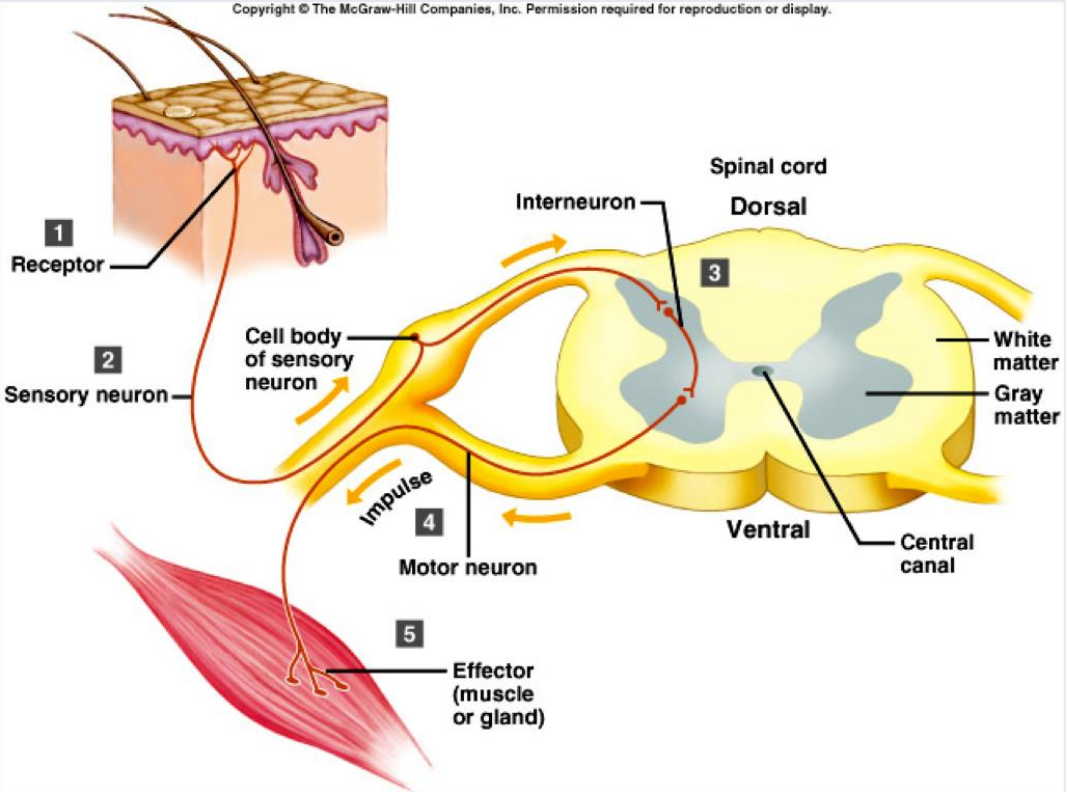
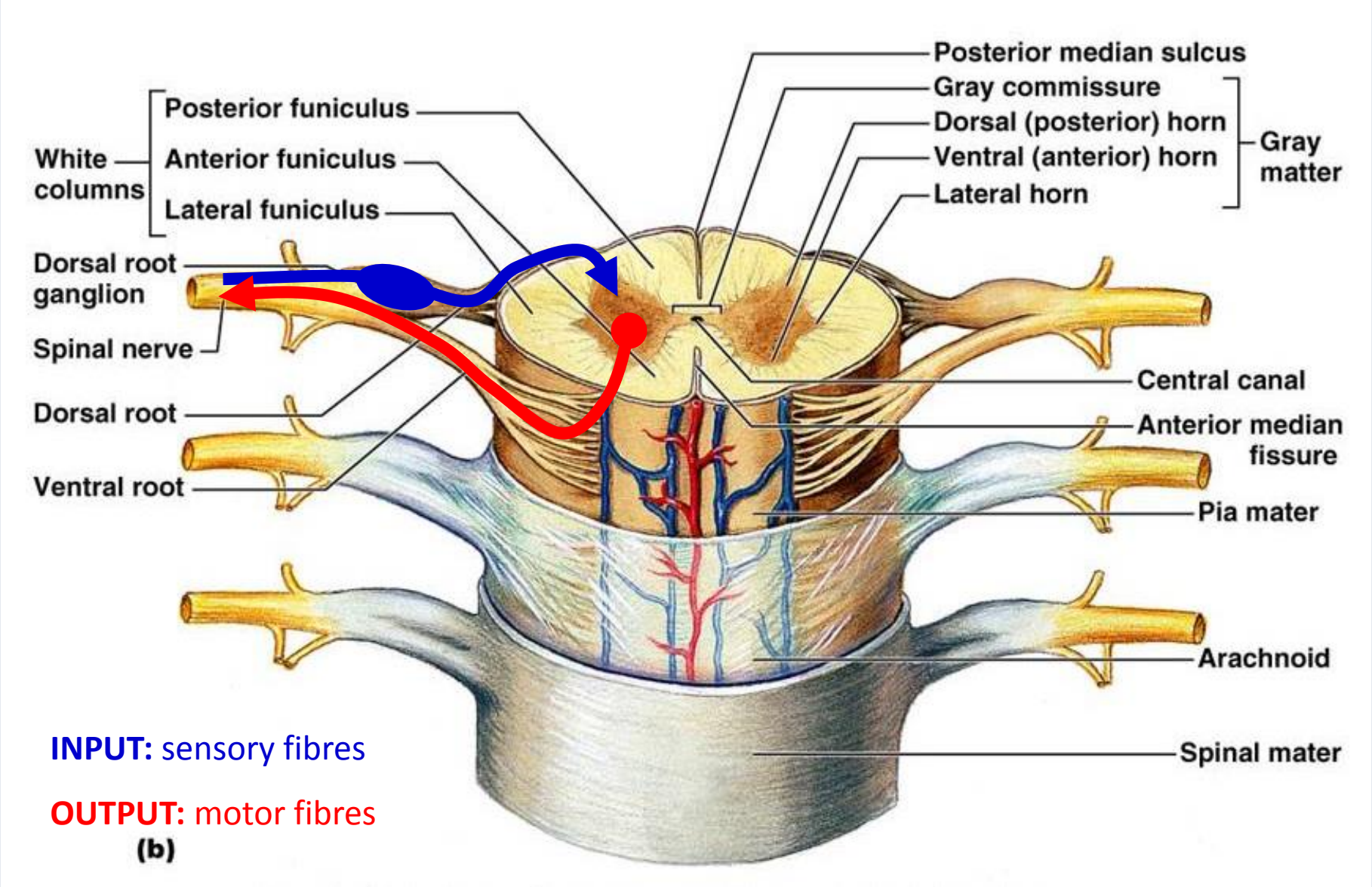
Neuronal architecture of the spinal cord
Proprioceptive and nociceptive reflex arcs

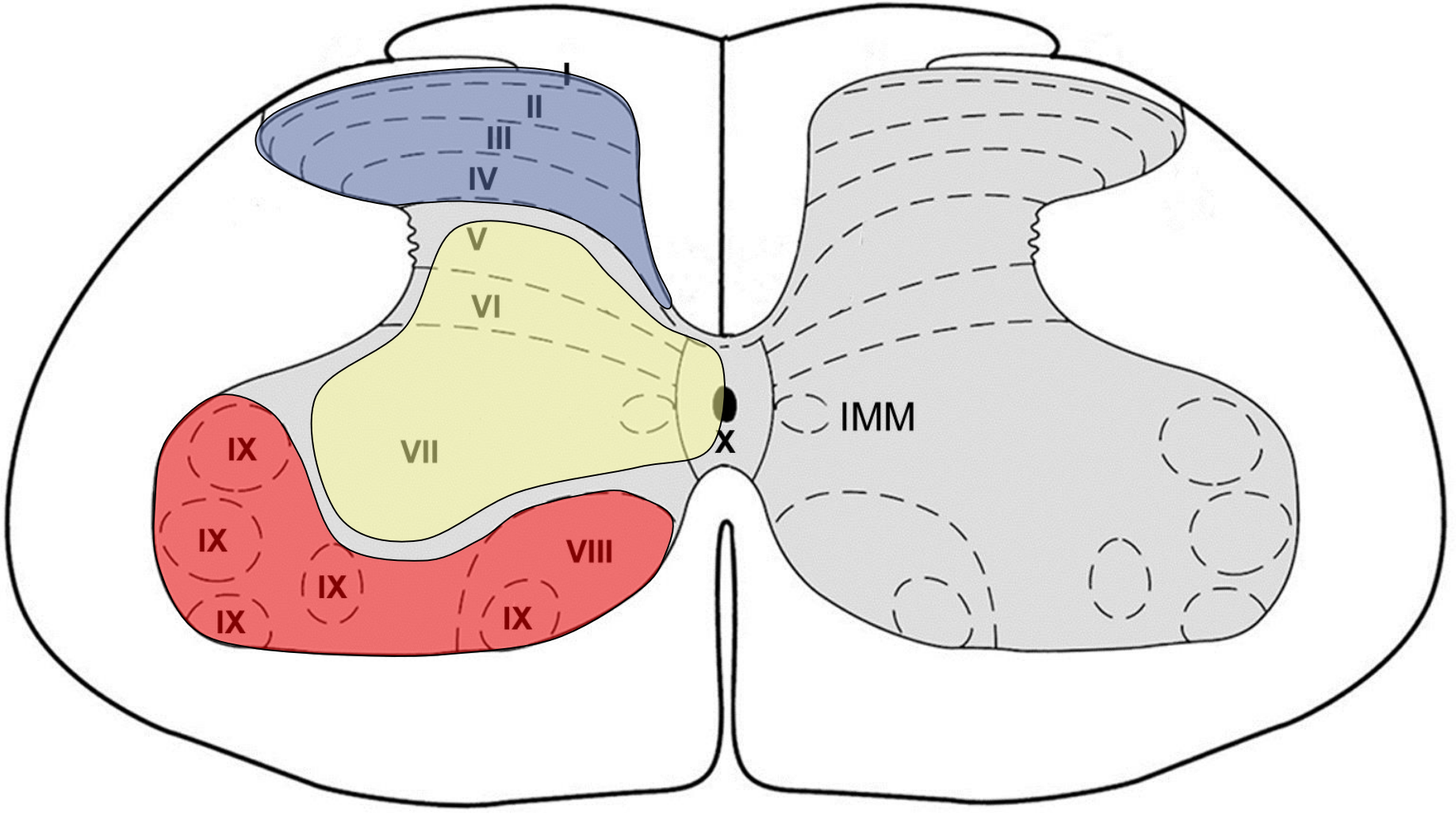


Ph.D., Dr. Dávid Lendvai
Anatomy, Histology & Embryology Institute
2018.
by: Dr. Márk Kozsurek



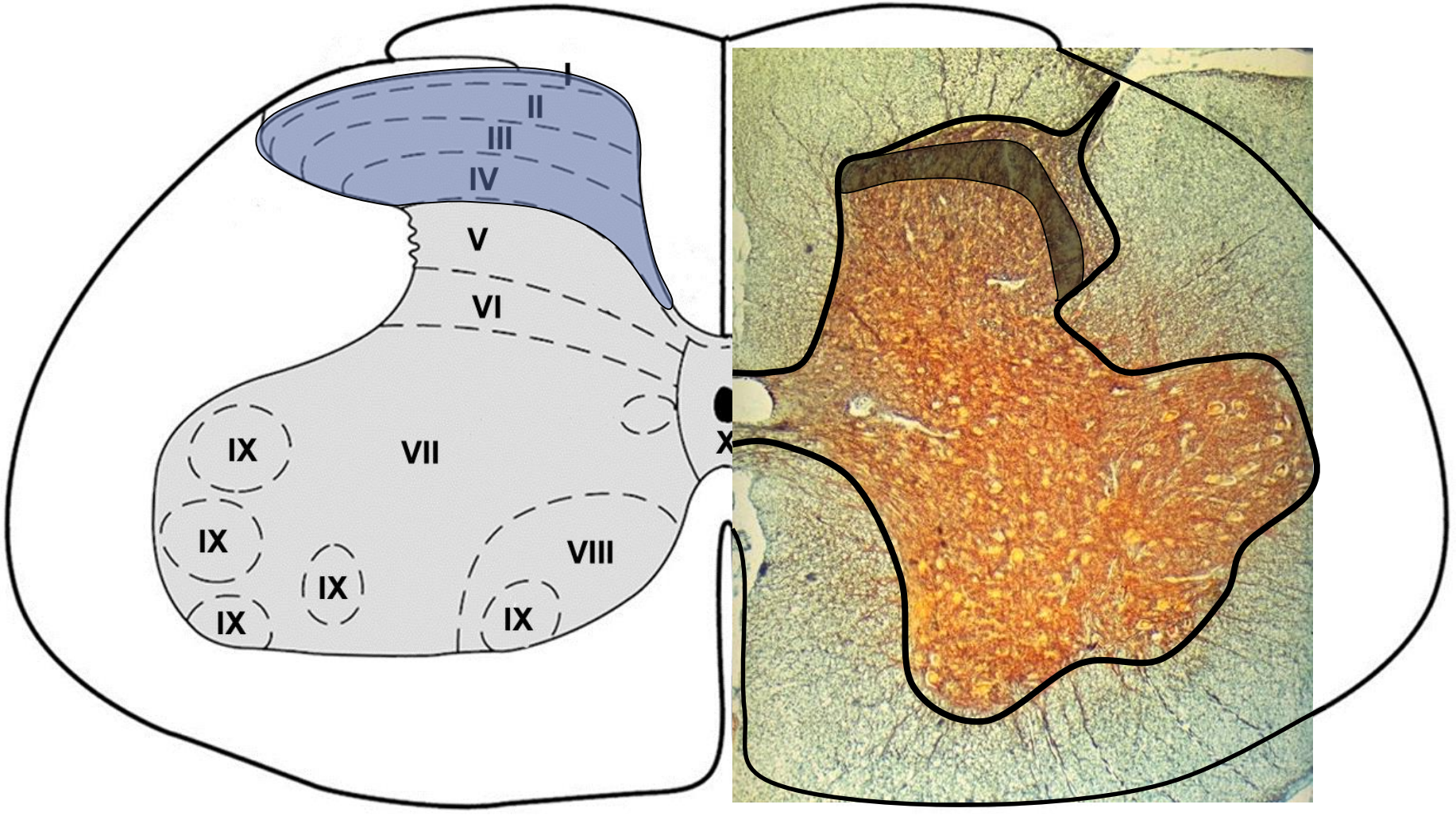
Terms: white and gray matter, spinal nerve, dorsal and ventral roots, spinal ganglion

I. Fine neuronal structure of the spinal cord

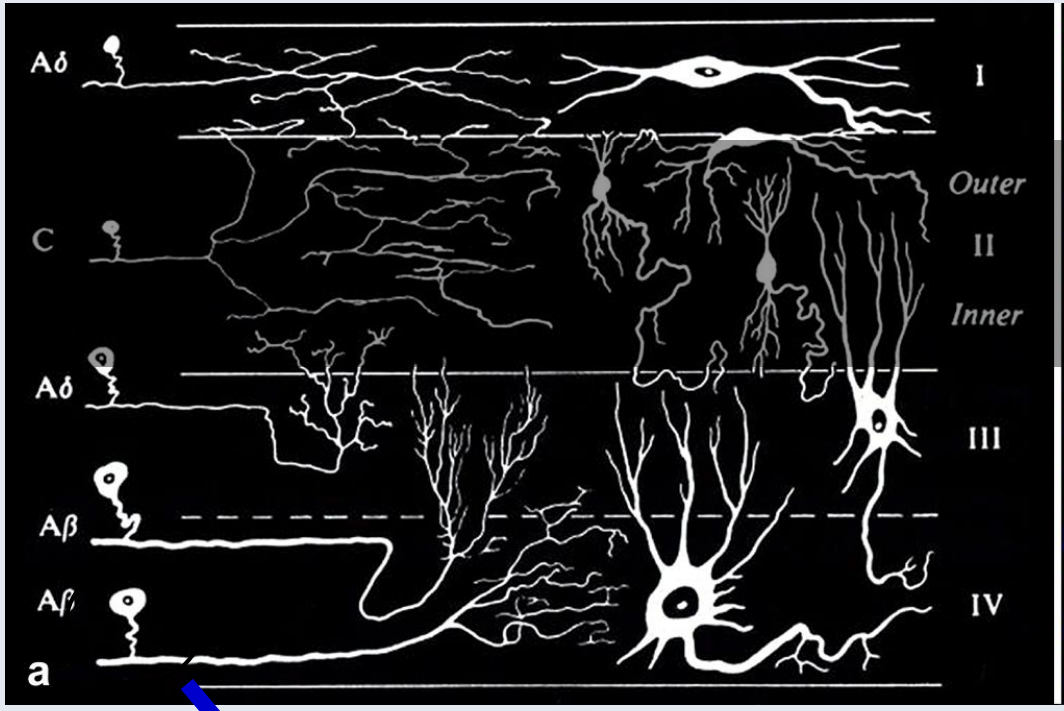


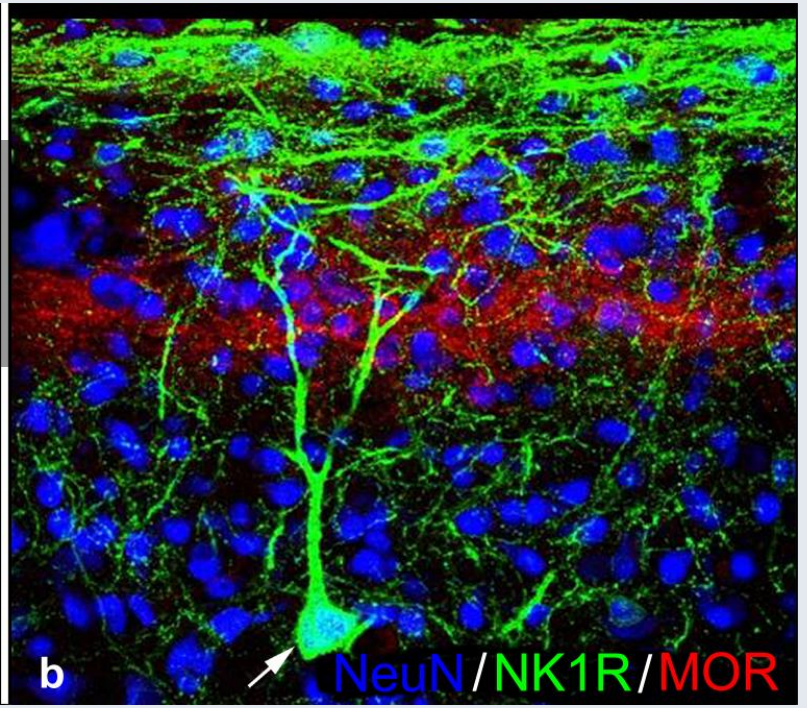
Laminar organization of the spinal cord: Rexed, 1952

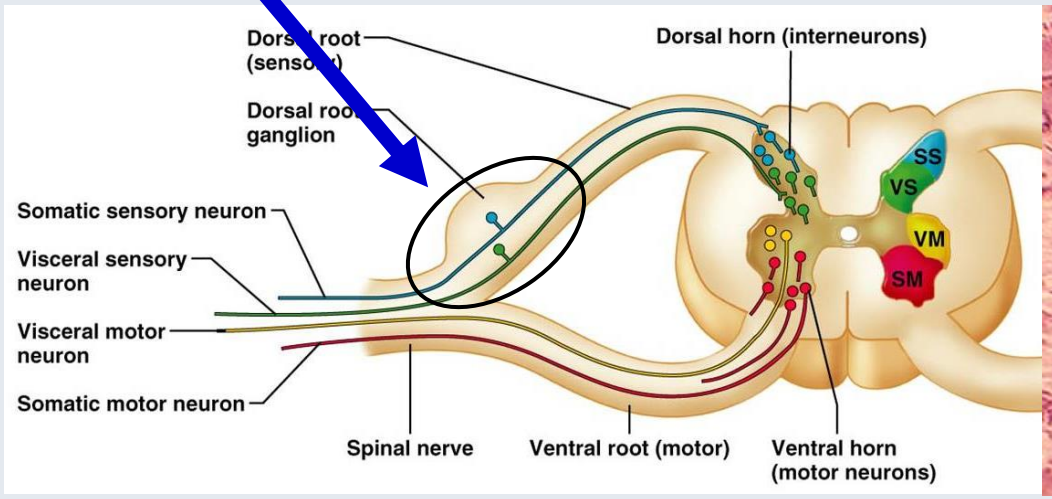
Dorsal horn

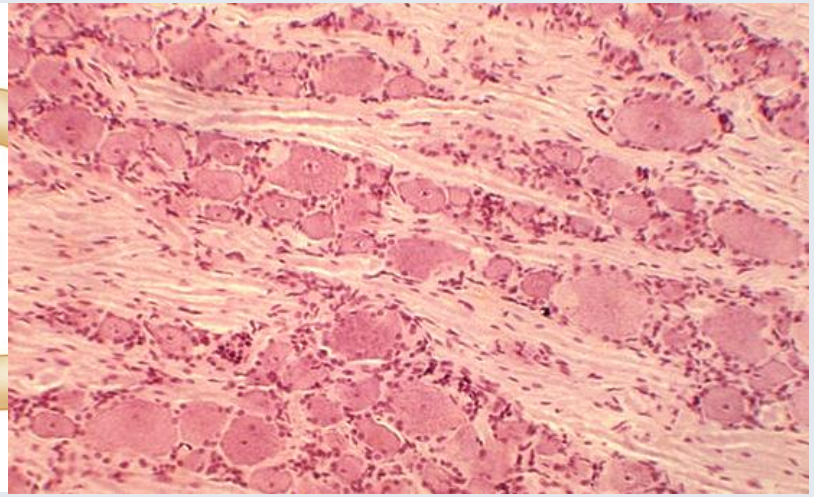


lamina II: substantia gelatinosa Rolandi


Aδ
C
Aδ
Aβ
Aβ
I
Outer
II
Inner
III
IV
a


b
NeuN/NK1R/MOR


Dorsal horn (interneurons)
Dorsal root ganglion
Somatic sensory neuron
Visceral sensory neuron
Visceral motor neuron
Somatic motor neuron
SS
VS
VM
SM
Spinal nerve
Ventral root (motor)
Ventral horn (motor neurons)

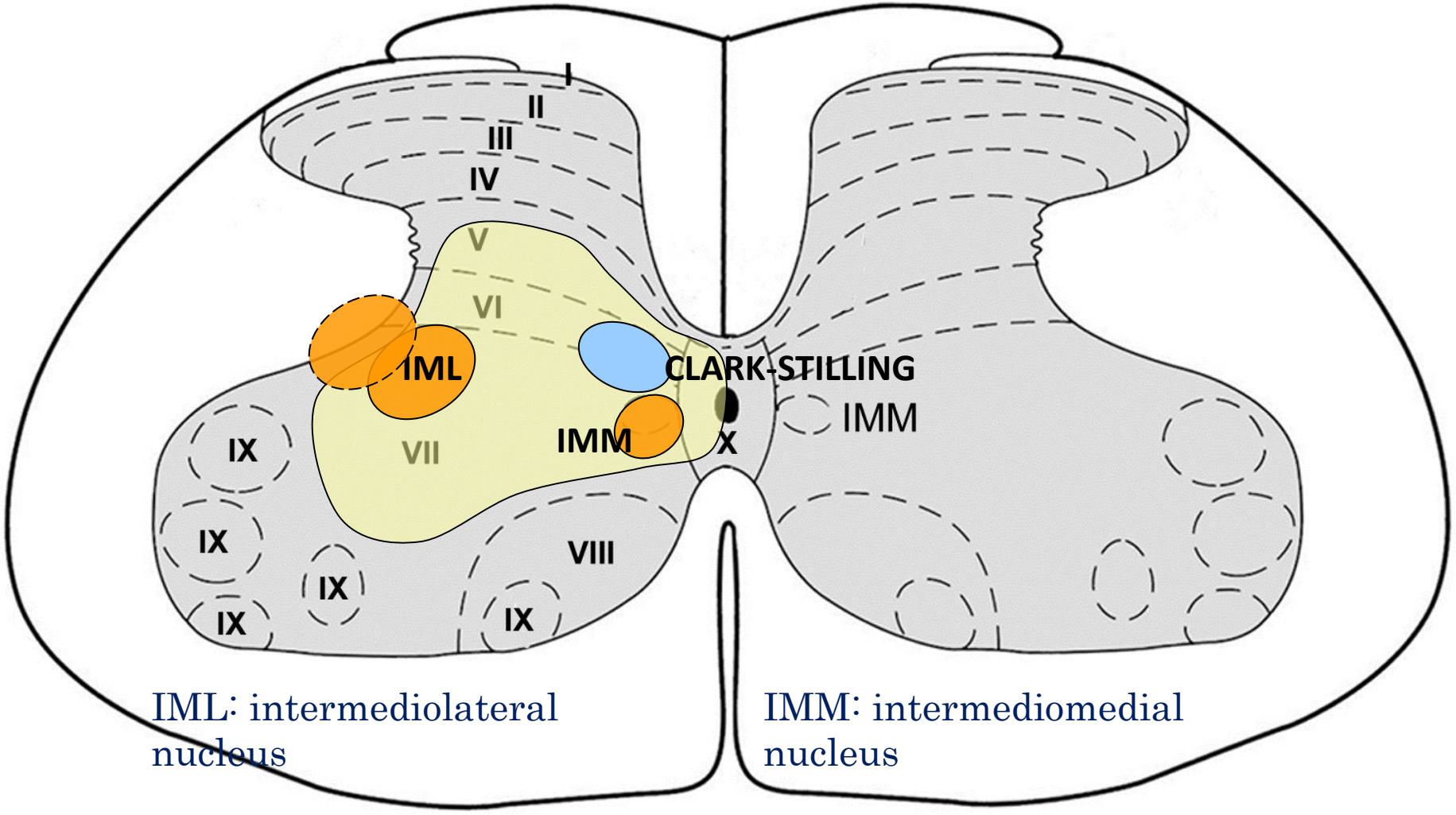


- High-threshold, slow-conducting, thin-myelinated Aδ and unmyelinated C fibres convey predominantly nociceptive information (pain, heat) to the lamina I-III. Low-threshold, high-conducting, thick-myelinated Aβ fibres carry non-painfull stimuli and terminate in deeper laminae of the spinal dorsal horn.

- Dorsal spinal horn plays a crutial role in sensory information processing. Local circuit neurons are more numerous, projection neurons forwarding stimuli to higher levels of the CNS constitute only 5-10%.

- Lamina II is densly packed with mu-opioid receptors binding morphine and other opioid analgesics.

Intermediate substance



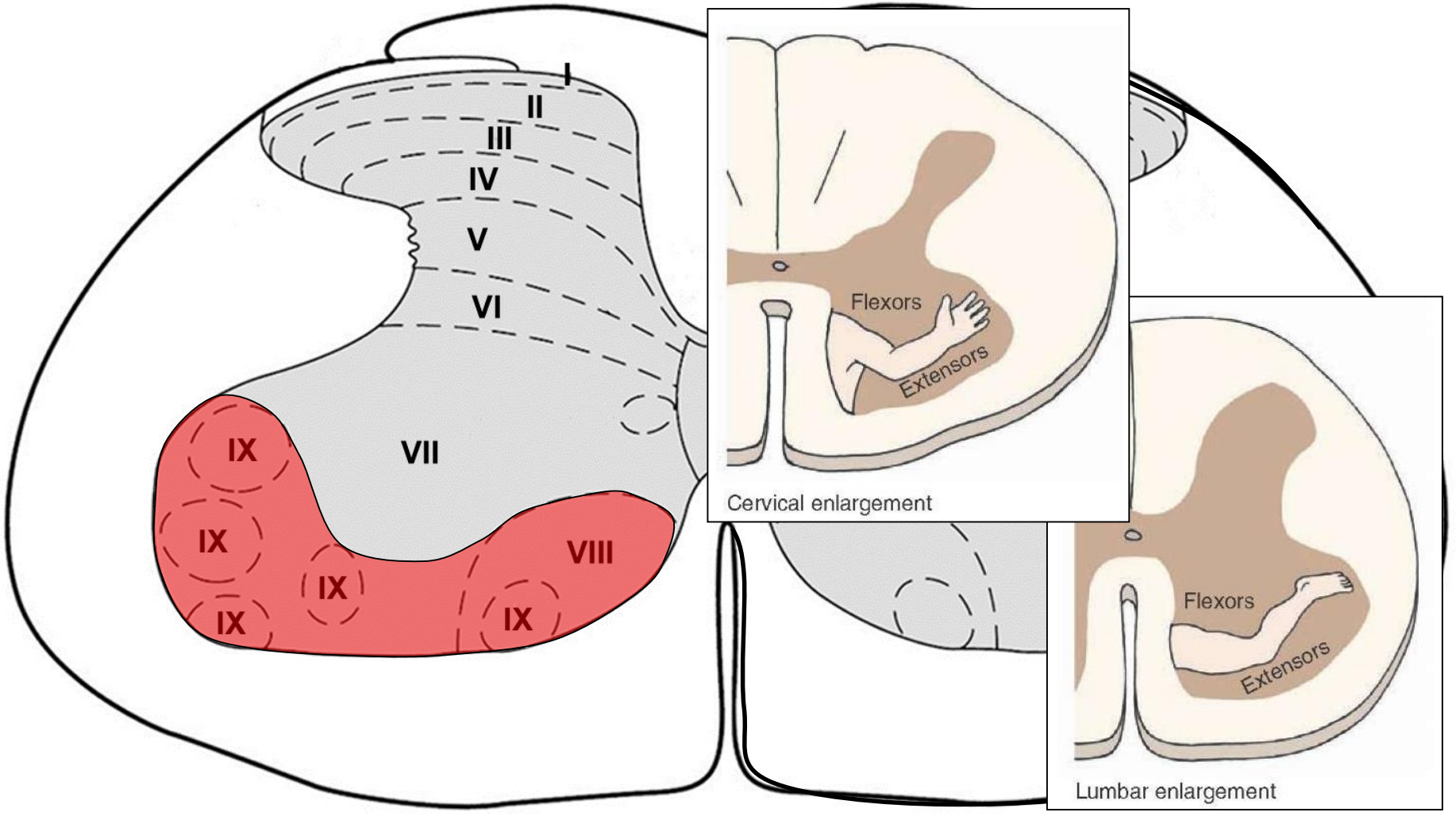
Note, that at the lower thoracic and upper lumbar levels the IML nucleus is situated more laterally and constitutes the lateral horn!

- Lateral horn exists only in the thoracic and upper lumbar segments. At these levels appearance of the lateral horn can be explained by the lateral transposition of the IML nucleus.

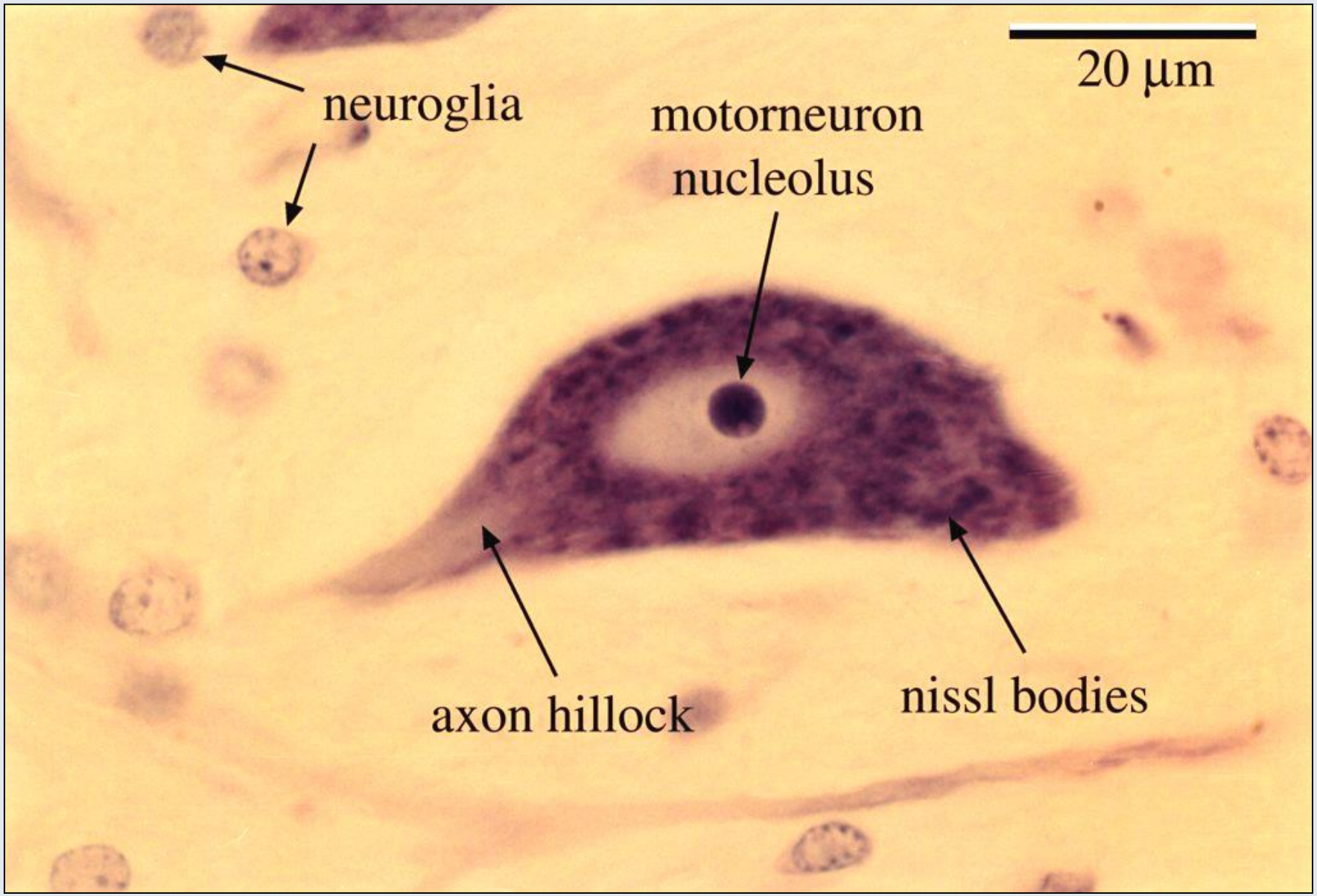
- IML nucleus contains preganglionic neurons of the sympathetic (thoraco-lumbar levels) and parasympathetic (sacrral segments) nervous system, with other words visceromotor fibres arise from this nucleus.
- IMM nucleus is considered as an autonomic spinal reflex centre.

- Dorsal or thoracic nucleus (of Clarke-Stilling) found in the Th9-L3 segments is the source of the dorsal spinocerebellar tract (of Flechsig). Downward continuation of this nucleus in L4-S3 segments is the approximate site of origin of the ventral spinocerebellar tract (of Gowers). Both of these tracts convay proprioceptiv information to the cerebellum.

Ventral horn



In the ventral horn instead of laminae rather groups of neurons are observable. Together with many local interneurons, alpha- and gamma-motoneurons directly innervating skeletal muscles are found here in somatotopic arrangement.



A typical neuron in the microscope: prominent nucleolus in the large, oval or rounded, poorly stained nucleus, surrounded by dark, basofilic, granulated cytoplasm, which is always darker then the nucleus.

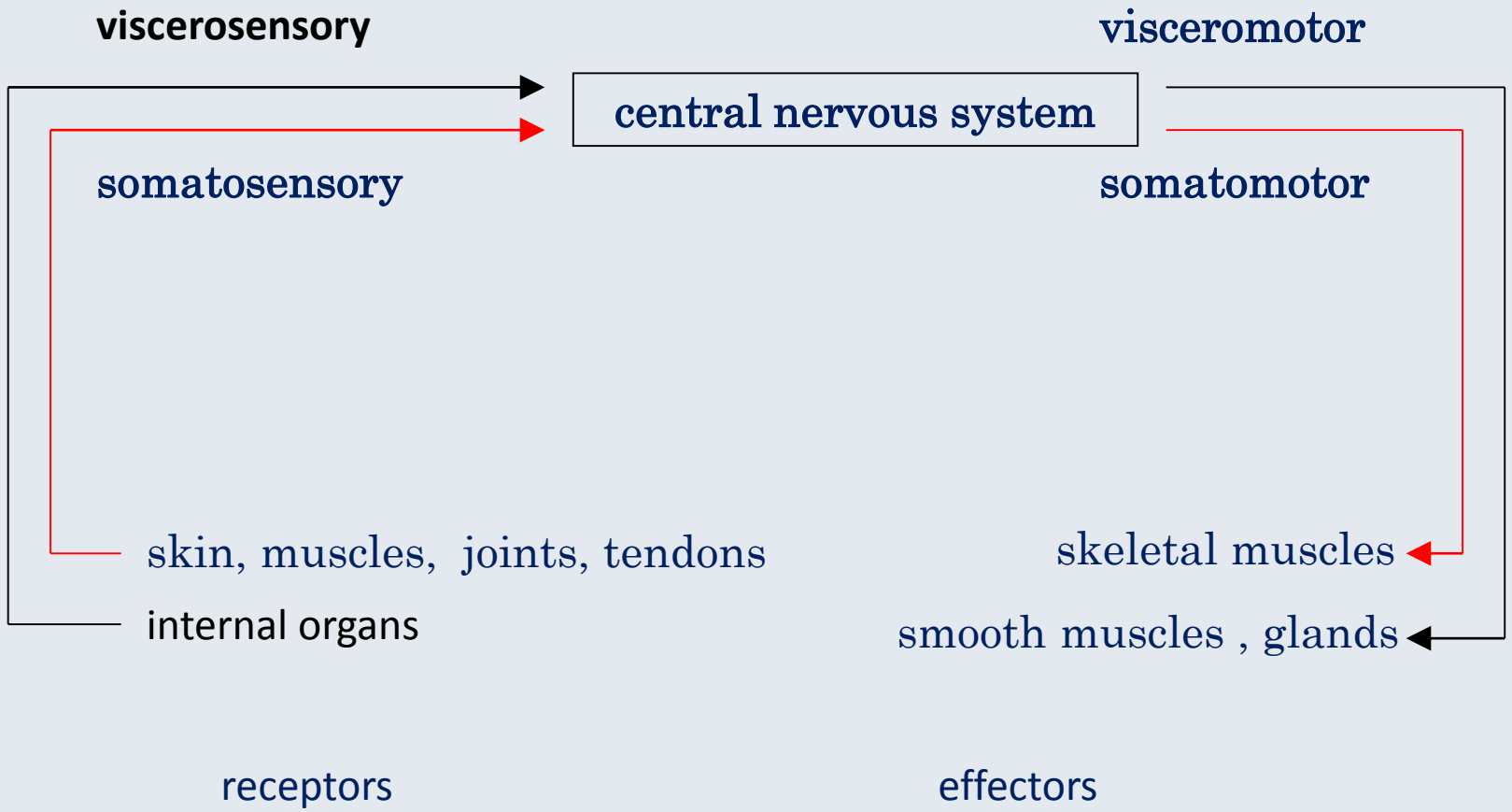
II. Spinal reflex arcs

- **Reflex:** involuntary and automatic response to a stimulus

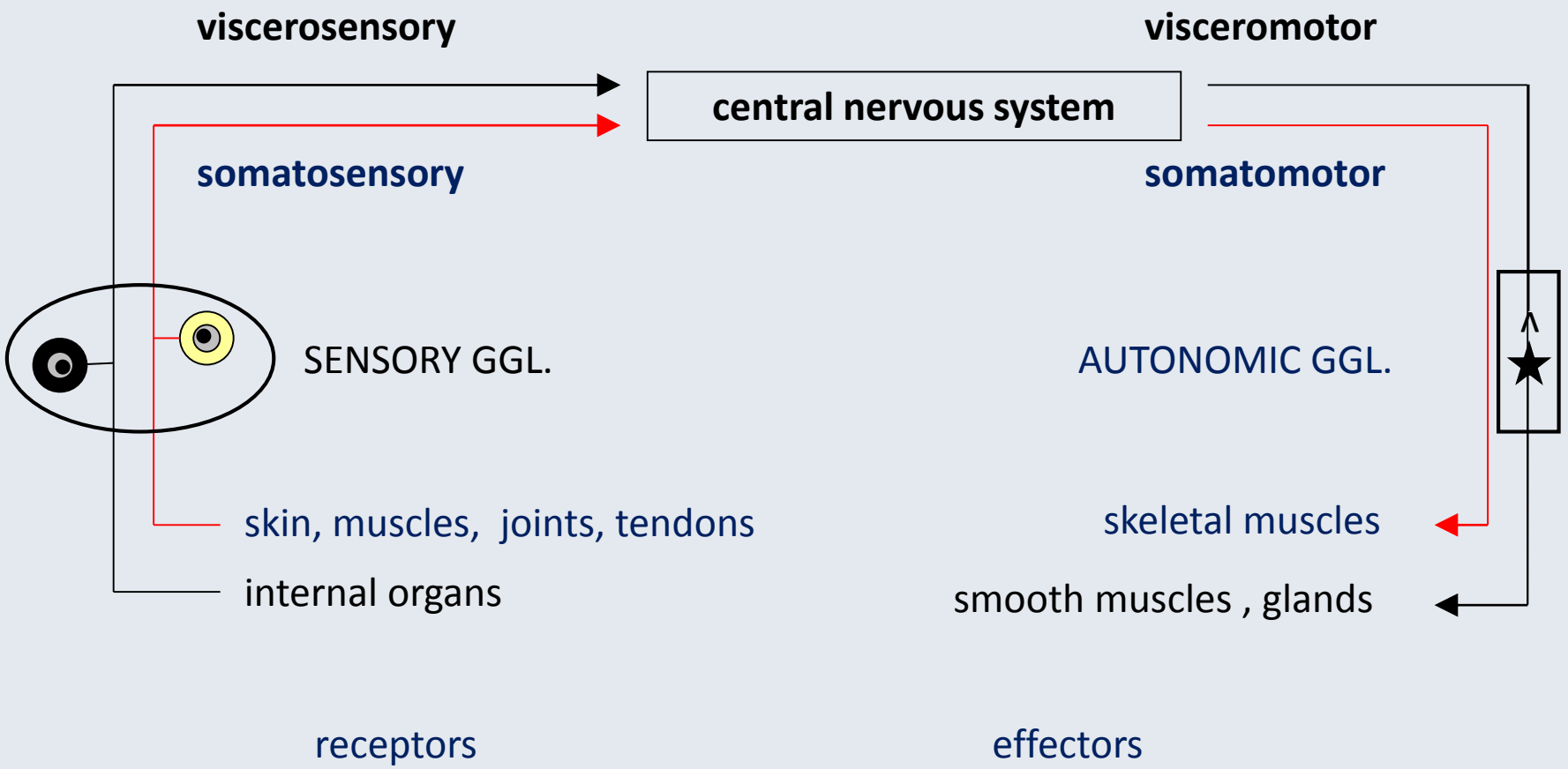
A **(1) receptor** is responsible for detecting a stimulus and converting it into a neuronal signal. Evoked action potentials reach the central nervous system through the **(2) afferent limb**. Decission is made and response is generated by the **(3) central processing neuronal networks**. **(4) Efferent limb** exits the central nervous system and terminates on the **(5) effector**, which might be a muscle or a gland. (1) to (5) components altogether constitute the reflex arc!

- **Spinal reflex:** In the case of spinal reflex arcs the stimulus is received and processed by the spinal cord and the response is organized and performed by the spinal neuronal circuits.
- Under normal circumstances stimuli evoking spinal reflexes also reach the brain and descending fibres from higher centres may modulate spinal reflexes but experimentally spinal reflexes can be evoked even after the removal of the brain!

Fundamentals of the nervous system

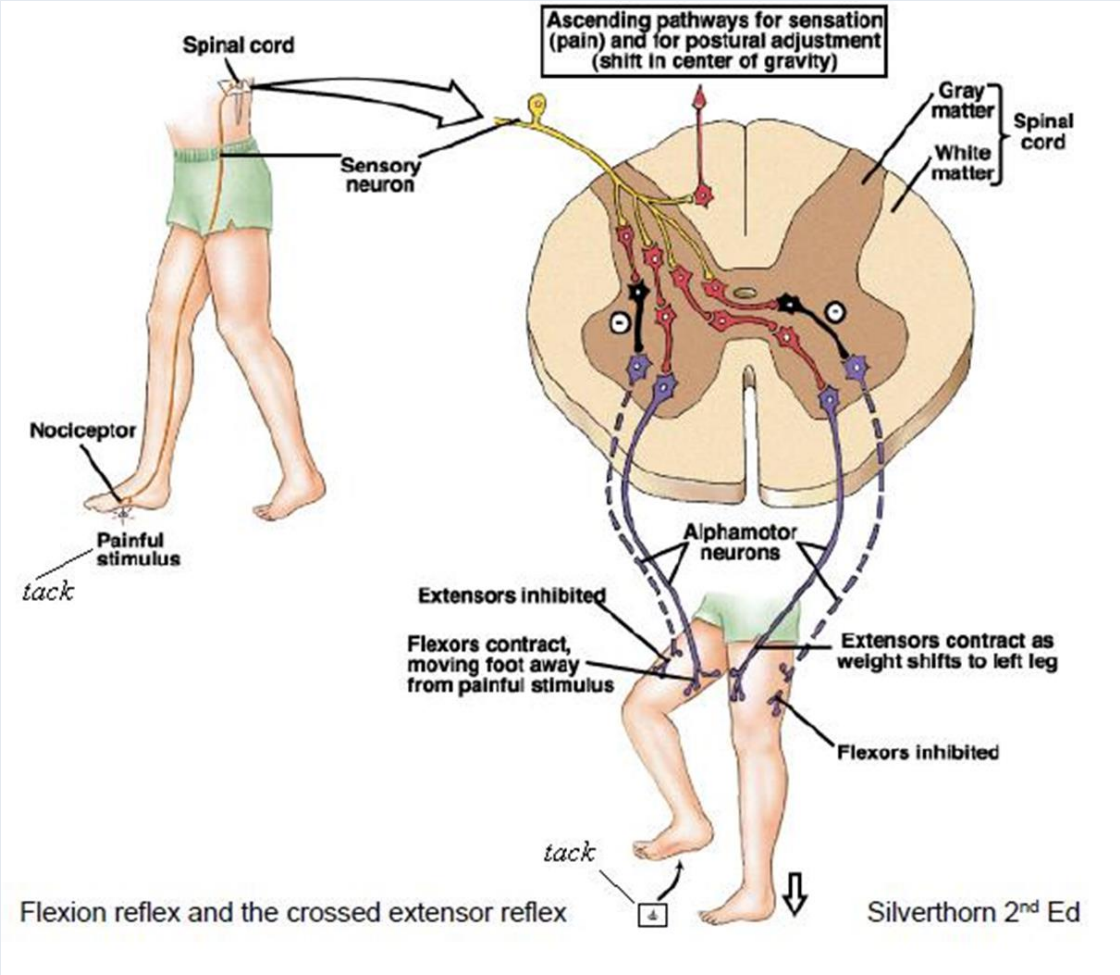


Fundamentals of the nervous system



1. Nociceptive reflex arc

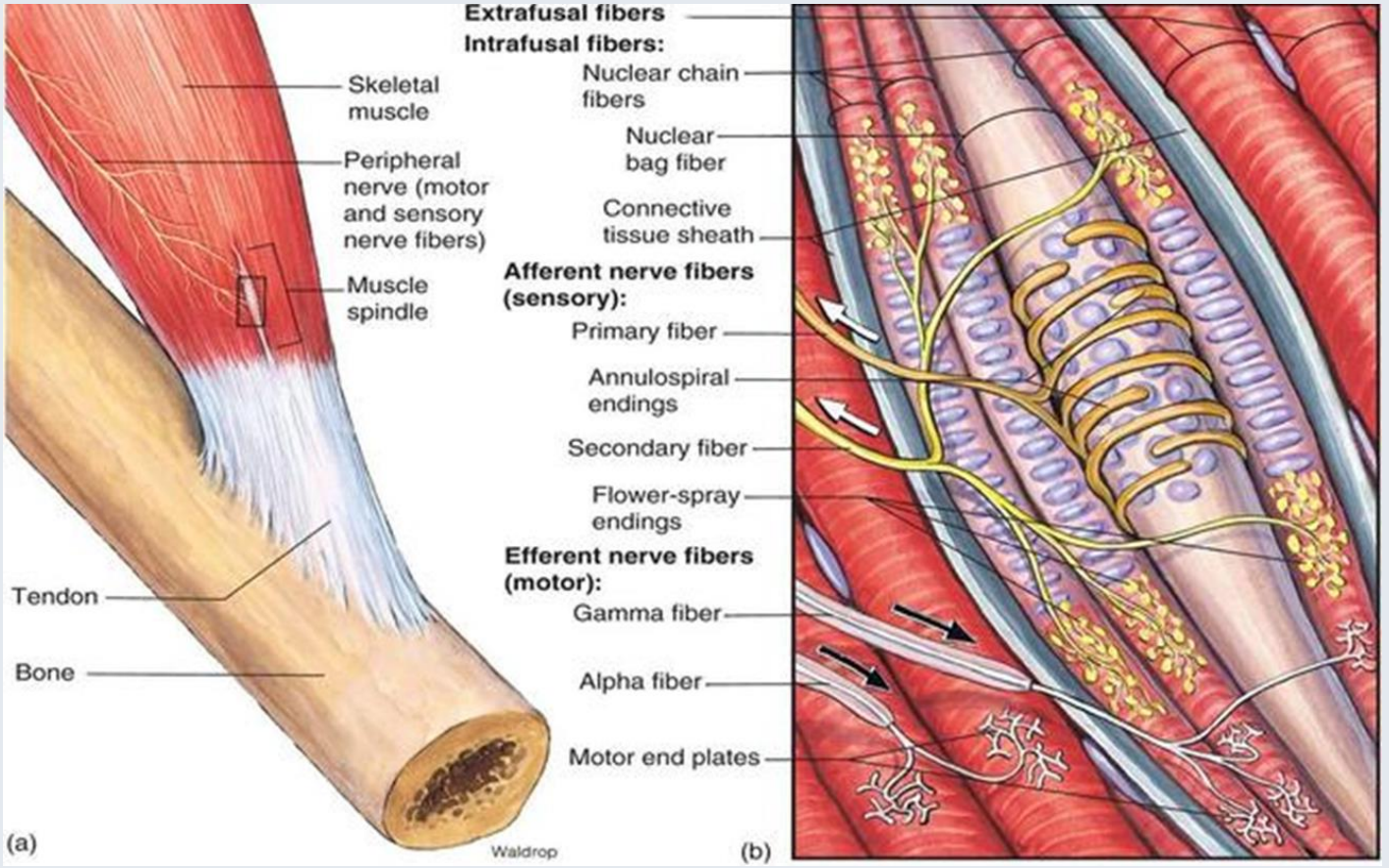
- *Synonyms:* flexor reflex, withdrawal reflex, polysynaptic spinal reflex
- Ancient reflex that protects the body from potentially damaging, noxious stimuli.



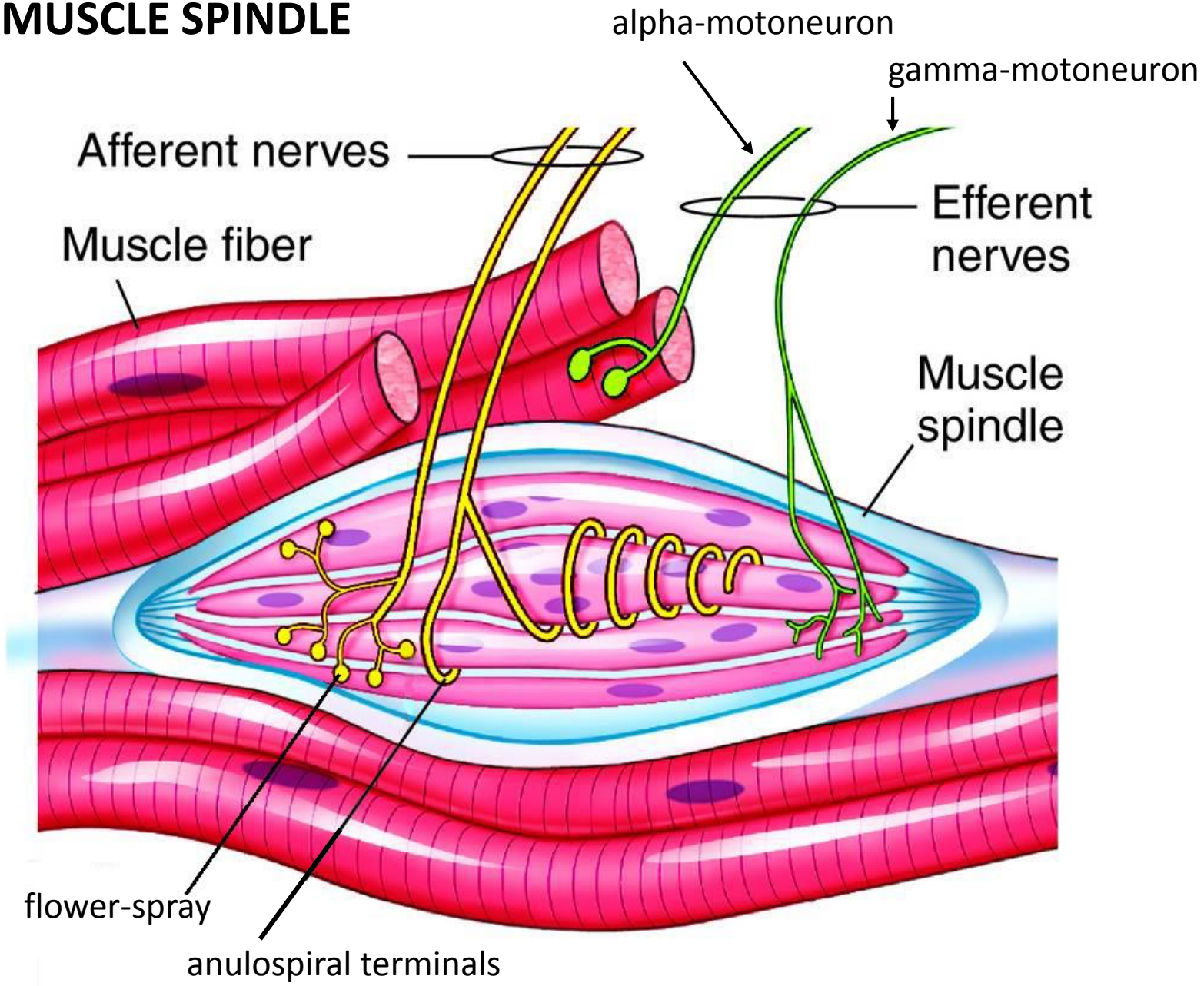
- Nociceptors of the skin and mucous membranes → Adelta and/or C fibres → spinal ganglion → spinal dorsal horn → numerous collaterals: excitacion of flexors and inhibition of extensor on the side of stimulus and stimulation of extensors together with inhibition of flexors on the contralateral side (flexor reflex with crossed extensor response).

2. Proprioceptive reflex arc

- *Synonyms:* stretch reflex, monosynaptic spinal reflex, myotatic reflex
- Stretching a muscle results in its contraction providing automatic regulation of skeletal muscle length and the posture of the body. The „stretch receptors” are the muscle spindles.

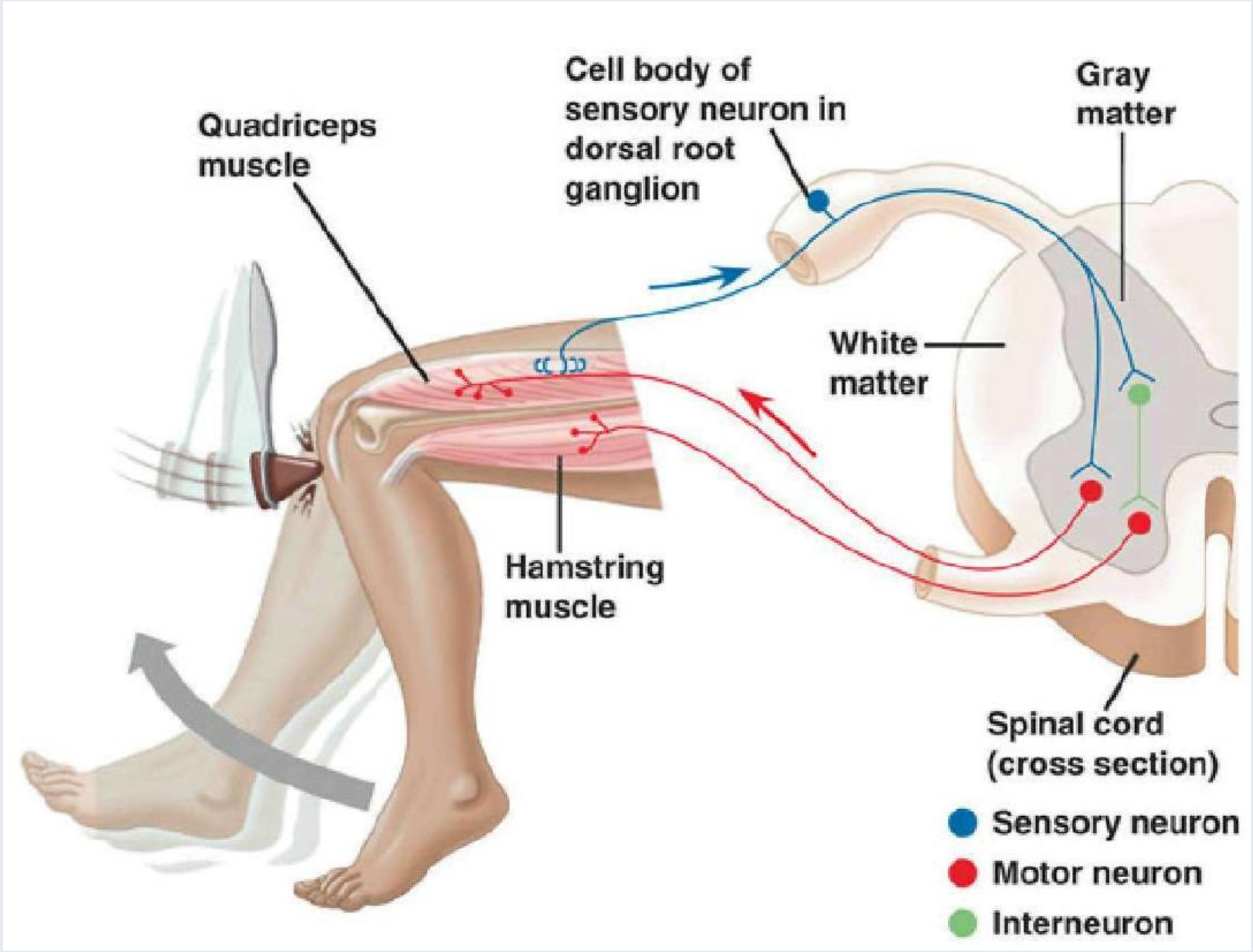


MUSCLE SPINDLE



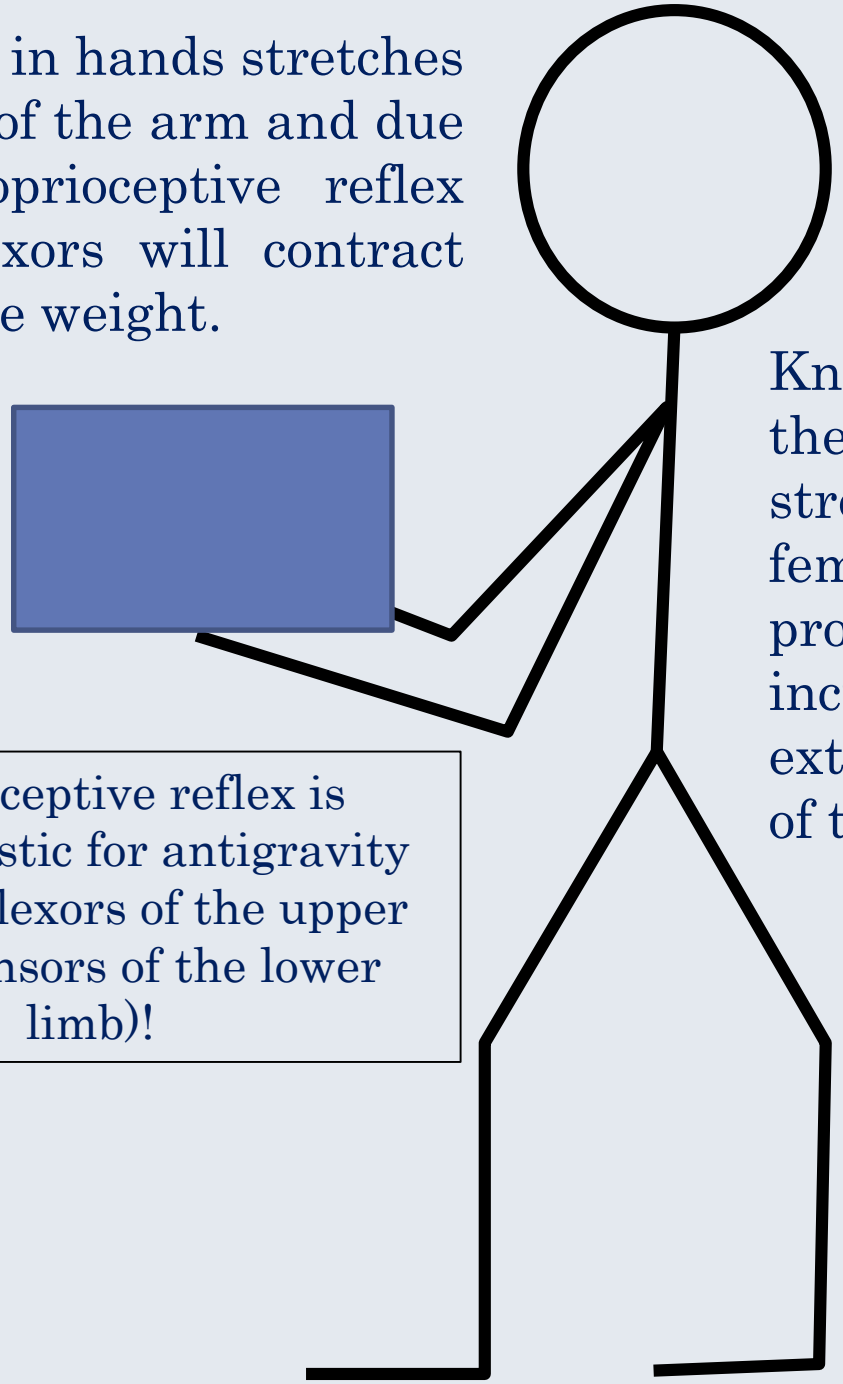
- Muscle spindles are special stretch receptors enclosed by a connective tissue capsule. Within the capsule the intrafusal fibres are present, while outside the extrinsic muscle fibres of the host muscle can be found. Intrafusal fibres are innervated by gamma-motoneurons and extrafusal fibres receive stimuli from alpha-motoneurons.

- Within the muscle spindle two types of sensory terminals, the anulospiral endings and the flower-spray terminals can be distinguished. These inform the CNS about the actual length and movement of the muscles.


Quadriceps muscle
Cell body of sensory neuron in dorsal root ganglion
Gray matter
White matter
Hamstring muscle
Spinal cord (cross section)
Sensory neuron
Motor neuron
Interneuron

- Muscle spindle → spinal ganglion → dorsal root → alpha-motoneuron in the ventral horn → peripheral nerve → skeletal muscle fibres surrounding the muscle spindle. Collaterals through inhibitory interneurons will avoid simultaneous contraction of the antagonist muscle groups.

Object held in hands stretches the flexors of the arm and due to the proprioceptive reflex arc the flexors will contract and hold the weight.



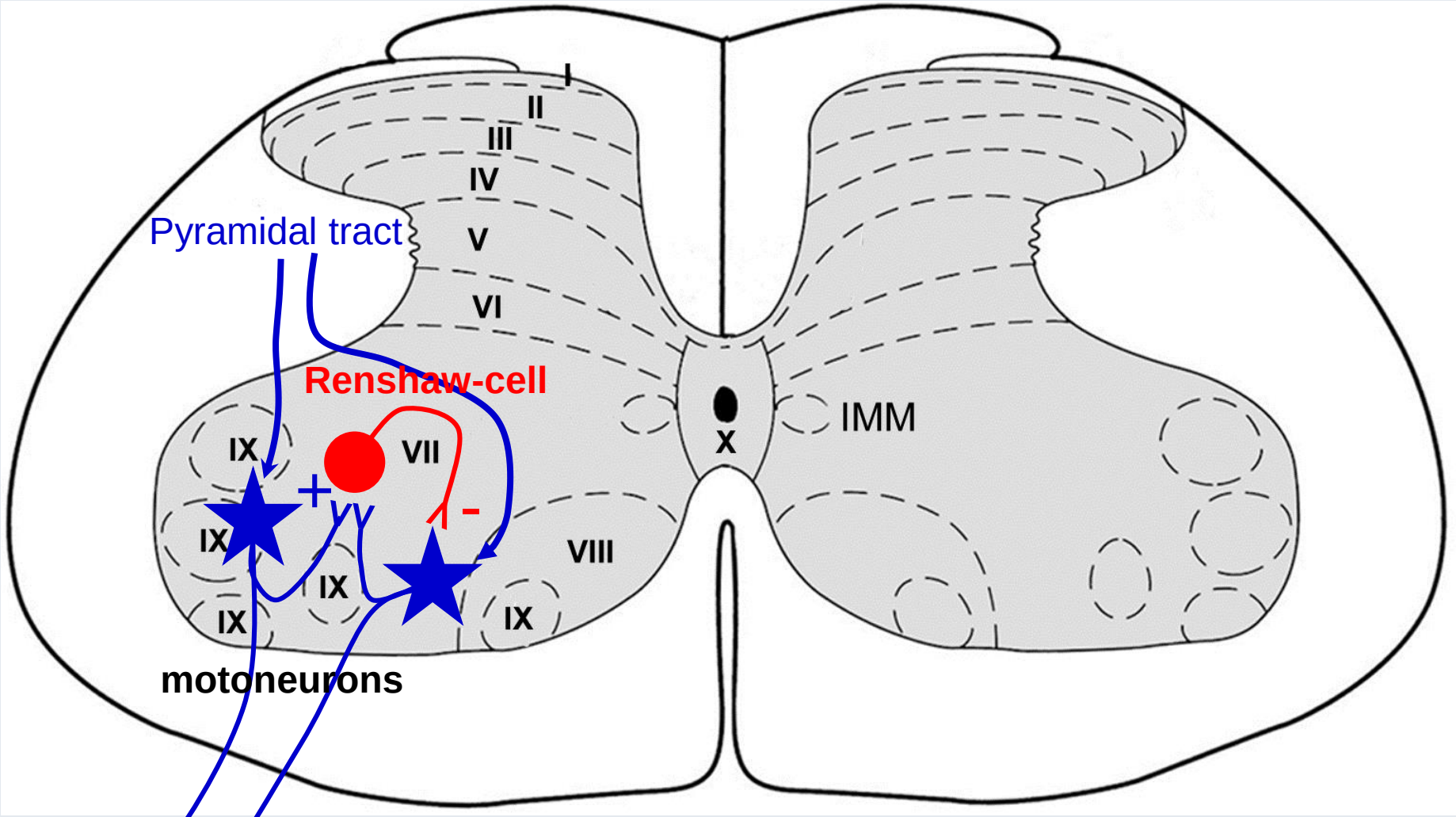
Knee joints tend to flex under the weight of the body, but stretching of the quadriceps femoris muscle activates the proprioceptive reflex which increases the tone of the extensors avoiding the collapse of the human body.

Proprioceptive reflex is characteristic for antigravity muscles (flexors of the upper and extensors of the lower limb)!

Further spinal mechanisms contributing to the control of fine movements

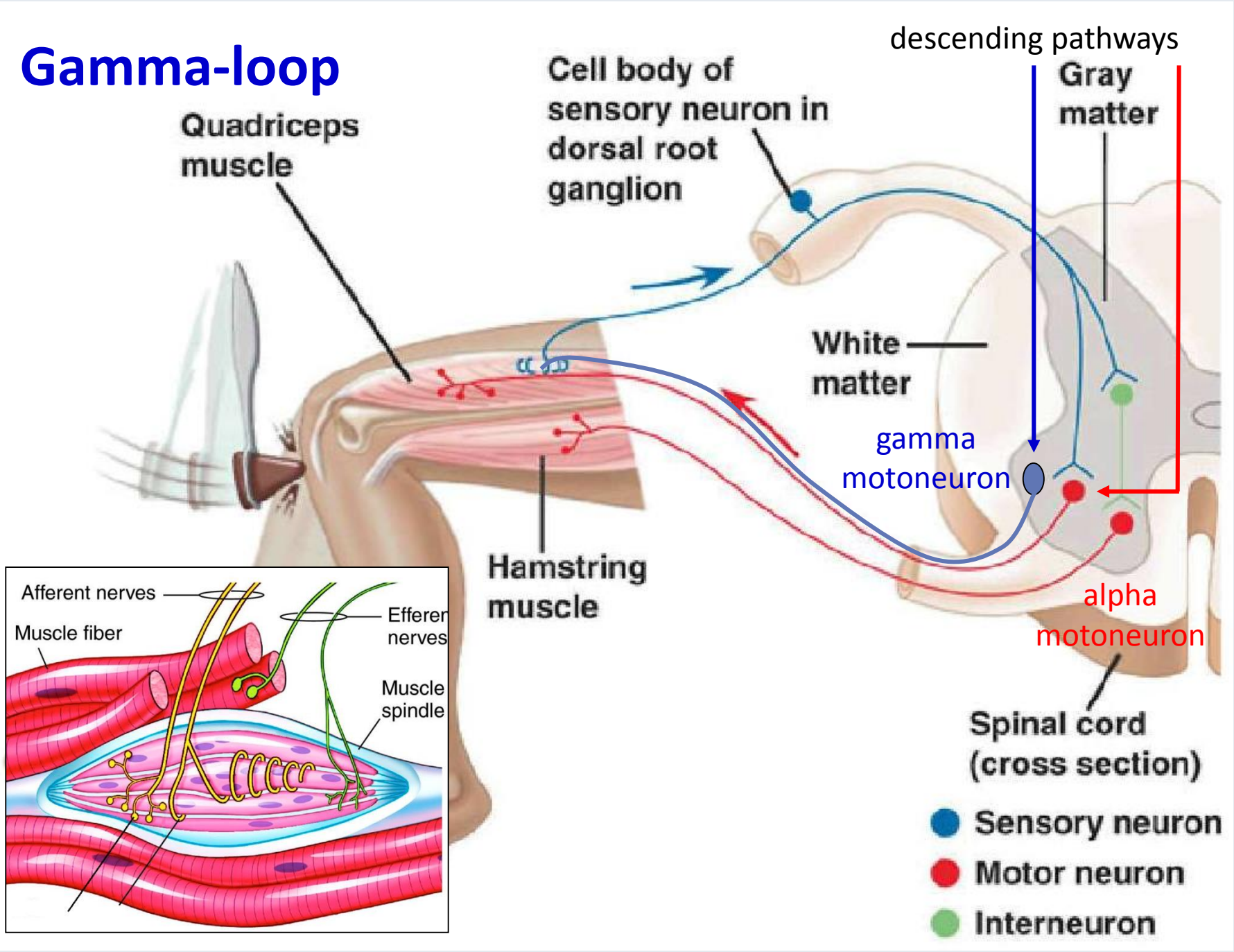
- Renshaw cells of the ventral horn
- Gamma-loop
- Golgi tendon organ

Renshaw-cell: recurrent inhibition (with red on the image).



Discharging motoneurons inhibit adjacent motoneurons via their recurrent axon collaterals and the Renshaw-neurons.

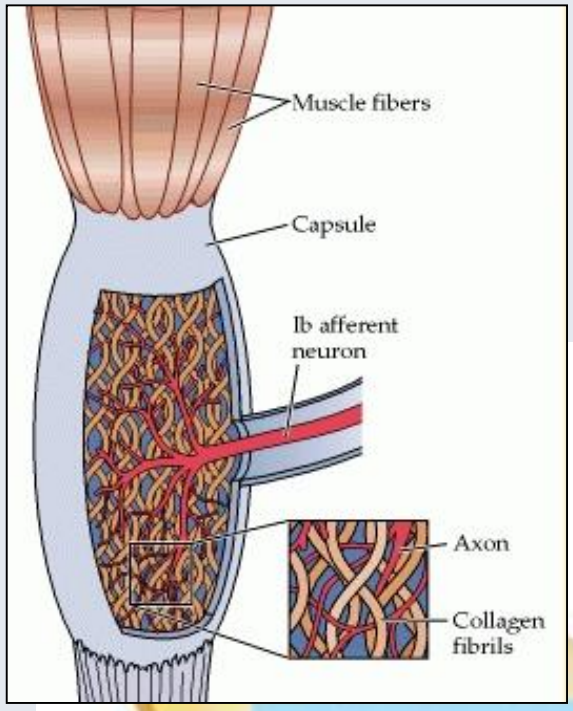
Gamma-loop

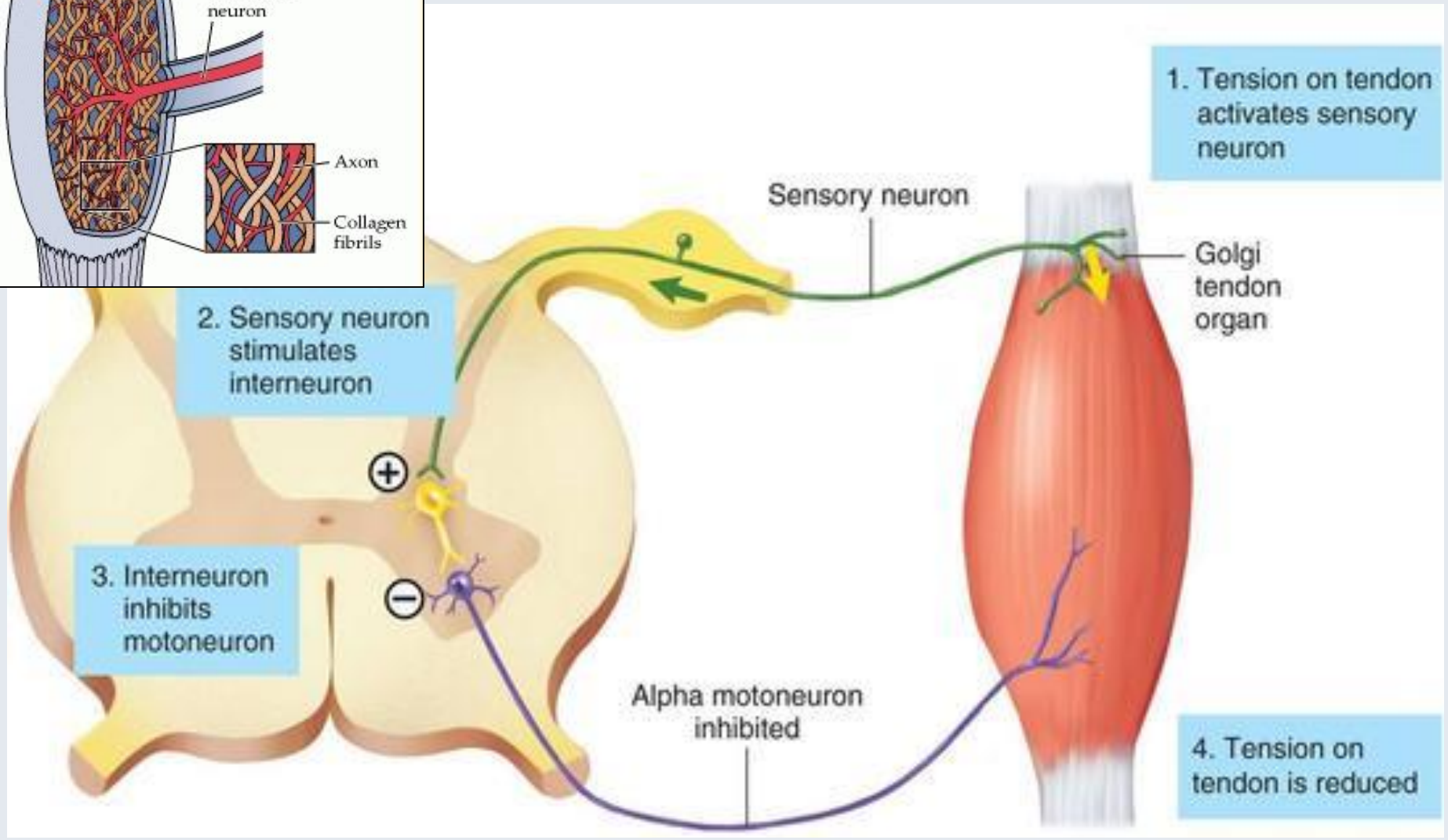

descending pathways
Cell body of sensory neuron in dorsal root ganglion
Quadriceps muscle
Gray matter
White matter
gamma motoneuron
alpha motoneuron
Hamstring muscle
Spinal cord (cross section)
Sensory neuron
Motor neuron
Interneuron
Afferent nerves
Efferent nerves
Muscle fiber
Muscle spindle

- A muscle contracton can beevoked in two different ways:
  - Directly, through alpha-motoneurons
  - Indirectly, through the activation of the gamma-loop and the proprioceptive reflex arc.

- Descending pathways can stimulate gamma-motoneurons which innervate intrafusal muscle fibres. Contracting intrafusal fibres shorten the muscle spindle itself which has a similar effect to that when the extrafusal fibres around the spindle are passively stretched. This stretch(-like) signal evokes the spinal proprioceptive reflex activating alpha-motoneurons, and finally contracting extrafusal fibres.

Golgi tendon organ





- In GTOs axons among collagen bundles can be activated by transformations of the musculotendinous junction.
- GTO is connected in series to the muscle fibres.
- Inhibits overstimulation of muscles and prevevents bone, tendon or joint injuries.

Thank you for your attention!