CNS

Anatomy

Sheet

Slide

Number

10

Done by:

Moayyad Al-Shafei

Corrected by:

Omar Sami

Doctor:

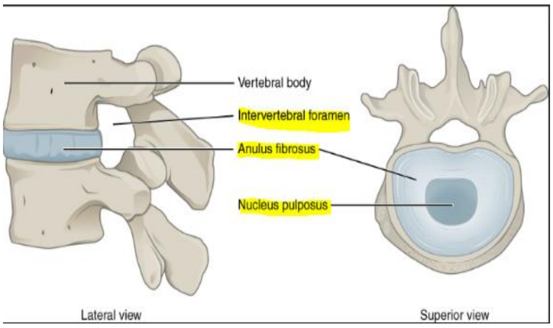
Muhammad Al-Salem

In today's lecture, we are going to cover the following topics:

1- Intervertebral disc herniation.
2- Cross section in the spinal cord.
3- And Sensory system (including the receptors, and an introduction into the sensory pathway).

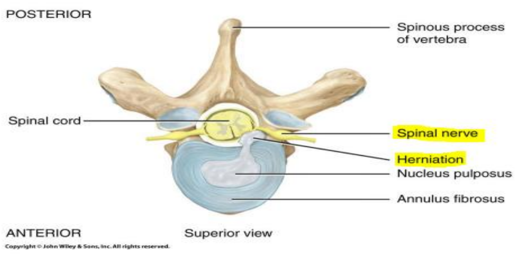
Now, starting with the Intervertebral disc herniation:

We said that the vertebral column is composed of vertebra, and between each 2 successive vertebrae, intervertebral disc is located, which is composed of:



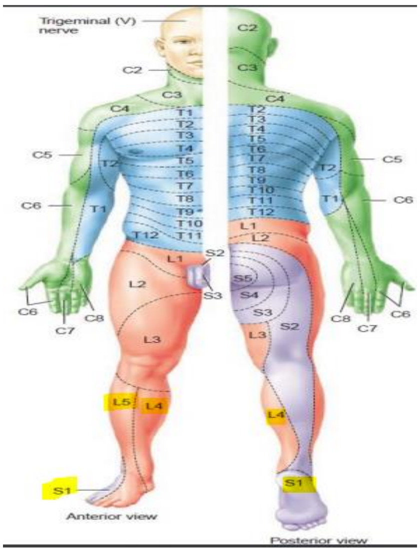
1- A central core of **Nucleus pulposus.**
2- And a surrounding fibrous lamina that is called **Annulus fibrosus**.

Any defect within the Annulus fibrosus, will lead to the protrusion (leakage) of the gelatinous nucleus pulposus through the defected anulus fibrosus of IV disc. The herniation mainly occurs Posterolaterally, due to the thinner annulus fibrosus. The herniated nucleus pulposus will cause a pressure on the spinal nerve that emerges from the IV foramen, causing clinical symptoms which are related to the spinal root that is affected.



NOW what are these symptoms? And how can we test them?

To be able to diagnose the disc herniation, you must understand what is meant by dermatomes and myotomes (mentioned in the last lecture, but to recap; A **dermatome** is an area of skin that is mainly supplied by a single spinal nerve, while a **myotome** is the group of muscles that



a single spinal nerve innervates). So, we expect to find specific symptoms (abnormal muscle reflex in a certain myotome and pain sensation in a certain dermatome) according to the affected nerve. The figure here shows the distribution map of dermatomes, and fortunately, they are not for memorization (in anatomy) except for the highlighted ones which we will discuss in the coming pages. **We will discuss only the L3-L4, L4-L5, and L5-S1 IVD herniations**.

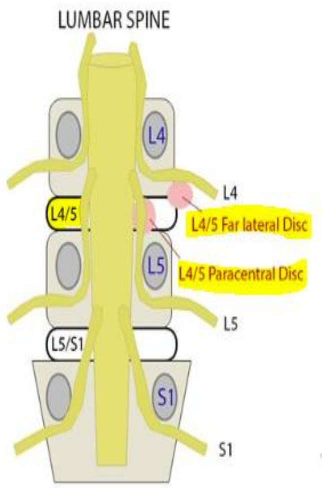
The doctor keeps using spinal roots instead of spinal nerves, but to be specific, the spinal nerve is composed of spinal roots(sensory and motor) so both sensory and motor roots of the spinal nerve are affected.

1-L3-L4, IVD herniation(3-10)%:

Firstly, what is the affected spinal root?

In most of the cases **L4 is affected;** though We expect it to be L3, and it could be. But Why **L4**? Here is an extra note:

You must know that the spinal nerve leaves the intervertebral foramen **from the upper part above the level of the interventricular disc** (for example nerve of L4 will leave above IVD L4-L5) as seen here.



Also, we can see from the figure here, that the affected nerve depends on the exact location where the herniation occurs. So, in most of the cases, a symptomatic **posterolateral** herniation between two vertebrae will actually impinge on the nerve exiting at the next intervertebral foramen down. While if the herniation is **far lateral**, it will impinge on the nerve exiting at the same IV foramen. (look at the figure)

The posterolateral one is the only case that is required from us, so if you are asked about a herniation in the L3-L4 IVD, you will expect L4 spinal nerve to be affected.

Now, what are the **symptoms** of such a herniation?

The patient will manifest **a weakness in muscle reflexes** in those muscles that are innervated via L4 spinal nerve (myotome), and they will **feel numbness** in the skin that is innervated via this nerve (dermatome).

So, if the L4 root is impinged, the patient will manifest a weakness in the muscles, mainly the **quadriceps muscle which extends the knee joint**. As we know from the MSS, the Quadriceps Femoris muscle is innervated by the **femoral nerve** which originates from the L2, L3 and L4 roots of spinal cord.

And we can test the aforementioned myotome by a test called "**Knee Jerk**" which is done by a sudden kicking movement of the lower leg in response to a sharp tap on the patellar tendon, which lies just below the knee. If the knee extends in response to this test, the root is almost normal, while if the reflex is weak, we expect the root to be impinged (mainly by IVD herniation).

In addition to the myotome, the patient will suffer from abnormal sensation in the **anteromedial side of the leg** (L4 root dermatome, which is highlighted in the dermatomes map above) which is innervated by the **saphenous nerve**, which is a branch of the femoral nerve (L2,L3,L4). (*Notice that there is a sensory impairment rather than sensation loss, as the later occurs when there is a complete cut of nerve*).

In clinical trials involving animals, researchers often press a certain nerve (Sciatic for example), and then follow up the symptoms that appear, including myotomes and dermatomes that are affected.

To recap:

Disc	Root	Percentage	Motor weakness	Sensory changes	Reflex affected
L3-L4	L4	3-10%	Knee extension (Quadriceps femoris)	Anteriomedial leg (saphenous)	Knee jerk

2-L4-L5 IVD herniation (40-45)% very common:

Firstly, what is the affected spinal root? It is L5

And such a herniation will press the root of L5 causing muscle weakness, mainly in **Extensor Hallucis longus and Tibialis Anterior muscles**, both are found in Anterior compartment of the leg and act **to extend the foot (Dorsiflexion** which is the movement of the foot upwards, so that the foot is closer to the shin.). Notice that the extension and flexion don't have the same orientation in the upper and lower limb (actually, they are opposing each other).

And it is common to ask your patient to **stand on his heels** (dorsiflex his foot) upon testing this root (L5). If the patient could, then the root is not pressed. But if they found a difficulty to do so, then we expect the herniation.

In addition to the muscle weakness, the patient will suffer from abnormal sensation in the **anterolateral side of the** leg (L5 root dermatome, which is highlighted in the map above) which is innervated by the **superficial peroneal (or the common Peroneal),** which is the son of the sciatic nerve that has the root value of L4-S3.

To recap:

Disc	Root	Percentage	Motor weakness	Sensory changes	Reflex affected
L4-L5	L5	40-45%	Big toe dorsifelxion (EHL) and TA	Big toe , anteriolateral leg (Common P)	Hamstring jerk

But notice that the hamstring jerk is not included, as there is a conflict if it does occur or not.

3- L5-S1 IVD herniation (45-50)%, the commonest:

Firstly, what is the affected spinal root? It is S1

And such a herniation will press the root of **S1** causing muscle weakness, mainly in the **Gastrocnemius**, which is found in posterior compartment of the leg and **act to flex the foot (Plantar flexion);** which is a movement in which the top of your foot points away from your leg.

And it is common to ask your patient **to stand on his tiptoes** (plantar flex his foot) upon testing this root (S1). If the patient could, then the root is not pressed. But if they found a difficulty to do so, then we expect the herniation.

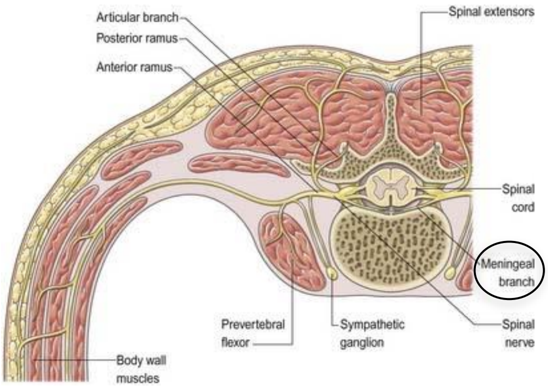
Or by doing **the ankle jerk reflex**, also known as **the Achilles reflex**, which occurs when the Achilles tendon is tapped while the foot is dorsiflexed. It is a type of stretch reflex that tests the function of the gastrocnemius muscle and the nerve that supplies it.

In addition to the muscle weakness, the patient will suffer from abnormal sensation in the **lateral aspect of the foot (S1** root dermatome, which is highlighted in the map above) which is innervated by the **Sural nerve**, a branch of Tibial nerve. And the Tibial is the other son of sciatic nerve that has the root value of L4-S3.

To recap:

Disc	Root	Percentage	Motor weakness	Sensory changes	Reflex affected
L5-S1	S1	45-50%	Foot planter flextion (Gastrocnemius)	Lateral border of foot (sural)	Ankle jerk

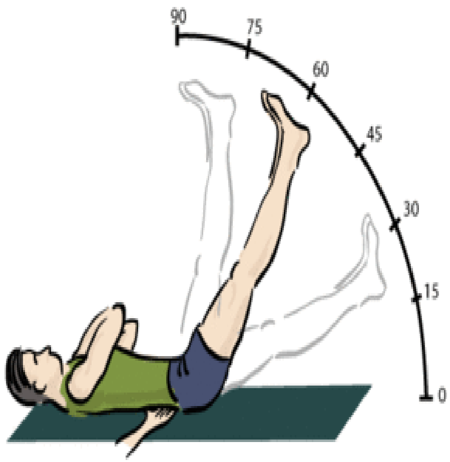
Including the previous symptoms of the IVD herniations, the patient will suffer from **Low pack pain**. And this pain is not specific for IVD herniation (It may occur with other situations, such as tumours and muscle spasm).



The cause behind this pain is that the spinal nerve, once exits the intervertebral foramen, will give a recurrent meningeal branch which goes back into the vertebral canal to supply the meninges (specifically the dura matter, the outermost layer). The dura matter is sensitive to stretch.

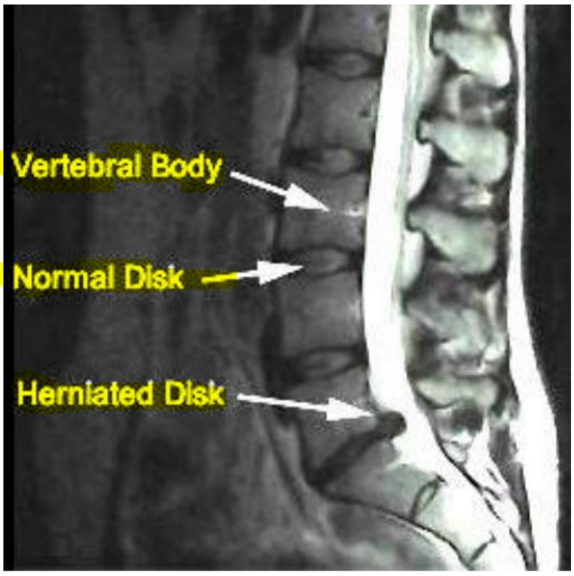
So, herniations will exert a pressure on the spinal nerve and on the dura as well, causing the pain.

And this pain can be determined by a test that is called **Straight Leg Raise Test (SLR),** (the name suggests the nature of the test), in which you lift the patient's fully extended leg. The test depends on the sciatic nerve (L4-S3), which is the largest nerve in the body. The goldstone behind this test is that when patient's leg is raised, the sciatic nerve will be tensed, which in turn tenses the dura matter with it (it is sensitive for stretch), giving the patient the feeling of low back pain.



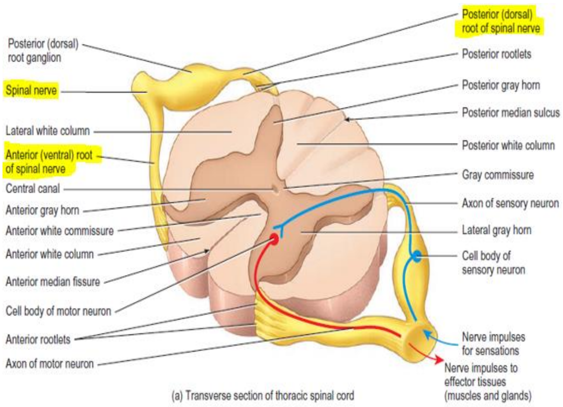
The angle to which the leg is raised, upon the feeling of pain, is very important. If the pain starts early (less than 30 degrees), we expect a far more dangerous problem (such as tumours). Usually, low back pain, that is associated with disc herniation, appears between 30-70 degrees.

All the previous tests are not enough to diagnose IVD herniations (they are sensitive but not specific). We must do an MRI to rule out other causes. We can observe, from the following MRI image, the normal vertebra and the IVD. We can also observe How a herniated disk is bulging into the spinal cord.

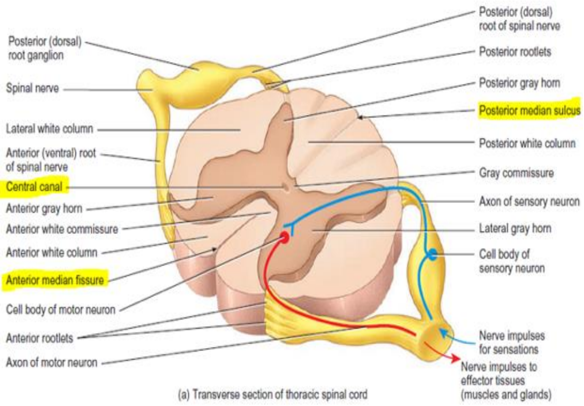


We are done with the IVD herniation, and we will go back to the spinal cord and study its cross section.

After observing the cross section in the spinal cord, we can notice that dorsal and ventral roots will join each other to form the spinal nerve. Also, it is arranged into outer White matter that surrounds the inner Grey matter.

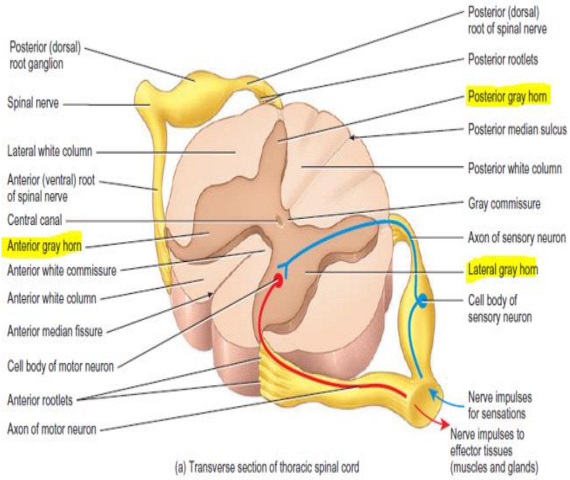


Some gross anatomy is noticed also:



1. **Anterior median fissure**: which is a wide groove on the anterior aspect.
2. **Posterior median sulcus**: Narrow groove on the posterior Aspect. _*Fissure is a deep sulcus*_.
3. In the centre, we have the **central canal** which:
   a- Represents the Cavity of the spinal cord.
   b- Is a Continuation of the 4th ventricle of the brain.
   c- Is Lined by ependymal cells, and
   d- within it, the CSF circulates.

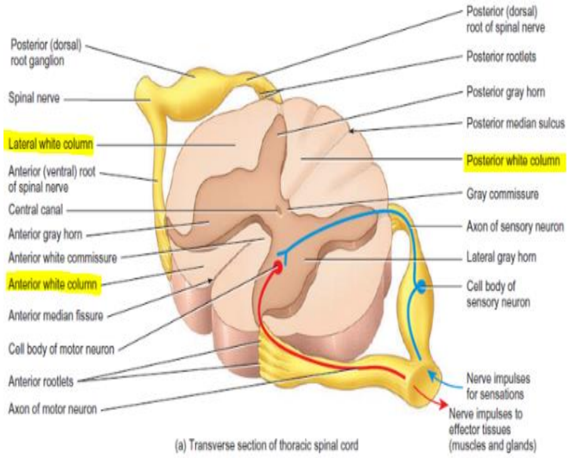
We divided the grey matter (which resembles a butterfly shape or letter H) **into horns:**



A. <u>ventral</u> (anterior) horn which is motor that contains cell bodies of lower motor neurons.
B. <u>Lateral</u> horn (in some segments, thoracic and upper lumber) which is autonomic.
C. And <u>dorsal</u> (posterior) horn which is sensory.

The white matter also is divided into columns;

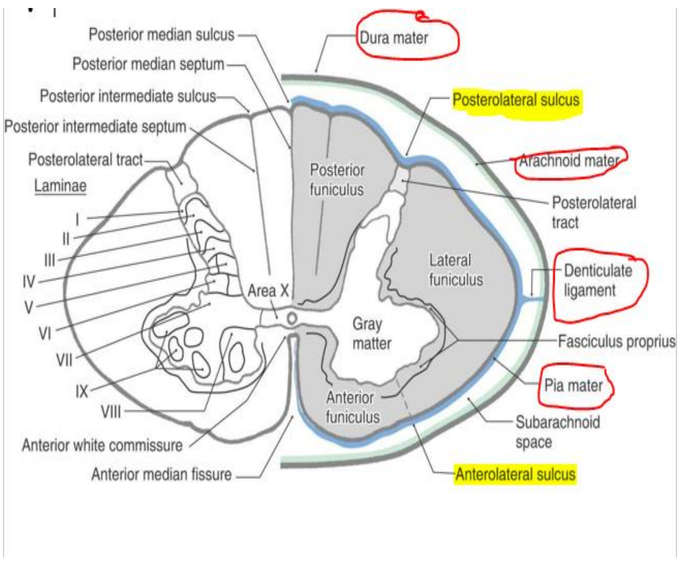
A. Anterior white column.
B. lateral white column (some people combine them as anterolateral system due to similarities existing between them).
C. Posterior white column.



As you know that the grey matter contains cell bodies, while white matter is occupied by myelinated axons (they are called tracts within the CNS), which are either:

1. Ascending (sensory) tracts.
2. Descending (motor) tracts.

Here we can also notice the posterolateral and anterolateral sulci from which the sensory (dorsal) and motor (ventral) roots of spinal nerve originate; respectively.
It is fine to remember the meninges, as they are very clear in this section. Notice also the denticulate ligament!



Notice also that the grey matter of the spinal cord used to be subdivided into many nuclei, until “Rexed”, a neuroscientist, made new classification and divided the grey matter into ten laminae: the dorsal horn consists of laminae 1- 7 (where laminae **7 forms the base** of the dorsal horn), the ventral horn consists of laminae 8 and 9 (related to the motor system), and lamina 10 is around the central canal.

All the tracts that we are going to study can be elaborated upon the following figure:

1)Sensory tracts are:

A. ***Posterior white column system*** (involved in the Posterior White Column-Medial Lemniscal Pathway (PCML)); divided into:

I. Gracile fasciculus.

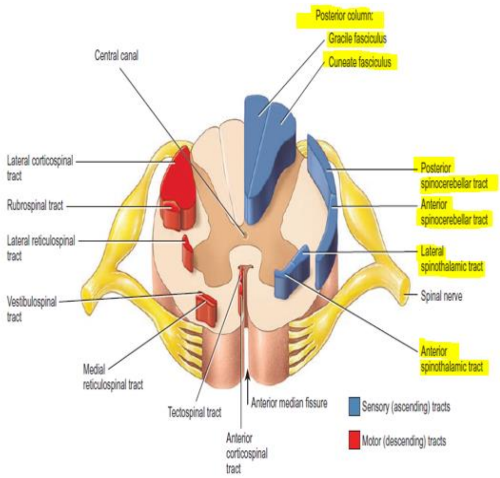
II. Cuneate fasciculus.

B. ***Posterior spinocerebellar tract*** “spinal cord to cerebellum”

C. ***Anterior spinocerebellar***

D. ***Lateral spinothalamic tract*** “spinal cord to thalamus”

E. ***Anterior spinothalamic tract***



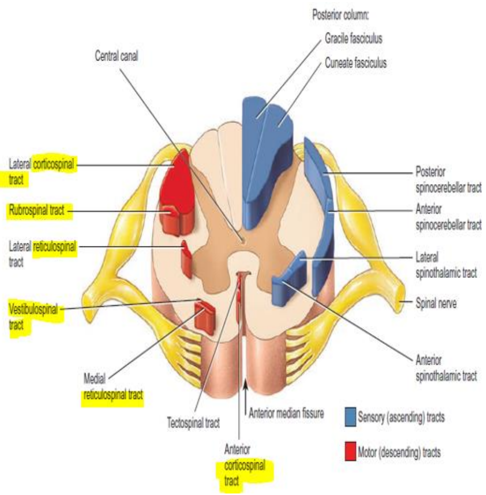
2) Motor Tracts (they will be discussed later) :

A. ***corticospinal tract*** “from cortex to spinal cord”.

B. ***Rubrospinal*** “from red nucleus to spinal cord”.

C. ***Reticulospinal*** “from reticular formation to spinal cord”.

D. ***Vestibulospinal tract*** “from the vestibular nucleus to the spinal cord”.



Before we start talking about the sensory pathways, there are some principles that we need to know:

- The sensory system always begins with a **<u>receptor</u>**. *A receptor is defined by its ability to turn certain kinds of energy into action potentials.*
- **<u>Adaption</u>** is the response of a receptor to a continuous stimulus by decreasing its sensitivity. Adaptive receptors are generally categorized into two types (remember that there are non-adaptive receptors):
  1. **Rapidly adapting**: signals fade away after stimulus exposure, best at detecting rapidly changing signals.
  2. **Slowly adapting**: signals are transmitted as long as the stimulus is present, they are for detecting long, continuous signals.
- Since there are multiple forms of energy, we have different groups of receptors:

1- Receptors sensing <u>mechanical energy</u> (e.g. touch, pressure, stretch…etc.) are called **<u>Mechanoreceptors</u>**. This group comprises (the doctor said you should at least know the names as there are controversies regarding their functions. *However, he read them all, so I copied them here)*:

a) <u>Meissner's corpuscle:</u>

➢ Respond to touch, pressure and low frequency vibration (low frequency)

➢ rapidly adapting

b) <u>Merkel's disc (Tactile Disc)</u>

➢ Discriminative touch

➢ Slowly adapting

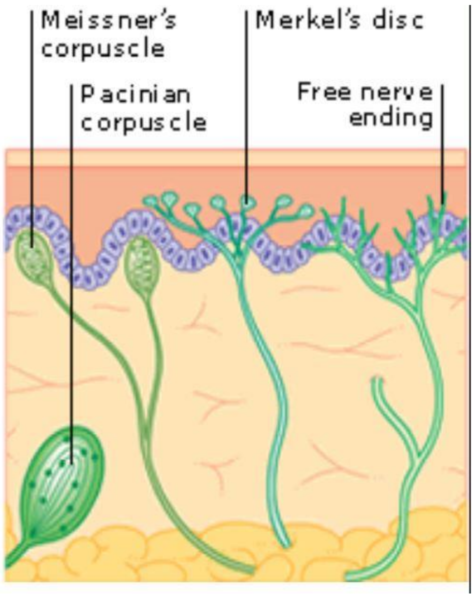
c) <u>End organ of Ruffini</u>

➢ sensitive to skin stretch

➢ Slowly adapting

d) <u>Pacinian corpuscles</u>

➢ Vibrations (high frequency) ➢ rapidly adapting.



2- The second group is **<u>Thermoreceptors</u>** and those are specialized in sensing **temperature**. **Free (not-encapsulated) nerve endings** are the main structure in this group. Those endings contain special ion channels that respond to temperature change by a conformational change. This change will affect the ions flow which will affect the action potential. An example of those cannels is a family called the **TRP family** (TRP V1/V2/V3/V4/M…etc.).

3- **Nociceptors** are the last group we are going to talk about. Those receptors sense **pain** (Noci- means pain in Latin). Since there is no energy called pain in nature; what those receptors really detect are **the extremes and exaggerated forms of energies**, such as: extreme temperature (either hot or cold), extreme pressure…etc. and that's why they are called **multimodal**, because they can sense multiple forms of energy.

Types of nerve fibers:

Receptors are usually on periphery and the signal is delivered to the CNS by different types of nerve fibers:

TABLE 25.1 Summary of Primary Afferent Fibers and Their Roles

Modality	Submodality	Receptor	Fiber type	Conduction velocity ($m\,s^{-1}$)	Role in perception
Mechanoreception	SAI	Merkel cell	$A\beta$	42–72	Pressure, form, texture
	RA	Meissner corpuscle	$A\beta$	42–72	Flutter, motion
	SAII	Ruffini corpuscle	$A\beta$	42–72	Unknown, possibly skin stretch
	PC	Pacinian corpuscle	$A\beta$	42–72	Vibration
Thermoreception	Warm	Bare nerve endings	C	0.5–1.2	Warmth
	Cold	Bare nerve endings	$A\delta$	12–36	Cold
Nociception	Small, myelinated	Bare nerve endings	$A\delta$	12–36	Sharp pain
	Unmyelinated	Bare nerve endings	C	0.5–1.2	Burning pain
Propioception	Joint afferents	Ruffini-like and paciniform-like endings, bare nerve	$A\beta$	42–72	Protective function against hyperextention
	Golgi tendon organs	Golgi endings	$A\alpha$	72–120	Muscle tension
	Muscle spindles	Type I	$A\alpha$	72–120	Muscle length and velocity
		Type II	$A\beta$	42–72	Muscle length
	SAII	Ruffini corpuscle	$A\beta$	42–72	Joint angle?

- this table is very important as we will go back to it a lot during this course.
- Notice that the numbers are not for memorization however, you should know which one is faster/slower.

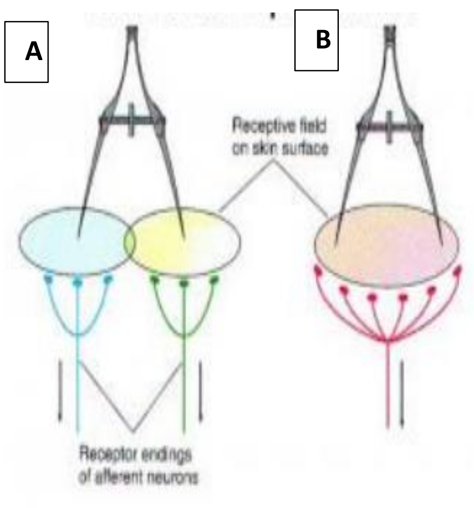
- Notice that as the diameter increases the velocity increases and vice versa.
- Their order from biggest to smallest:
    1. **Aα**: the largest, most myelinated and fastest in conductance.
    2. **Aβ**: smaller, less myelinated and slower than Aα.
    3. **Aδ**: smaller, less myelinated and slower than Aβ.
    4. **C**: the smallest, unmyelinated and conductance here is the slowest.

Receptive field

➢ Every receptor receives sensation from a certain area of the skin, (receptive field).

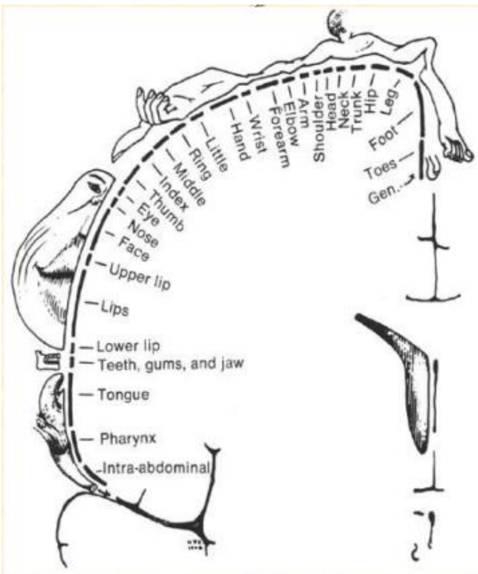
• The greater the density of receptors, the smaller the receptive fields of individual afferent fibre that transmits the information from the receptor toward the brain (pathway).

- In the figure to the right, notice the difference in receptors' density between A&B.
- (A): two stimuli, distant from each other by (x), activate two discrete 1st order neurons. (Higher density of receptors, smaller receptive fields).
- (B): two different stimuli, distant from each other by (x), activate the same 1st order neuron. (Lower density of receptors, larger receptive field).



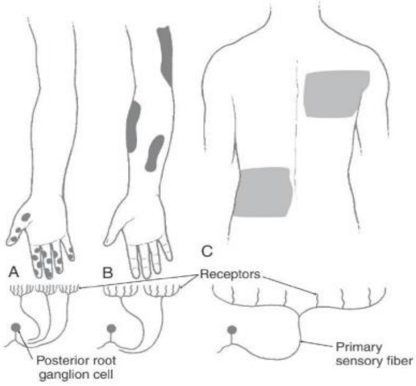
- The **smaller the receptive field the greater is the acuity or the discriminative touch.**
- It is important to recognize 2 main things about the somatosensory cortex:

- That the density of receptors for various parts of the body is not the same which is why **the homunculus** represents different sizes as it extends over the cortex.



- The surface area of the anatomical body part also does not influence the amount of the cortex dedicated to that body part, but rather reflects the density of cutaneous tactile receptors dedicated to that body part.

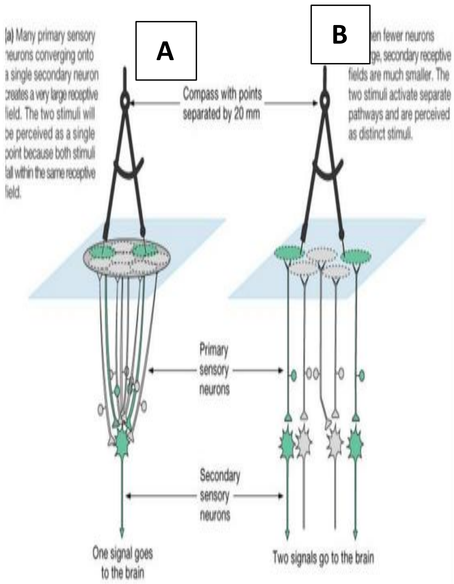
For example, the hand makes up a small surface area compared to the back but yet, has a greater density of receptors which allows hand to differentiate between close stimuli on the contrary to the back, which labelled them as one-point touch.



- Another difference noted in sensory pathways at the level of 2nd order neurons:

As you can see in the figure to the below, in both cases the area of skin has the same density of receptors, but the perception of sensations received from them is still different!

The idea here lies in the different ways of synapses between 1st and 2nd order neurons.



(A): many 1^{st} order neurons synapse on the same 2^{nd} order neuron, so the acuity of sensation is lost.
(B): each 2^{nd} order neuron receives signals from only one (or very small number) of 1^{st} order neurons, which preserves the high acuity of sensation (the area touched is well defined).

Labelled line theory

The function of the receptors is to change certain types of energy into action potential, so how our brain distinguishes the different stimuli (temperature, touch,..) if all what it receives is action potential?!

-Individual receptors preferentially transduce information about an **adequate stimulus**.
➢ Note: **The adequate stimulus** is the amount and type of energy required to stimulate a specific sensory organ.
-Individual primary afferent fibres carry information from a single type of receptors.
-Pathways carrying sensory information centrally are therefore also specific, forming a "labelled line" regarding a particular stimulus. *So, if sensory neuron (X) activates its pathway, the brain will know that the stimulus is high temperature for example, since neuron X has been labelled in the brain as temperature sensor.*

this box may help, you can skip:
The afferent neuron with its peripheral receptor that first detects the stimulus is known as a **first-order sensory neuron.** It synapses on a **second-order sensory neuron,** either in the spinal cord or the medulla, depending on which sensory pathway is involved. This neuron then synapses on a **third-order sensory neuron** in the thalamus, and so on. With each step, the input is processed further.

A **particular sensory modality** detected by a specialized receptor type is sent over **a specific afferent and ascending pathway** (a neural pathway committed to that modality) to excite a **defined area in the somatosensory cortex**—that is, a particular sensory input is **projected** to a specific region of the cortex.

Thus, different types of incoming information are kept separated within specific labeled lines between the periphery and the cortex. In this way, even though all information is propagated to the CNS via the same type of signal (action potentials), the brain can decode the type and location of the stimulus.

Sensation has some characteristics that should be defined: The next table is fine to fully understand the theory, you can skip also>

1. Modality: type of energy.
2. Locality: of the stimulus.
3. Intensity: the frequency of receptor's firing.

TABLE 6-1 Coding of Sensory Information

Stimulus Property	Mechanism of Coding
Type of stimulus (stimulus modality)	Distinguished by the type of receptor activated and the specific pathway over which this information is transmitted to a particular area of the cerebral cortex
Location of stimulus	Distinguished by the location of the activated receptive field and the pathway that is subsequently activated to transmit this information to the area of the somatosensory cortex representing that particular location
Intensity of stimulus (stimulus strength)	Distinguished by the frequency of action potentials initiated in an activated afferent neuron and the number of receptors (and afferent neurons) activated

Now, after we have discussed the receptor’s physiology, and the structure of the spinal cord, we can learn further about the sensory pathways. The first pathway that will be discussed in this sheet is **Posterior White Column-Medial Lemniscal Pathway (PCML**).

Posterior White Column-Medial Lemniscal Pathway (PCML).

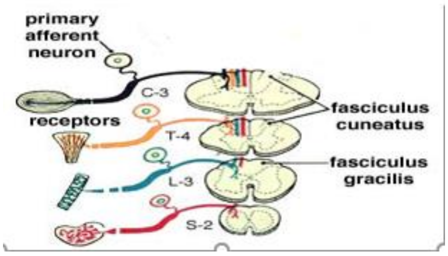
The white matter is divided into 3 columns; anterior, lateral, and posterior. In this pathway, we’re concerned with the posterior column as the first half of the name implies (in a moment, we will be able to understand the last part of the name).

For each pathway, we will study the Modality, receptor, neurons (1st, 2nd, and 3rd order), and the termination.

Modality of the pathway: it's the type of stimuli (energy) that is transported along the pathway, PCML pathway transports stimuli of **discriminative touch** (is the ability to discern that two nearby objects touching the skin are truly two distinct points) (including vibration) and **conscious proprioception** to the cerebral cortex.
Proprioception: it's the sense of position of the body, received by proprioceptors in muscles, tendons, and joints like:
- Muscle spindle receptors, also called intrafusal fibers, these sense stretch (tension) of muscle fibers.
- Golgi tendon apparatus which senses stretch (tension) of tendons.

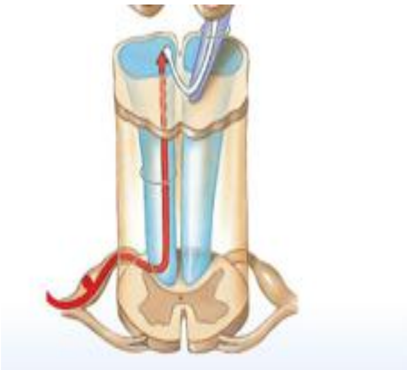
Important note: Most of proprioceptive signals are sent to cerebellum, so they're subconscious (anything that doesn't reach the cerebral cortex is subconscious), but ***proprioception*** transported by PCML pathway reaches the cerebral cortex and that's why it's conscious proprioception.

Receptors of the pathway: this pathway involves all the receptors we have mentioned, except the free nerve endings. Fibres of this pathway are of high velocity (larger diameter). From the table presented earlier, you can see that PCML uses fibres of Aα and Aβ types.



From the receptors, the signals are carried through neurons via a pathway which includes:

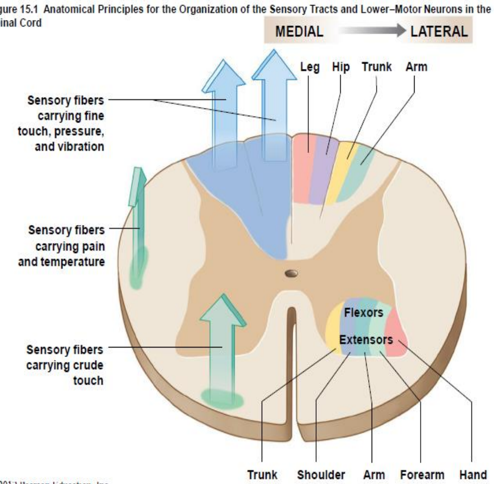
1- **1st order neuron (primary afferent):** since it's a sensory neuron, it's pseudo-unipolar and the body of the neuron is located at the **dorsal root ganglia**.



The peripheral process(dendrites) of the neuron goes to the skin or other tissue where receptors are located. While the central process (axons) of the neuron enters the spinal cord via the dorsal sensory root (not horn), but it doesn't synapse with a 2nd order neuron at the posterior horn, instead it ascends **ipsilaterally** in the posterior white column (hence the name).

And as we mentioned earlier, the Posterior column system is divided into: I. Gracile fasciculus. II. Cuneate fasciculus.

Figure 15.1 Anatomical Principles for the Organization of the Sensory Tracts and Lower-Motor Neurons in the Spinal Cord

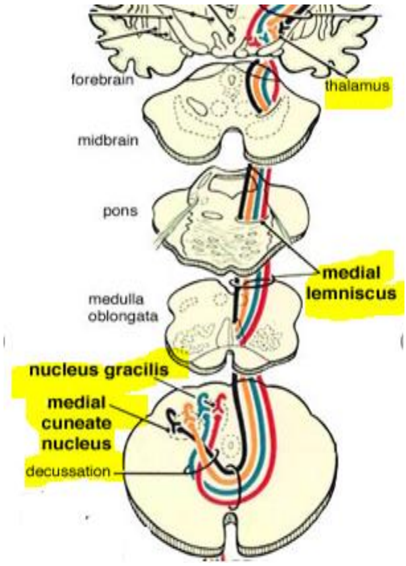


Fibres from *lower parts of the body* are the first to enter the posterior white column, so they *take their position closest to the midline* and start ascending upward ipsilaterally. The next fibres to enter, take positions lateral to the previous ones and so on (medial to lateral rule).*The last fibres to enter* (from the upper part of the body) *will be the most lateral in the posterior white column*. Along the way up, fibres in the posterior white column are divided into two fasciculi (bundles of axons):

- **Fasciculus Gracilis**; medial bundle, which contains fibres from spinal nerves T6 and below.
- **Fasciculus Cuneatus**; lateral bundle (in the posterior column), which contains fibres from spinal nerves above the T6. Fibers in the two fasciculi keep ascending along the posterior white column until they reach the medulla oblongata.

From the previous info, the cuneatus only appear at the level of T6. The lower limb's sensations are carried via Fasciculus Gracilis.

2- 2nd order neuron: in the **lower part of medulla oblongata**, fibres from the posterior white column synapse with two collections of cell bodies (two nuclei): *1- Fibers from fasciculus Gracilis synapse with cell bodies in nucleus Gracilis.*
2- Fibers from fasciculus Cuneatus synapse with cell bodies in nucleus Cuneatus.



The cell bodies in the two nuclei are those of 2nd order neurons. 2nd order neurons cross to the other side (right to left and left to right) in an arch-like manner, that's why they're called internal arcuate fibres (arcuate=arch). While crossing to the other side, internal arcuate fibres **form the major sensory decussation.**

After decussation and complete crossing, internal arcuate fibers ascend in the brain stem as a bundle of axons close to the midline, this bundle is called medial lemniscus (lemniscus is similar to fasciculus but crescent in shape, and from this, the last part of the name is originated). Then fibers leave the brain stem and enter the thalamus, precisely in VPL (ventro-postero-lateral) nucleus of the thalamus.

3- **3rd order neuron:** fibres of 2nd order neurons synapse with cell bodies of the 3rd order neurons in VPL nucleus in the thalamus. The thalamus is a relay station (secretary) for any pathway that reach the cerebral cortex (the big boss).
Then fibres of 3rd order neurons are projected to cerebral cortex. During projection, the fibres through the internal capsule, surrounded medially by the thalamus and caudate nucleus and laterally by lentiform nucleus. The internal capsule is very important because it is narrow and well surrounded by structures, so it's a common site for a stroke to affect this area producing sensory or motor deficits (motor fibres pass there too but they're not of the PCML system). Fibres of PCML mainly pass in the posterior limb of internal capsule.

Termination: Primary Somesthetic Area.