tr>
</tbody>
</table>

The somatosensory organization does not correlate with the level of the spinal cord, but 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.

The cells for the extensor musculature are arranged in the ventral area of the ventral horn, while the cells for the 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 which originate in the spinal cord itself. These nerve fibres either extend the length of several spinal segments, or run inside a single segment connecting different levels of the spinal cord, or they cross each other. The propriospinal system lays the foundations for the monosynaptic and polysynaptic reflexes.

**Propriospinal system cell types**

- **Association cells**: association cells connect flat lying nerve cells on different spinal segments via the *fasciculi proprii ipsilateral*
- **Commissural cells**: connect contralateral lying cells of the same segment through the *commissura alba*
- **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 damage 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 fibres, of which these strands (*funiculi*), bundles (*fasciculi*) and tracts (*tractus*) connect areas of grey 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:

- *Funiculus posterior* (can be found between the posterolateral and posterior median sulcus, above all ascending fibres)
- *Funiculus lateralis* (between the exit of the anterior nerve roots and the posterolateral sulcus)
- *Funiculus anterior* (between the anterior median fissure and the lateral anterior nerve roots)

The last two also make up part of the ventral funiculus.

### White matter ascending tracts

<table>
<thead>
<tr>
<th>Ventral funiculus tracts</th>
<th>Dorsal funiculus tracts</th>
<th>Spinocerebellar projection tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractus spinothalamicus lateralis</td>
<td>Fasciculus gracilis</td>
<td>Tractus spinothalamus posteriorm</td>
</tr>
<tr>
<td>Tractus spinothalamicus anterior</td>
<td>Fasciculus cuneatus</td>
<td>Tractus spinothalamus anterior</td>
</tr>
<tr>
<td>Tractus spinotectalis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### White matter descending tracts

<table>
<thead>
<tr>
<th>Pyramidal tract = Tractus corticospinalis</th>
<th>Extrapyramidal tracks</th>
<th>Vegetative tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractus corticospinalis lateralis</td>
<td>Tractus vestibulospinalis</td>
<td>Tractus parependymalis both sides of the central canal</td>
</tr>
<tr>
<td>Tractus corticospinalis anterior</td>
<td>Tractus reticulospinalis ventralis et lateralis from the arch</td>
<td>The vegetative tracts rarely build closed bundles</td>
</tr>
<tr>
<td></td>
<td>Tractus reticulospinalis lateralis out of the Medulla oblongata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tractus tegmentospinalis</td>
<td></td>
</tr>
</tbody>
</table>

**Fasciculi proprii** (*Fasciculi proprii*) latch directly onto the grey matter of the spinal cord proprioceptive apparatus.

### The Reflex Arc

Reflex = stereotyped response to a stimulus.

There are afferent nerve fibres which 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 one or more interneurons which connect sensory – afferent- signals with motor -efferent- signals (polysynaptic reflex).

Monosynaptic reflex

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

An example:

**The patellar reflex = PSR**

The patellar reflex is an example of a monosynaptic reflex.

A blow to the patellar ligament causes the quadriceps muscle to extend. Here, receptors produce a signal which 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, then the efferent fibres send an impulse to the lumbar plexus which is isolated in the femoral nerve and sent back to the muscle to cause its contraction.

The purpose of testing this reflex lies in testing not the strength of the reflex, 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 one interneuron.

An example:

**Polysynaptic withdrawal reflex**

The withdrawal reflex is a protective reflex. Nociceptors trigger a sensory impulse in the nerves whose excitation 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.

- Cremasteric reflex
- Abdominal reflex
- Blink reflex

Spinal Cord Blood Supply

Supply of blood via arteries

The three 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 sulcocommissural artery.
- **Posterior spinal arteries**: these two supply arteries run adjacent to the entrance of the dorsal root and branch out within the spinal cord.

Additionally, the **intercostales posteriores** arteries in the thorax region and the lumbar arteries in the lumbar region (both outlets of the aorta) release **Rami spinales** to supply the thoracic spine and the lumbar spine.

Here, relevant is the large **Rami spinalis in the intumescentia lumbalis area**: **Arteria radicularis magna (Adamkiewicz)**.

The spinal cord is surrounded by a vasocorona (vascular ring) where the artery **spinalis ventralis Anastomosen** branches off from the **spinales dorsales arteries**. These branches from 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 is membranes which 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 spinalis)**

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 which contains the venous plexus (**plexus venosus vertebralis internus**) and fatty tissues. The dural sac works as soft padding for the spinal cord and is used as protection during spinal movements.

**Epidural anesthesia (PDA)**

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 two 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 which is largely composed of the interstitial fluid of other tissues. It contains little protein and some lymphocytes. An infection of the CNS changes the appearance of the cerebrospinal fluid so that it is possible to diagnose
Lumbar puncture

A lumbar puncture is an extraction of cerebrospinal liquid from the subarachnoid space, which is used for diagnostic purposes. The puncture point is located around the cauda equina between the lumbar vertebrae LIII and LIV, LIV and LV, as here there is less risk of damage to the spinal cord. 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.

The cerebrospinal fluid is taken from the cisterna cerebellomedeullary. The cisternal puncture is sometimes carried out on small children, because, in a child’s body, the spinal cord is much more caudal which means that 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 operation.

Spinal Cord Injuries

Meningocele and myelomeningocele (spina bifida aperta) = “split spine”

This is a birth defect where 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 which causes the meninges to be forced into the gaps between the vertebrae (meningocele). In other 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 of the middle back as well as the neck have been handled in the past decade.
Only with the 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 the splits in the vertebrae are so small that the spinal cord does not protrude. The skin at the site may have some hair growing from it, a dimple in the skin, or a birthmark.

The treatment of spina bifida is a neurosurgical closure and subsequent therapies to maintain its integrity. Whether the operation is successful or not, depends on the level of the spinal cord 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 closely associated with the combination of the genetic as well environmental conditions. Lack of enough folate during the pregnancy duration also plays a major role.

Problems associated with this defect include challenges in bladder control, poor walking abilities as well as learning problems.

**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
- **Quadriplegia** = total paralysis of both arms and legs

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

**Note:** Every spinal cord injury is a neurological emergency!

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

This spinal cord condition is caused either by trauma or the degeneration of the intervertebral disc, whose contents (nucleus pulposus) get pressed against the spinal cord, resulting in the rupture of the membrane. In medical terms a distinction is made between:

- **Prolapsed disk**: complete prolapse of the nucleus pulposus through a damaged annulus fibrosis.
- **Protruded disc**: 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.

Different types of myelitis:

Parainfectious myelitis

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

Poliomyelitis (infantile paralysis)

Poliomyelitis is an infectious disease caused by the polio virus which causes a viral infection in the grey matter leading to muscle paralysis, muscle weakness or death. Therefore, the STIKO (= the immunization commission of the Robert Koch Institute) recommends a vaccination after the 2nd month of the baby’s life.

Tetanus

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

Transverse Myelitis

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

Meningococcal Myelitis

Meningitis (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 causing damage. 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, like in polio. Viruses like HIV that affect immunity could cause chronic myelitis.
- Fungal: In some cases, fungal infections can cause myelitis by affecting the bone, which could pressure the spinal cord.
Autoimmune conditions: In some cases, autoimmune disorders could 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

Review Questions

The correct answers can be found below the references.

Which statement about the spinal cord propriospinal system is correct?

A. Commissure cells connect the nerve cells of different segment heights.
B. Association cells bind ipsilaterally lying nerve cells of different segment heights via the fasciculi proprii.
C. Association cells bind contralaterally lying nerve cells of the same segment height.
D. Renshaw cells acting as inhibitory interneurons bind contralaterally lying cells of the same segment.
E. The infection by the pathogen clostridium tetani leads to weakness and paralysis of skeletal muscles because the activity of the inhibitory interneurons is increased.

Which statement about spinal meninges is true?

A. Pia mater and arachnoid mater caudally fill the spinal canal.
B. The dura mater lies directly on top of the spinal cord and ends at the conus medullaris.
C. During an epidural procedure, a local anesthetic is injected into the epidural space which is filled with cerebrospinal fluid leading to a rapid elimination of the pain that occurs during childbirth.
D. There is currently no method to extract cerebrospinal fluid from children because the entire spinal cord is full of fluid so the risk of spinal damage is too high.
E. Inflammation in the CNS changes the composition of the cerebrospinal fluid.

Which statement about spinal disorders is not true?

A. Spina bifida is a hereditary malformation of the spine and spinal cord.
B. Spina bifida occulta is the most severe form of myelomeningocele, exhibiting severe damage to the spinal cord and the meninges.
C. A paraplegic spinal cord injury means complete paralysis of the legs.
D. Poliomyelitis is caused by the poliovirus leading to inflammation of the grey matter in the spinal cord. It is also known as “infantile paralysis”.
E. Myelitis can also result from the inflammation of the endocardium.

References

Horsley, V. (2012). The structure and functions of the brain and spinal cord: Being the Fullerian Lectures for 1891.
Young, R. R., & Woolsey, R. M. (1995). Diagnosis and management of disorders of the
spinal cord.

Correct answers: 1B, 2E, 3B

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