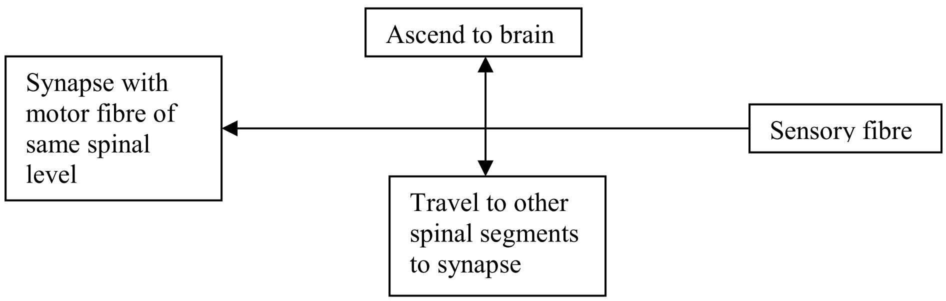
Lecture 14 - Somatosensory System

The somatosensory system means = "somato" (somatic arm of peripheral nervous system) + "sensory" (sensation from somatic arm of peripheral nervous system).

Primary sensory afferents (Notes)
The options for a sensory fibre after entering the spinal cord:



General anatomy of spinal cord
Note that the spinal cord is made up of white and gray matter. Gray matter is strictly made up of cell bodies of neurons and some dendrites. White matter is strictly made of axons, the "whiteness" is the reflection of the myelin sheath (both unmyelinated/myelinated sheaths). There is a dorsal, lateral (T1-L2), ventral horn associated with the gray matter. There is a dorsal, ventral, lateral column associated with the white matter. **Any pathway conveying sensory information to the cerebral cortex can be perceived consciously. Any pathway conveying sensory information to the cerebellum is unconscious "perception".**

Dorsal Column-Medial Lemniscal pathway (Nolte 5th Ed pp 238, Fig 10.17, Neuroscience Practical Handbook)
The dorsal column medial lemniscal pathway is responsible for conveying proprioception, vibration, touch, and 2 point discrimination to the cerebral cortex. This information can be perceived consciously. To understand this pathway we must first consider the arrangement of fibres in the dorsal column of the spinal cord. You must understand the following:

- Dorsal column below T6 contains single fasciculus
- Dorsal column rostral to T6 contains two fasciculi split by glial partition called – posterior intermediate septum
- Sensory information containing, touch, vibration, proprioception and 2 point discrimination from lower limbs travels medially whereas the same information from upper limbs travels laterally → this is called somatotopic organisation of the spinal cord → associated with the homunculus of the cerebral cortex (caudal to rostral organisation from midline laterally).
- Note that dorsal rootlets entering the spinal cord branch into medial and lateral divisions. Medial divisions go to the dorsal column medial lemniscal pathway, whereas lateral divisions go to the anterolateral system → spinothalamic tract etc.

What happens?

- Proprioception, touch, vibration, 2 point discrimination = sensory information → comes through the dorsal root ganglion (mainly Aα + Aβ fibres).
- If sensation is from lower limb (for example) → then afferent fibres travel via fasciculus gracilis (medially) rostrally. If sensation is above T6 (upper limbs for example) → then afferent fibres travel via fasciculus cuneatus (laterally) rostrally.
- These posterior column fibres now reach the brain stem (they travel ipsilaterally up to this point) → and synapse in nucleus gracilis / nucleus cuneatus accordingly.

- 2nd order neurons from nucleus gracilis / cuneatus cross the midline and travel contralaterally, forming the medial lemniscus. This bundle of fibres proceeds even further rostrally right through the brain stem to terminate on the VPL nucleus of thalamus.
- 3rd order neurons ascend from here through the internal capsule (posterior part of the capsule → capsule has anterior, posterior and genus (middle) part), to the primary somatosensory cortex (i.e.: post central gyrus) to synapse here.
- Note where the neurons synapse is dependent on which part of the body is involved. The more lateral it synapse on the post central gyrus – then the more rostral the sensation is → SOMATOTOPIC ORGANISATION (also maintained in VPL nucleus of thalamus) → HOMONCULUS

One thing to note:

- Note that nucleus gracilis is medial to nucleus cuneatus (lateral). But the 2nd order neurons from here, change position when entering the medial lemniscus. The medially located 2nd order neuron from nucleus gracilis is now located lower down in the medial lemniscus, whilst the laterally located 2nd order neuron from nucleus cuneatus is located in the upper portion of the medial lemniscus. Refer to Fig: 10-17 Nolte 5th Ed pp 240).

Another thing to note:

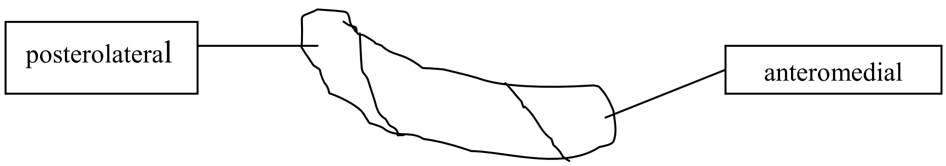
- Know this pathway really well, but also know where the fibres cross. Remember, they cross after synapse in their respect nuclei located in the caudal medulla. So any lesion in the pathway means you lose the following
    - Vibration, proprioception, tactile discrimination, some touch (because touch is also transmitted via the spinothalamic pathway discussed below), loss of kinesthesia (movement sense). All of this leads to uncoordinated movement due to inadequate feedback to brain → Romberg's sign (falling over to side when eyes closed + feet together).

DORSAL COLUMN MEDIAL LEMNISCAL PATHWAY

Anterolateral System – Spinothalamic tract – direct, indirect pathways – Nolte 5th Ed pp 242, Fig 10.20)

The anterolateral system contains the spinothalamic tract, and others as well. We will consider the spinothalamic tract first. This is responsible for conveying pain, temperature and some touch sensation to the post-central gyrus (primary somatosensory cortex). With respect to pain, there is sharp and dull variety. These follow different pathways which will be considered in this section. Consider the organisation of the anterolateral system in the spinal cord:

- Anterolateral = anterior half of lateral column. Identify this in the spinal cord segment.
- Note that "new" fibres (i.e.: as you move rostrally, new fibres come from upper limbs etc) joining the anterolateral system will join in the ventral portion (anteromedial), whilst "old" fibres (i.e: lower limbs) will be located in the posterolateral portion. Compare this to the dorsal column medial lemnisus pathway. What do you find?



Spinothalamic tract – direct pathway / indirect pathway – sharp pain/dull pain (Aδ fibres / C fibres)

What happens?

- Pain + temperature (Aδ & C fibres) afferents enter the spinal cord via the dorsal roots (lateral division), via the Lissauer's tract (Fig 10.19 Nolte 5th Ed pp 243)
- They synapse onto 2nd order neurons in lamina I & V of the substantia gelatinosa (sharp pain), or lamina II & III (dull pain), and also onto interneurons of the substantia gelatinosa which, in turn, convey the information onto neurons of other lamina
- These 2nd / 3rd order neurons send their axons across the midline (now contralateral) with a slight rostral inclination (i.e.: these axons travel 1 or 2 spinal cord segments) to form the spinothalamic tract (Fig 10.20 – smaller diagram on right).
    - A subset of 2nd / 3rd order neurons send their axons across the midline (now contralateral) with a slight rostral inclination (same as b4) and now follow a POLYSYNAPTIC pathway through the reticular formation (occupies much of core of brainstem) to the intralaminar nuclei of thalamus + other areas. Referred to as: **spinoreticular fibres** within spinothalamic tract. More likely responsible for changes in levels of attention in response to pain.
- The axons of the spinothalamic tract terminate on the VPL nucleus of thalamus (various parts), some in the intralaminar nuclei (dull pain, described above), and others on cells of the thalamus. Note that the VPL projections maintain their somatotopic organisation, whilst the intralaminar projects do not maintain this organisation.
- 3rd/4th order neurons from the VPL/intralaminar nuclei + others project to the primary somatosensory cortex (alias: post central gyrus).
- If you have a lesion of this tract, then you will have contralateral analgesia, and insensitivity to temperature in 1 or 2 spinal cord segments caudal to lesion (i.e.: "slight rostral inclination")

Spinomesencephalic fibres (Nolte 5th Ed pp 243)

Some 2nd/3rd order neurons, also coming from lamina I & V, are involved in intrinsic pain modulation from descending input. These fibres send information to the reticular formation about the level of noxious stimuli. Depending on this information, the periaqueductal gray matter is activated, where efferents project to one of the nucleus raphe magnus, which in turn suppress the transmission of pain via the spinothalamic pathway. Morphine works by activating the periaqueductal gray matter, hence achieving analgesia.

DIRECT & INDIRECT SPINOTHALAMIC PATHWAY

INFLUENCE OF SPINOMESENCEPHALIC FIBRES

Spinocerebellar pathways (Nolte 5th Ed pp 245, Fig 10-21)
The cerebellum is involved in recognising what the body is doing, and what it should be doing. Thus, it requires sensory information from the spinal cord. The sensory information is sent via the spinocerebellar pathways. Thus these pathways are involved in **non-conscious proprioception**.

A number of these pathways have been described but only three have been characterised. It is these three which we will deal with now: posterior, anterior, & cuneocerebellar tracts.

Posterior spinocerebellar and cuneocerebellar tracts
The posterior spinocerebellar and cuneocerebellar tracts primarily receive afferents from proprioceptors, and movement receptors from the limbs. These are basically: golgi tendon organs & muscle spindles. The pathways involving unconscious proprioception from upper and lower limb are different.

Lower limb:

- The pathway is called: posterior spinocerebellar tract (only exists from L2 level → rostral)
- Afferents travel via the DRG and dorsal roots into the spinal cord. Afferents coming from muscle spindles + golgi tendon organs form collaterals and synapse on Clarke's nucleus. If the afferents arrive caudal to L2 – then they ascend to Clarke's nucleus (L2) via nucleus gracilis (lower limb).
- Axons from Clarke's nucleus are sent to the lateral funiculus ipsilaterally, and then project rostrally → forming the posterior spinocerebellar tract. This tract lies at the surface of the spinal cord.
- The posterior spinocerebellar tract projects via the inferior cerebellar peduncle to the medial zones of the cerebellum (e.g.: vermis). Collaterals of some of these fibres end in nucleus gracilis, forming an important side pathway to the dorsal-column medial lemniscal pathway.

Upper Limb:

- The pathway is called: cuneocerebellar tract
- Afferents travel via the DRG and dorsal roots. They don't synapse with Clarke's nucleus, rather travelling rostrally in the fasciculus cuneatus ipsilaterally to the medulla

- In the medulla there is a nucleus similar to Clarke's nucleus, called lateral cuneate nucleus (lying just lateral to nucleus cuneatus) . Axons from this nucleus form the cuneocerebellar tract, which projects ipsilaterally to the medial zones of the cerebellum, via the inferior cerebellar peduncle.

Anterior spinocerebellar tract (Nolte 5th Ed pp 247, Fig 10.21)
This tract is also primarily concerned with the lower limbs, but their pathway to the cerebellum is different to the posterior spinocerebellar tract.
What happens?

- Afferents to this tract arise from various receptors (i.e.: golgi tendon, cutaneous, muscle spindle, descending tracts, spinal interneurons)
- Cells on the lateral aspect of the lumbar anterior horn give axons that form this tract. Axons cross the midline at the spinal cord level, then ascend on the contralateral side
- It ascends as far as the rostral pons, then turns caudally travelling through the superior cerebellar peduncle, crossing the midline again, to terminate in the medial zones of the cerebellum (i.e.: vermis etc). Thus, fibres end ipsilateral to side at first.

Notice that all the spinocerebellar tracts terminate ipsilateral to the side their inputs originated. Note, I said "inputs" not "tracts". The latter would be wrong.

SPINOCEREBELLAR PATHWAYS

Primary Somatosensory Cortex (Nolte 5th Ed pp 73 Fig 3-28, Marieb → good too!)
Note the somatotopic organisation of the primary somatosensory cortex. This means, the more rostral a sensation is picked up, the more lateral it is mapped on the somatosensory cortex. Note the mapped areas for hand, and lips are quite large compared to other parts. This is because; these areas are highly sensitive to sensory information. The primary somatosensory cortex is supplied by anterior and middle cerebral arteries.

Brown-Sequard Syndrome – Hemisection of spinal cord (Nolte 5th Ed pp 258/f, Fig 10-29)
This syndrome refers to the characteristic loss of somatosensation as a result of a hemisection of the spinal cord at a particular level. Although rare, it gives a good example of some of the sympatoms experienced if it were to occur – relating to the tracts just discussed.

The tracts we would consider is: lateral corticospinal tract (discussed earlier/later), dorsal-column medial lemniscal pathway, anterolateral system → spinothalamic, spinocerebellar tracts (clinical signs of lesion to this tract is rarely evident → i.e.: **unconscious** proprioception).

- Spastic paralysis of area below + ipsilateral to lesion (interruption of lateral corticospinal tract)
- Dorsal column medial lemniscal pathway: loss of vibration, touch, proprioception and 2 point discrimination ipsilateral + below to lesion
- Spinothalamic: loss of pain, temperature contralateral + 1 / 2 spinal segments below to lesion. Pain, temperature retained ipsilateral to lesion.
- Reflexes intact except at segments interrupted

Syringomyelia – "syrinx = central canal" (Nolte 5th Ed pp 258, Fig 10-30)
Syringomyelia is when there is inappropriate enlargement of the central canal in the spinal cord. Affected areas include: fibres crossing over in the white commissure (spinothalamic tracts) and ventral roots in the ventral horn of spinal cord. Accordingly, symptoms include: bilateral loss of pain + temperature sensation, and progressive weakness + atrophy of muscles pertaining to that spinal segment. Notice, posterior-column medial lemniscal pathway is usually intact, unless the problem affects the caudal medulla.

Pathway of Dorsal Column Medial Lemniscal Pathway

- Sensory neurons project from the dorsal root ganglion, travel with the dorsal roots, which enter the dorsal horn. Here the dorsal root splits into medial and lateral divisions. Fibres concerning touch, vibration, proprioception and 2point discrimination travel in the medial divisions and ascend more rostral. If the sensations are from below T6 spinal cord segment - then the fibres ascend in fasciculus gracilis located medial to posterior intermediate septum (above T6) in the dorsal colum and in whole dorsal column (if below T6). If the sensations are from above T6 spinal cord segment - then the fibres ascend in fasciculus cuneatus located more lateral to the posterior intermediate septum. Fibres ascend to synapse in their respective nuclei: nucleus gracilis / nucleus cuneatus located at the level of the caudal medulla. The 2nd order neurons located here cross the midline at the level of the caudal medulla and ascend further to synapse in VPL nucleus of thalamus. These bundle of fibres are called medial lemniscus. Notice the arrangment of fibres in this pathway - the fibres arising from the more medial nucleus gracilis are now located more caudal in this lemniscus, while those fibres arising from the more lateral nucleus cuneatus are located more rostral in this lemniscus. The 3rd order neurons located in the VPL of thalamus have a specific arrangement. Notice fibres arising from the nucleus gracilis synapse more laterally here, while fibres arising from the nucleus cuneatus synapse more medially here. 3rd order neurons arise from the VPL nucleus if thalamus and ascend to the post central gyrus of parietal lobe, referred to as the primary somatosensory cortex. Notice the somatopic arrangement here - the fibres from more caudal regions of the body are represented more medially

- while fibres from more rostral regions of the body are represented more laterally. HOMUNCULUS.

Pathway of Spinothalamic Tract - part of the anterolateral system
The spinothalamic tract conveys pain (sharp + dull), temperature, and some tactile information to the post central gyrus of parietal lobe, known as primary somatosensory cortex. Notice that these can be perceived consciously. The spinothalamic tract forms part of the anterolateral system - located anterolaterally along the lateral and ventral columns of spinal cord. New fibres joining this system are located more anteromedially, while "older fibres" or fibres from caudal regions of the body are located more posterolaterally.

Pain (sharp, dull), temperature, and some touch sensation is transmitted along the dendrites, cell bodies (located in dorsal root ganglion) and axons of these primary sensory neurons and into the dorsal horn via the dorsal roots. The dorsal roots enter the dorsal horn, and split into medial and lateral divisions - and fibres concerned with spinothalamic tract enter the lateral division. From here they traverse the Lissauer's tract. Fibres concerning with sharp pain (A delta fibres) synapse in lamina I & V of substantia gelatinosa, while fibres concerning with dull pain (C fibres) synapse with lamina II/III of subtantia gelatinosa. Some fibres also synapse on interneurons of the substantia gelatinosa and these project to other neurons in other lamina. Axons of 2nd / 3rd order neurons here cross the midline at the level of the spinal cord, and ascend rostrally in a slight inclination. These fibres are referred to as the spinothalamic tract. A small subset of fibres that represent 2nd and 3rd order neurons do the same thing, but as they travel in the spinothalamic tract - they follow a polysynaptic pathway through the reticular formation (occupies core of brain stem) to synapse with intralaminar nuclei of thalamus. These set of fibres are called spinoreticular fibres - and are involved in transmission of dull pain - This pathway is known as the indirect pathway. Meanwhile, the spinothalamic tract (direct pathway) travels rostrally to synapse with VPL nucleus of thalamus. 3rd / 4th order neurons located here travel rostrally and synapse with 4th / 5th order neurons located in the post central gyrus of parietal lobe - primary somatosensory cortex. Notice that fibres travelling more anteromedially in the anterolateral system - synapse more medially in the thalamus - while fibres travelling more posterolaterally synapse more laterally in the thalamus. This type of somatotopic organisation is not maintained by the indirect pathway. Also notice that fibres arising from caudal regions of the body synapse at more medial areas of the primary somatosensory cortex, while fibres arising more rostrally synapse in more laterally areas.