Central Nervous System

Sheet 2 + 3

Subject | Physiology

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Correction | ...

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I highly recommend studying this sheet colored.

The Somatosensory System

The somatosensory system is a complex system of sensory neurons and neural pathways that responds to changes at the surface or inside the body.

Recall: the nervous tissue is made up of grey matter (cell bodies) and white matter (axons).

Types of sensations

1- **General sensations**: somatic.
2- **Special sensations**: taste, smell, vision, etc.

Sensation receptors

- Sensory receptors are activated by different stimuli, **transforming** it into **signals** which are transmitted along **axons** (afferent neurons) to the spinal cord while being **processed**. Signals end up in the brain for further processing.

- The receptors only **identify** the signal, but the response depends more on the **processing** throughout the pathway. Thus, one receptor can give 2 different sensations depending on the pathway of processing.

- **Types of sensory receptors:**

1- **Mechanoreceptors**: detect deformation.
2- **Thermoreceptors**: detect changes in temperature.
3- **Nociceptors**: detect damage (pain receptors).
4- **Electromagnetic**: detect light.
5- **Chemoreceptors**: detect taste and smell.

- **Somatic sensations are divided mainly into:**

1- **Mechanoreceptive**: stimulated by mechanical displacement.

a- **Tactile:**
- Touch
- Pressure
- Vibration
- Tickle and itch

b- **Position or proprioceptive:**
- Static position
- Rate of change

2- **Thermoreceptive**: detect heat and cold.

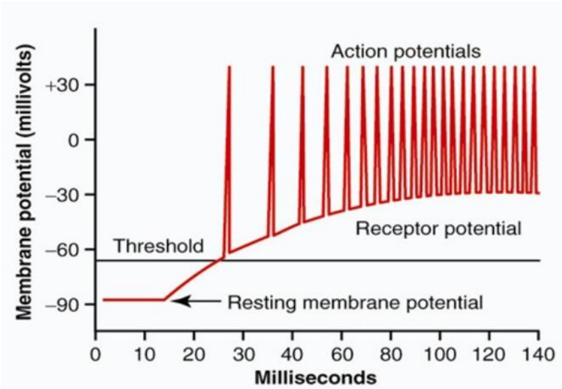
3- **Nociceptive**: detect pain and are activated by any factor that damages tissue by an exaggerated amount of energy.

Excitation of sensory receptors

- **Receptor potential**: it is a type of **graded potential** produced by activation of a sensory receptor and is **proportionally** graded according to the **stimulus intensity**.

When the receptor potential rises **above** the **threshold**, action potentials appear. The **greater** the **intensity** of the stimulus, the **greater** the receptor potential, and the **greater** the amount of generated action potentials is.

⇨ As seen in this figure, when the membrane receptor potential increased **above** the threshold, action potential was generated. The frequency of action potentials **increased** in **proportion** with the increased **intensity** of the stimulus.



Extra:

GRADED POTENTIALS	ACTION POTENTIALS
Graded potential change; magnitude varies with magnitude of triggering event	All-or-none membrane response; magnitude of triggering event coded in frequency rather than amplitude of action potentials
Duration varies with duration of triggering event	Constant duration
Decremental conduction; magnitude diminishes with distance from initial site	Propagated throughout membrane in undiminishing fashion
Passive spread to neighboring inactive areas of membrane	Self-regeneration in neighboring inactive areas of membrane
No refractory period	Refractory period
Can be summed	Summation impossible

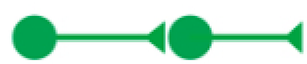
Somatosensory pathway

- Information is received through receptors inside or at the surface of the body. This information, about pain, temperature, touch, position, and vibration, are processed throughout the somatosensory pathway.
  - ⇨ Signals are **transmitted** by **axons** (white matter) and **processed** in **cell bodies** (ganglia / nucleus).
- Sensory pathways consist of a **chain of neurons**, from the receptor reaching the brain.
  - ⇨ The number of neurons making up a pathway solely depends on the **complexity** of the signal; i.e. as the complexity of the signal **increases**, the number of neurons in a pathway **increase**.

Types of sensory pathways

The main three pathways are:

1- **Linear**: allows **one** neuron to relay information to the following **one** in a linear manner. This pathway causes the signals to be **more precise**.



2- **Convergence**: allows a **neuron** to receive input from **many** neurons. In this pathway, the summation of inputs facilitates detecting **low** sensations, however, it **decreases preciseness** and **discrimination** of signals.

Convergence/divergence

3- **Divergence**: allows **one** neuron to communicate with **many** other neurons.

Sensation destination

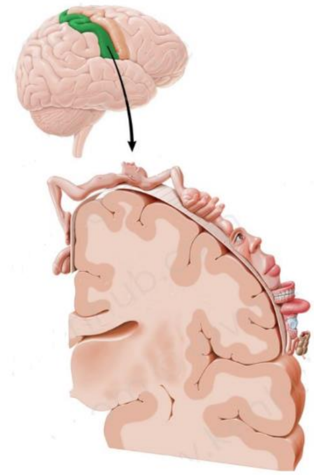
1- **Cortex** 'mainly': **perception, consciousness, and voluntary activities.**

2- **Subcortex: unconscious involuntary reactions**, e.g. unconsciously, we react to the smell, sight and even thought of food with increased secretion of saliva.

3- **Spinal cord**: **quick spinal reflexes**.

Cortical Representation

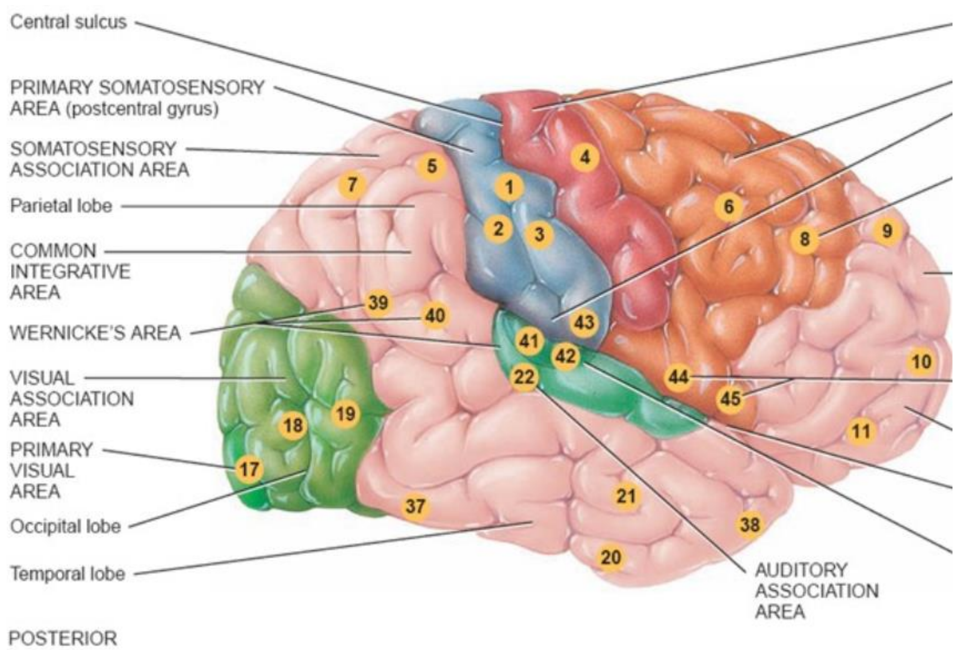
- A cortical map is a representation of the human body within the brain, **based on the nerves** dedicated to processing motor functions, or sensory functions, for different parts of the body.



- Nerve fibers conducting **somatosensory information** from all over the body, terminate in an area of the **parietal lobe** in the **cerebral cortex**, which is known as the **primary somatosensory area** (physiologically) or the **postcentral gyrus** (anatomically).

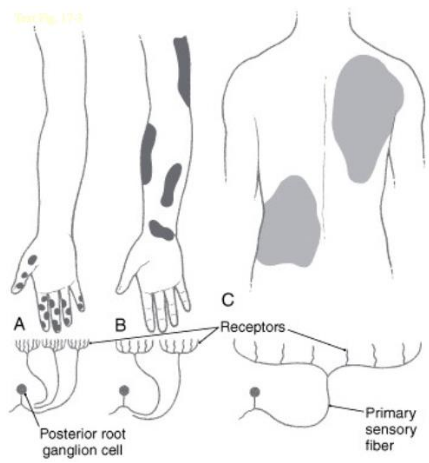
  Note: gyrus is the term used for the **prominent** raise or outward fold in the brain. On the other hand, the **sulcus** is the **depression** or the shallow groove surrounding the gyrus.

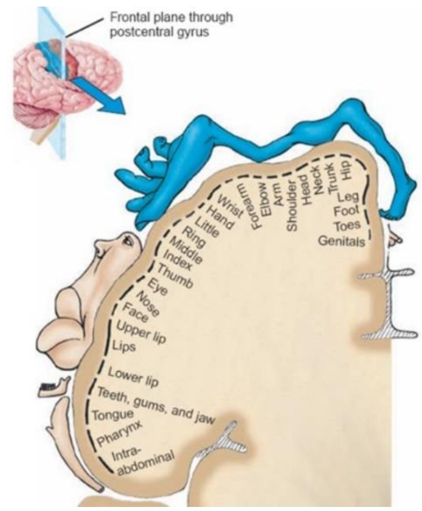
- Brodmann, a German anatomist, divided the areas of the cerebral cortex based on **histological** features and numbered them. **Brodmann areas 1, 2 and 3** comprise the primary somatosensory cortex of the human brain.



The relationship between cortical representation and receptive fields:

The receptive field is a **portion of sensory space** that can elicit neuronal responses when stimulated.





The **greater** the **density** of sensory receptors on a body part, the **smaller** the required **receptive field** is. This relationship allows **better discrimination** in sensory inputs.

In the **cortex**, the **smaller** the **receptive** area, the **larger** its represented **cortical area** is and vice versa.

- ⇨ **For example:** the hand has a **high** density of receptors, thus its receptive area is **small** while its cortical area representation is **large** as seen in the picture above.

Sensation Modalities

- Stimulation of a receptor usually produces one sensation; receptors are modality-specific. An exception is the free nerve ending sensory receptors, in which they can sense more than one sensory modality.

- There are 2 types of sensation modalities:

  1- **Fast** → Sensations are transmitted through the **'Posterior column-medial lemniscus'**. It detects:

  a- Proprioception: the ability to know where and how your body's orientation.
  b- Fine touch and pressure (two-point discrimination).
  c- Vibration

  2- **Slow** → Sensations are transmitted through the **'Anterolateral system'** (also known as the spinothalamic pathway). It detects:

  a- Temperature
  b- Crude touch and pressure (itching)
  c- Pain

> **Note**: **Fine touch** (or discriminative touch) allows a subject to sense and **localize** touch. It permits 'Two-point discrimination', which is the ability to **distinguish** that two nearby objects touching the skin are truly two distinct points, not one.
>
> **Crude touch** (or non-discriminative touch) allows the subject to sense that something has touched them, **without** being able to localize where they were touched.

- **Labeled line theory**: it suggests that each sensory modality is processed throughout a fixed, direct-line communication system from the skin to the brain.

⇨ **In conclusion**:

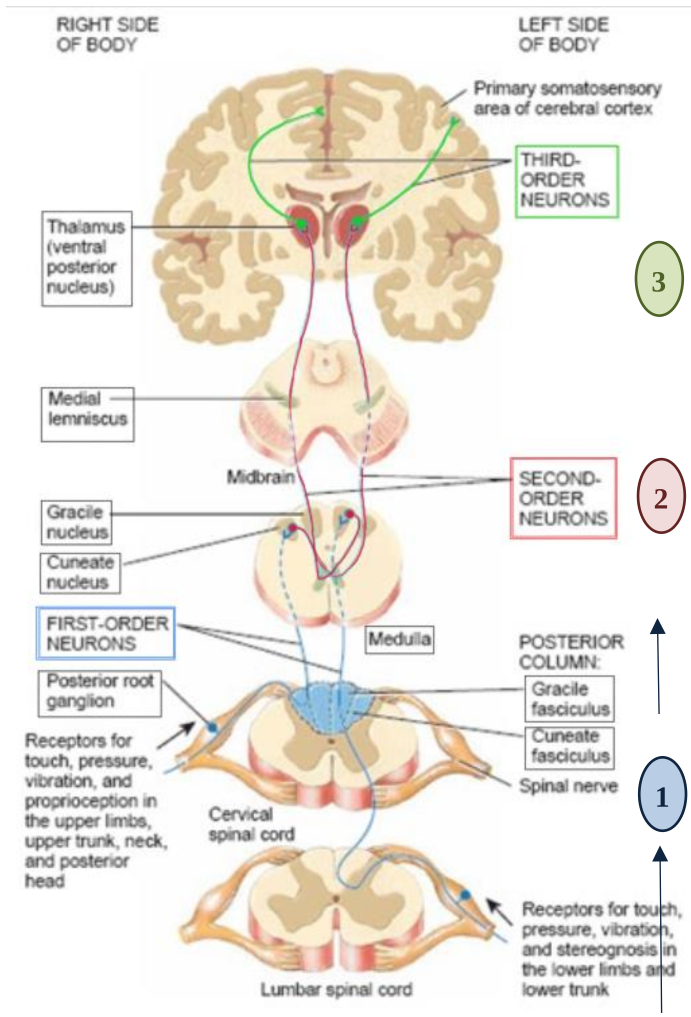
Fast modalities are transmitted by the **Posterior column-medial lemniscus pathway**. Whereas **slow** modalities are transmitted by the **Anterolateral pathway**.

Now, we will discuss major **ascending** (from the body to the brain) sensory pathway in details:

1- Posterior column-medial lemniscus (PCML)

This pathway conveys sensations of **fine touch**, two-point discrimination, **vibration**, and **proprioception**. It transmits information from the body to the **primary somatosensory cortex** in the postcentral gyrus of the parietal lobe of the brain.

1- First-order neurons 'blue':



The first-order neurons are pseudounipolar sensory neurons that pass through the **dorsal root ganglia** and send their afferent fibers through the **two posterior columns / tracts** of white matter: the **gracile fasciculus** (lower body) and the **cuneate fasciculus** (upper body).

> **Note:** The **gracile fasciculus** is present **throughout** the length of the spinal cord and contains **afferents** from the **lower** trunk (below the T6). The **cuneate fasciculus** is present **laterally** to the gracile fasciculus **only** in the **upper** thoracic and **cervical** spinal cord segments (above T6) and contains **afferents** from the **upper** trunk.

2- Second-order neurons 'red':

The first-order axons synapse with second-order neurons in the **medulla**. First-order axons of the gracile tract and the cuneate tract synapse with the posterior nuclei- **gracile nucleus** and the **cuneate nucleus**- in the medulla respectively (these nuclei contain the cell bodies of the second-order neurons).

The **axons of second-order neurons** that leave the gracile and cuneate nuclei of the medulla are called **'internal arcuate fibers'**. Upon **crossing** (decussation) from one side of the medulla to the other, they ascend as **'medial lemniscus'**, i.e. the medial lemniscus is a large ascending bundle of secondary-order axons that **decussated** in the medulla.

> **Note**: processing in the PCML does not occur along the spinal cord, it occurs starting from the medulla where synapse between first and second-order neurons happens.

3- **Third-order neurons 'green':**

The second-order neurons bundle of axons (medial lemniscus) synapse with the third-order neurons in the **thalamus** (ventral posterolateral nucleus) where further processing occurs. The third-order neurons fibers ascend to the **'primary somatosensory area'**.

> **Note**: the **thalamus** is responsible for processing most of the **somatosensory** signals.

⇨ **Summary of the PCML pathway:** The pathway receives information from sensory receptors throughout the body, and carries this in nerve tracts in the **white matter** of the **dorsal columns** of the spinal cord to the **medulla**, where it is continued as the **medial lemniscus**, on to the **thalamus** and from there to the **primary somatosensory area**.

PCML Function

As mentioned, PCML conveys sensations of two-point discrimination, vibration, and proprioception. Thus, it is important for:

1- **Stereognosis**: the ability to perceive and recognize the form of an object in the absence of visual and auditory information.

2- **Graphesthesia**: the ability to recognize writings on the skin by the sensation of touch.

3- **Movement** and **weight recognition**.

PCML lesion associated symptoms 'lesions in the posterior columns'

Dysfunction of the PCML pathways causes loss of two-point discrimination, vibration, and proprioception sensations. This causes:

1- **Astereognosis.**

2- **Agraphesthesia.**

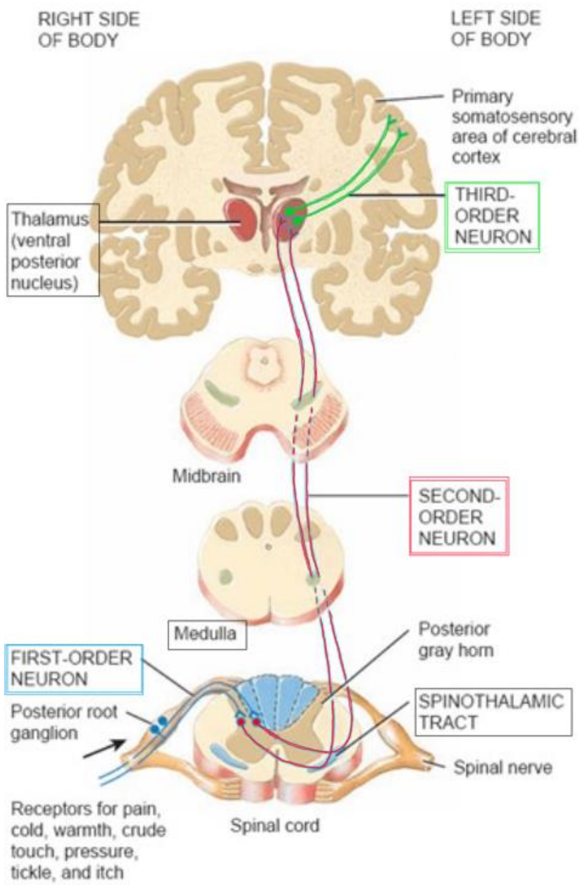
3- **Abarognosis**: loss of the ability to detect the weight of an object held in the hand or to tell the difference in weight between two objects, i.e. loss of the ability to sense weight.

4- **Sensory Ataxia**: it is a form of ataxia (loss of coordination) caused not by cerebellar dysfunction but by loss of sensory input into the control of movement.

   Note: Ataxia is the lack of voluntary coordination of muscle movements that can cause gait abnormality, speech changes, and abnormalities in eye movements.

2- Anterolateral system (Spinothalamic tract)

This pathway conveys sensations of **pain, temperature, and crude touch**. The spinothalamic tract, like the dorsal column medial lemniscus pathway, uses three neurons to convey sensory information from the periphery to conscious level at the cerebral cortex:



1- **First-order pseudounipolar neurons** located within the dorsal root ganglion extend from the skin to the **posterior gray horn** of the spinal cord.

2- First-order neurons synapse with the **nuclei of the second-order neurons** in the **grey matter** of the spinal cord.

3- The axons of the secondary neurons **cross** over (decussate) to the other side in the **spinal cord**. The axons travel up the length of the spinal cord through the **spinothalamic tract** (which is present in the ventral column) into the **medulla**.

> **Note**: the **PCML** pathway fibers ascend in the spinal cord through the **posterior column** (gracile and cuneate tracts), whereas in the **anterolateral** system, they ascend through the **anterior column** (spinothalamic tract).

4- Traveling up the medulla, the tract moves dorsally. The neurons ultimately synapse with **third-order neurons** in the **thalamus**. From there, signals go to the **primary somatosensory cortex**.

⇨ Notice: the **second-order neurons** in both pathways, PCML and the anterolateral, are where crossing-over (decussation) and processing happen.

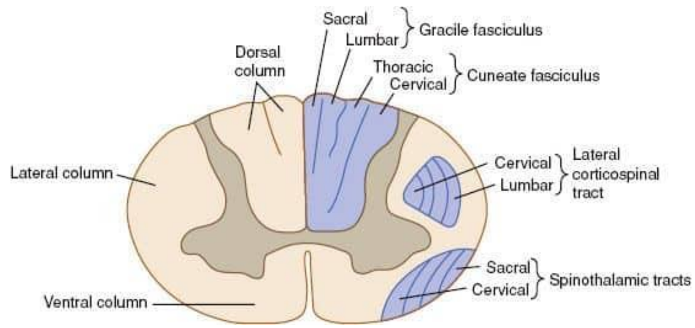
a- **PCML pathway**: decussation of 2nd order neurons occur in the **lower medulla**.
b- **Anterolateral pathway**: decussation of 2nd order neurons occurs in the **spinal cord**.

Somatotopic Arrangement

- Somatotopy is the point-for-point correspondence of an area of the body to a specific point on the central nervous system.

1- In the spinal cord:

In the PCML pathway**, a**s we **ascend** in the **spinal cord**, fibers are added **laterally**. Thus, as seen in the picture, the **lower extremities** are **medially** represented then fibers are added **laterally** as we ascend to the **upper extremities**.



⇨ Medial to lateral:
Legs → Trunk → Arms → Neck

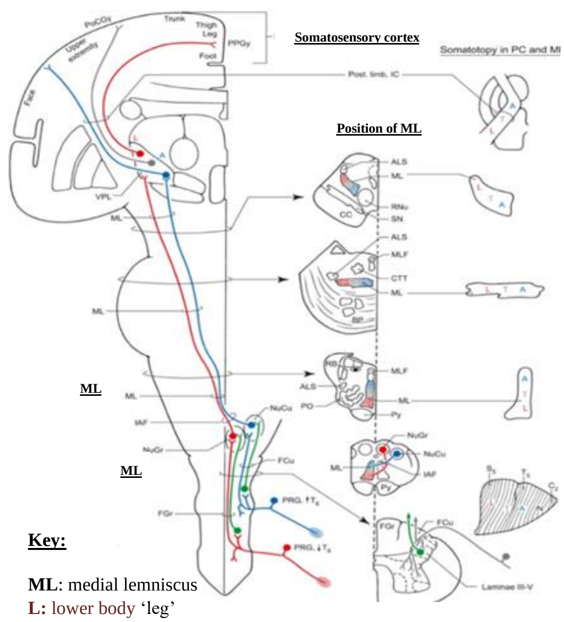
As for the **Anterolateral pathway**, it is the opposite; fibers are added **medially**.

2- Subcortex: *'this is for the PCML pathway only, the picture to the right represents the PCML pathway, check slide 34 for the anterolateral system'*

At first, the medial lemniscus in the **lower part** of the brainstem is oriented in which the fibers from the **lower body 'red'** are **anterior**, whereas the **upper body 'blue'** is **posterior.**

Then, the medial lemniscus rotates where the fibers of the **lower body** become **lateral**, whereas the **upper body** becomes **medial**.

Finally, in the **upper part** of the brain stem, the medial lemniscus further rotates. The **lower body** fibers end up being **posterolateral** and the **upper body** remains **medial**.



Key:

ML: medial lemniscus
L: lower body 'leg'
T: trunk
A: upper body 'arm'

> **Note**: in the **anterolateral** system the fibers ascend directly with the **upper body** being **medially**, whereas the **lower body** is **lateral;** similar to the spinal cord.

3- In the cortex: *'in both pathways'*

Somatosensory information that arrives at the thalamus is brought to the primary somatosensory cortex. In the cortex, similar to the spinal cord, the information is somatotopically organized with the **upper extremities** (e.g. face) also being **most lateral**, whereas the **lower extremities** (e.g. legs) are **most medial**.

⇨ Being able to visualize the somatotropic organization of the body is important clinically to distinguish what would an injury to the CNS cause. For example, if there is a **medial** injury in the medial lemniscus of the **upper** brain stem, then the loss of sensations will affect the **upper body**.

Clinical Aspects

1- Injury in the spinal cord:

- Recall that, decussation of fibers in the **PCML** pathways occurs in the **medulla**, whereas decussation in the **anterolateral** pathway occurs **almost** at the level of sensation in the **spinal cord**. Therefore ↓ :

  ⇨ Injury to the posterior and anterior columns (in the spinal cord) on one side results in:

  a- Loss of **PCML** sensations (proprioception, discriminative touch, and vibration) **below** the level of the lesion on the **same side**.

  b- Loss of **Anterolateral** sensations (pain, temperature, and crude touch) **below** the level of the lesion on the **opposite** side.

- Recall that, in the posterior columns, the **gracile fasciculus** is present **throughout** the length of the spinal cord and contains afferents from the **lower trunk** (below the T6), while the **cuneate fasciculus** is present laterally to the gracile fasciculus only in the **upper** thoracic and cervical spinal cord segments (above T6) and contains afferents from the **upper trunk**.

  ⇨ Therefore, when the injury of the spinal cord is at the **cervical level**, consequently, **both** the **upper** and **lower** trunks PCML sensations will be affected. Whereas if the injury is at the **lumbar** level, **only** the **lower** trunk will be affected sparing the upper trunk.

Example 1: Injury of a **lumbar segment** on the **right side:**

➔ affect **lower** trunk only: loss of **PCML** sensations on the **right** side and loss of **anterolateral** sensations on the **left** side.

Example 2: Injury to the **upper cervical** segment on the **right side**:

➔ affect **lower** and **upper** trunk: loss of **PCML** sensations on the **right** side and loss of **anterolateral** sensations on the **left** side.

2- Injury in the brainstem (medulla) or higher:

- If a lesion occurs in the **brainstem** (medulla) or **higher**, the patient presents with **loss** of both, the **anterolateral** and **PCML** pathways, sensations on the **opposite** side; since the decussation in both pathways already occurred.

Good Luck