Spinal cord

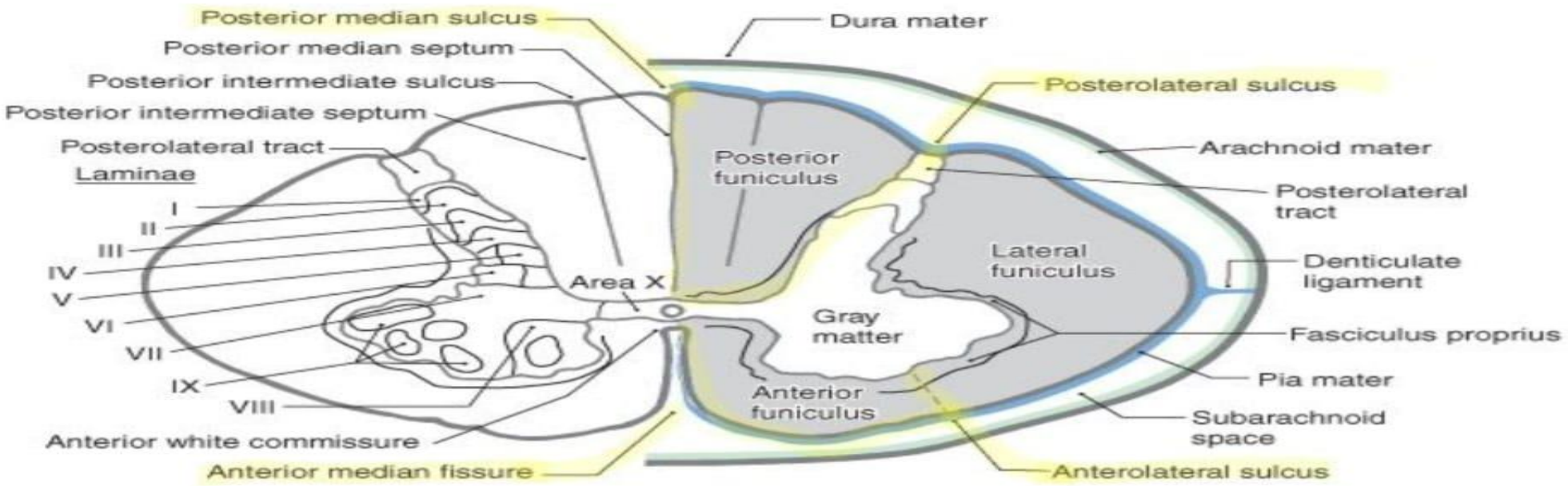
- Is a simple relay station between the brain and effector organs (muscles, skin, etc.).
- The spinal cord receives information both from higher centers and from the periphery.
- It has a huge receptor area, and both receive and modulate information from the whole body (except the head), before the information is transmitted to other systems or translated into muscle activity.

- Also, it contains both quite basic reflex arcs and more complex neuronal circuits controlling central pattern generated motor behaviors.
- In several species, **research** has shown that the rhythmic muscle activation of some movements is programmed at the spinal level where it can be modulated according to the environment.
- Spinal network producing locomotion (Central pattern generator)(CPG).

- It contains white and gray matter.
- The white matter surrounds the gray matter throughout the spinal cord and serves as a relay for descending and ascending information.
- **The white matter** is divided into: dorsal, lateral, and ventral columns (bundles of axons also referred to as tracts).
- The dorsal and lateral columns transmit sensory signals.
- The ventral columns are associated mainly with descending motor signals.
- **Gray matter**: Characterized by its butterfly or H-shape, consists of unmyelinated fibers.
- The lateral aspects of the gray matter are divided into: Dorsal, lateral, and ventral horns.
- The dorsal horn: processes sensory information.
- The ventral horn: processes motor information .
- The lateral horns : are present at only the thoracic level and contain the cell bodies of the preganglionic sympathetic neurons, and thereby process autonomic information.

It contains white and gray matter.

-The white matter surrounds the gray matter throughout the spinal cordand serves as a relay for descending and ascending information.

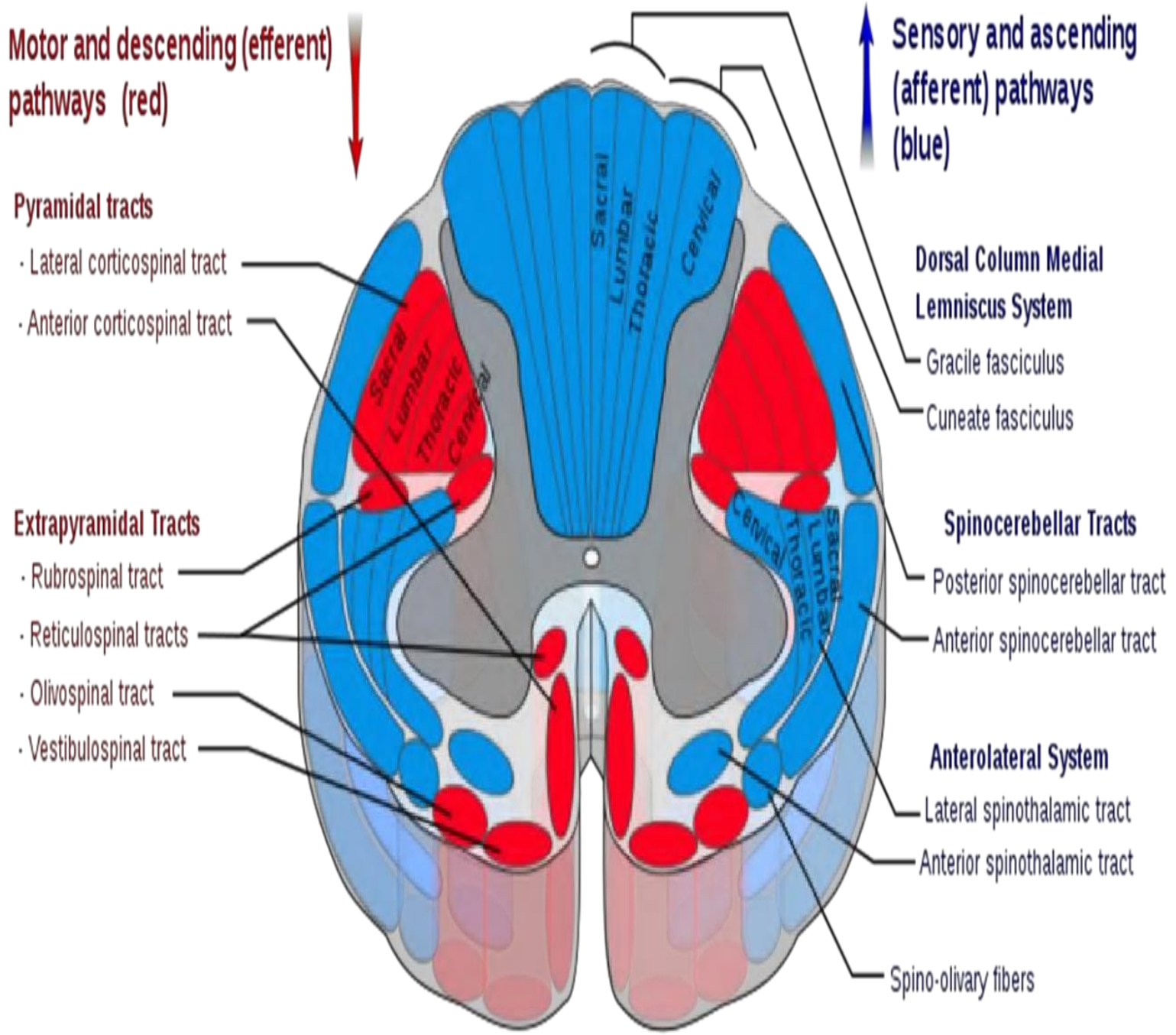


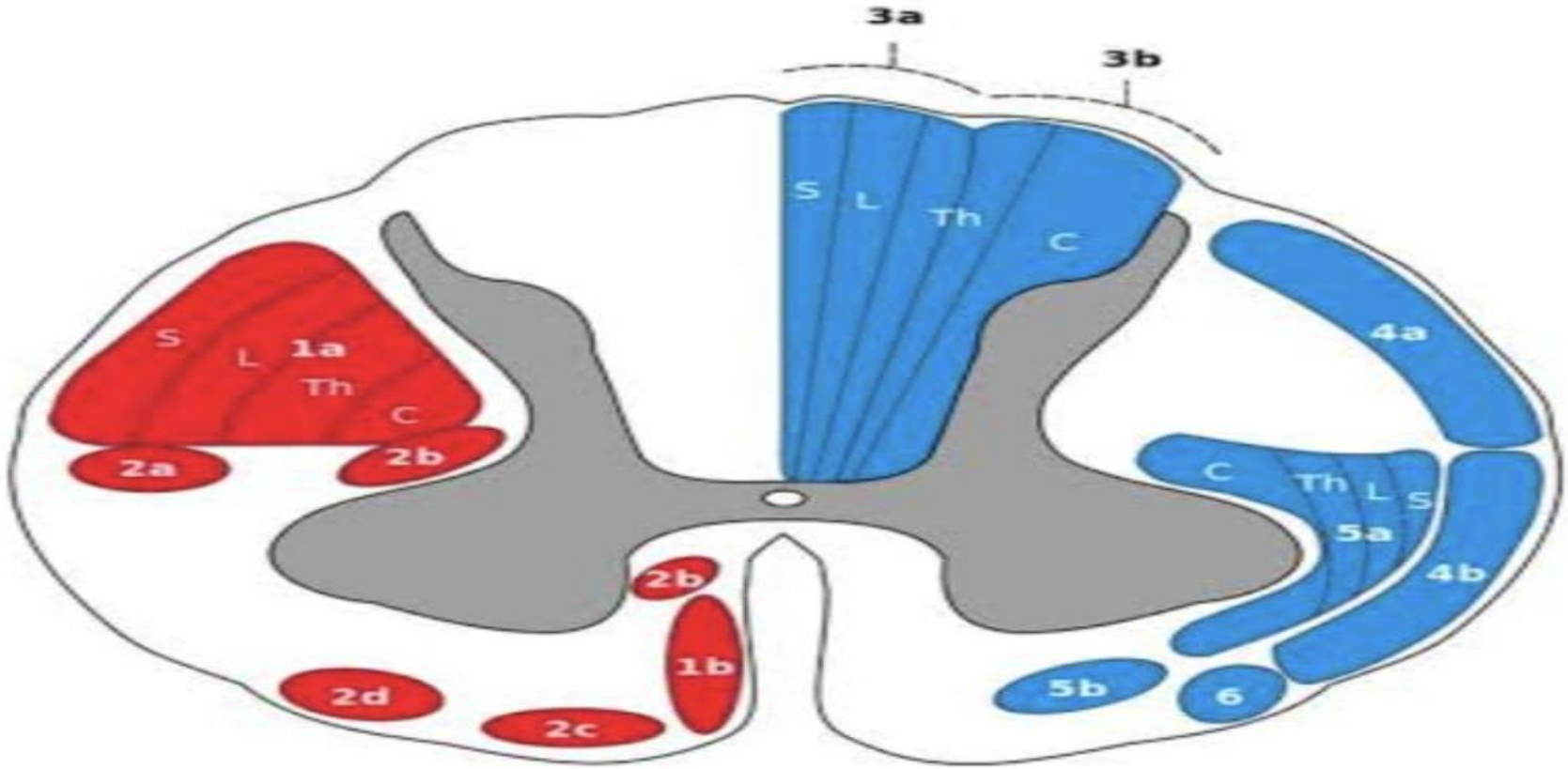
white matter

- It divides into: dorsal, lateral, and ventral columns (bundles of axons also referred to as tracts).
- The dorsal and lateral columns transmit sensory signals.

N.B also lateral columns receives motor tract (lateral corticospinal).

- The ventral columns are associated mainly with descending motor signals .





Motor and decending (efferent) pathways (left, red)

1. Pyramidal Tracts

1a. Lateral corticospinal tract

1b. Anterior corticospinal tract

2. Extrapyramidal Tracts

2a. Rubrospinal tract

2b. Reticulospinal tract

2c. Vestibulospinal tract

2d. Olivospinal tract

Somatotopy Abbreviations:

S: Sacral, **L: Lumbar**

Th: Thoracic, **C: Cervical**

Sensory and ascending (afferent) pathways (right, blue)

3. Dorsal Column Medial Lemniscus System

3a. Gracile fasciculus

3b. Cuneate fasciculus

4. Spinocerebellar Tracts

4a. Posterior spinocerebellar tract

4b. Anterior spinocerebellar tract

5. Anterolateral System

5a. Lateral spinothalamic tract

5b. Anterior spinothalamic tract

6. Spino-olivary fibers

Ascending Systems

- Somatosensory information is received and carried through the peripheral nervous system from the different receptors in the body to the spinal cord.
- Tracts are communication pathways within the CNS.
- The ascending tracts are sensory pathways and deliver information to the brain.
- Somatosensory tracts are named based on the origin and termination of the tracts. e.g Spinocerebellar.
- The transmission of conscious somatosensory information is through two major pathways(The dorsal column medial lemniscus pathway & The anterolateral system).

The dorsal column

- Carry fine touch, proprioception, stereognosis and vibration.
- pathway

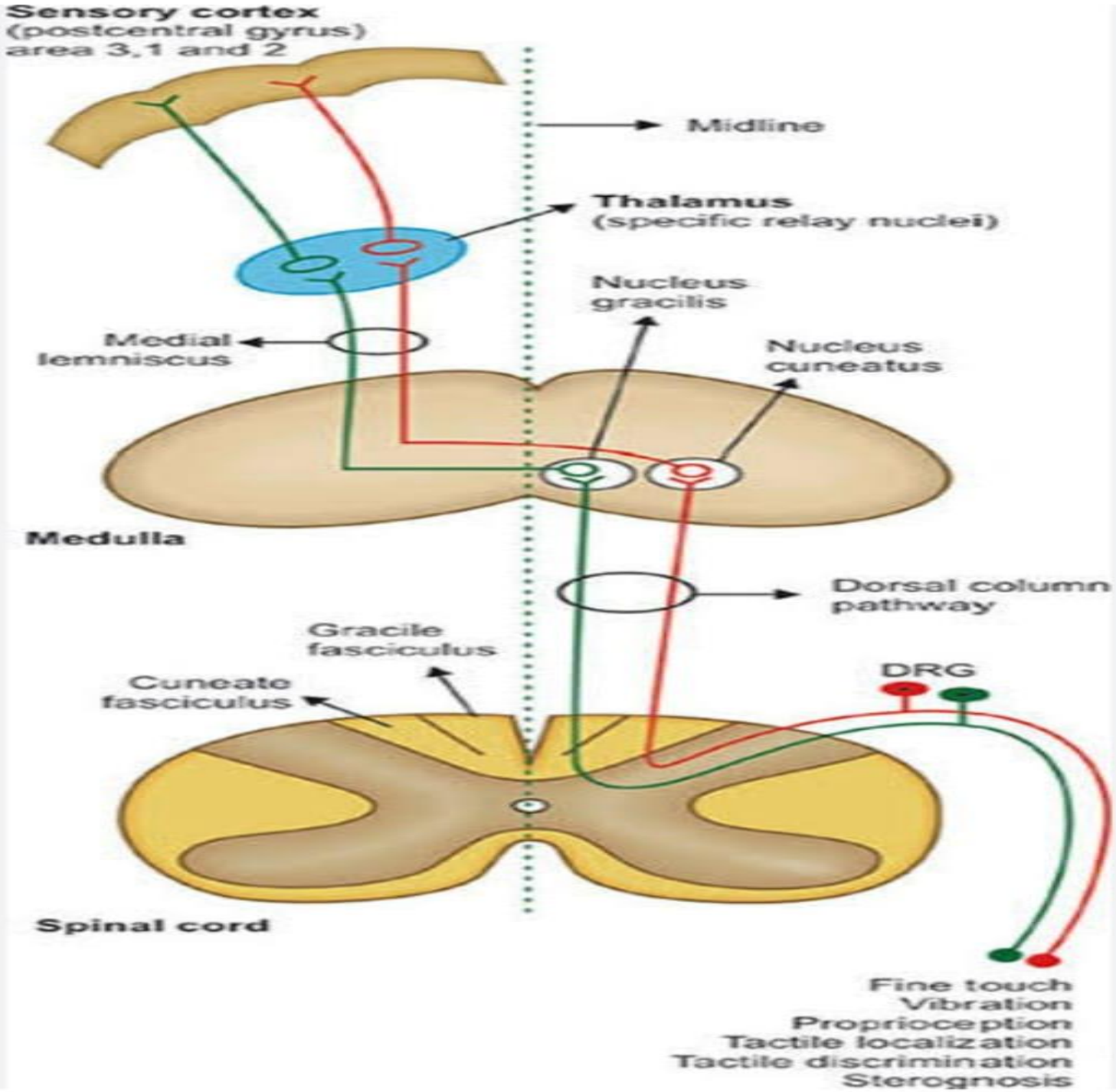
1st order neuron: afferent enter SC via medial portion of dorsal root>>>enter ipsilaterateral dorsal column ascend as gracile & cuneate tracts >>> gracile & cuneate nuclei in medulla.

2nd order neuron: fiber cross to opposite side >>> pass upward as medial lemniscus ventrobasal nuclei of thalamus (VBNT).

3rd order neuron: fibers arise from VBNT >>> ascend in posterior limb of internal capsule >>> somatic sensory cortex.

N.B

- The medial portion (gracilis fasciculus): These fibers receive information from the lower part of the body, from areas inferior to T6.
- The lateral portion(cuneate fasciculus):These fibers receive information from areas superior to T6 (i.e., upper limbs, trunk, and neck).


Sensory cortex
(postcentral gyrus)
area 3,1 and 2
Midline
Thalamus
(specific relay nuclei)
Nucleus
gracilis
Medial
lemniscus
Nucleus
cuneatus
Medulla
Dorsal column
pathway
Gracile
fasciculus
Cuneate
fasciculus
DRG
Spinal cord
Fine touch
Vibration
Proprioception
Tactile localization
Tactile discrimination
Sterognosis

Anterolateral System

- It includes three pathways:

a) the spinothalamic tract.

b) the spinoreticular tract.

c) The spinomesencephalic tract(which terminates in the periaqeductal gray of the midbrain, center for controlling & inhibit pain)

Spinothalamic (anterolateral/ventrolateral)

- Carry different sensation

a) lateral spinothalamic tract carry pain &temperature.

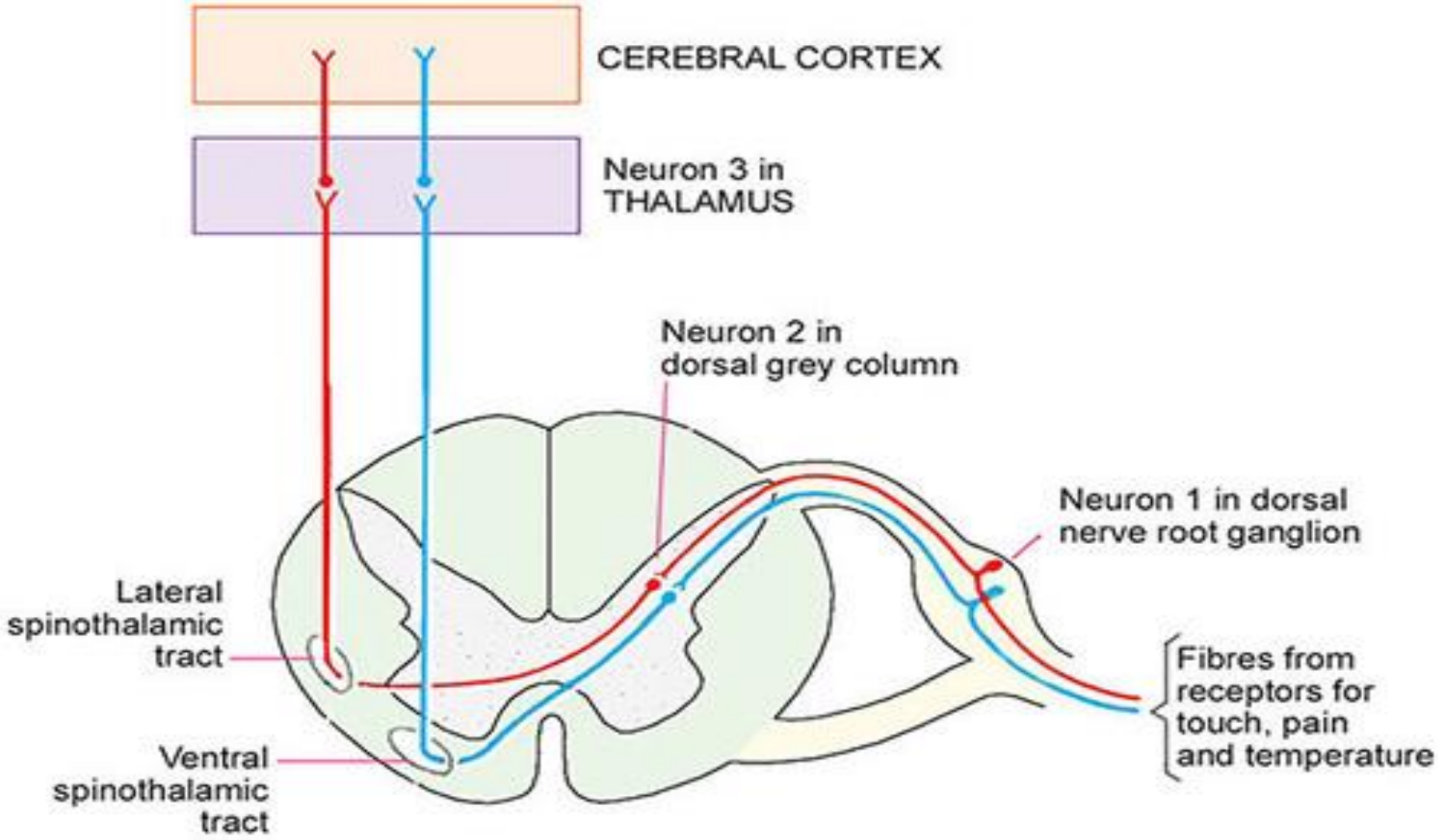
b) ventral spinothalamic tract carry crude touch &tickle and itch.

Pathway

1st order neuron: afferent enter SC via lateral division of dorsal roots >>>fibers asend or desend few segments before synapsing in posterior horn cells.

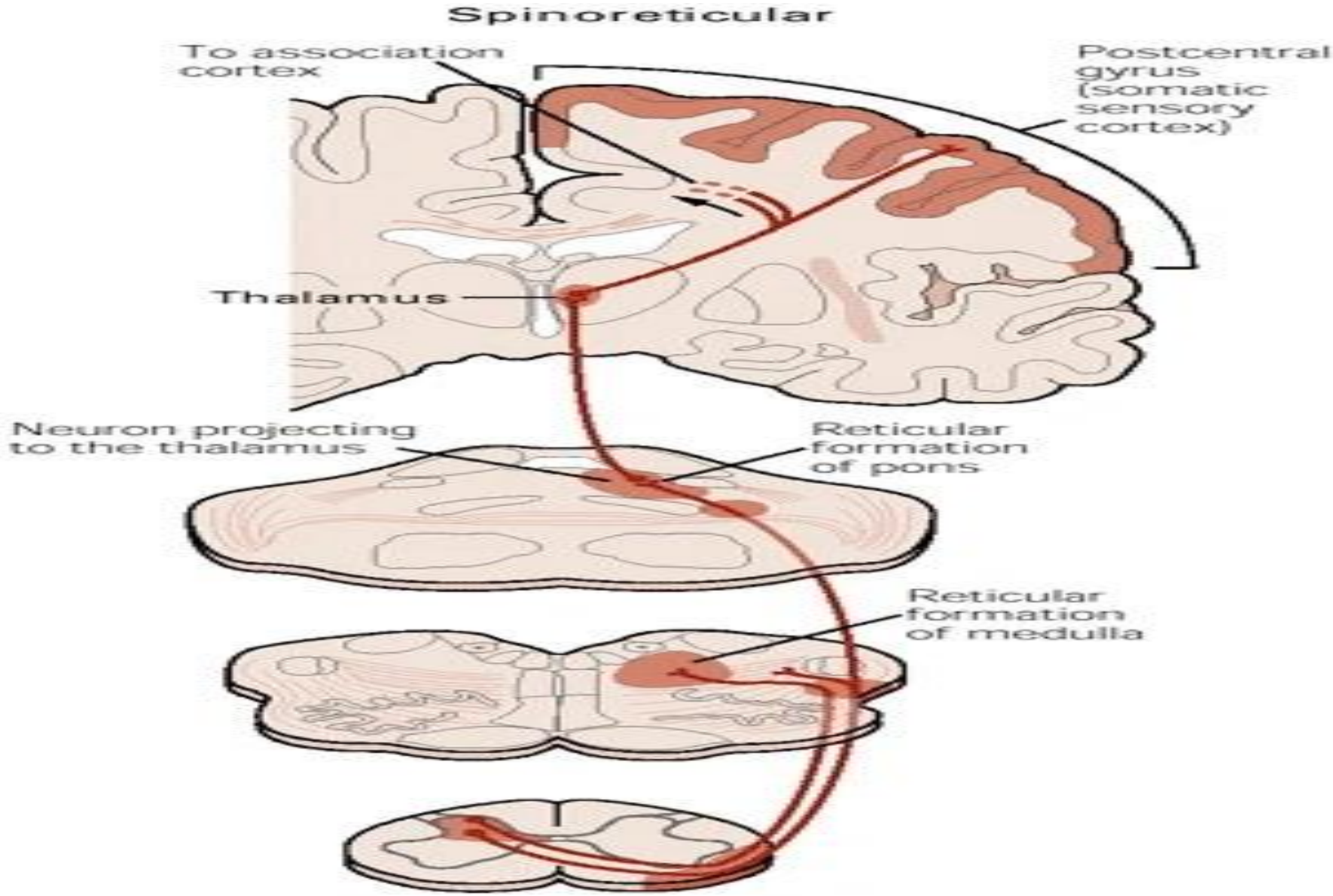
2nd order neuron: fibers of pain & temperature cross immediately infront of central canal >>> ascend as lateral spinothalamic tract in opposite side. Fibers for tactile sensation cross farther from central canal & ascend as ventral spinothalamic tract in opposite side >>>fibers ends in VBNT.

3rd order neuron: fibers arise from VBNT >>> ascend in posterior limb of internal capsule >>> somatic sensory cortex.


CEREBRAL CORTEX
Neuron 3 in THALAMUS
Neuron 2 in dorsal grey column
Neuron 1 in dorsal nerve root ganglion
Lateral spinothalamic tract
Ventral spinothalamic tract
Fibres from receptors for touch, pain and temperature

Spinoreticular tract

- It is an ascending pathway in the white matter of the spinal cord, positioned closely to the lateral spinothalamic tract.
- The tract is from spinal cord >>>to reticular formation >>> to thalamus.
- Reticular formation part from reticular activating system (arousal and consciousness function).
- It is responsible for automatic responses to pain, such as in the case of injury
- Perception of dull, aching, or burning pain, and is also involved in the emotional aspects of pain.


Spinoreticular
To association cortex
Postcentral gyrus (somatic sensory cortex)
Thalamus
Neuron projecting to the thalamus
Reticular formation of pons
Reticular formation of medulla

Spinocerebellar Tracts (Ventral and Dorsal)

- Sensory information do not reach consciousness.
- Spinal cord >>> Spinocerebellum.
- **The dorsal spinocerebellar tract** (not crossed): Conveys somatosensory information from muscle and joint receptors, both when a limb actively moves and when it is passively moved.
- **The ventral spinocerebellar trat** (crossed) :solely transmits information when the limb actively moves.
- These inputs inform the cerebellum about different aspects of movement activity at the same moment in time, and permit comparison of signals.

Grey matter

- It divided to laminae (Rexed laminae) from I to IX and area X around central canal.
- Laminae I to V, forming the dorsal horns, receive sensory input >>> Laminae II substantia gelatinosa.
- Laminae III& IV >>> nucleus proprius.
- Laminae VII at thoracic level >>> dorsal nucleus of Clarke.
- Lamina VII forms the intermediate zone at the base of all horns. Lamina IX is composed of clusters of large alpha motor neurons and small gamma motor neurons.
- Lamina VI is present only in the cervical and lumbosacral enlargements.
- lateral corticospinal tract of the cord >>> terminates in interneurons laminae IV-VII

Anterior Horn Cell (AHC)

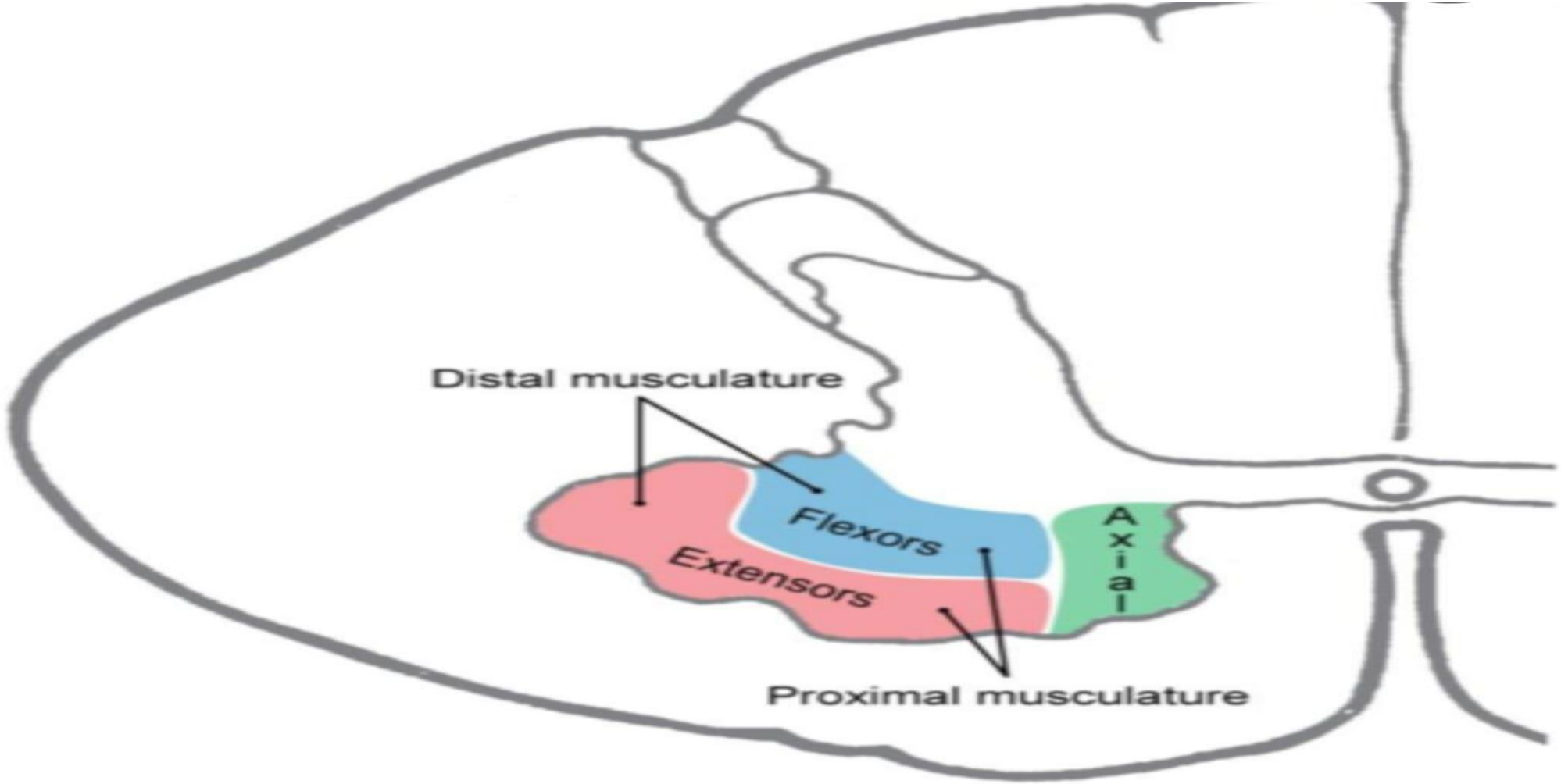


Fig. 9-8. Representation of the general organization of motor neurons in the anterior horn.

- Cells innervating proximal muscle are located medially.
- cells innervating more distal muscle located more laterally.
- This explain why the AHC is smaller and narrower at thoracic than at cervical and lumber level. At thoracic level the anterior horn contain motor neuron innervating the axial muscles of the trunk , whereas at cervical and lumber level it also contain the more lateral groups of motor neurons that innervate the limbs.
- Within the anterior horn at C4 to TI and LI to S2 motor neuron innervating extensors tends to be more anteriorly located in the horn, whereas those innervating flexors tend to be more posterior located.

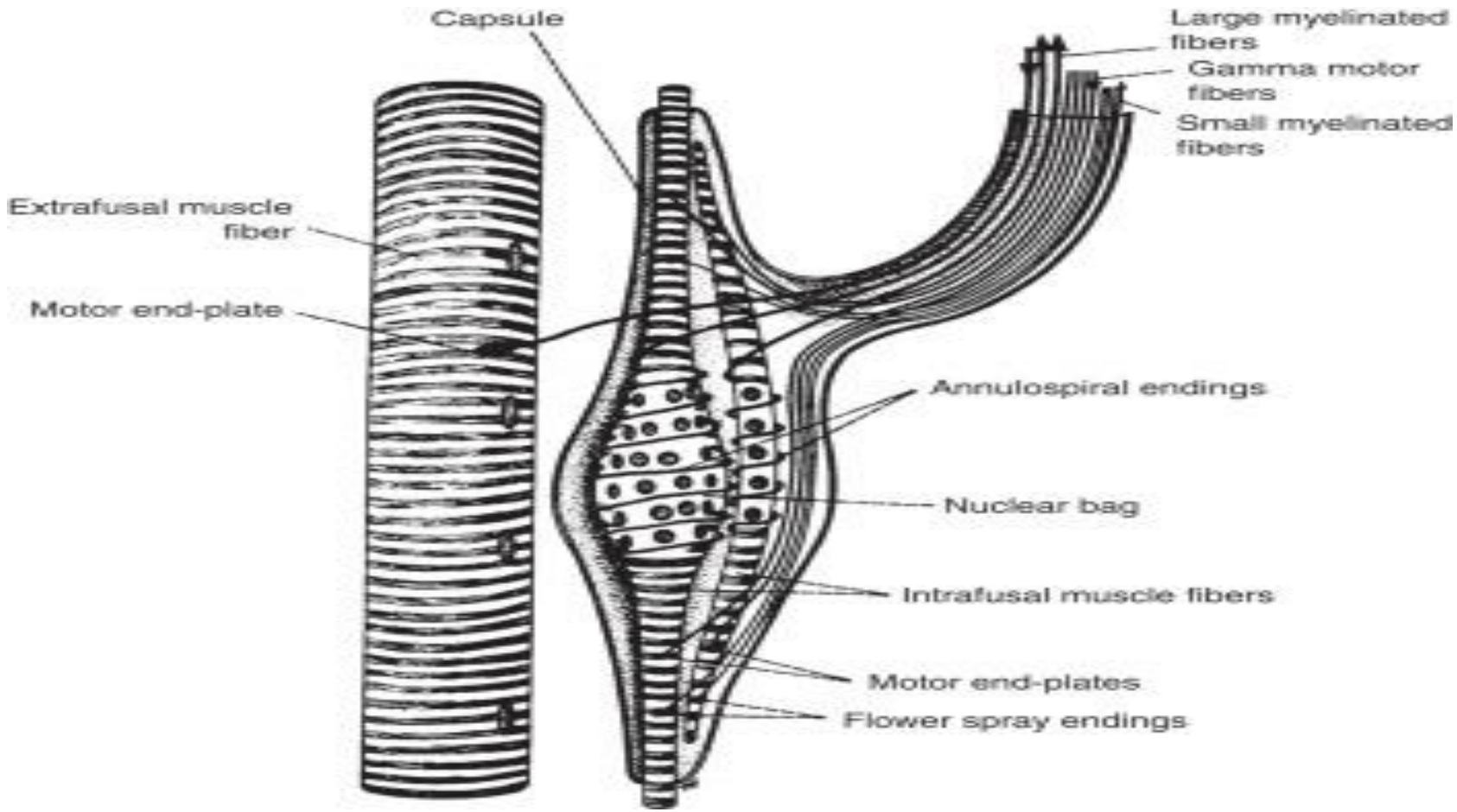
Muscle Spindle

- Sensory organs are found in between and in parallel with the muscle fibers in skeletal muscles.
- The muscle spindles are stretched when the muscle is stretched.
- Their main function is to inform the CNS of the length of the muscle, length changes, and the speed of change.
- The muscle fibers of a muscle spindle are called intrafusal fibers, whereas the muscle fibers of the muscle itself are called extrafusal fibers.

- Within a muscle spindle there are two types of specialized intrafusal muscle fibers: Nuclear bag and nuclear chain.
- The **nuclear bag fibers**: dilated central area with an aggregation of nuclei >>> very sensitive dynamic receptors >>> rate detector >>> change of rate of muscle length.
- The **nuclear chain fibers**: nuclei are spread in a chain along receptor area >>> static receptors >>> degree of change of muscle length.

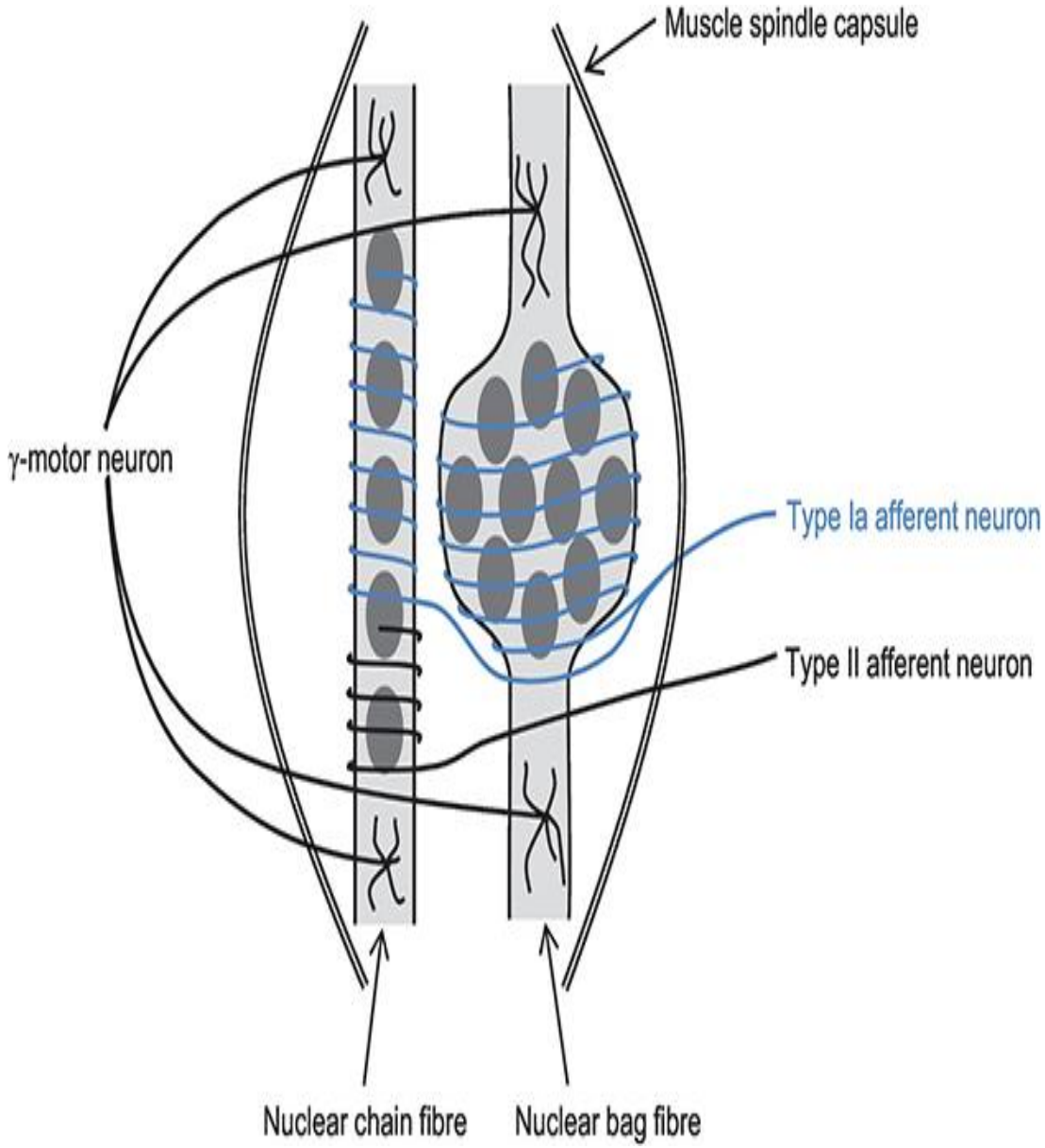
• These intrafusal muscle fibers have contractile elements only at each end, leaving a mid portion unable to actively contract.
Each mid portion is surrounded by sensory nerve endings that sense deformations induced by the stretch of the fibers.

• Afferent information from muscle spindle stretch is conveyed to the CNS by primary (Ia) afferent fibers (thick myelin sheath and high conduction velocity) and secondary (group II) afferent fibers.


Capsule
Large myelinated fibers
Gamma motor fibers
Small myelinated fibers
Extrafusal muscle fiber
Motor end-plate
Annulospiral endings
Nuclear bag
Intrafusal muscle fibers
Motor end-plates
Flower spray endings

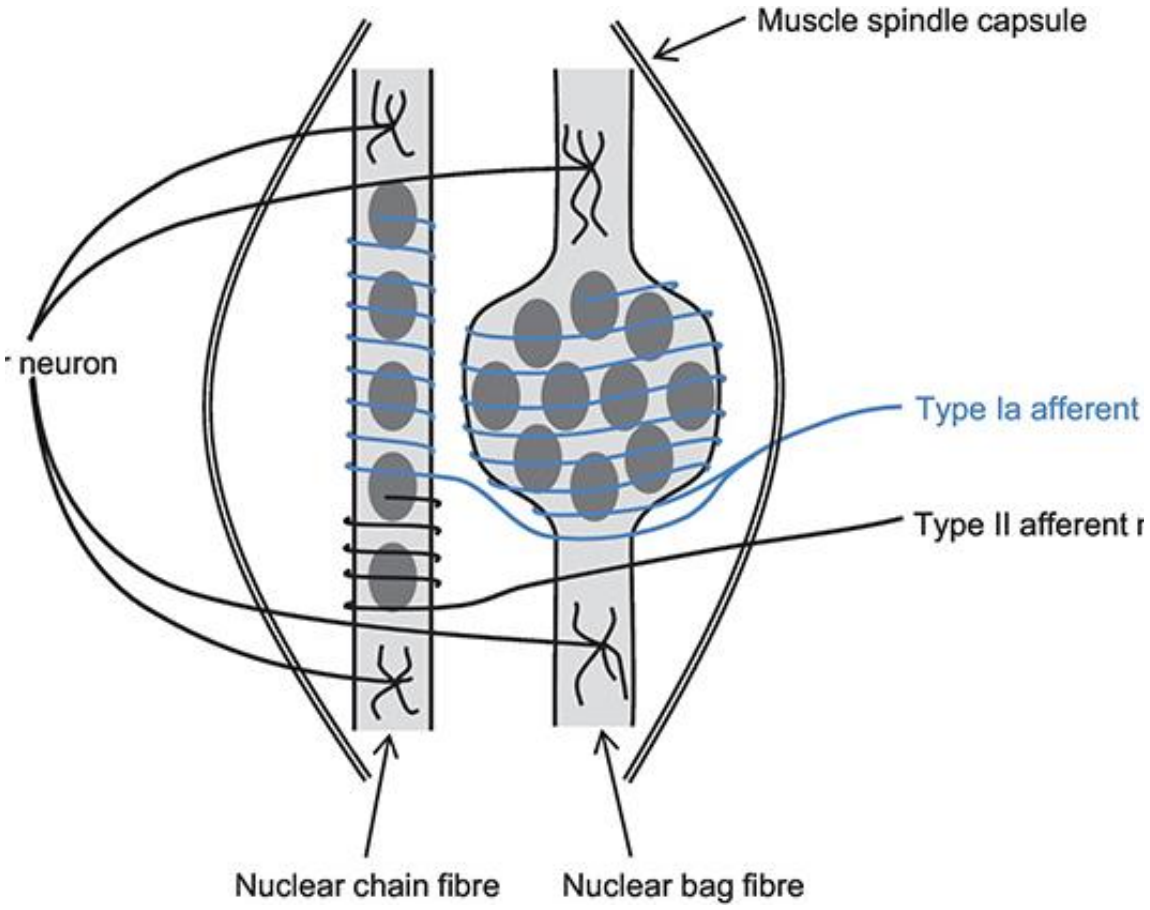
Primary (annulospiral) endings

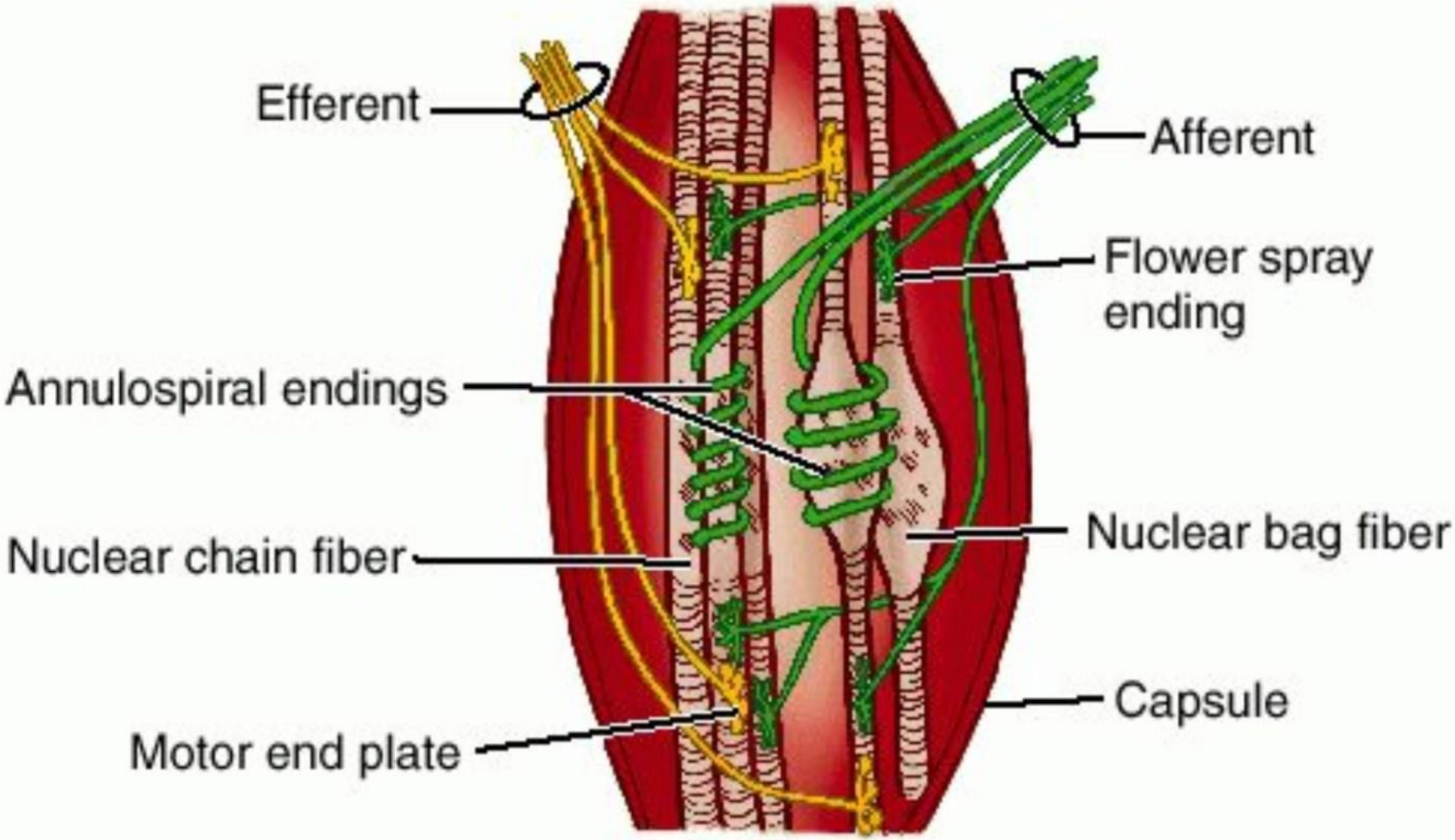
- Group Ia afferents/ thick /rapidly conducting.
- Encircle the receptor area of both nuclear bag &chain fibers.
- It provide information about both muscle length and velocity.



Secondary (flower spray) endings

- Group II afferents/ smaller myelinated fibers/slowly adapt.
- Encircle receptor area of nuclear chain fibers.
- It provide information about muscle length only




Efferent
Afferent
Flower spray ending
Annulospiral endings
Nuclear bag fiber
Nuclear chain fiber
Capsule
Motor end plate

efferent (motor) fibers

- Gamma motor neurons axons in anterior horn of spinal cord. It supply peripheral contractile parts of intrafusal muscle fibers.

a) Dynamic gamma efferents end mainly on nuclear bag fibers.

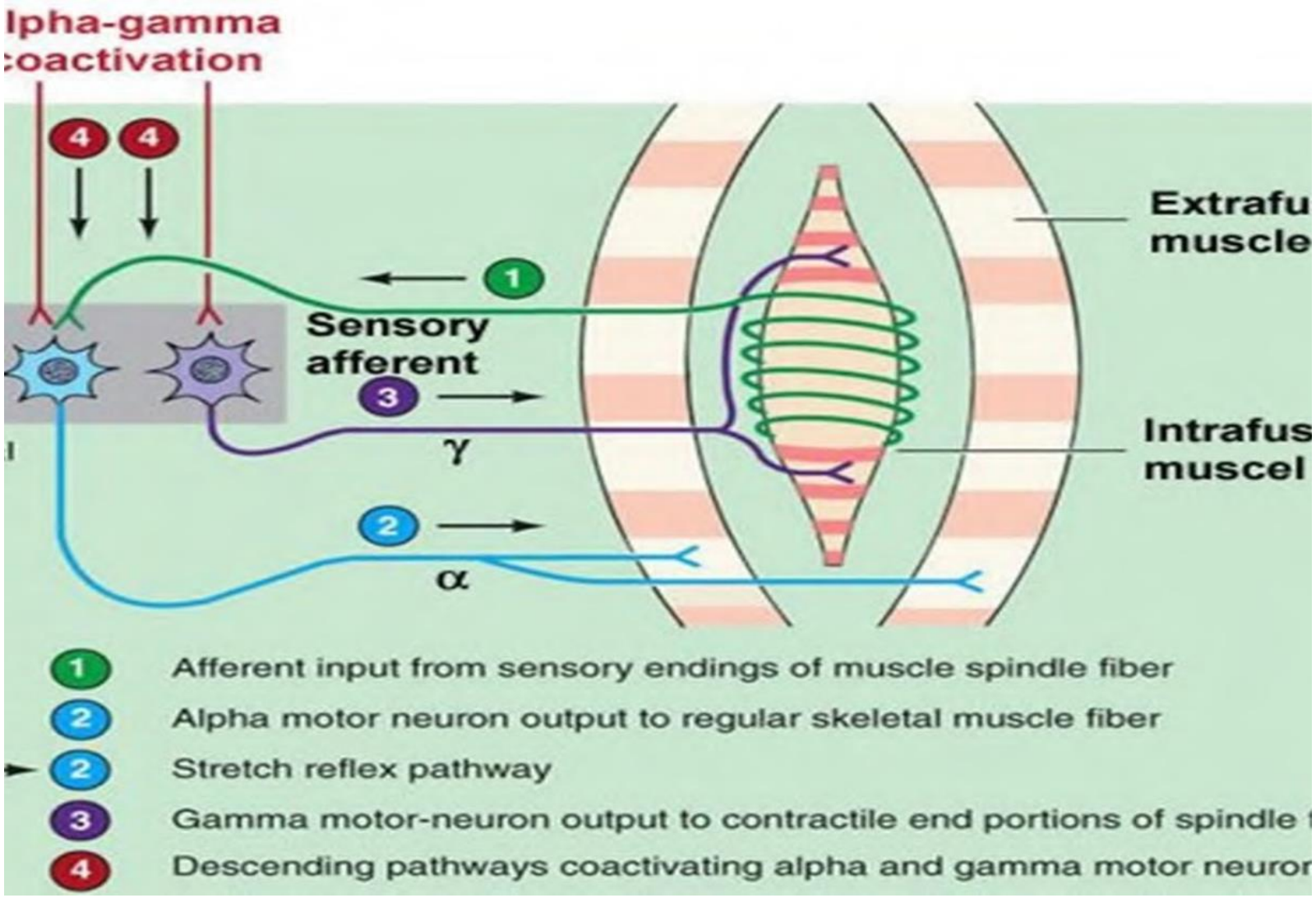
b) Static gamma efferents end mainly on nuclear chain fibers.

- Gamma activation of the intrafusal fiber is necessary to keep the muscle spindle taut, and therefore sensitive to stretch over a wide range of muscle lengths.
- Contraction of the ends of the intrafusal muscle fibers stretches the midportion, thereby changing the stiffness of the spindle and adjusting its sensitivity.

- There are more neurons in the motor cortex involved in the control of Gamma-motor neurons than those involved in the control of Alpha-motor neurons.
- Information from the muscle spindles is used for our conscious and unconscious awareness of joint position sense.
- Thus the muscle spindle is involved in assessing the initial state of the body, monitoring movement progression, and evaluating the outcome of executed motor actions.
- The number of muscle spindles in different muscles varies, with greater numbers present where the need for precise grading of activity is necessary (e.g., in the small muscles of the hand or the deep postural muscles of the back).
- The CNS, therefore, knows at all times about the movement that is about to happen, is happening, or has happened, and compares these(feed forward & feed back).

Alpha-Gamma coactivation

- When the CNS instructs a muscle to contract, it not only sends the appropriate signals to the alpha motor neurons, it also instructs gamma motor neurons to contract the intrafusal fibers appropriately.



Stretch reflex (SRACEER)

S:Stimulus: Stretch

R:Receptor: Muscle spindle.

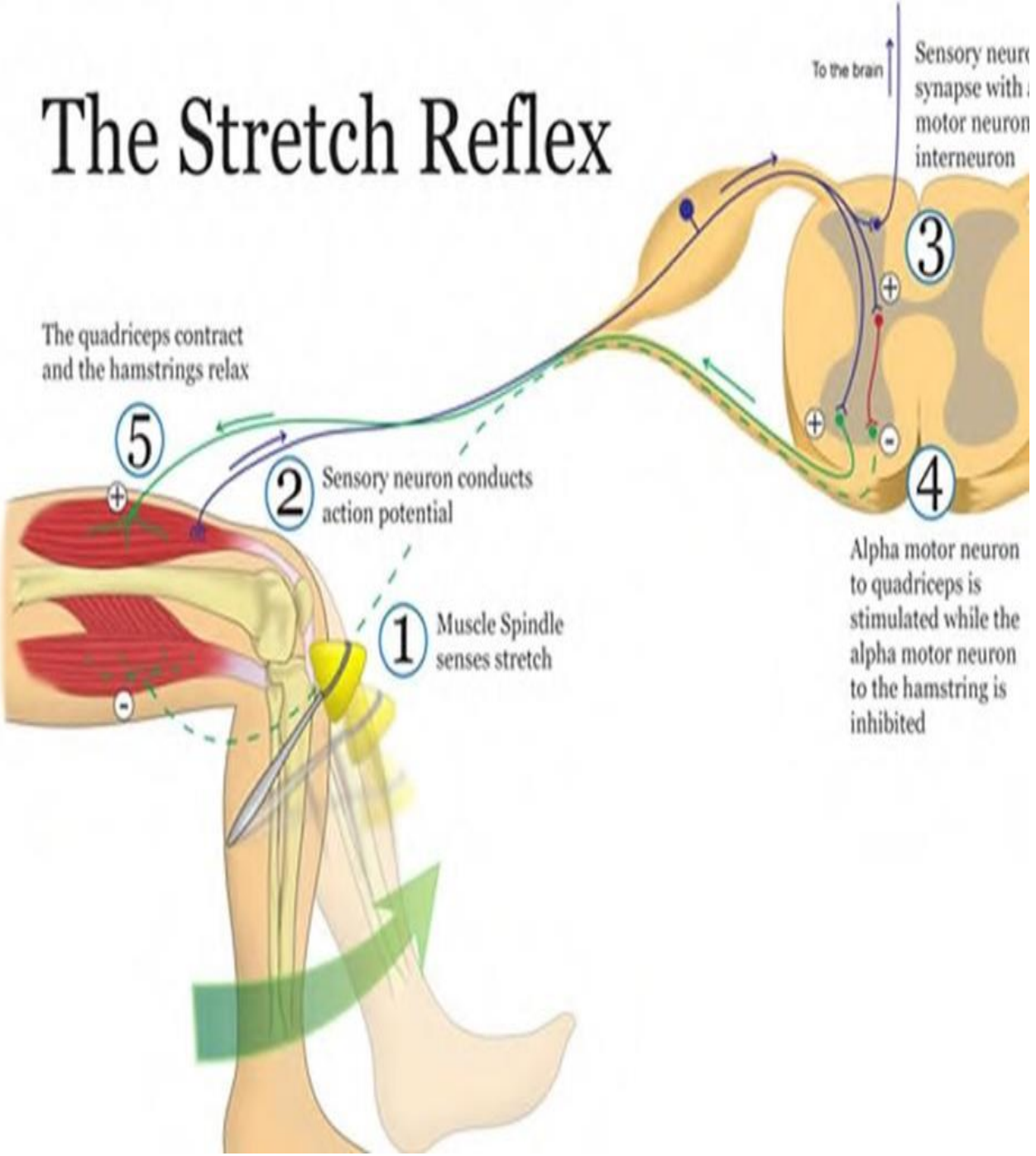
A :Afferent: Ia & II

C :Center: AHC /Spinal cord(monosynaptic)

E :Efferent: Alpha motor neuron & gamma motor neuron.

E :Effector: Extrafusal muscle fibers.

R:Response:Muscle contraction (agonist),Inhibition of antagonist.



Golgi Tendon Organs

- Are specialized mechanoreceptors arranged in series with extrafusal muscle fibers.
- Located in the area in between the muscle and tendon near the myotendinous junction.
- Providing the CNS with feedback concerning muscle tension.
- The GTO is innervated by a sensory nerve fiber called the Ib afferent(thick myelin sheath and high conduction velocity).
- When stimulated, inhibition of the corresponding muscle, by the Ib interneurons in the spinal cord, so it has a protective role in preventing damage to the muscle.
- The GTO has no efferent innervation from the CNS; therefore the CNS cannot adjust its sensitivity.

GTO reflex/inverse stretch reflex

S: Over muscle tension.

R: GTO.

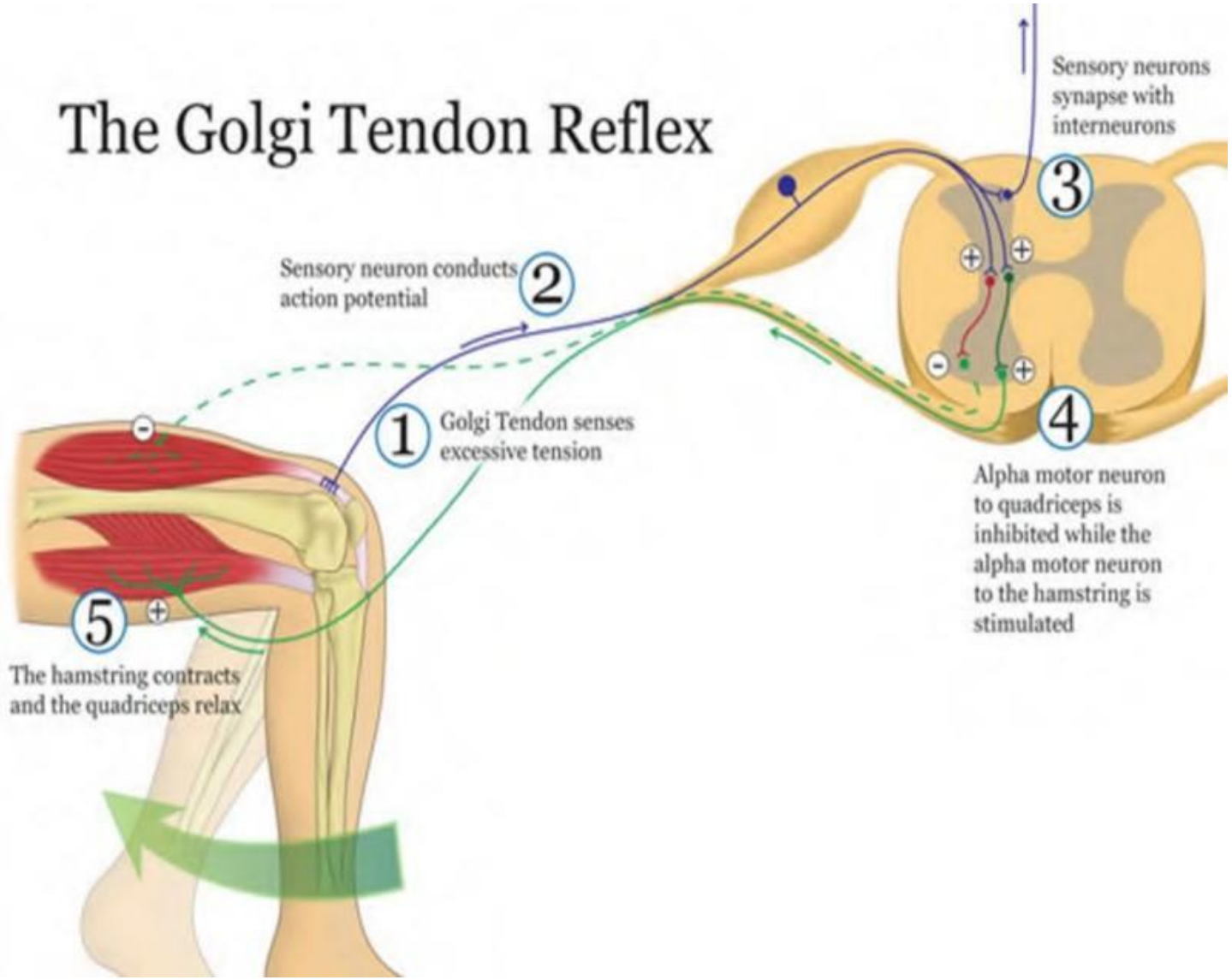
A: Ib.

C: Spinal cord (synapse on Ib inhibitory interneurons for same muscle, direct excitatory synapses onto motoneurons that innervate the antagonist muscle)

E: Alpha motor neuron.

E: Extrafusal muscle fibers.

R: Inhibition of agonist, facilitation of antagonist

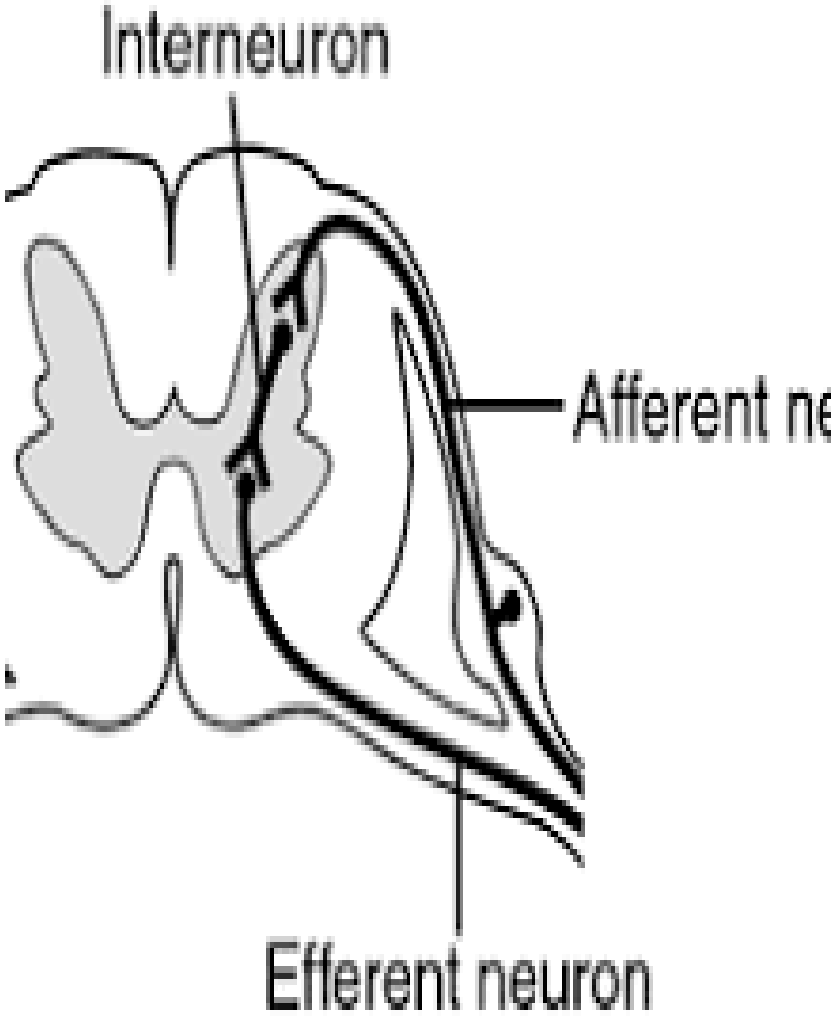


Clinical significance

- In humans, it is believed that both central commands and feedback from sensory receptors contribute to the control of locomotion.
- The contribution of load and/or length feedback, sensed by GTOs, muscle spindles, and joint and cutaneous receptors, is thought to give important feedback signals for motor control of walking.

Interneurons (association neurons)

- Only present in the central nervous system (there are more than 100 billion interneurons in the human body).
- Conduct impulses from the sensory neuron to a motor neuron (acts as a middle-man).
- These cells are numerous, small, and highly excitable (often exhibiting spontaneous activity and capable of firing as rapidly as 1500 times per second). They have many interconnections and many of them directly innervate the anterior motor neurons. The interconnections among the interneurons and anterior motor neurons are responsible **for many of the integrative functions of the spinal cord**.



propriospinal neurons (PNs)

- They are found throughout the white matter of the spinal cord.
- PNs function: integration and modulation of inputs from descending supraspinal pathways and peripheral afferents.
- Recently as an important substrate for functional recovery after incomplete spinal cord injury (SCI); PNs have the possibility of forming new spinal circuits.

- **Renshaw neurons** are specialized inhibitory interneurons producing recurrent inhibition of their own motor neurons(auto inhibition).
- **Ia inhibitory interneuron** receives excitatory input from the Ia afferents of the muscle spindles and provides inhibitory connections to the antagonist motor neurons(reciprocal inhibition).
- **Ib interneurons** receive synaptic input from Golgi tendon organ afferents and produce inhibition of synergistic motor neurons(other branch from Ib synapses with excitatory interneurons to activate antagonists).(reciprocal activation/ autogenic inhibition).
- Interneurons inhibited by GABA (gamma aminobutyric acid) & glycine and facilitated by A.CH

Central Pattern Generators and Locomotion

- The existence of networks of nerve cells producing specific, rhythmic movements , without conscious effort and without the aid of peripheral, afferent feedback, is indisputable in a large number of vertebrates.
- CPGs, neural networks in the spinal cord, can produce rhythmical movements.
- It provides automatic, changing activity coordinating the two halves of the body, and have been mostly studied in vertebrates.
- CPGs for vital functions, such as breathing, chewing, and swallowing have been in the brain stem whereas those for locomotive functions are contained in the spinal cord (lower thoracic , lumbar regions).

- CPGs are in the spinal cord of both cats and humans
- The early stepping reactions of babies demonstrate rhythmical spinal activity and suggest that these networks are innate and may be an expression of pattern generation
- The CPGs for each side are linked together through complex interneuronal networks.
- The CPGs are, in their original form, independent of somatosensory information.
- Studies in humans and monkeys have shown that voluntary motor tasks, such as reaching and grasping, and other rhythmical movements, including swimming and walking, can be performed following deafferentation (cutting of afferent).

Proprioception

• Proprioception refers to perception of joint and body movement as well as position of the body, or body segments, in space. More specifically, proprioception enables us to:

- ➢Check on spatial orientation of our bodies or body parts in space.
- ➢The rate and timing of our movements.
- ➢How much force our muscles are exerting.
- ➢How much and how fast a muscle is being stretched.

Sources of proprioception

- Muscle spindle.
- Mechanoreceptors of the skin.
- GTO.
- Joint receptors.
- Prior to the early 1970S, a classic differentiation was made between conscious joint proprioception (kinesthesia), and unconscious proprioception, thought muscle spindle and tendon receptors.
- A recent trend, however, is to use the terms proprioception and kinesthesia synonymously

Nerve fiber types

A fibers: large, myelinated, fast conducting.

Alpha >>> Proprioception, somatic motor(muscle it self) (afferent, efferent) (**Ia ,Ib**)

Beta >>> Touch, pressure **(II**).
Gamma >>> Motor to muscle spindles.

Delta >>> Fast pain, temperature (cold), touch(**III**).

B Fibers: Small, moderately myelinated, conductless rapidly; preganglionic autonomic.

C fibers: Smallest, unmyelinated, slowest conducting (slow pain, warmth , postganglionic autonomic)(**IV**)