General Sensory Systems

Principles and Practices of Osteopathic Medicine I

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Session Objectives

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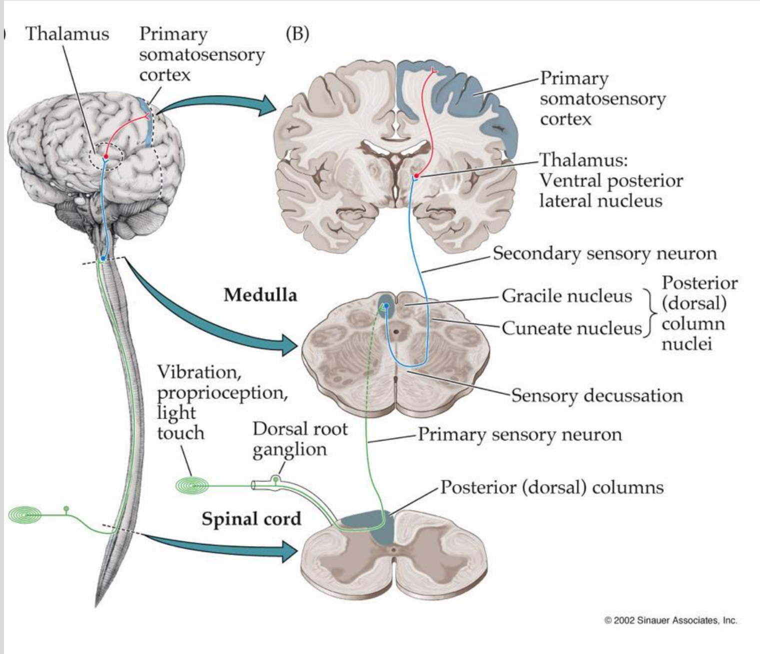
- Identify somatosensory receptors and their encoding.
- Describe the transmission of touch and proprioception to the cerebral cortex.
- Describe the transmission of pain and temperature information to the cerebral cortex.
- Understand the relation between somatosensory lesions and clinical symptoms.



See detailed objectives in CPG.

PLEASE READ THE Scholar Rx Brick!

Session Objectives Mapped to COMLEX Blueprint

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- **Dimension 2**
  - **Clinical presentation 4**. Patient presentations related to the nervous system and mental health
    - 4.11 Sensory disturbances and pain
      - tactile disturbances, including sensory loss, numbness, vibration/temperature/proprioception loss, tingling, and paresthesia
      - pain, chronic nonmalignant
      - pain, neuropathic, nociceptive, mixed, sympathetic
      - nerve-, muscle-, and pain-related syndromes, including complex regional pain syndrome, post-herpetic neuralgia, meralgia paresthetica

Source: https://www.nbome.org/Content/Exams/COMLEX-USA/COMLEX-USA_Master_Blueprint_2018-2019.pdf

Session Objectives Mapped to USMLE Blueprint

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V. Nervous System & Special Senses

A. Normal Processes

2. Organ structure and function

iv. Sensory systems

a. general sensory modalities, including sharp, dull, temperature, vibratory, and proprioception

B. Abnormal Processes: Health and Health Maintenance, Screening, Diagnosis, Management, Risks, Prognosis

5. Cranial and peripheral nerve disorders

iii. Neurologic pain syndromes**:** complex regional pain syndrome (reflex sympathetic dystrophy, causalgia); fibromyalgia; postherpetic neuralgia; phantom limb pain/syndrome; thalamic pain syndrome; trigeminal neuralgia

Source: https://www.usmle.org/sites/default/files/2022-01/USMLE_Content_Outline_0.pdf

Different size, sheath, and speed of afferent fibers

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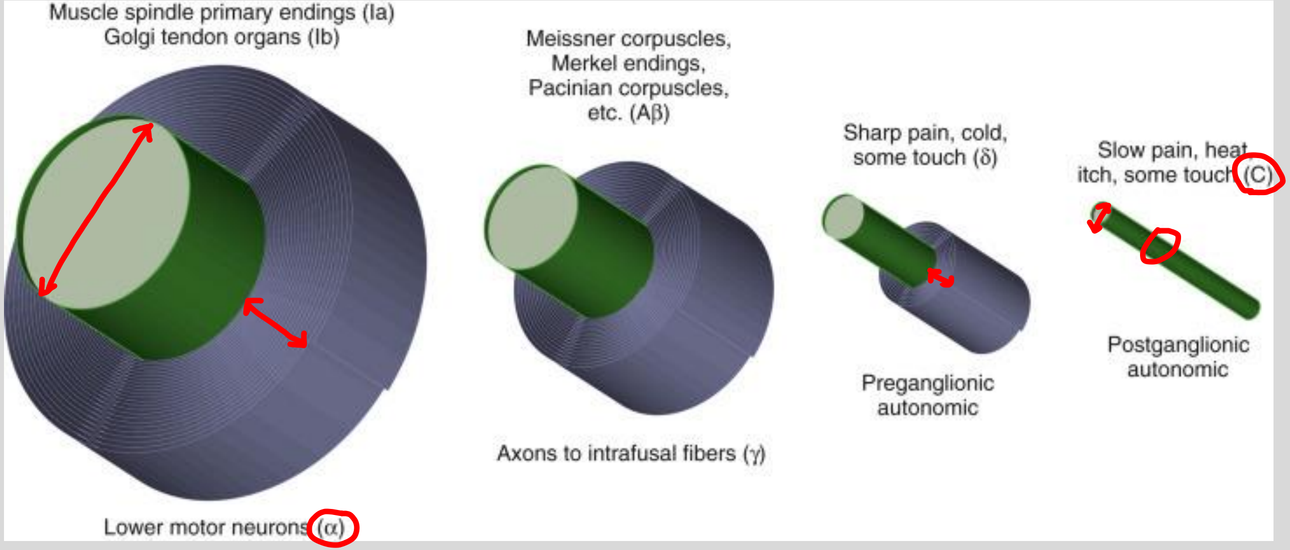

Conduction velocity increases with ↑diameter & ↑myelination

Range from 0.5 m/s – 60 m/s*

*textbooks often report a max of 120 m/s which comes from cats, not people.

Classification of peripheral fibers

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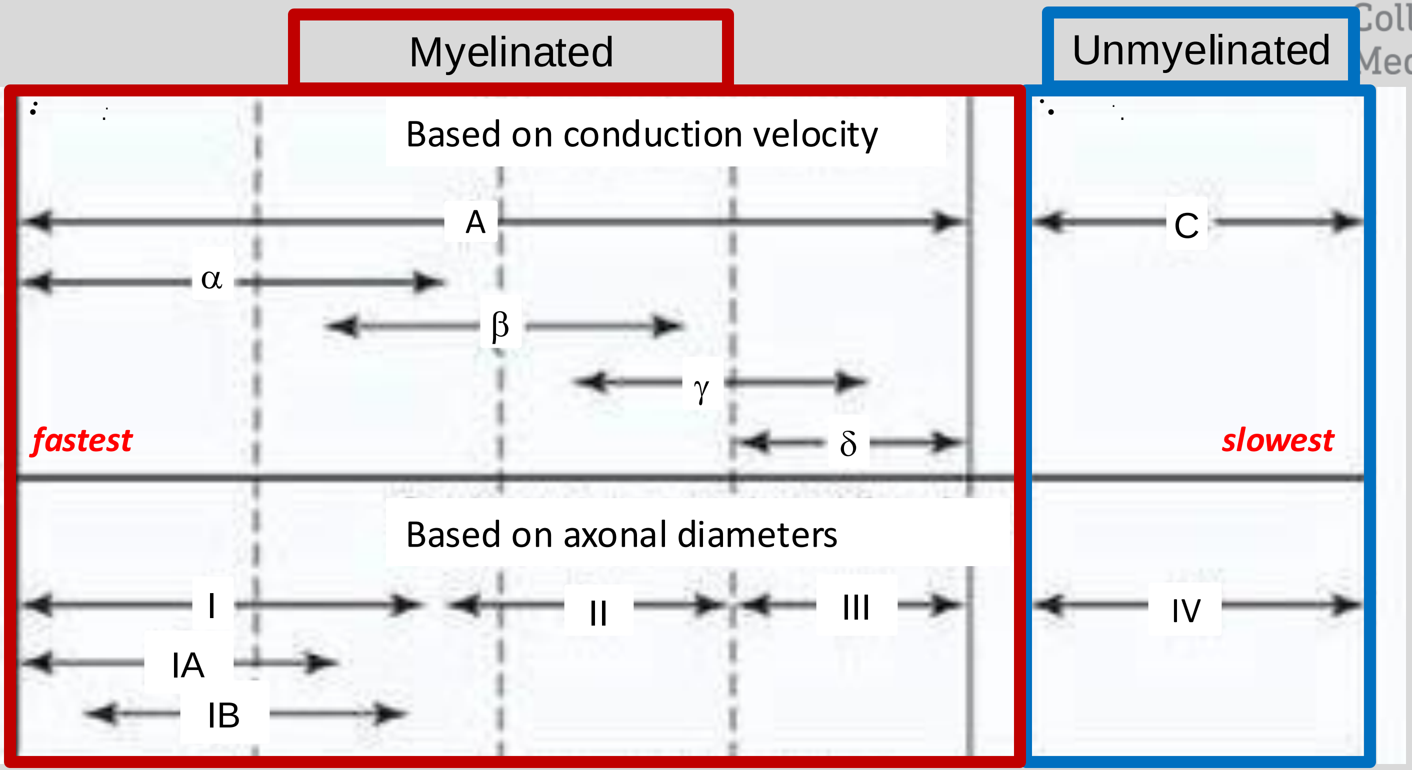

Kandell and Schwartz, Principles of Neuroscience

Reasonable Simplification

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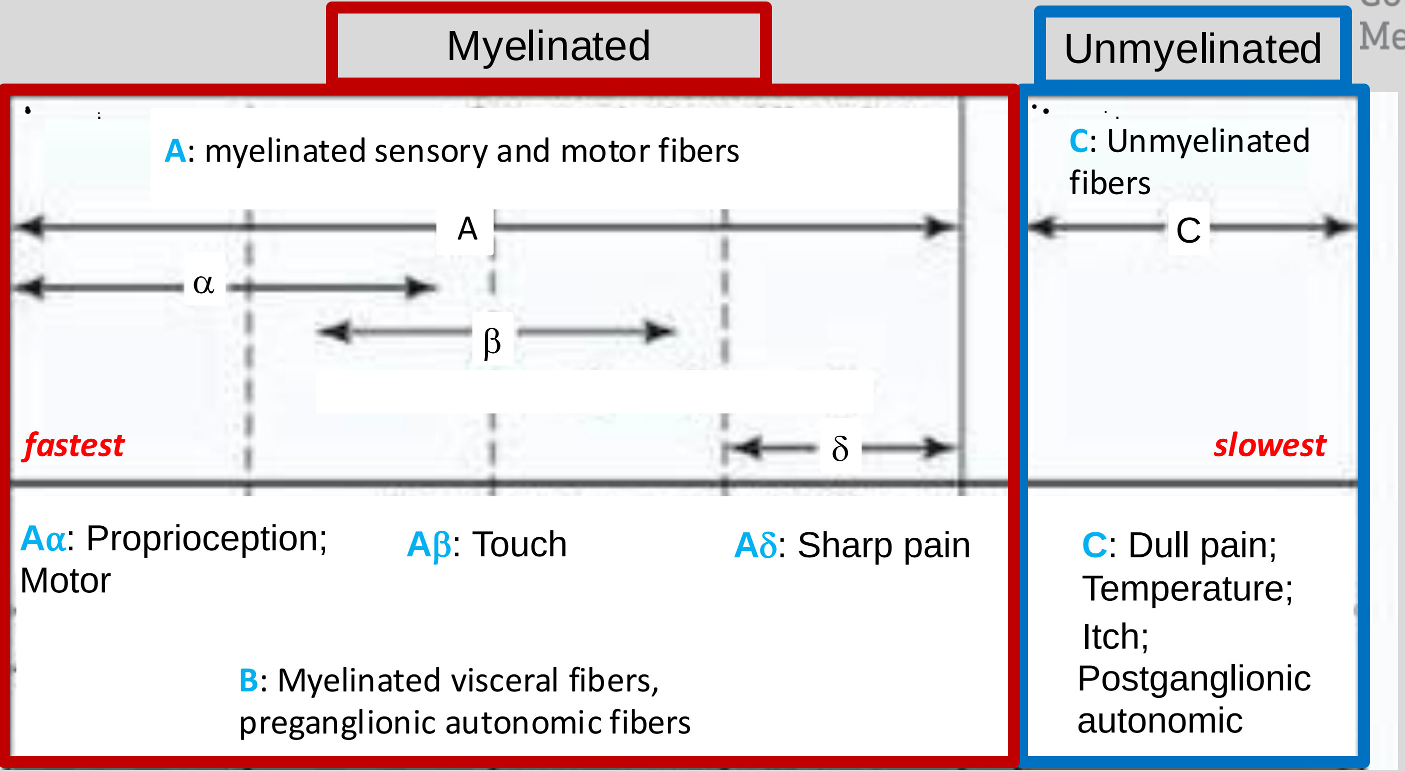

Source: Kandell and Schwartz, Principles of Neuroscience

Conduction Speed

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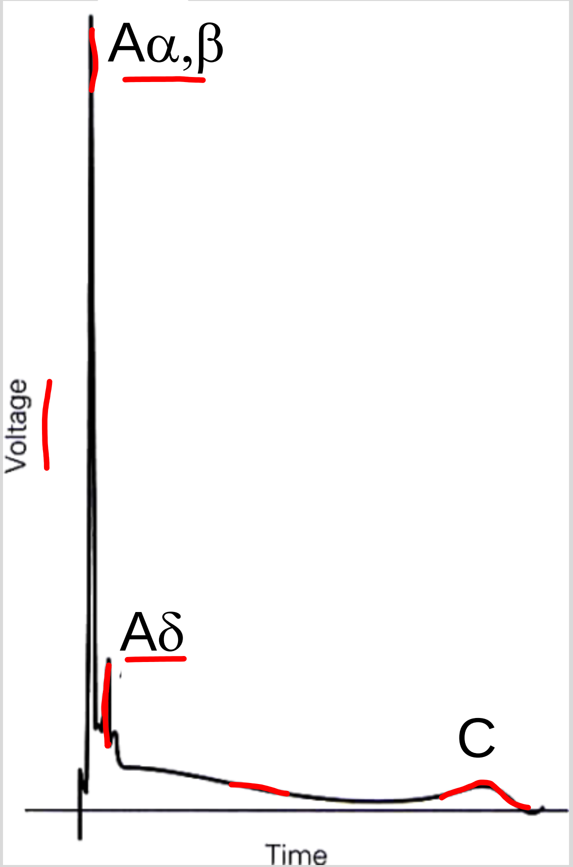
A strong electrical stimulus of the skin will evoke a compound action-potential in a nerve fiber.

Its complex waveform reflects the summed response of individual axons having different diameters or myelination

Note the delayed response by C fibers



Source: Kandell and Schwartz, Principles of Neuroscience

Diversity of receptors for somatosensation

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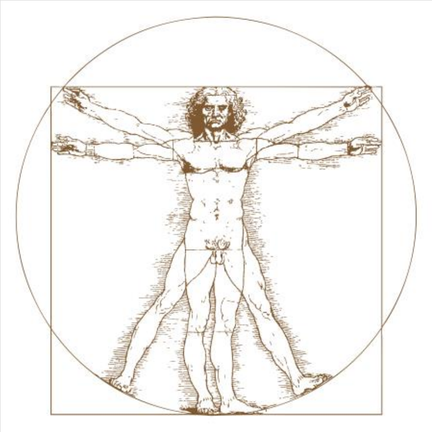
1 Rod
3 Cones



1 Hair cell

4 touch
2 proprioception
1 force,1 joint, 1 hair
> 2 temperature
> 2 pain/itch/ache
visceral
(plus more not mentioned & being discovered)

Categories of receptors for somatosensation

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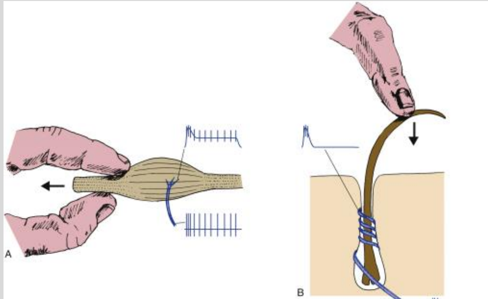
Based on the source of stimuli

- **Interoceptors**:
  - Internal stimuli within the body, e.g., baroceptors, pH sensors
- **Exteroceptors**
  - External stimuli outside the body, e.g., skin touch, heat sensors
- **Proprioceptors**
  - Position changes of the body parts, e.g., receptors at joints



Based on the types of stimuli

- Chemoreceptors
  - Smell, taste, pH, etc.
- Photoreceptors
  - Visual signals
- Thermoreceptors
  - Temperature sensors
- Mechanoreceptors
  - Detecting physical deformation
- **Nociceptors** (latin "*nocere*" = to hurt)
  - Noxious stimuli: mechanical, thermal, chemical, etc.

Skin/cutis is richly embedded with touch sensors

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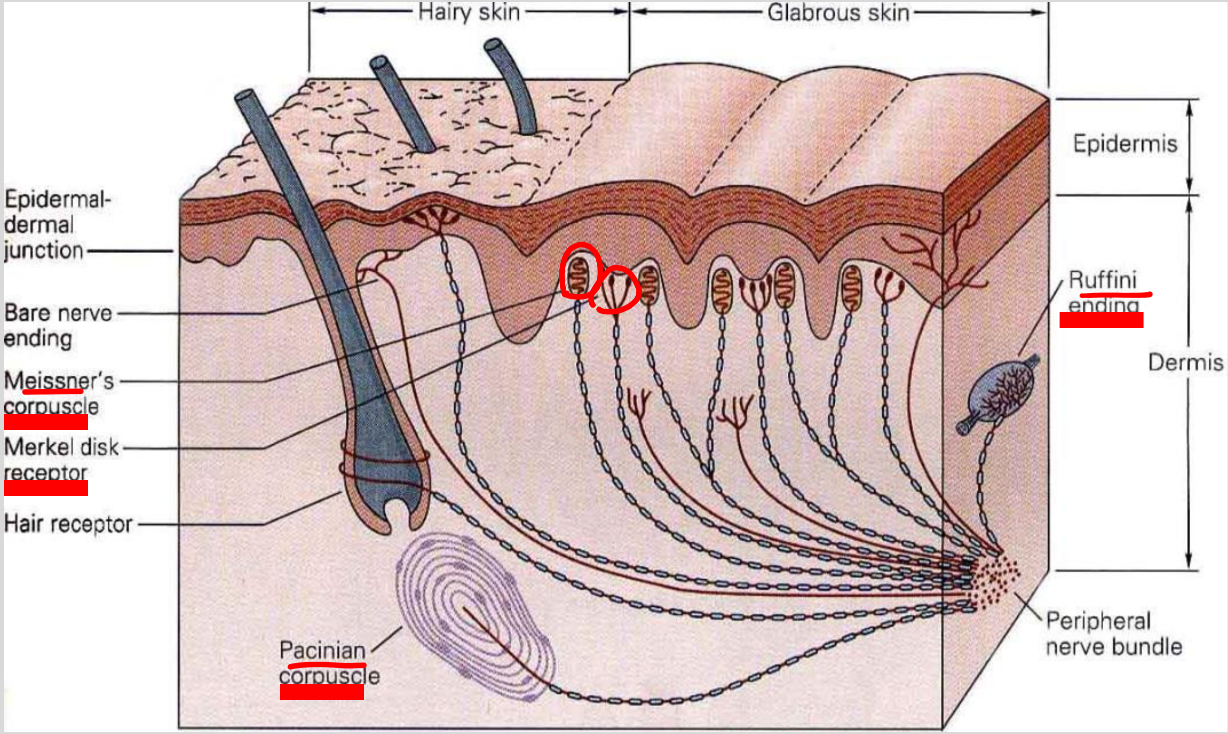

These are _“exteroceptors”_, also _“mechanoreceptors”_ (type of receptors).

Source: Kandell and Schwartz, Principles of Neuroscience

Touch receptors have different sensitivity

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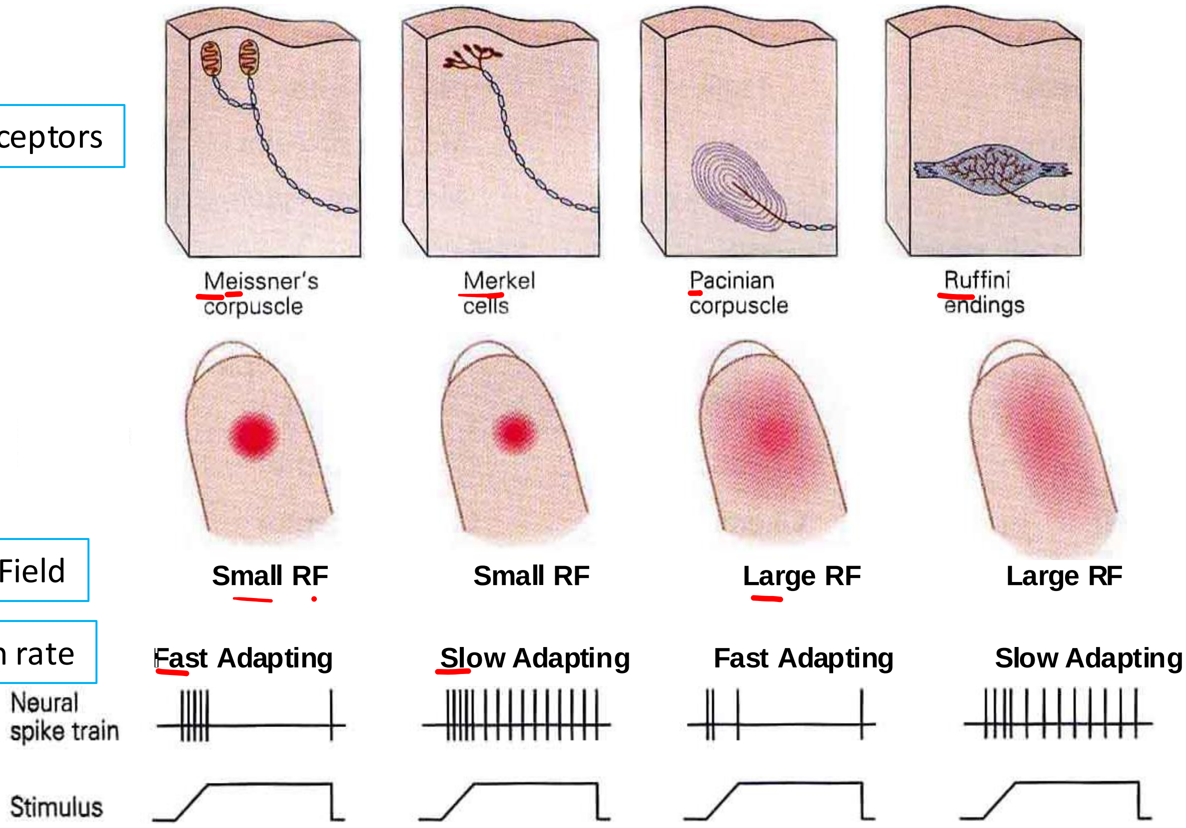
Receptors

Receptive Field

Adaptation rate



Touch

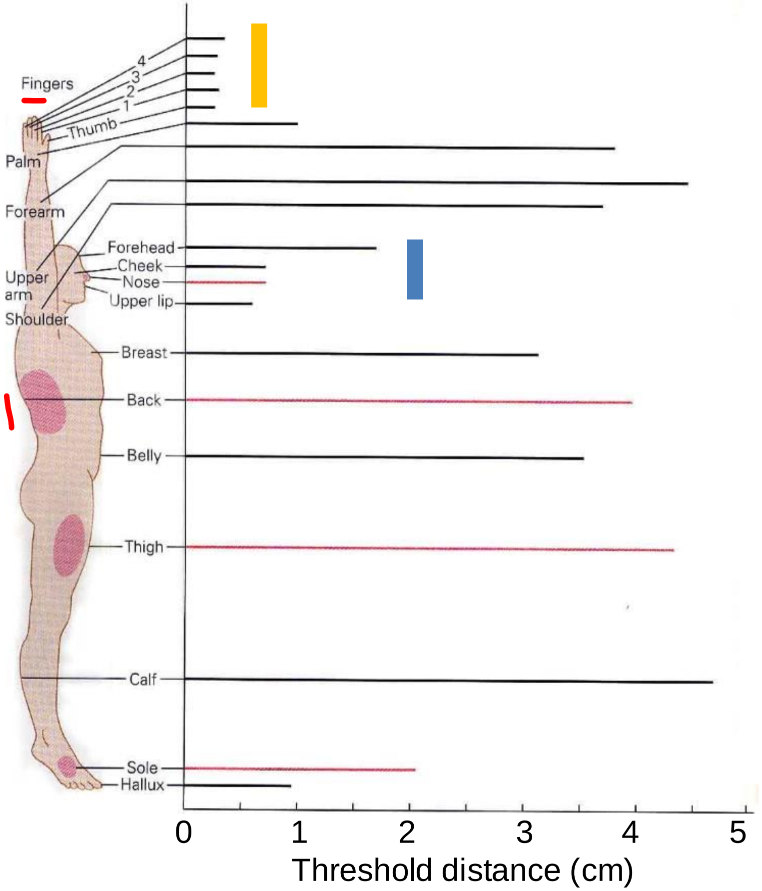
Vibration, pressure

Source: Kandell and Schwartz, Principles of Neuroscience

Touch sensitivity varies across body surface

- Reflects **density** of receptors
- Packed highest where there is most important physical interaction: **hands** and **face**

Use two point-discrimination to assess: is it “one” or “two”?



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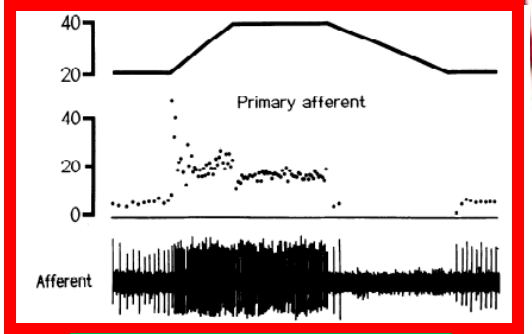
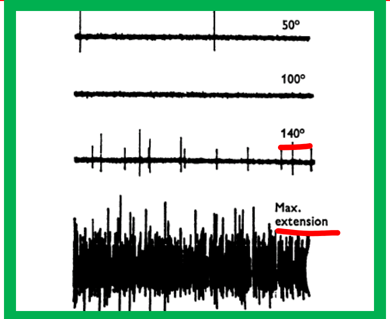
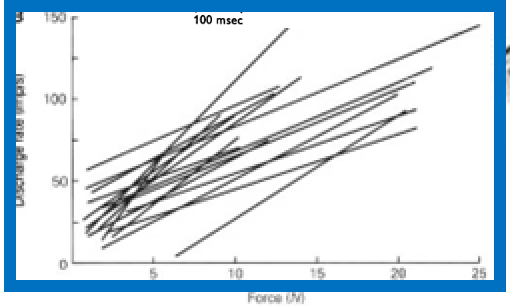
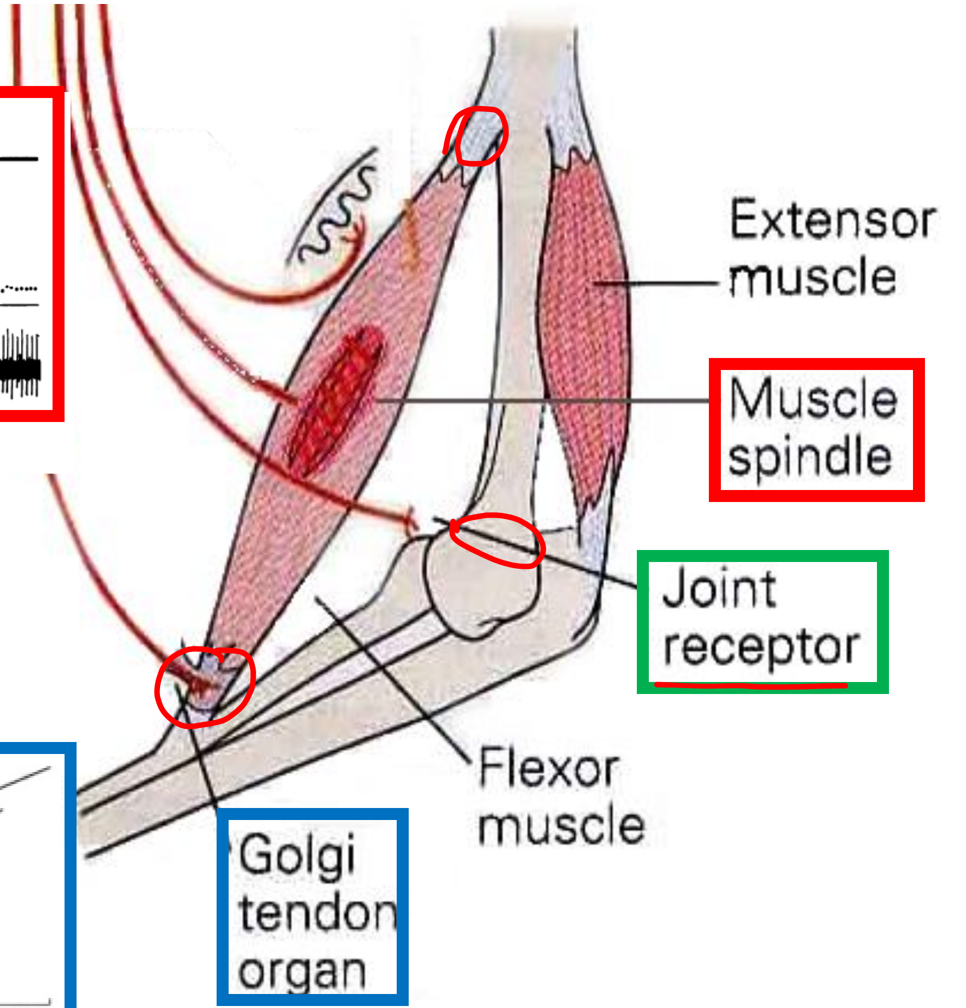
Source: Kandell and Schwartz, Principles of Neuroscience

Proprioceptors



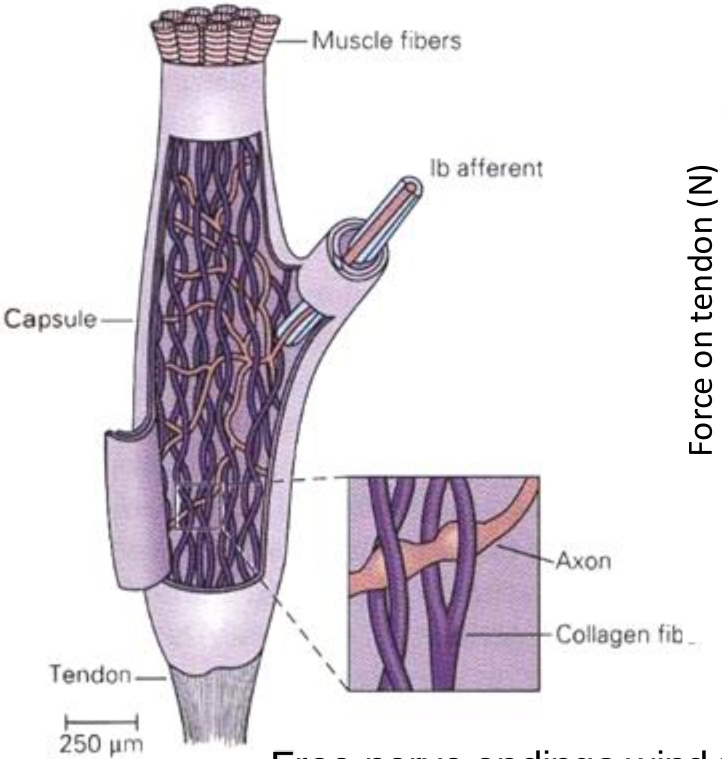


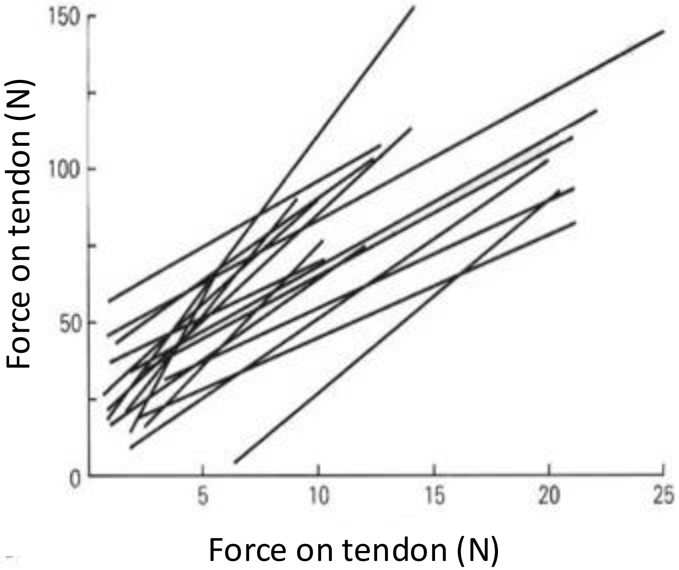




"**proprio**ceptors" convey information about the state of the musculo-skeletal apparatus.

Golgi tendon organs sense force at the tendon





Free nerve endings wind through collagen

Pulling force at the junction (from external load or active muscle) bends the free nerve endings, opens the ion channels, and depolarizes the membrane.

Joint receptors are sensitive to capsule strain

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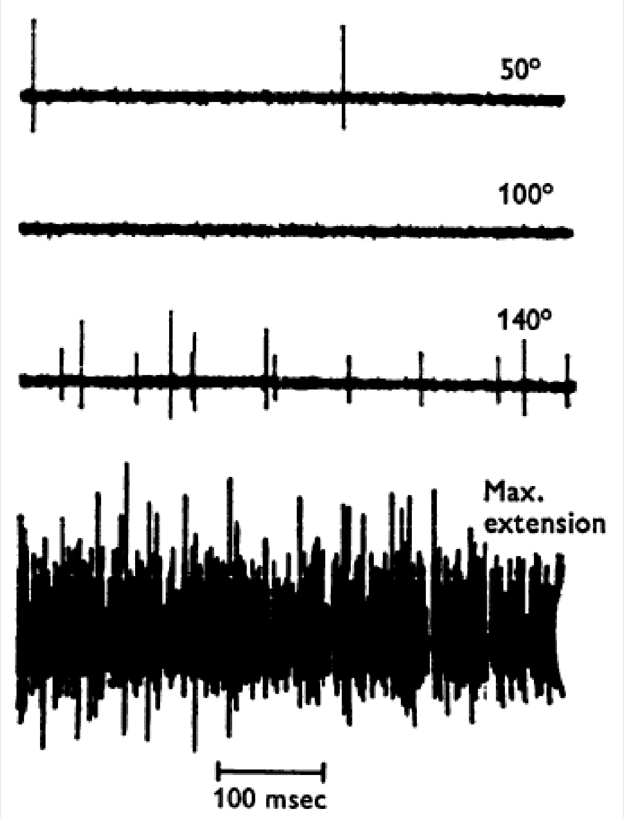

Free nerve endings embedded within the joint capsule

Insensitive to limb position within its normal range of motion

Detects limb position at **extremes and/or inappropriate directions**

For example, they are recruited during valgus/varus motion of the knee

Source: Burgess and Clark (1969) Characteristics of knee joint receptors in the cat

Nociceptors for pain sensation

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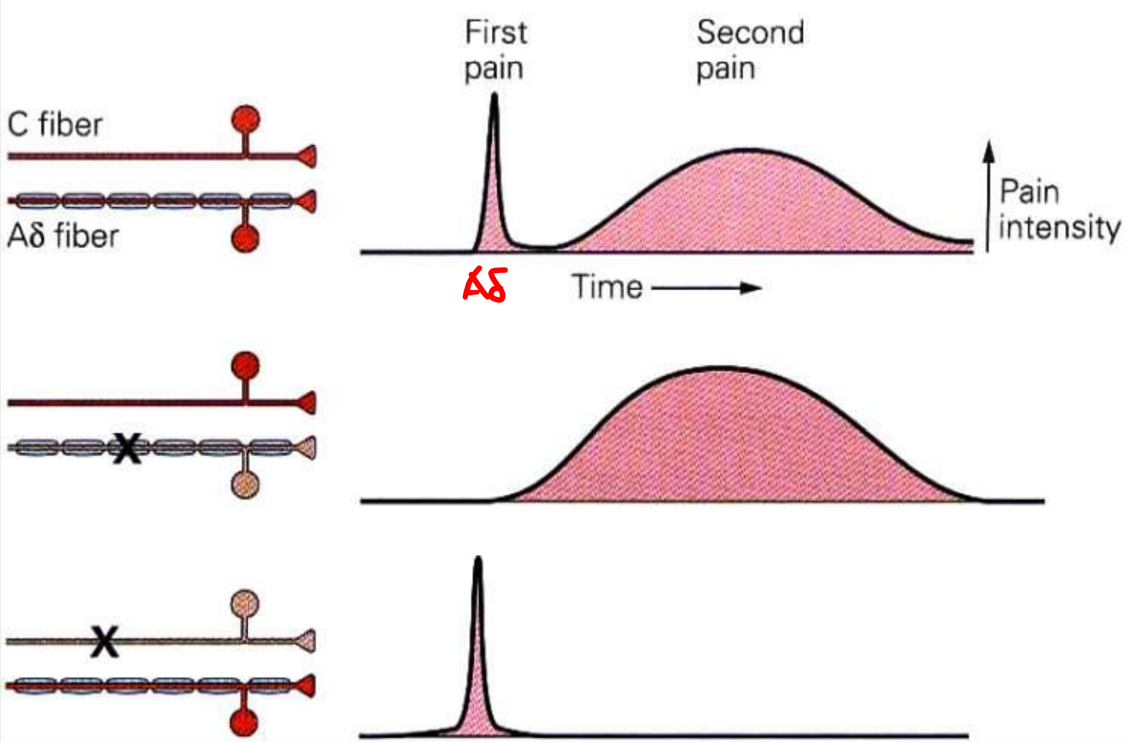

Aδ fibers - thermal, mechanical nociceptors

C fibers - polymodal nociceptors incl. chemosensitive

Ascending modulation of pain

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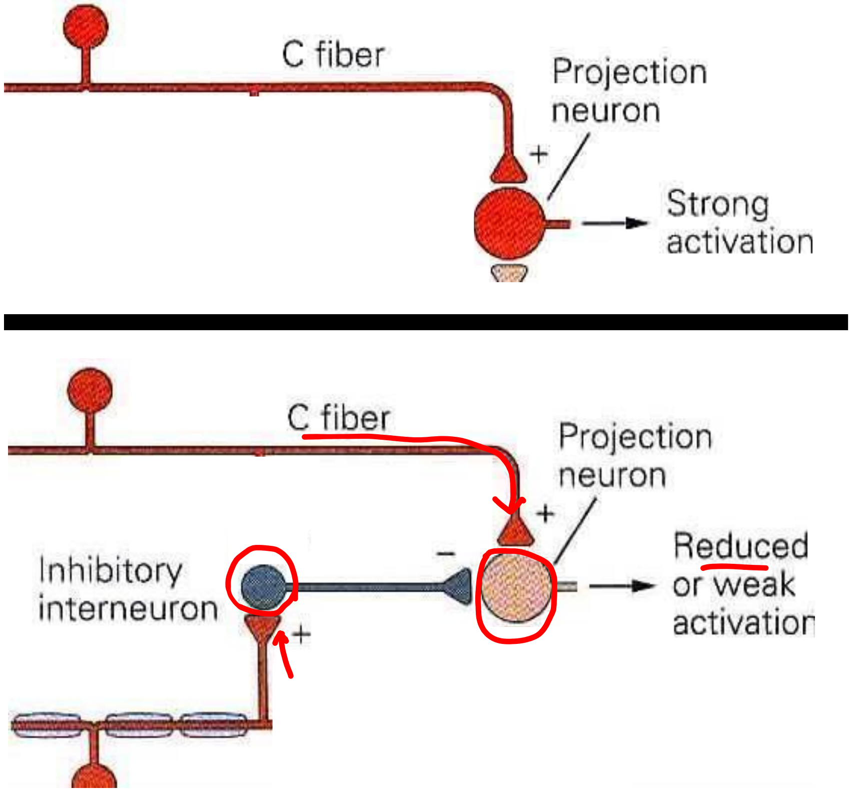
Gate Theory

<u>Low-threshold tactile afferents inhibit nociceptive pathway, i.e. “closes a gate”.</u>

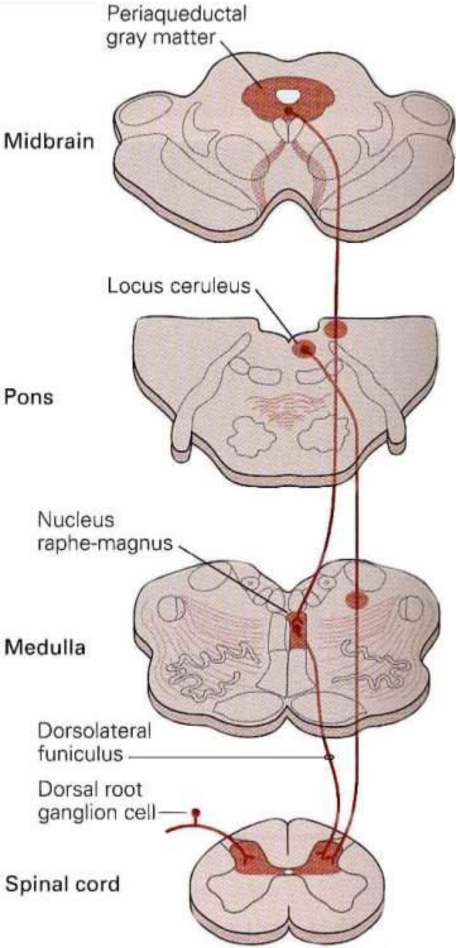
The projection neuron response is weakened when the non-pain activity occurs during C fiber activity.

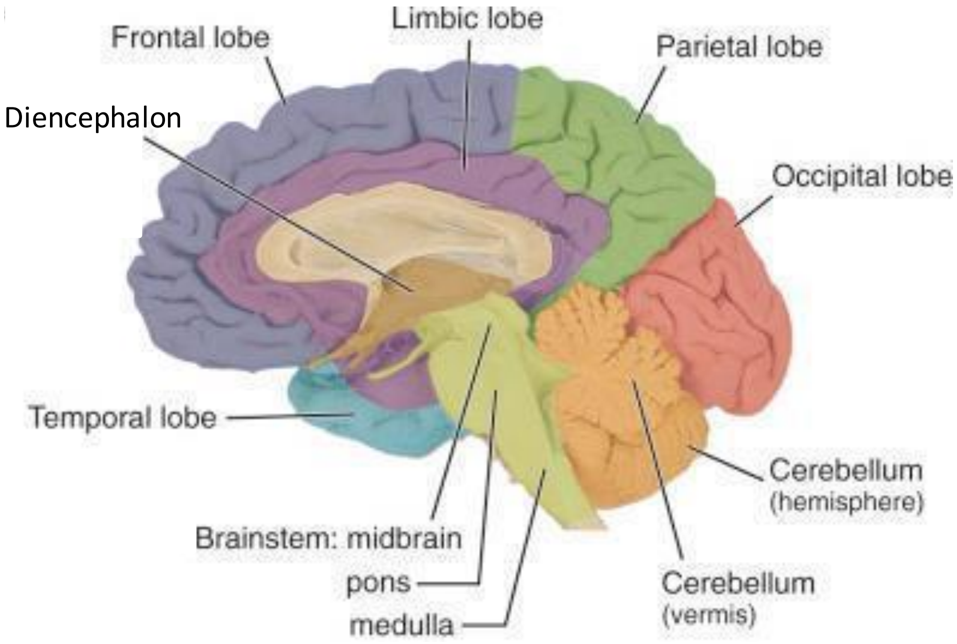
Explains why rubbing the area around your injury makes it feel better.



Non-nociceptive neuron

Descending modulation of pain





Descending modulation of pain

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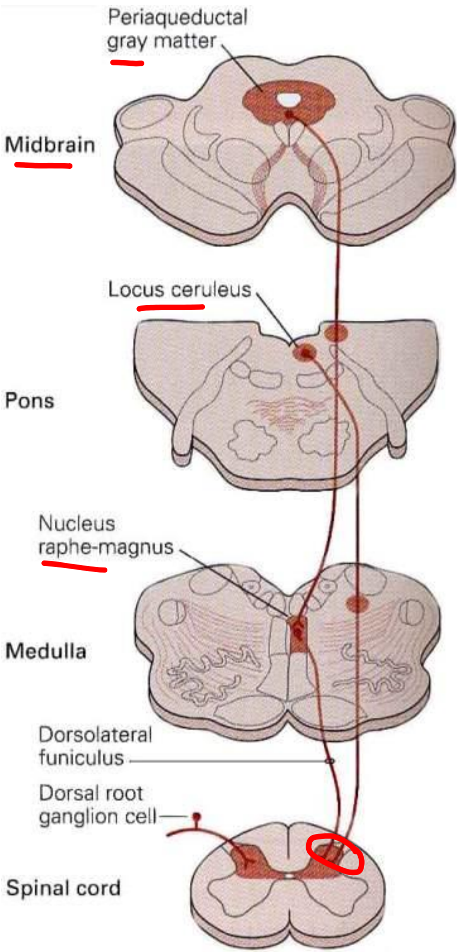
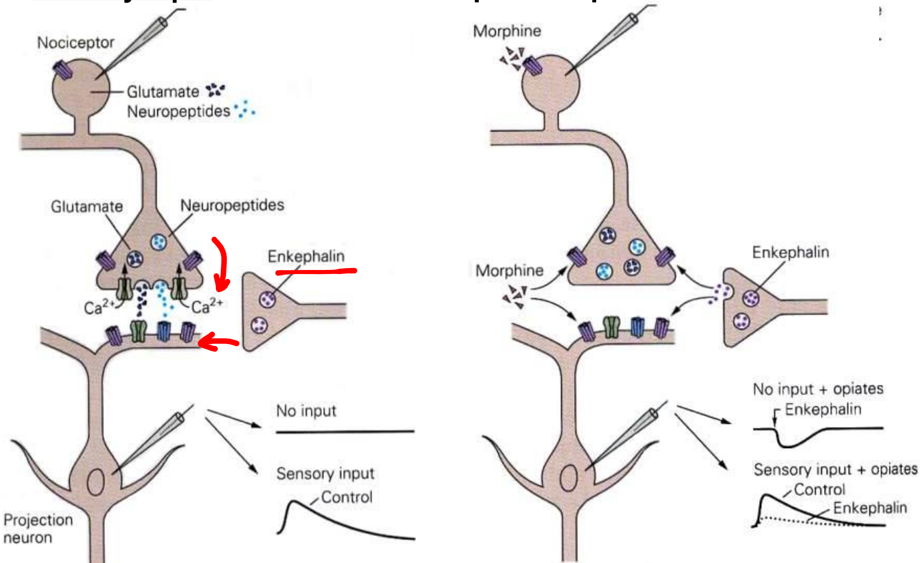


Stimulation of periaquaductal gray matter excites locus coeruleus (NE) and raphe nucleus (5HT).
These project to the dorsal horn (substantia gelatinosa) and activate enkephalin-containing interneurons:

1) Prevent calcium influx in the presynaptic pain neuron
2) Which reduce transmitter release
3) And reduces postsynaptic depolarization and activity.



Itch (Pruritis)

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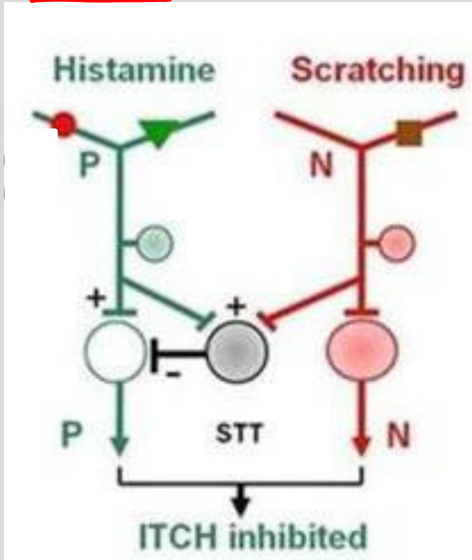
- Different behaviors for itch (scratch) versus pain (withdrawal)
- Specific to skin (no visceral itch)
- Evoked by many conditions (dry skin, pregnancy, morphine)
- Conducted by c-fibers

Histamine-sensitive & mechanically insensitive pathway
Histamine-independent & mechanically sensitive



Pain inhibits itch
(Similar principles as "gate theory")

Source: LaMotte et al (2014) Sensory neurons and circuits mediating itch

Fill in the blank

Summary of sensory receptors

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Receptor type	Characteristics	Fiber type	Conduction
Touch (mechanoreceptors)			
Pain (nociceptors)			
Proprioception (proprioceptors)			

Summary of sensory receptors

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Receptor type	Characteristics	Fiber type	Conduction
Touch (mechanoreceptor) Meissner's corpuscles Merkel cells Pacinian corpuscles Ruffini endings	Light touch, fast adapting, small RF Static touch, slow adapting, small RF Vibration & pressure, fast adapting, large RF Pressure, slow adapting, large RF	Aβ, large diameter, myelinated	Fast
Pain (nociceptors) Free nerve endings Noxious stimuli (thermal, chemical, etc.)	Sharp pain Dull pain	Aδ, small diameter, myelinated c, small diameter, unmyelinated	Fast Slow
Proprioception Free nerve endings Joint receptors Golgi tendon organ	Extreme limb position or directions Pulling force at the junction of nerve endings and tendon collagen fibers	Aα, large diameter, myelinated	Fast

Sample question #1

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Stimulating the afferent for a Meissner's receptor embedded in the hand should lead to what sensation?

A. Joint motion
B. Sharp pain
C. Light touch
D. Temperature
E. Itch

Sample question #1

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Stimulating the afferent for a Meissner’s receptor embedded in the hand should lead to what sensation?

A. Joint motion
B. Sharp pain
C. Light touch
D. Temperature
E. Itch

Some signposts on the road to the brain

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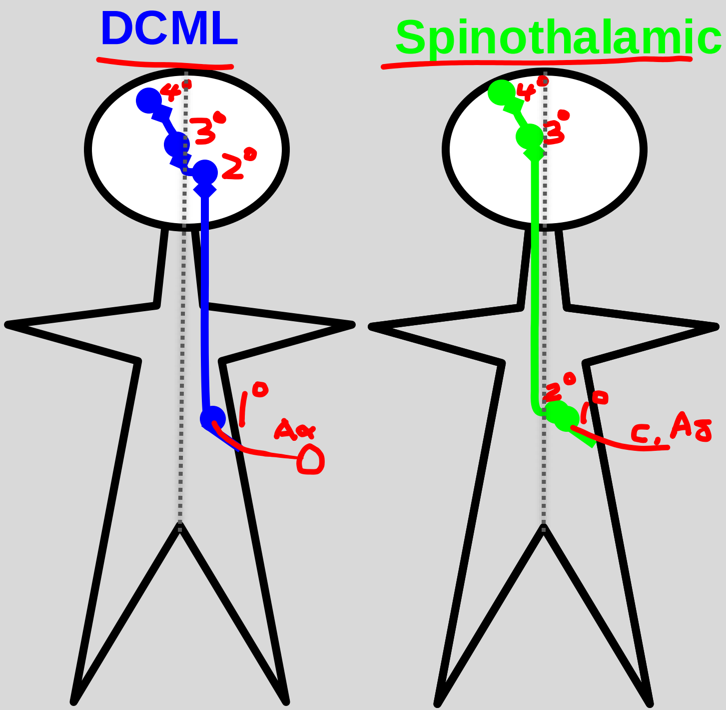
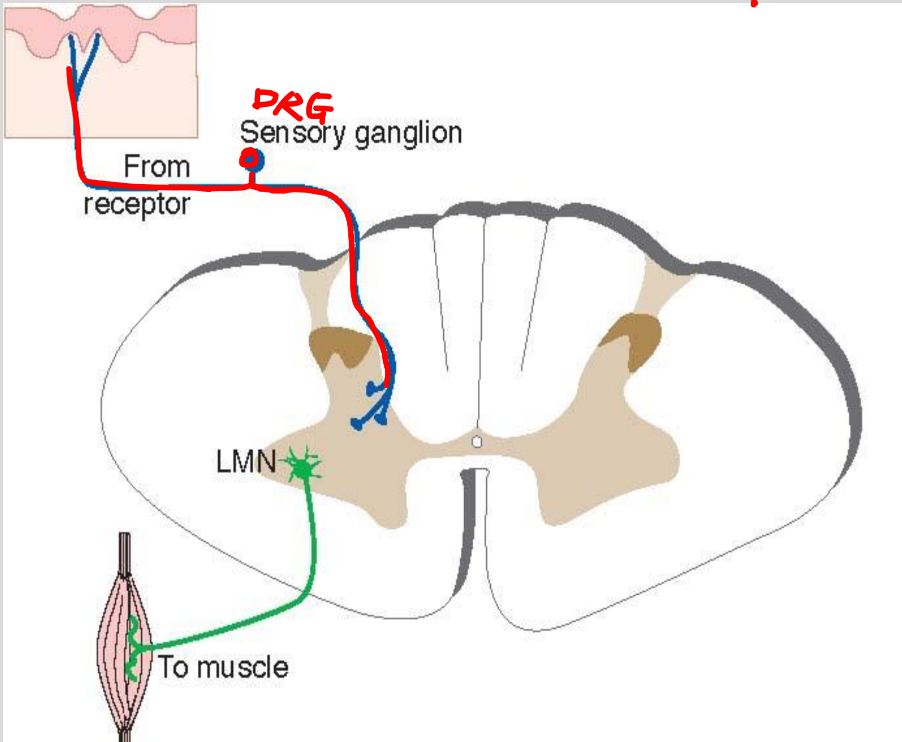
1. 1st order neurons are sensory neurons with cell bodies in the dorsal root ganglia (DRG).
2. Sensory neurons do not decussate.
3. 2nd order neurons decussate.
4. 3rd order neurons at the thalamus, the gateway to cortex.
5. Final destination at the somatosensory cortex.



Primary Afferents

1°



(From Nolte J: Essentials of The Human Brain, 2010, Mosby.)

- Cell bodies of 1° afferents live outside the CNS* at the dorsal root ganglia (DRG) or trigeminal ganglia (**pseudounipolar neurons**)
- Primary afferents for somatic neurons end on the ipsilateral side of the CNS*
- Damage to 1° afferents – lose part or all perception and reflex (if one exists)

* With some exceptions

Anatomical Organization of the Nervous System

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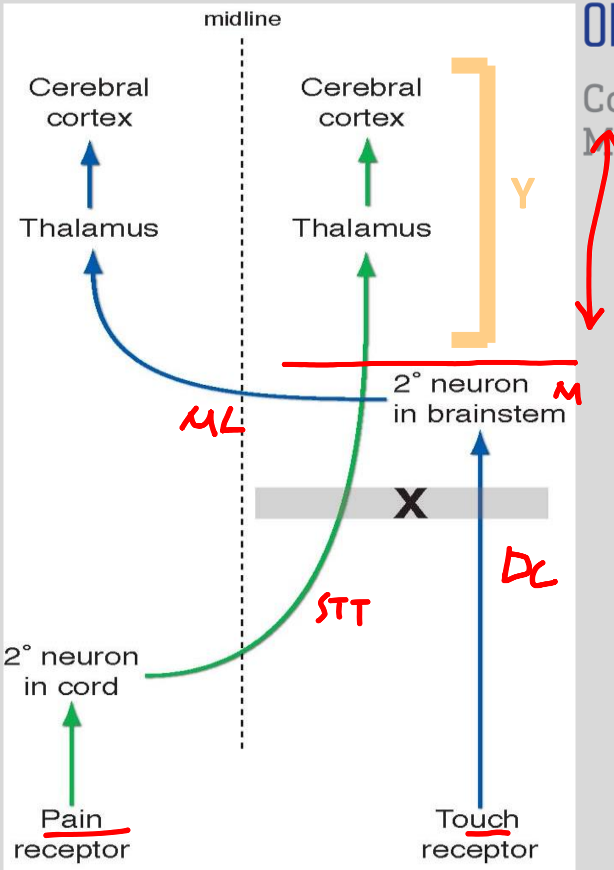
- 2° Afferents for pain and temperature cross at the level they enter the spinal cord

- 2° Afferents for touch and proprioception cross at the level of the brainstem

Damage at X
- Ipsilateral loss of touch and proprioception
- Contralateral loss of pain and temperature

Damage at Y
- Contralateral loss of both sensory modalities



Spinothalamic Pathway

4° - Primary sensory cortex

3° - Ventral posterior lateral (VPL) thalamic nucleus

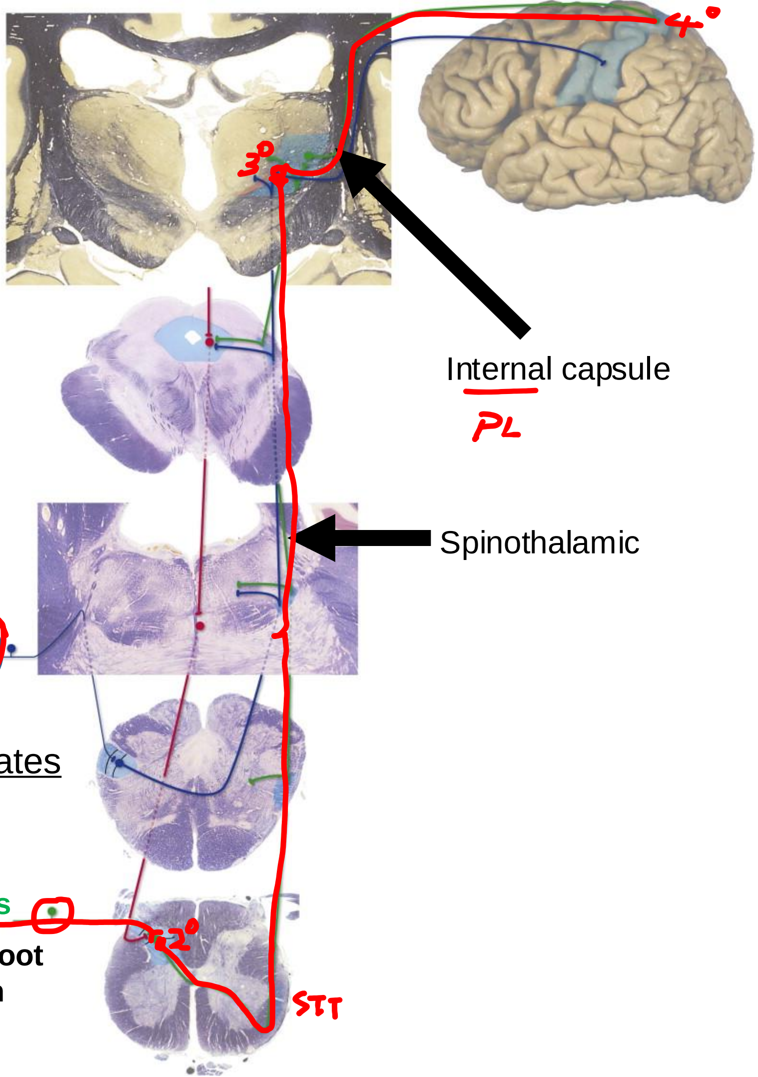
Targets primary somatosensory cortex just like DCML

S1 processes conscious intensity and location of Pain, Itch, and Temperature, not the affective experience

Spinothalamic decussates in spinal cord

2° - Nucleus proprius

1° - Dorsal root ganglion



Internal capsule

PL

Spinothalamic

Source: Nolte,The Human Brain in Photos and Diagrams, “Functional systems”

Dorsal Column-Medial Lemniscus Pathway (DCML)

4˚ - Primary somatosensory cortex

3˚ - Ventral posterior lateral (VPL) thalamic nucleus

Conveys "conscious proprioception" and "discriminative touch"
Above & below T_6

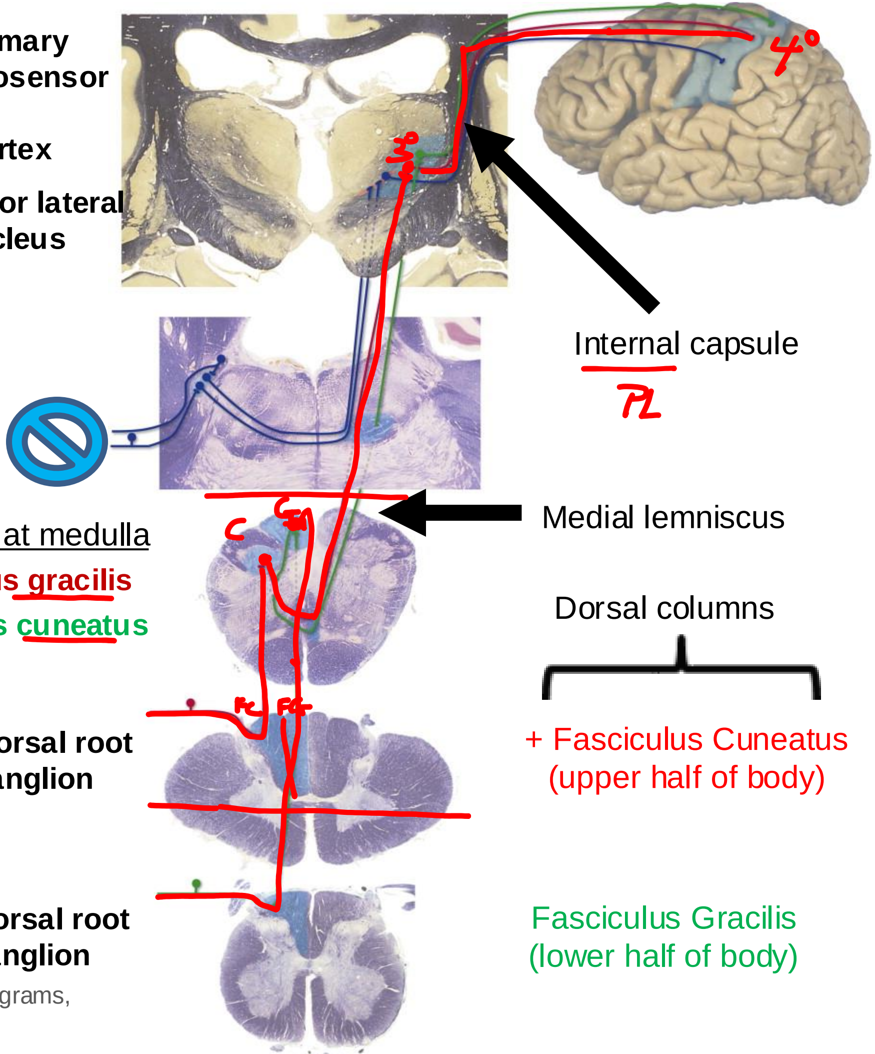
Decussates at medulla

2˚ - Nucleus gracilis

2˚ - Nucleus cuneatus

1˚ - Dorsal root ganglion

1˚ - Dorsal root ganglion



Internal capsule

PL

Medial lemniscus

Dorsal columns

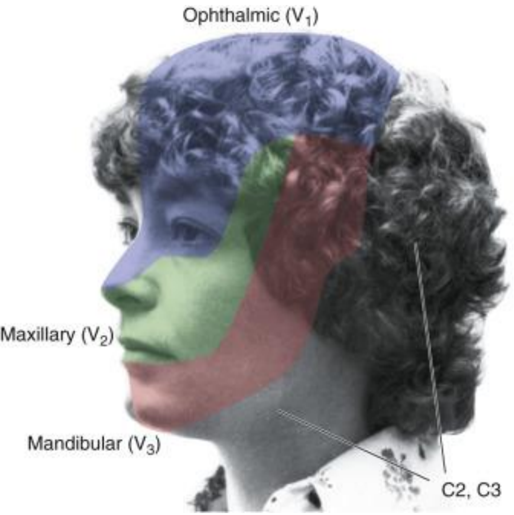
+ Fasciculus Cuneatus (upper half of body)

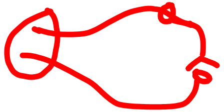
Fasciculus Gracilis (lower half of body)

1^o = 1^{st} order in series
2^o = 2^{nd} order in series
3^o = 3^{rd} order in series

Source: Nolte, The Human Brain in Photos and Diagrams, "Functional systems"

Somatosensation in the head processed by three nuclei





Principal/main/pontine trigeminal nucleus (pons)

- analogous to dorsal column nuclei for DCML
- receives touch and proprioceptive information from face, cornea, tongue, ear, oronasal mucous membranes, dura, oropharynx, and laryngopharynx

Spinal trigeminal nucleus (medulla)

- analogous to nucleus proprius for STT
- receives nociceptive signals and temperature info from the same areas as the above

Mesencephalic trigeminal nucleus (midbrain)

- Analogous to dorsal root ganglia (DRG), where the cell bodies of pseudounipolar neurons (1st order neurons) for the proprioception of jaw muscles and periodontal regions are located
- Receives proprioceptive information from the mandible and projects to the trigeminal motor nucleus to mediate jaw jerk reflex

Pontine/principal trigeminal pathway

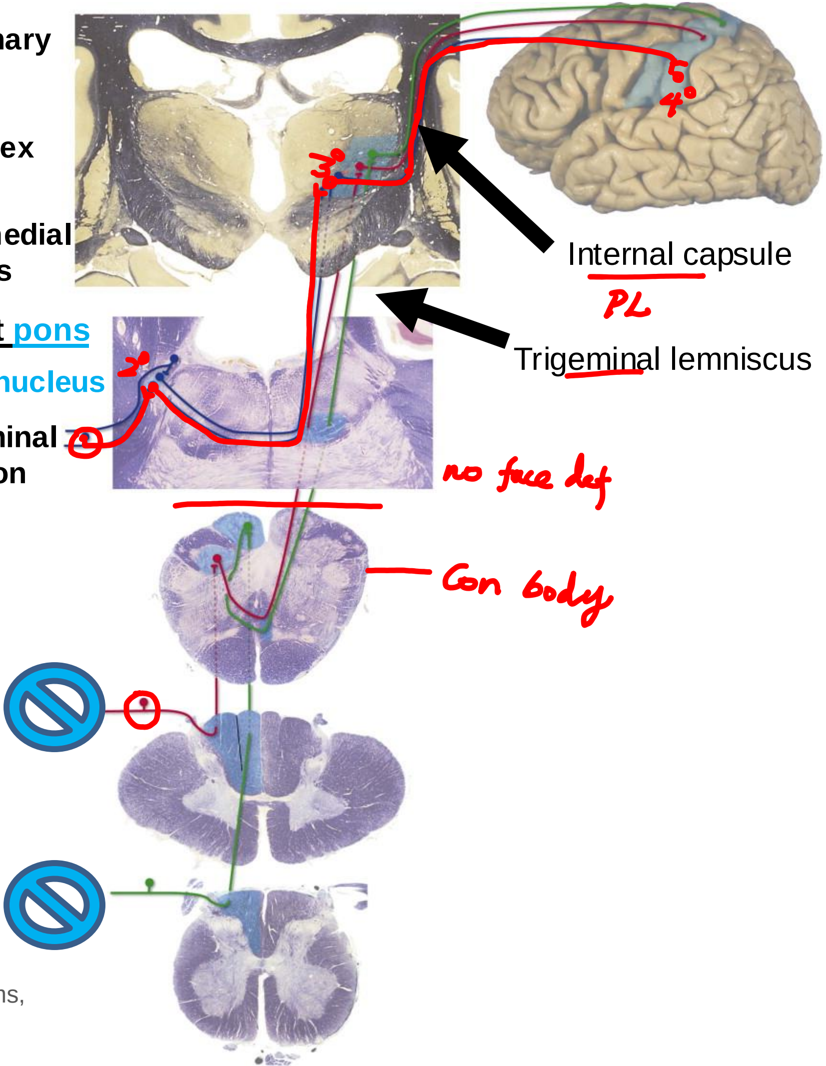
4˚ - Primary sensory cortex

3˚ - Ventral posterior medial (VPM) thalamic nucleus

Decussates at pons

2˚ - Principal/pontine nucleus

1˚ - Trigeminal ganglion



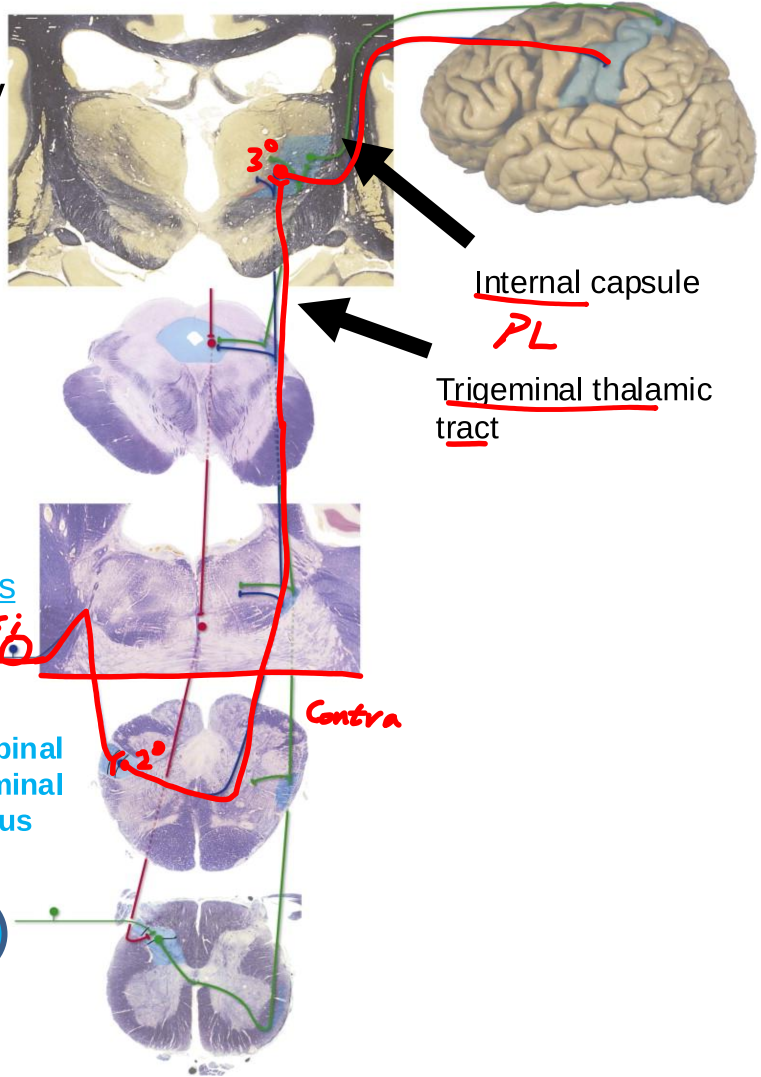
- Conveys "conscious proprioception" and "discriminative touch" of the head
- analogous to DCML

Source: Nolte, The Human Brain in Photos and Diagrams, "Functional systems"

Spinal trigeminal pathway

4° - Primary somatosensory cortex

3° - Ventral posterior medial (VPM) thalamic nucleus



Internal capsule

PL

Trigeminal thalamic tract

- Conveys conscious intensity and location of pain (and Itch) and temperature information of the head.
- Analogous to spinothalamic tract.

Descends to medulla, synapse and decussates

ipsi

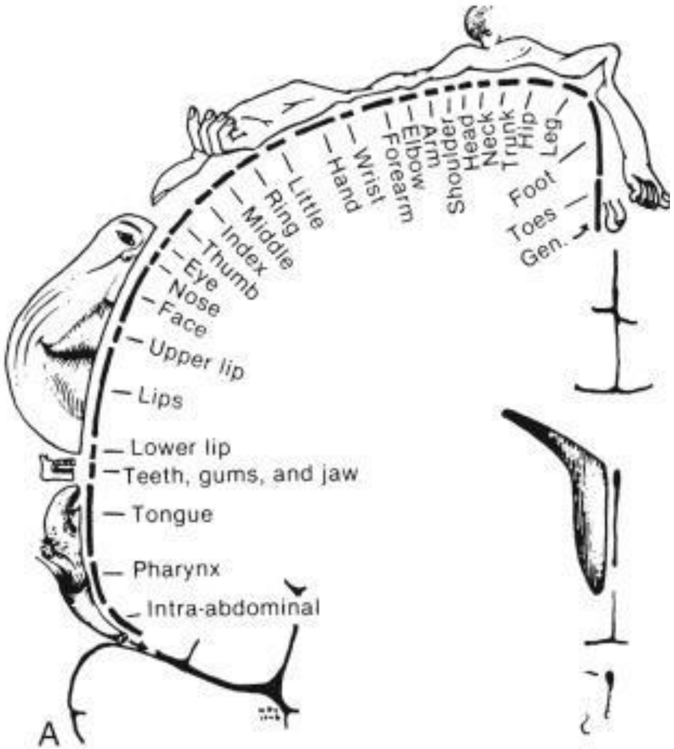
1° - Trigeminal ganglion

Contra

2° - Spinal trigeminal nucleus

Source: Nolte,The Human Brain in Photos and Diagrams, “Functional systems”

Sensory homunculus of the somatosensory cortex



Penfield and Rasmussen (1950)
The cerebral cortex of man

Primary somatosensory cortex is the **entire post-central gyrus including medial wall**.

Classically, this is the first receiving station within cortex for somatosensory information. Unimodal (no visual or auditory processing which occurs in more posterior parietal cortex).

"Somatotopy" – nearby portions of the body are represented by nearby portions of cortex.

Area of cortex for a given portion of the body/face reflects the density of sensory innervation.

The leg is most medial, then trunk, hand, face, and then oral/pharanyx.

Somatosensory pathways from the body and face

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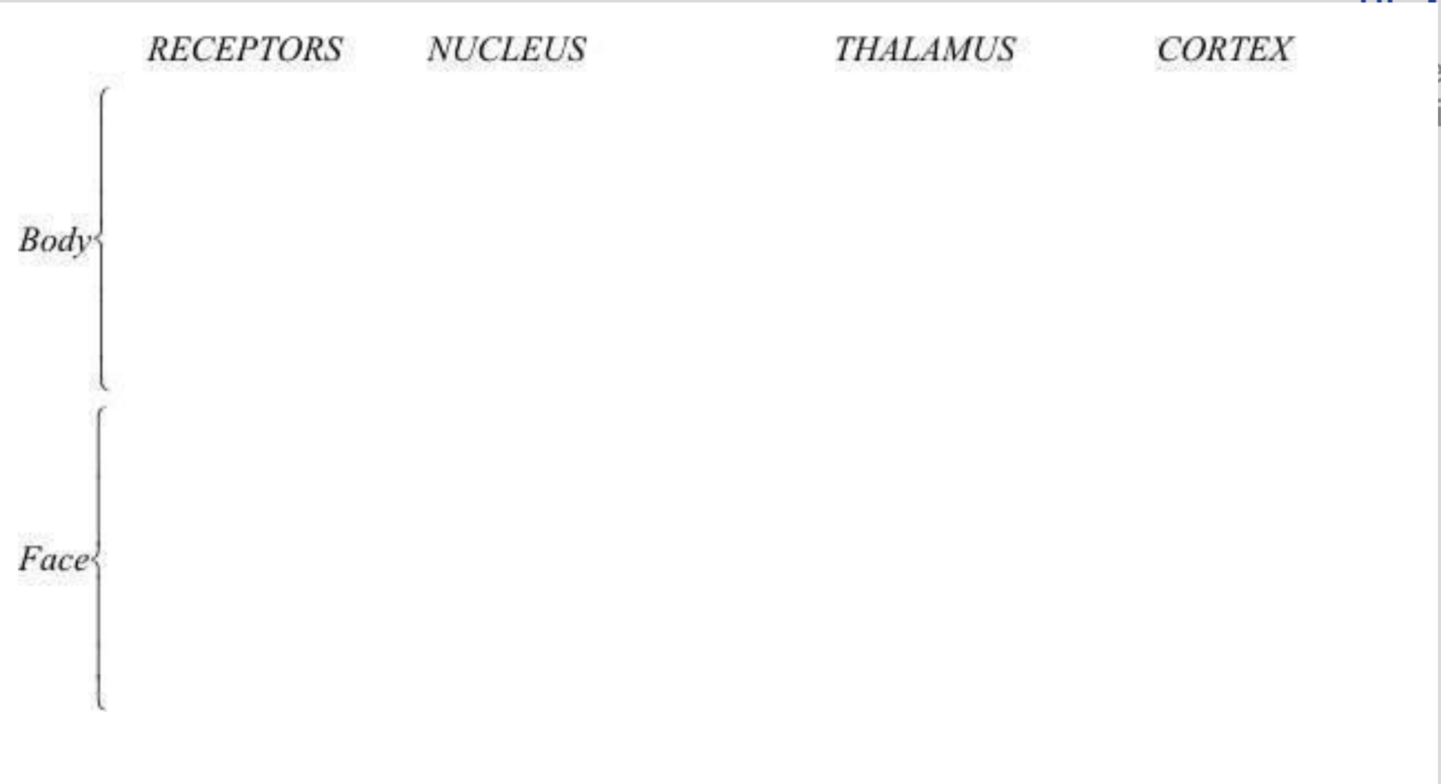

Source: Kandell and Schwartz, Principles of Neuroscience

Somatosensory pathways from the body and face

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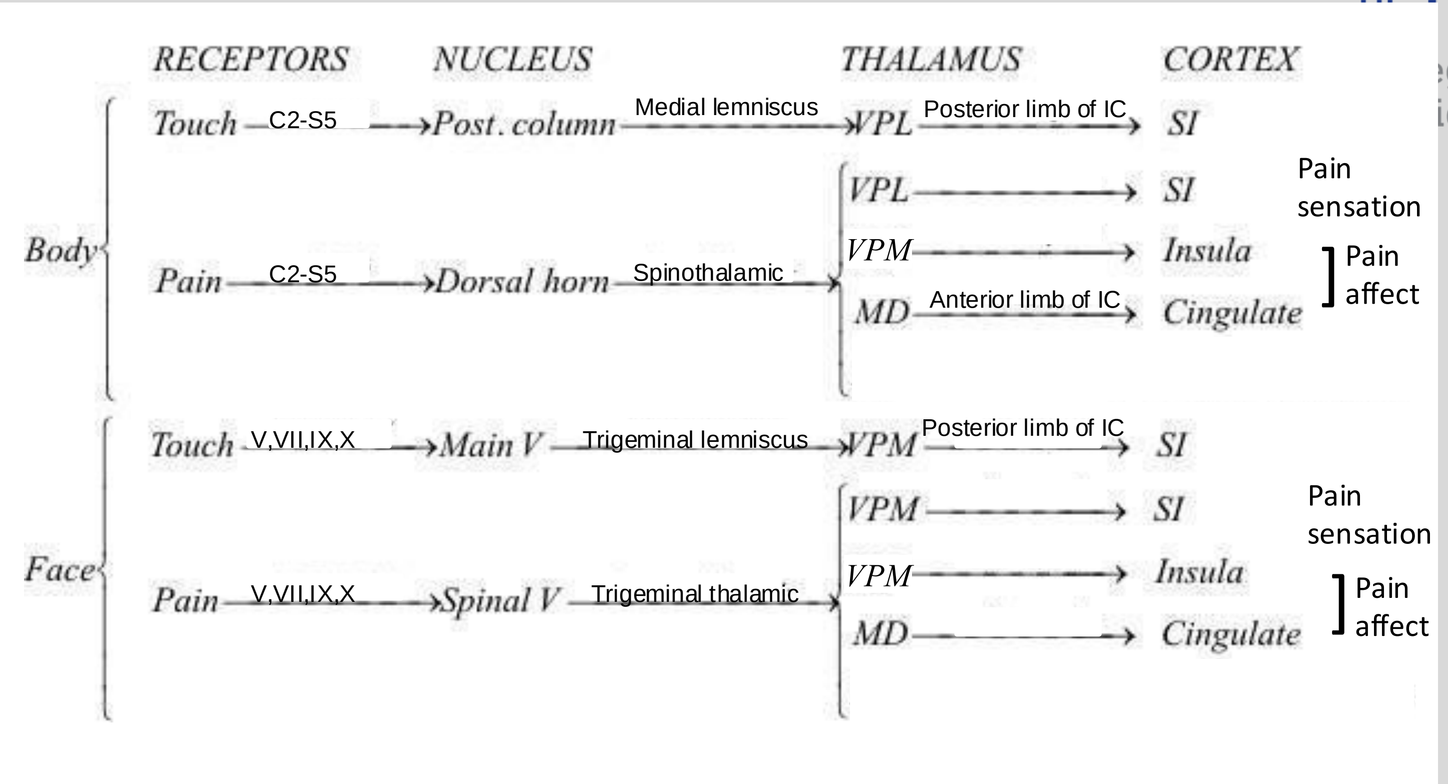
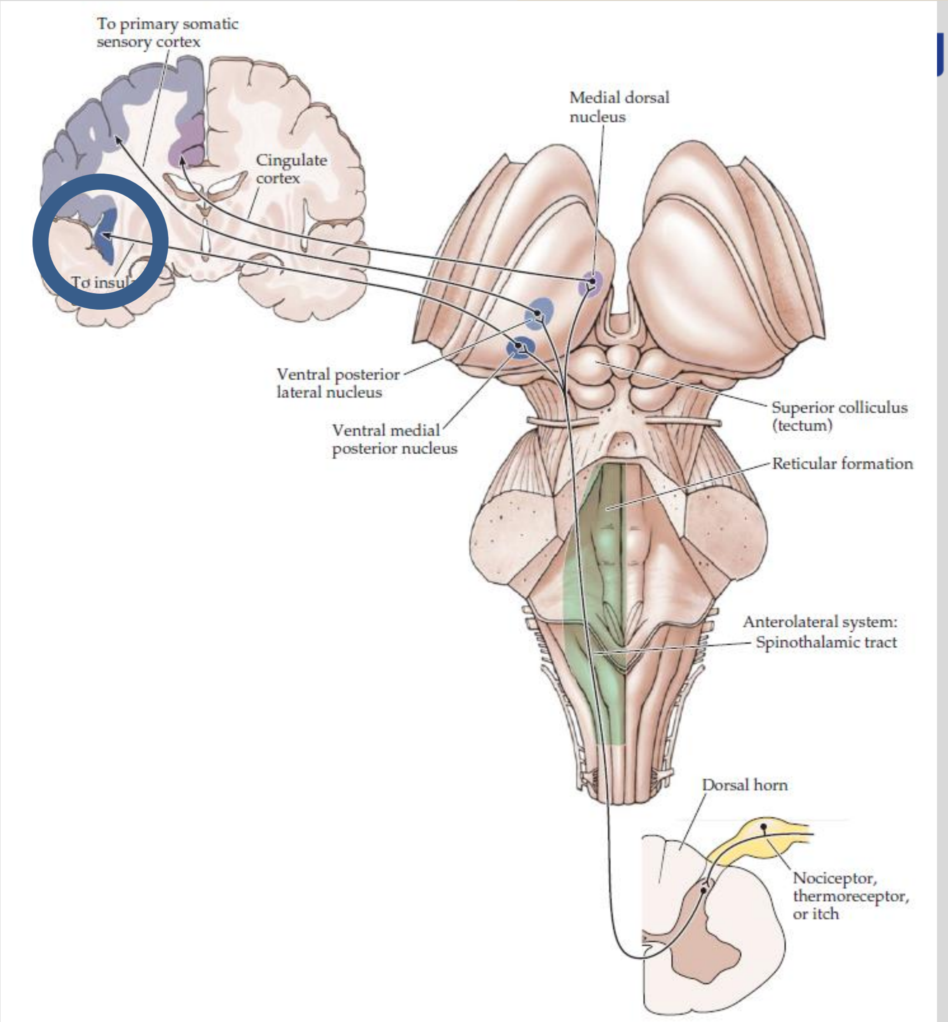


Source: Kandell and Schwartz, Principles of Neuroscience

“Where does it hurt?”

Ascending nociceptive pathway also projects to **insular** cortex and **cingulate** cortex, which process the affective (unpleasantness) aspects of pain.

For example, dense lesion of insula can lead to blunted pain thresholds for some stimuli despite the ability to recognize and rate intensity.



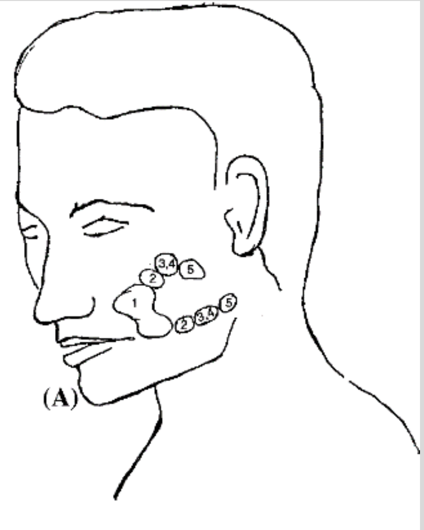
Source: Nolte,The Human Brain in Photos and Diagrams, “Functional systems”

‘Phantoms’ of the body

The compelling experience that the body part is still present following its **sudden removal** whether by surgery, accident, or violence.

Phantom arm, phantom leg, …

Often painful sensation (e.g. burning, fingernails pressing into skin, contortions) and typically weak voluntary control. Resistant to medication.



Body representation changes but still orderly.

Cortical reorganization as face area expands into unused arm area.

Ramachandran and Hirstein (1990)
The perception of phantom limbs

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Ipsilateral or contralateral?

- Lesions **above** the decussation cause **contralateral** deficits; **below** the decussation cause **ipsilateral** deficits

What kind of deficits would be presented when the lesions are at these levels?

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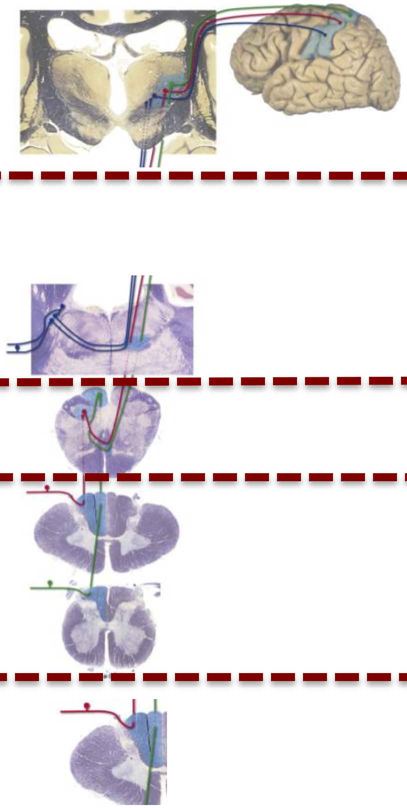
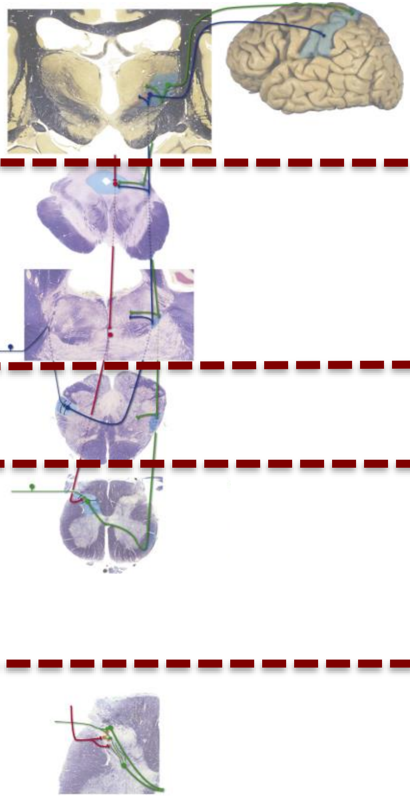
Touch/Proprioception



body/head

Pain/Temperature



Forebrain

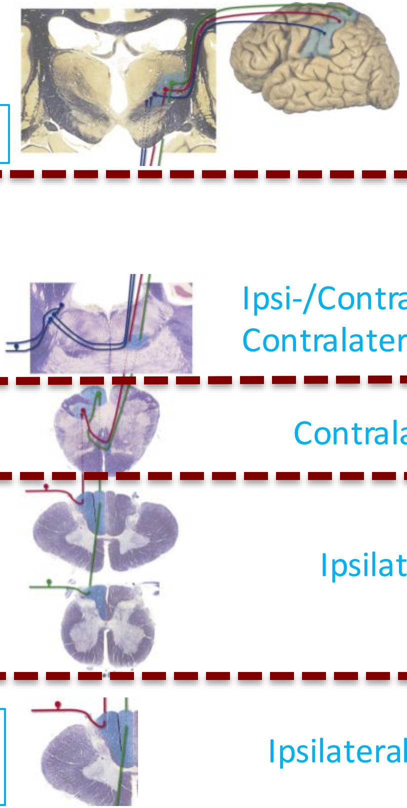
Pons

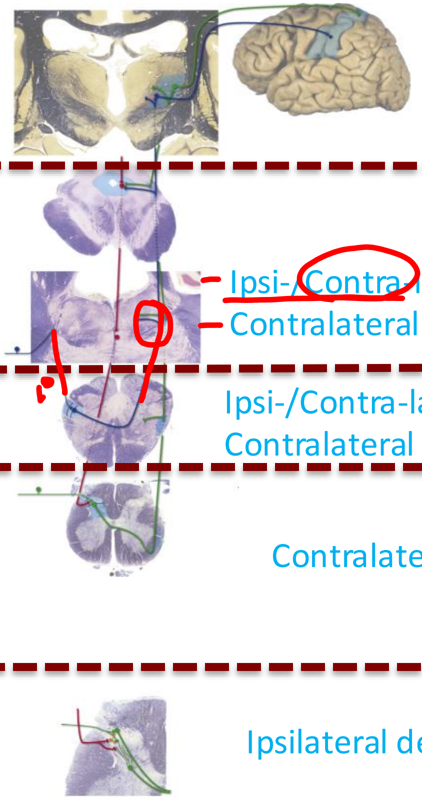
Medulla

Spinal cord

Primary afferent

What kind of deficits at different levels?





	Touch/Proprioception	Pain/Temperature
Forebrain	Contralateral Face & Body	Contralateral Face & Body
Pons	Ipsi-/Contra-lateral face; Contralateral body	Ipsi-/Contra-lateral face; Contralateral body
Medulla	Contralateral body	Ipsi-/Contra-lateral face; Contralateral body
Spinal cord	Ipsilateral body	Contralateral body
Primary afferent	Ipsilateral dermatome	Ipsilateral dermatome

Test yourself

Summary

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Lesions at the spinal levels –

________________ deficits for pain/temperature sensation

________________ deficits for touch/proprioception sensation and voluntary movement for the body

Lesions above brainstem (e.g., thalamus, internal capsule, cortex) -

________________ deficits for all modalities for the body

Lesions at brainstem (e.g., midbrain, pons, medulla) -

________________ deficits for the body;

________________ deficits for the face

Summary

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Lesions at the spinal levels –

__contralateral______ deficits for pain/temperature sensation

__ipsilateral________ deficits for touch/proprioception sensation and voluntary movement for the body

Lesions above brainstem (e.g., thalamus, internal capsule, cortex) -

__contralateral______ deficits for all modalities for the body

Lesions at brainstem (e.g., midbrain, pons, medulla) -

___contralateral_____ deficits for the body;

ipsi- or contra-lateral__ deficits for the face (depending on the level of the CN nuclei)

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Sample question #2

A lesion to the right ventral posterolateral nucleus would blunt this sensation:

A. Touch and proprioception of the right face
B. Touch and proprioception of the left face
C. Touch and proprioception to the left face and body
D. Touch and proprioception to the right body
E. Touch and proprioception to the left body

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Sample question #2

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Sample question #3

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A 76-year-old male presents to the emergency department with complaint of fatigue and general weakness. History reveals hypertension. Physical examination reveals hemiparesis in his upper and lower extremities on the left side, as well as hemianesthesia for the left side of the body and face. Visual field examination is unremarkable. Which of the following is the most likely location for a stroke causing these clinical signs?

a) Genu of internal capsule
b) Lateral geniculate nucleus of thalamus
c) Posterior limb of internal capsule
d) Ventral posterolateral nucleus of thalamus
e) Ventral posteromedial nucleus of thalamus

Sample question #3

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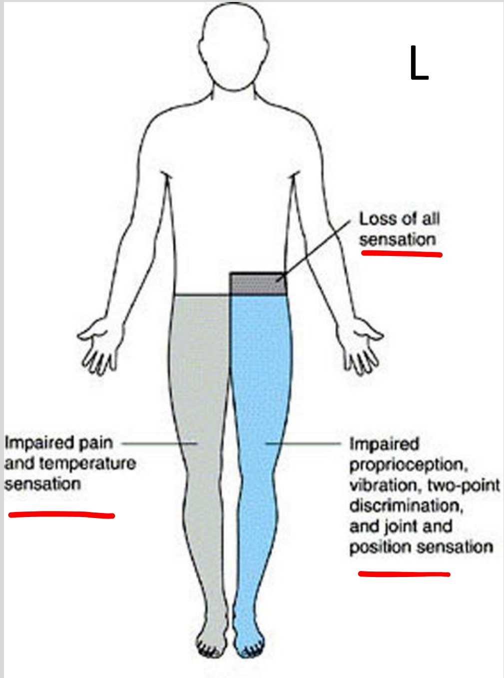
Find the lesion

At what level?

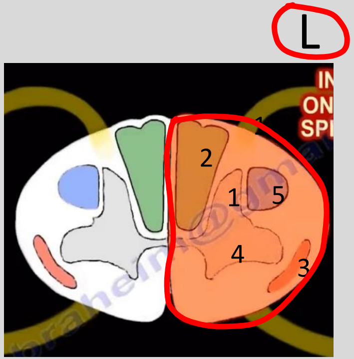
Which side?

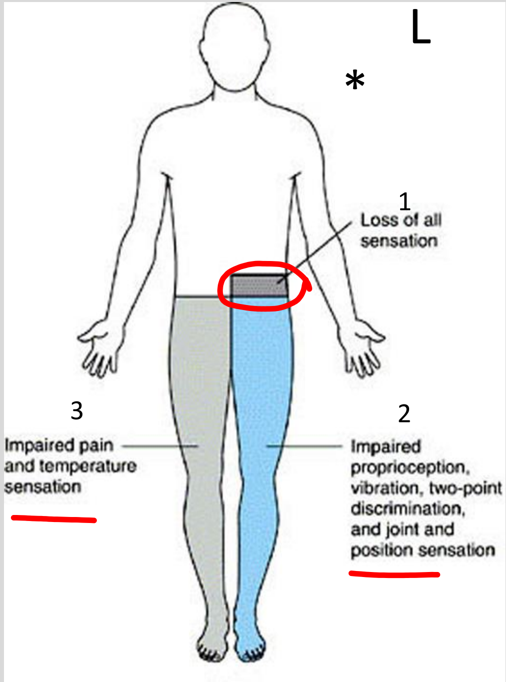


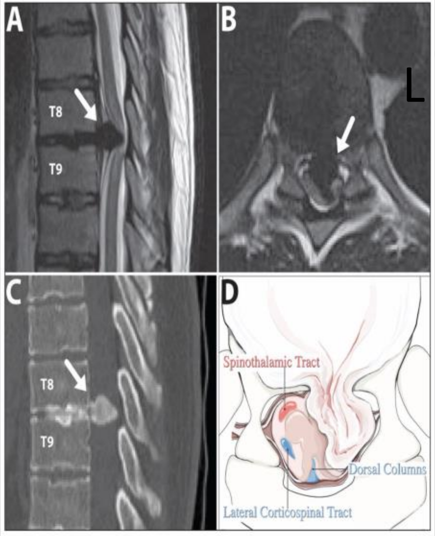
Brown-Sequard syndrome

At what level?

Which side?







All lesions at the lower body – damage to the lumbar cord:

1. loss of all sensation **at the level** of the lesion at the left side – **ipsilateral dorsal horn** lesion
2. loss of proprioception, vibration, discriminative touch, and tactile sense **below the level** of the lesion at the left side – **ipsilateral DCML** lesion
3. loss of pain, temp, and crude touch **below the level** of the lesion at the right side – **contralateral spinothalamic tract** lesion
4. LMN signs **at the level** of the lesion at the left side – **ipsilateral ventral horn** lesion
5. UMN signs **below the level** of lesion at the left side – **ipsilateral corticospinal tract** lesion

Lecture Feedback Form _ Dr. Jennifer Xie

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