PHYSIOLOGY OF THE PROPRIOCEPTORS IN BALANCE & ITS PATHWAYS

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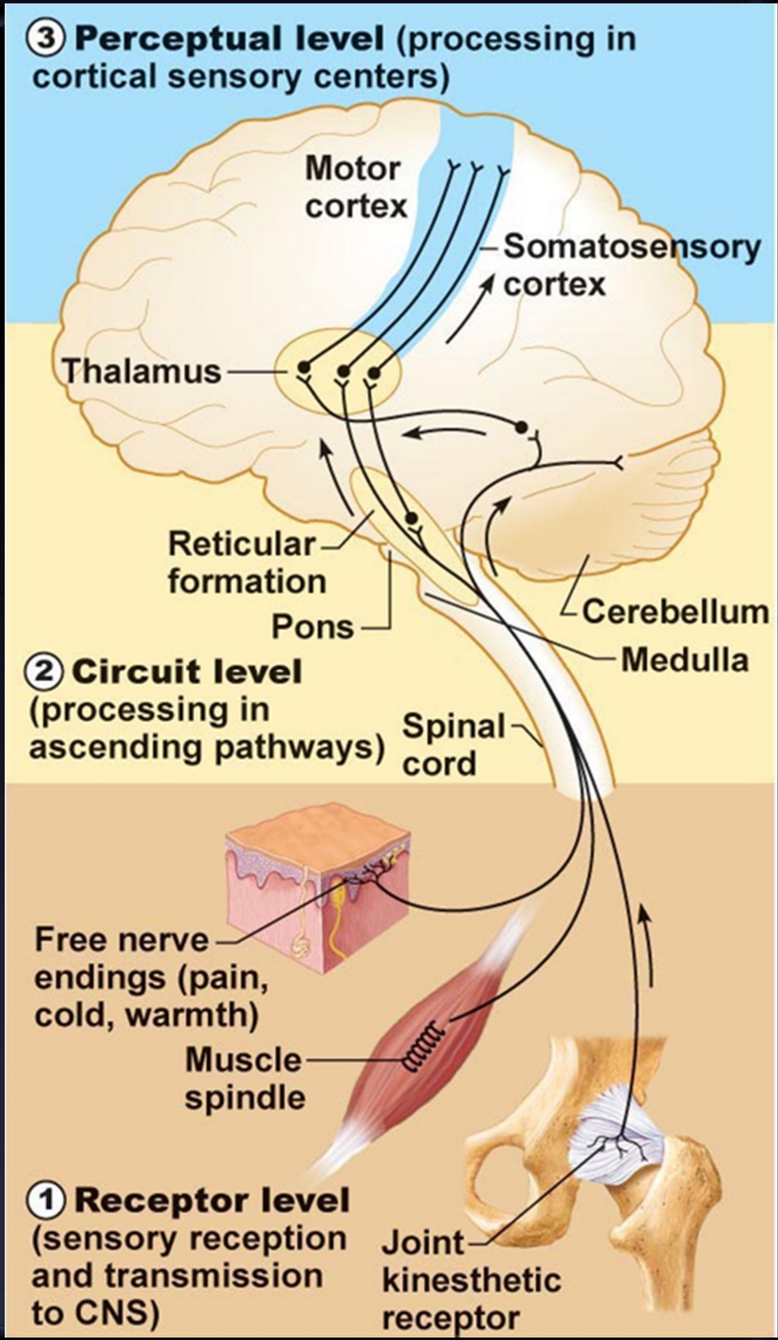


OBJECTIVES

At the end of this lecture you should be able to:

- Identify the major sensory pathways
- Describe the components, processes and functions of the sensory pathways
- Appreciate the dorsal column system in conscious proprioception
- Describe the pathway of spinocerebellar tract in unconscious proprioception from muscles, tendons and joints
- Differentiate between sensory and motor ataxia

PROPRIOCEPTION

Latin proprius, meaning "one's own", "individual" and perception, is the sense of the relative position of neighbouring parts of the body and strength of effort being employed in movement.

exteroception, by which one perceives the outside world

interoception, by which one perceives pain, hunger, etc., and the movement of internal organs.

MECHANORECEPTORS: **which detect mechanical compression or stretching of the receptor or of tissues adjacent to the receptor**

PROPRIOCEPTION

Perception about the relative positions of different body parts and strength of effort being employed in movements.

Three Types of Proprioceptors

- Muscle spindles – measure the changing length of a muscle
  – Imbedded in the perimysium between muscle fascicles
- Golgi tendon organs – located near the muscle-tendon junction
  – Monitor tension within tendons
- Joint kinesthetic receptors
  – Sensory nerve endings within the joint capsules

PROPRIOCEPTORS

- **Proprioceptors include the muscle spindles, Golgi tendon organs, and joint receptors.**
- **These provide a sense of body position and allow fine control of skeletal movements**

(1) Static position sense: which means conscious perception of the orientation of the different parts of the body with respect to one another, and
(2) Rate of movement sense: also called kinesthesia or dynamic proprioception

SENSORY RECEPTORS TYPES

- (1) ***MECHANORECEPTORS:*** which detect mechanical compression or stretching of the receptor or of tissues adjacent to the receptor eg proprioceptors
- (2) ***THERMORECEPTORS***, which detect changes in temperature, some receptors detecting cold and others warmth.
- (3) ***NOCICEPTORS*** (pain receptors), which detect damage occurring in the tissues, whether physical damage or chemical damage eg free nerve endings
- (4) ***ELECTROMAGNETIC RECEPTORS***, which detect light on the retina of the eye eg rods and cones
- (5) ***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

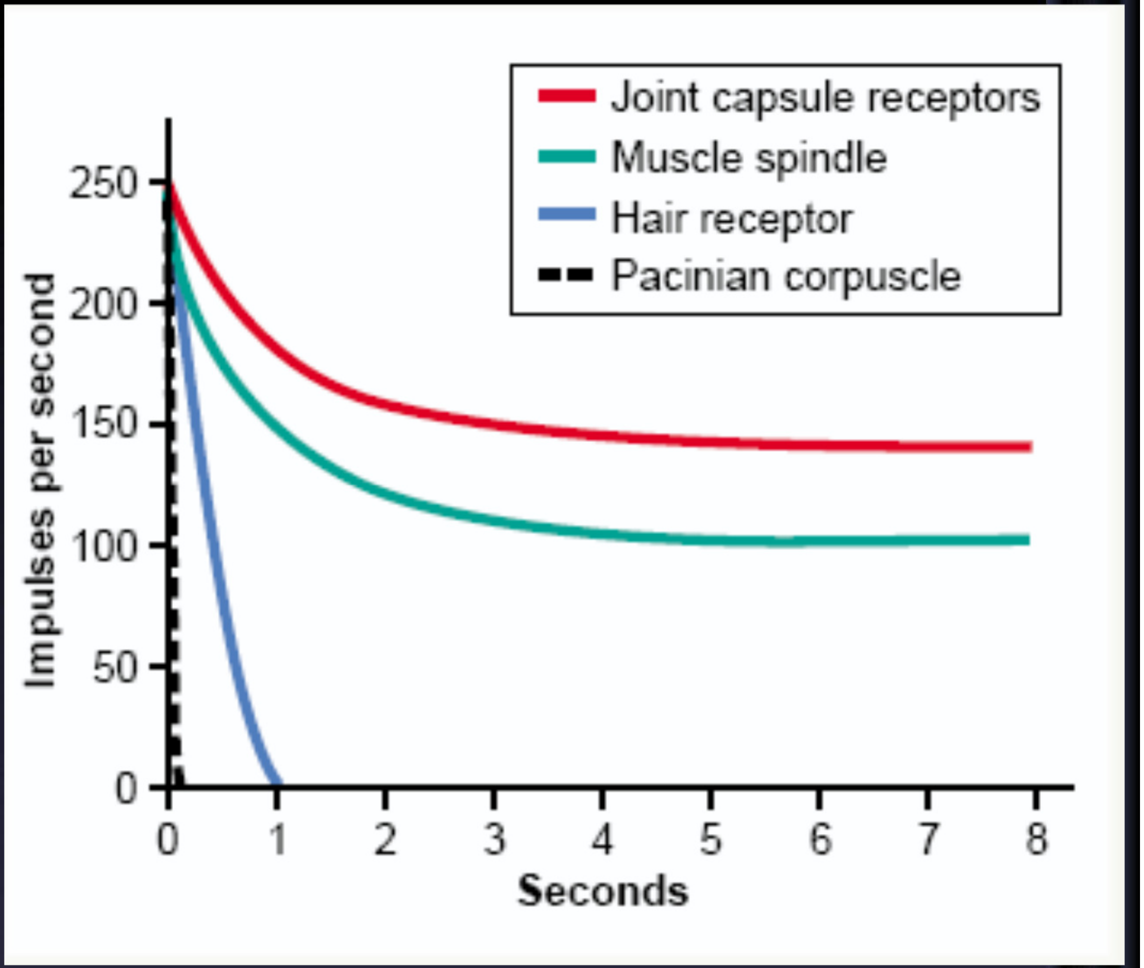
STRUCTURES CONCERNED WITH PROPRIOCEPTION

SPATIAL ORIENTATION (four inputs)

- Proprioceptors
- Brain Stem (Cortico,Rubro,Vestibulo,Reticulo,Olivo,Tectospinal)
- vestibular system (apparatus, nuclei etc)
- Ascending Tracts
- Visual system
- Cerebellum (flocculonodular lobe→dynamic equilibrium, Uvula → Static equilibrium)
- Cerebral cortex (primary cortical center for equilibrium located in the parietal lobe deep in the sylvian fissure)

Adaptation of Receptors

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.



Adaptation of Receptors

1. **Rapid adapting or phasic receptors** eg meissner's corpuscles(touch), pacinian corpuscles(vibration)
2. **Slowly adapting or tonic receptors** eg ruffini's (pressure ,skin stretch) krause's end bulbs,and Merkel's disks.
3. **Non adapting receptors** eg Free nerve endings for pain sensation

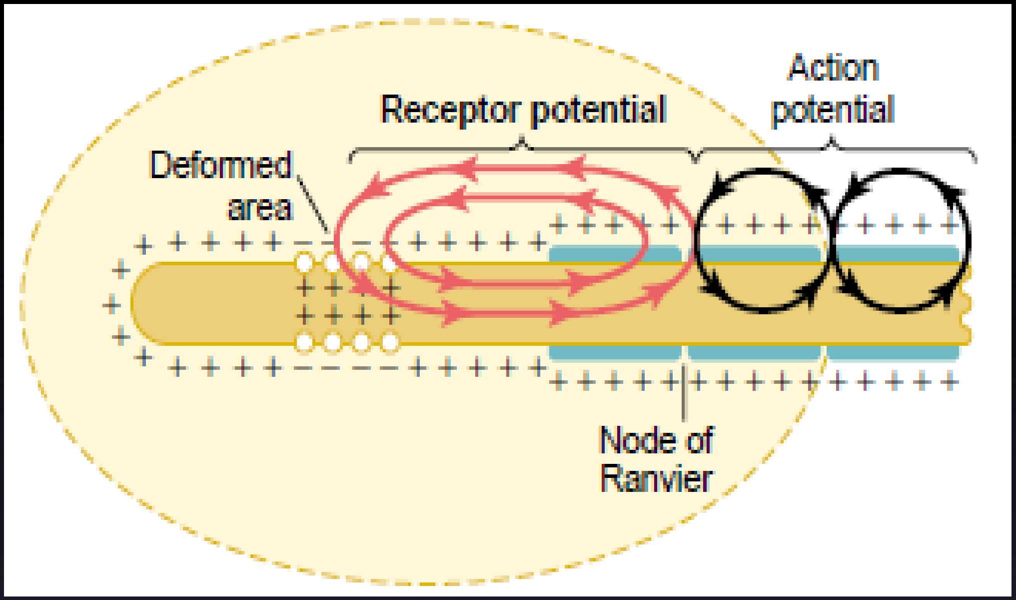
Mechanisms by which Receptors Adapt.

- First, the pacinian corpuscle is a viscoelastic structure so that after stimulation within few hundredths of a second, **the fluid within the corpuscle redistributes**, so that the receptor potential is no longer elicited.

- The second mechanism of adaptation of the pacinian corpuscle, but a much slower one, results from *accommodation*, which occurs in the nerve fiber itself. This probably results from **progressive "inactivation" of the sodium channels in the nerve fiber membrane**

Receptor Potential of the Pacinian Corpuscle

For joint position and vibration sensation (Also Ruffini's Endings)



- The receptor potential produced by compression induces a local circuit of current flow that spreads along nerve fiber.
- The frequency of repetitive action potentials transmitted from sensory receptors increases approximately in proportion to the increase in receptor potential

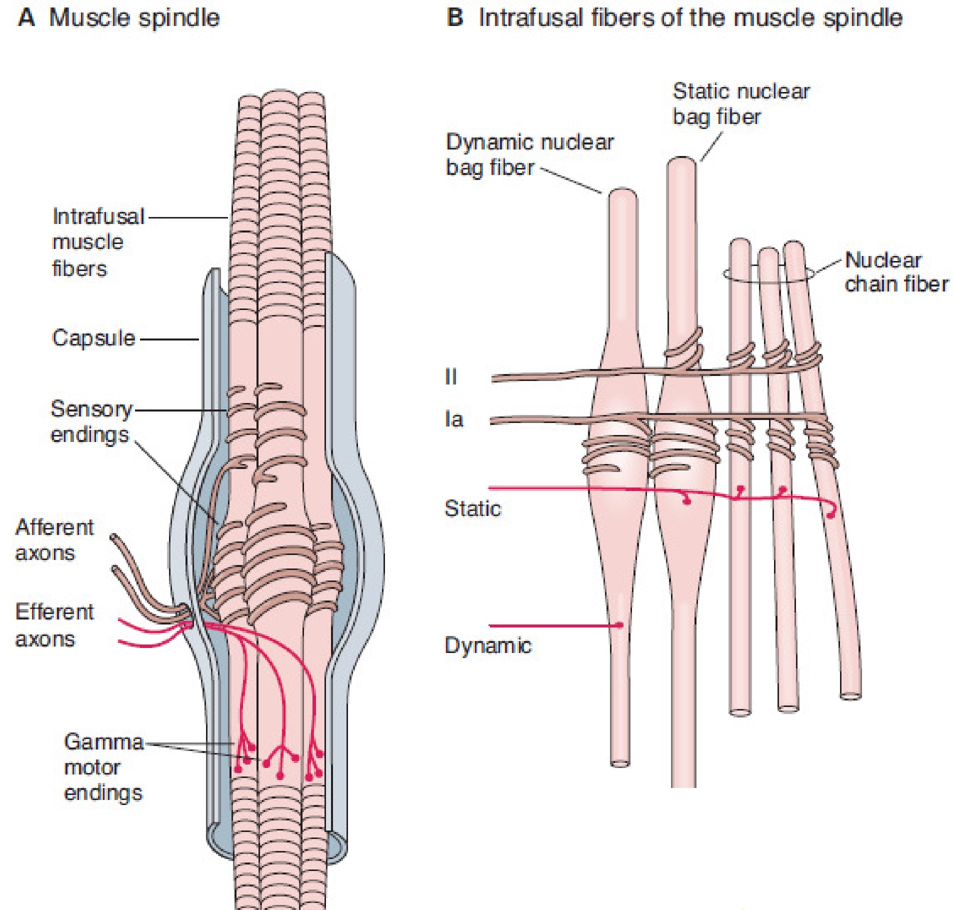
Types of proprioception

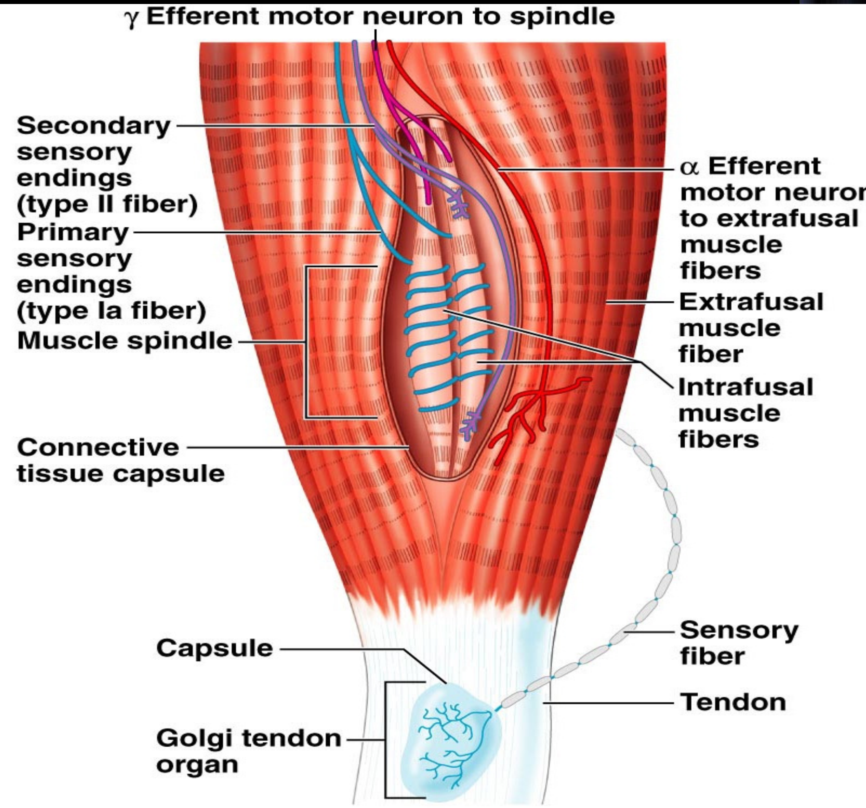
1- Conscious proprioception reach the level of cerebral cortex sensory area via dorsal column tract.

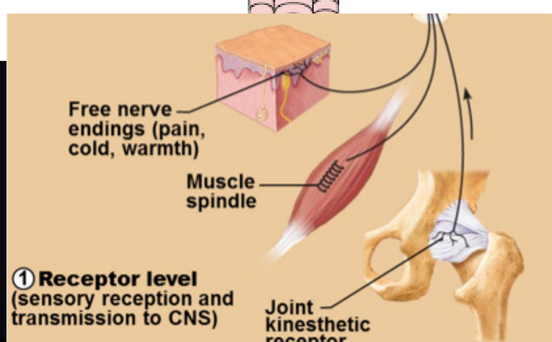
2- Subconscious proprioception reach the level of cerebellum via spinocerebellar tracts

Where is the location of these tracts?

Structure of Proprioceptors







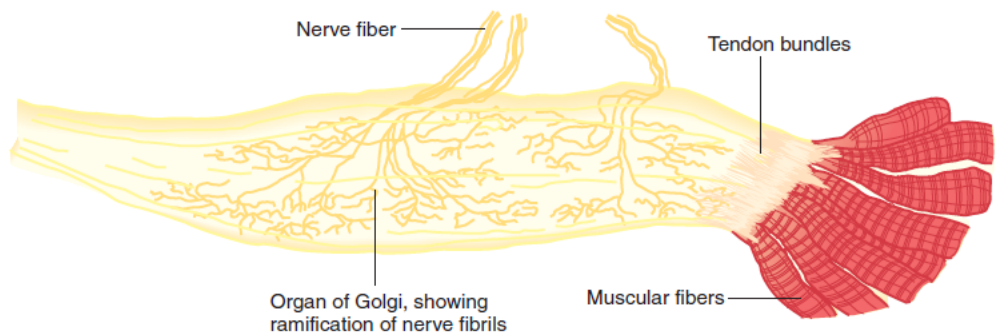
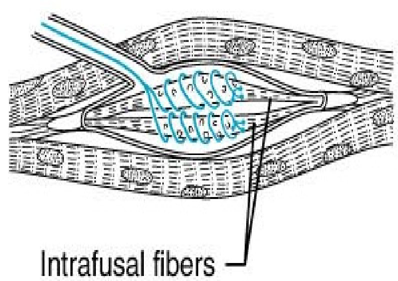
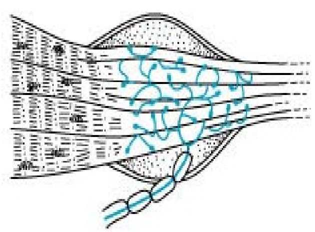


FIGURE 12–5 Golgi tendon organ. This organ is the receptor for the inverse stretch reflex and consists of a netlike collection of knobby nerve endings among the fascicles of a tendon. The innervation is the Ib group of myelinated, rapidly conducting sensory nerve fibers. (Reproduced with permission from Gray H [editor]: *Gray's Anatomy of the Human Body,* 29th ed. Lea & Febiger, 1973.)

Encapsulated Nerve Endings

Meissner's corpuscles, Pacinian corpuscles' Ruffini's corpuscles, Proprioceptors

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

Unencapsulated Nerve Endings

Table 14.1 General Sensory Receptors Classified by Structure and Function (1 of 3)

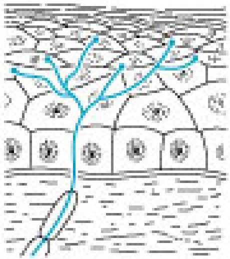
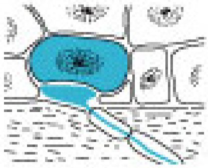
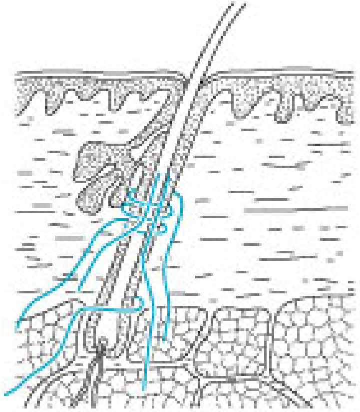
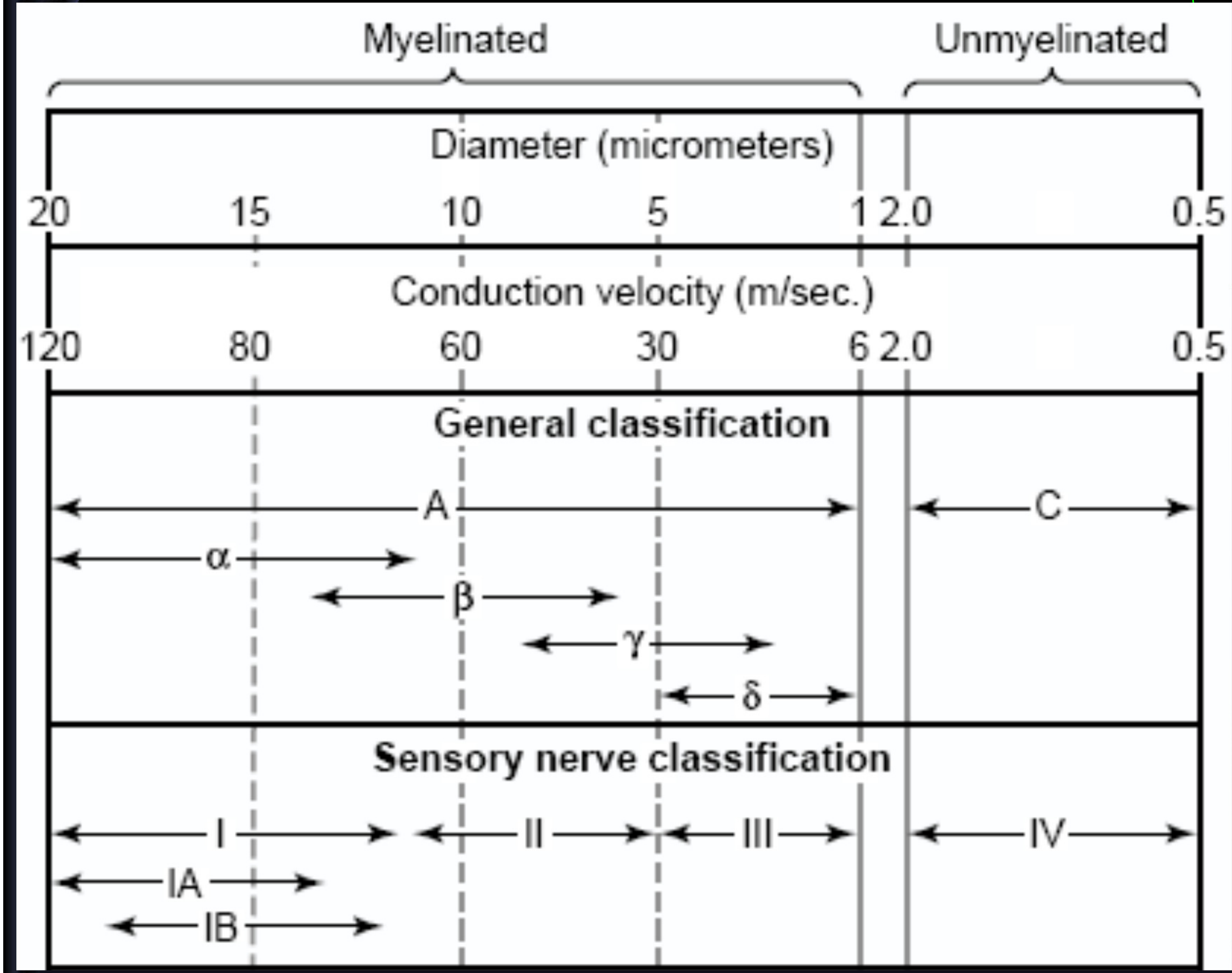
Anatomical Class (structure)	Illustration	Functional Class According to Location (L) and Stimulus Type (S)	Body Location
UNENCAPSULATED			
Free nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Nociceptors (pain), thermoreceptors (heat and cold), possibly mechanoreceptors (pressure)	Most body tissues; densest in connective tissues (ligaments, tendons, dermis, joint capsules, periostea) and epithelia (epidermis, cornea, mucosae, and glands)
Modified free nerve endings: Merkel discs		L: Exteroceptors S: Mechanoreceptors (light pressure)	Basal layer of epidermis
Hair follicle receptors		L: Exteroceptors S: Mechanoreceptors (hair deflection)	In and surrounding hair follicles

TABLE 8–1 Principle sensory modalities.

Sensory System	Modality	Stimulus Energy	Receptor Class	Receptor Cell Types
Somatosensory	Touch	Tap, flutter 5–40 Hz	Cutaneous mechanoreceptor	Meissner corpuscles
Somatosensory	Touch	Motion	Cutaneous mechanoreceptor	Hair follicle receptors
Somatosensory	Touch	Deep pressure, vibration 60–300 Hz	Cutaneous mechanoreceptor	Pacinian corpuscles
Somatosensory	Touch	Touch, pressure	Cutaneous mechanoreceptor	Merkel cells
Somatosensory	Touch	Sustained pressure	Cutaneous mechanoreceptor	Ruffini corpuscles
Somatosensory	Proprioception	Stretch	Mechanoreceptor	Muscle spindles
Somatosensory	Proprioception	Tension	Mechanoreceptor	Golgi tendon organ
Somatosensory	Temperature	Thermal	Thermoreceptor	Cold and warm receptors
Somatosensory	Pain	Chemical, thermal, and mechanical	Chemoreceptor, thermoreceptor, and mechanoreceptor	Polymodal receptors or chemical, thermal, and mechanical nociceptors
Somatosensory	Itch	Chemical	Chemoreceptor	Chemical nociceptor
Visual	Vision	Light	Photoreceptor	Rods, cones
Auditory	Hearing	Sound	Mechanoreceptor	Hair cells (cochlea)
Vestibular	Balance	Angular acceleration	Mechanoreceptor	Hair cells (semicircular canals)
Vestibular	Balance	Linear acceleration, gravity	Mechanoreceptor	Hair cells (otolith organs)
Olfactory	Smell	Chemical	Chemoreceptor	Olfactory sensory neuron
Gustatory	Taste	Chemical	Chemoreceptor	Taste buds

NERVE FIBERS CLASSIFICATION



- Type A
  - Alpha
  - Beta
  - Gamma
  - Delta
- Type C

	Stretch Reflex	Inverse Stretch Reflex
Stimulus	Muscle Stretch	Over Stretch
Receptor	Muscle Spindle	Golgi Tendon Organ
Afferent	Afferent 1a	Afferent 1b
Center	Spinal Cord (Center)	Spinal Cord (Center)
		Inhibitory Interneuron
Efferent	Efferent αMotor	Efferent αMotor
Effector	Extrafusal Fibers	Extrafusal Fibers
Effect	Ms Contration	Ms Relaxation (lengthening reaction)
	Reciprocal Inhibition of antagonist	Reciprocal Excitation of antagonist

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

SPINAL CORD TRACTS

Sensory information from receptors throughout most of the body is relayed to the brain by means of ascending tracts of fibers that conduct impulses up the spinal cord.

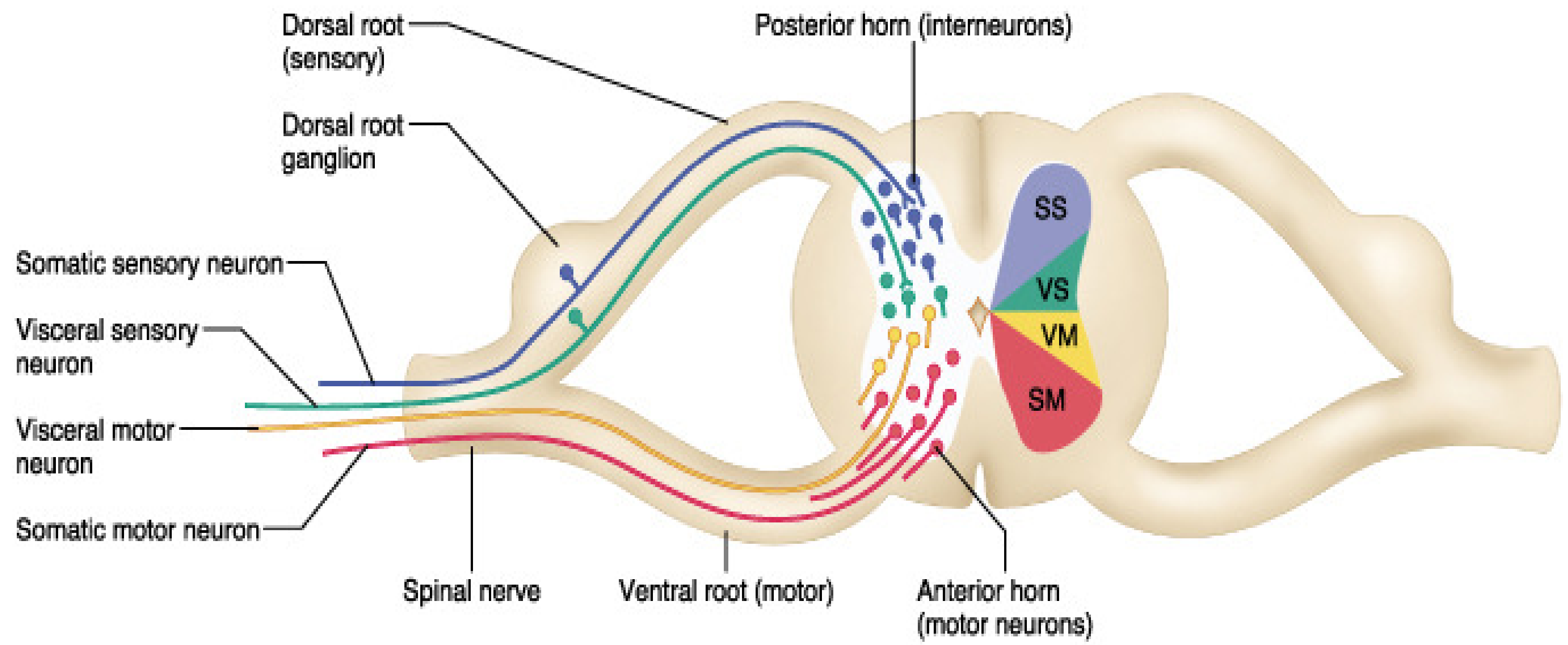
When the brain directs motor activities, these directions are in the form of nerve impulses that travel down the spinal cord in descending tracts of fibers.

Ascending Tracts (Sensory)

Descending Tracts (Motor)

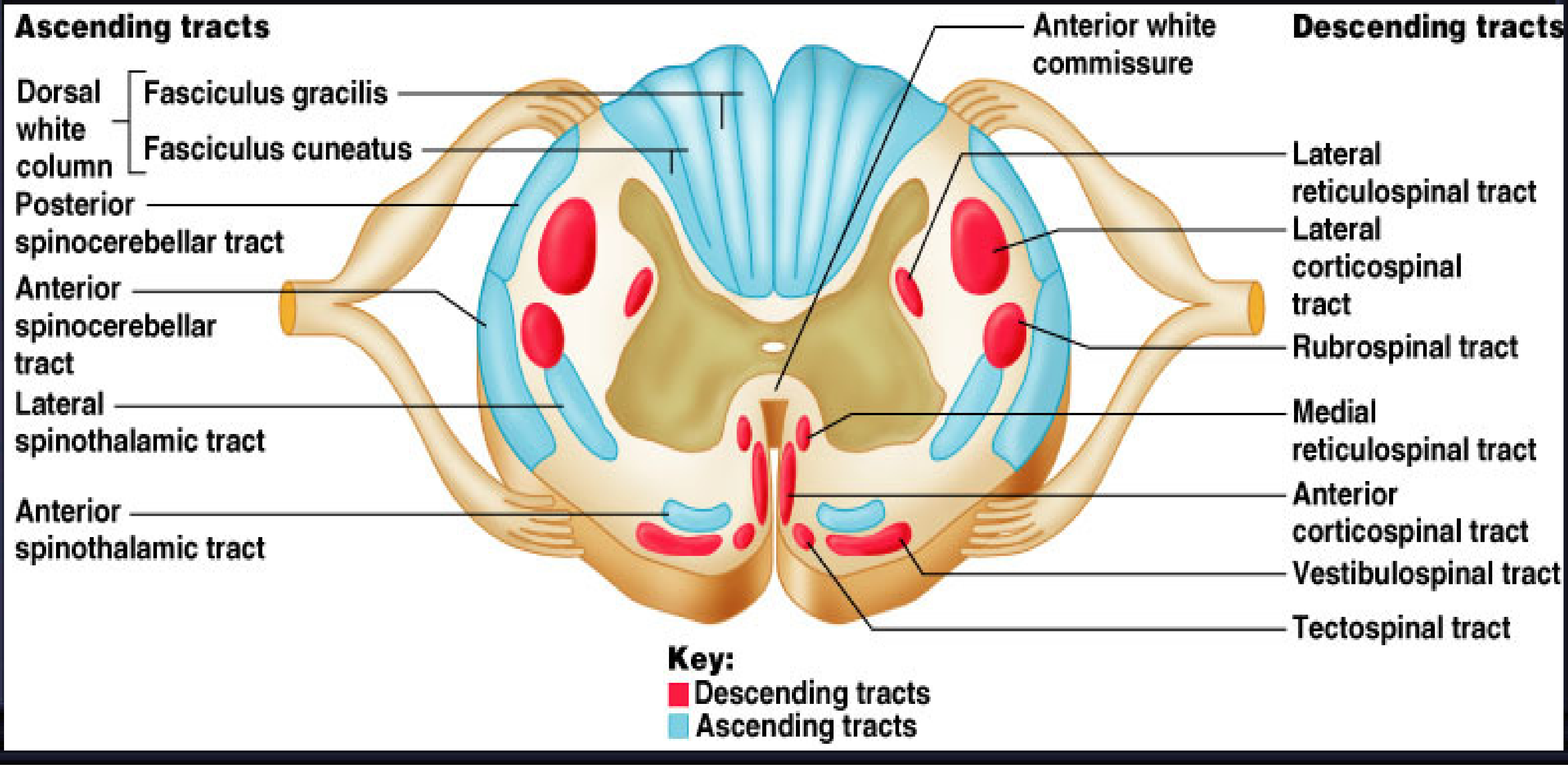
Gray Matter: Organization

- 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



SENSORY TRACTS

- DORSAL COLUMN SYSTEM
- ANTEROLATERAL SYSTEM

Each system carries different types of sensations which are known as **MODALITIES** like pain, temperature, fine touch, crude touch, vibration, proprioception etc

1. <u>Dorsal column pathway</u>- carries signal of fine touch, pressure, vibration , stereognsis and proprioception,

2. Spinothalamic pathway- carries signals of pain, temperature, deep pressure, and course touch.

3,4- <u>Posterior and anterior spinocerebellar pathways-</u> carry subsconcious proprioception. Dorsal gray horn- to lateral column- to medulla oblongata- to pons – to cerebellum.

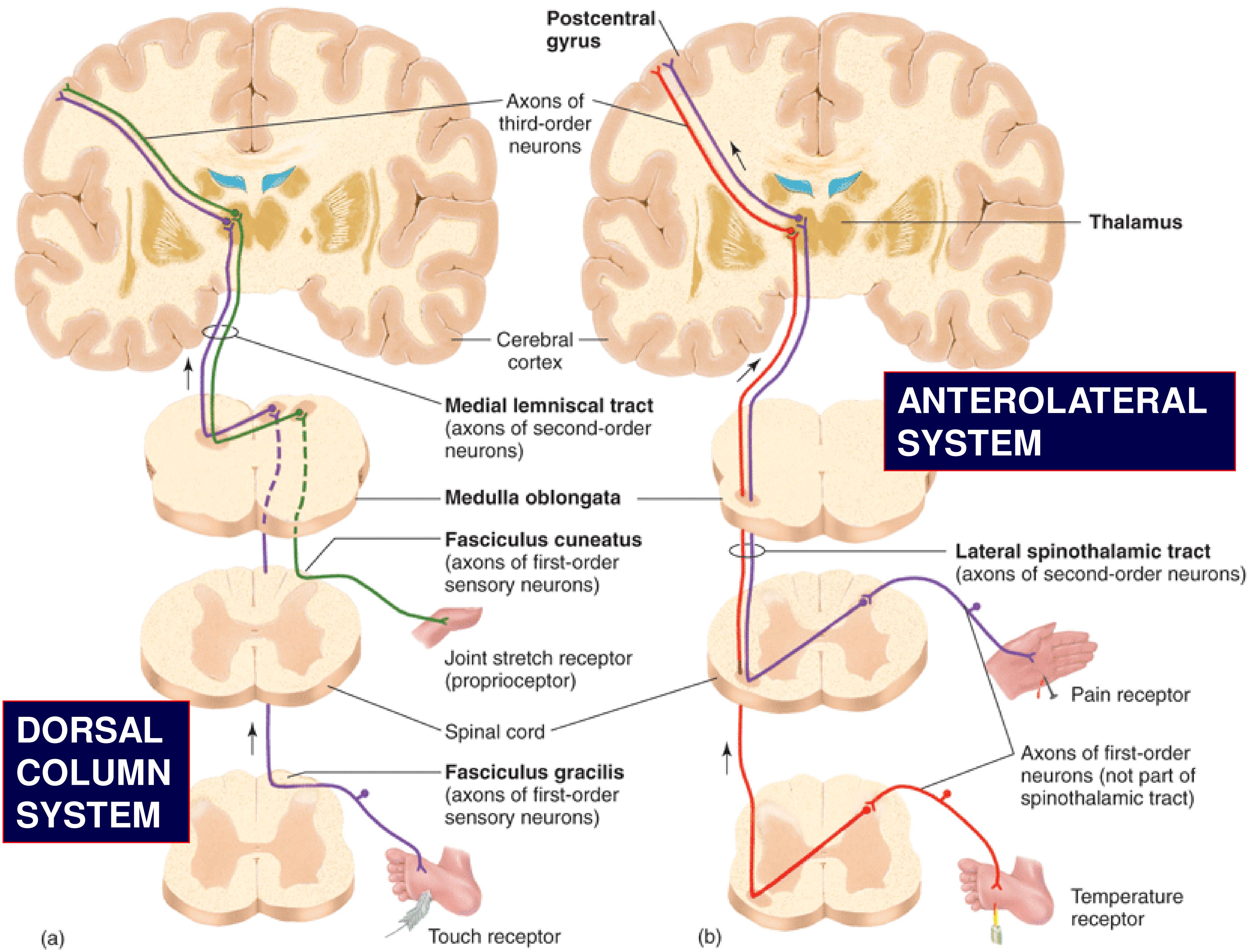
DORSAL COLUMN MEDIAL LEMNISCAL SYSTEM

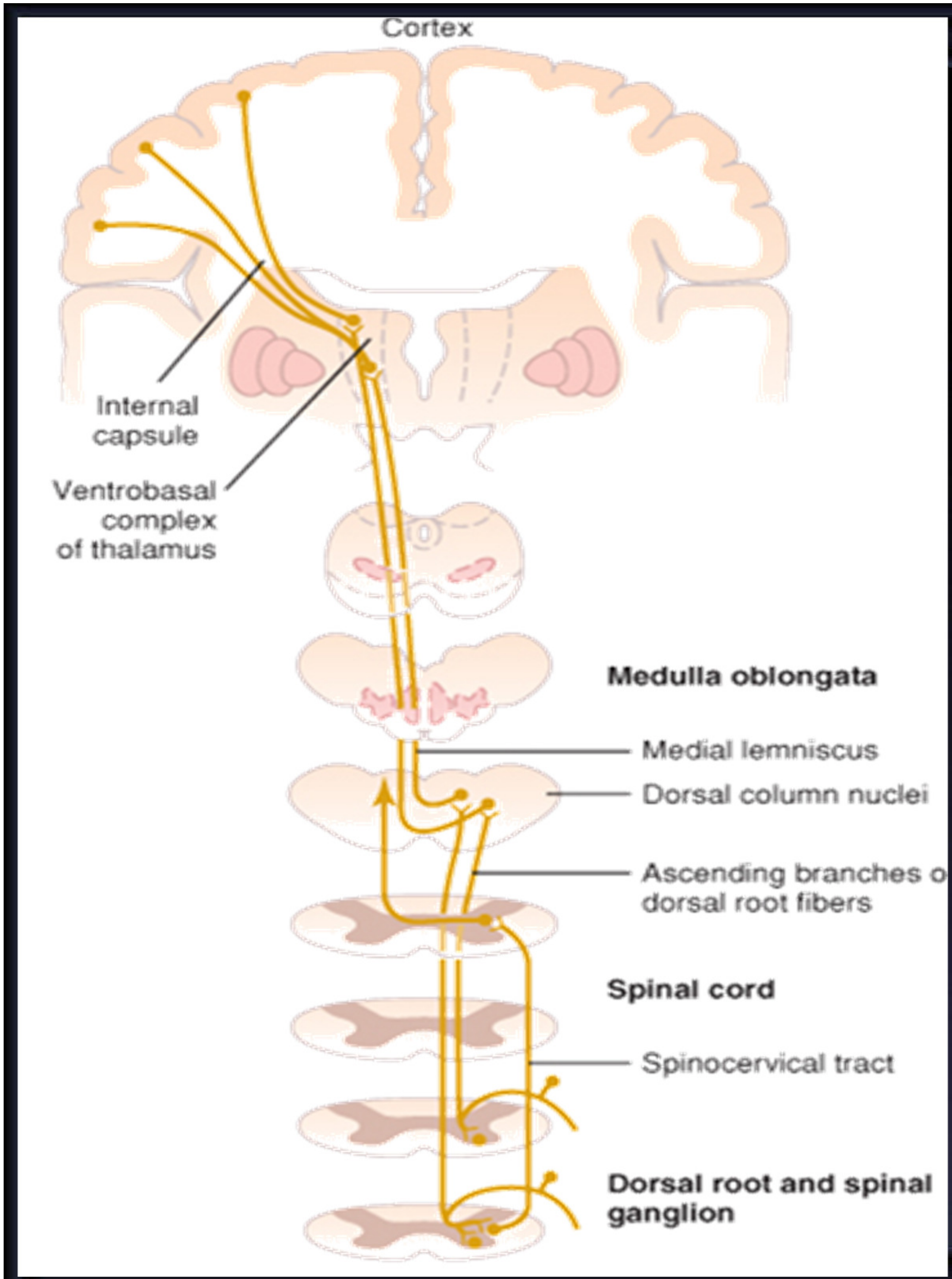
1. Touch sensations requiring a high degree of localization of the stimulus
2. Touch sensations requiring transmission of fine gradations of intensity
3. Phasic sensations like vibratory sensations
4. Sensations that signal movement against skin
5. Joints Position sensations (Proprioception)
6. Pressure sensations requiring fine degrees of judgment of intensity
7. Strereognosis

ANTEROLATERAL SYSTEM

Ventral & lateral spinothalamic tracts

1. Pain
2. Thermal sensations, (warmth & cold)
3. Crude touch and pressure sensations capable only of crude localizing ability on the surface of the body
4. Tickle and itch sensations
5. Sexual sensations


Postcentral gyrus
Axons of third-order neurons
Thalamus
Cerebral cortex
Medial lemniscal tract (axons of second-order neurons)
ANTEROLATERAL SYSTEM
Medulla oblongata
Fasciculus cuneatus (axons of first-order sensory neurons)
Lateral spinothalamic tract (axons of second-order neurons)
Joint stretch receptor (proprioceptor)
Pain receptor
Spinal cord
DORSAL COLUMN SYSTEM
Axons of first-order neurons (not part of spinothalamic tract)
Fasciculus gracilis (axons of first-order sensory neurons)
Temperature receptor
Touch receptor
(a)
(b)

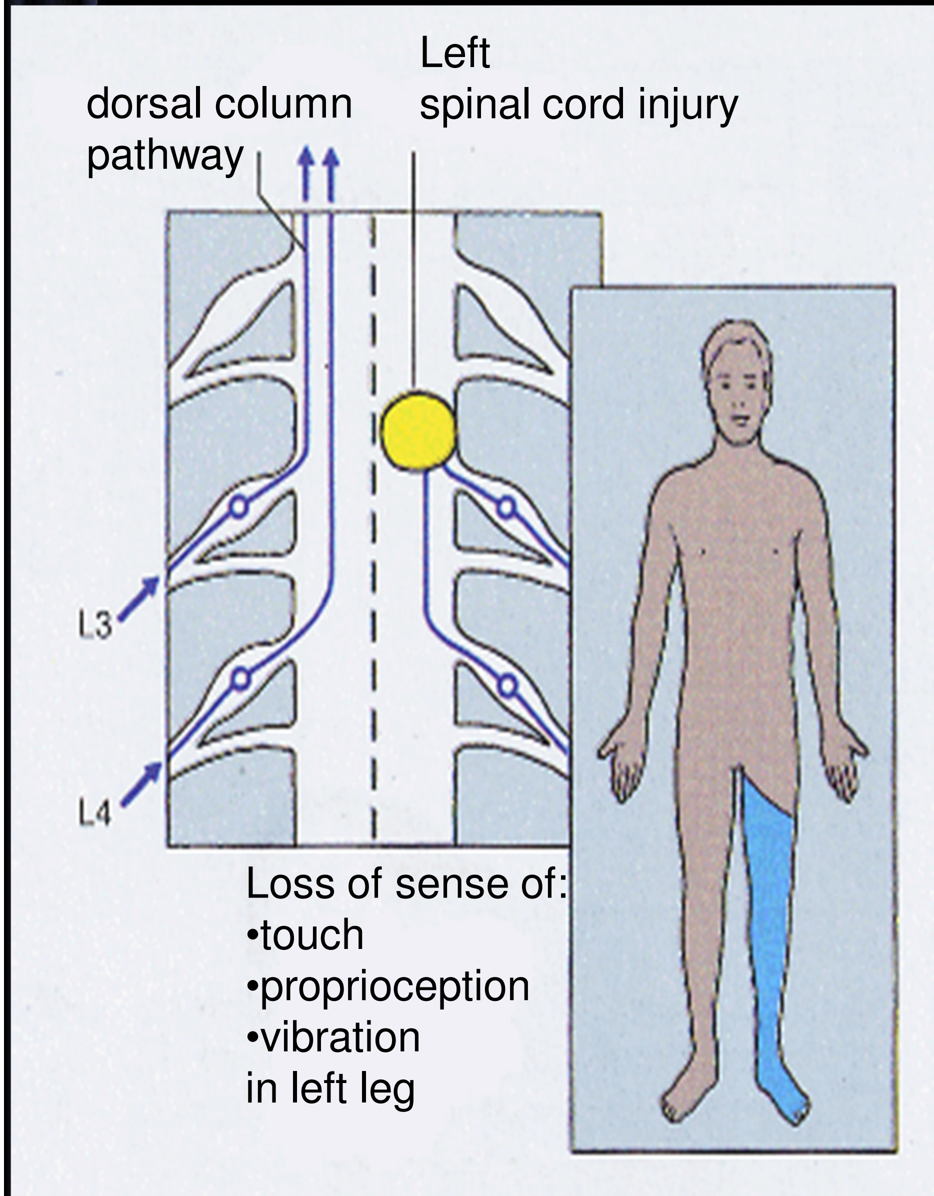


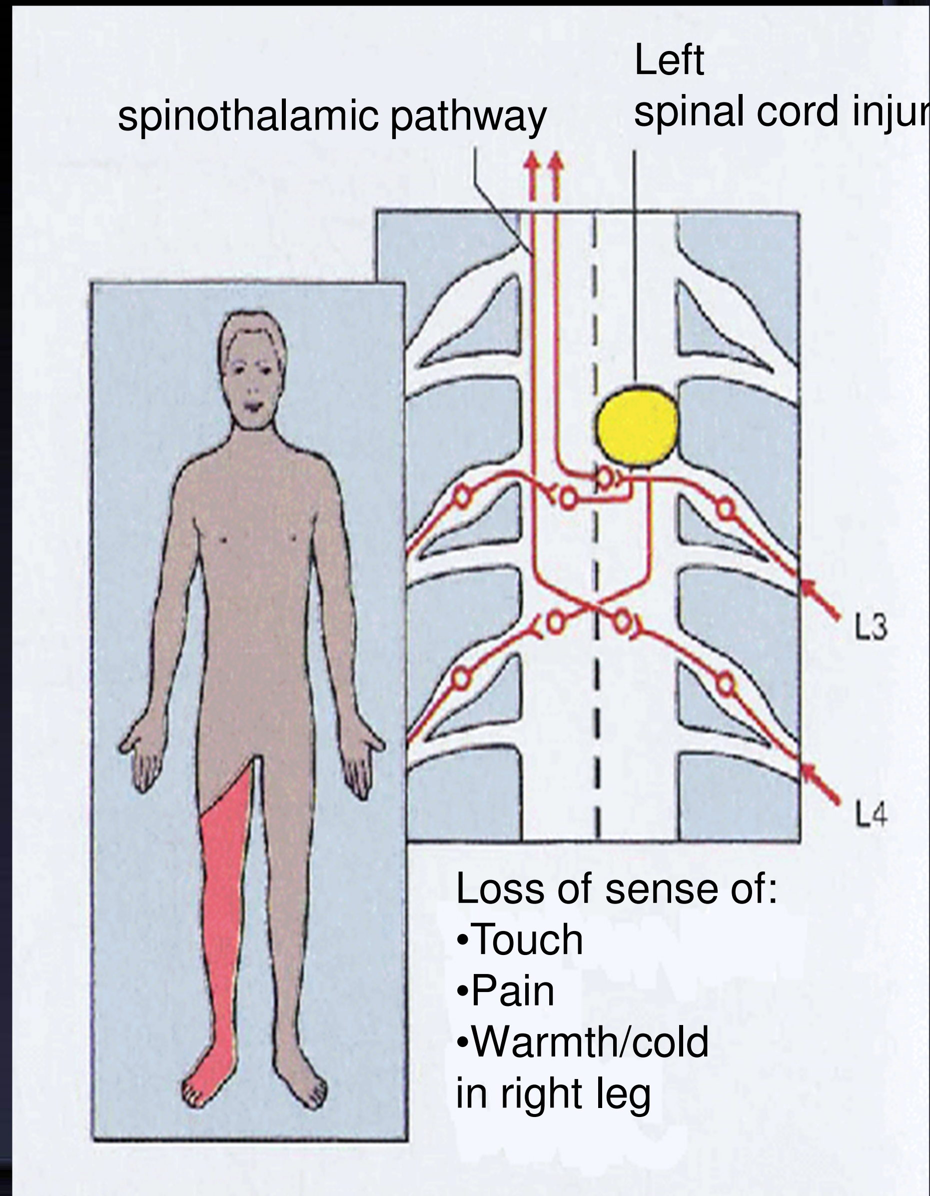
PROPRIOCEPTION FROM HEAD

In this pathway through the brain stem, each medial lemniscus is joined by additional fibers from the <u>sensory nuclei of the trigeminal nerve</u>; these fibers subserve the same sensory functions for the head that the dorsal column fibers subserve for the body.

Dorsal column lesion

Spinothalamic lesion



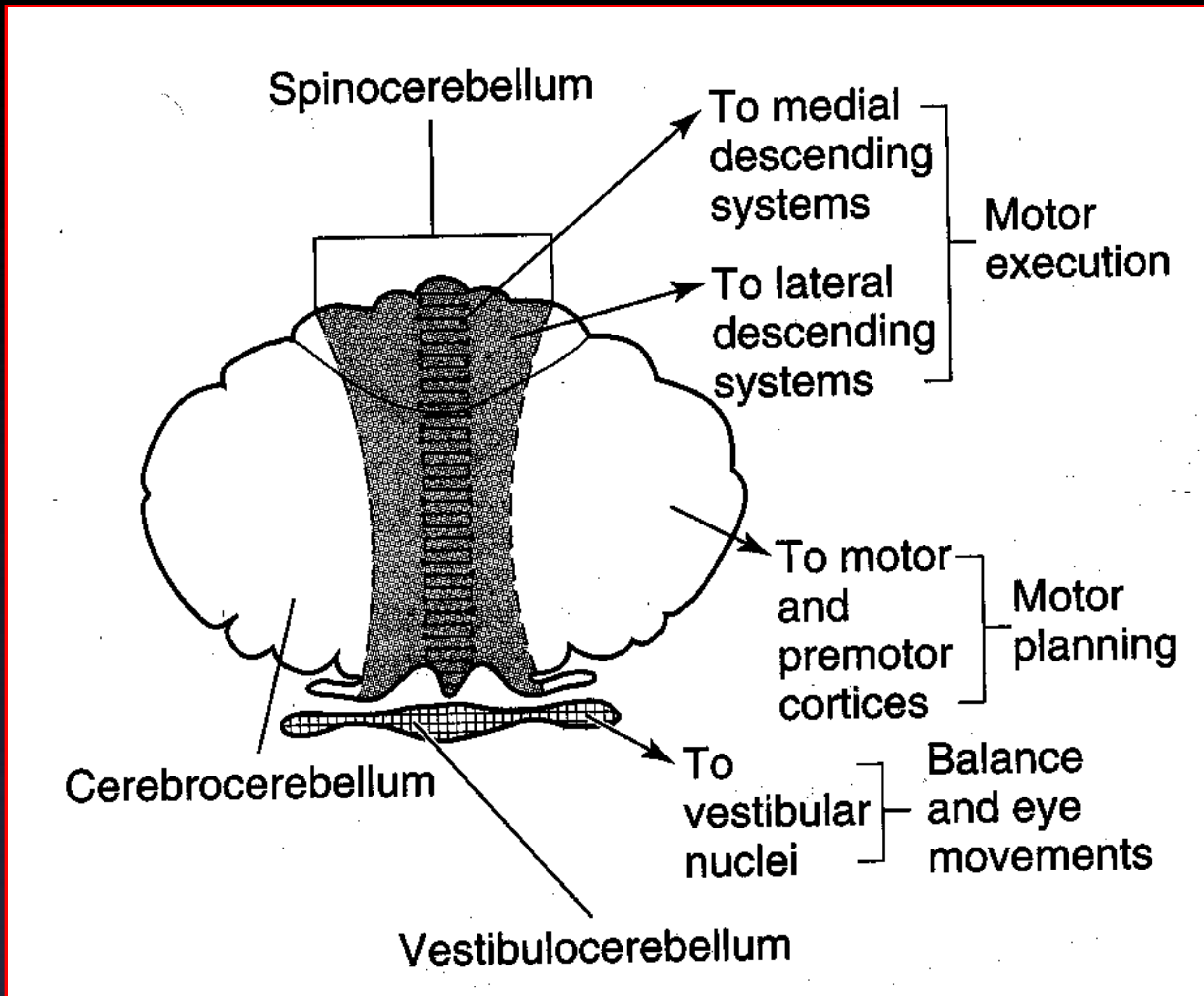


Dorsal column damage

- **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.

FUNCTIONAL DIVISION OF CEREBELLUM



Role of Cerebellum in Proprioception

Vestibulocerebellum (Flocculonodular Lobe)— In Association with the Brain Stem and Spinal Cord Control Equilibrium and Postural Movements

during performance of rapid motions specially with changes in direction controlling balance between agonist and antagonist muscle contractions of the spine, hips, and shoulders during rapid changes in body positions as required by the vestibular apparatus

Spinocerebellum (Vermis+Intermediate Zone)— Feedback Control of Distal Limb Movements by Way of the Intermediate Cerebellar Cortex and the Interposed Nucleus

feedback information from the peripheral parts of the body, especially from the distal proprioceptors of the limbs, telling the cerebellum what *actual movements* result.

Cerebrocerebellum— Function of the Large Lateral Zone of the Cerebellar Hemisphere to Plan, Sequence, and Time Complex Movements

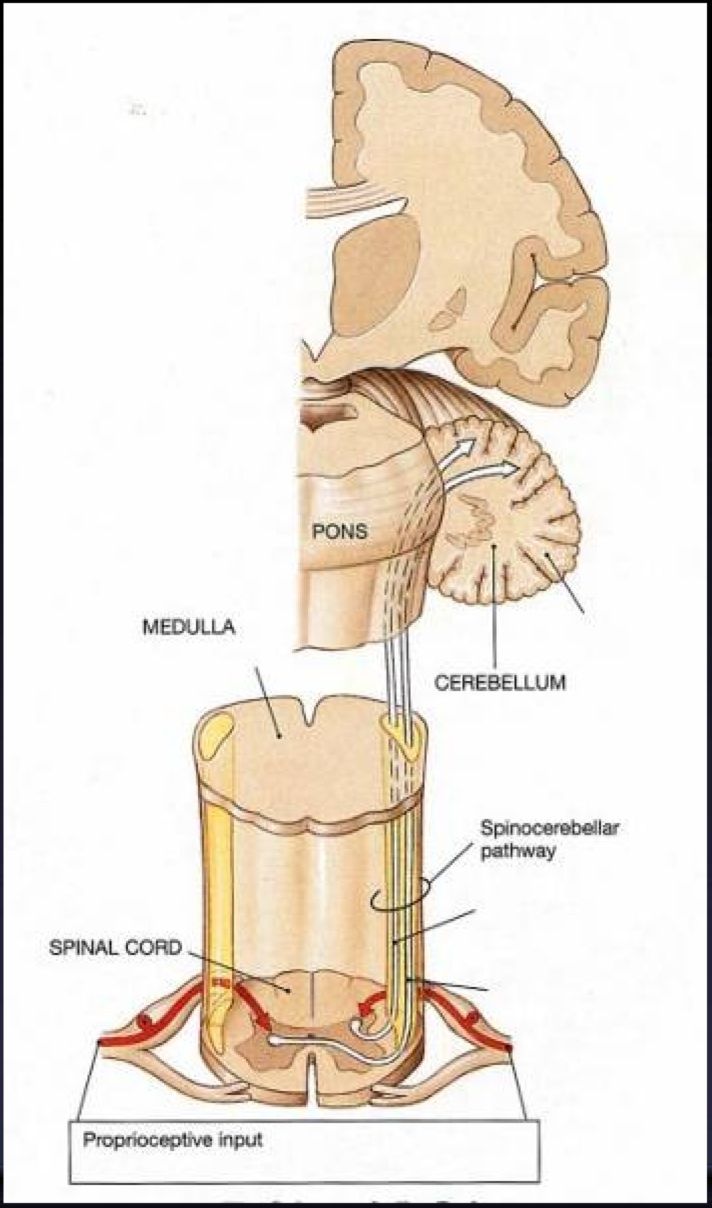
TABLE 12–2 Function of principal afferent systems to the cerebellum.[a]

Afferent Tracts	Transmits
Vestibulocerebellar	Vestibular impulses from labyrinths, direct and via vestibular nuclei
Dorsal spinocerebellar	Proprioceptive and exteroceptive impulses from body
Ventral spinocerebellar	Proprioceptive and exteroceptive impulses from body
Cuneocerebellar	Proprioceptive impulses, especially from head and neck
Tectocerebellar	Auditory and visual impulses via inferior and superior colliculi
Pontocerebellar	Impulses from motor and other parts of cerebral cortex via pontine nuclei
Olivocerebellar	Proprioceptive input from whole body via relay in inferior olive

[a]The olivocerebellar pathway projects to the cerebellar cortex via climbing fibers; the rest of the listed paths project via mossy fibers. Several other pathways transmit impulses from nuclei in the brain stem to the cerebellar cortex and to the deep nuclei, including a serotonergic input from the raphé nuclei to the granular and molecular layers and a noradrenergic input from the locus coeruleus to all three layers.

Spinocerebellar pathway

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



Spinocerebellar tract damage

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

Ataxia and Gait Disturbances

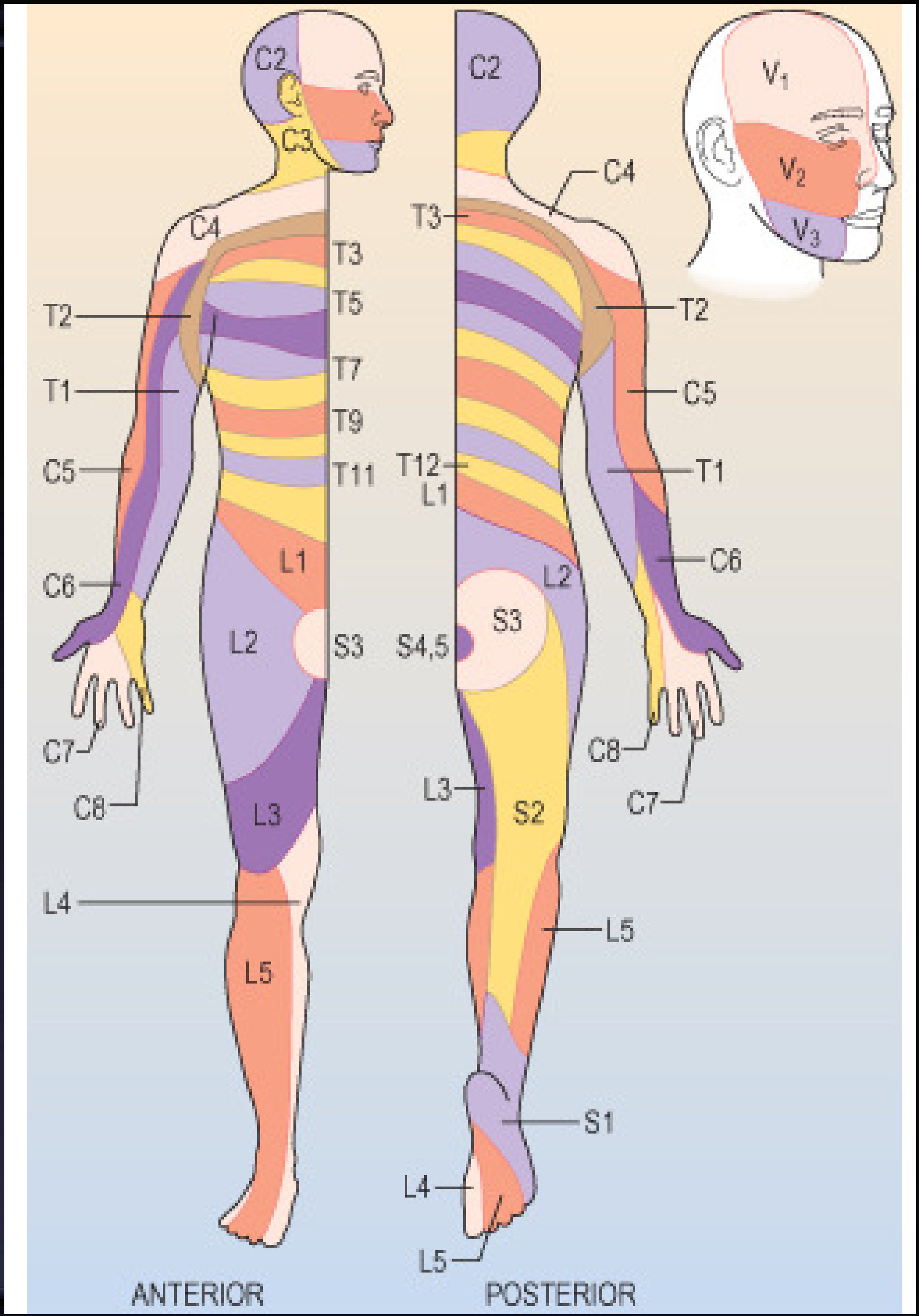
- **Pathophysiology**
  - **Result from any condition that affects the central and peripheral nervous systems**
  - **Ataxia: Types**
    - **Motor ataxia**
    - **Sensory ataxia**

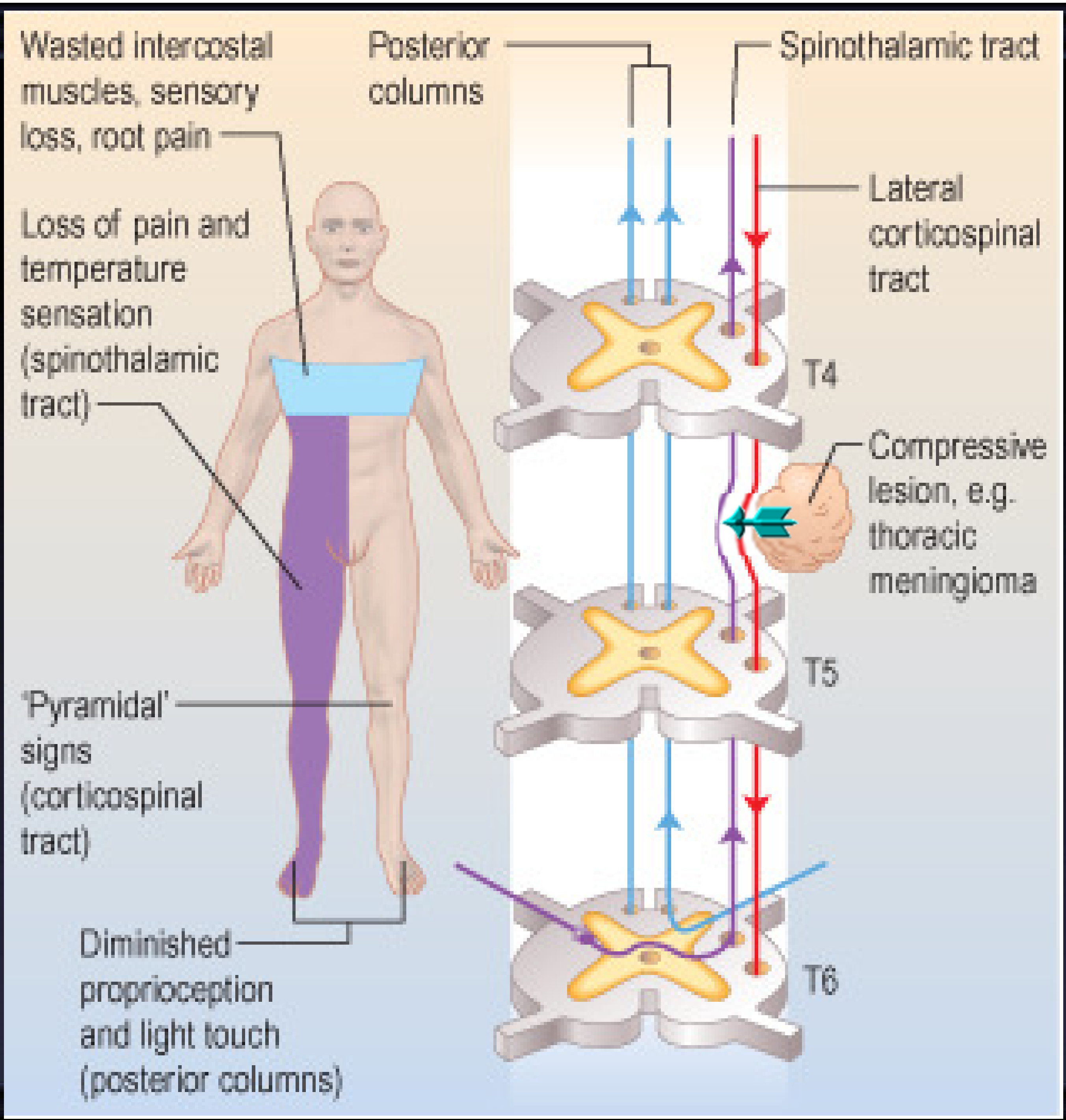
Ataxia and Gait Disturbances

- 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 contralateral ataxia with sensory loss

Dermatomes

Dermatome is area on skin supplied by a single spinal nerve




Wasted intercostal muscles, sensory loss, root pain
Posterior columns
Spinothalamic tract
Lateral corticospinal tract
Loss of pain and temperature sensation (spinothalamic tract)
T4
Compressive lesion, e.g. thoracic meningioma
T5
'Pyramidal' signs (corticospinal tract)
T6
Diminished proprioception and light touch (posterior columns)

Brown Sequard syndrome

HEMISECTION OF SPINAL CORD

Ipsilateral Loss:

- Fine touch, Vibration, Proprioception (Dorsal Column)
- Leg Ataxia (Dorsal Spinocerebellar)
- Spastic Paresis below lesion (Lat Corticospinal)
- Flaccid Paralysis (Vent horn destruction)
- Dermatomal Anesthesia (Dorsal Horn destruction)

Contralateral Loss:

- Loss of pain and temp (lat Spinothalamic)
- Loss of crude touch and Pressure (Vent Spinothalamic)
- Minor Contralat Muscle Weakness (Vent Corticospinal)
- Leg Ataxia (Vent Spinocerebellar)

SENSORY ATAXIA

- Peripheral sensory lesions (e.g. polyneuropathy) cause ataxia because there is loss of the sense of joint position - proprioception. Broad-based, high-stepping, stamping gait develops.

- This ataxia is made worse by removal of additional sensory input (e.g. vision) and is worse in the dark. First described in sensory ataxia of tabes dorsalis, this is the basis of…………..Romberg's test. Ask the patient to close the eyes while standing: observe whether the patient becomes unstable (and prevent falling).