Spinal Cord Organization

The spinal cord . . .

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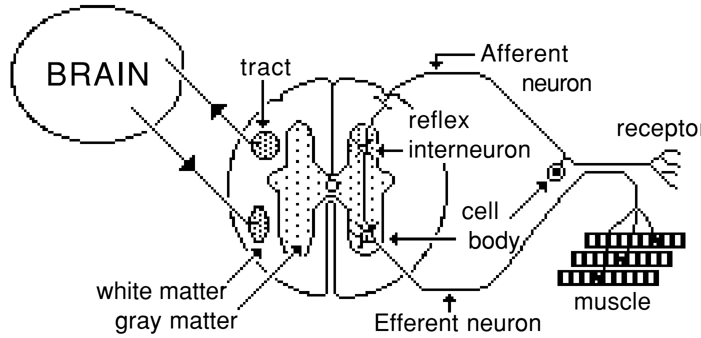
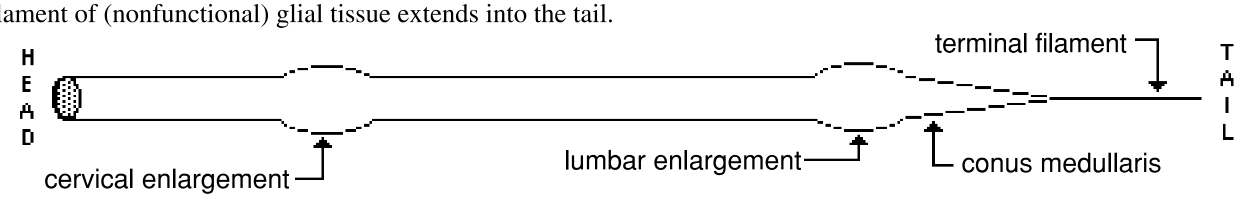
- communicates with the brain, by means of ascending and descending pathways that form tracts in spinal white matter; and
- gives rise to spinal reflexes, pre-determined by interneuronal circuits.



Spinal Cord Section

Gross anatomy of the spinal cord:

The spinal cord is a cylinder of CNS. The spinal cord exhibits subtle cervical and lumbar (lumbosacral) enlargements produced by extra neurons in segments that innervate limbs. The region of spinal cord caudal to the lumbar enlargement is *conus medullaris*. Caudal to this, a terminal filament of (nonfunctional) glial tissue extends into the tail.



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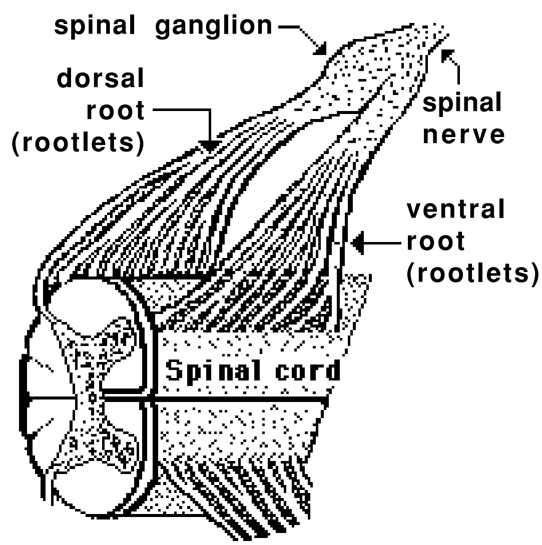

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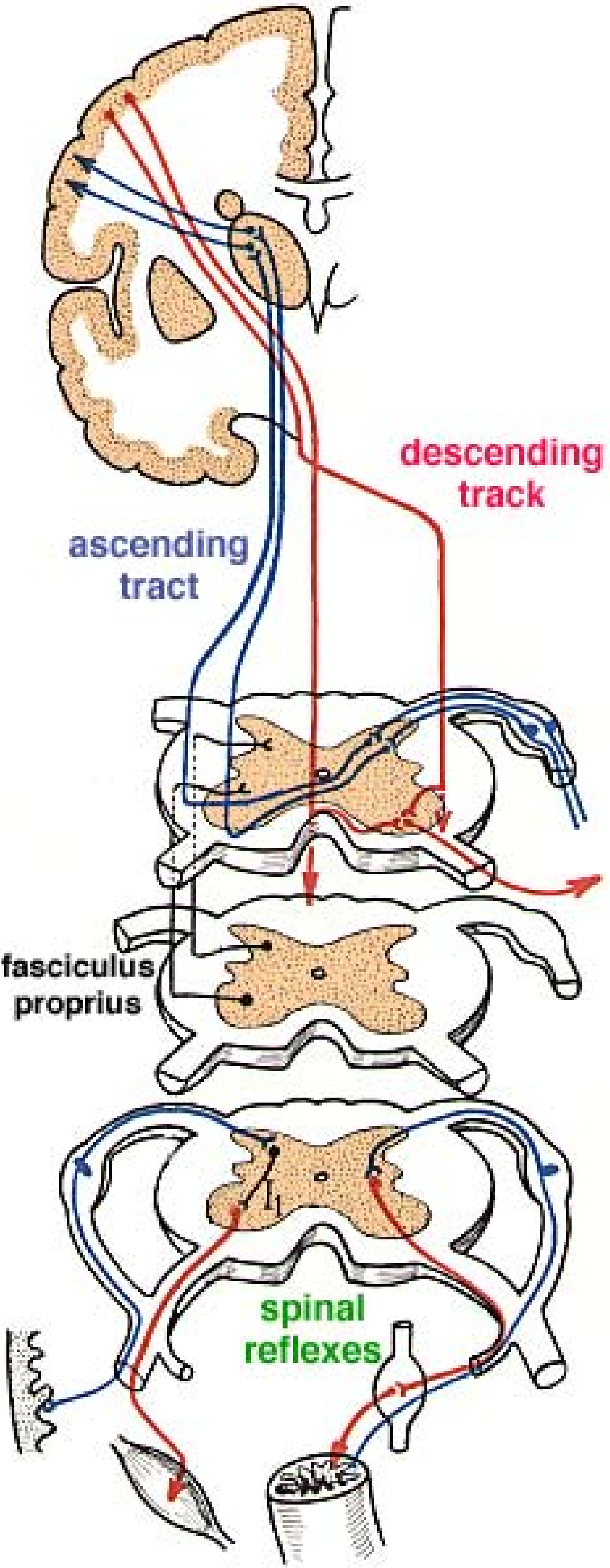
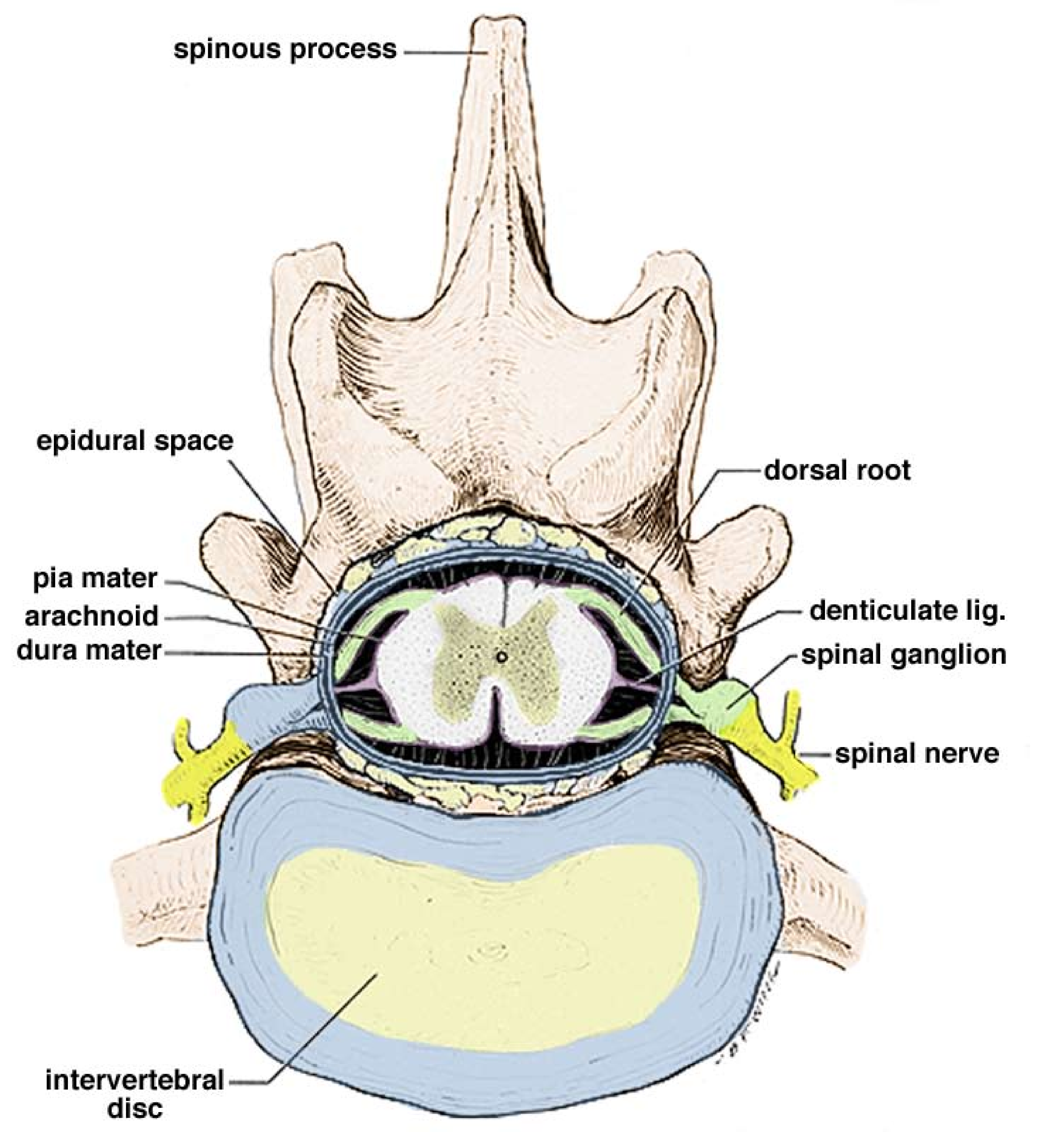
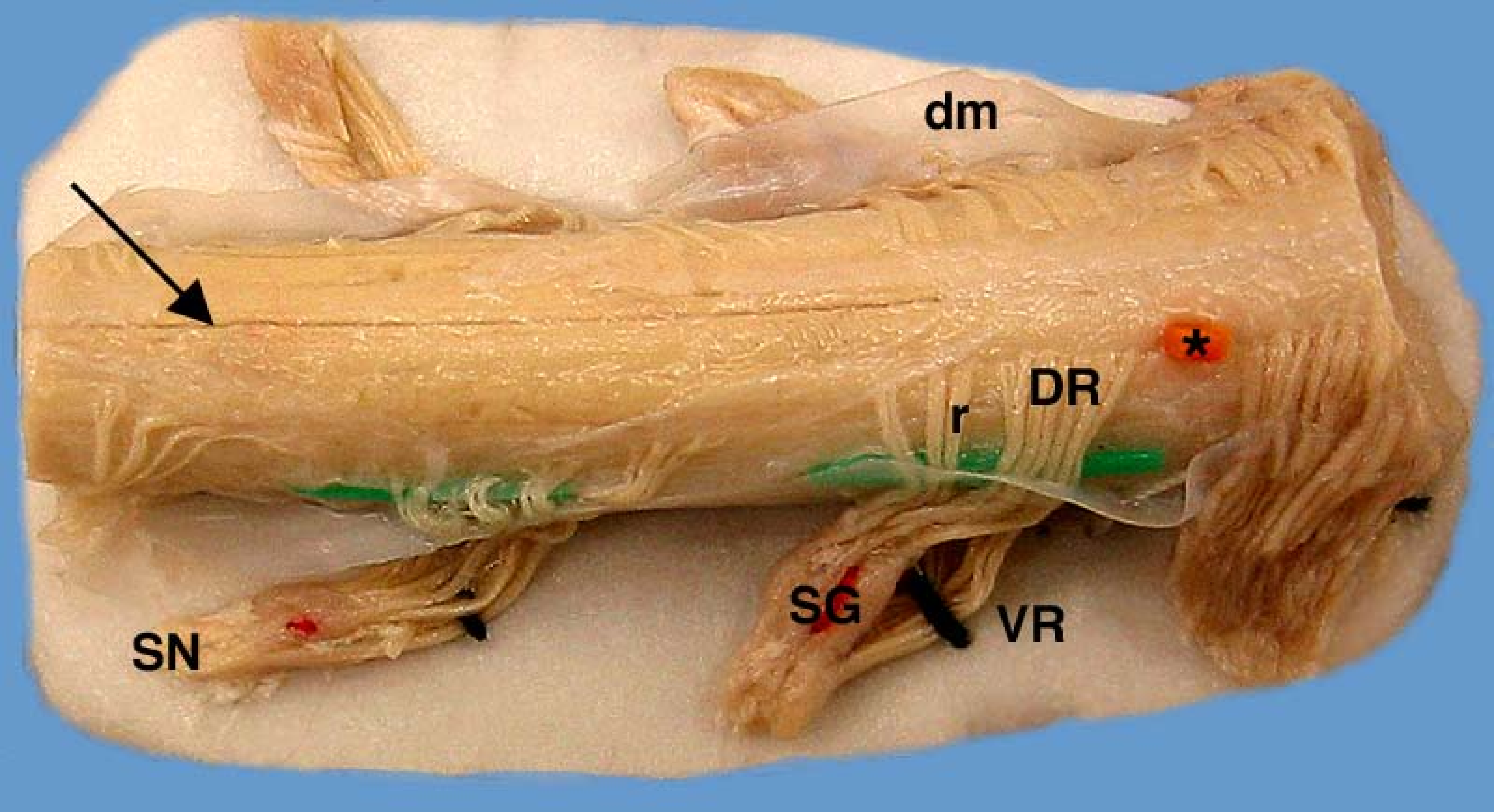
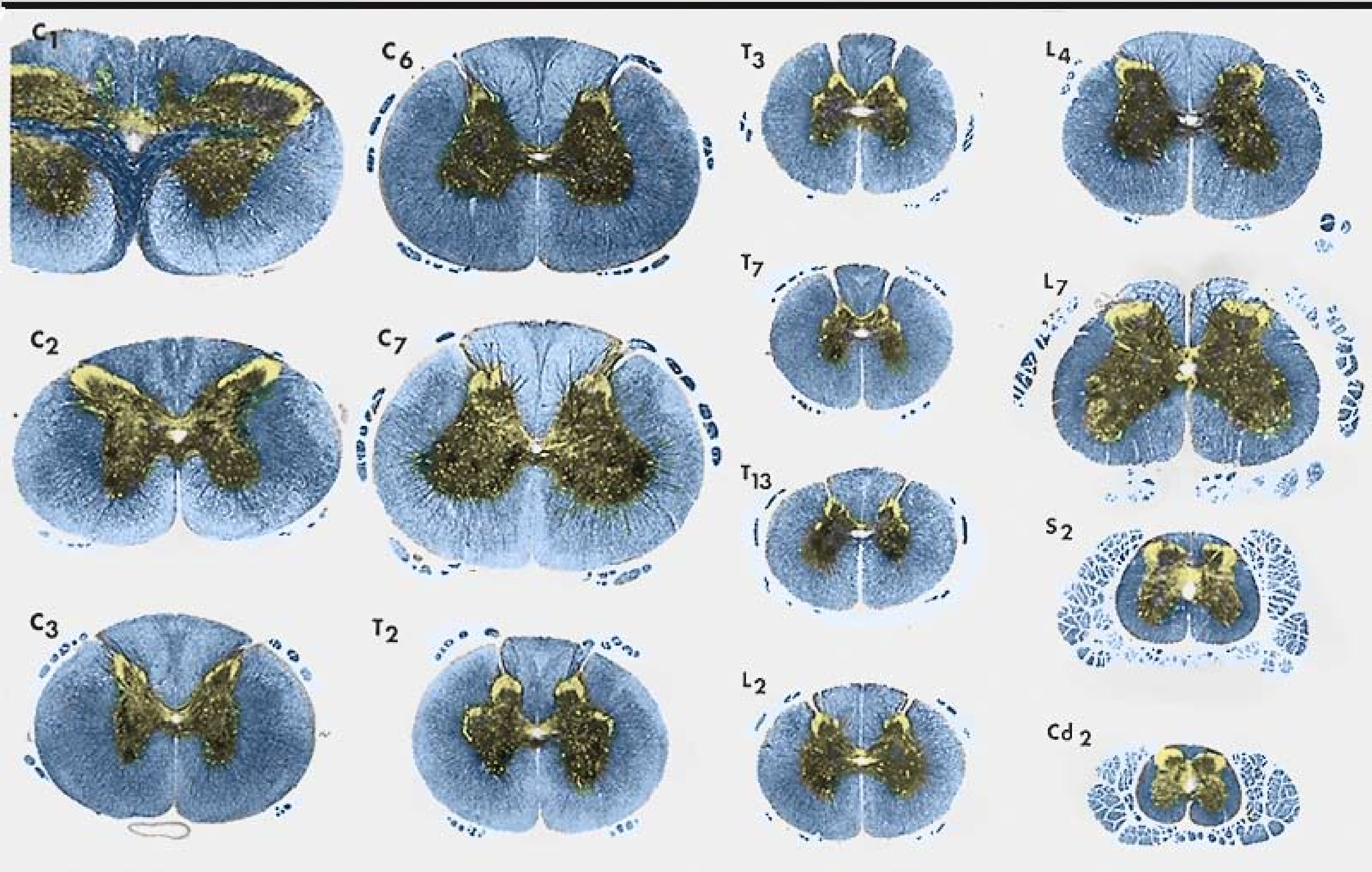
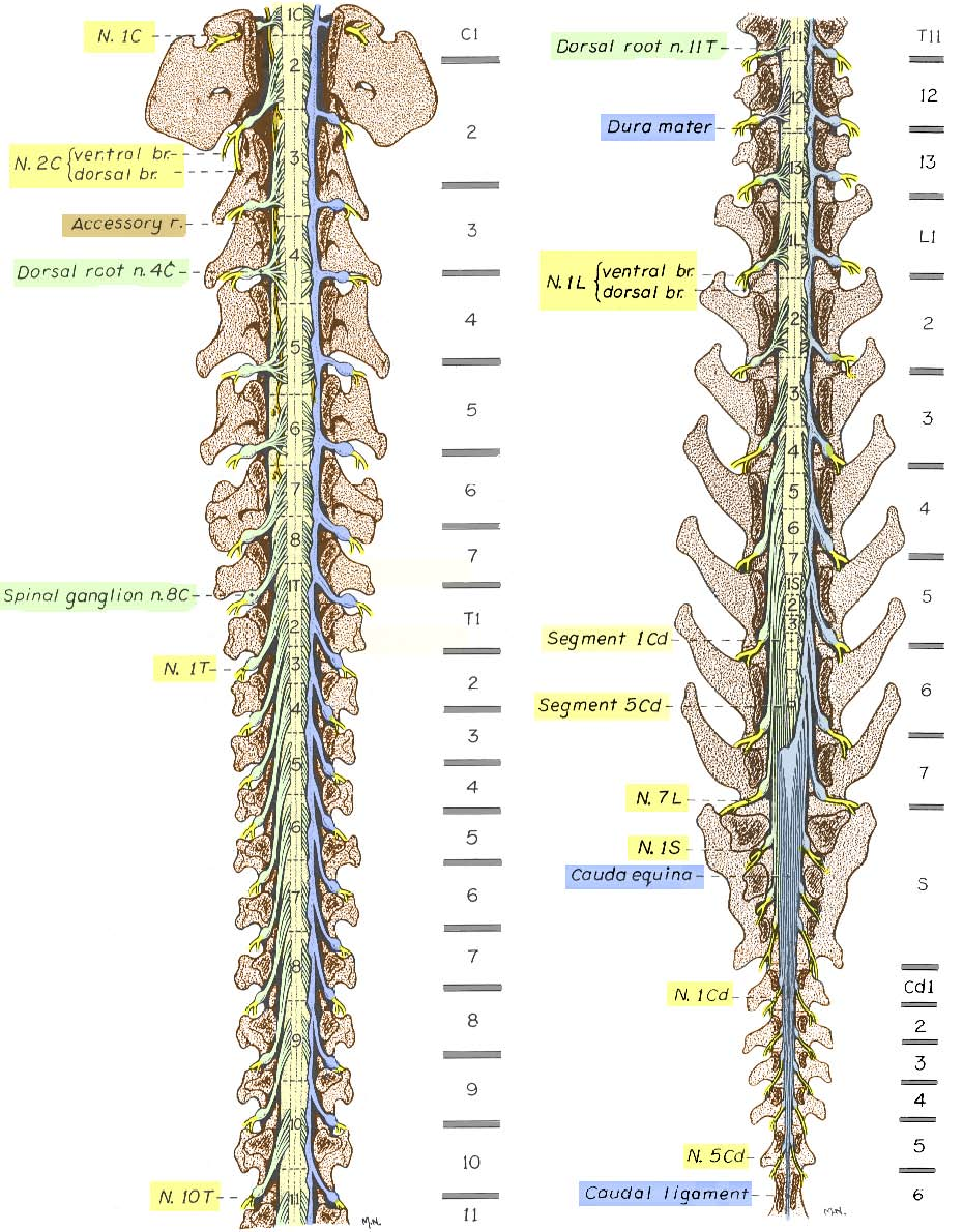

descending
track
ascending
tract
fasciculus
proprius
spinal
reflexes

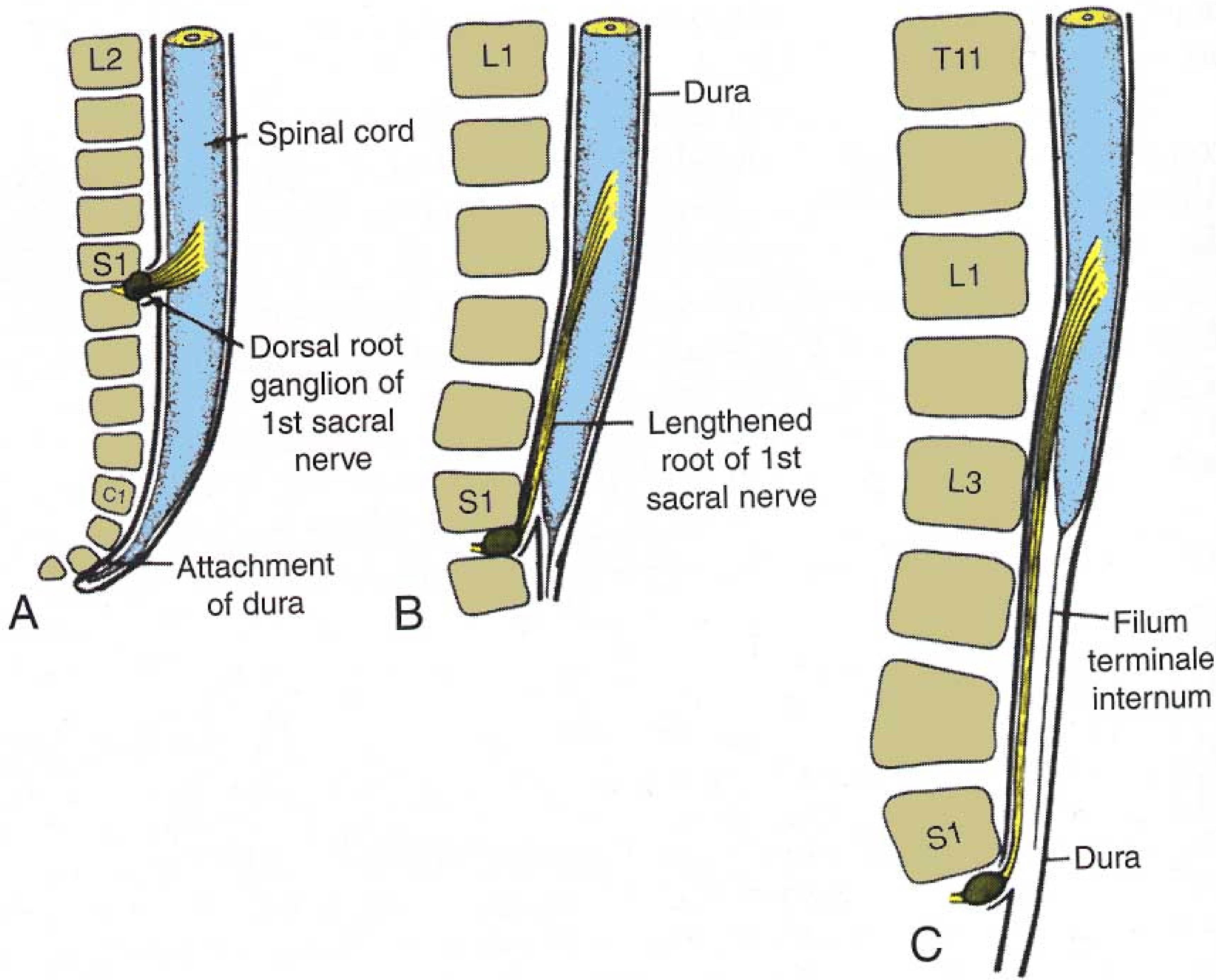

spinous process
epidural space
dorsal root
pia mater
arachnoid
dura mater
denticulate lig.
spinal ganglion
spinal nerve
intervertebral
disc

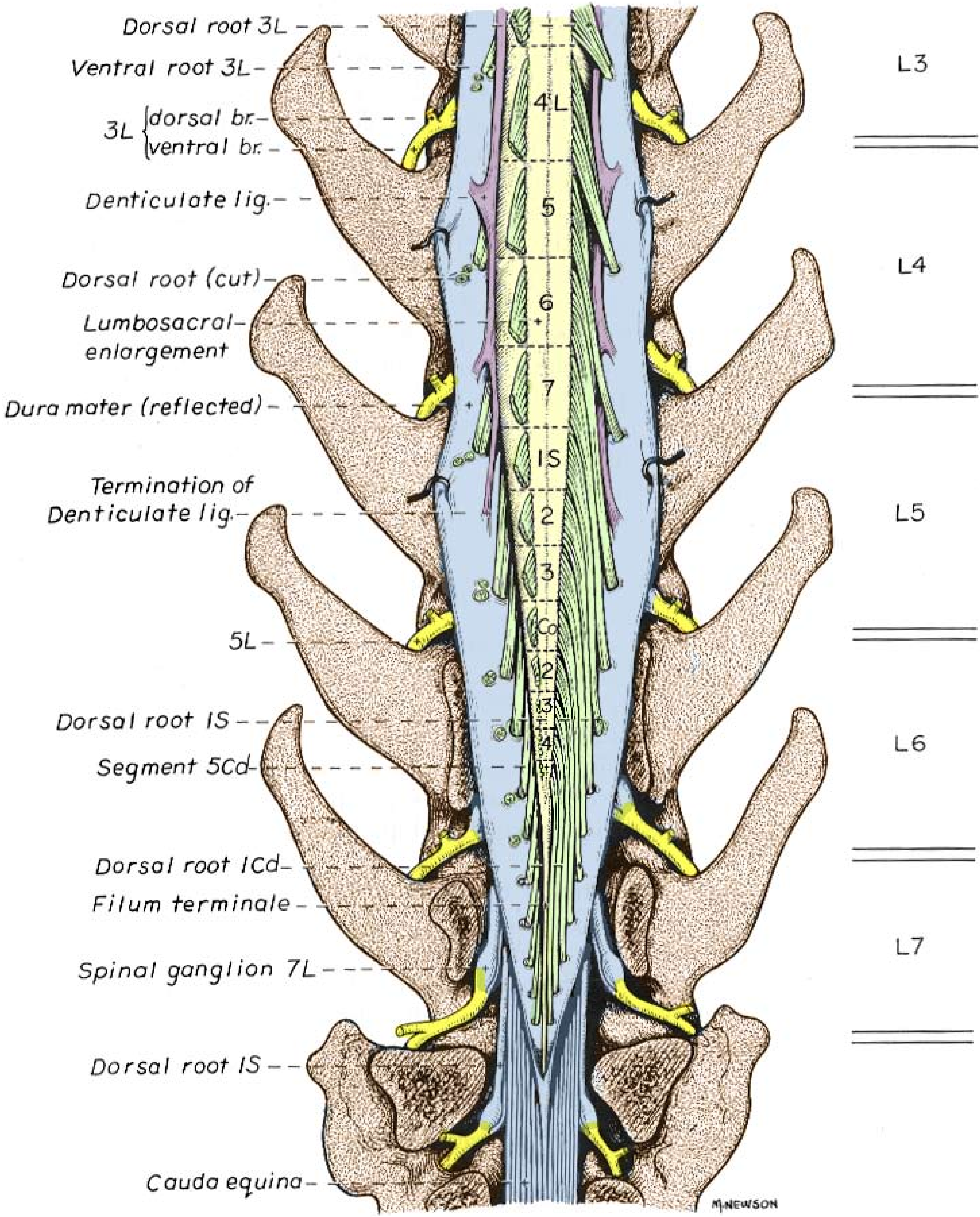

dm
*
DR
r
SG
VR
SN



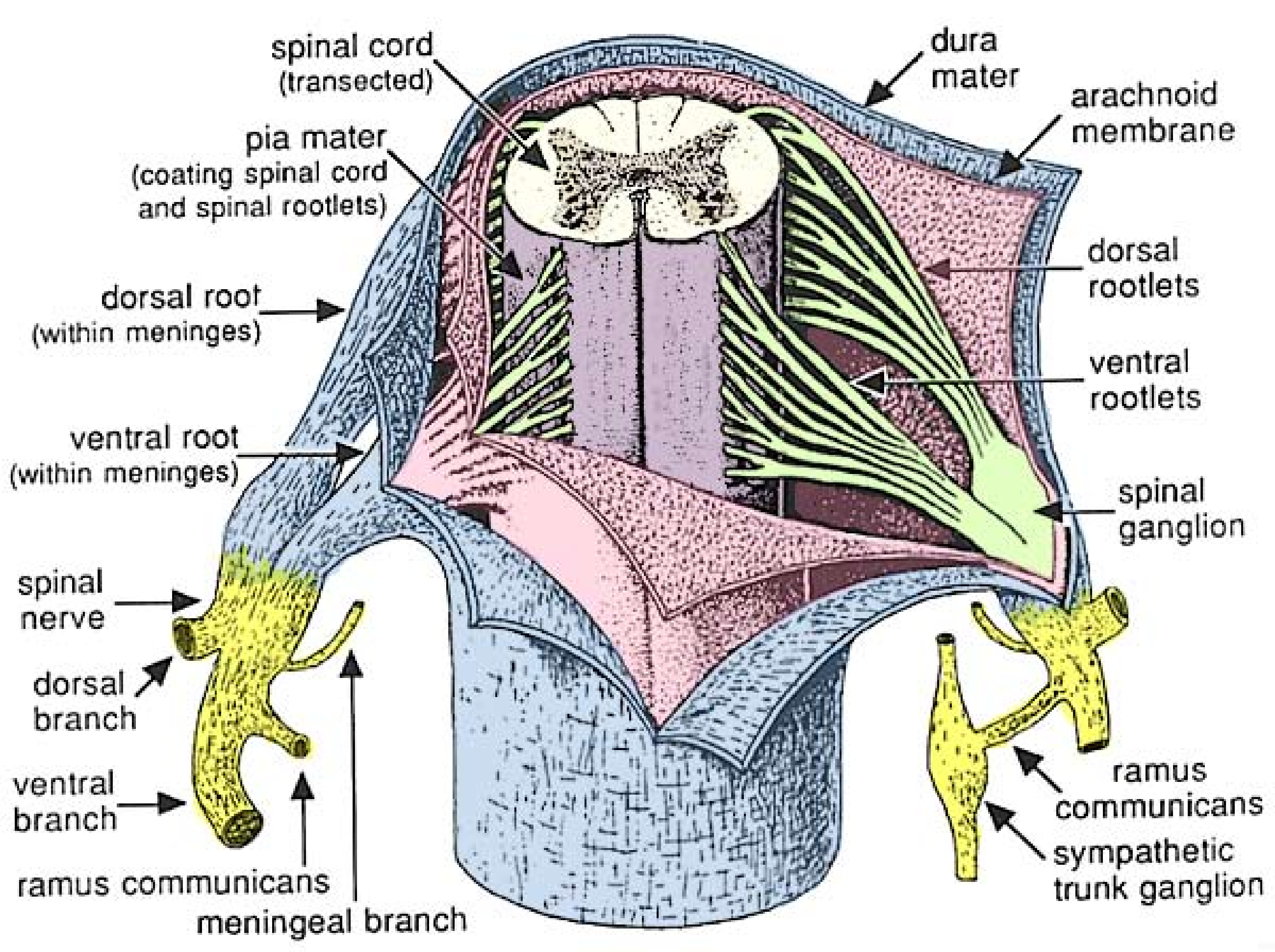
C1
C6
T3
L4
T7
L7
C2
C7
T13
S2
C3
T2
L2
Cd 2


N. 1C
N. 2C {ventral br. / dorsal br.
Accessory r.
Dorsal root n. 4C
Spinal ganglion n. 8C
N. 1T
N. 10T
C1
2
3
4
5
6
7
T1
2
3
4
5
6
7
8
9
10
11
Dorsal root n. 11T
Dura mater
N. 1L {ventral br. / dorsal br.
Segment 1Cd
Segment 5Cd
N. 7L
N. 1S
Cauda equina
N. 1Cd
N. 5Cd
Caudal ligament
T11
12
13
L1
2
3
4
5
6
7
S
Cd1
2
3
4
5
6


L2
S1
C1
Spinal cord
Dorsal root
ganglion of
1st sacral
nerve
Attachment
of dura
A
L1
S1
Dura
Lengthened
root of 1st
sacral nerve
B
T11
L1
L3
S1
Filum
terminale
internum
Dura
C



Dorsal root 3L
Ventral root 3L
3L dorsal br.
ventral br.
Denticulate lig.
Dorsal root (cut)
Lumbosacral enlargement
Dura mater (reflected)
Termination of Denticulate lig.
5L
Dorsal root 1S
Segment 5Cd
Dorsal root 1Cd
Filum terminale
Spinal ganglion 7L
Dorsal root 1S
Cauda equina
L3
L4
L5
L6
L7
4L
5
6
7
1S
2
3
Co
2
3
4
M. NEWSON


spinal cord
(transected)
dura
mater
arachnoid
membrane
pia mater
(coating spinal cord
and spinal rootlets)
dorsal
rootlets
dorsal root
(within meninges)
ventral
rootlets
ventral root
(within meninges)
spinal
ganglion
spinal
nerve
dorsal
branch
ventral
branch
ramus communicans
meningeal branch
ramus
communicans
sympathetic
trunk ganglion

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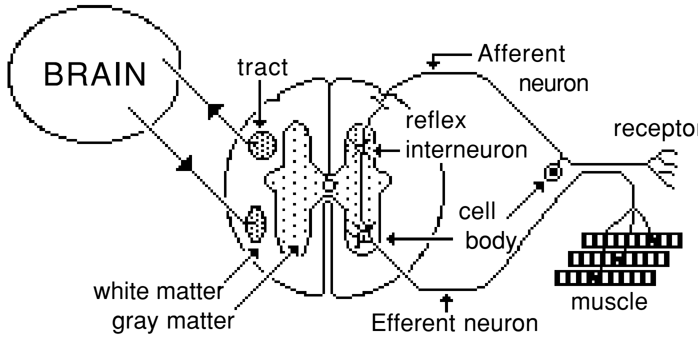

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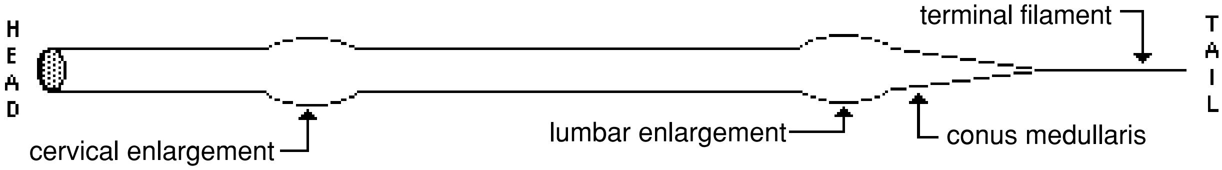

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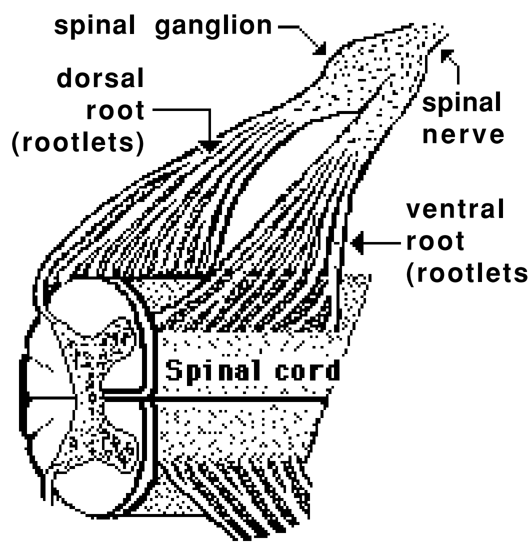

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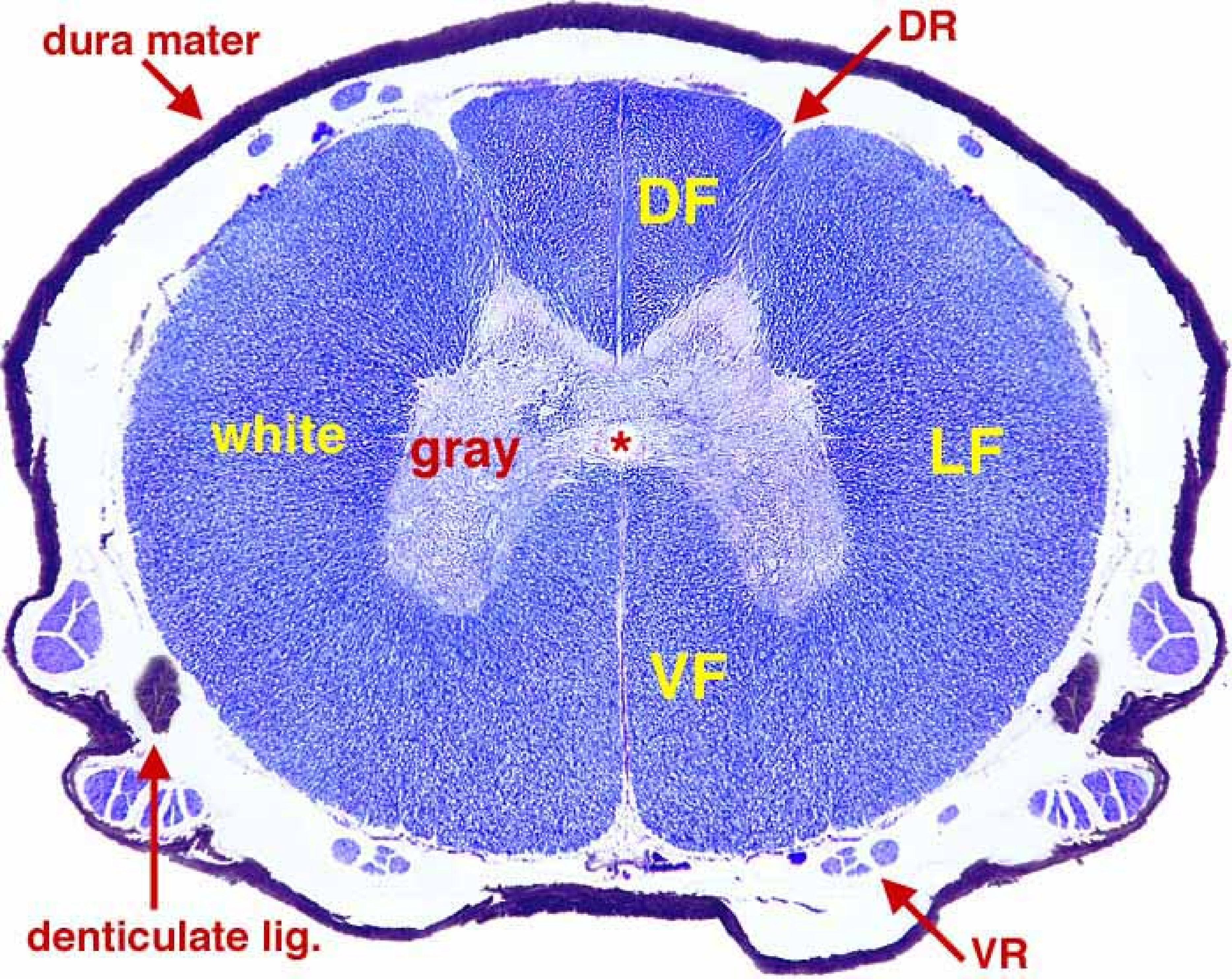
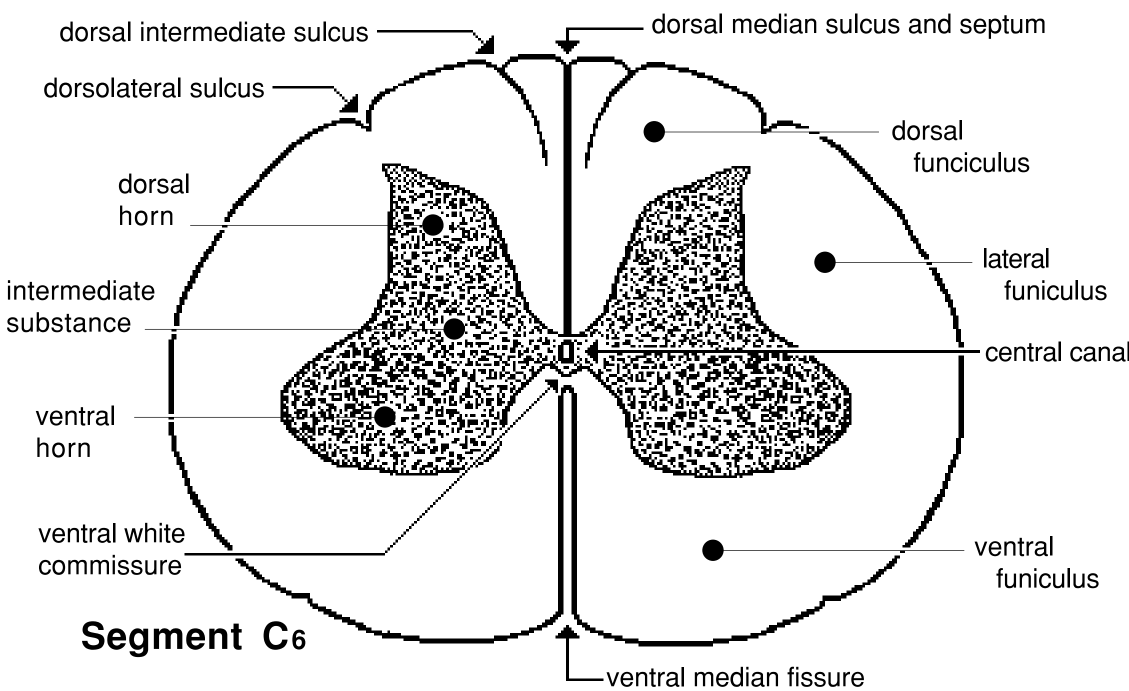

dura mater
DR
DF
white
gray
*
LF
VF
denticulate lig.
VR

White matter (derived from embryonic marginal layer) is superficial to gray matter. It is composed of concentrated myelinated fibers, gliocytes, and low capillary density. White matter regions include: dorsal funiculus; ventral funiculus; lateral funiculus; and white commissure.

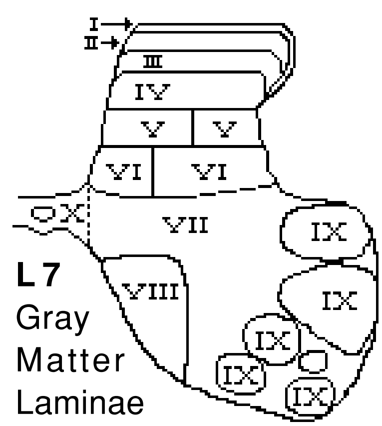


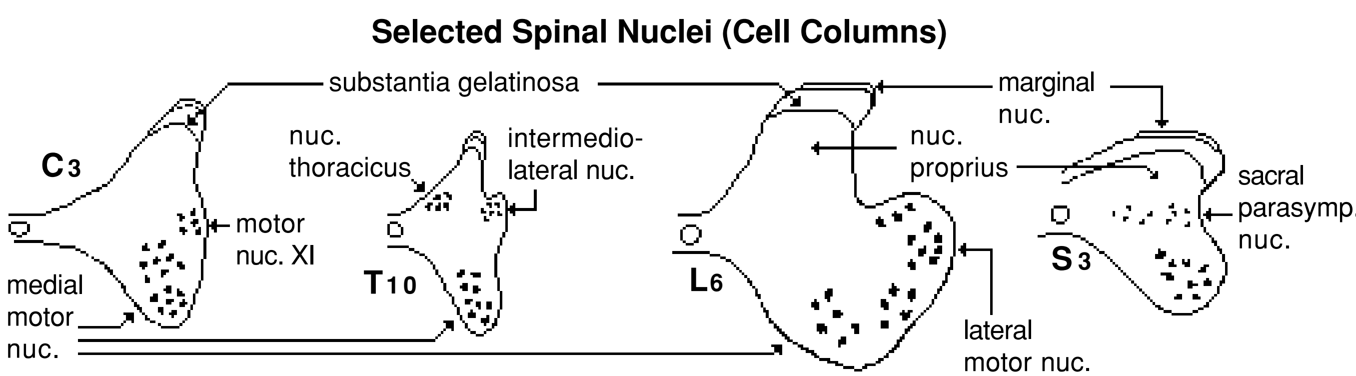
Gray matter organization:

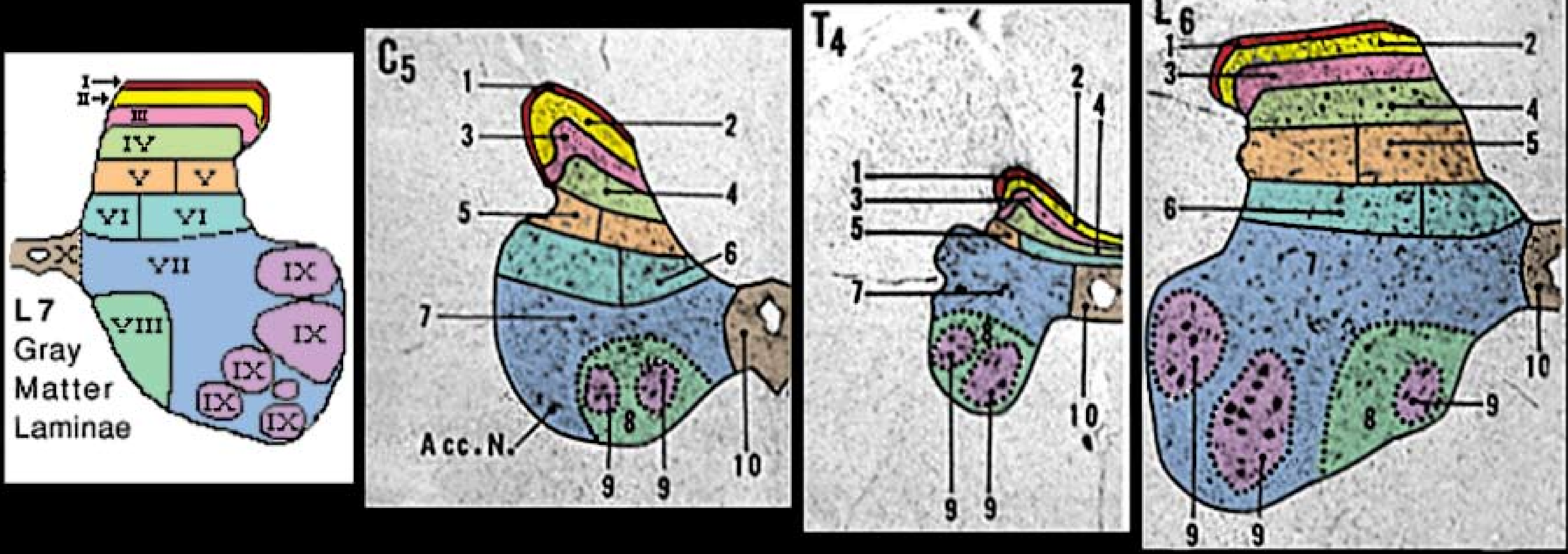
Two schemes have evolved for organizing neuron cell bodies within gray matter. Either may be used according to which works best for a particular circumstance.

1] **Spinal Laminae**—spinal gray matter is divided into ten laminae (originally based on observations of thick sections in a neonatal cat). The advantage is that all neurons are included. The disadvantage is that laminae are difficult to distinguish.

2] **Spinal Nuclei**—recognizable clusters of cells are identified as nuclei [a nucleus is a profile of a cell column]. The advantage is that distinct nuclei are generally detectable; the disadvantage is that the numerous neurons outside of distinct nuclei are not included.






I
II
III
IV
V
V
VI
VI
VII
VIII
IX
IX
IX
IX
IX
L 7
Gray
Matter
Laminae
C5
1
2
3
4
5
6
7
8
9
9
10
Acc. N.
T4
1
2
3
4
5
7
8
9
9
10
L6
1
2
3
4
5
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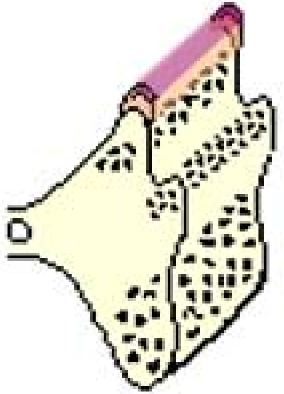
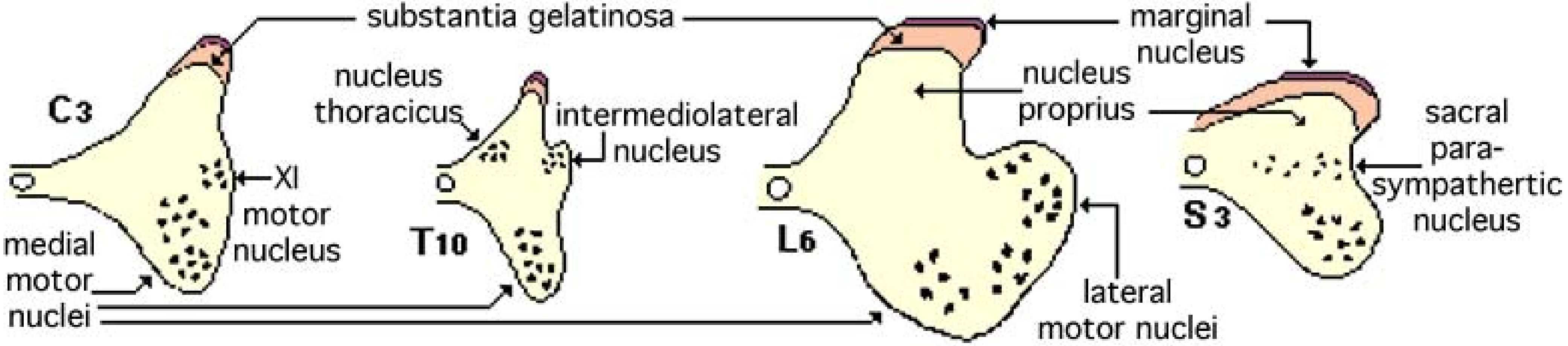
7
8
9
9
9
10

Spinal Cord
Neuron Cell Columns and Nuclei in Selected Gray Matter Segments





Types of spinal neurons:

All neurons in spinal cord gray matter have multipolar cell bodies. Based on axon destination, they can be divided into three major types, each of which has several subtypes:

1] **Efferent neurons** (embryologically derived from basal plate) send axons into the ventral root. Cell bodies of efferent neurons are located in ventral horn (somatic efferents) or in intermediate substance (visceral efferents).

• somatic efferent (SE) neurons:
 alpha motor neurons— innervate ordinary skeletal muscle fibers (motor units);
 gamma motor neurons—innervate intrafusal muscle fibers (within muscle spindles);
• visceral efferent (VE) neurons: preganglionic sympathetic and parasympathetic neurons.

2] **Projection neurons** send axons into spinal white matter to travel to the brain (or to a distant part of the spinal cord). The axons form *tracts* associated with ascending spinal pathways that have different functions.

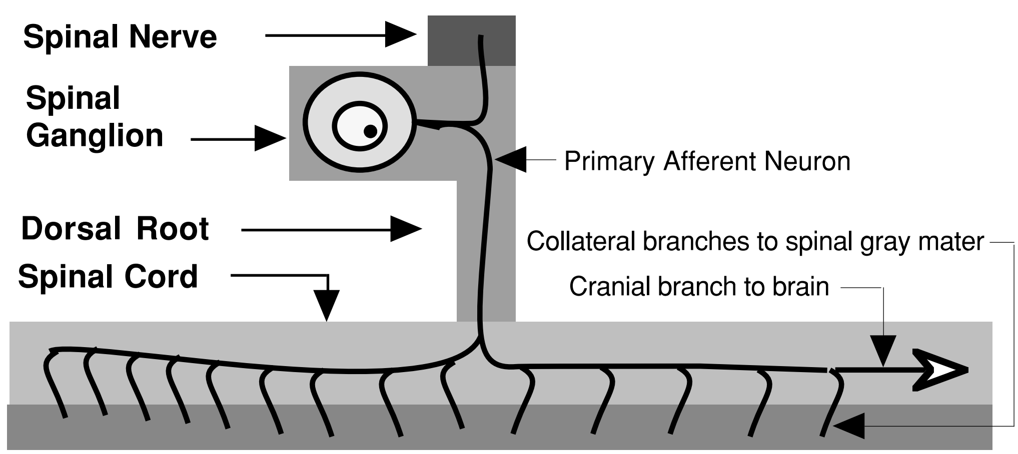
Projection neurons may be categorized according to the types of stimulation that ultimately excites them: Some projection neurons respond specifically to thermal or mechanical mild or noxious stimuli; however, many projection neurons respond non-specifically to both mild and noxious stimuli (they function to maintain alertness). Some projection neuron respond only to somatic stimuli (exteroceptors or proprioceptors); others respond to both somatic and visceral stimuli. The latter are the basis for the phenomenon of referred pain.

3] **Interneurons** have axons that remain within spinal gray matter. Interneurons are interposed between spinal input (from peripheral nerves or brain) and spinal output (efferent neurons). By establishing local circuits, interneurons "hardwire" input to output and thus determine the inherent reflex responses of the spinal cord (spinal reflexes).

Spinal Pathways

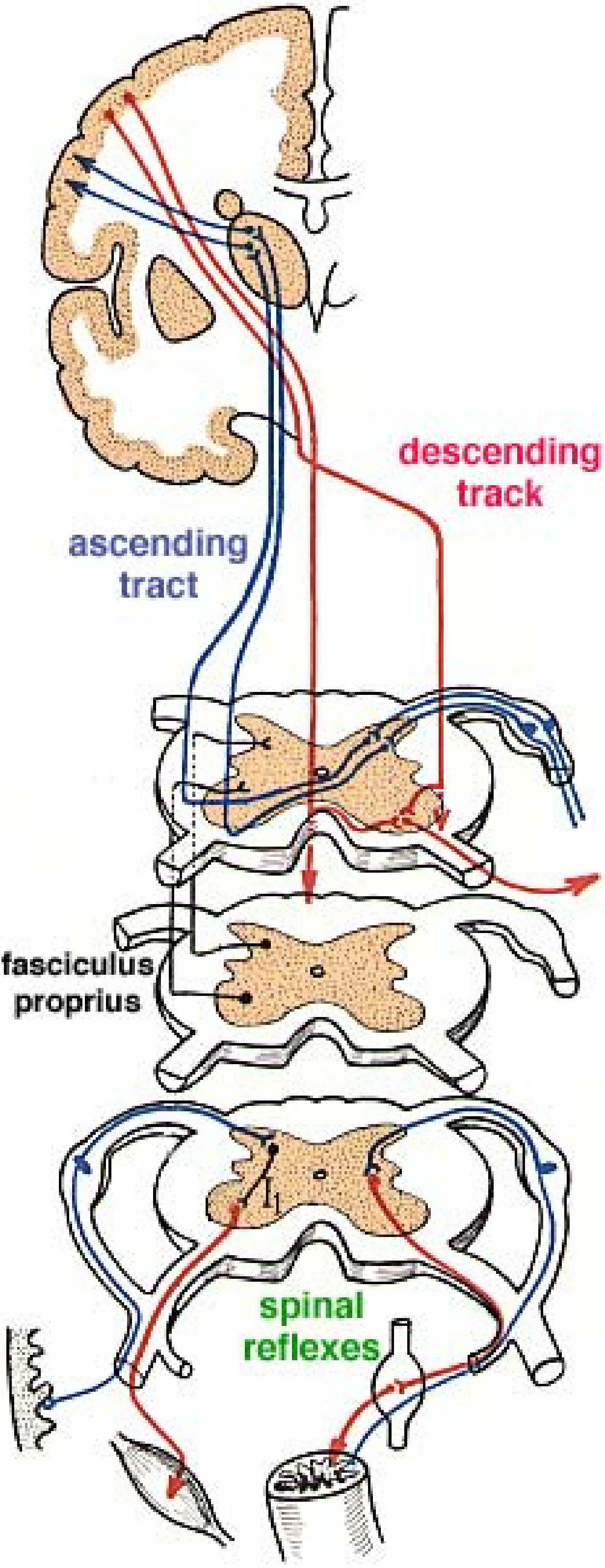
Primary Afferent Neuron = the first neuron in a spinal reflex or ascending spinal pathway.

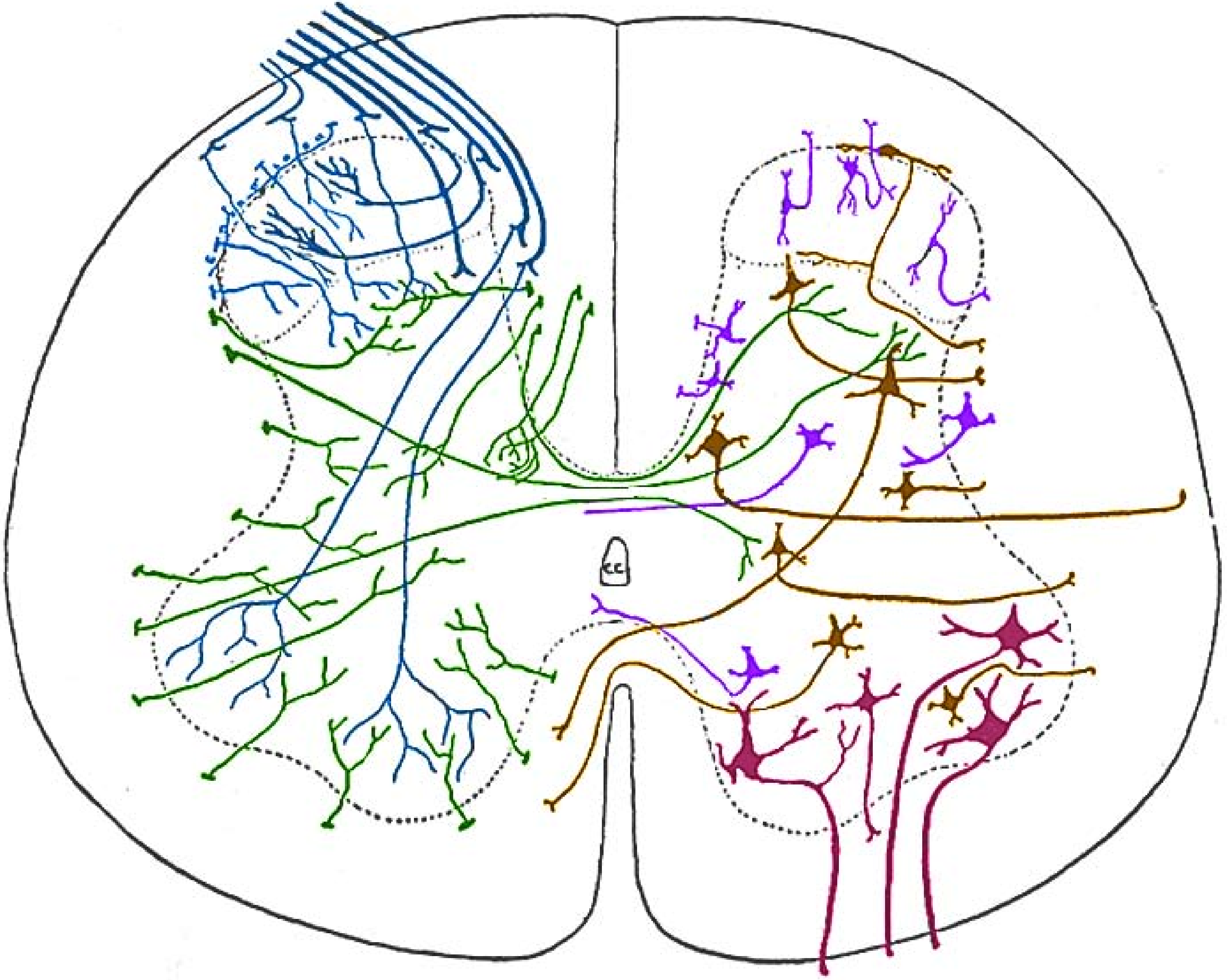
Primary afferent neurons have their unipolar cell bodies in spinal ganglia. Receptors are found at the peripheral terminations of their axons. Their axons traverse dorsal roots, penetrate the spinal cord (at the dorsolateral sulcus) and bifurcate into cranial and caudal branches which extend over several segments within white matter of the dorsal funiculus.

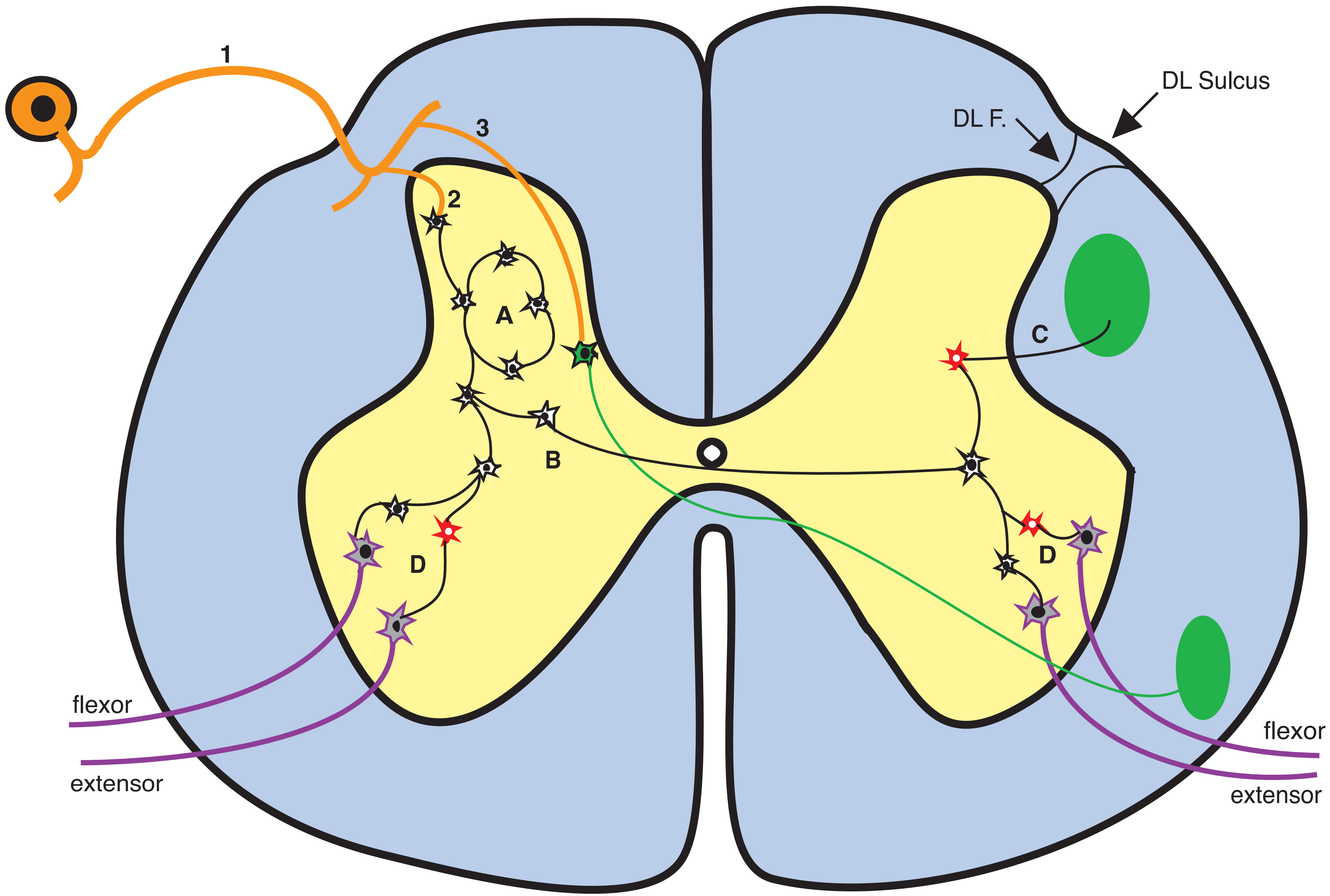


Collateral branches from the cranial and caudal branches enter the gray matter to synapse on interneurons and projection neurons (or directly on efferent neurons for the myotatic reflex).

In some cases (discriminative touch), the cranial branches of incoming axons ascend directly to the brainstem where they synapse on projection neurons of the pathway.


descending
track
ascending
tract
fasciculus
proprius
spinal
reflexes


cc



1
3
2
A
B
C
D
D
DL F.
DL Sulcus
flexor
extensor
flexor
extensor

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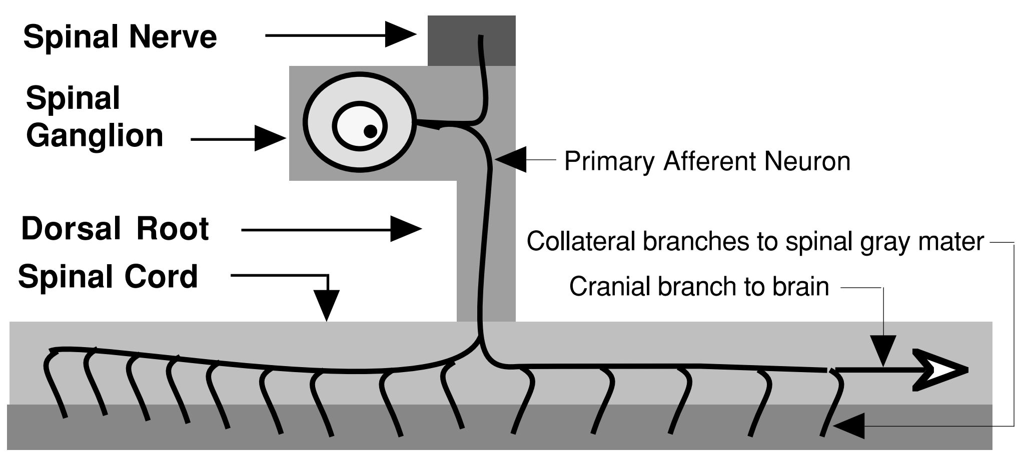

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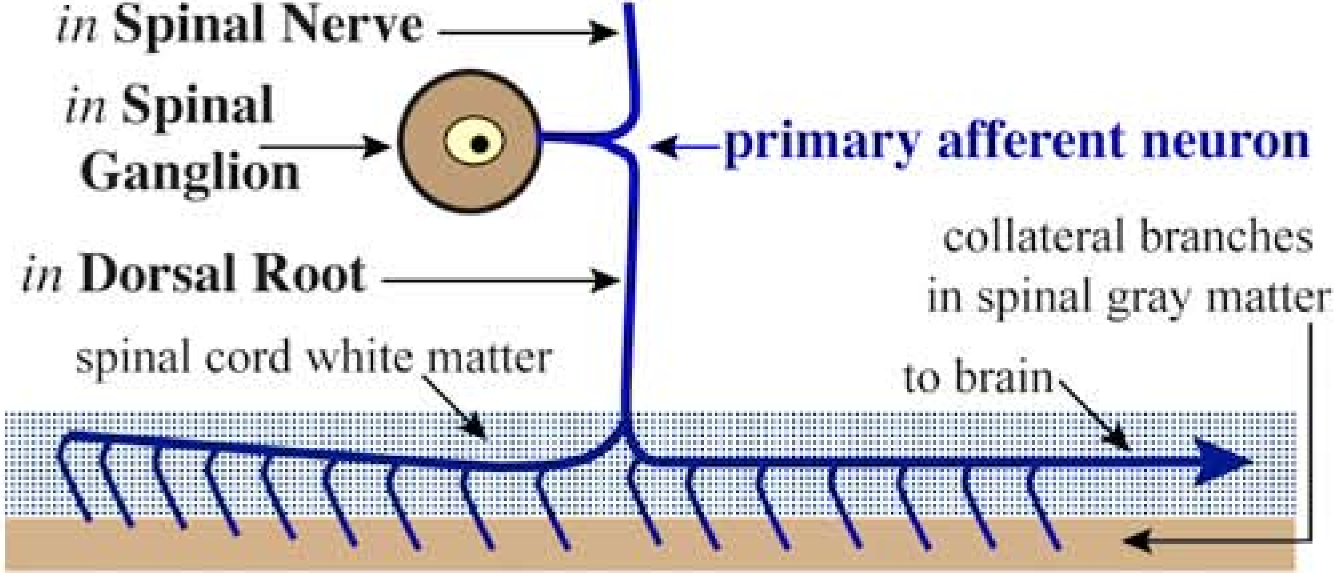
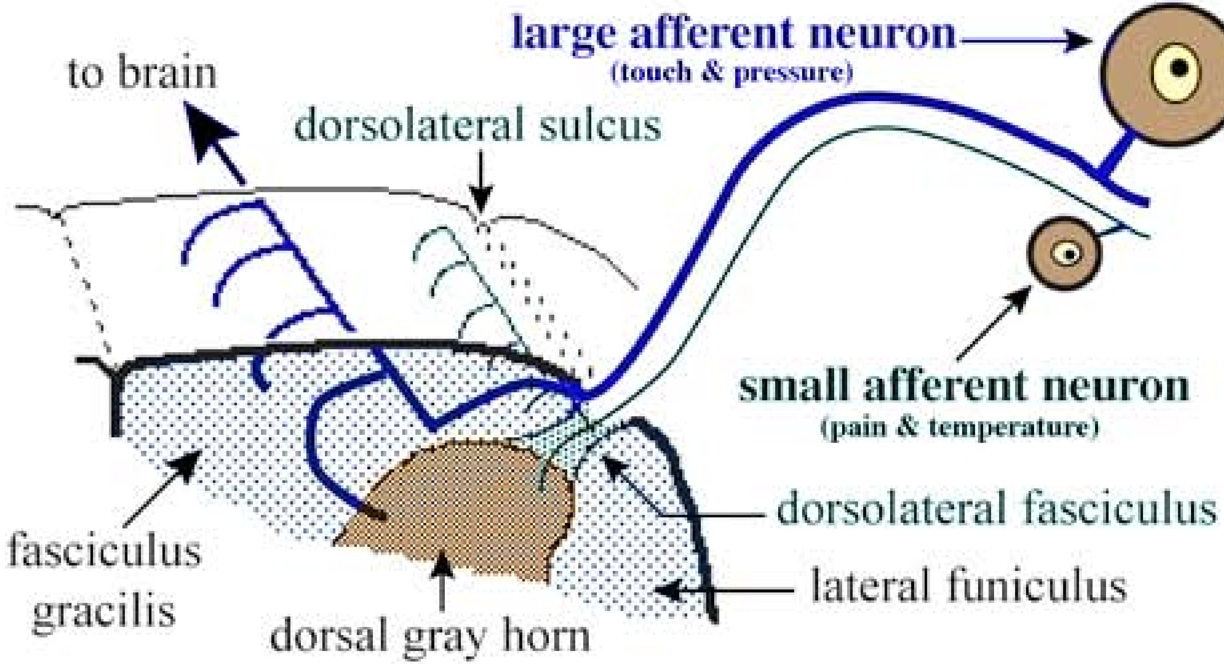
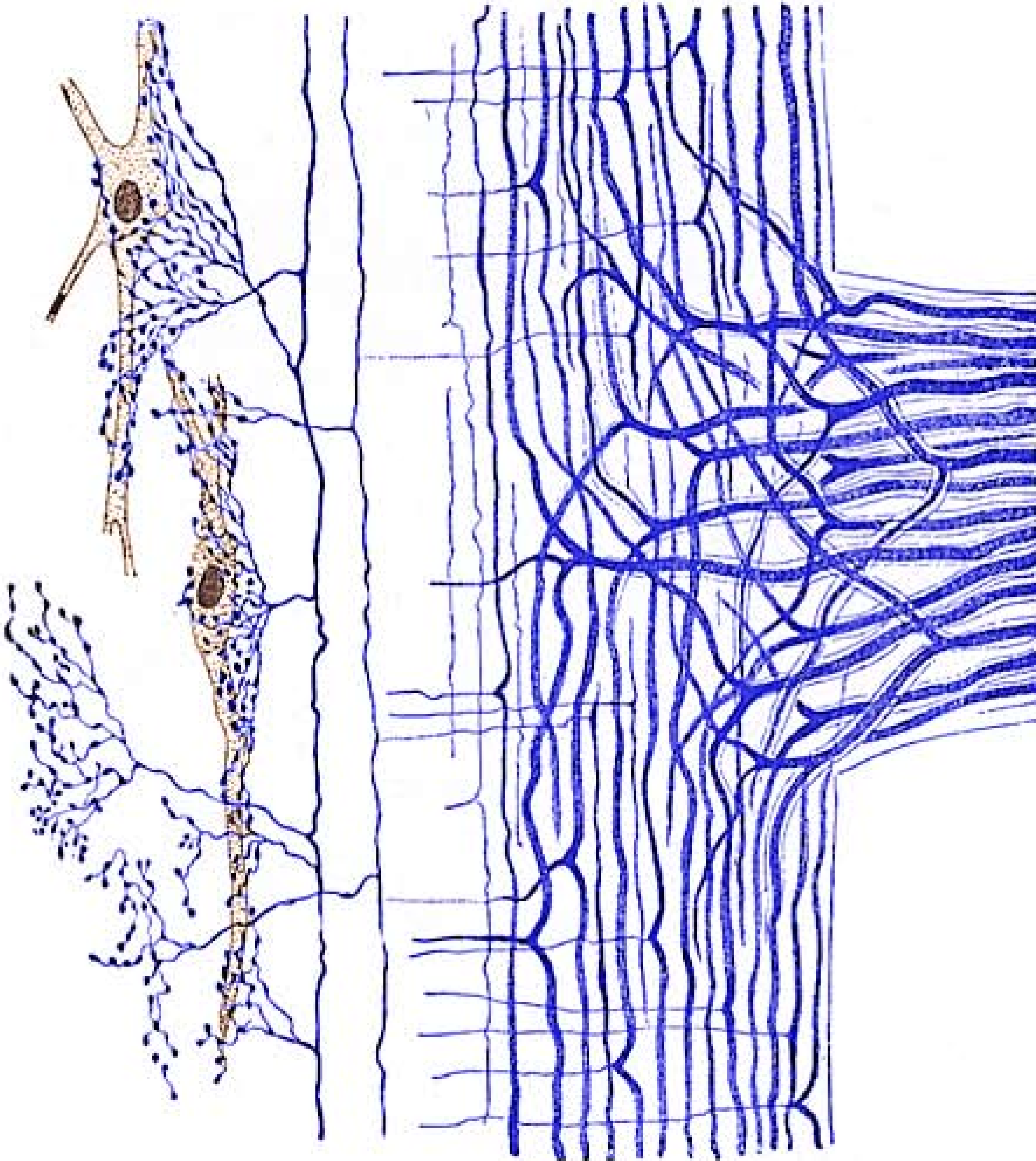
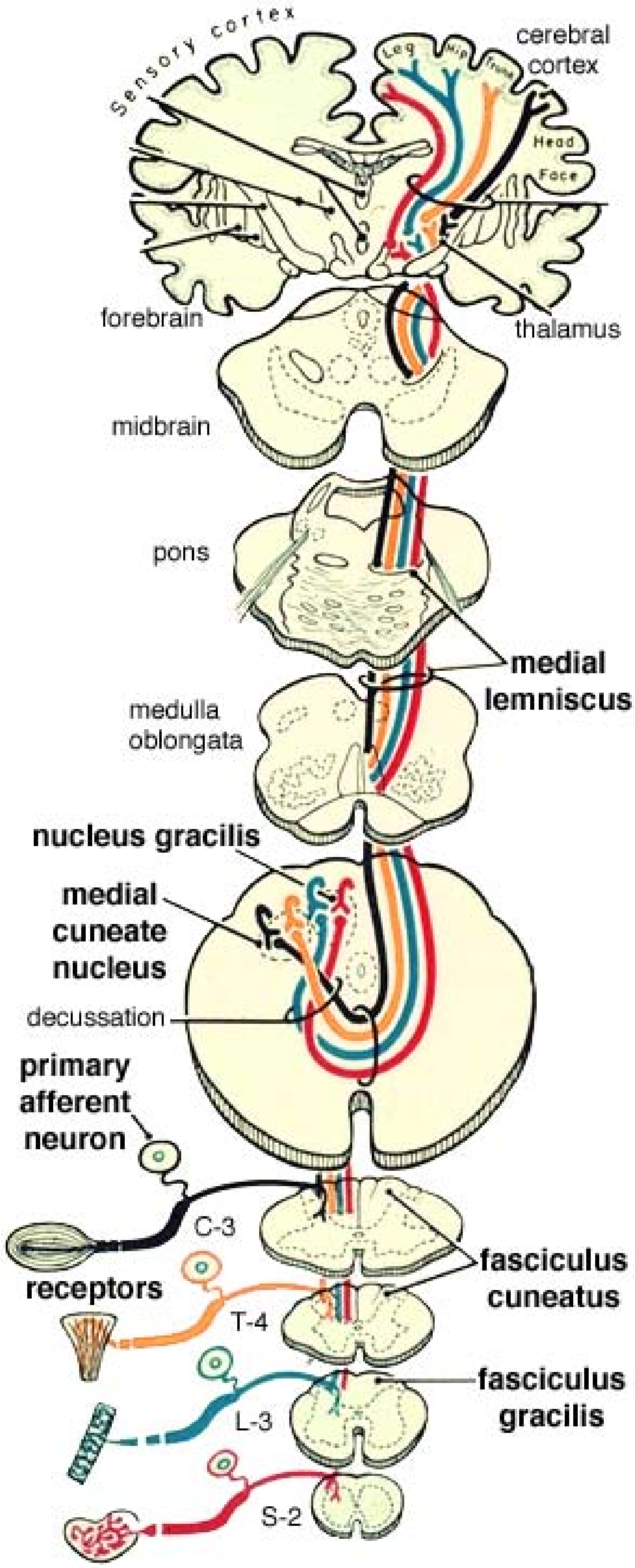

in Spinal Nerve
in Spinal Ganglion
primary afferent neuron
in Dorsal Root
collateral branches in spinal gray matter
spinal cord white matter
to brain


large afferent neuron
(touch & pressure)
to brain
dorsolateral sulcus
small afferent neuron
(pain & temperature)
dorsolateral fasciculus
lateral funiculus
fasciculus gracilis
dorsal gray horn





Sensory cortex
cerebral cortex
Leg
Hip
Trunk
Head
Face
forebrain
thalamus
midbrain
pons
medial lemniscus
medulla oblongata
nucleus gracilis
medial cuneate nucleus
decussation
primary afferent neuron
C-3
receptors
T-4
L-3
S-2
fasciculus cuneatus
fasciculus gracilis

> *Note:* **Pathway** = sequence (chain) of neurons synaptically linked to convey excitability changes from one site to another.

Ascending Pathways:

Chains of neurons carrying information from receptors to the brain (cerebral cortex).

Neuronal sequence:

Primary afferent neurons synapse on projection neurons typically located in spinal gray matter. The axons of projection neurons join *ascending tracts* and synapse on neurons in the brain. Ultimately, the pathway leads to thalamic neurons that project to the cerebral cortex.

The function of a particular pathway is determined by: 1] which primary afferent neurons synapse on the particular projection neurons of the pathway, and 2] where the projection neurons synapse in the brain.

In general, pathways may be categorized into three broad functional types:

1] *Conscious* discrimination/localization (e.g., pricking pain, warmth, cold, discriminative touch, kinesthesia) requires a specific ascending spinal pathway to the contralateral thalamus which, in turn, sends an axonal projection to the cerebral cortex. Generally there are three neurons in the conscious pathway and the axon of the projection neuron decussates and joins a contralateral tract (see the first two pathways on the following page; the third pathway is the one exception to the general rule).

2] *Affective* related (emotional & alerting behavior) information involves ascending spinal pathways to the brainstem. Projection neurons are non-specific. They receive synaptic input of different modalities and signal an ongoing magnitude of sensory activity, but they cannot signal where or what activity.

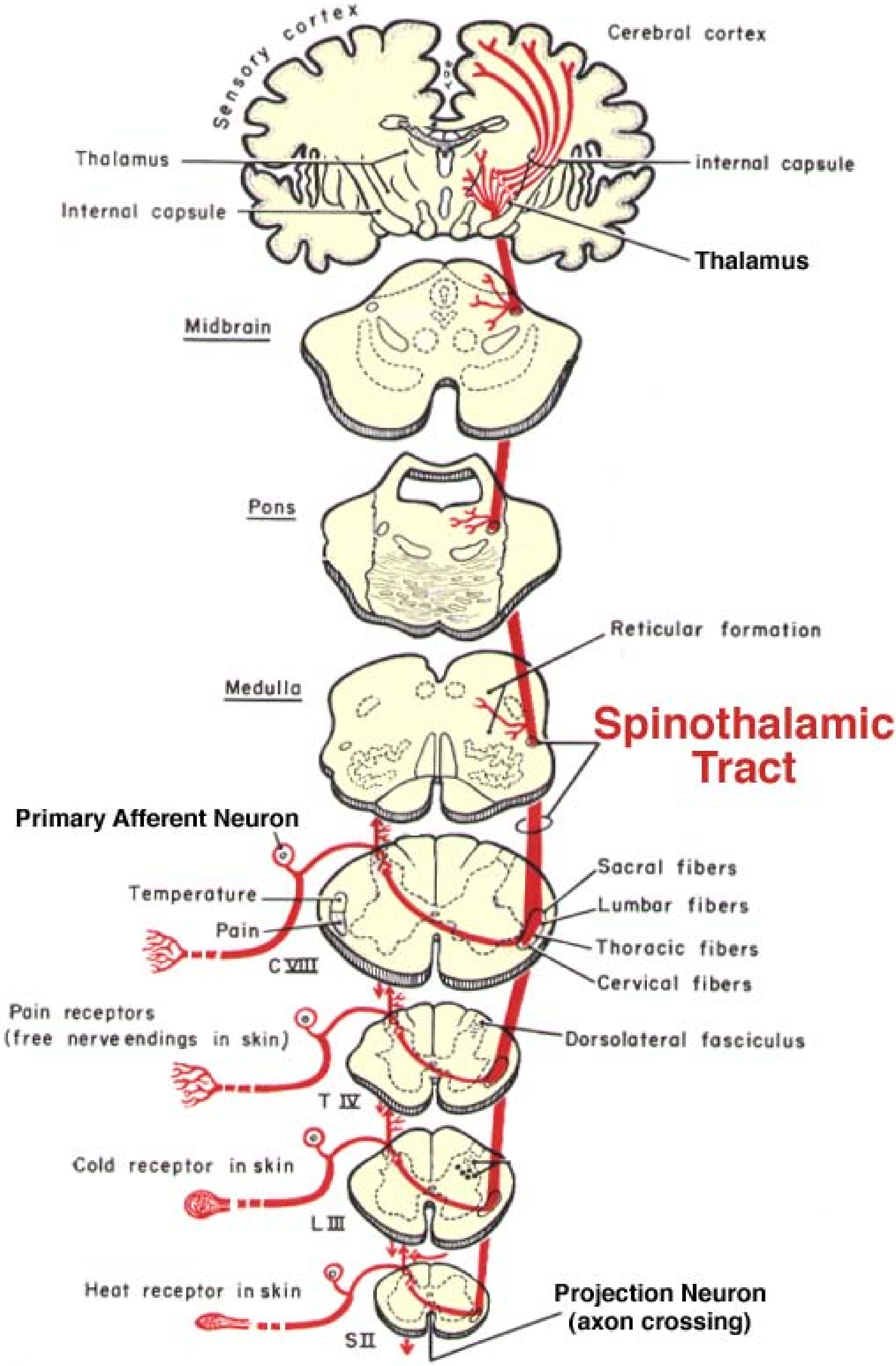
3] *Subconscious* sensory feedback for posture/movement control involves ascending spinal pathways principally to the cerebellum or brainstem nuclei that project to the cerebellum. Generally there are only two neurons in a subconscious pathway and the axon of the projection neuron joins an ipsilateral tract (see the last pathway on the following page).

Descending Spinal Pathways:

Axons of brain projection neurons travel in descending tracts in spinal white matter. They arise from various locations in the brain and synapse primarily on interneurons.

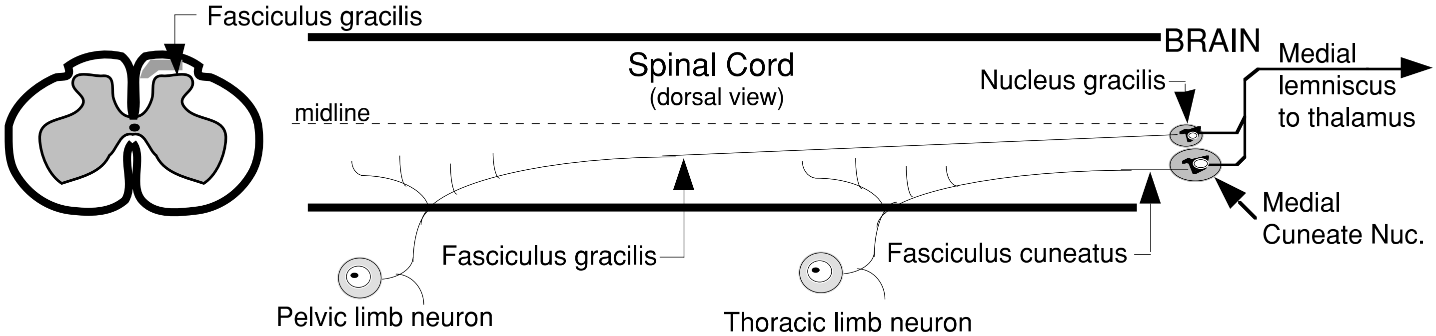
By synapsing on interneurons, descending tracts regulate:

1] spinal reflexes;
2] excitability of efferent neurons (for posture and movement); and
3] excitability of spinal projection neurons, i.e., the brain is able to regulate sensory input to itself. In some cases, descending tracts affect axon terminals of primary afferent neurons, blocking release of neurotransmitter (presynaptic inhibition).

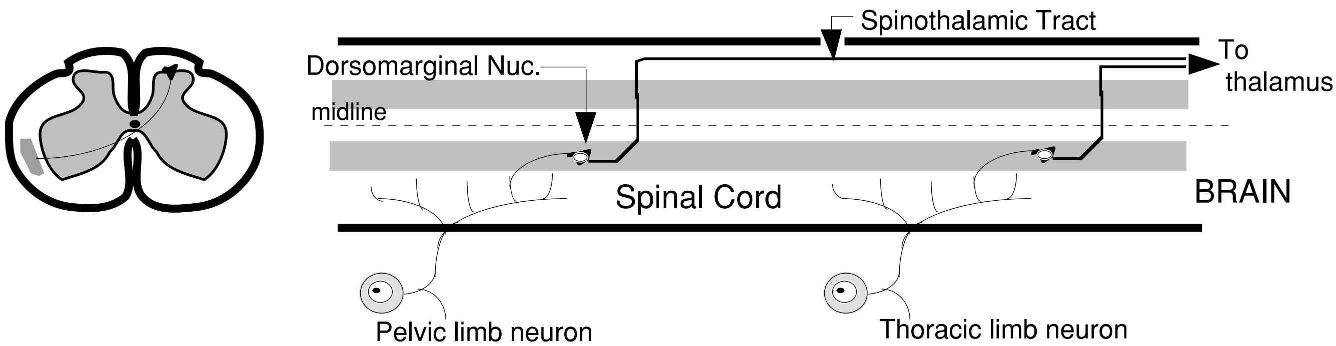

Sensory cortex
Cerebral cortex
Thalamus
internal capsule
Internal capsule
Thalamus
Midbrain
Pons
Reticular formation
Medulla
Spinothalamic Tract
Primary Afferent Neuron
Sacral fibers
Temperature
Lumbar fibers
Pain
Thoracic fibers
C VIII
Cervical fibers
Pain receptors
(free nerve endings in skin)
Dorsolateral fasciculus
T IV
Cold receptor in skin
L III
Heat receptor in skin
Projection Neuron
(axon crossing)
S II

Ascending Pathway Examples

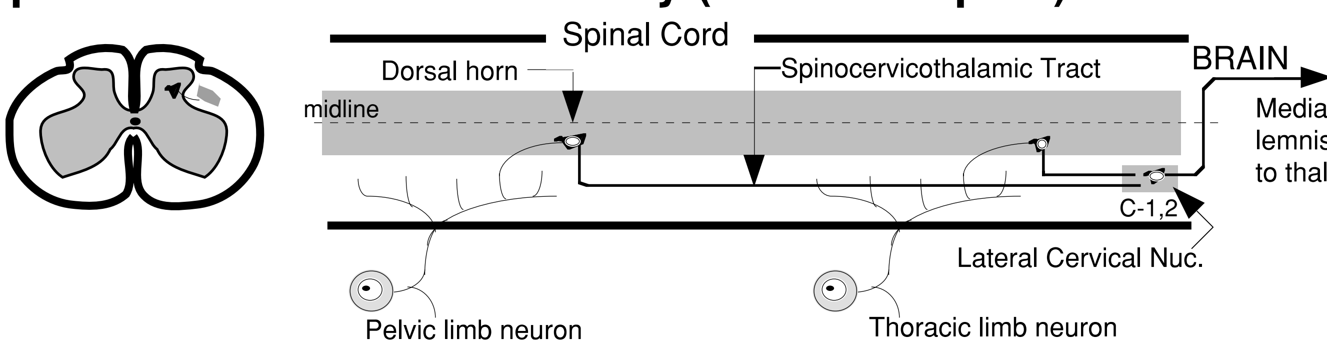
Discriminative Touch Spinal Pathway



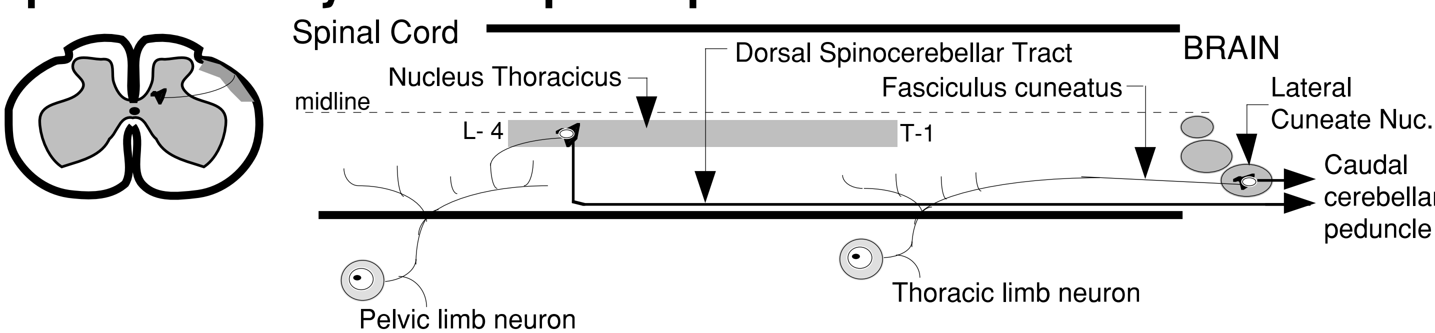
Spinothalamic Pathway (pain & temperature)



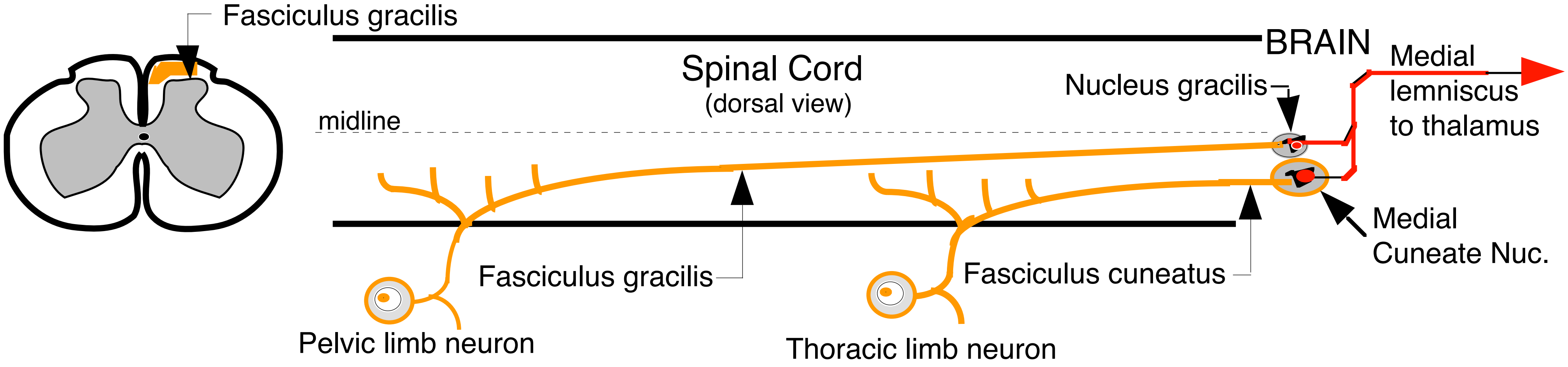
Spinocervicothalamic Pathway (touch and pain)



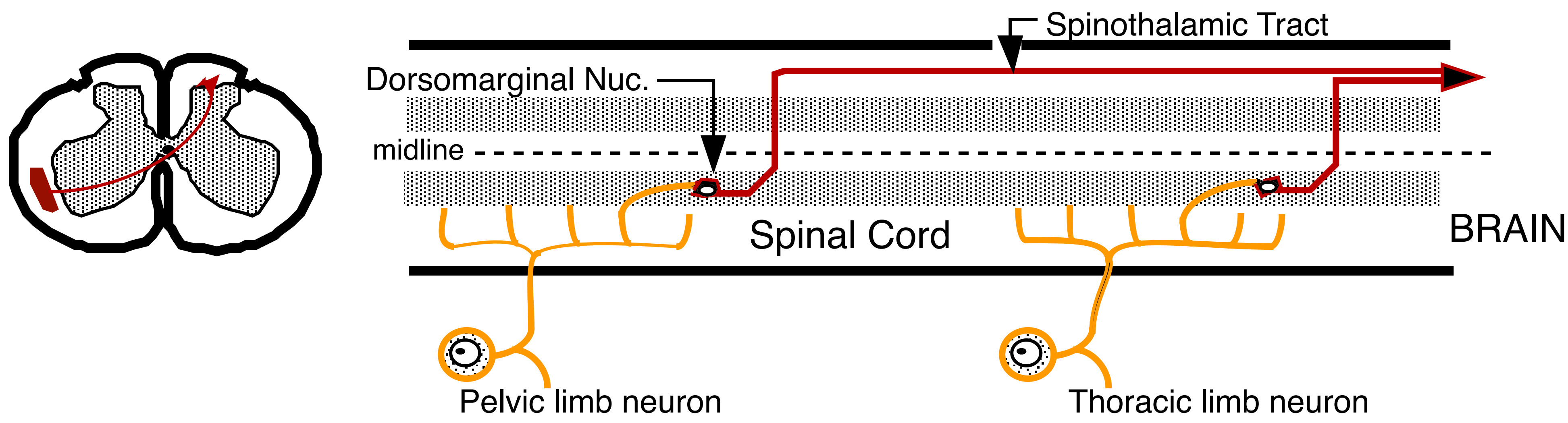
Spinal Pathways for Proprioceptive Feedback to Cerebellum



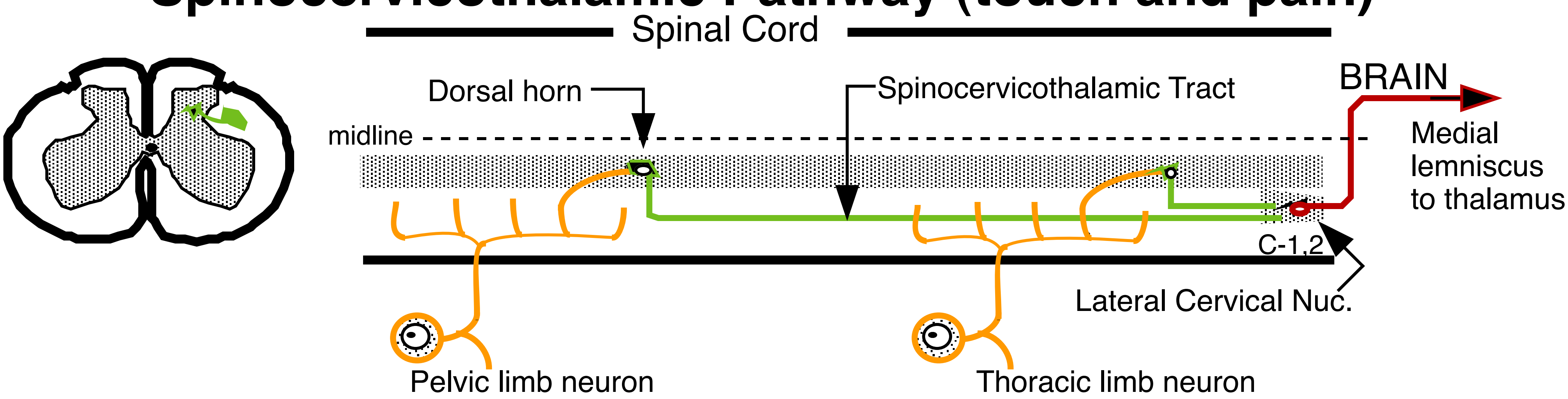
Discriminative Touch Spinal Pathway

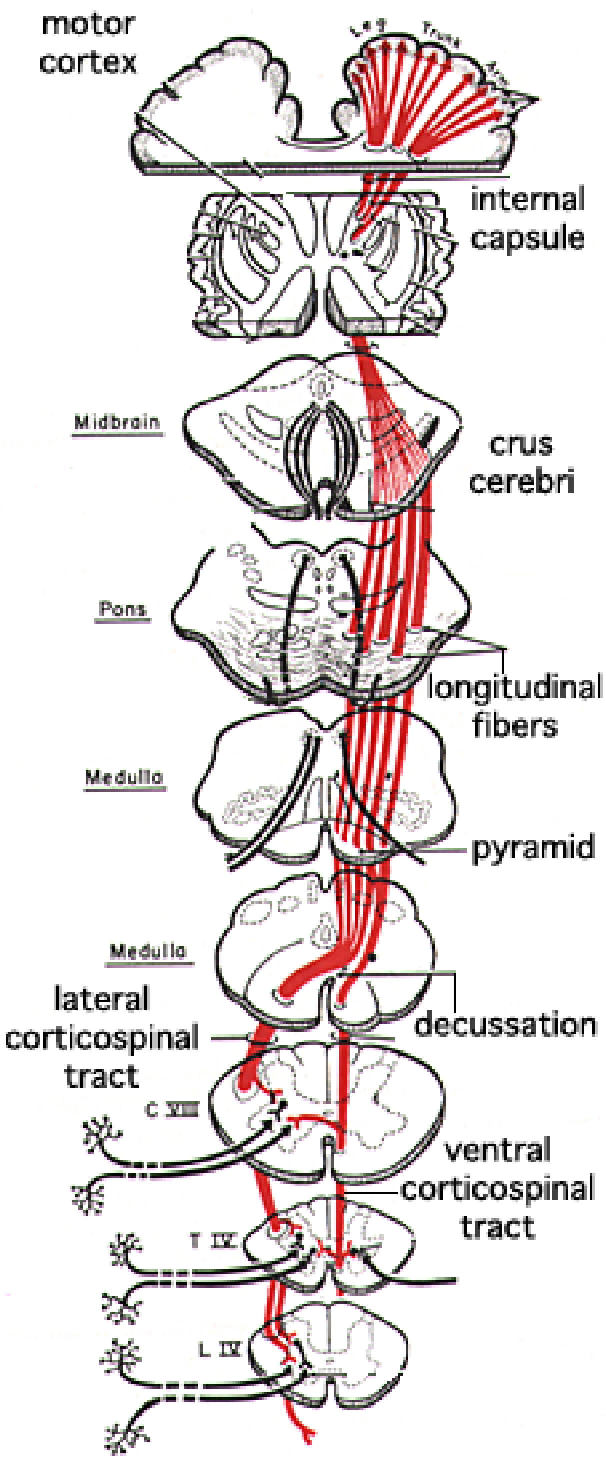


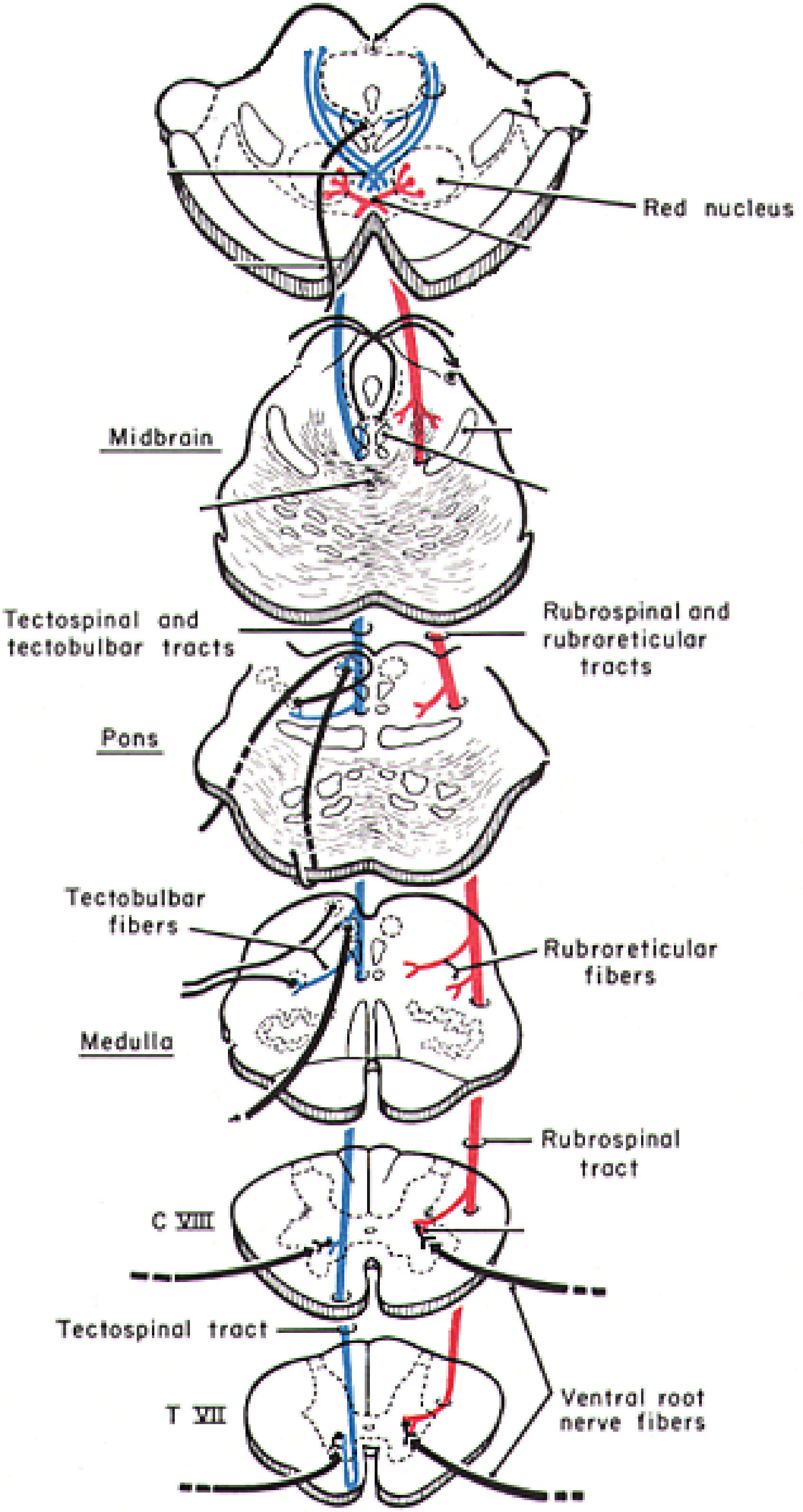
Spinothalamic Pathway (pain & temperature)



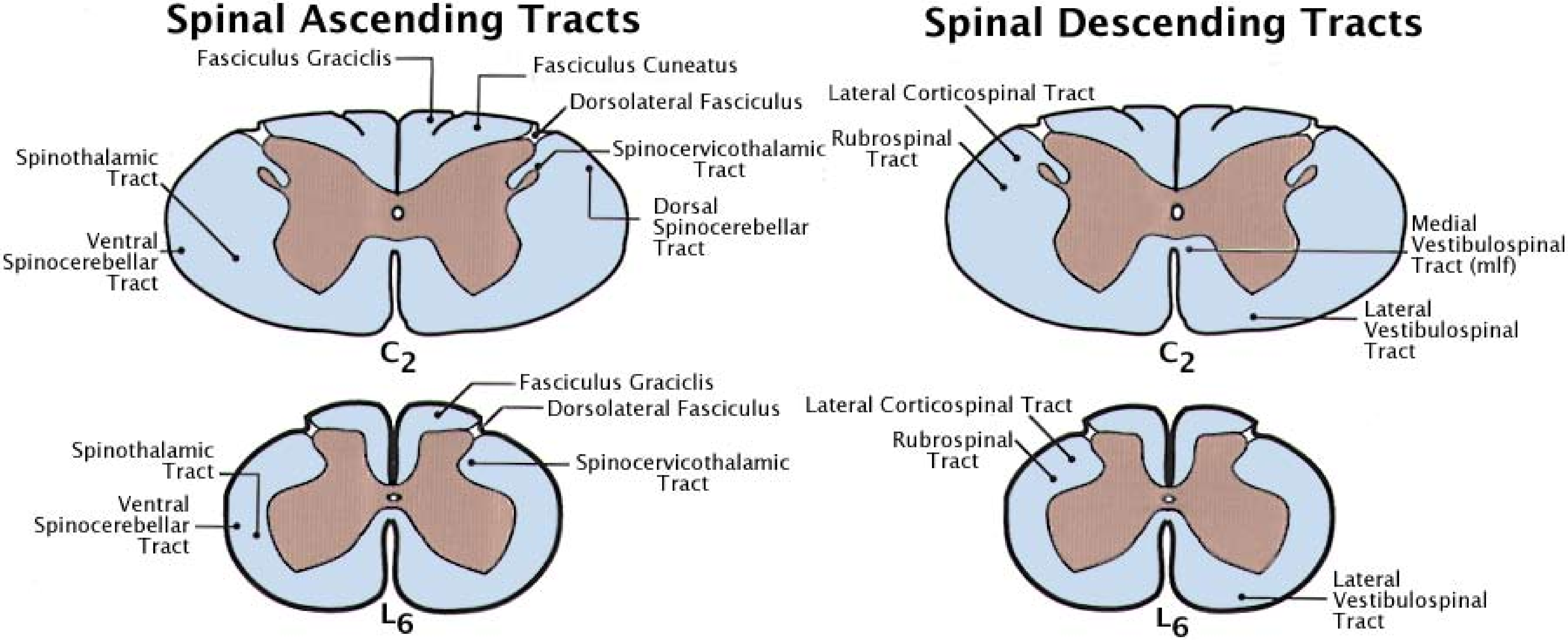
Spinocervicothalamic Pathway (touch and pain)

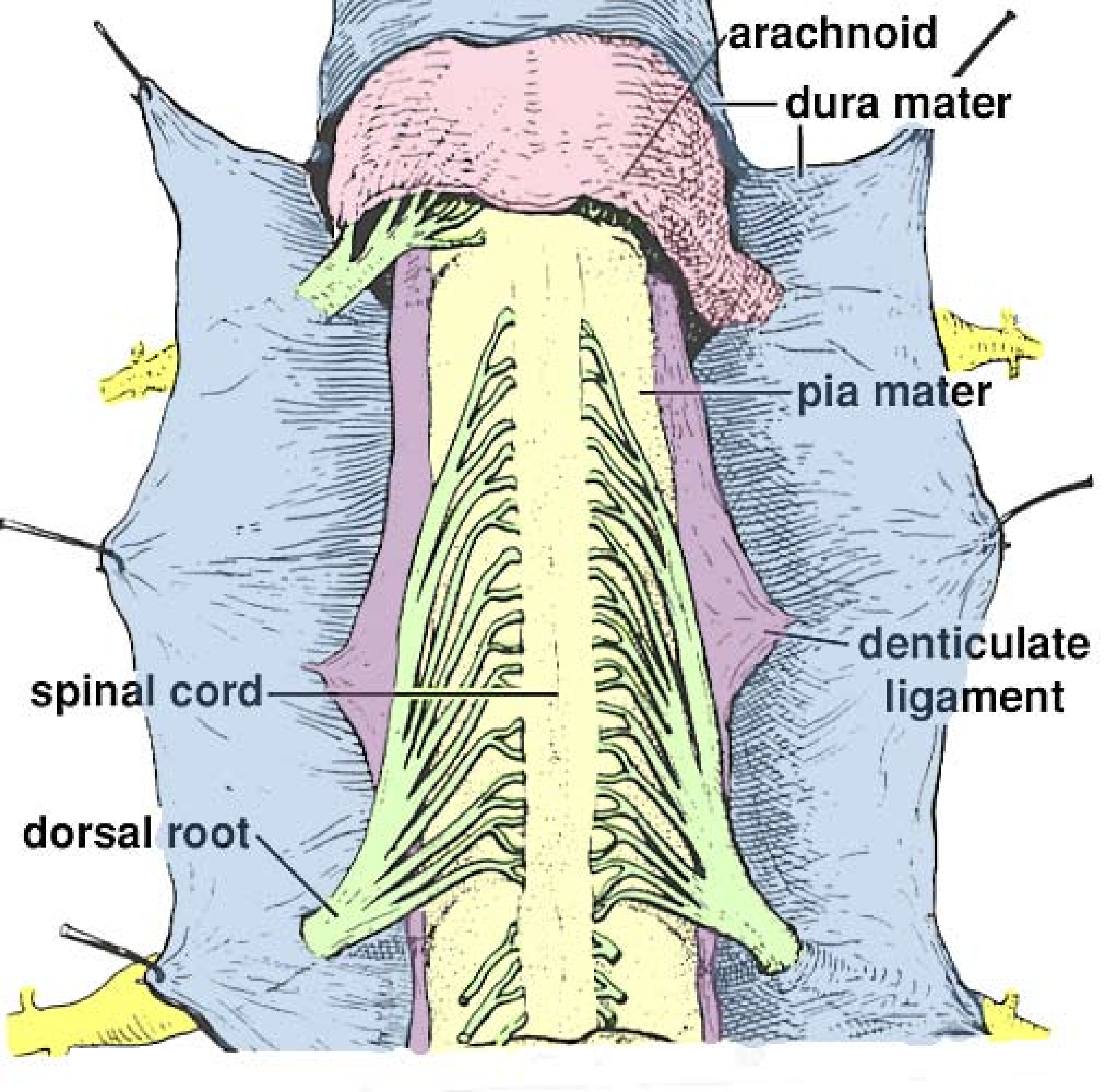


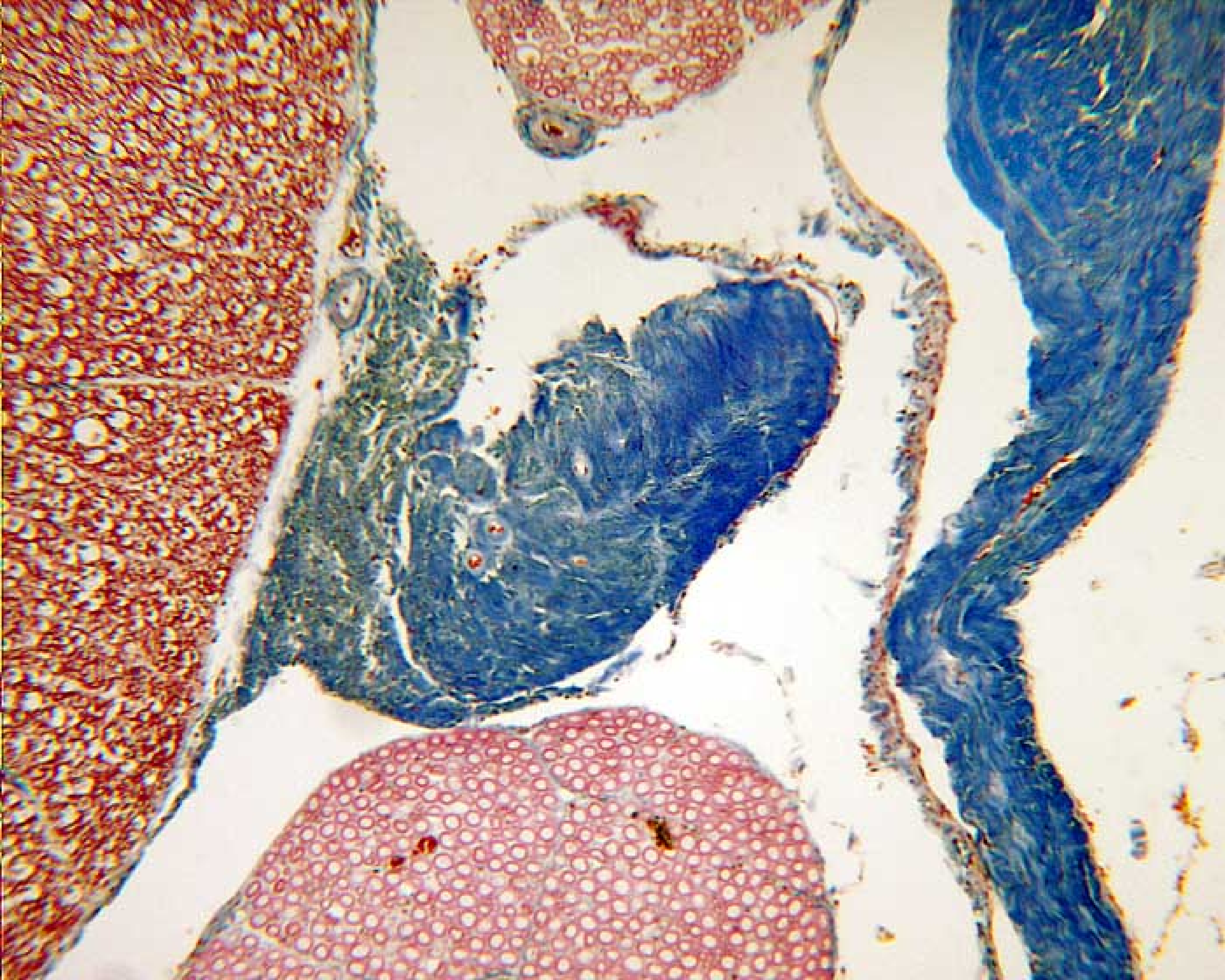

motor cortex
Leg
Trunk
internal capsule
Midbrain
crus cerebri
Pons
longitudinal fibers
Medulla
pyramid
Medulla
lateral corticospinal tract
decussation
C VIII
ventral corticospinal tract
T IV
L IV

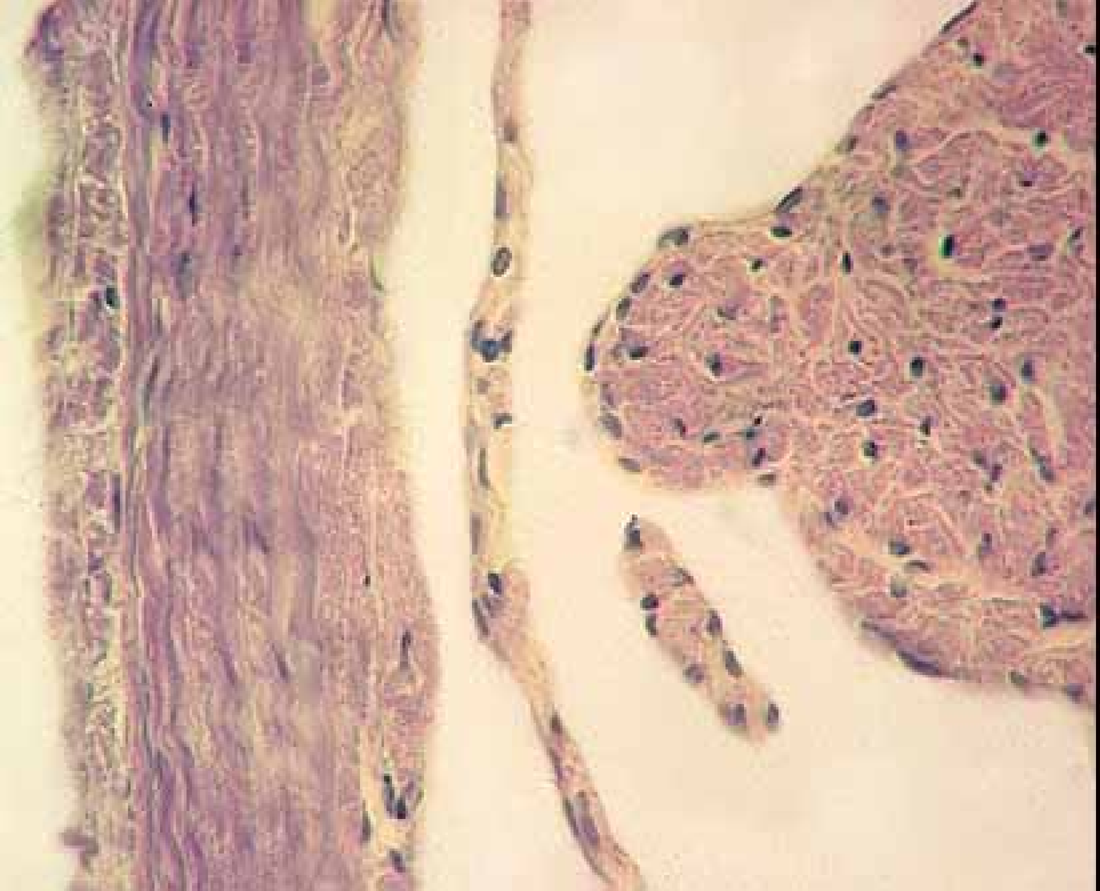


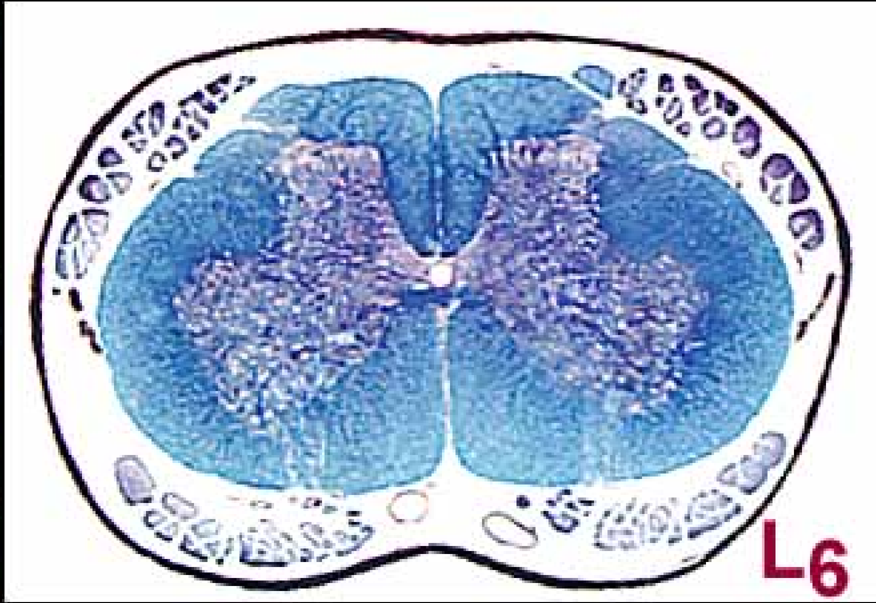
Red nucleus
Midbrain
Tectospinal and
tectobulbar tracts
Rubrospinal and
rubroreticular
tracts
Pons
Tectobulbar
fibers
Rubroreticular
fibers
Medulla
Rubrospinal
tract
C VIII
Tectospinal tract
T VII
Ventral root
nerve fibers

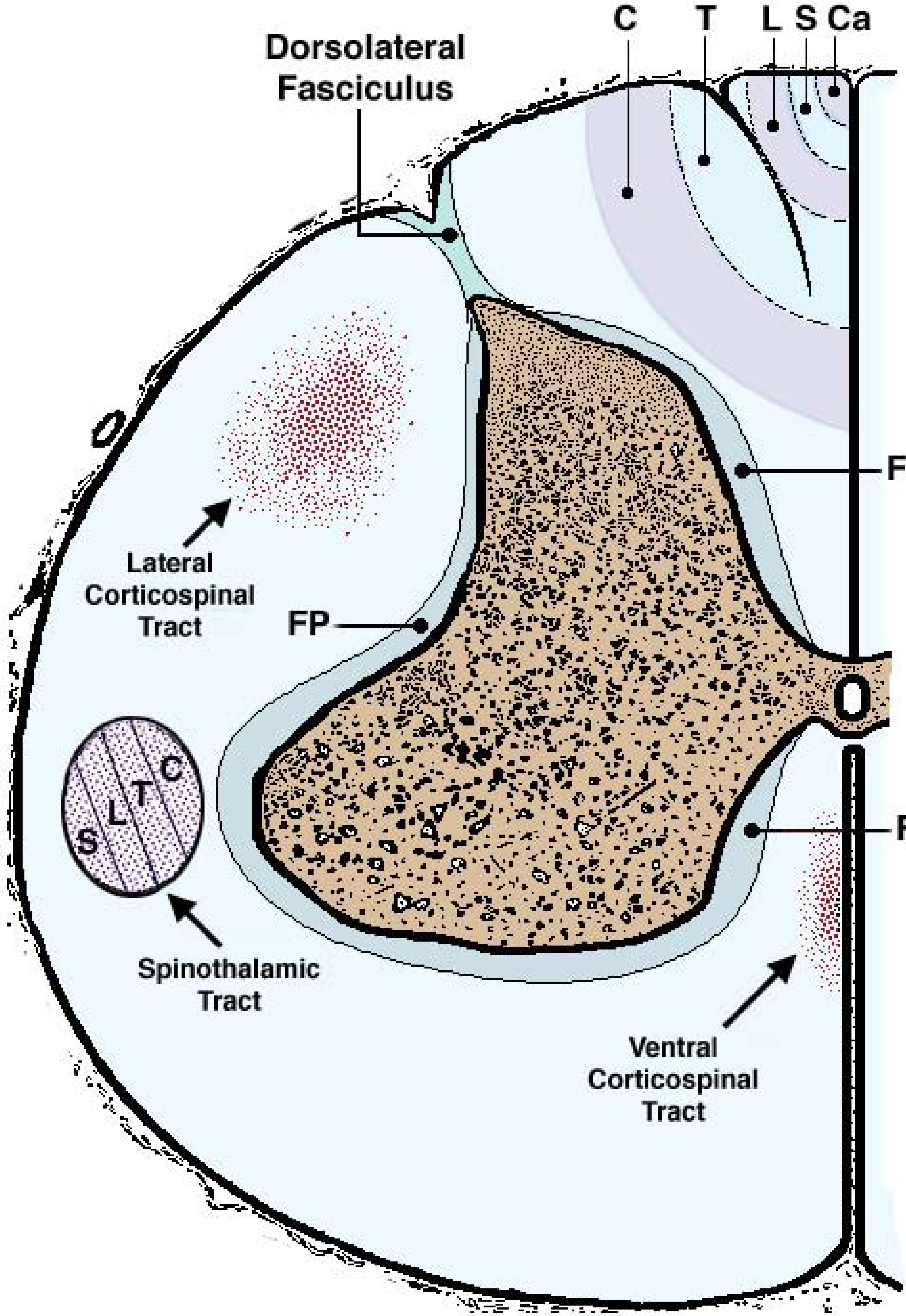

Spinal Ascending Tracts
Fasciculus Graciclis
Fasciculus Cuneatus
Dorsolateral Fasciculus
Spinothalamic Tract
Spinocervicothalamic Tract
Dorsal Spinocerebellar Tract
Ventral Spinocerebellar Tract
C2
Fasciculus Graciclis
Dorsolateral Fasciculus
Spinothalamic Tract
Spinocervicothalamic Tract
Ventral Spinocerebellar Tract
L6
Spinal Descending Tracts
Lateral Corticospinal Tract
Rubrospinal Tract
Medial Vestibulospinal Tract (mlf)
Lateral Vestibulospinal Tract
C2
Lateral Corticospinal Tract
Rubrospinal Tract
Lateral Vestibulospinal Tract
L6


arachnoid
dura mater
pia mater
denticulate ligament
spinal cord
dorsal root






L6


C
T
L
S
Ca
Dorsolateral
Fasciculus
FP
Lateral
Corticospinal
Tract
FP
C
T
L
S
FP
Spinothalamic
Tract
Ventral
Corticospinal
Tract