THE BACK

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Spinal Cord

The spinal cord is the elongated caudal part of the CNS. It starts as the inferior continuation of the medulla oblongata at the level of foramen magnum, & ends as an inverted cone (the conus medullaris) at the lower end of L1 vertebra. The spinal cord conveys motor signals from the brain to the spinal nerves, & sensory information from the spinal nerves to the brain. In addition, the spinal cord itself mediates nerve reflexes without involving the brain.

Morphologically, the spinal cord resembles a long cylinder with 2 swellings in the cervical & lumbosacral regions. (for the innervation of the upper & lower limbs respectively). Along its length, the spinal cord gives rise to the ventral spinal nerve rootlets anterolaterally, & dorsal rootlets posterolaterally. In the upper 5 cervical segments, the rootlets of the spinal accessory nerve (CN-XI) emerge from the lateral side of the spinal cord, between the ventral & dorsal rootlets of the cervical spinal nerves. The spinal cord has the following external features:

- Anterior median fissure: a deep median fissure along the anterior aspect of the cord. It extends into the anterior white commissure, & is covered by the anterior spinal artery (& vein) & contains its sulcal (central) branches, & is filled with CSF.
- Posterior median sulcus: a shallow median depression along the posterior aspect of the cord. It is covered by the posterior spinal vein.
- Anterolateral sulcus: a shallow depression along the anterolateral aspect of the cord, in which the anterior rootlets are attached.
- Posterolateral sulcus: a shallow depression along the posterolateral aspect of the cord, in which the posterior rootlets are attached.
- Posterior intermediate sulcus: a shallow paramedian longitudinal depression between the posterior median sulcus & the posterolateral sulcus. It separates gracile fascicle from cuneate fascicle.

Internally, the spinal cord is made by a huge number of myelinated nerve fibers (white matter), surrounding an inner mass of nerve cell bodies (gray matter). **Gray matter** extends along the spinal cord, & has "H" or butterfly shape in horizontal sections. Spinal cord gray matter has the following parts:

- Anterior (ventral) horn: this column of gray matter extends throughout the whole spinal cord. It is wide, short, & doesn't reach to the surface of the spinal cord. The anterior horn is made of groups of large multipolar neurons (anterior horn cells) which are purely motor in function. These neurons receive impulses from the motor cortex of the brain (through the corticospinal tract, described below) & send their axons through the anterior rootlets of the spinal nerves, to supply the skeletal muscles of the whole body (except the muscles supplied by the cranial nerves). Note the following:
    - The anterior horn becomes very large, & contains distinct groups of neurons, in the cervical & lumbosacral regions of the spinal cord, due to the presence of the large number of neurons supplying the upper & lower limbs, respectively.
    - In the thoracic region, the anterior horn is relatively small, containing neurons innervating the intercostal & abdominal wall muscles, in addition to the corresponding levels of deep back muscles.
    - In the cervical & lumbar regions, the anterior horn contains cell groups responsible for supplying specific muscles groups. These groups are arranged in the horn (from the medial to the lateral side) as follows: spine muscles, shoulder or pelvis, arm or thigh, forearm or leg, hand or foot.
    - Similarly, within each neuronal group mentioned above, cells innervating the extensor muscles of certain region are located peripherally, while those innervating the flexor muscles are located more centrally.
- Posterior (dorsal) horn: this column of gray matter extends throughout the whole spinal cord. It is narrow, long, & almost reaches to the surface of the spinal cord. The posterior horn is made of groups of intermediate & small multipolar neurons which are purely sensory in function. These neurons receive sensory impulses from the body (through the central processes of pseudounipolar neurons in the dorsal root ganglia) & send their axons ipsilaterally or contralaterally to the higher sensory areas of the brain. Note the following:
    - Most of the fibers entering through the posterior rootlets synapse in the intermediate zone of the posterior horn, with small & medium sized multipolar neurons.

- Nucleus dorsalis (of Clarke): a neuronal cell column situated in the medial portion of the base of the posterior horn. It extends from C8 to L3 levels, being most prominent in T12 & L1 levels. The axons of those neurons ascend ipsilaterally in the lateral funiculus as the posterior spinocerebellar tract.

- Intermediate gray zone: this is the area of gray matter existing between the anterior horn, posterior horn, & the gray commissure (the horizontal bar of gray matter). It contains neurons of variable sizes that are distributed homogenously. Note the following:
  - The lateral horn (intermediolateral nucleus): this is a column of gray matter the protrudes from the lateral surface of the intermediate gray zone, extending from C8 to L2 or L3 level. This nucleus is made of small size oval neurons that represent the preganglionic sympathetic neurons. Their axons pass through the anterior rootlets & spinal nerves, then become the white rami communicants that enter the ganglia of the sympathetic chain to synapse with the postganglionic neurons.
  - The sacral autonomic nucleus: this is a column of neurons present in the same location of the lateral horn but in the S2,3,4 levels only. Its intermediate size neurons represent the preganglionic parasympathetic neurons supplying abdominal & pelvic viscera not supplies by the vagus nerves. Their axons pass via the anterior rootlets & spinal nerves (S2,3,4) to leave as the "pelvic nerves", that synapse with the postganglionic neurons in the parasympathetic ganglia of the pelvis.
- Gray commissure: It is the thin transverse strip of gray matter extending from right to left, & contains the central canal of the spinal cord. The CSF-filled central canal is continuous superiorly with the 4th ventricle of the brainstem, & closes inferiorly with the end of the spinal cord.

White Matter of the Spinal Cord:

The white matter is located externally, & is made of bundles of myelinated nerve fibers running up & down in the cord. Grossly, the white matter is divided by the gray matter into 3 this columns (funiculi):

- Anterior column: this is the white mater part existing between the anterior median fissure, the anterior gray horn, & the origin of the anterior rootlets. Just anterior to the gray commissure, the 2 anterior columns communicate with each other via the anterior white commissure.
- Lateral column: this is the white mater part existing between the anterior & posterior gray horns (between the origins of the anterior & posterior rootlets).
- Posterior column: this is the white mater part existing between the midline & the posterior gray horn. The right & left posterior columns are separated by a midline sulcus & septum (the posterior median sulcus & septum). Each posterior column is subdivided into a medial fascicle (fasciculus gracilis) & a lateral fascicle (fasciculus cuneatus), separated by the posterior intermediate sulcus & septum.

Spinal Cord Tracts:

A tract is a bundle of nerve fibers (axons) connecting different regions within the central nervous system. Similar structures in the peripheral nervous system are called "nerves". The spinal cord contains a very large number of tracts. However, only the major tracts will be mentioned here. Spinal cord tracts are either carrying sensory information from the body (or spinal cord) to the brain (ascending tracts); or, carrying motor orders from the brain to the spinal cord & body (descending tracts).

Ascending tracts:

1. The posterior white column (fasciculus gracilis & fasciculus cuneatus): this is the sensory tract responsible for conveying the sensation of discriminative touch, vibration, movement, & proprioception (from muscles & joints) to the brain. Fibers of this tract occupy the whole posterior white column. The central processes of pseudounipolar neurons (in the dorsal root ganglion) enter the spinal cord via the posterior root, then each process bifurcates into short descending & long ascending branches, both branches run in the posterior column. Fibers from the legs, pelvis & abdomen ascend medially as the fasciculus gracilis, while those from the thorax, arms & neck ascend laterally as the fasciculus cuneatus. Both fascicles reach the medulla uncrossed (in the same side), to synapse on nucleus gracilis & nucleus cuneatus, respectively. Further course of the pathway will be studied later.
2. Anterior spinothalamic tract: this pathway is responsible for transmitting the sensation of touch & pressure to the brain. Central processes of pseudounipolar neurons of dorsal root ganglia enter the cord via the dorsal

rootlets, then synapse near the tip of posterior gray horn with second order neurons. Axons of second order neurons cross the midline via the white (& gray) commissure to ascend in the anterior white column as the anterior spinothalamic tract. These fibers reach the thalamus to synapse with third order neurons.

3. Lateral spinothalamic tract: this pathway is responsible for transmitting the sensation of pain & temperature to the brain. Central processes of pseudounipolar neurons of dorsal root ganglia enter the cord via the dorsal rootlets, then synapse near the tip of posterior gray horn with second order neurons. Axons of second order neurons cross the midline via the white (& gray) commissure to ascend in the lateral white column as the lateral spinothalamic tract. These fibers reach the thalamus to synapse with third order neurons.
4. Anterior & posterior spinocerebellar tract: this pathway is responsible for transmitting the sensation of muscles & joint proprioception to the cerebellum. Central processes of pseudounipolar neurons of dorsal root ganglia enter the cord via the dorsal rootlets, then synapse on the nucleus dorsalis (of Clarke) with second order neurons. The majority of axons of second order neurons cross the midline to ascend in the contralateral white column as the anterior spinocerebellar tract. This tract enters the cerebellar cortex via the superior cerebellar peduncle. The minority of second order neurons axons pass ipsilaterally to ascend in the lateral white column as the posterior spinocerebellar tract. These fibers reach the cerebellar cortex via the inferior cerebellar peduncle.

Descending Tracts:

1. Corticospinal tracts: the corticospinal pathway mediates the movement of skeletal muscles. It starts in the motor cortex of the cerebrum, where the axons of first order neurons (upper motor neurons) descend as a thick bundle. At the lower medulla oblongata, the majority (> 90%) of the fibers cross the midline, to descend in the lateral white column of the spinal cord as the "lateral corticospinal tract". Those fibers synapse in the anterior gray horn with the anterior horn cells (lower motor neurons) directly or through interneurons. Anterior horn cells axons emerge as the anterior roots of spinal nerves. The remaining (< 10%) fibers descend in the anterior white column of the same side of the spinal cord as the "anterior corticospinal tract". Fibers of this tract also cross the midline (via the white commissure) just before synapsing with the anterior horn cells of the anterior horn.
2. Rubrospinal tract: Fibers from the red nucleus (a motor nucleus in the midbrain) descend to enter the lateral white column of the spinal cord. The fibers synapse with neurons in the anterior gray column of the cord. The red nucleus is connected with the cerebral cortex and the cerebellum. The rubrospinal tract affects the the skeletal muscles movements by facilitating the activity of the flexor muscles and inhibiting the activity of the extensor or antigravity muscles.
3. Reticulospinal tract: The reticular formation is a collection of groups of neurons extending in the midbrain, pons, medulla oblongata & upper segments of the spinal cord. Its function is related to wakefulness & sleep. Fibers from the pons descend in the ipsilateral anterior white column as the "pontine reticulospinal tract", while those from the medulla descend in the lateral white column (of both sides) as the "medullary reticulospinal tract". Reticulospinal tract fibers synapse with neurons in the anterior gray horn to influence voluntary movements & reflex activity.
4. Vestibulospinal tract: Fibers descending from the vestibular nuclei (of the vestibular nerves, CN-VIII) to the anterior motor neurons of the spinal cord. They regulate body balance by facilitating the extensor muscles & inhibiting the flexor muscles.
5. Tectospinal tract: Fibers from the superior colliculi (of the tectum of the midbrain) descend to the anterior motor neurons of the spinal cord in the cervical & upper thoracic levels. They control visual reflexes (head & neck movement in response to visual stimuli).
6. Descending autonomic fibers: fibers from many higher centers in the CNS (cerebral cortex, hypothalamus, reticular formation, etc) cross the midline & descend in the lateral white column of the spinal cord, to synapse with the lateral gray horn neurons in the thoracic (preganglionic sympathetic) & mid-sacral (preganglionic parasympathetic) regions. They may influence the autonomic activity.

Intersegmental Tracts:

Short ascending and descending tracts that originate and end within the spinal cord exist in the anterior, lateral, and posterior white columns (around the gray matter). The function of these pathways is to interconnect the neurons of different segmental levels, and the pathways are particularly important in intersegmental spinal reflexes.

Spinal Cord Reflexes:

A reflex is involuntary response to a stimulus. It depends on the integrity of the reflex arc (pathway). Simply, a reflex arc consists of the following anatomical structures: (1) a receptor organ, (2) an afferent neuron, (3) an effector neuron, and (4) an effector organ. A reflex arc involving only one synapse is a monosynaptic reflex arc (similarly, 2 synapses: bisynaptic reflex arc, more than 2 synapses: multisynaptic reflex arc). Interruption of the reflex arc at any point along its course would abolish the response.

In the spinal cord, reflex arcs play an important role in maintaining muscle tone, which is the basis for body posture. The receptor organ is situated in the skin, muscle, or tendon (a sensory receptor). The afferent neuron is the pseudounipolar neuron located in the posterior root ganglion, and the central axon of this first-order neuron terminates by synapsing on the effector (efferent) neuron. Since the afferent fibers are of large diameter and are rapidly conducting and because of the presence of only one synapse, a very quick response is possible. Clinically, reflexes (of the upper limb, lower limb, & even the abdomen) are useful to access the integrity of the reflex pathway.

Spinal Cord Lesions

The spinal cord lesions are common. They can result from injuries (especially fractures of the vertebrae), neurological diseases, or congenital anomalies involving the spinal cord. According to the site of the lesion & the affected components, spinal cord lesions present with very different modes of sensory & motor function defects. To understand the clinical picture of spinal cord lesions, we need to understand the following terms:

- Paralysis: inability to move
- Paresis: muscle weakness (partial paralysis)
- Anesthesia: loss of sensation
- Upper motor neuron: neurons in the motor cortex in the brain & their axons descending as the corticospinal tracts. Lesions of these neurons cause "spastic paralysis" (paralysis of muscles with increased muscle tone).
- Lower motor neurons: those are the motor neurons in the anterior horn of the spinal cord. Lesions of these neurons cause "flaccid paralysis" (paralysis of muscles with decreased muscle tone).

The following are examples of spinal cord lesions:

1. **Total cord transection**: here, the spinal cord is completely cut (eg: in car accidents). Here, the patient has the following:
    a. Bilateral lower motor neuron lesion (flaccid paralysis) at the level of cord injury,
    b. Bilateral upper motor neuron lesion (spastic paralysis) below the level of cord injury,
    c. Bilateral loss of all sensations below the level of the lesion,
    d. Loss of bladder and bowel voluntary control, due to destruction of descending autonomic fibers.
2. **Spinal cord hemisection (Brown-Sequard syndrome)**: this occurs when on side of the spinal cord is totally injured at certain level. The patient has the following:
    a. Ipsilateral lower motor neuron paralysis in the segment of the lesion,
    b. Ipsilateral upper motor neuron paralysis below the level of the lesion,
    c. Ipsilateral band of cutaneous anesthesia in the segment of the lesion,
    d. Ipsilateral loss of tactile discrimination and vibratory and proprioceptive sensations below the level of the lesion,
    e. Contralateral loss of pain and temperature sensations below the level of the lesion,
    f. Contralateral but partial loss of tactile sensation below the level of the lesion.
3. **Anterior cord syndrome**: this syndrome results usually from occlusion of the anterior spinal artery, so the anterior 2/3s of the cord are deprived of blood supply. The patient has the same picture of total cord transection, but the dorsal column sensation (Tactile discrimination and vibratory and proprioceptive sensations) are preserved because the posterior white columns on both sides are undamaged.
4. **Central cord syndrome**: this syndrome results in cases of syringomyelia: congenital enlargement of the central canal of the spinal cord, usually in the cervical region, forming a sac in the center of the cord, pressing on the central parts of the spinal cord. The patient presents with bilateral loss of pain & temperature sensation in the levels of the deformity (arms & upper chest) due to interruption of the lateral spinothalamic tracts as they cross the midline in the anterior gray and white commissures. Muscle weakness of the upper limb may occur later when the sac expands due to pressure on the anterior horn cells.
5. **Poliomyelitis**: childhood infection with polio virus results in destruction of the anterior horn cells of one or both sides in the lumbar (or other) region. The result is permanent lower motor neuron (flaccid) paralysis of the affected segments.

6. **Dorsal column disease**: certain diseases (like syphilis) may affect the dorsal column of the spinal cord bilaterally. The patient has impaired or lost dorsal column sensation (vibration, proprioception, etc) with locomotor ataxia.
7. **Amyotrophic lateral sclerosis (ALS)**: a chronic disease confined to the corticospinal tracts and the motor neurons of the anterior gray columns of the spinal cord. There is a mixture of lower & upper motor neuron disease signs, with muscles atrophy & spasticity.
8. **Vitamin B12 neuropathy**: chronic vitamin B_{12} deficiency may result in this syndrome, in which the dorsal columns & lateral corticospinal tracts are affected bilaterally. Clinically, there is reduction in dorsal column sensation (tactile discrimination, vibration & proprioception) & bilateral upper motor neuron paresis.
9. **Multiple sclerosis (MS)**: a neurological disease characterized by areas of demyelination affecting any part of the CNS white matter in the brain & the spinal cord. In the spinal cord, any tract can be interrupted if it is involved in the demyelination process.

Notes:

- Read the lectures while you watch the images of each lecture.
- Regarding the 2 tables of intervertebral disc prolapse, you are responsible only for the lower one (of the lumbar discs).
- Regarding the tables of the back muscles, you are responsible for the last one (suboccipital muscles) in details. For the rest of back muscles, you should know the general arrangement (gross origin, insertion, & main action). Small details are not mandatory to memorize.