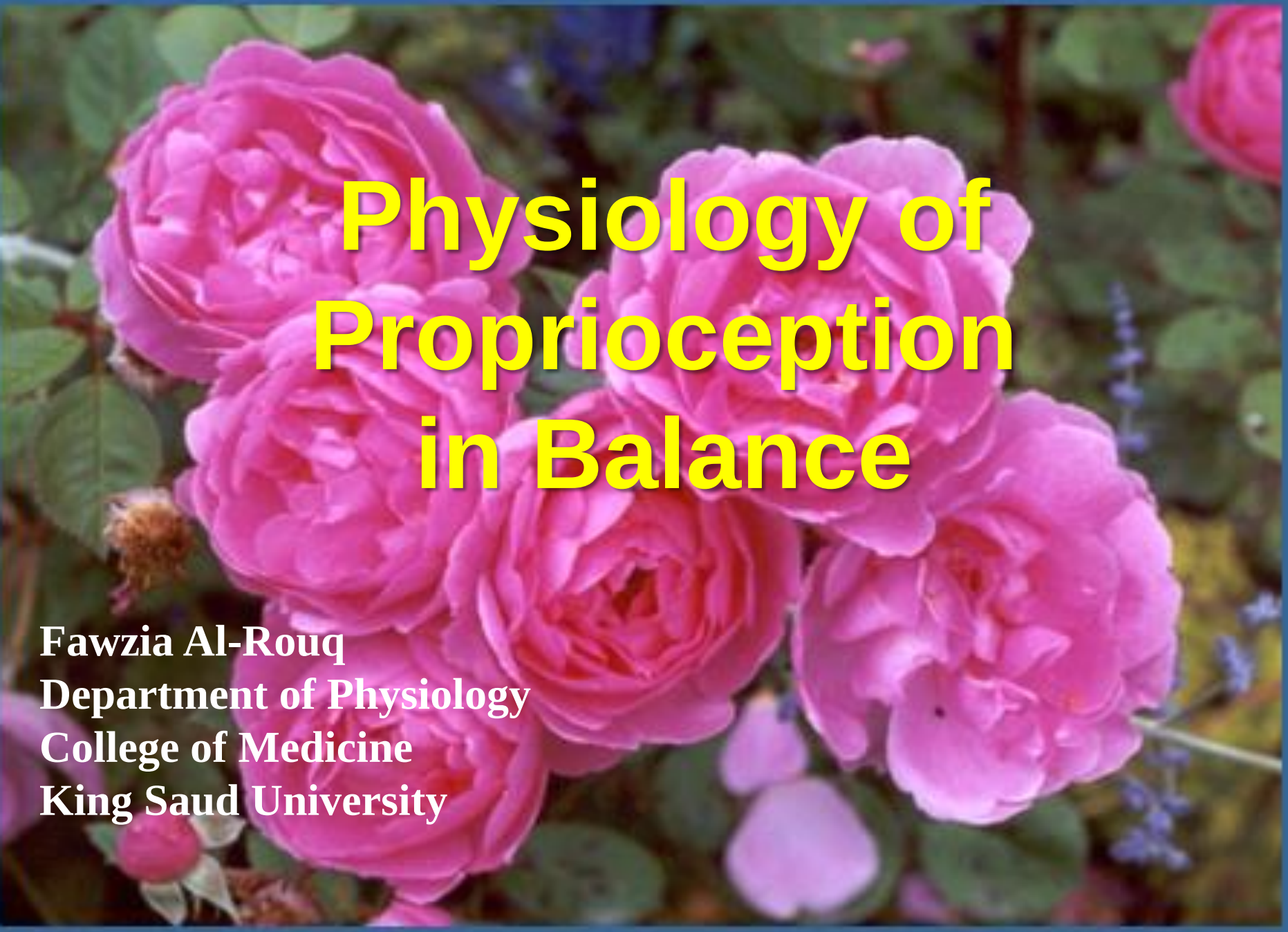


Physiology of Proprioception in Balance

Fawzia Al-Rouq
Department of Physiology
College of Medicine
King Saud University

OBJECTIVES

Pathways of proprioception

At the end of this lecture the student should be able to:-

1-Identify the major sensory pathways

Describe the components, processes and functions of the sensoty pathways

2-appreciate the dorsal column system in conscious proprioception (anatomy&functions)

3- describe the pathway of spinocerebellar tract in unconscious proprioception from muscles,tendons,and joints

4-differentiate between sensory and motor ataxia

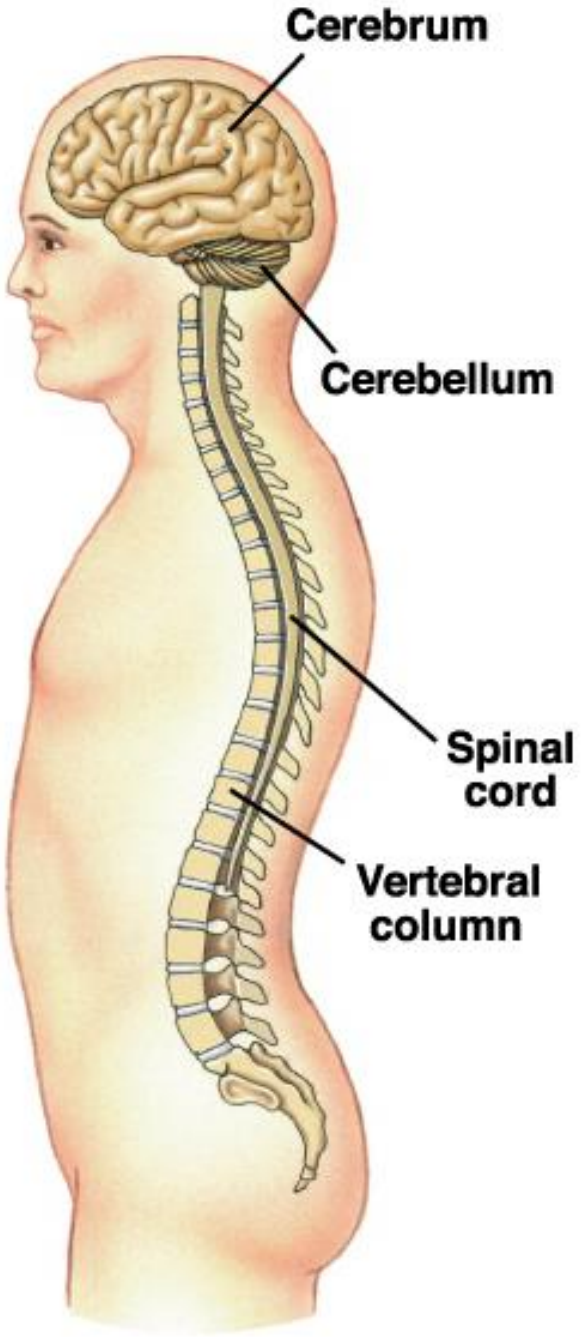
- Introduction
- Sensory receptors
- major sensory pathways
- dorsal column system
- spinocerebellar tract
- sensory and motor ataxia

INTRODUCTION

Organization of the Nervous System

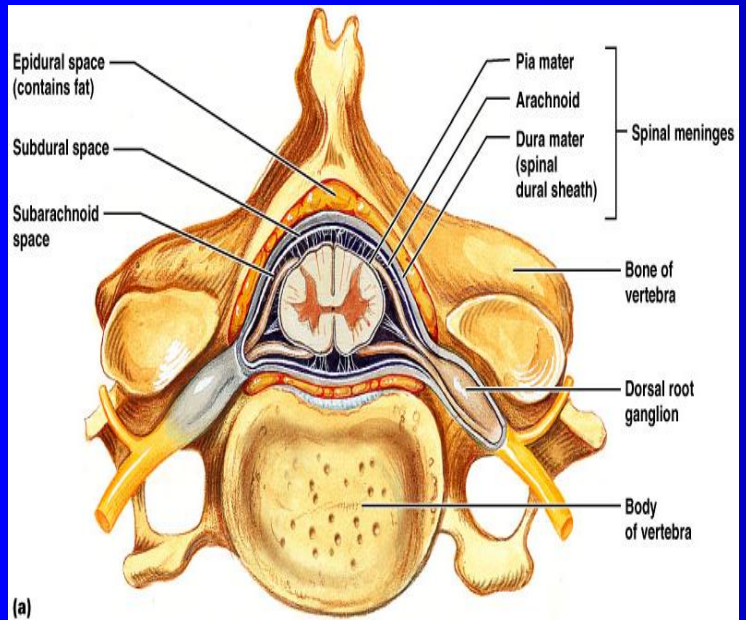
2 big initial divisions:

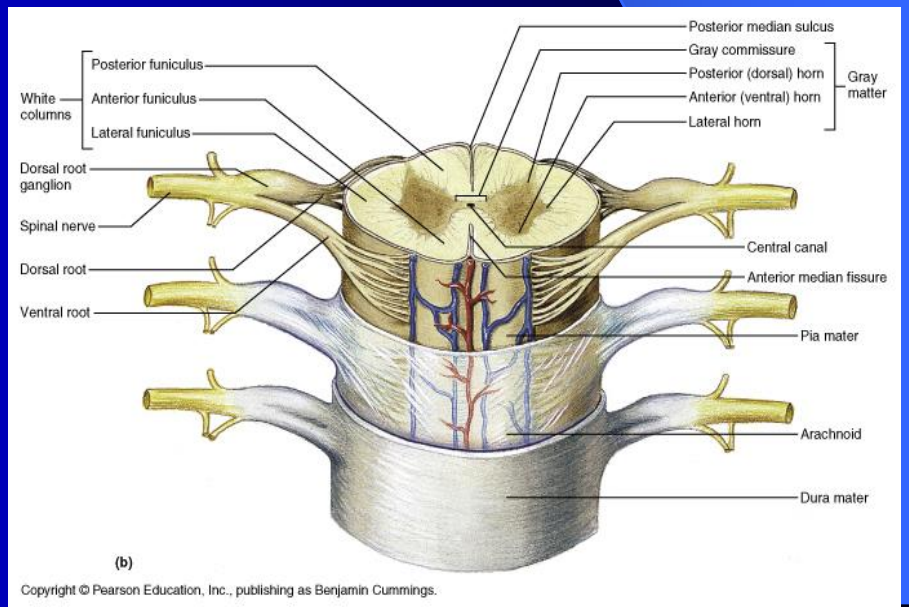
- Central Nervous System
  - The brain + **the spinal cord**
    - The center of integration and control
- Peripheral Nervous System
  - The nervous system outside of the brain and spinal cord
  - Consists of:
    - 31 Spinal nerves
      - Carry info to and from the spinal cord
    - 12 Cranial nerves
      - Carry info to and from the brain



Spinal cord

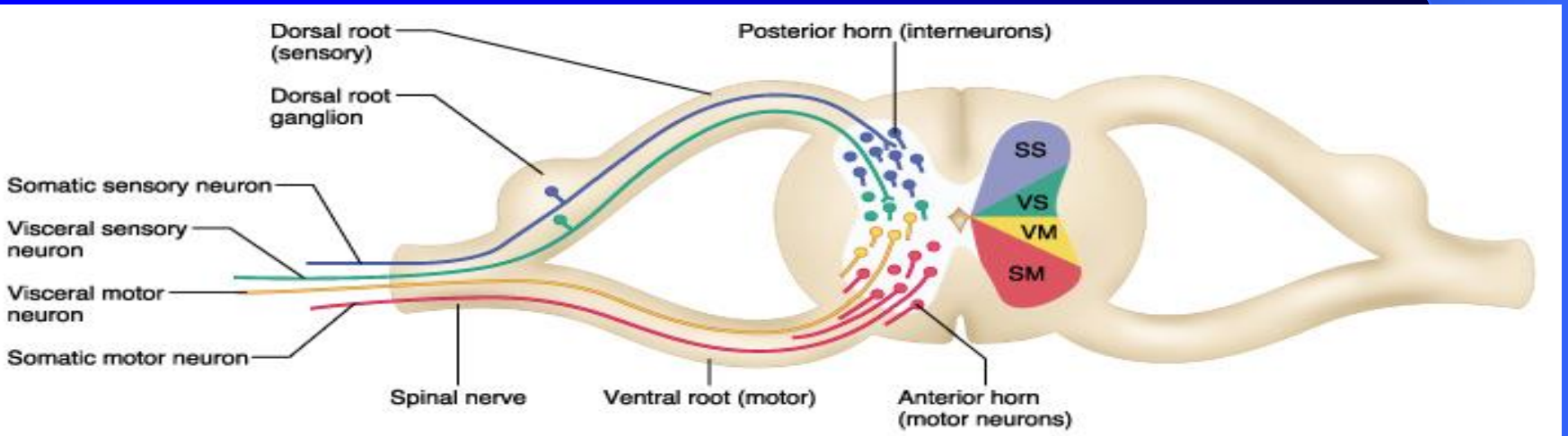
- A Cross-section view of spinal cord- wider laterllay than anteroposteriorly. In the middle on the dorsal side is a shallow groove called the posterior median sulcus and on the ventral side is the anterior median fissure (deeper).
- center consist of gray matter shaped like a butterfly and there is an opening at the center
- Spinal cord is protected by three layers of meninges. The only difference from the brain is that the dural matter does not attach to bone. The dural matter is surrounded externally by a layer of cushioning fat called epidural space.





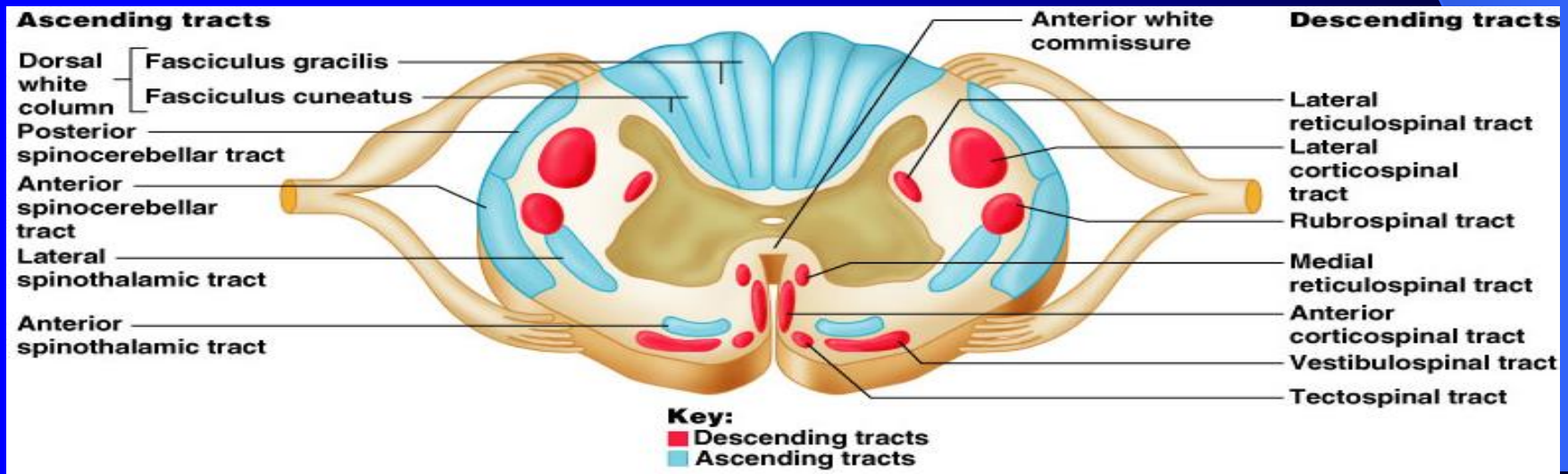
Gray Matter: Organization

- Dorsal half – sensory roots and ganglia
- Ventral half – motor roots
- Dorsal and ventral roots fuse laterally to form spinal nerves
- Four zones are evident within the gray matter – somatic sensory (SS), visceral sensory (VS), visceral motor (VM), and somatic motor (SM)



White Matter in the Spinal Cord

- Fibers run in three directions – ascending, descending, and transversely
- Divided into three funiculi (columns) – posterior, lateral, and anterior
- Each funiculus contains several fiber tracks
  - Fiber tract names reveal their origin and destination
  - Fiber tracts are composed of axons with similar functions



- Introduction
- Sensory receptors
- major sensory pathways
- dorsal column system
- spinocerebellar tract
- sensory and motor ataxia

Sensory Receptors

Somatic Receptors

- Somatic receptors are specialized structure present at the peripheral terminations of afferent fiberes.
- Receptors are detectors and transducers which transduce different form of energy into action potential
- They are found in many parts of the body including the skin (cutaneous receptors), skeletal muscles, bones and joints (proprioceptors)

- They differ from specific receptors that mediate the special senses of vision, hearing, smell, taste and equilibrium.

Classification of Sensory Receptors-1

A/Based on their location (Sherrington 1906):

- ❶ Exteroceptors: concerned with the external environment
  - Found on the surface of the body
  - E.g. touch and temperature receptors
- ❷ Interoceptors: concerned with the internal environment e.g. chemoreceptors ,osmoreceptors .
- ❸ Proprioceptors: concerned with potion of the body in the space.
  - Are found in joint, tendons and muscles.

Classification of Sensory Receptors-2

B/Based on their adequate stimulus

- *(Adequate stimulus is the particular form of energy to which the receptors is most sensitive)*

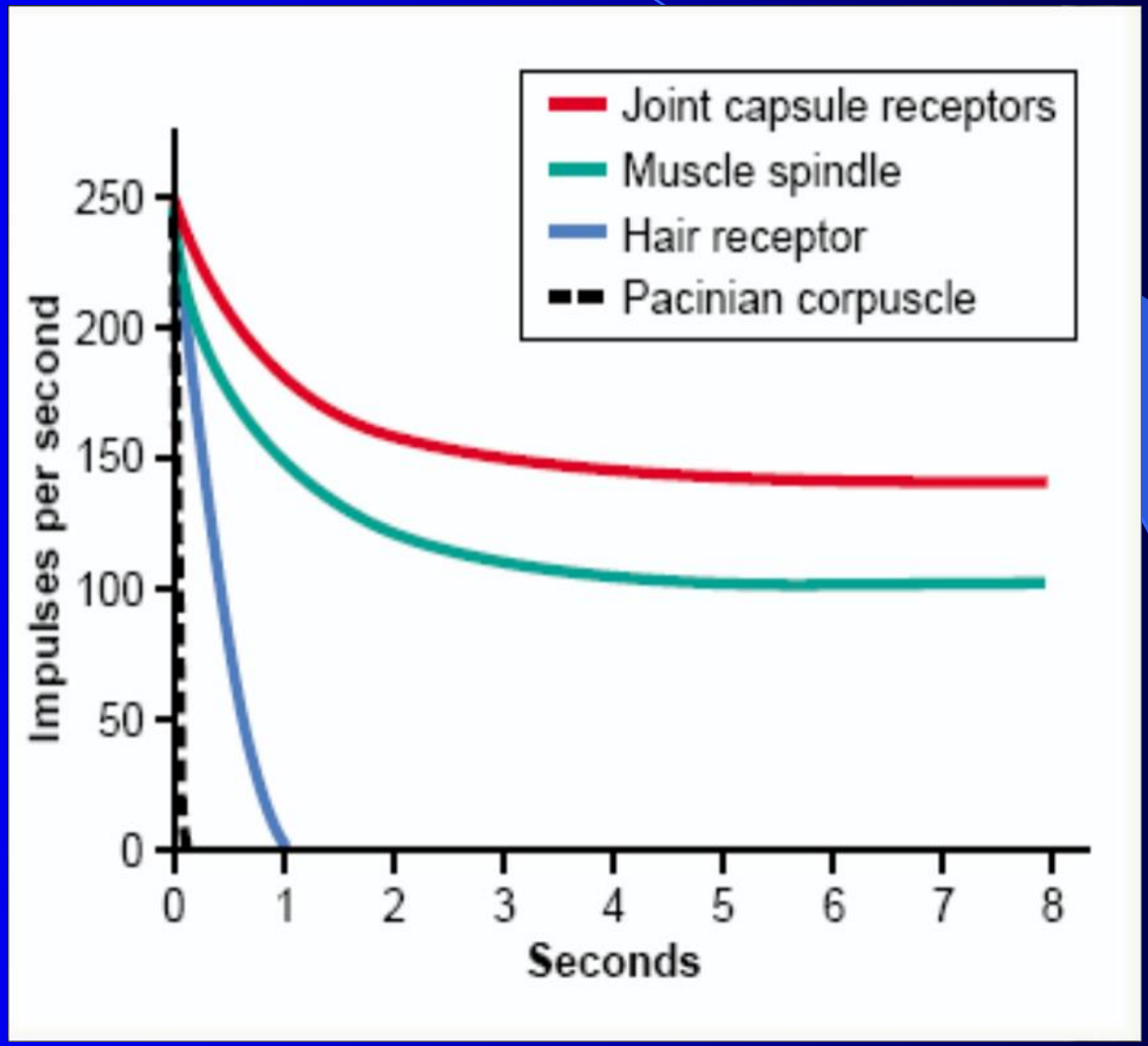
- Mechanoreceptors :which detect mechanical compression or stretching of the receptor or of tissues adjacent to the receptor eg proprioceptors
- Thermoreceptors which detect changes in temperature, some receptors detecting cold and others warmth.
- Chemoreceptors, which detect taste in the mouth, smell in the nose, oxygen level in the arterial blood, osmolality of the body fluids, carbon dioxide concentration, and perhaps other factors that make up the chemistry of the body. Eg chemo R in carotid bodies
- Electromagnetic receptors, which detect light on the retina of the eye eg rods and cones.
- Nociceptors (pain receptors) , which detect damage occurring in the tissues, whether physical damage or chemical damage eg free nerve endings

Classification of Sensory Receptors-3

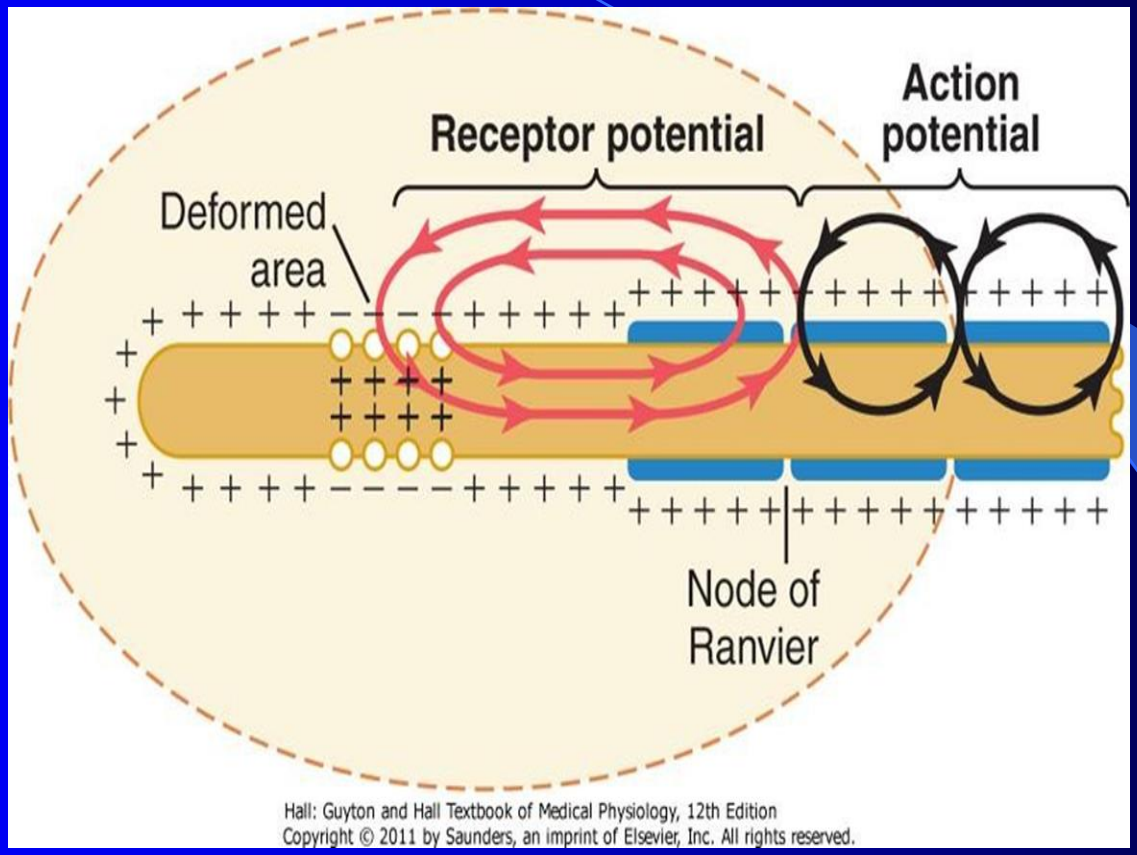
C. Based on their speed of adaptation

- Adaptation means when a continuous sensory stimulus is applied, the receptor responds at a high impulse rate at first and then at a progressively slower rate until finally the rate of action potentials decreases to very few or often to none at all.
- Accordingly receptors can be classified Into:
- Slowly adapting (SA) or tonic receptors:
  - Muscle spindle, joint receptors, baroreceptors .
  - Pain receptors do not adapt at all.

- Rabidly adapting (RA) or phasic receptors:
- eg meissner's corpuscles(touch), pacinian corpuscles(vibration)

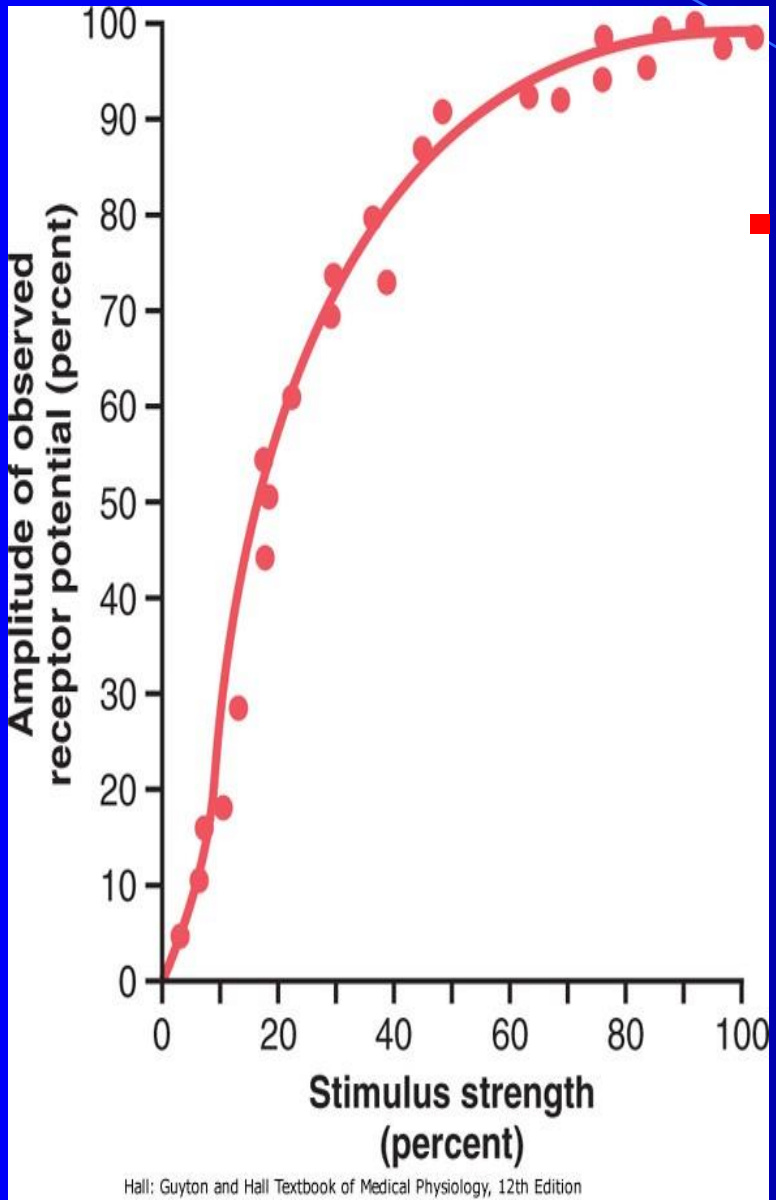

Joint capsule receptors
Muscle spindle
Hair receptor
Pacinian corpuscle
Impulses per second
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Seconds

Activation of Sensory Receptors: Generation of Receptor Potential (RP)



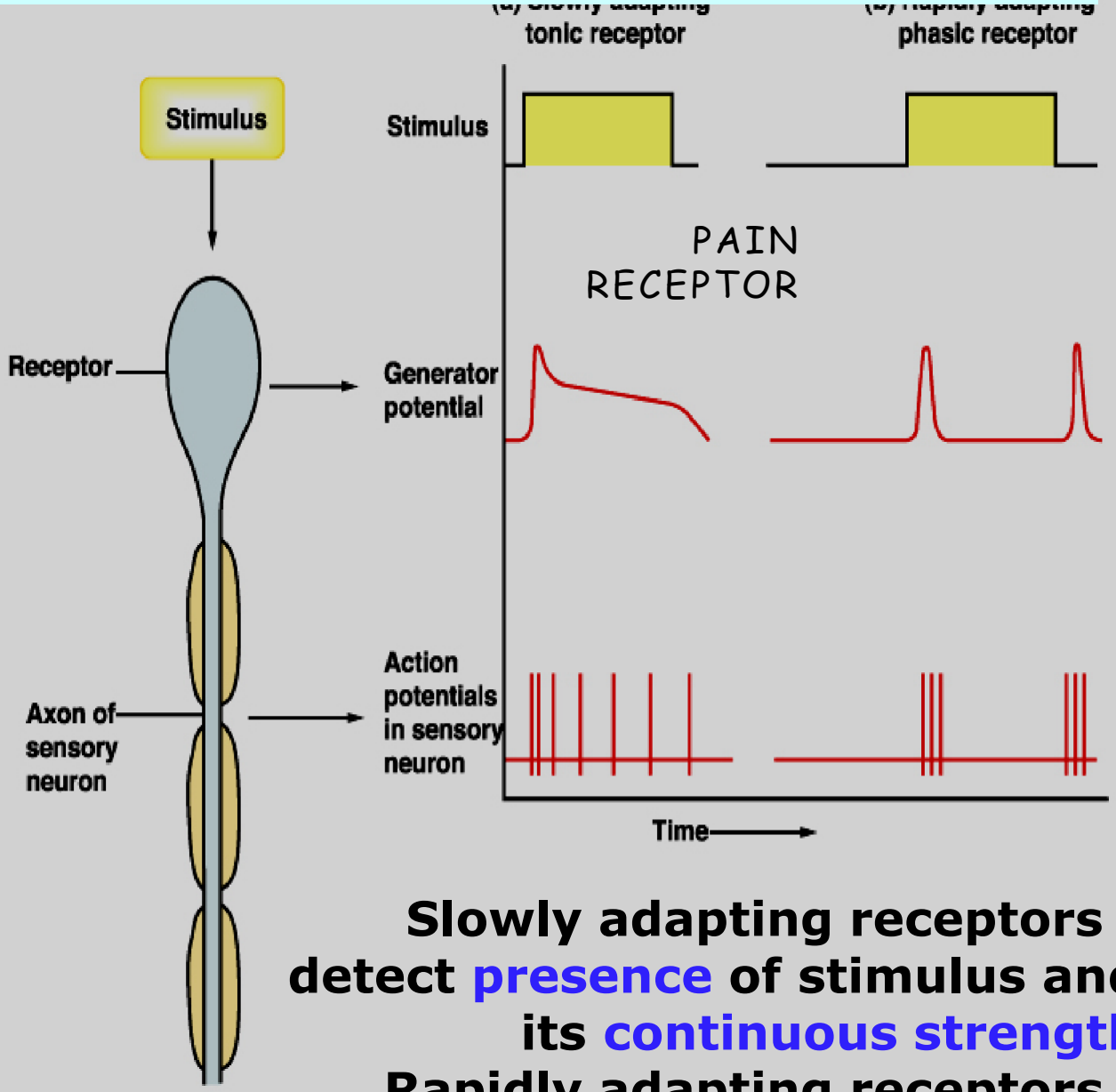
- Stimuli (mechanical, thermal, chemical) cause deformation in the sensory receptors
- This causes influx of positive ions and generation of RP

Relation Between Stimulus Strength & Receptor Potential Amplitude



- Receptor potential is directly related to stimulus strength

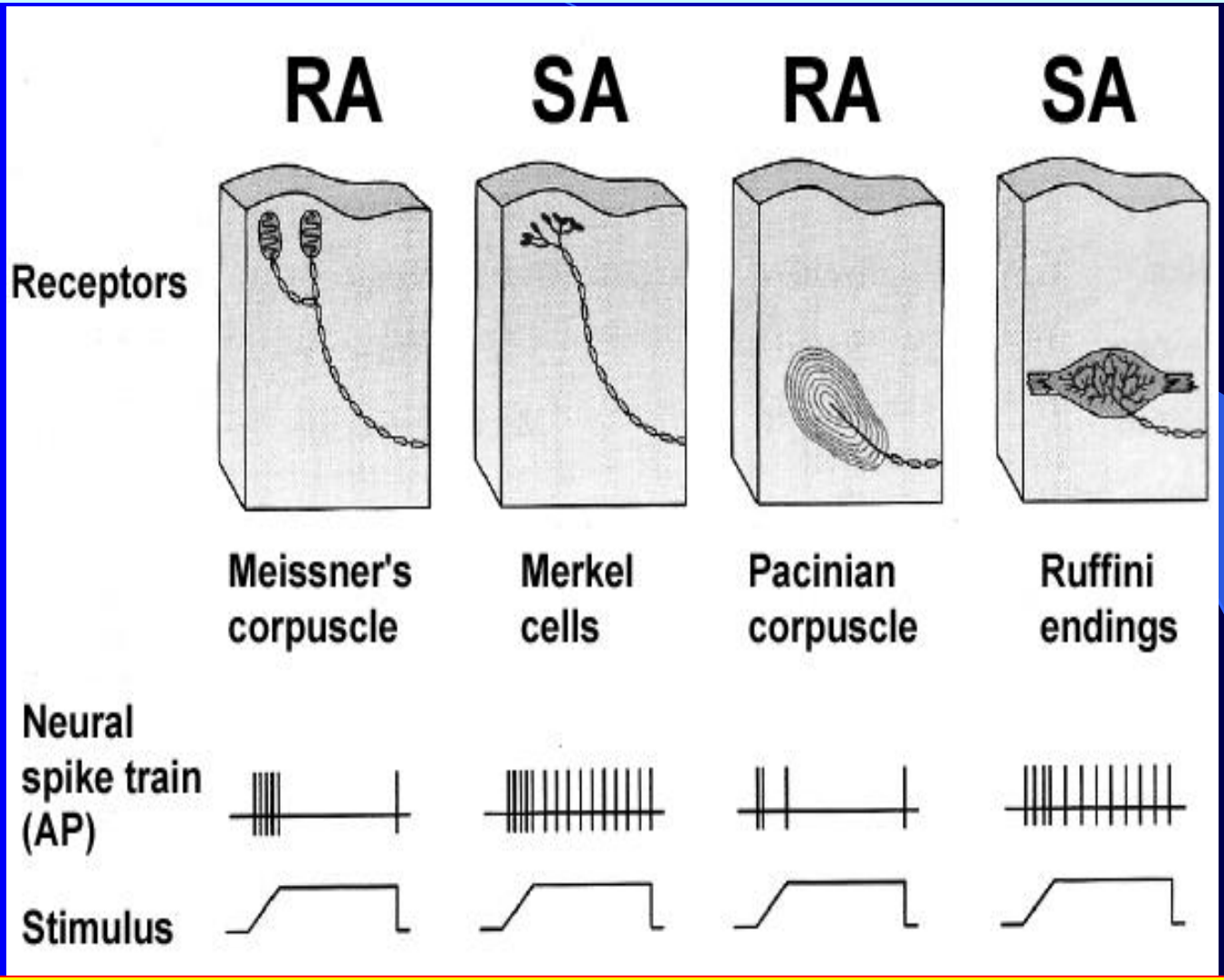
Generation of a Receptor Potential



Slowly adapting receptors ▪ detect presence of stimulus and its continuous strength

Rapidly adapting receptors ▪

Examples of RA and SA Receptors



Muscle spindles & nociceptors are other examples of SA receptors

What Are the Stimulus Features That Are Mediated by Sensory Receptors?

Sensory receptors mediate 4 features of a stimulus:

- Modality: is what we perceive after a stimulus
  - Many sensory modalities: vision, hearing, smell, taste, touch and temperature
  - Each modality has many sub-modalities (e.g. taste can be sweet, bitter, sour, salty), Temperature sub-modalities: cold and heat

- Intensity: depends on the stimulus strength and is encoded by action potential frequency.
- Location: the site on the body or space where the stimulus originated.
- Duration: time from onset to offset of a stimulus.
  - If persists for long time, the perceived intensity diminishes (adaptation)

Classification of Nerve fi

- **Myelinated (A-fiber)**
  - **αA** ylkciht) etanileym (d
  - **Aβ** demretni) (.m etai
  - ylniht)**Aδ** etanileym (d
- **Unmyelinated (C-fiber)**

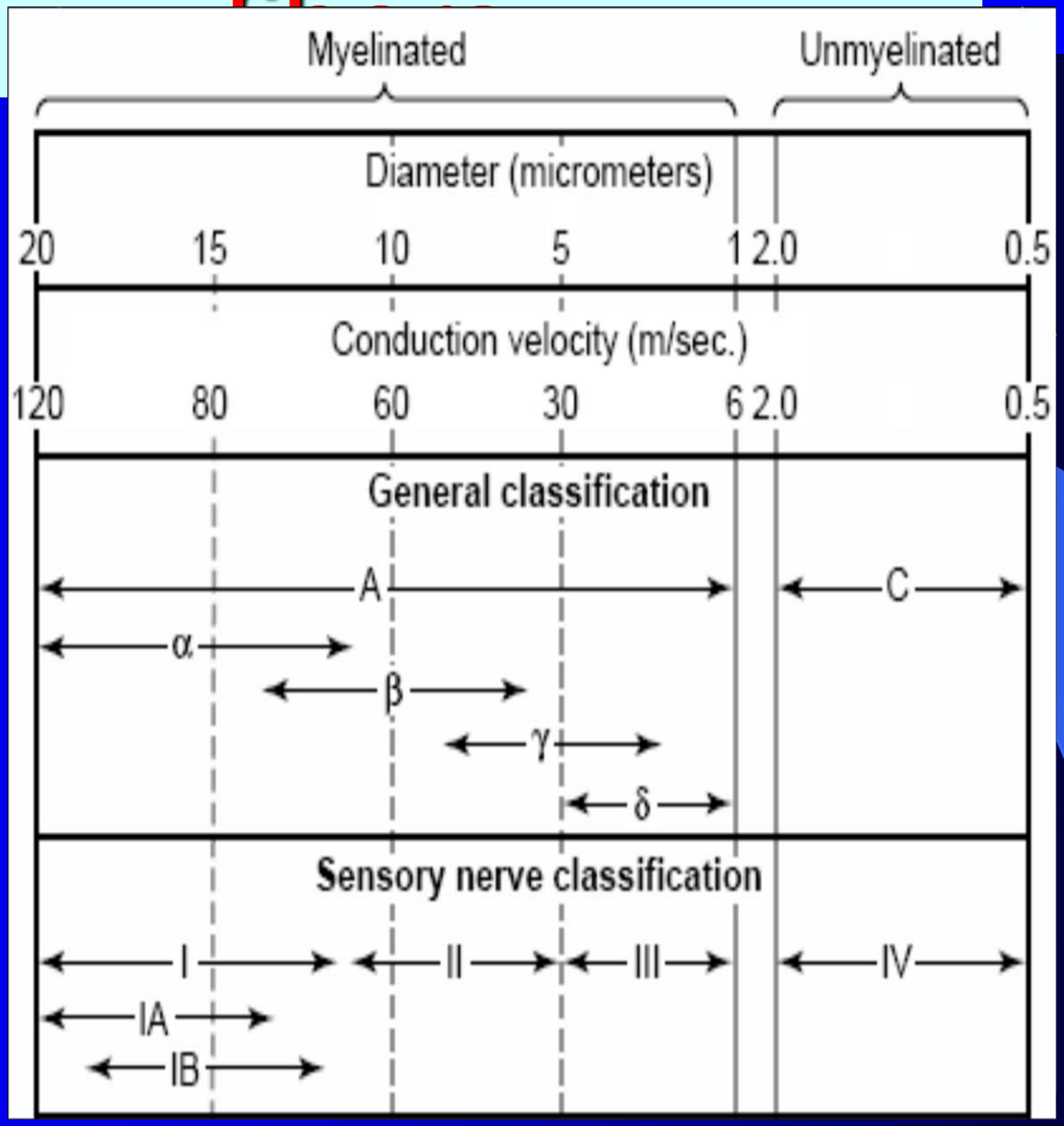


TABLE 4–1 Types of mammalian nerve fibers.

Fiber Type	Function	Fiber Diameter (μm)	Conduction Velocity (m/s)	Spike Duration (ms)	Absolute Refractory Period (ms)
Aα	Proprioception; somatic motor	12–20	70–120		
Aβ	Touch, pressure	5–12	30–70	0.4–0.5	0.4–1
Aγ	Motor to muscle spindles	3–6	15–30		
Aδ	Pain, temperature	2–5	12–30		
B	Preganglionic autonomic	<3	3–15	1.2	1.2
C, Dorsal root	Pain, temperature	0.4–1.2	0.5–2	2	2
C, Sympathetic	Postganglionic sympathetic	0.3–1.3	0.7–2.3	2	2

TABLE 4–2 Numerical classification of sensory nerve fibers.

Number	Origin	Fiber Type
Ia	Muscle spindle, annulo-spiral ending	Aα
Ib	Golgi tendon organ	Aα
II	Muscle spindle, flower-spray ending; touch, pressure	Aβ
III	Pain and cold receptors; some touch receptors	Aδ
IV	Pain, temperature, and other receptors	Dorsal root C

Ascending Sensory Tracts

- There are several ascending sensory systems
- Each system carries different types of sensations or MODALITIES: touch, proprioception, pain, temperature, … etc.,
- Main ascending sensory pathways
- ❶ Spinothalamic pathway: carries signals of pain, temperature, deep pressure, and crude touch.
- ❷ Dorsal column pathway: carries signals of fine touch, pressure, vibration, and proprioception.
- ❸ Posterior (dorsal) spinocerebellar pathway
- ❹ Anterior (ventral) spinocerebellar pathway
- The latter pathways (3 &4) carry subconscious proprioception.
- Objective: Identify the major sensory receptors & pathways

What is Proprioception ?

- Proprioception stems from the Latin word proprius which means "one's own" or "individual"
- It is the sense of one`s own body position
- It is also called proprioceptive/position sense
- It is the awareness of body position and of movements of body parts
- It can be divided into:
  - Static proprioception: conscious perception of the orientation of the different parts of the body with respect to one another,
  - Dynamic proprioception: rate of movement sense (also called kinesthesia)

Types of Proprioception

- There are two types of proprioception:

1. Conscious proprioception:

- It reaches the level of sensory cerebral cortex (cerebrum) via the dorsal column-medial lemniscus pathway

2. Unconscious proprioception:

is communicated to the cerebellum primarily via:

- The dorsal spino-cerebellar tract (dSCT)
- The ventral spino-cerebellar tract (vSCT)
  - *These are main ascending sensory pathways for proprioception*

Role of Proprioception

Proprioception informs us about:

- The location of a body part in relation to other parts
- The rate of movement of a body part when it is moving
- The degree to which our muscle are being contracted or stretched
- The amount of tension created in our tendons
- The head orientation in relation to the ground and in response to movement

- Proprioceptive information is carried from periphery to the CNS by proprioceptors and other somatic receptors

Types of Proprioceptors

Muscle spindles 1

Detect how much a muscle is stretched *

Golgi tendon organs 2

Detect tension of a muscle on its tendon *

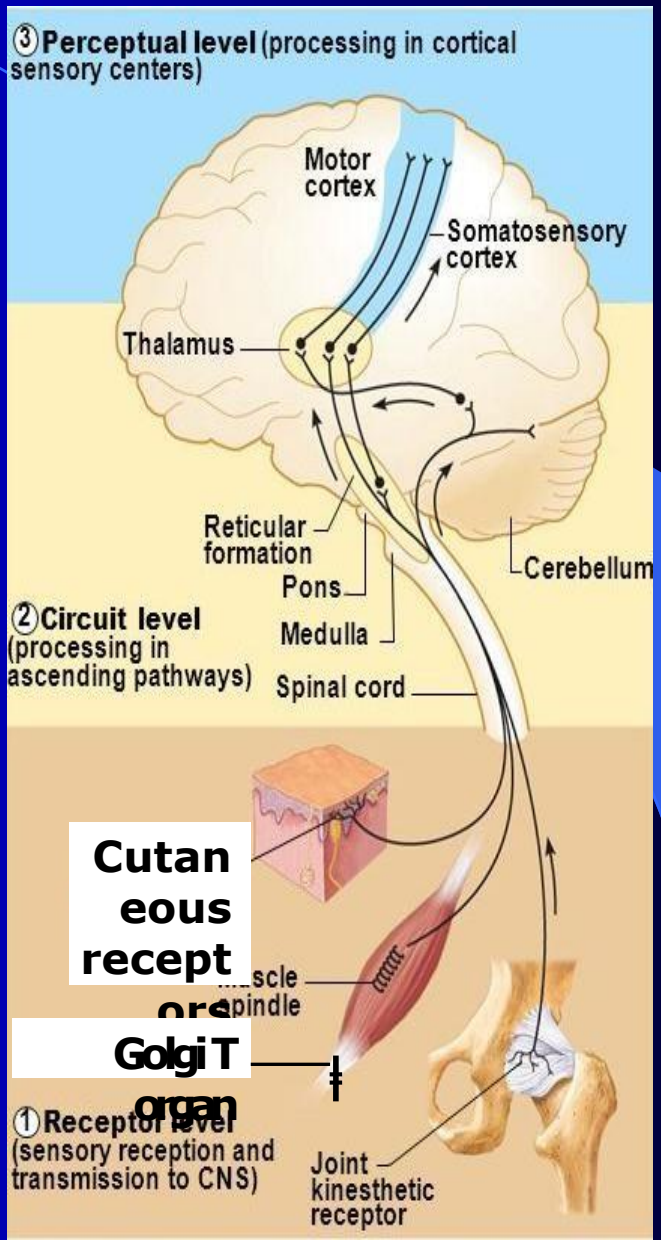
Provide information about the strength of contraction & tension *

Joint Kinesthetic 3

receptors

Are mechanoreceptors in the joint capsules; they detect *

Cutaneous & deep receptors also contribute to



Muscle Spindles & Golgi Tendon Organs

1. Muscle spindles
   - They detect changes in the length of muscle.
   - They convey length information to the CNS via group I and II afferent neurons
   - This information is important for determining the position of body part
2. Golgi tendon organ
   - They detect changes in muscle tension

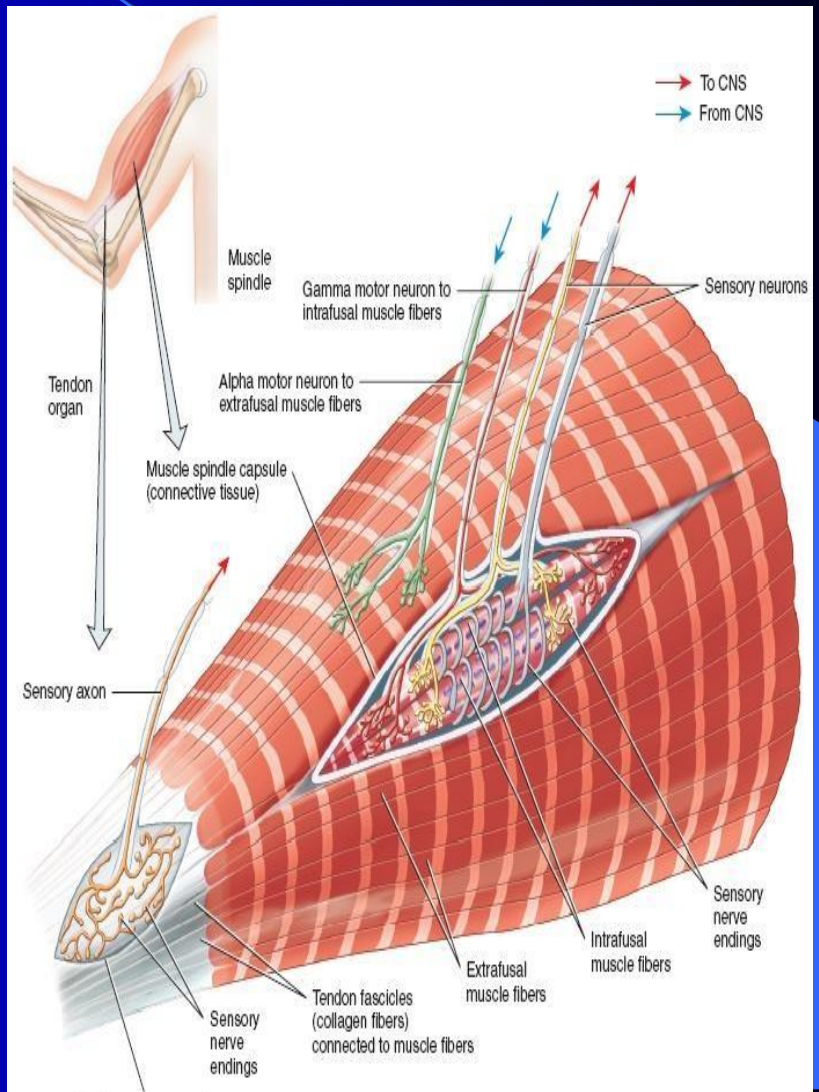
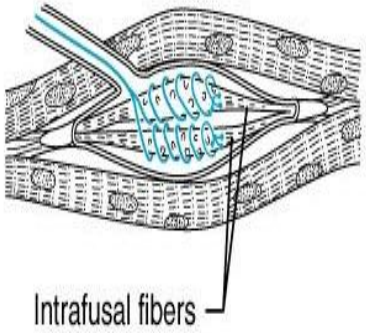
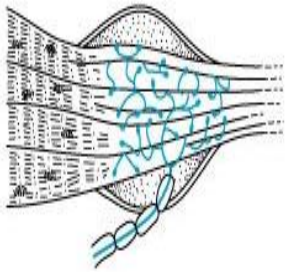


TABLE 14.1 General Sensory Receptors Classified by Structure and Function *(continued)*

Structural Class	Illustration	Functional Class According to Location (L) and Stimulus Type (S)	Body Location
PROPRIOCEPTORS			
Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch)	Skeletal muscles, particularly those of the extremities
Golgi tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch)	Tendons
Joint kinesthetic receptors (Pacinian and Ruffini endings, free nerve endings, and receptors resembling Golgi tendon organs)		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

- Introduction
- Sensory receptors
- major sensory pathways
- dorsal column system
- spinocerebellar tract
- sensory and motor ataxia

An Overview of Sensory Pathways and the Somatic Nervous System

Neural pathways

- **Afferent pathways**
  - Sensory information coming from the sensory receptors through peripheral nerves to the spinal cord and to the brain .
- Efferent pathways
  - Motor commands coming from the brain and spinal cord, through peripheral nerves to effecter organs .

Sensory pathways

Sensory pathways

- Sensory systems allow us to detect, analyze and respond to our environment
- “ascending pathways”
- Carry information from sensory receptors to the brain
- Conscious: reach cerebral cortex
- Unconscious: do not reach cerebral cortex
- Sensations from body reach the opposite side of the brain

- **Spinal tracts**- These are known as sensory and motor pathways consisting of multineuron pathways connecting the CNS to the PNS. At some point most pathways crossover (decussate),
- A. Ascending (sensory) Pathways : -

- 1. **Dorsal column pathway-** carries signal of fine touch, pressure, vibration , stereognosis and concious proprioception, ascends up dorsal white column in fasciculus gracilis or cutaneatus to medulla oblongata to the thalamus to primary somatosensory cortex (post central gyrus).
- 2 . **Posterior and anterior spinocerebellar pathways-** carry subsconcious proprioception. Dorsal gray horn- to lateral column- to medulla oblongata- to pons – to cerebellum.

- 3. Spinothalamic pathway- carries signals of pain, temperature, deep pressure, and course touch. From psterior gray horn decussate into lateral and anterior funiculi up to the thalamus to primary somatosensory cortex (postcentral gyrus).

ANTEROLATERAL SYSTEM

Ventral & lateral spinothalamic tracts

- Pain
- Thermal sensations, (warmth & cold)
- Crude touch and pressure sensations capable only of crude localizing ability on the surface of the body
- Tickle and itch sensations
- Sexual sensations

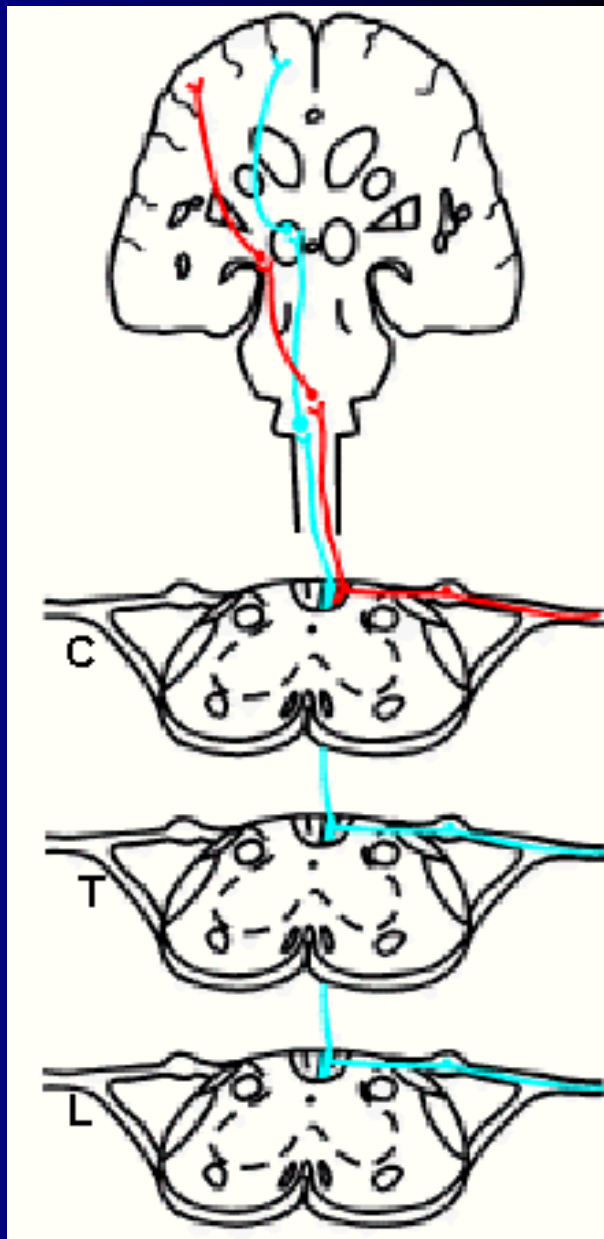
Sensory pathways: 3 neurons

- 1st: enters spinal cord from periphery
- 2nd: crosses over (decussates), ascends in spinal cord to thalamus
- 3rd: projects to somatosensory cortex

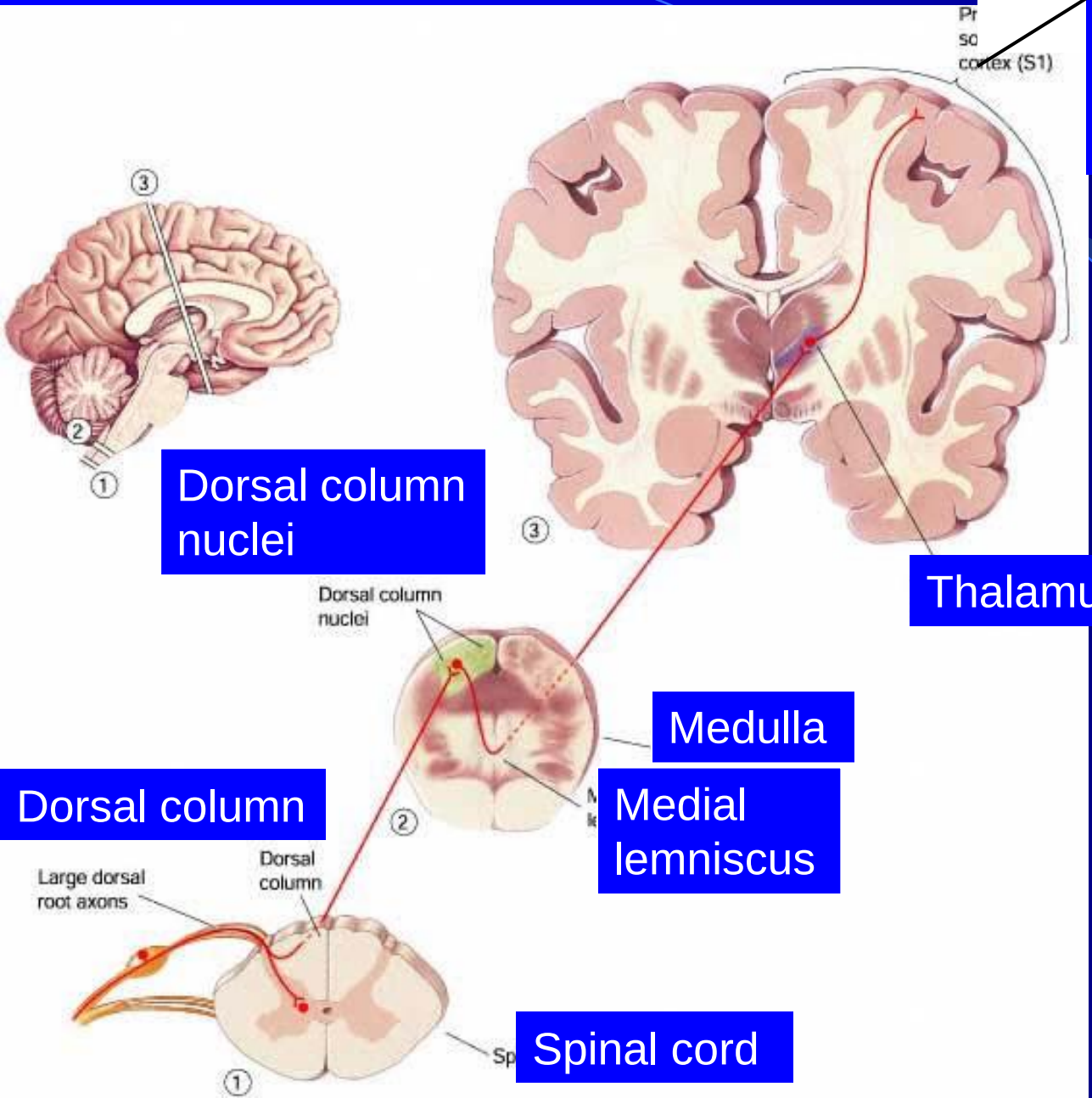
- Introduction
- Sensory receptors
- major sensory pathways
- dorsal column system
- spinocerebellar tract
- sensory and motor ataxia

Dorsal column pathway

- Carries fine touch, tow point discrimination ,pressure ,vibratio n ,stereognosis and conscious proprioception signals
- 1st neuron enters spinal cord through dorsal root; ascends to medulla (brain stem)
- 2nd neuron crosses over in medulla; ascends to thalamus
- 3rd neuron projects to somatosensory cortex



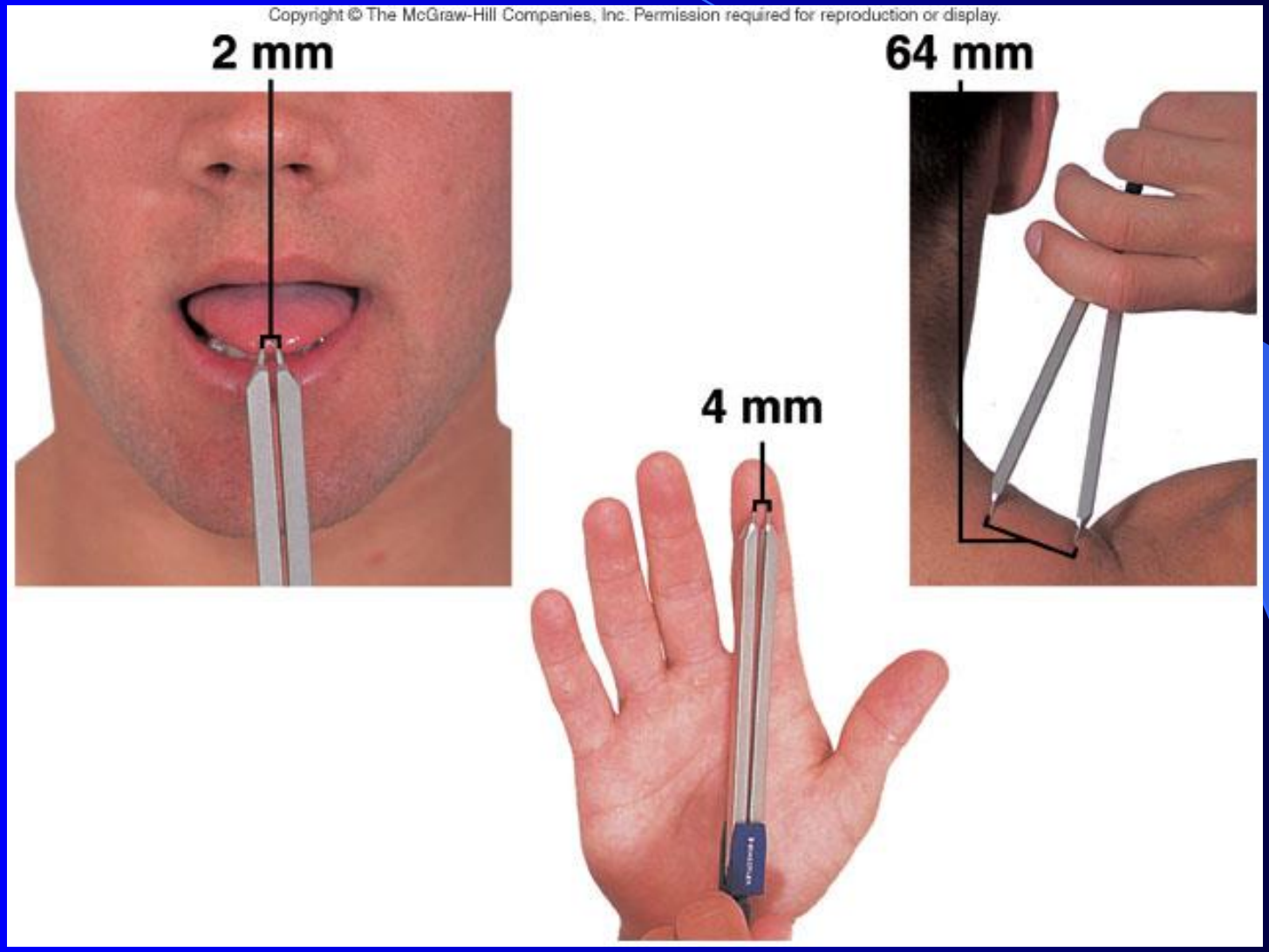
Dorsal column pathway



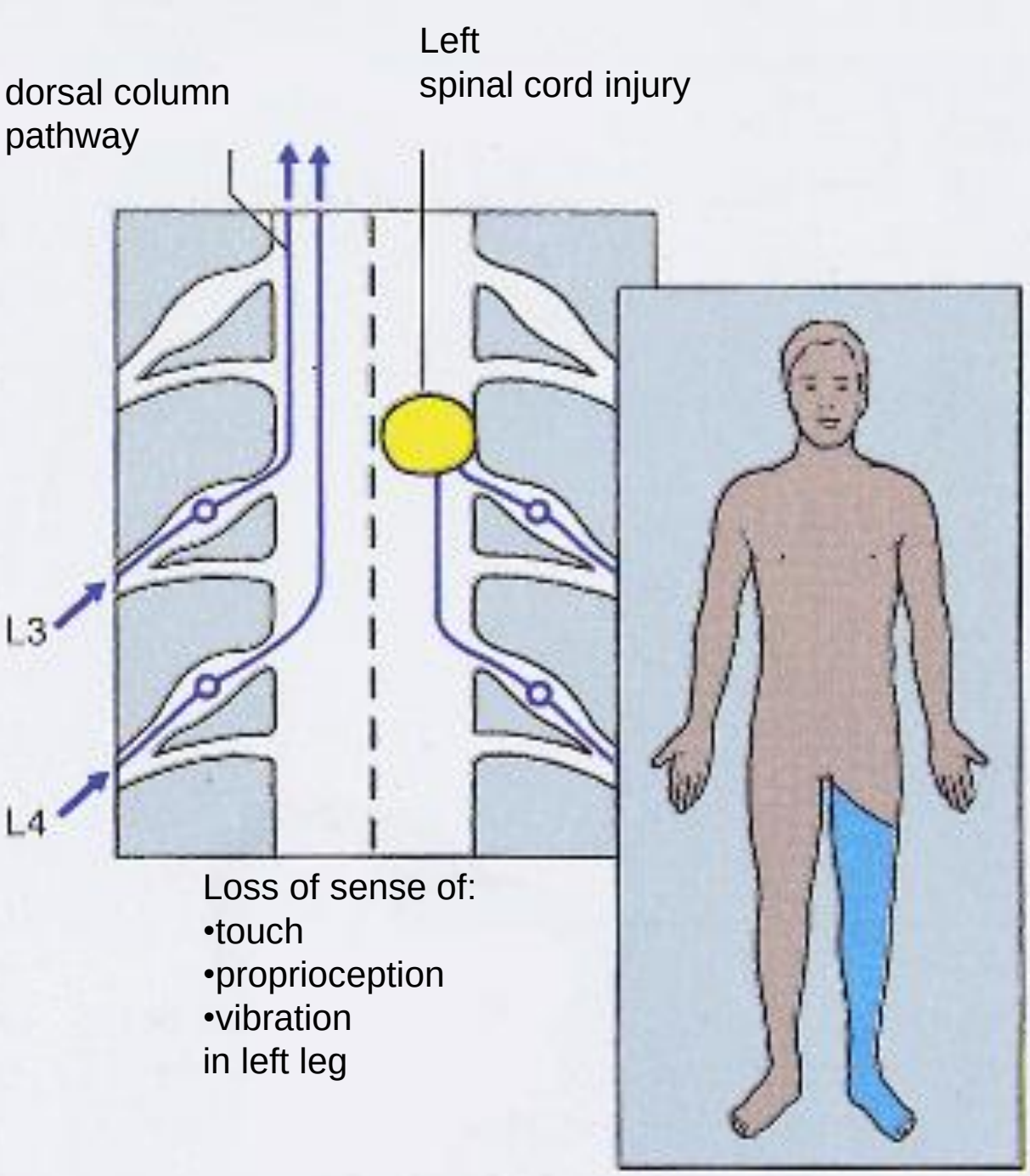
Dorsal Column–Medial Lemniscal System

- Touch sensations requiring a high degree of localization and high intensity of discrimination (i.e. fine)
- Rapidly repetitive sensation such as vibration
- Joints Position sensations (Proprioception)
- Pressure sensations characterized by high intensity discrimination(i.e. fine touch)

Two-Point Discrimination



Dorsal column damage



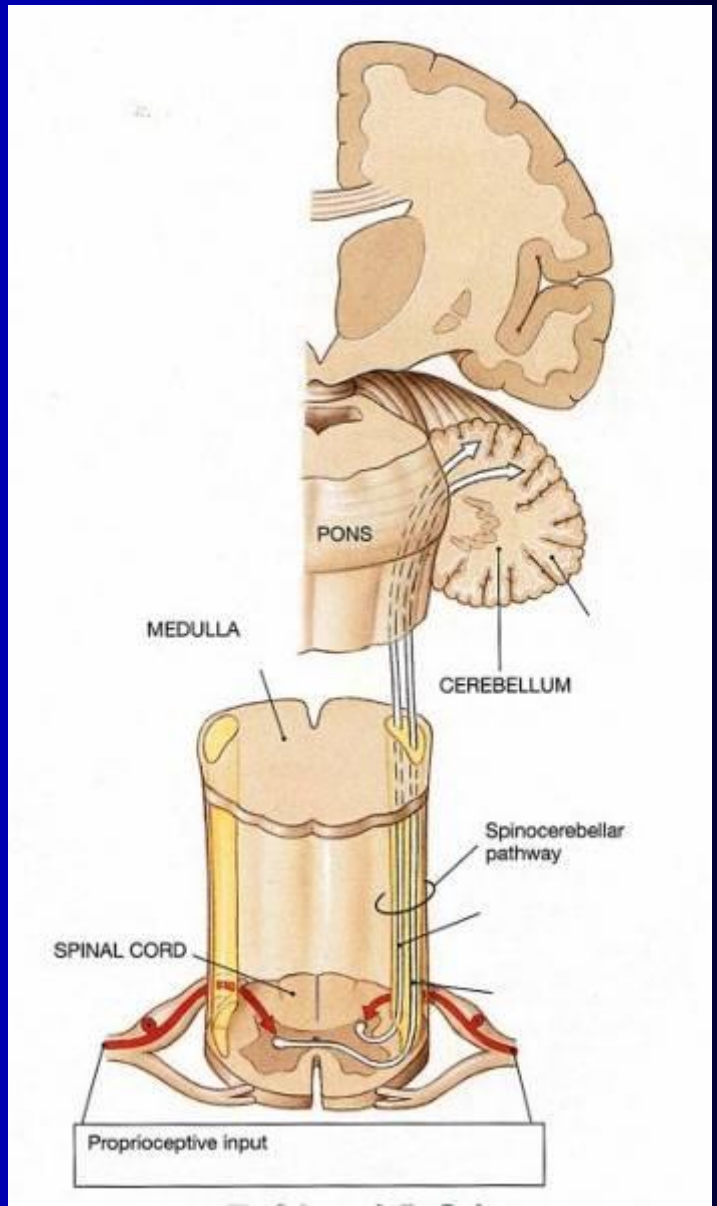
Dorsal column damage

- Sensory ataxia
- Patient staggers; cannot perceive position or movement of legs
- Visual clues help movement

- Introduction
- Sensory receptores
- major sensory pathways
- dorsal column system
- **spinocerebellar tract**
- sensory and motor ataxia

Spinocerebellar pathway

- Carries unconscious proprioception signals
- Receptors in muscles & joints
- 1st neuron: enters spinal cord through dorsal root
- 2nd neuron: ascends to cerebellum
- No 3rd neuron to cortex, hence unconscious



Spinocerebellar tract damage

- Cerebellar ataxia
- Clumsy movements
- Incoordination of the limbs (intention tremor)
- Wide-based, reeling gait (ataxia)
- Alcoholic intoxication produces similar effects!

- Introduction
- Sensory receptores
- major sensory pathways
- dorsal column system
- spinocerebellar tract
- **sensory and motor ataxia**

Motor & Sensory Ataxia

Ataxia and Gait Disturbances

- Pathophysiology
  - Result from any condition that affects the central and peripheral nervous systems
  - Ataxia: Types
    - Motor ataxia
    - Sensory ataxia

Ataxia and Gait Disturbances

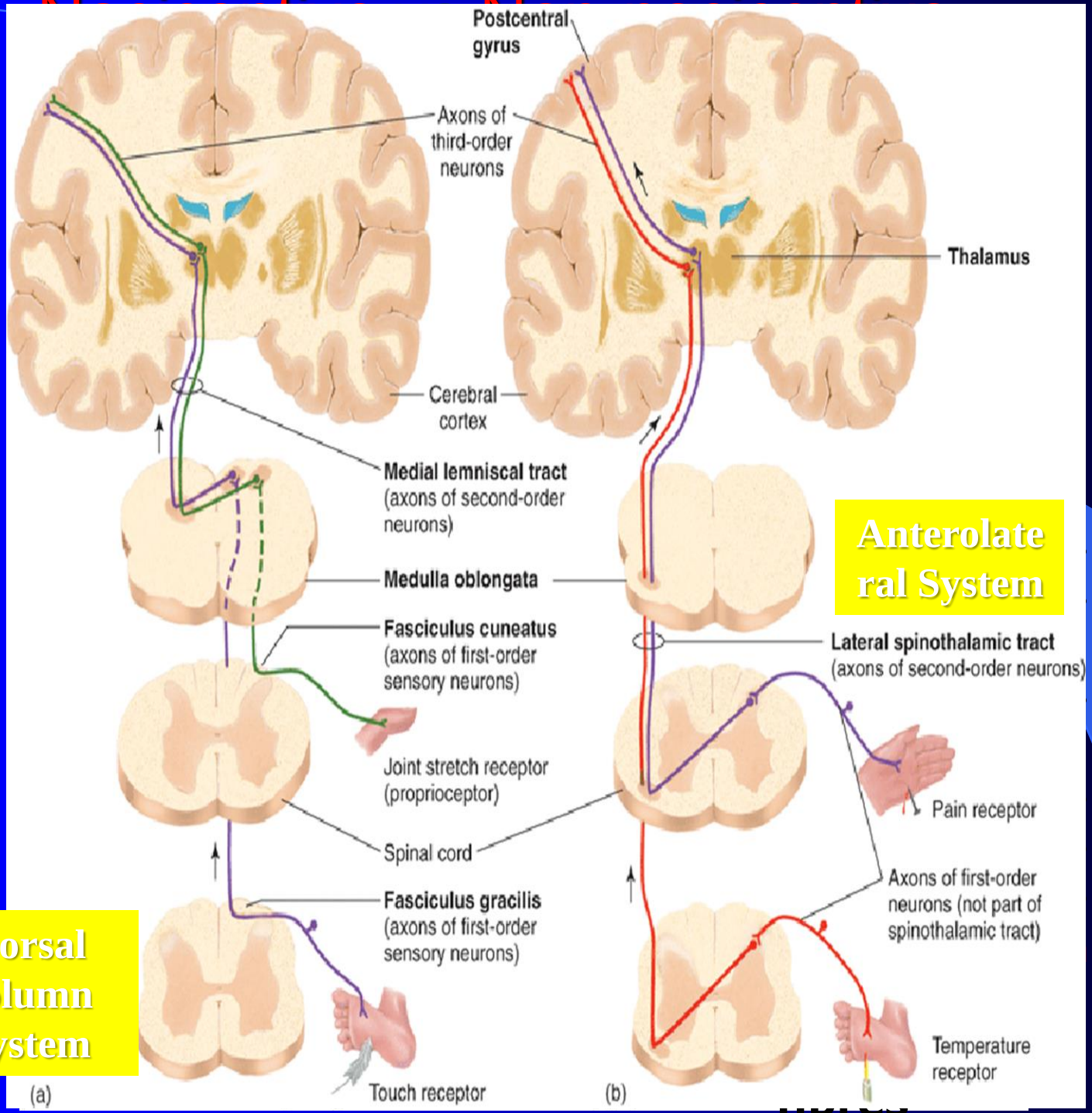
- Motor Ataxia
  - Caused by cerebellar disorders
    - Intact sensory receptors and afferent pathways
    - Integration of proprioception is faulty
    - Midline cerebellar lesions cause truncal ataxia
    - Lateral cerebellar lesions cause limb ataxia
    - Thalamic infarcts may cause contra lateral ataxia with sensory loss
    - N.B cerebellar ataxia will discussed later with cerebellum lecture.

Ataxia and Gait Disturbances

- Sensory Ataxia
  - Failure of proprioceptive information to the CNS
  - May be due to disorders of spinal cord or peripheral nerves
  - Can be compensated for by visual inputs

Thank you

Extra informations

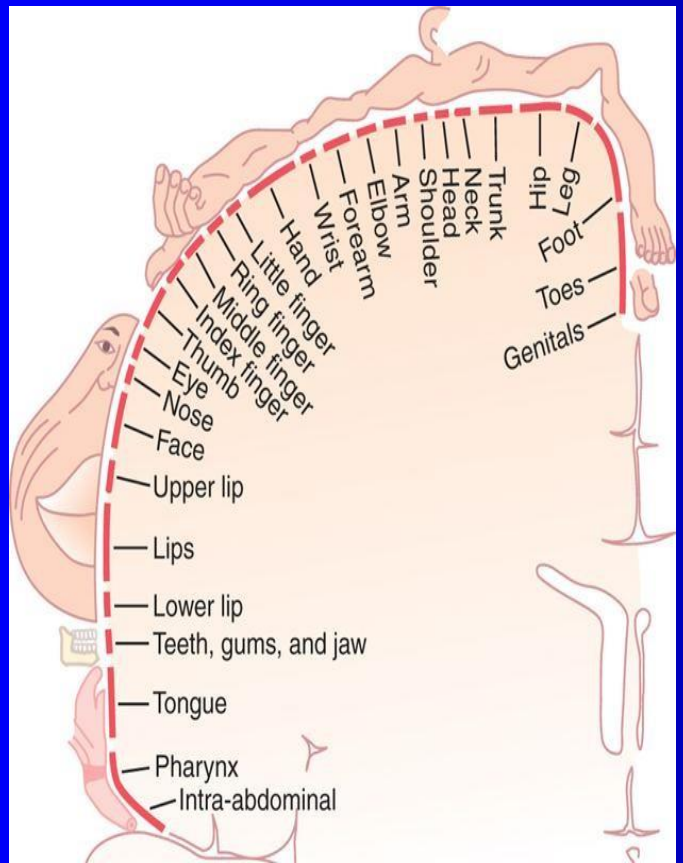


Anterolateral System

Dorsal column System

Sensory Homunculus (Little Man)

- Body is represented upside-down, with large representation of hands & lips
- The extent of representation is proportional to the **density of sensory receptors**



Dorsal column damage

- Sensory ataxia
- Patient staggers; cannot perceive position or movement of legs
- Visual clues help movement

Positive Romberg test The test depends on the integrity of proprioception from the joints of the legs •

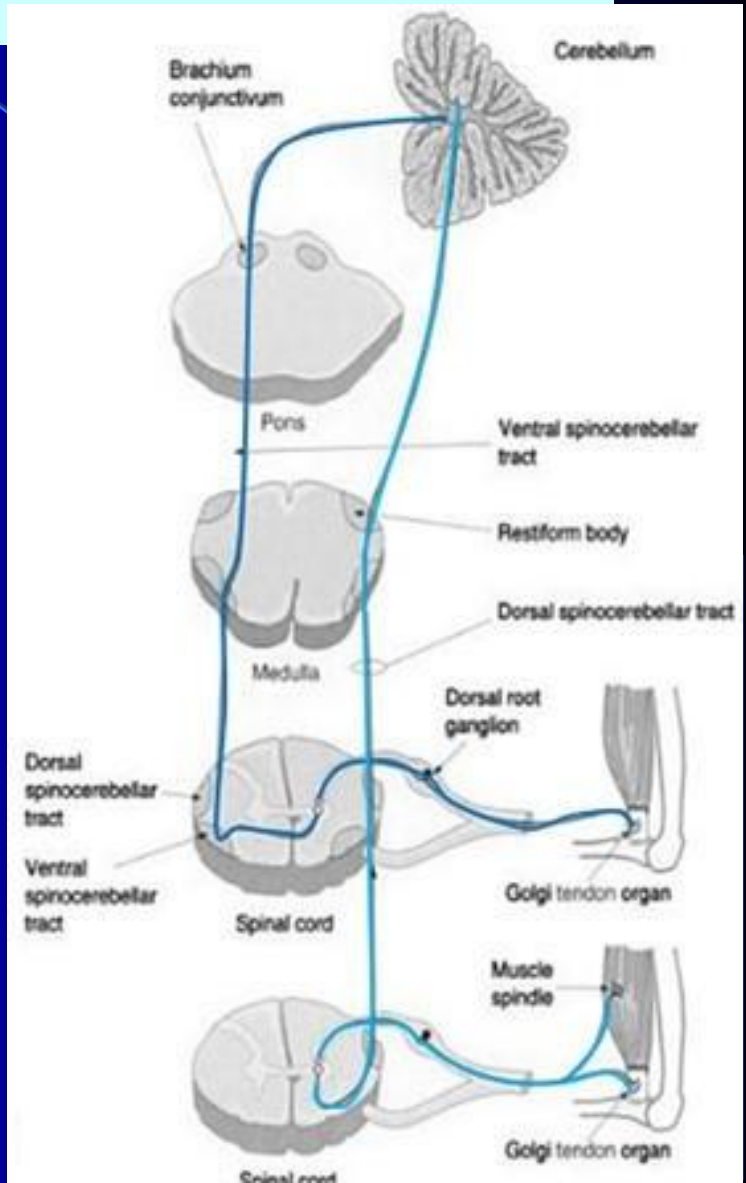
The Dorsal & Ventral Spinocerebellar Tracts

- They carry subconscious proprioception signals

1 The Dorsal Spinocerebellar tract (dSCT)

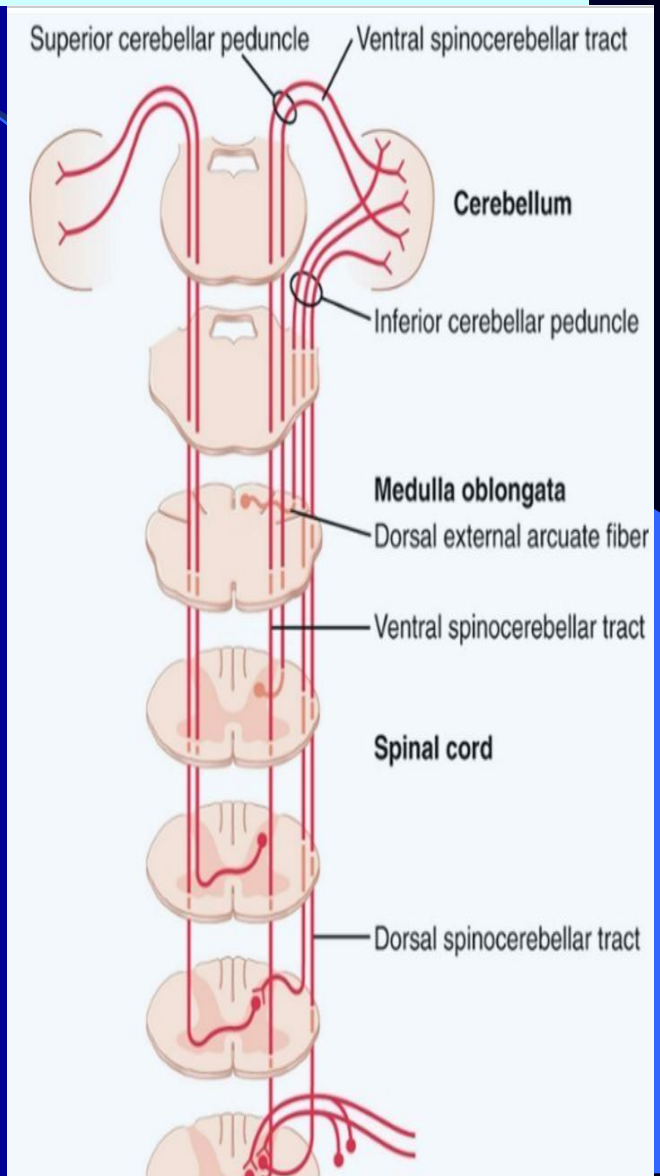
- Carry signals directly to cerebellum at a speed of up to 120 m/s mainly from muscle spindles, but also from GTO, skin receptors & joint receptors
- Enter cerebellum through inferior cerebellar peduncle
- Terminate in vermis & intermediate zone

- Function of dSCT:
- informs the cerebellum about:
  - Muscle length and contraction
  - Degree of tension on tendons
  - Position and rate movement of parts of body.
  - Forces acting on the body surfaces



The Dorsal & Ventral Spinocerebellar Tracts

- The Ventral Spinocerebellar tract (vSCT):
- Carry some signals from periphery (mainly from Golgi tendon organs) directly to cerebellum, but excited mainly by descending motor signals from brain (corticospinal & rubrospinal tracts) and from the spinal cord itself
- Enter cerebellum through superior cerebellar peduncle and terminate on both sides of cerebellum
- Function of vSCT:
- informs the cerebellum about:
- Which motor signals have arrived to the spinal cord.

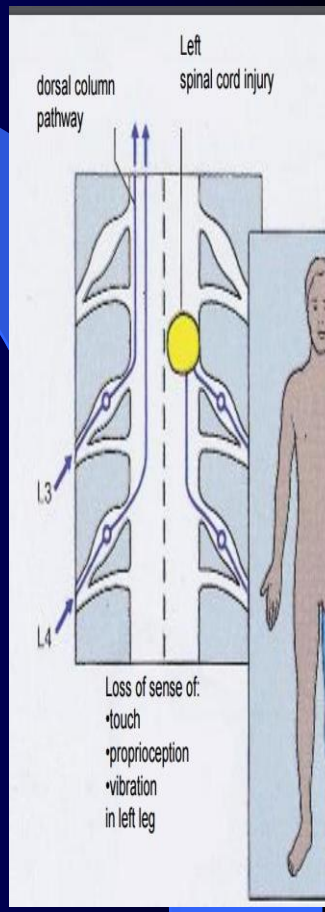


Ataxia and Gait Disturbances-1

- Ataxia:
- inability to coordinate voluntary muscular movements that is due to nerve damage (CNS or PNS) and not due to muscle weakness (called also incoordination)
- Types of Ataxia: 1 Sensory ataxia 2 Motor ataxia

Pathophysiology of sensory ataxia:

- PNS lesions (e.g. polyneuropathy)
  - injury to sensory receptors and afferent neurons
- Dorsal column lesion
  - Loss of proprioception, vibration and touch
  - Ataxia is made worse in the dark or no vision
- Lesion in thalamus & sensory cortex
- Romberg's test. Ask the patient to close the eyes while standing with feet together.
- The affected patient becomes unstable (+ Romberg's test)

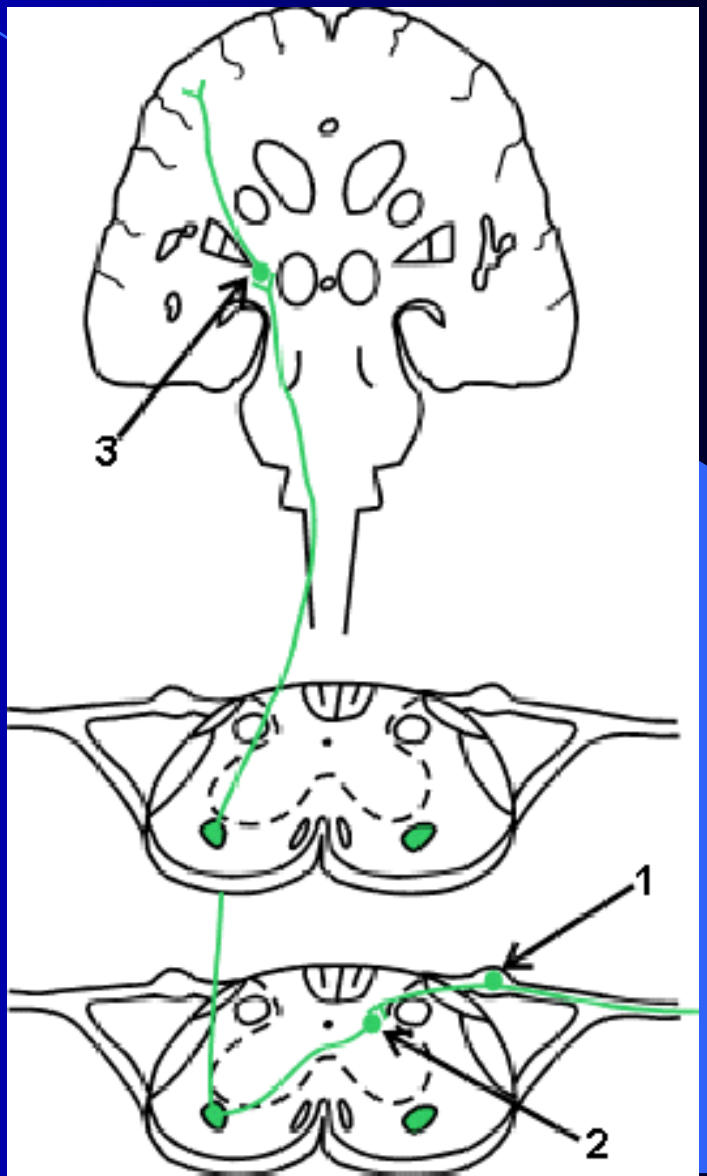


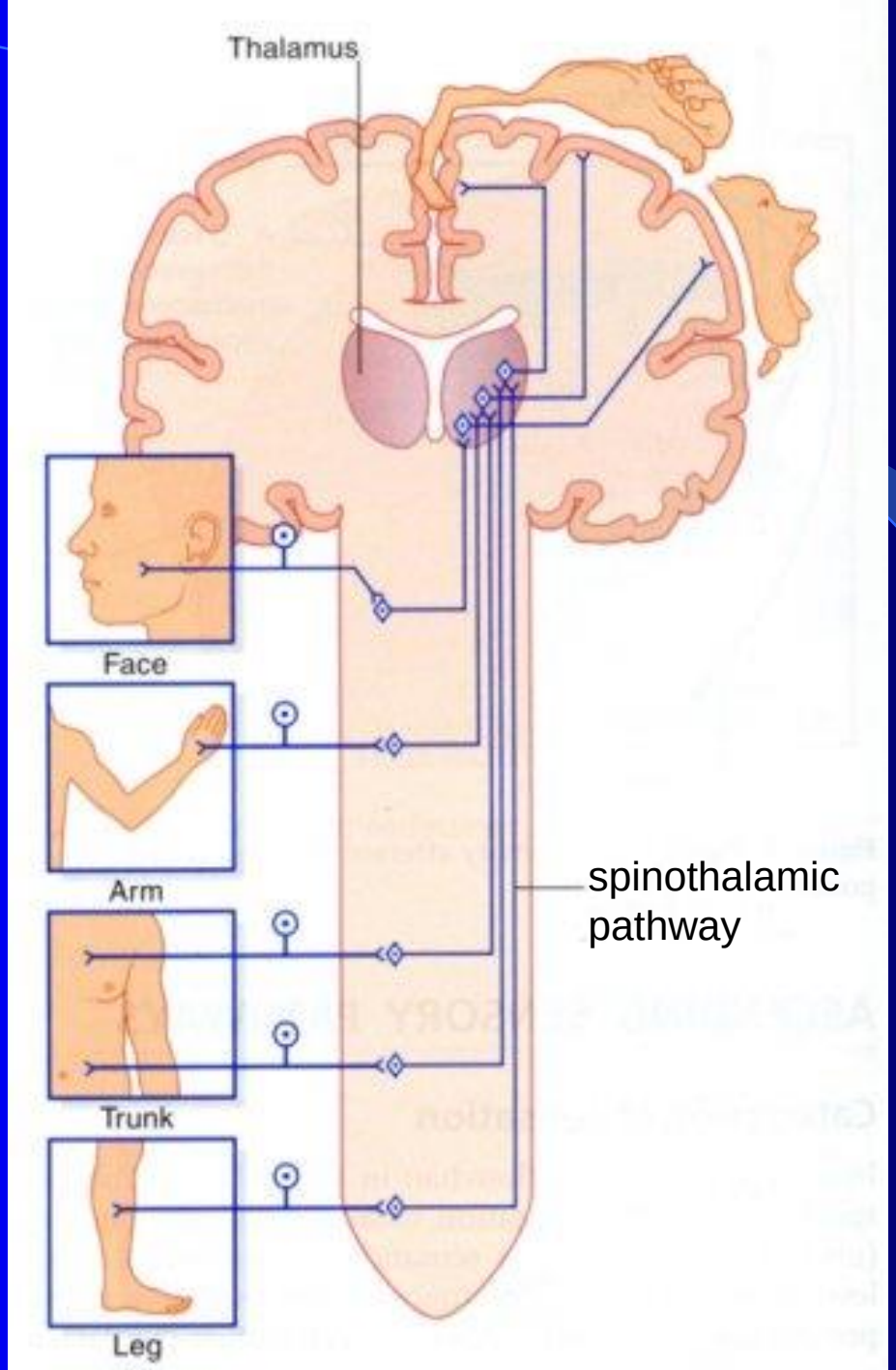
Ataxia and Gait Disturbances-2

- Motor Ataxia: caused by cerebellar disorders
  - Intact sensory receptors and afferent pathways
  - Integration of proprioception is faulty
  - Midline cerebellar lesions cause truncal ataxia
    - Lateral cerebellar lesions cause limb ataxia
- Features of Cerebellar ataxia
  - Clumsy movements
  - Incoordination of the limbs
  - Reeling gait (unsteadiness, and irregularity of steps; often with a tendency to fall to one or other side, forward or backward)
  - Alcoholic intoxication produces similar effects!

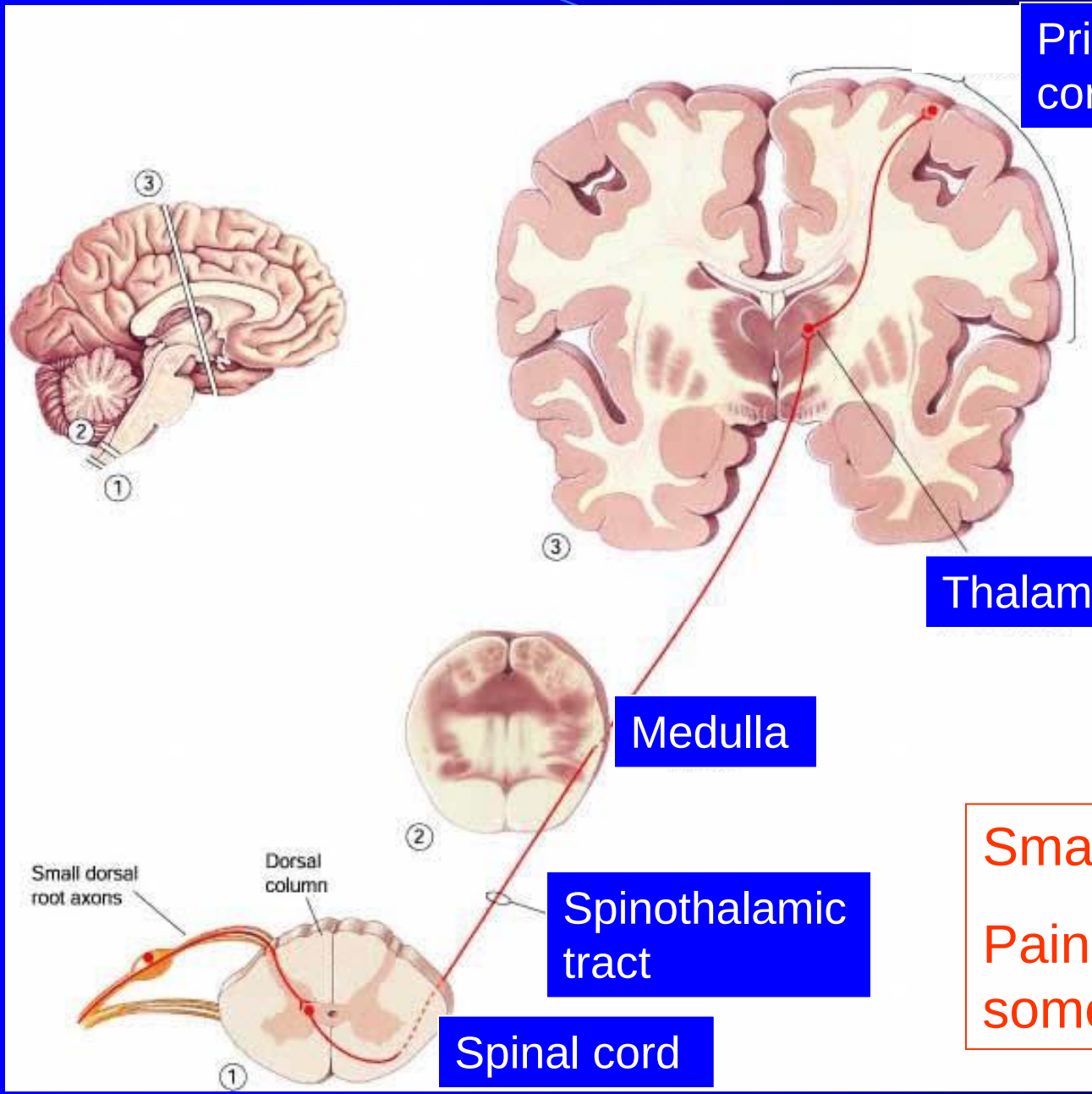
Spinothalamic pathway

- Carries pain, temperature, touch and pressure signals
- 1st neuron enters spinal cord through dorsal root
- 2nd neuron crosses over in spinal cord; ascends to thalamus
- 3rd neuron projects from thalamus to somatosensory cortex




Thalamus
Face
Arm
Trunk
Leg
spinothalamic pathway

Spinothalamic Pathway



Primary somatosensory cortex (S1)

Thalamus

Medulla

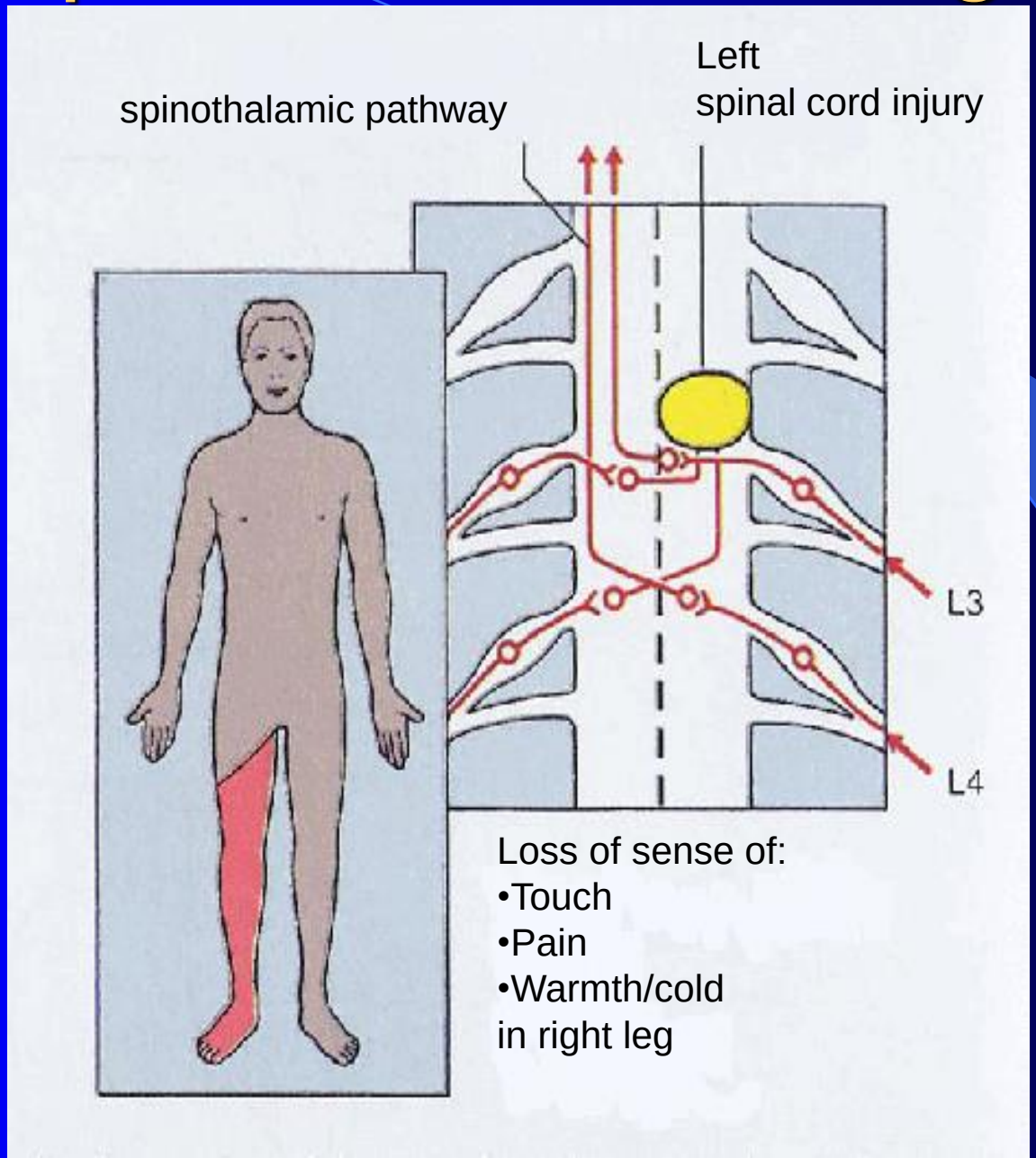
Spinothalamic tract

Spinal cord

Small sensory fibres:

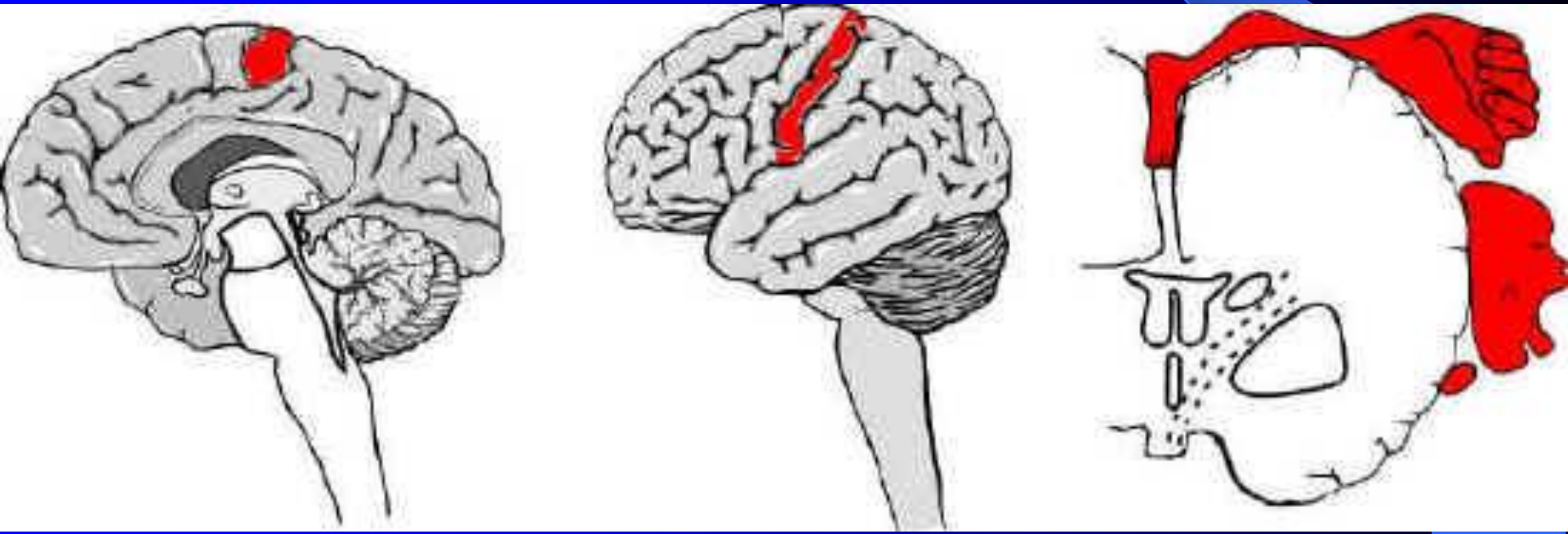
Pain, temperature, some touch

Spinothalamic damage



4. Somatosensory cortex

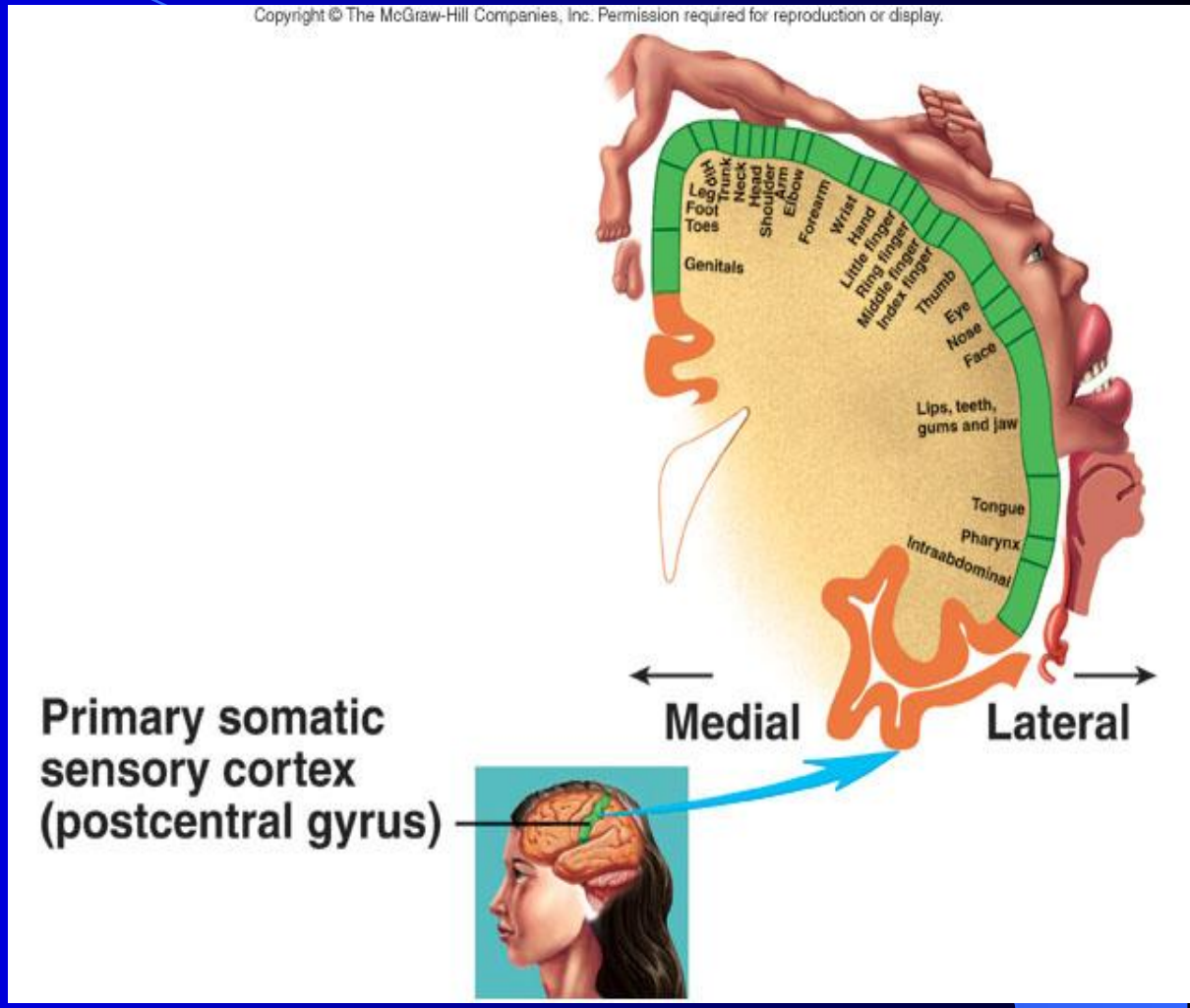
Located in the postcentral gyrus of the human cerebral cortex.



Spatial orientation of signals.

1) Each side of the cortex receives sensory information exclusively from the opposite side of the body

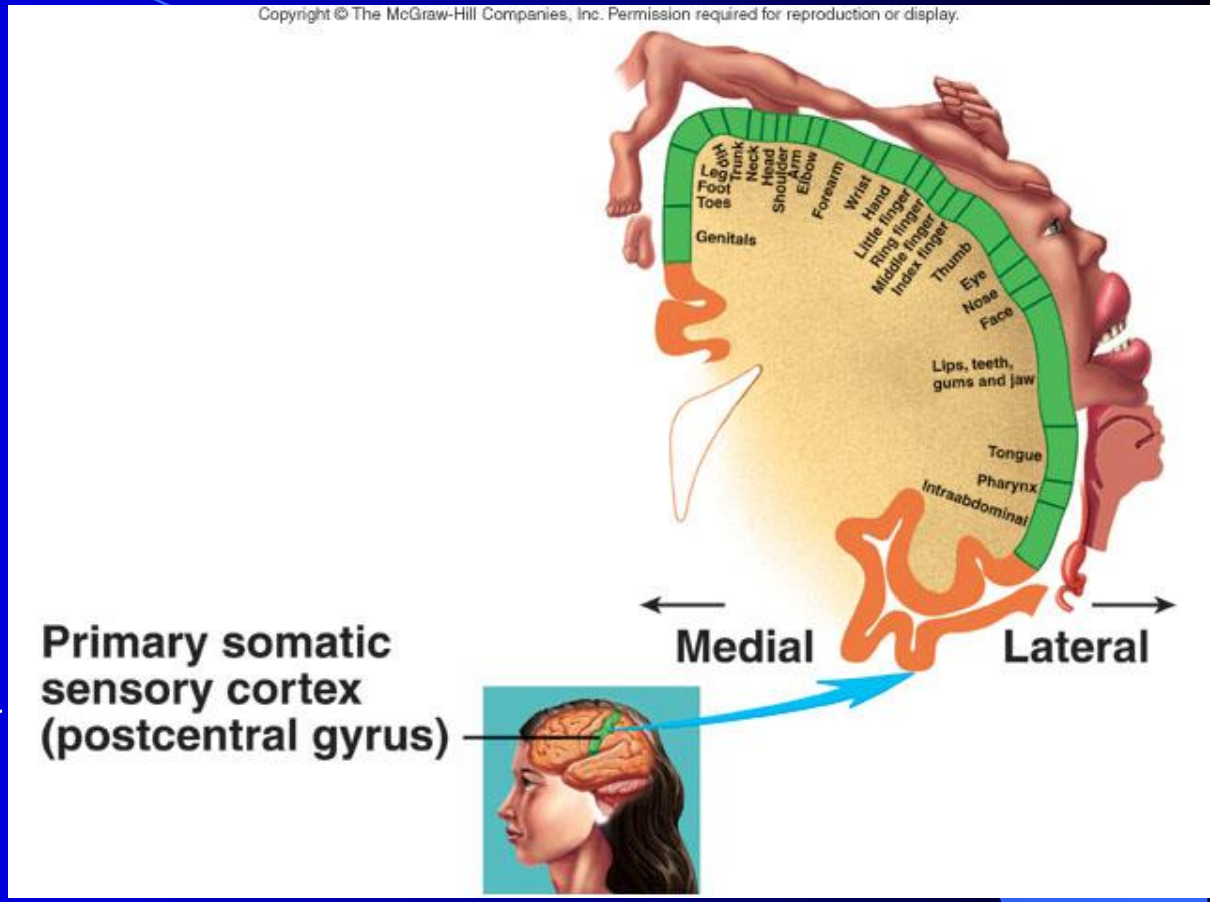
(the exception: the same side of the face).



Spatial orientation of signals.

2)The lips, face and thumb are represented by large areas in the somatic cortex,

whereas the trunk and lower part of the body, relatively small area.



3)The head in the most lateral portion, and the lower body is presented medially