CENTRAL NERVOUS SYSTEM

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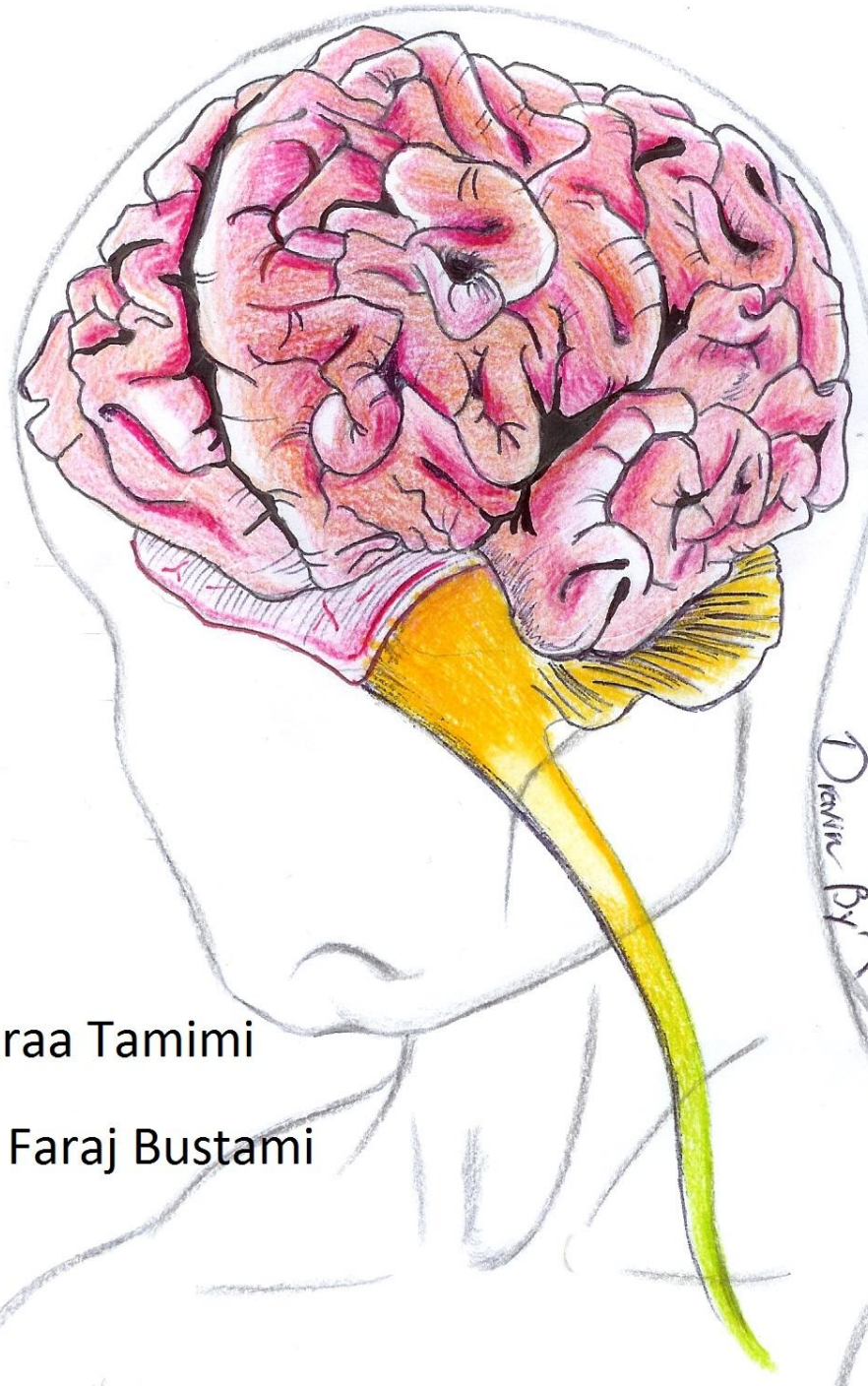

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Sensory Pathways

The Dorsal Column Medial Lemniscal System:

In the last lecture we started talking about the Dorsal Column Medial Lemniscal System, the second major sensory pathway. There are two concepts to consider: the old concept and the new concept.

The old concept: Like any sensory pathway, the Dorsal Column Medial Lemniscal System has first, second, and third order neurons. The first order neuron, as usual, is present in the dorsal root ganglia. Once the first-order neuron approaches the spinal cord, it will divide into medial and dorsal divisions. The Dorsal Column Medial Leminscal System is concerned with the medial division. The type of fibers involved in this pathway are I or II (A-Beta) fibers which are rapidly conducting. These fibers ascend ipsilaterally in the spinal cord. THEY DO NOT CROSS IN SPINAL CORD.

Eventually, they reach the medulla to synapse with the second order neurons in the Gracile and Cuneate nuclei. After the first-order neurons synapse at the nuclei, second-order neurons leaving their nuclei will cross; this occurs at the level of the medulla. The outcome of this crossing is a collection of ascending fibers called the **medial lemniscus**. The medial lemniscus will continue in the brain stem until it reaches the thalamus where it synapses with the **ventrobasal complex or Ventro-posterolateral complex (VPL)**. The VPL receives sensations from the body while the VPM (Ventro-posteromedial complex) receives sensations from the face. Arising from the thalamus are the third-order neurons that will cross through the posterior limb of the internal capsule to terminate and synapse at the sensory cortex (specifically, areas 3,1,2). See Figure 17.14.

NOTE: The most important feature of second order neurons of sensory pathways is that they cross the midline. The location where second-order neurons cross varies. For example, the Anterolateral system (a sensory pathway) will have their second-order neurons cross at the level of the spinal cord WHILE for the Dorsal Column Medial Lemniscus System, the crossing occurs high up at the level of the Medulla.

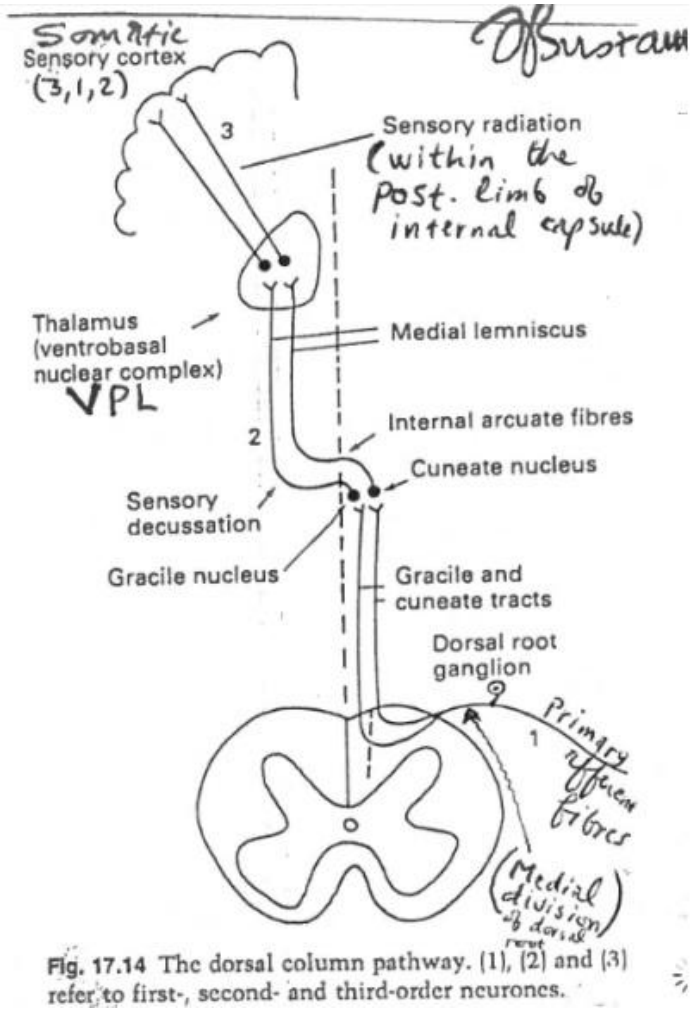


Fig. 17.14 The dorsal column pathway. (1), (2) and (3) refer to first-, second- and third-order neurones.

The dorsal column system carries out the following sensations:

1. Discriminative touch: determining the exact site of touch, including two point discrimination.

How do we test for Discriminative touch?

You put two pins simultaneously on the skin of the patient. The patient should be able to feel these two points as two different points of stimulation, provided that the distance between them is not less than 3-4mm (up till 5 mm) on the tips of the fingers or a few centimeters (5-6 cm) on the front of the leg. When the two pins stimulate two different receptive fields, we perceive them as two different stimuli. When they get close to one another, they stimulate one receptive field and we feel them as one stimulus.

The two-point discrimination test tests the function of the dorsal column.

2. Tactile localization: it is also a function of the dorsal column medial lemniscal system. It's the ability to determine/localize the exact site of touch.

3.Position sense (proprioception): there are two types:

a. Static proprioception: the awareness of the position of the body in space. (During Rest)

b. Dynamic proprioception: the ability to sense the movement of a joint.

How do we test for proprioception?

Move a toe or a finger while the patient has his/her eyes closed. Then, ask the patient what position the toe/finger is in, and whether it's moving or stable.

4. Vibration: this is tested via placing a vibrating tuning fork on any bony prominence on the body.

5. Graphesthesia/Stereognosis:

Definitions from Wikipedia:

- Graphesthesia: the ability to recognize writing on the skin purely by the sensation of touch without any visual guidance. This term is usually used for the lower limbs.
- Stereognosis: the perception of depth or three-dimensionality. The ability to recognize objects by touch without any visual guidance. This term is usually used for the upper limbs.

If someone puts a pencil in your hand while your eyes are shut, you should be able to recognize that it is a pencil.

How do we test for stereognosis and graphesthesia?

For stereognosis: Place an object in the patient's hand. The patient should be able to identify this object without any visual guidance.

For Graphesthesia: Draw random shapes (like; triangles, circles, squares) on the anterior shaft of the tibia. The patient should be able to identify the shape without any visual guidance.

Absence of stereognosis is called **astereognosis.**

Mentioned above was all about the old concept of the Dorsal Column Medial Lemniscus System. The gracile tract or fasciculus gracilus (and the cuneate tract/fasciculus cuneatus) conducts all these sensations that we've discussed above. Gracile for lower limb and Cuneate for the upper limb.

The New Concept:

Consider patients who are injured in the gracile and cuneate tracts in the dorsal column in in the upper thoracic or cervical region.

If the injury is in the cervical region: you expect, according to the old concept, that the patient would lose stereognosis and sense of position in the upper and lower limbs.

However, such patients lose position sense and stereognosis in upper limb, while ONLY losing STEREOGNOSIS in the lower limb. Therefore, one can conclude that the gracile nucleus conveys stereognosis of the lower limb while **some other pathway conveys the position sense (proprioception) of the lower limb.**

Therefore, according to the new concept, the gracile nucleus **does not transfer position sense from the lower limb.**

So, what is the pathway that **transfers the position sense of the lower limb**?

The Dorsal Spinocerebellar Tract.

The mother cells of the dorsal spinocerebellar tract are in **the dorsal nucleus of Clarke**. From previous information about the cerebellar tracts, the dorsal spinocerebellar tract transmits **Unconscious proprioception**; the new concept describes that this pathway also carries out **conscious proprioception from the lower limb.**

NOTE: Unconscious proprioception is transferred to the cerebellum only while conscious proprioception is transferred to the thalamus and cerebral cortex.

From the lower limb, sense of position enters along the dorsal root and runs along the spinal cord in the gracile tract. Fibers in the gracile tract ascend up to the level of L3. L3 contains the lower limit of the Clarke nucleus (The Clarke nucleus is

located from L1-L3, although some texts say from C8-L2). Fibers leave the gracile tract and enter the Clarke nucleus that contains the second-order neurons. Fibers of second-order neurons will leave Clarke nucleus as the dorsal spinocerebellar tract, which runs in the lateral column, up until it reaches the medulla. In the medulla, part of the dorsal spinocerebellar tract goes to the cerebellum via the inferior cerebellar peduncle, carrying unconscious proprioception. The other part continues in the medulla and ends up in nucleus "Z" to synapse there.

Now we know that the gracile nucleus does not receive sense of position from the lower limb. (Students who have taken step 1 have told the doctor that they were asked questions about this distinction! Make sure you know the old versus new concepts).

We said that the axons coming from the gracile and cuneate nuclei cross the midline and form the medial lemniscus. Axons of the Z nucleus also run in the medial lemniscus. The medial lemniscus runs to the thalamus, and so on.

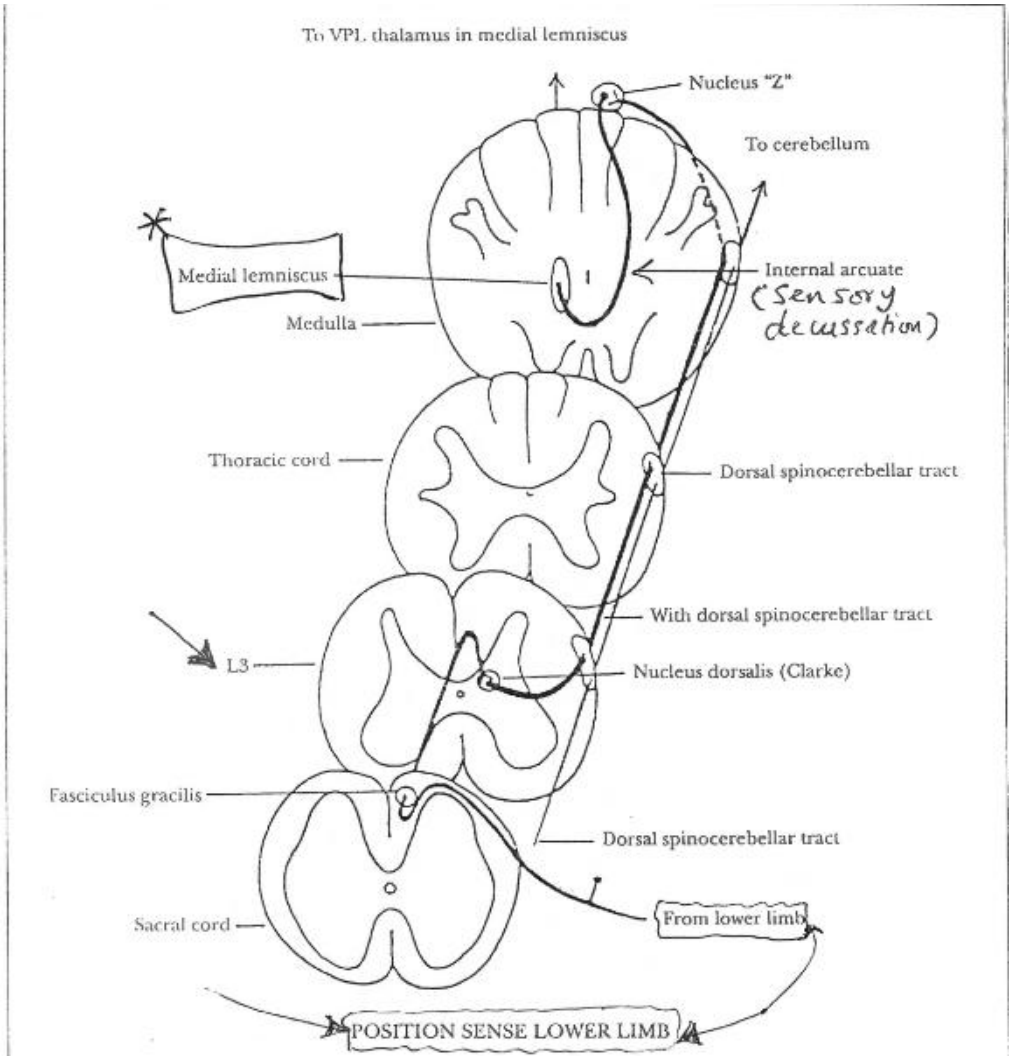
The gracile nucleus in the medulla only transfers stereognosis from the lower limb while the cuneate nucleus transfers both position sense and stereognosis of the upper limb.

If the lesion was below L3 in the spinal cord → Loss of both position sense and stereognosis of the lower limb.

If the lesion was above L3 (like, in the thoracic region) in the spinal cord → Loss of Stereognosis from the lower limb ONLY: The Clarke nucleus and dorsal spinocerebellar tract responsible for conveying proprioception from lower limb are still intact and functioning.

Does the sense of position from the lower limb need the gracile tract?

**Yes, because it contains fibers headed to the Clarke nucleus. We need the Clarke nucleus and dorsal spinocerebellar tract, but do we need the Gracile NUCLEUS? No. It's been replaced by nucleus "Z". See the figure below.



Somatotopic Organization:

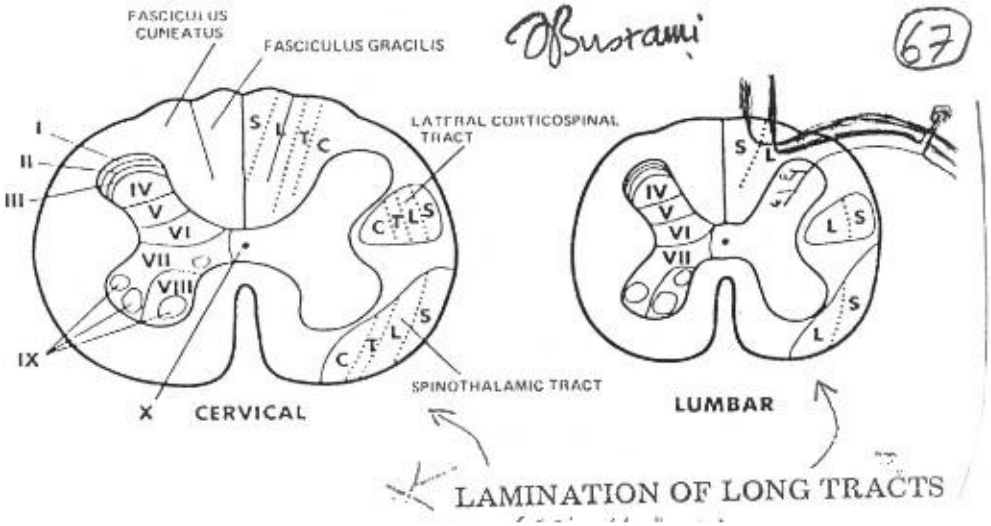
Before we move further in our discussion, it is important to know the following facts. The figure below is an important one. Take a look at the cervical section:

- The dorsal column system: the gracile tract receives fibers from lumbar and sacral regions, meaning the lower limb. The cuneate tract receives fibers from the thoracic and cervical regions, meaning the upper limb.
- The lateral corticospinal tract is a major motor pathway. Its fibers are organized as follows (From medial to lateral): cervical, thoracic, lumbar, and sacral.

- The spinothalamic tract is organized in a way similar to the lateral corticospinal tract. (From medial to lateral): cervical, thoracic, lumbar, and sacral.

The denticulate ligament serves a very important landmark for the spinothalamic tract. If a tumor pressed in from outside of the dura mater or arachnoid mater near the denticulate ligament, sensations conducted via the spinothalamic tract will be compromised. The first things it would compress are the sacral and lumber areas, so the first thing the patient would lose is lower limb sensations. On the other hand, if the tumor arises from the inside, it would compress the cervical and thoracic areas, so the first sensations to be lost are those of the upper limb.

Look at the lumbar section below: below **T6** there is NO cuneate tract. Only the gracile tract is shown and so only the lumbar and sacral fibers can be seen.



Now we will differentiate between some of the characteristics of the **spinothalamic tract** in the **anterolateral system** and the **dorsal column medial lemniscal system**.

1. At the level of the spinal cord, the spinothalamic tract crosses, while the dorsal column system stays ipsilateral and crosses at the level of the medulla. This is important to remember when considering lesions.

<u>Left hemisection of the spinal cord:</u> A bullet injury that cuts the left side of the spinal cord. What happens below level of the lesion? We lose the spinothalamic

tract (loss of pain, temperature, touch), the dorsal column system (sense of position, etc) and motor pathways (pyramidal and extrapyramidal tracts) below lesion.

If it's a left hemisection of the spinal cord **at T10**, it mostly affects the lower limb. Below the lesion on the same side: left lower limb, loss of all sensations transferred by the dorsal column on same side. On the opposite side, the right limb only loses sensations transferred by the spinothalamic tract. Why? Because the spinothalamic tract crosses at the level of the spinal cord.

In addition, the pyramidal and extrapyramidal tracts are also affected. Below the lesion we will get ipsilateral spastic paralysis, hyperreflexia, Babinski sign.

Why do we get spastic paralysis below the lesion?

The injury is in the spinal cord, where fibers from the pontine reticulospinal tract (excitatory) and the medullary reticulospinal tract (inhibitory) are carried, we get an increase of tone as a result of release from both excitation and inhibition. When we lose both, the effect of loss of inhibition increases the tone (release from both excitation and inhibition BUT MORE FROM INHIBITION). We get Ipsilateral Spastic Paralysis.

Another type of lesion in the internal capsule will also result in spastic paralysis because the pontine reticulospinal tract has been released from inhibition and is strongly stimulating the alpha and gamma neurons, which is over activating the stretch reflex and increasing the tone. Here, we have contralateral spastic paralysis.

2. The dorsal column has a high degree of spacial orientation. This means it enables us to know exactly the site of stimulation on the skin and to know if it's one stimulus or two stimuli (two point discrimination is strong). The spinothalamic tract is less organized. It can transfer simple touch that is not specific or complex and does not need to be localized.

3. The spinothalamic is affected by endogenous pain pathway inhibitor.

4. Somatotopic Organization: In the dorsal column system, fibers from the lower limb are located most medially, while for the anterolateral system, the fibers of the lower limb are localized most laterally.

5. Speed of conduction: most fibers that transfer dorsal column system sensations are A-Beta (rapidly conducting 30-110m/min), while in spinothalamic fibers they are A-Delta and C (slow 8-40m/min). A-delta fibers transfer fast pain, and C fibers transfer slow pain.

6. Types of receptors: the dorsal column system conducts mechanoreceptive sensations (only one type of stimuli/sensations. Touch, pressure, two point discrimination, and vibration are all included in this). The spinothalamic tract transfers a broad spectrum of stimuli. Namely, two types of pain (fast and slow), temperature (cold and hot), touch (non discriminative), itch, tickle, sexual sensations.

All types of sensations ultimately reach thalamus before reaching the cortex. Some books say that olfaction does not pass through it while others say it does. The doctor says he follows a modern textbook which says olfaction runs through the dorsomedial nucleus of the thalamus. So we can generalize and say that all types of sensations must pass through the thalamus first before reaching the cortex.

At the level of the thalamus we can feel sensations **crudely**. Although it is said that pain can be fully appreciated/perceived at the level of the thalamus, we **can't tell details** about the pain at that level.

A patient with an injury at the level of the cerebral cortex or in the internal capsule can only feel pain crudely, meaning that he feels pain but can't tell how severe it is or the quality of the stimulus (prick or hot water?) or the localization. In order to determine all these details, the signal needs to travel to the cortex. Intensity, localization and type of pain need the cortex.

The somatosensory cortex is areas 3,1,2. It is located in the parietal lobe in the postcentral gyrus. The body is presented upside down, precisely (every part of the body is represented) but disproportionately. The size of the area of representation in the cortex does not match the size of the body part. Rather, it reflects the density

of the receptors. The smaller the receptive field, the more dense the receptors and the larger the representation in the sensory cortex. The lips and the tips of the fingers have small receptive fields, and therefore have larger representations on the somatosensory cortex.

Area 3 is divided into 3a and 3b. Thus, areas 3a and 2 are responsible for proprioception (sense of position: from joints and muscles), while areas 3b and 1 are responsible for exteroception (pain, pressure, and touch).

Areas 3,1, and 2 receive stimuli from the opposite side of the body, except the face. The face is bilaterally represented. The left side of face is represented by the left and the right sensory cortex, unlike the body.

What types of sensations is the sensory cortex needed for?

1. Spacial recognition: **tactile localization** (to determine the exact site of touch) and **two-point discrimination**. They are conducted both by the dorsal column and the cortex. If there is an injury to the dorsal column system or the parietal cortex, these types of sensations would be affected (we will discuss how in a bit).
2. The sensory cortex is needed for recognition of the **intensity of the stimulus**. Intensity cannot be determined on the level of the thalamus. Intensity is increased as a result of two changes:
    a. Increased frequency of action potentials in each sensory fiber.
    b. Increased number of afferent sensory fibers stimulated.

    The receptors always convert stimuli into graded potential that will eventually be converted into action potentials.
3. **Stereognosis:** to know objects by touch without the help of vision. Astereognosis is the opposite of stereognosis.

All of these could be lost due to a lesion in the cortex or dorsal column.
If the lesion is in the dorsal column, like in the gracile tract or gracile and cuneate nuclei, there would be loss of stereognosis, sense of position, vibration, and pressure. If the lesion is in the cortex, we don't lose vibration or sense of position, we will only lose stereognosis and two-point discriminative touch.

We can describe sensations as two types:

- **Protopathic:** can be felt at the level of the thalamus. Crude sensations: crude pain, tactile sensations (crude touch) and extreme temperatures (above 38 degrees is hot and below 24 degrees as cold). They can be felt/perceived at the level of the thalamus. They need a strong stimulus of high threshold.
- **Epicritic**: cannot be felt at level of thalamus. These types of sensations need the cortex to be perceived. It includes tactile localization, two point discrimination, stereognosis, and fine grades of temperature (between 24-38 degrees Celsius). They can be elicited by weak stimuli of low threshold.

Types of pain sensations according to site of stimulation:

1. Cutaneous pain: pain in the skin. It occurs in two phases: fast pain and slow pain. **It is accurately localized** because it occurs in the skin, which is full of receptors (sensory nerve endings). This type of pain is well-localized.
2. Deep somatic pain: pain in muscles, bones, joints and ligaments. **It's diffuse, dull (can't be localized easily), and prolonged**. It's usually associated with autonomic stimulation that alerts the autonomic nervous system (sympathetic and parasympathetic) and results in either tachycardia or bradycardia (Bradycardia is more dangerous because it reduces cardiac output and the patient may experience shock if it reaches 30-40bpm). Autonomic stimulation may involve changes in the cardiac output, heart rate, sweating, vomiting, rise or drop in blood pressure.

Story: A patient presented with a fracture. There were autonomic manifestations due to severe pain. The vomiting and sweating were not caused by food poisoning. They were a result of the severe pain.

NOTE: Adequate stimulus is the stimulus necessary for the receptor to respond with the lowest threshold.

Types of stimuli:

a. Mechanical: a lot of pressure on the bone/muscle/tendon
b. Chemical: venoms and poisons.
c. Ischemia: ischemia in the heart leads to angina pectoris. Ischemia in skeletal muscle leads to **intermittent claudication**.

Intermittent claudication of calf muscles: ischemia in the calf muscle of a diabetic patient. In the long run, atherosclerosis narrows vessels and results in ischemia. The patient walks for a few meters then stops for rest, walks again, feels pain and stops to rest. During rest, blood flow is sufficient and the metabolic wastes (like lactic acid) are properly washed out and removed. During walking, increased metabolic activity in muscle increases lactic acid deposition and thus causes pain. Lactic acid can only be cleared out during rest. This explains why the pain goes away at rest.

This patient is diabetic and has atherosclerosis and narrowing in vessels of the lower limb. How do you test for intermittent claudication? Let him walk for a bit and see if he feels pain and needs to rest. If he does, then he probably has intermittent claudication. This is a bad sign. When we see it, we need to do imaging for the leg to see where narrowing is. If we see that there is a block, we need to do surgery. If we leave it, intermittent claudication transforms into rest pain (pain while resting). If we leave it for longer, the patient gets gangrene. Do not ignore these symptoms.

3. Visceral pain: caused by

    a. Distention: An example of this are intestines filled with gases causing pain. Another cause is the bladder filling with urine (another type of distension).
    b. Spasm: continuous contraction leads to a type of ischemia, which causes pain.
    c. Chemical irritant: perforated peptic ulcer. HCl leaves the stomach and irritates the peritoneum. This is one of the worst types of pain.

Pain receptors are very few in the viscera, so you won't feel pain unless the pathology is considerable.

Characteristics of visceral are like those of deep somatic pain: **poorly localized** (for example, gastritis can be felt by patient over a wide area, not specific), **pain is accompanied by autonomic manifestations** (sweating, vomiting, change in heart rate and blood pressure). In addition, visceral pain can be accompanied by rigidity of nearby skeletal muscle. For example, in appendicitis, the inflammation spreads to the peritoneum of the anterior abdominal wall. As a result, abdominal muscles

experience involuntary contractions. Severe rigidity in the abdomen indicates that the infection has transferred to the parietal peritoneum.

Referred Pain:

Visceral pain is usually referred. In appendicitis, the first pain that is felt is around the umbilicus. Eventually, the pain can be felt over McBurney's point (over the appendix).

Why is the pain felt around the umbilicus? Sensory fibers from the appendix run along the sympathetic and parasympathetic fibers and enter along the dorsal root to the T10 spinal segment. Skin around the umbilicus also has sensory fibers that enter spinal cord at T10.

The viscus (appendix) and the skin are connected via a second-order neuron in the dorsal horn. Consider that the appendix sends sensory fibers that enter to synapse with the second order neuron in the spinal cord at T10 and the sensory fibers from the skin around the umbilicus also enter and synapse on same second-order neuron. When impulse reaches the spinal cord, the spinothalamic tract transfers the pain to cortex. Here, the cortex makes a mistake. The cortex usually receives pain from skin more often than from viscera. The cortex misinterprets pain. Instead of feeling pain localized around the appendix, it tells you to feel it on the skin around the umbilicus. The sensory cortex makes a mistake because the skin around the umbilicus has more sensory nerve endings and is more prone to stimulation.

Referred pain is a very important concept. At first we feel referred pain and eventually the pain becomes localized over the location of the affected organ.

Another example of referred pain: the heart gives referred pain to the precordium, the area of the chest wall in front of heart between T2 and T5. T2 is the dermatome in front of the sternal angle. The sternal angle has the second rib right beside it on each side. The second rib "divides" the skin. Below the second rib, the skin is supplied by T2. Above the second rib/sternal angle, the skin is supplied by C4. The dermatomes in between (C5,6,7,8 T1) all supply the upper limb.

Additional examples of referred pain:

- The small intestine >> to the umbilicus.
- The central part of diaphragm >> to tip of shoulder. The phrenic nerve is C3,4,5 and supplies the central part of diaphragm. The skin on the shoulders is supplied by C4. Any inflammation of peritoneum on the inferior surface of diaphragm is felt as pain on the shoulder.
- The pleura >> to the abdomen. A child may come and complain of upper abdominal pain. He is feverish and coughs which means the problem is in thorax. Why is the referred pain in the abdomen? The nerve supply of the chest wall and abdominal wall are the intercostals. Therefore, inflammation in the pleura is felt as upper abdominal pain.
- The kidneys >> to the costovertebral angle (the angle between the last rib and the first lumbar vertebra).
- The Ureter >> to the lower abdomen and external genitalia. If there is a stone and peristalsis occurs in the ureters, the pain is referred to the lower abdomen and external genitalia of males and females. In males, it's referred to the testes.

THE END