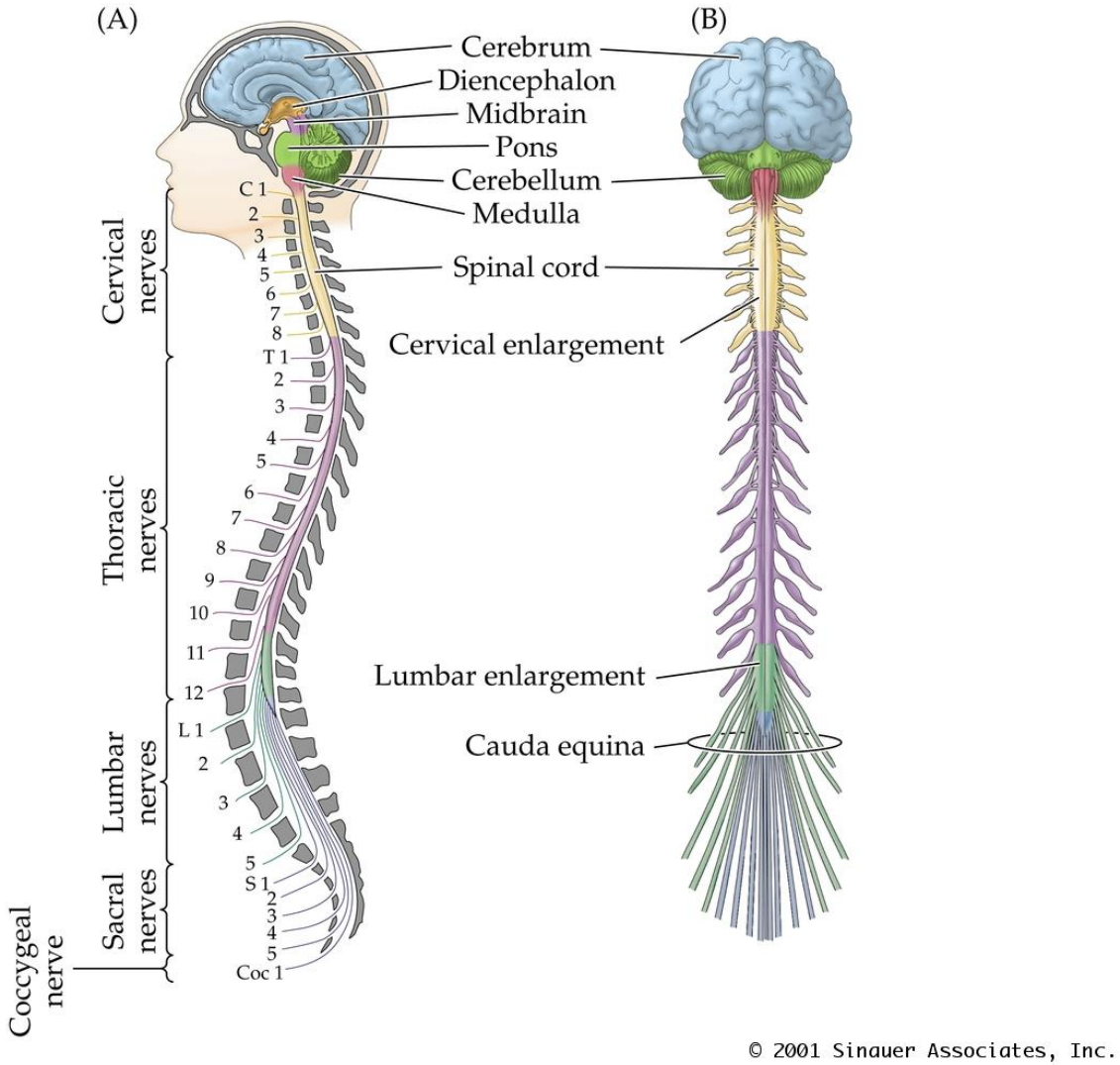
# NS201C

# Anatomy 1: Sensory and Motor Systems

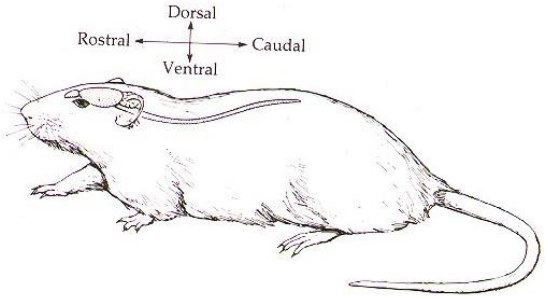
25th January 2017

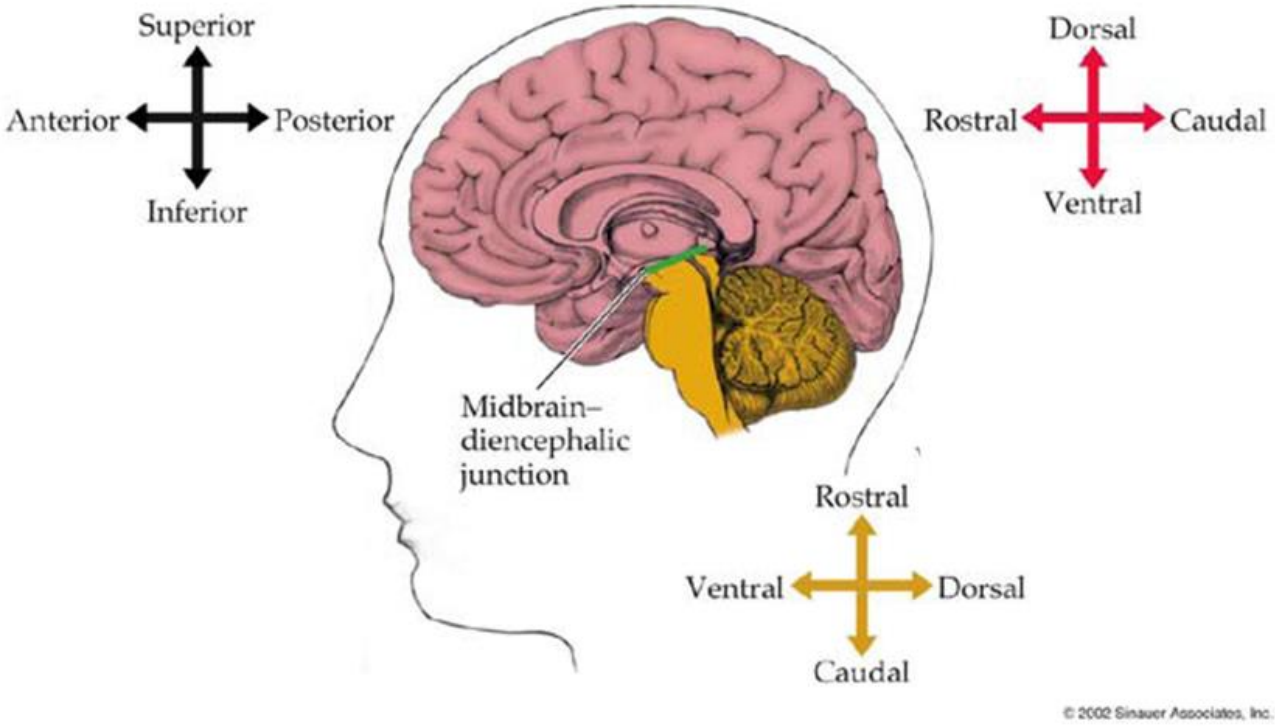
Peter Ohara
Department of Anatomy
peter.ohara@ucsf.edu

# The Subdivisions and Components of the Central Nervous System

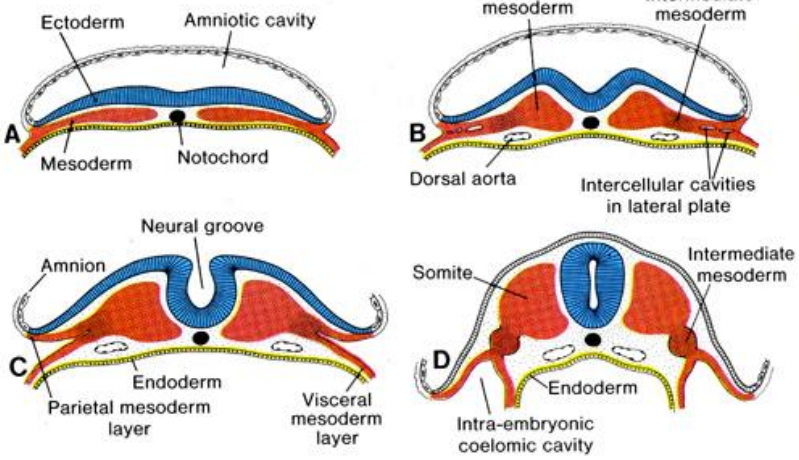


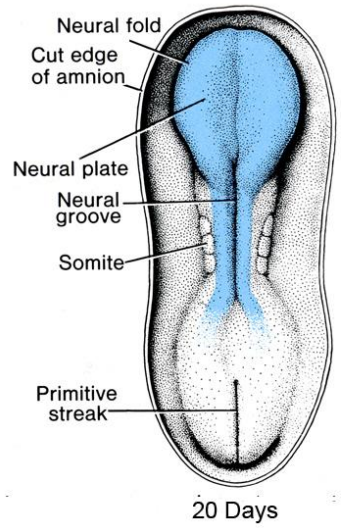
# Axes and Anatomical Planes of Sections of the Human and Rat Brain

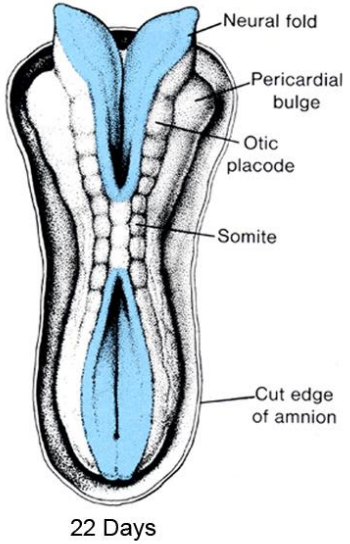


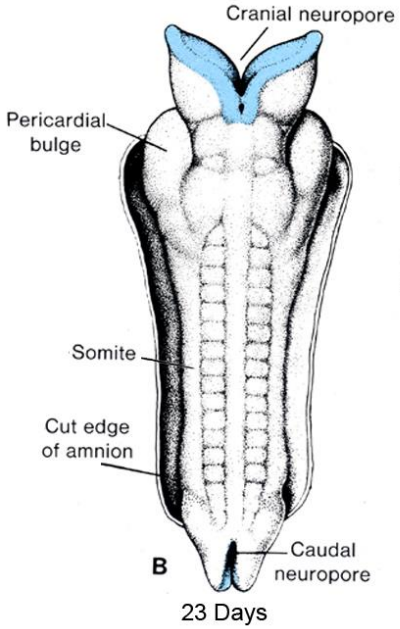



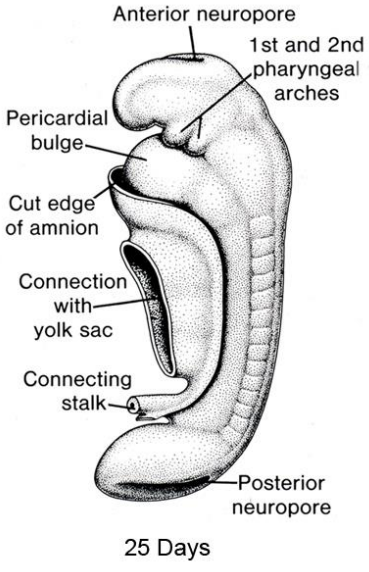
# Development of the neural tube 1



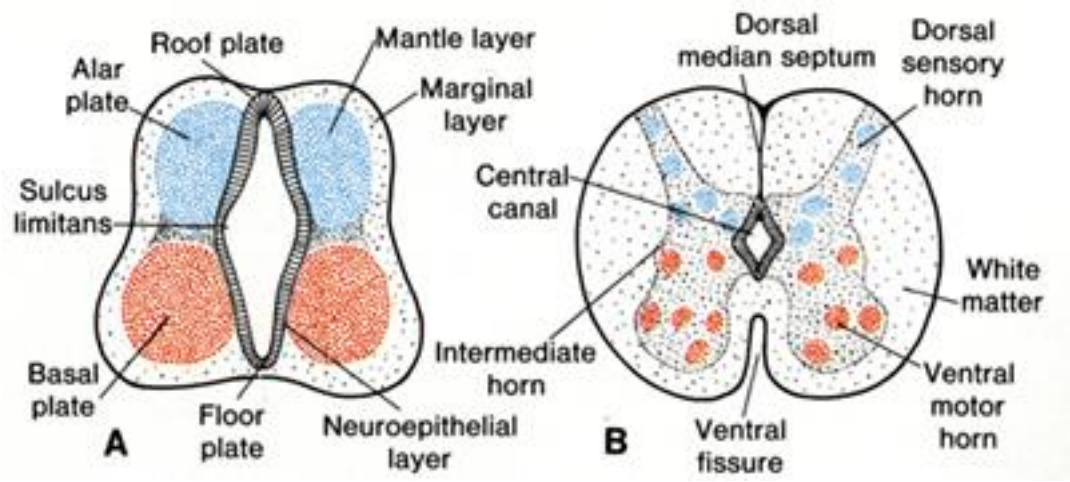



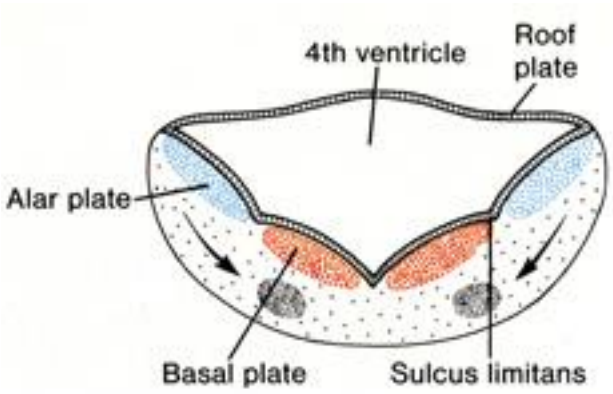



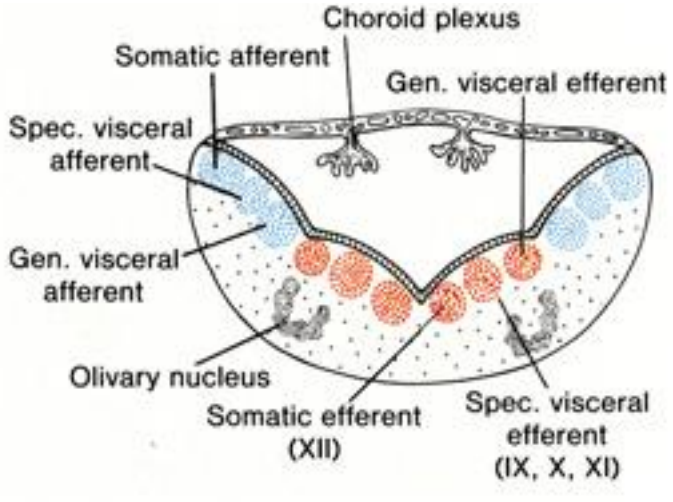



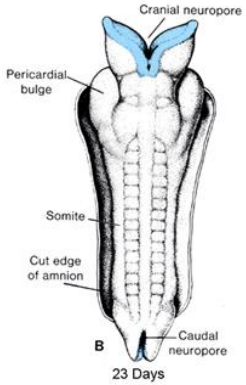
# Dorsal and ventral cell groups

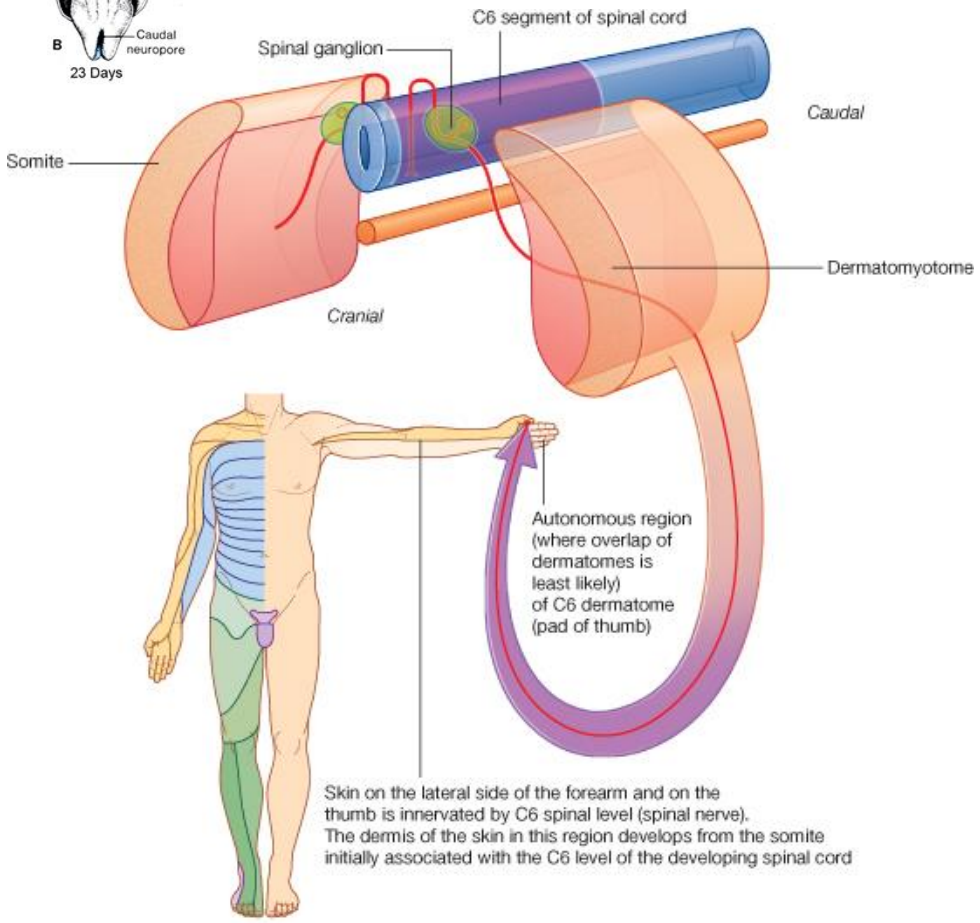


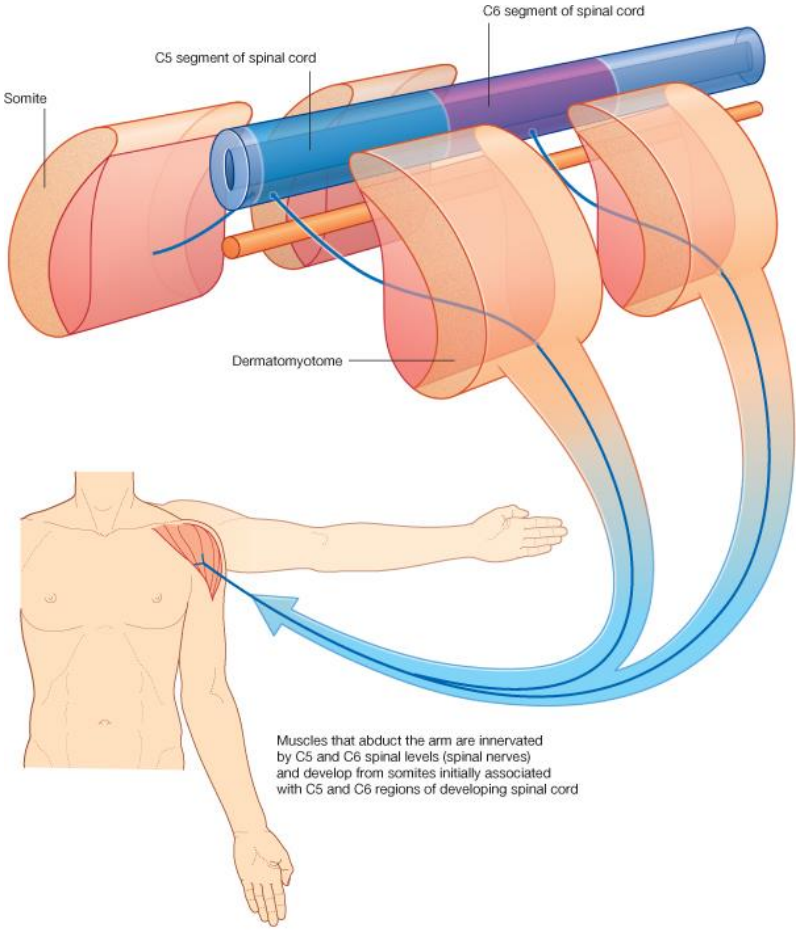



# Dermatomes and myotomes

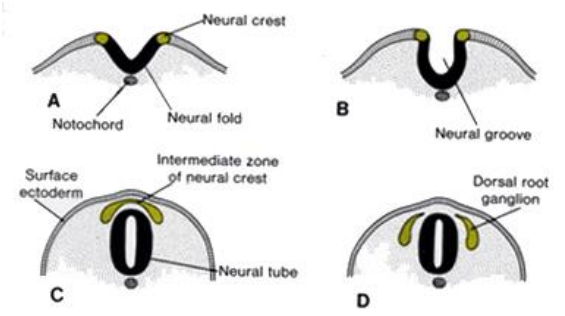


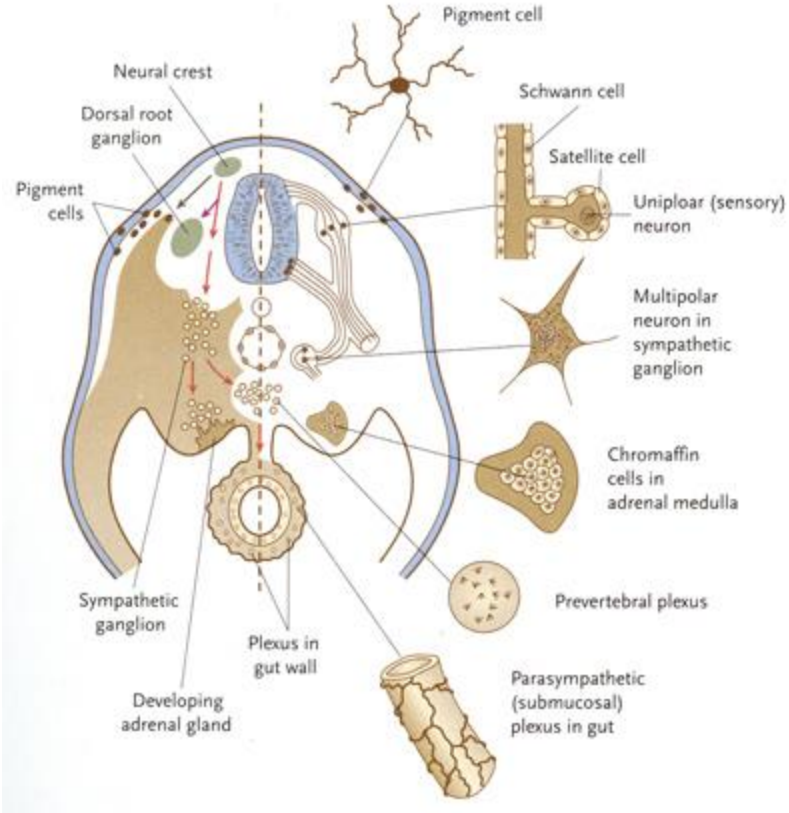





# Neural crest derivatives: 1

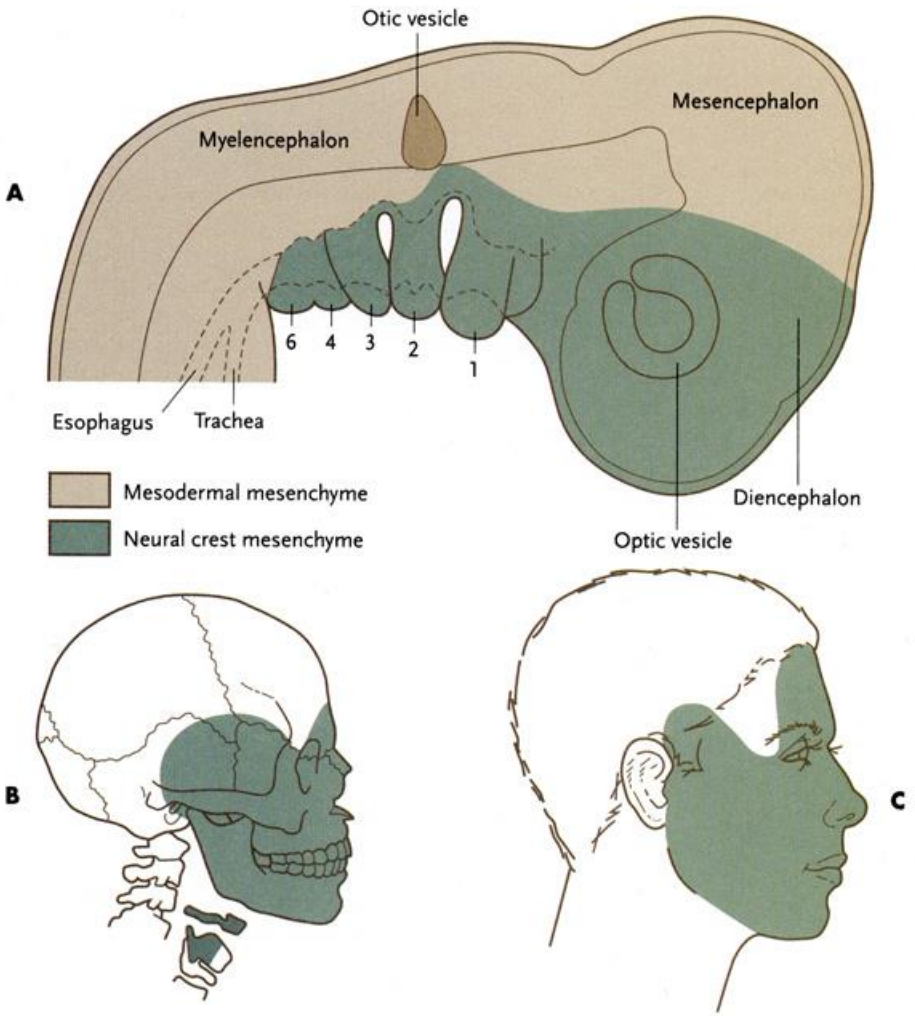


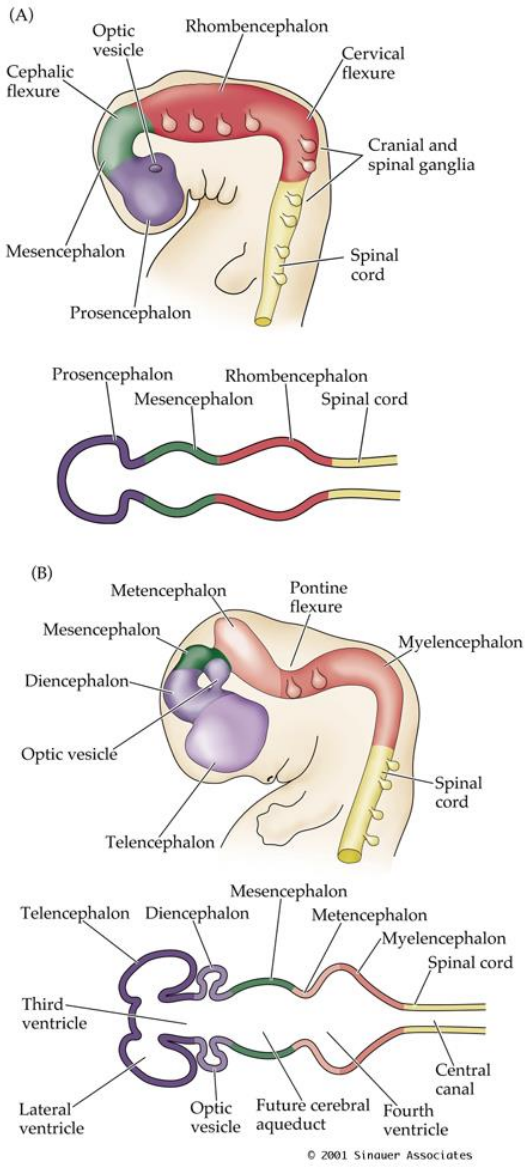
# Neural crest derivatives: 2

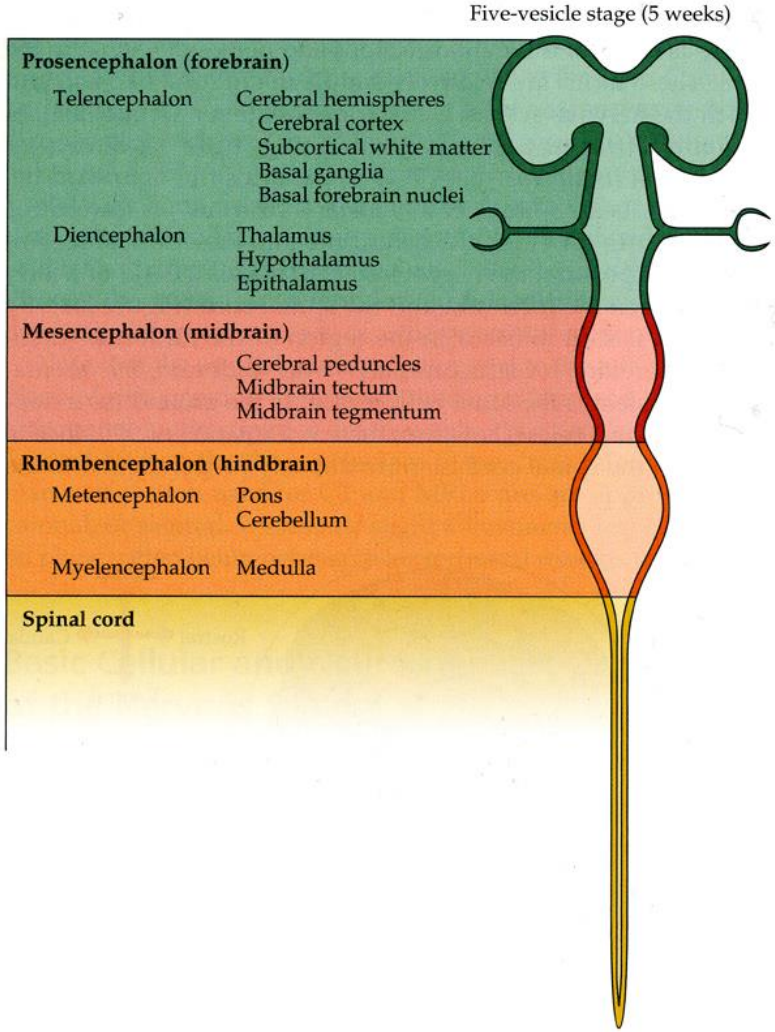
## Environmental Factors Promoting Differentiation of Neural Crest Cells

| Neural crest derivative | Interacting structure |
|---|---|
| Bones of cranial vault | Brain |
| Bones of base of skull | Notochord, brain |
| Pharyngeal arch cartilages | Pharyngeal endoderm |
| Meckel's cartilage | Cranial ectoderm |
| Maxillary bone | Maxillary ectoderm |
| Mandible | Mandibular ectoderm |
| Palate | Palatal ectoderm |
| Otic capsule | Otic vesicle |
| Dentine of teeth | Oral ectoderm |
| Glandular stroma: thyroid, parathyroid, thymus, salivary | Local epithelium |
| Adrenal medullary chromaffin cells | Glucocorticoids secreted by adrenal cortex |
| Enteric neurons | Gut wall |
| Sympathetic neurons | Spinal cord, notochord, somites |
| Sensory neurons | Peripheral target tissue |
| Pigment cells | Extracellular matrix along pathway of migration |

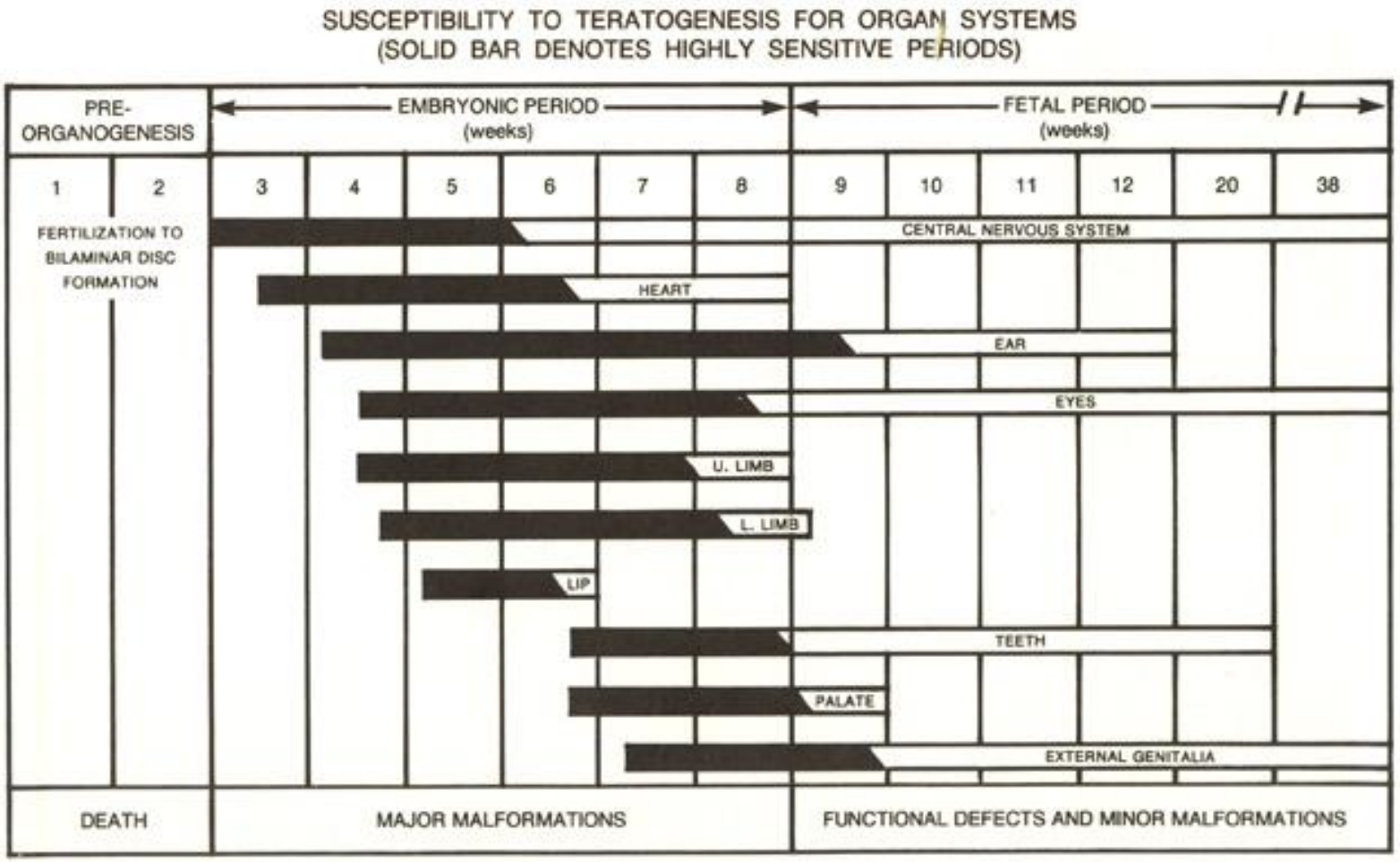


# Development of the neural tube 2



# Timing of development of the neural tube and its derivatives



# Timing of development of the neural tube and its derivatives

| Gestational age (Weeks) | Crown-rump length (mm) | Structure(s) |
|---|---|---|
| 3 | 3 | cerebral vesicles |
| 4 | 4 | Optic cup, otic placode (future internal ear) |
| 5 | 6 | cerebral vesicles, cranial nerve nuclei |
| 6 | 12 | Cranial and cervical flexures, rhombic lips (future cerebellum) |
| 7 | 17 | Thalamus, hypothalamus, internal capsule, basal ganglia |
| 8 | 30 | Hippocampus, fornix, olfactory bulb, longitudinal fissure that separates the hemispheres |
| 10 | 53 | First callosal fibers cross the midline, early cerebellum |
| 12 | 80 | Major expansion of the cerebral cortex |
| 16 | 134 | Olfactory connections established |
| 20 | 185 | Gyral and sulcul patterns of the cerebral cortex established |

# Clinical case

A 68 year old woman with hypertension and diabetes develops abrupt onset numbness and tingling on the right half of the face and head and the entire right hemitrunk, right arm and right leg. She does not experience any weakness or incoordination.

Physical Examination:
Vitals: T 37.0° C; BP 168/87; P 86; RR 16
Cardiovascular, pulmonary, and abdominal exam are within normal limits.

Neurological Examination:
**Mental Status:** Alert and oriented x 3, 3/3 recall in 3 minutes, language fluent.
**Cranial nerves:** CN II-XII intact except for objective loss of all sensation (including fine touch, two point discrimination, pain and temperature) on the right side of the face.
**Motor:** Normal bulk and tone. Strength and reflexes are as follows:

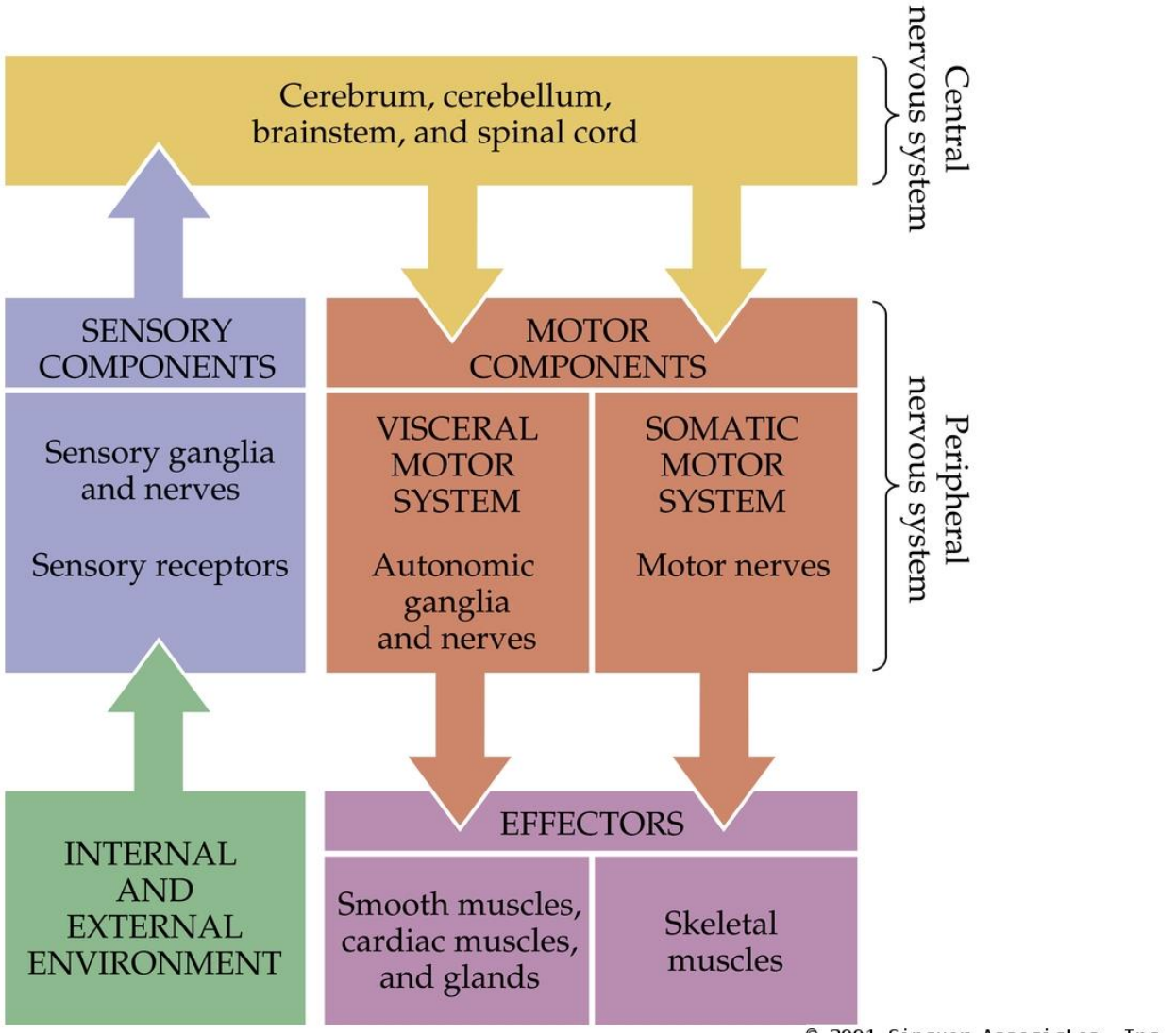
**Reflexes:**

| | Deltoids | Biceps | Triceps | Wrist Ext. | Wrist Flex. | Finger Ext. | Finger Flex. |
|---|---|---|---|---|---|---|---|
| R | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 |
| L | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 |
| | illiopsoas | Hams | Quads | Tibialis ant. | Gastroc. | | |
| R | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | | |
| L | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | | |

**Sensation**: Intact fine touch, two point discrimination, vibration, joint position sense, pain and temperature sensation in the left arm, left leg and left hemitrunk. Complete sensory loss of all modalities in the right arm, right hemitrunk and right leg.
**Coordination:** Normal rapid alternating movements in the upper and lower extremities, and normal finger-to-nose and heel-knee-shin testing.
**Gait:** Normal

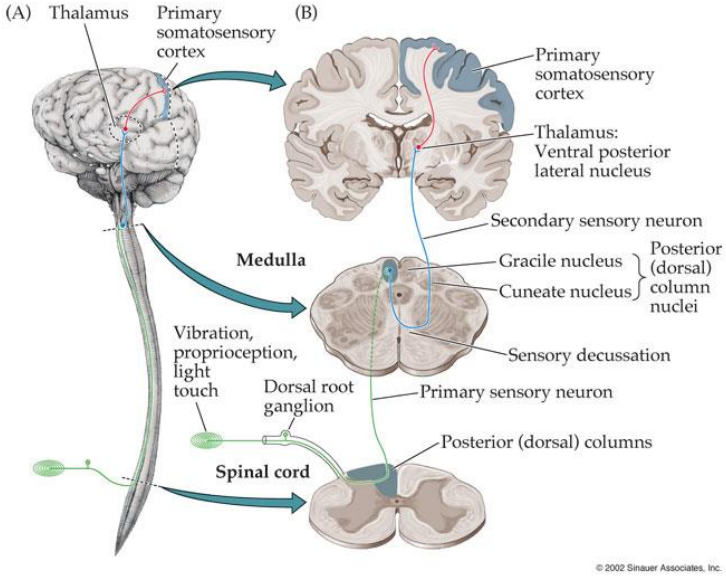
Where is the most likely location of the lesion that gives rise to these symptoms?

# The Major Components of the Nervous System and Their Functional Relationships

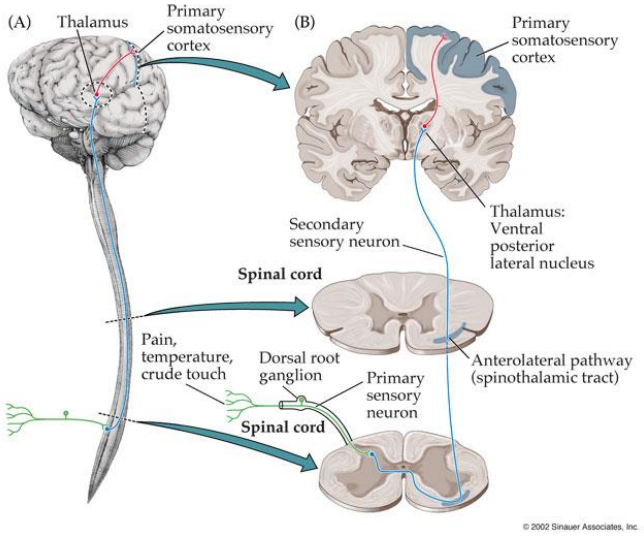


# The somatosensory and motor pathways

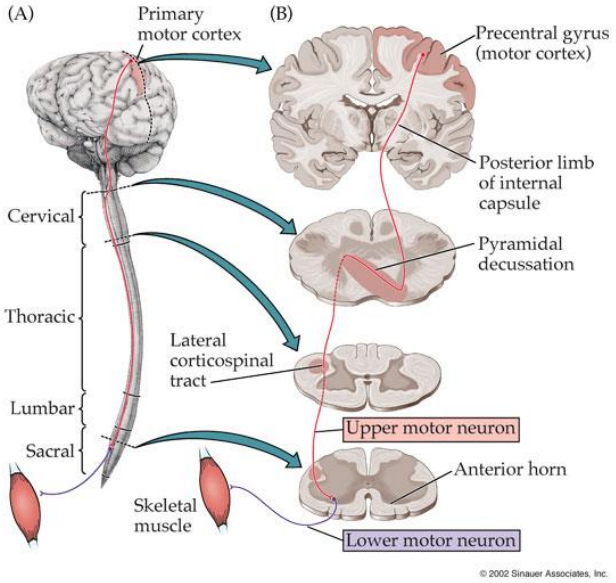
## Fine touch pathway




## Nociceptive pathway



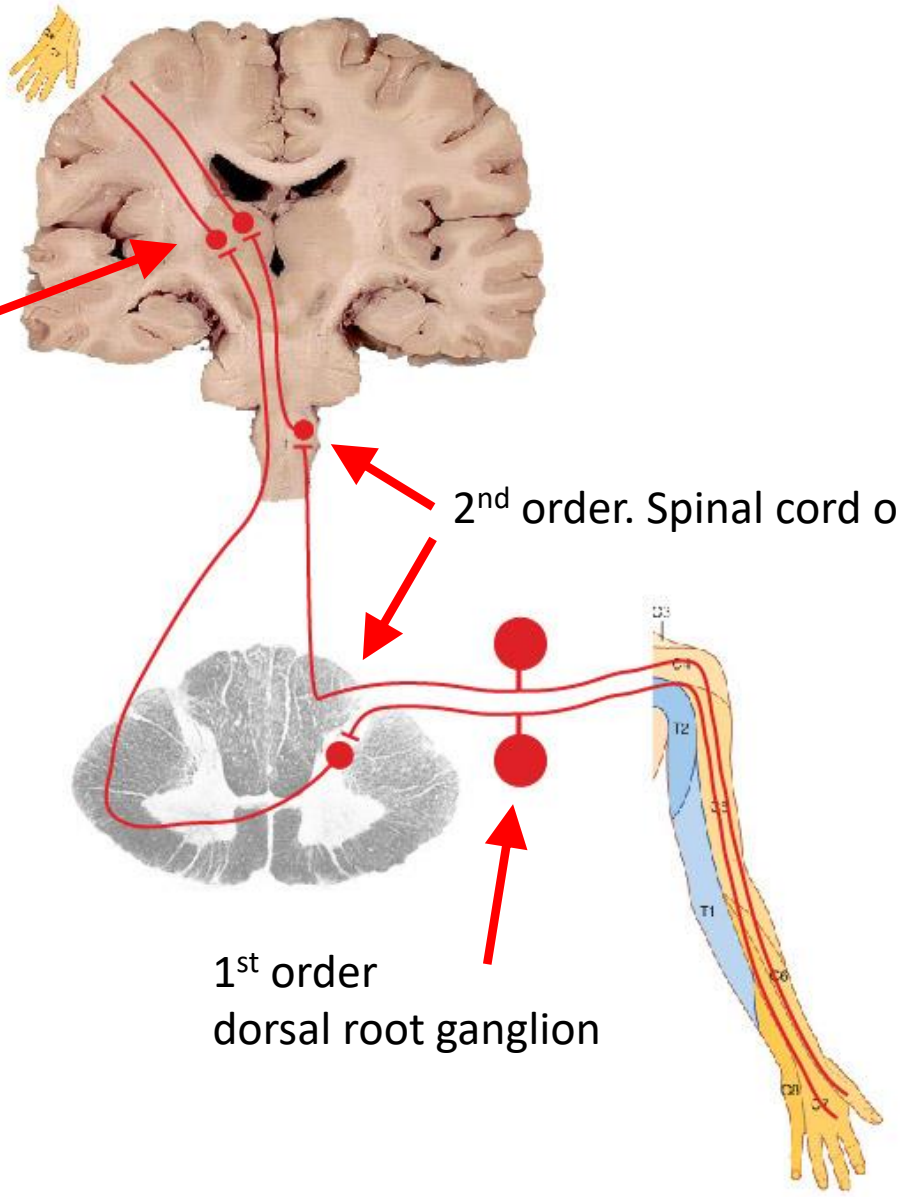

## Motor pathway



# Somatosensory pathways

Cortex

3rd order
Thalamus

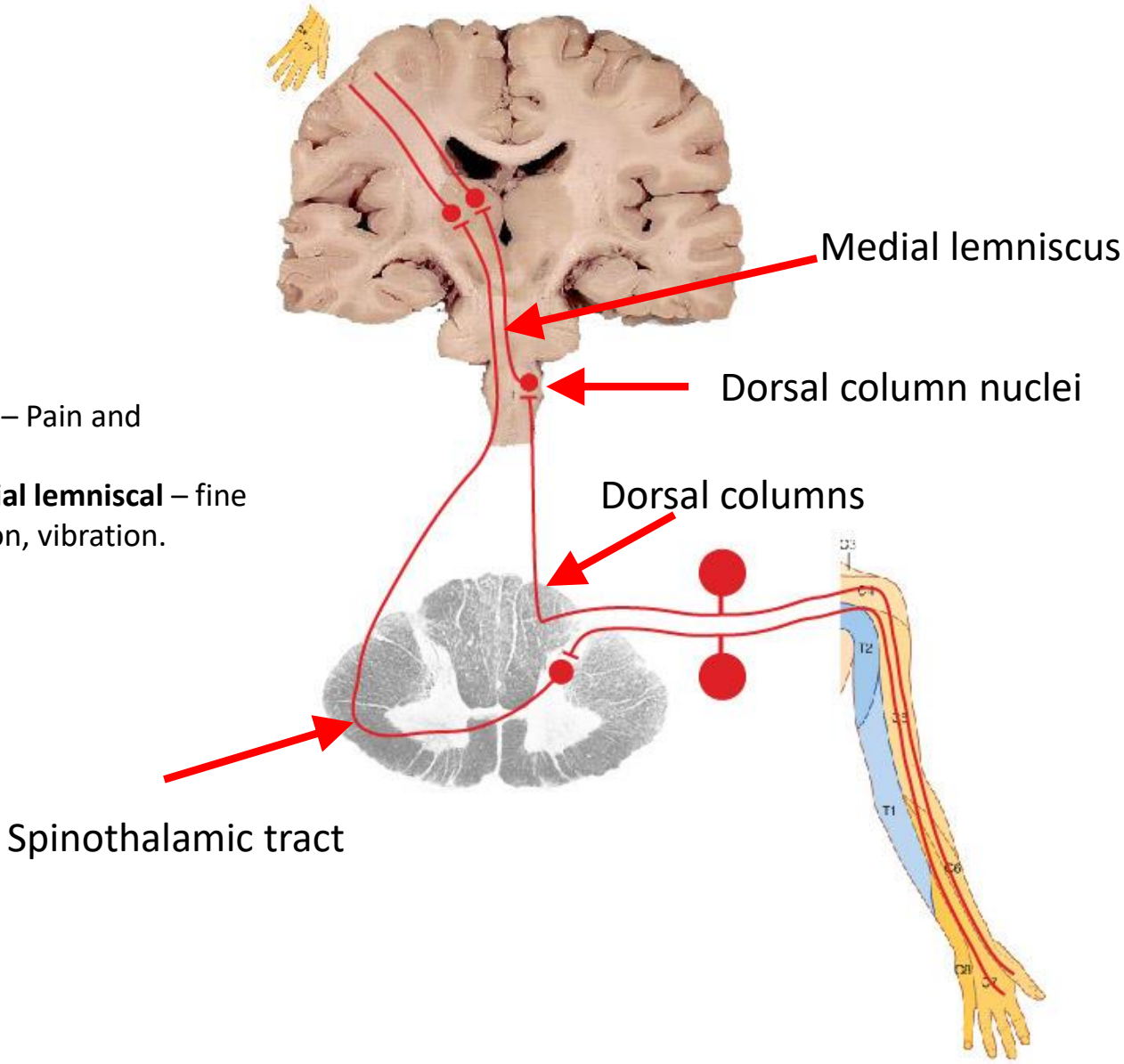


2nd order. Spinal cord or brainstem

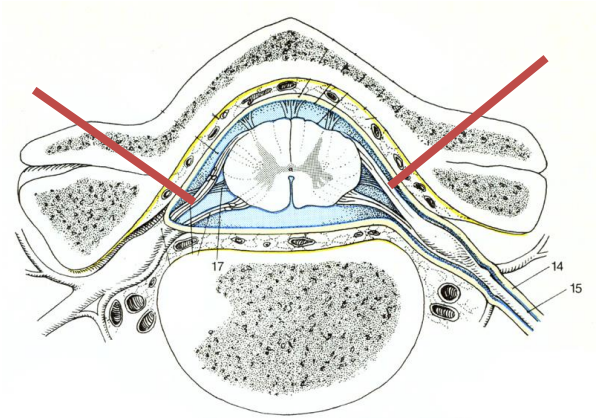
1st order
dorsal root ganglion

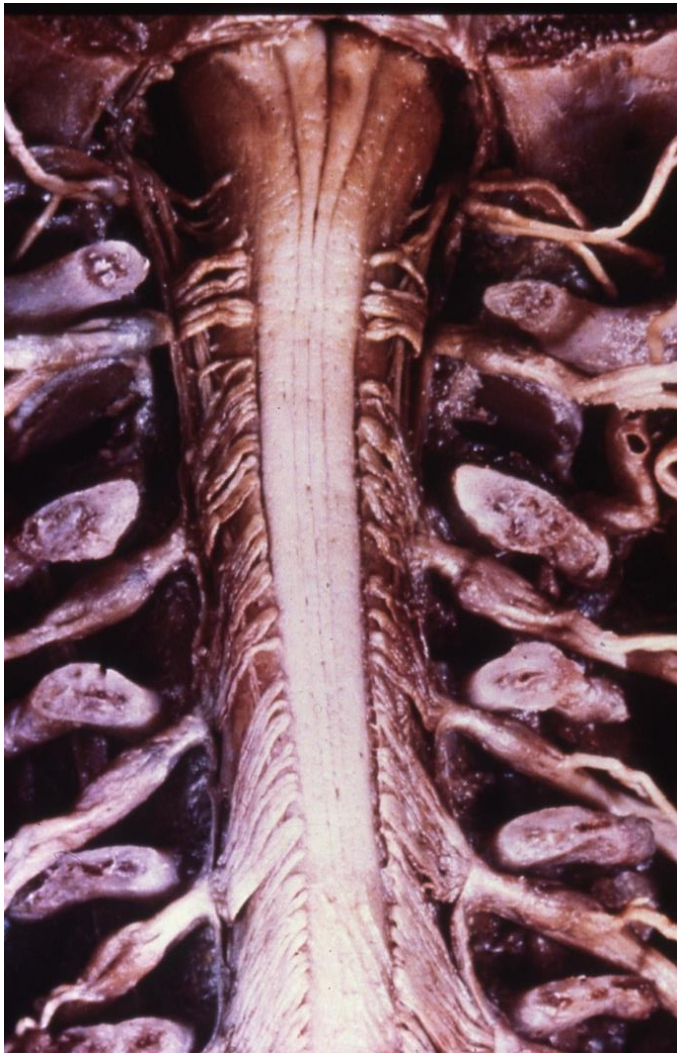
# Somatosensory pathways

**Spinothalamic path** – Pain and temperature.
**Dorsal column medial lemniscal** – fine touch, proprioception, vibration.

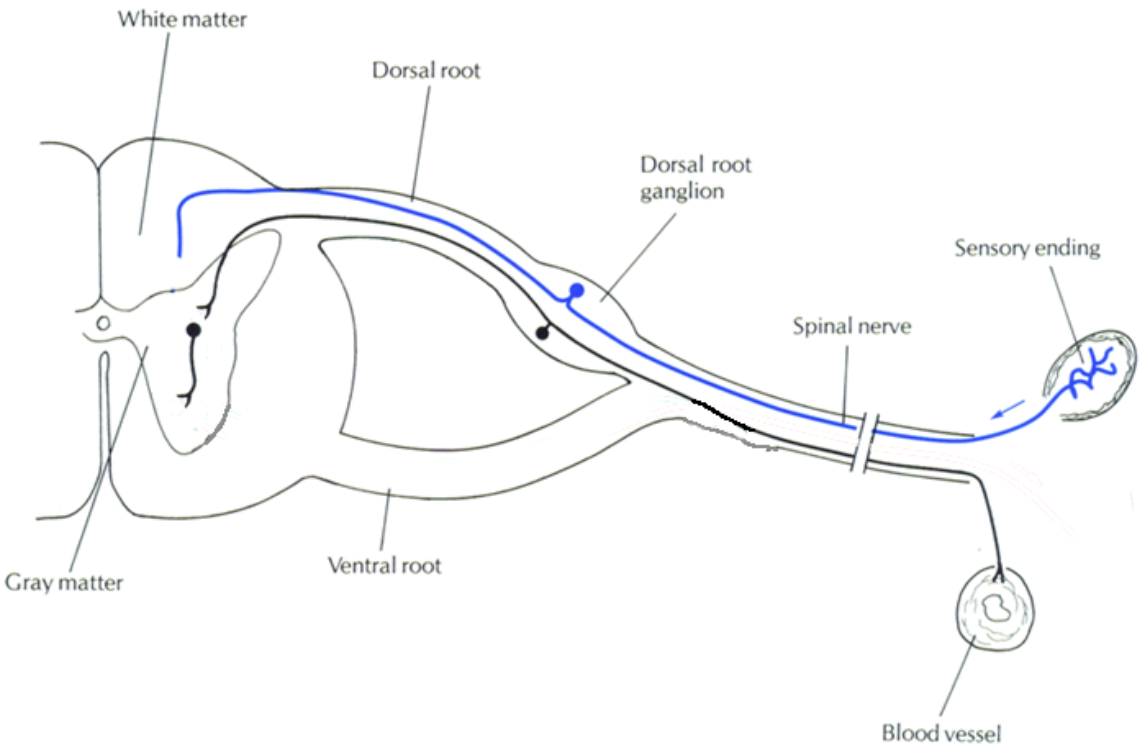


# Spinal cord and dorsal root ganglia

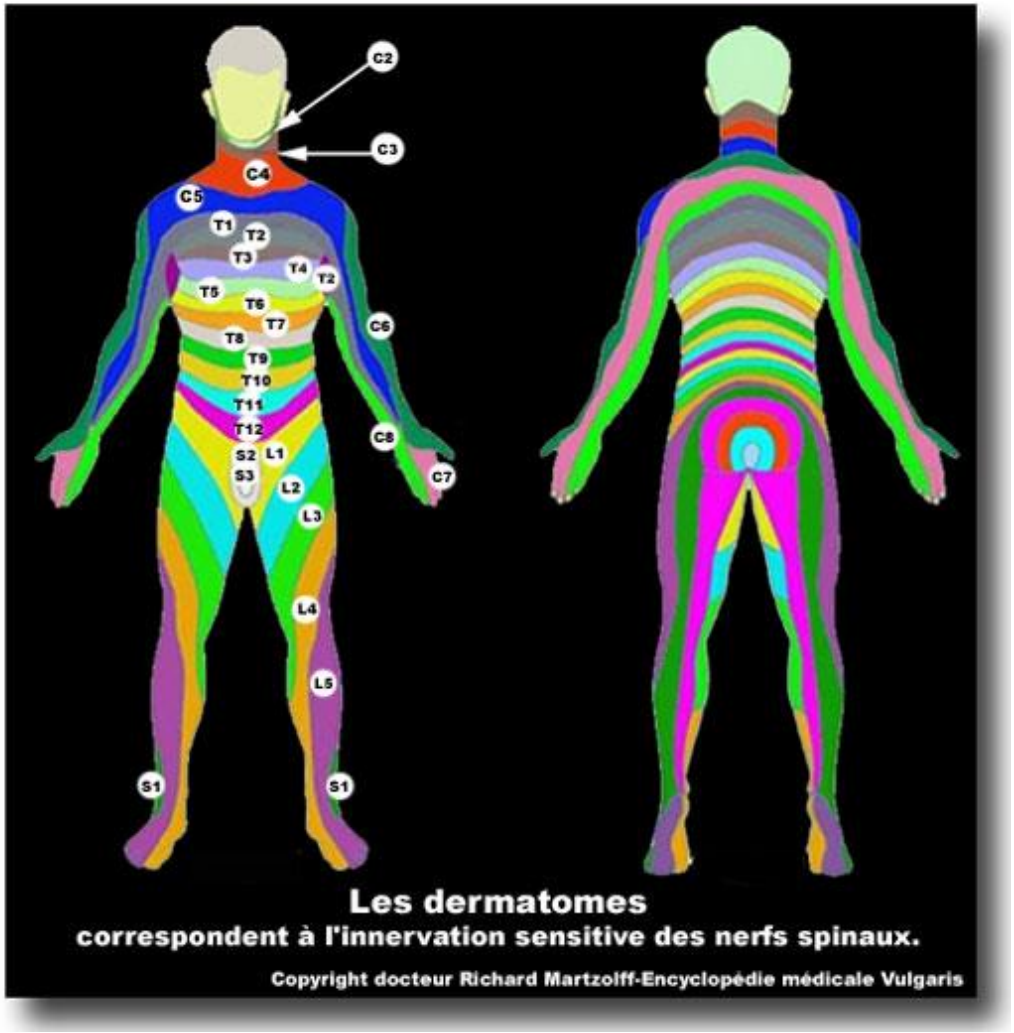


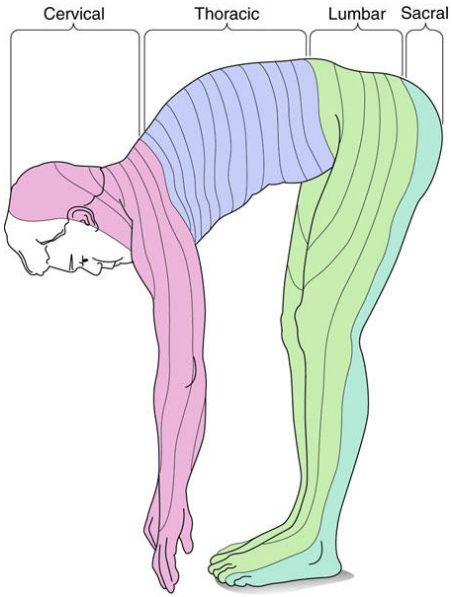



# Spinal cord and sensory component of peripheral nerves

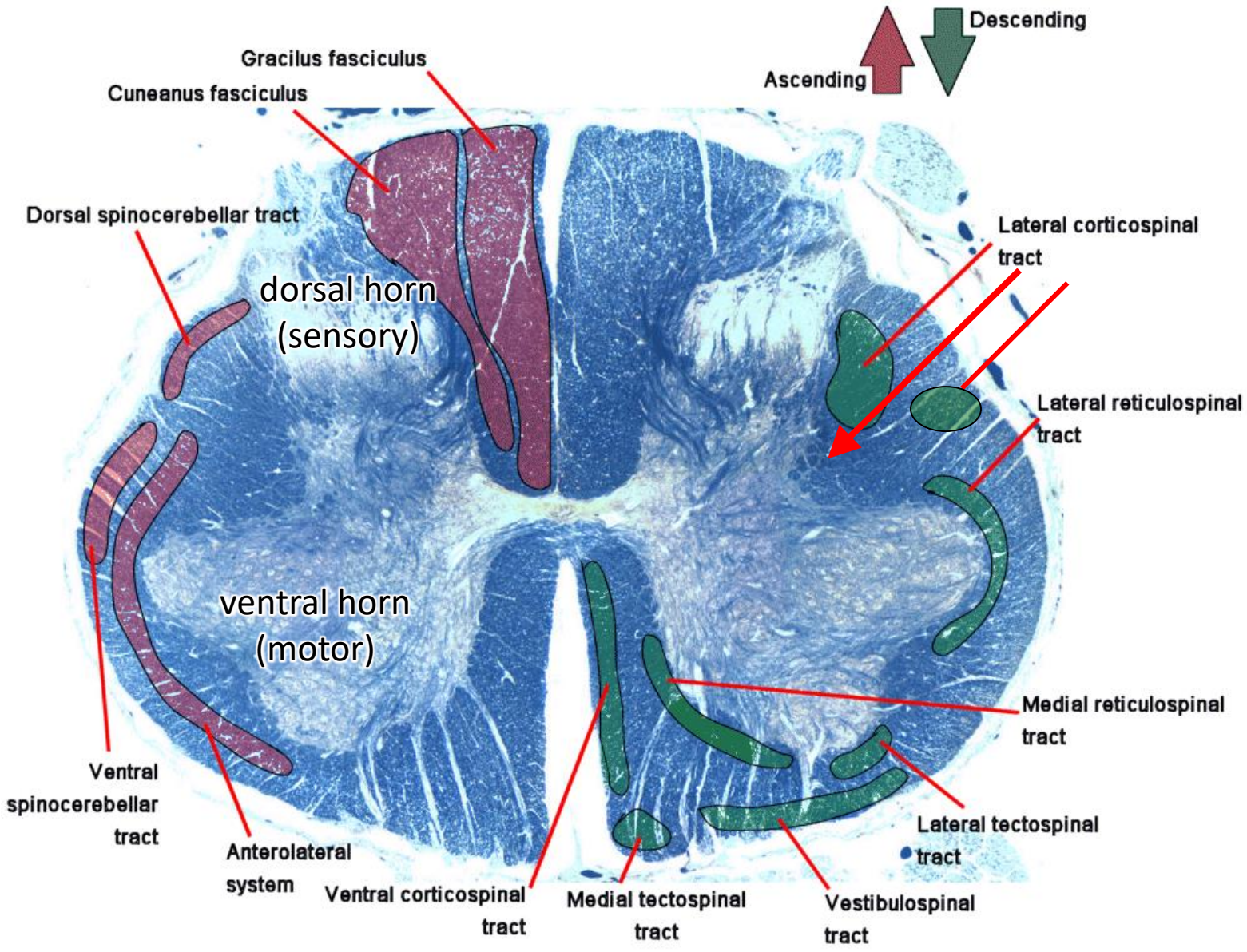


# Dermatomes

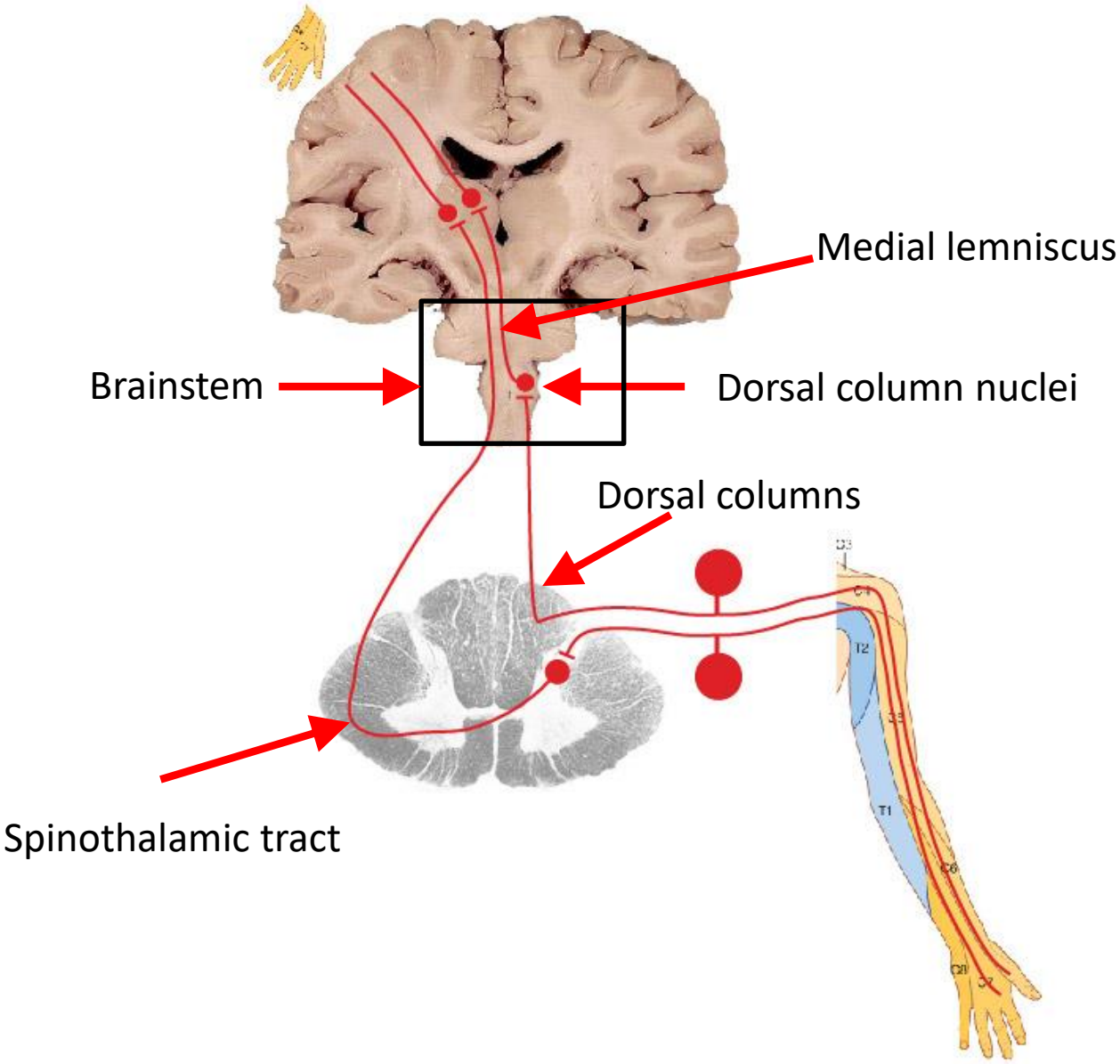

C2
C3
C4
C5
T1
T2
T3
T4
T2
T5
T6
T7
C6
T8
T9
T10
T11
T12
C8
S2
L1
S3
C7
L2
L3
L4
L5
S1
S1
Les dermatomes
correspondent à l'innervation sensitive des nerfs spinaux.
Copyright docteur Richard Martzolff-Encyclopédie médicale Vulgaris


Cervical
Thoracic
Lumbar
Sacral

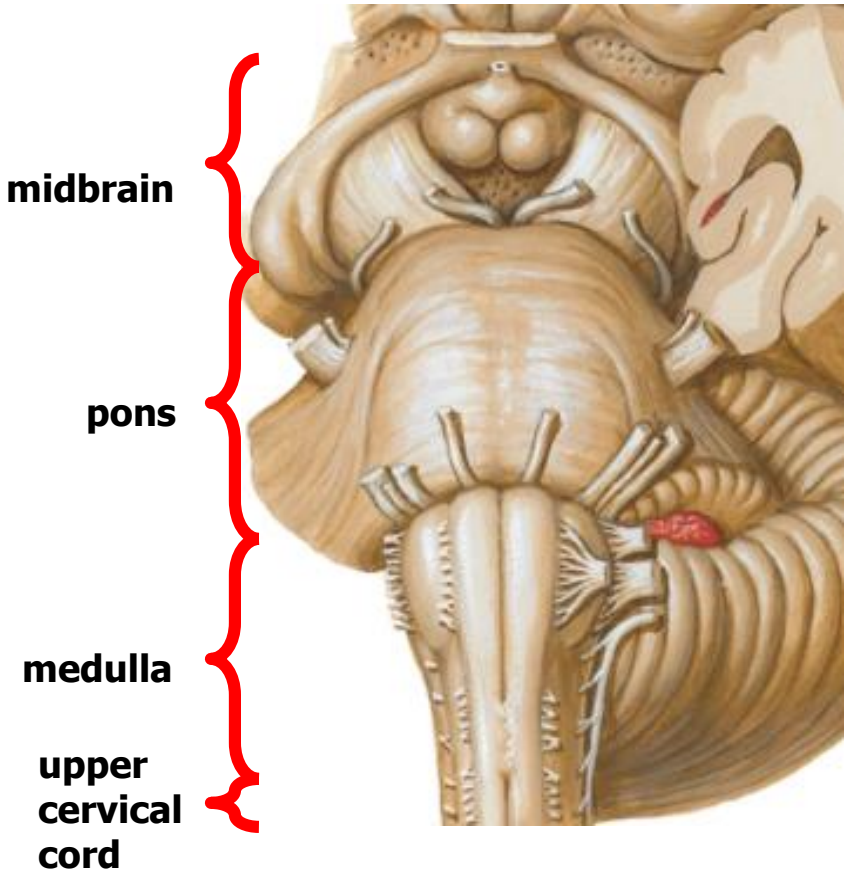
# Spinal cord tracts



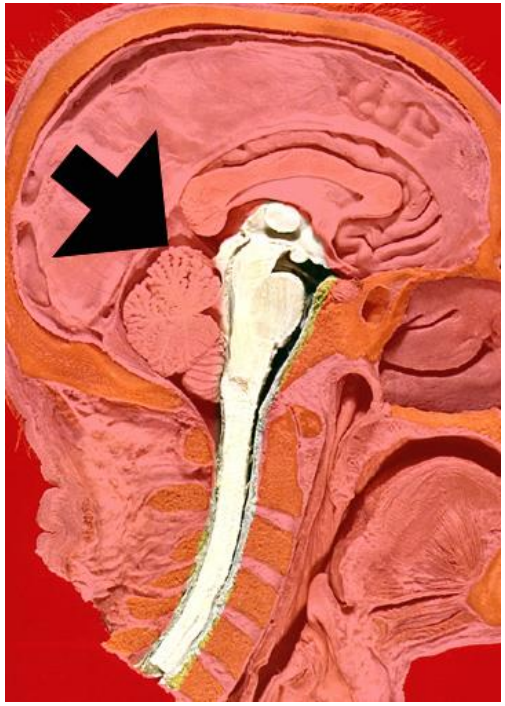
# Somatosensory pathway: **Brainstem**



# Brainstem



# Dorsal view of brainstem and spinal cord



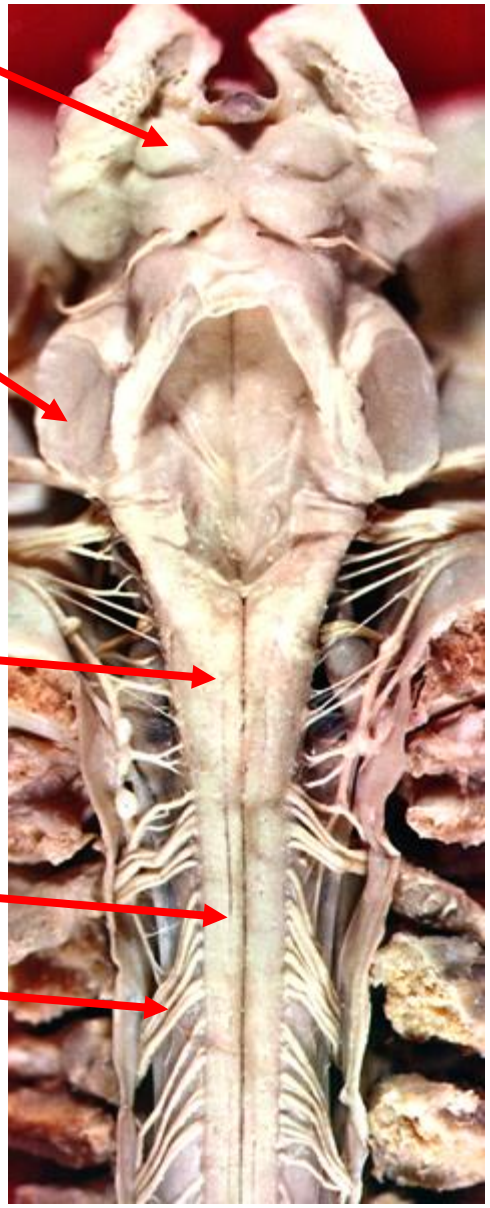
Superior colliculi

Cut cerebral peduncles

Dorsal column nuclei

Dorsal columns

Dorsal roots

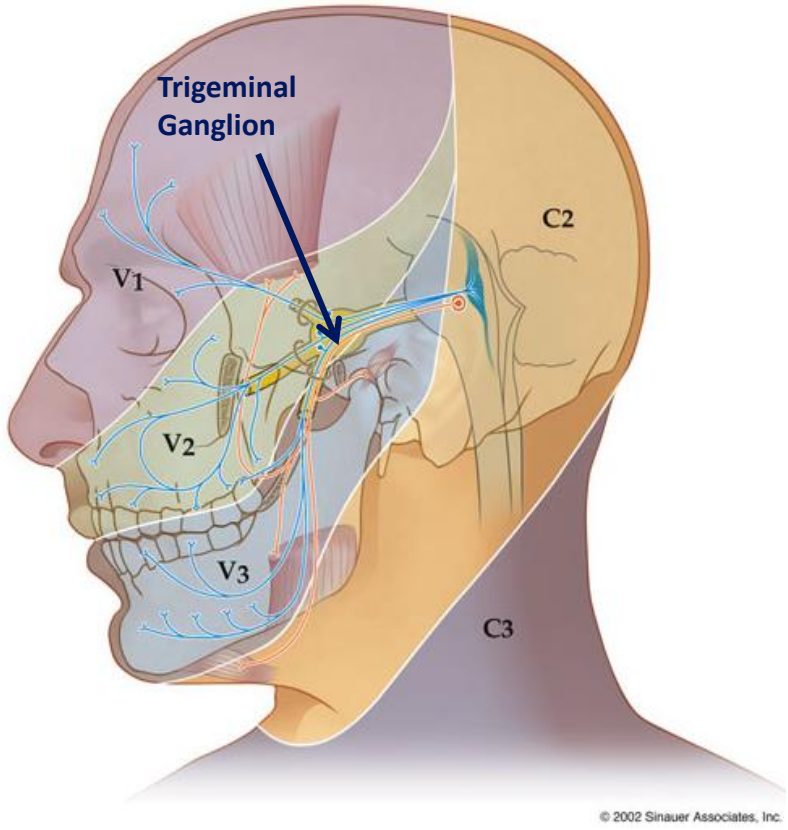


# Trigeminal Pathway

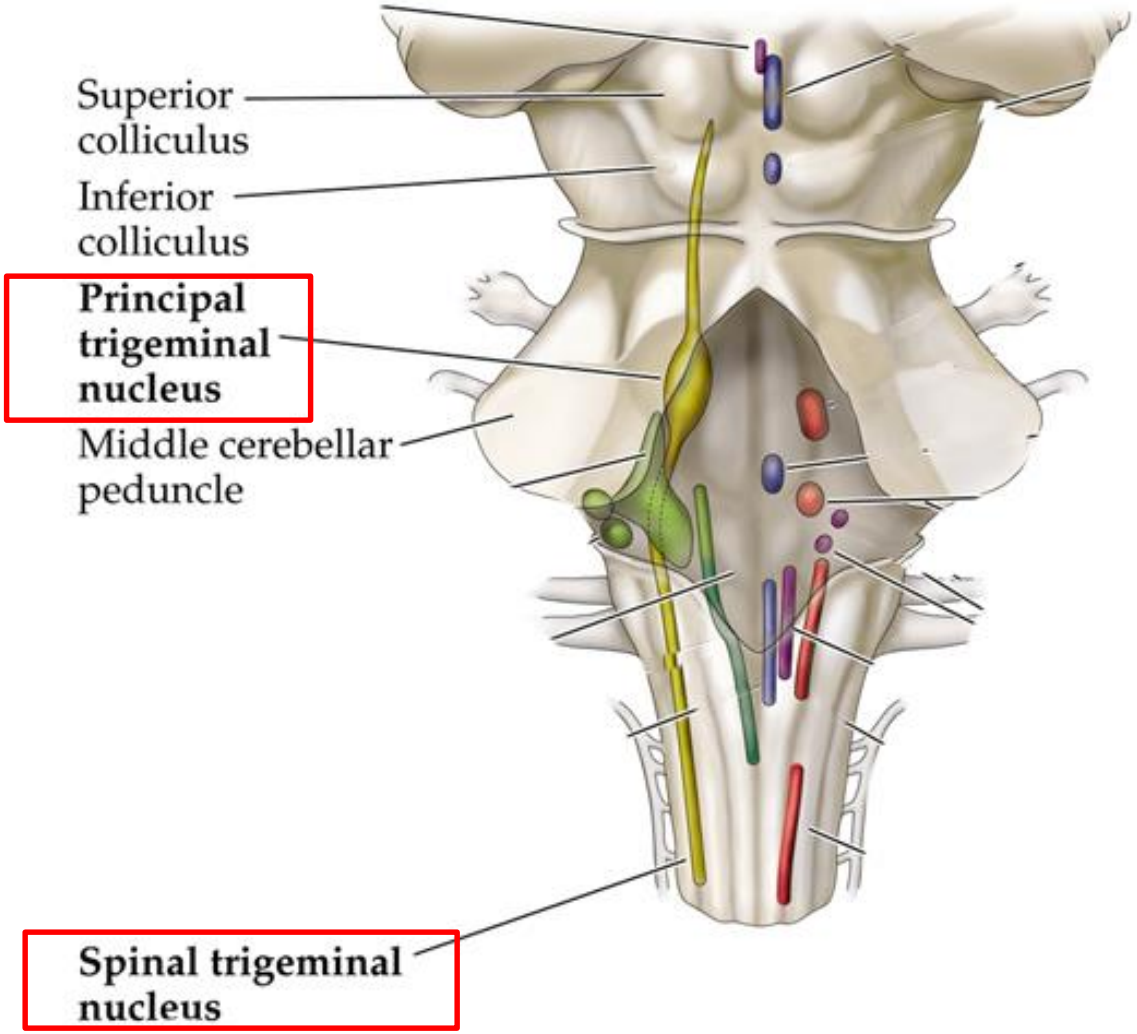
1. All sensory information for the face is carried in the three branches of the Vth cranial nerve that has three sensory divisions (V1, V2, V3).

2. All 1st order sensory neurons have their cell body in the trigeminal GANGLION (equivalent to the dorsal root ganglion in the spinal cord).

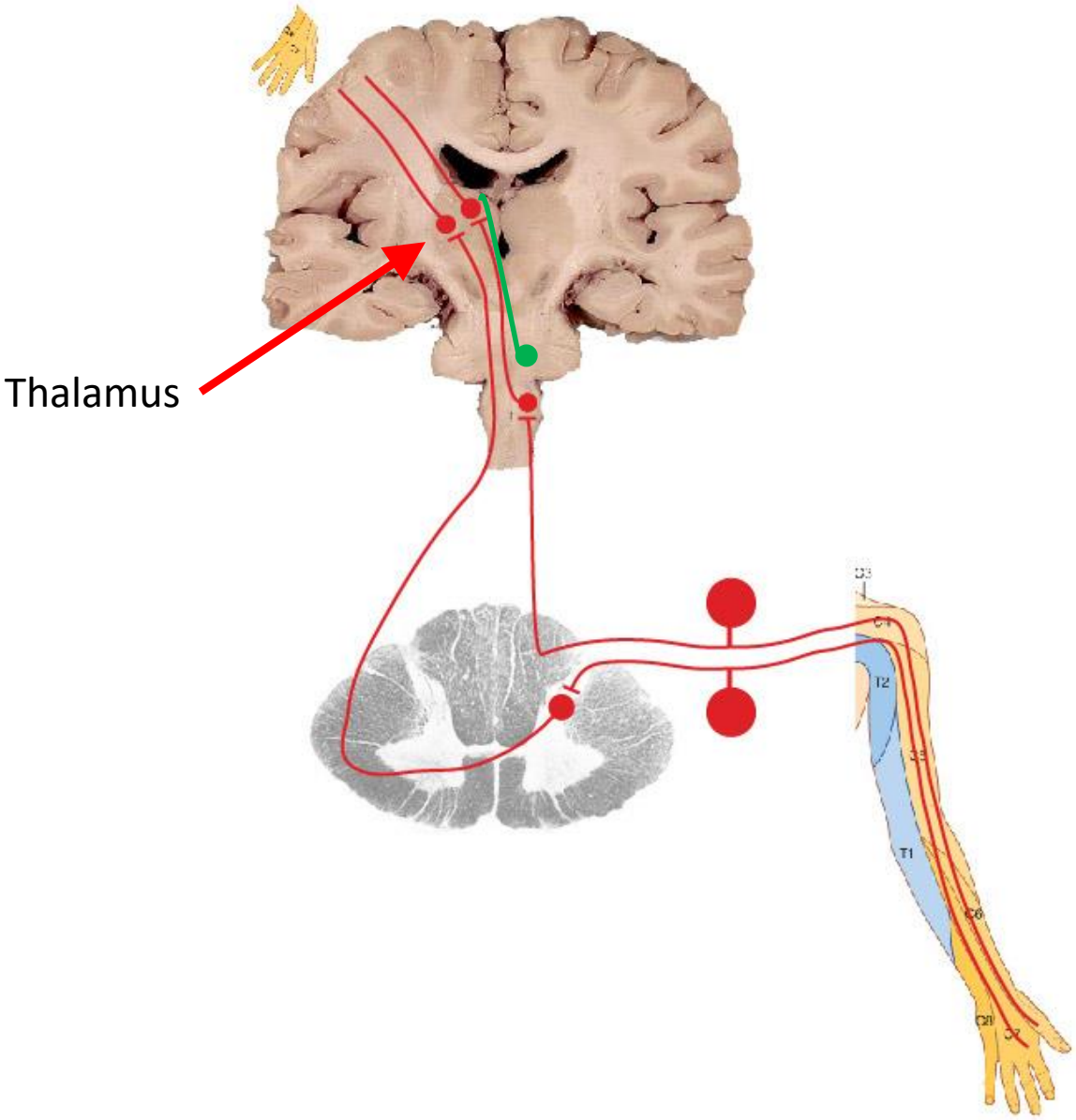
3. Our rules for 1st, 2nd and 3rd order sensory neurons still apply. The second order neurons are in the trigeminal NUCLEUS.



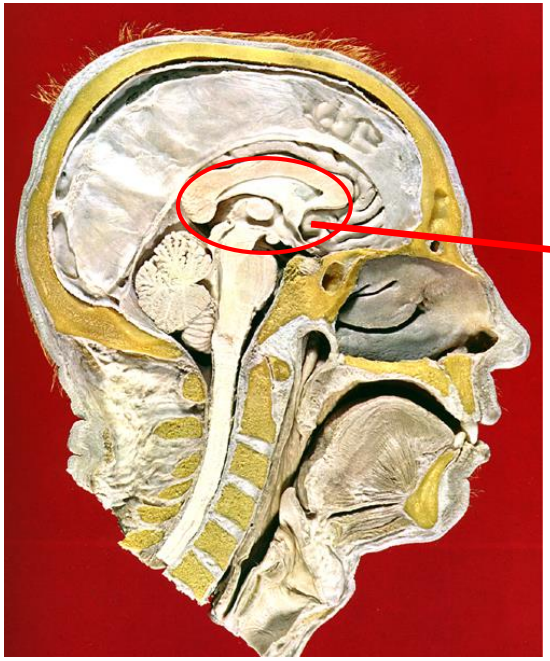
# Trigeminal nuclei

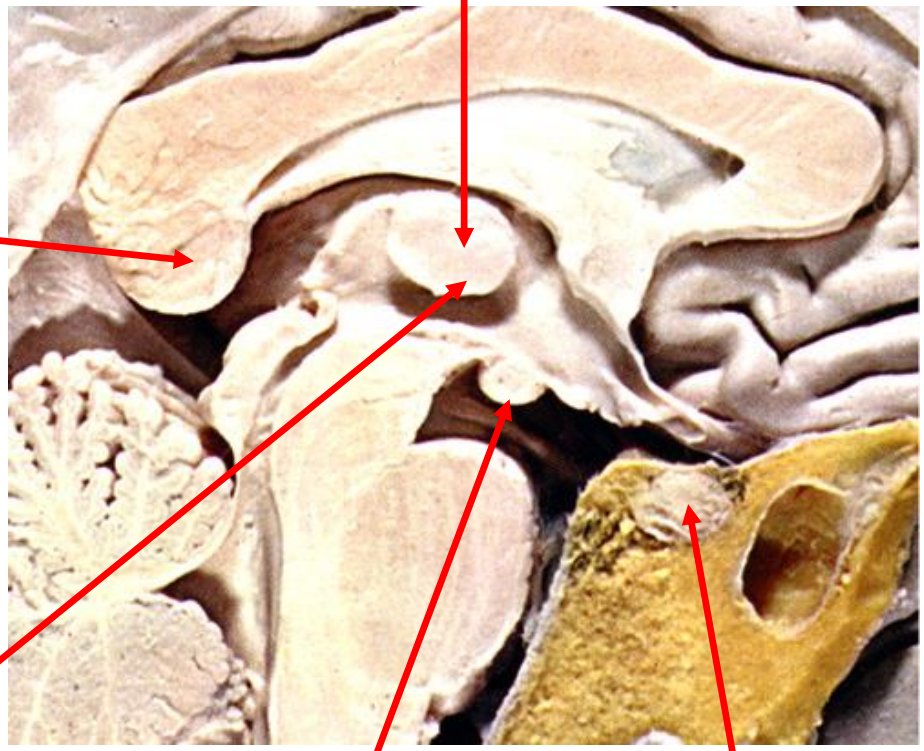


# Sensory pathway: **Thalamus**

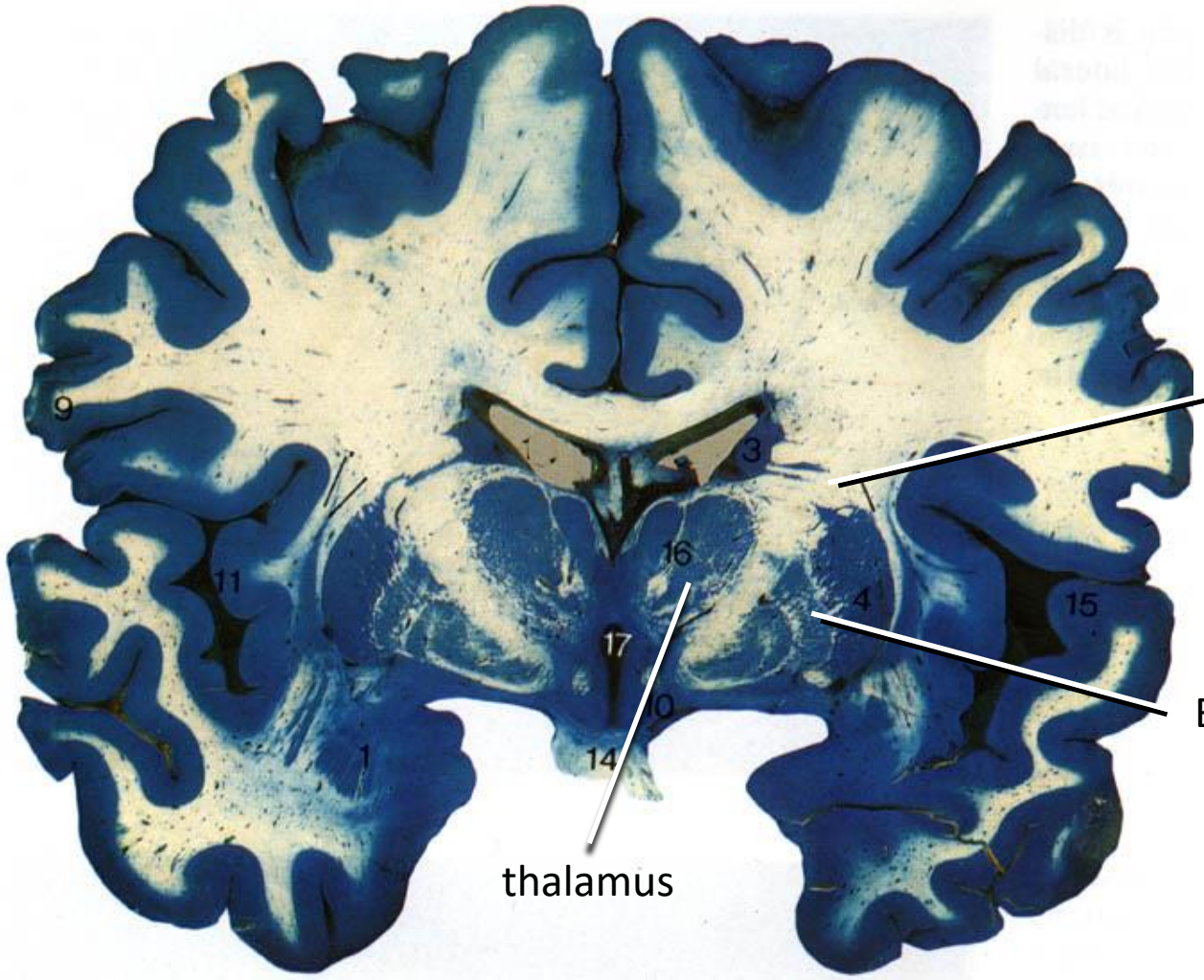


# Thalamus: medial view

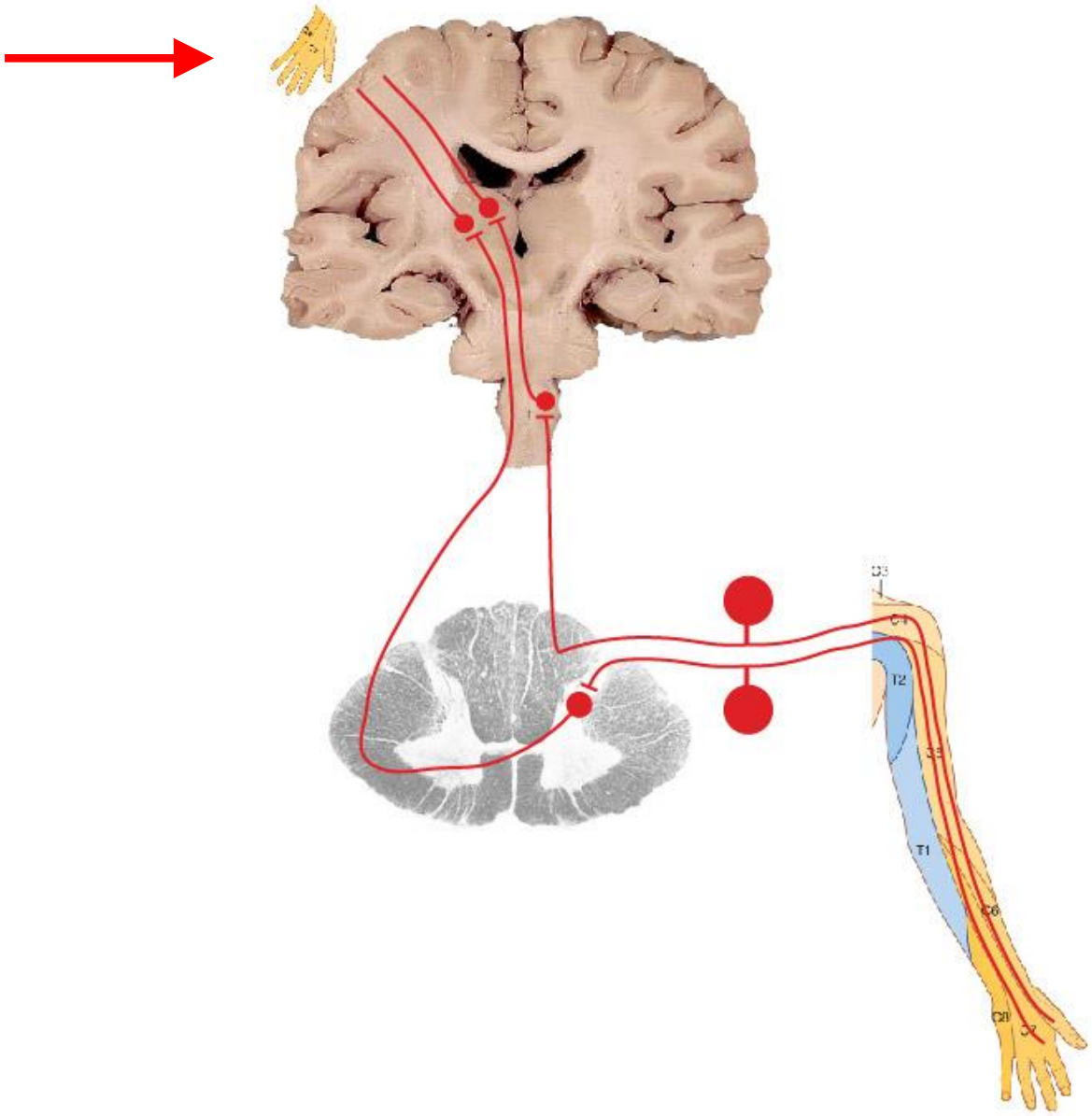




# Thalamus: Coronal view

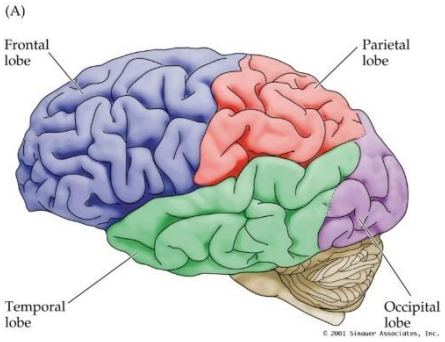


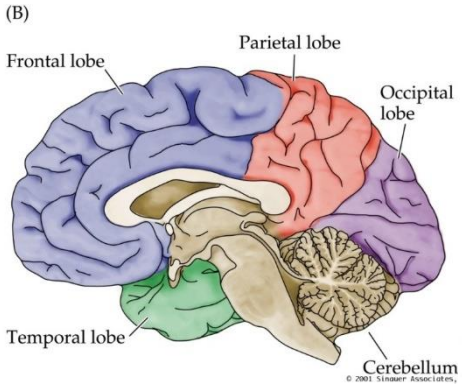
# Sensory pathway: **Cortex**

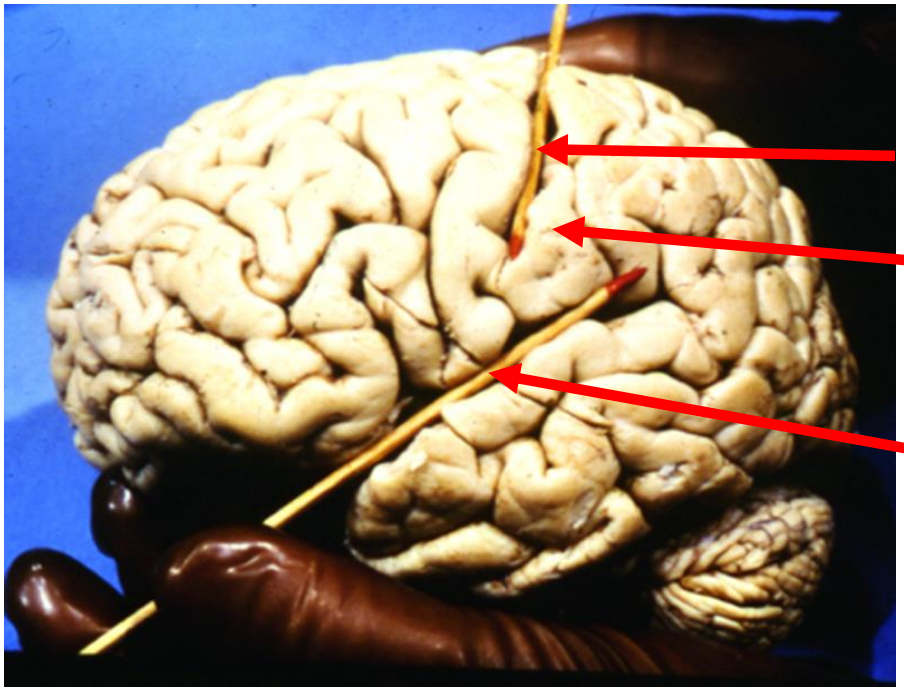


# Lateral view of cortex

# Lateral view cortex



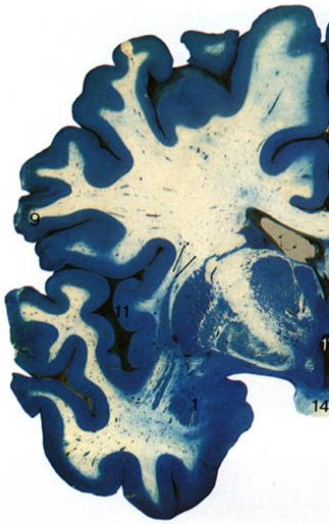



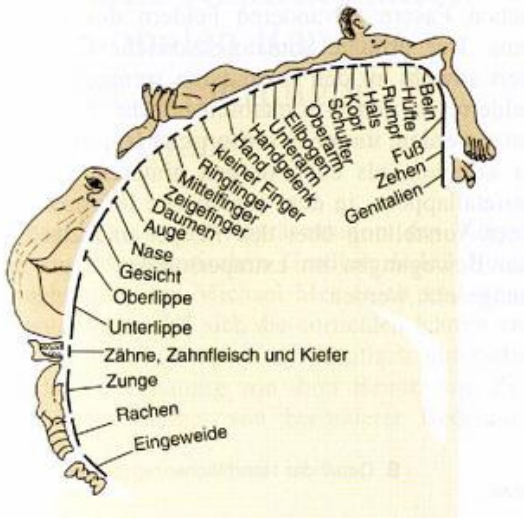



Central sulcus

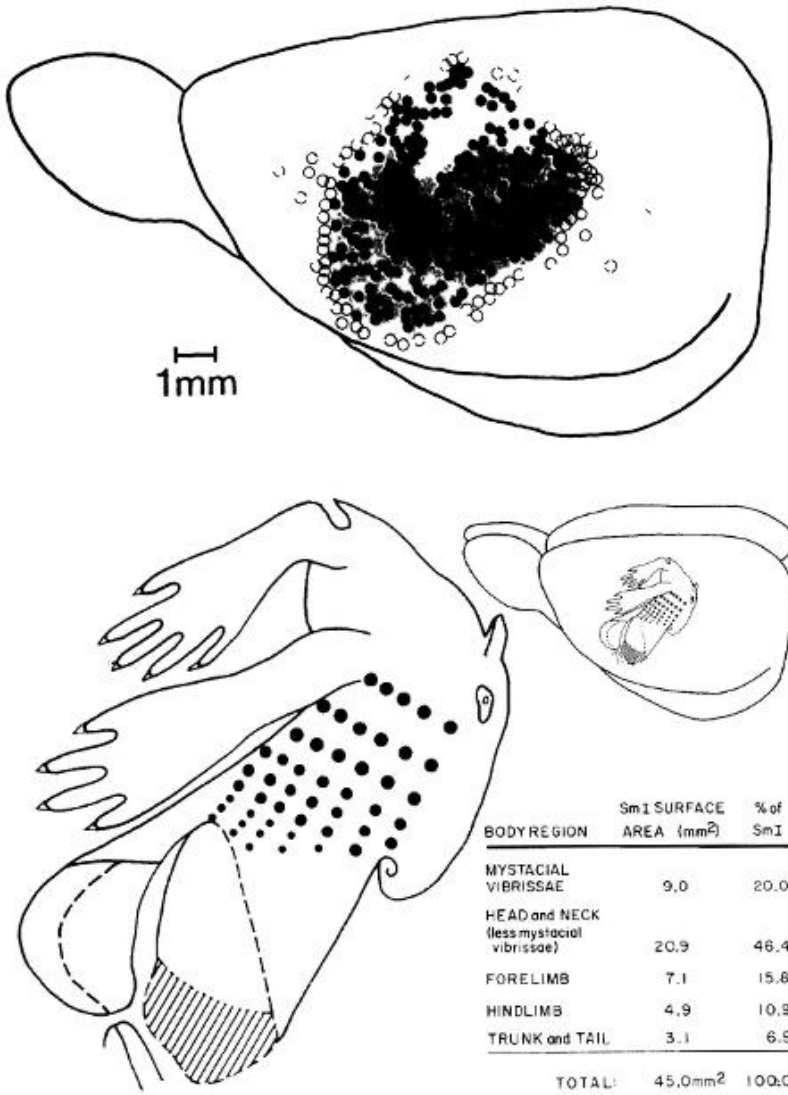
Primary sensory cortex (S1)

Lateral fissure



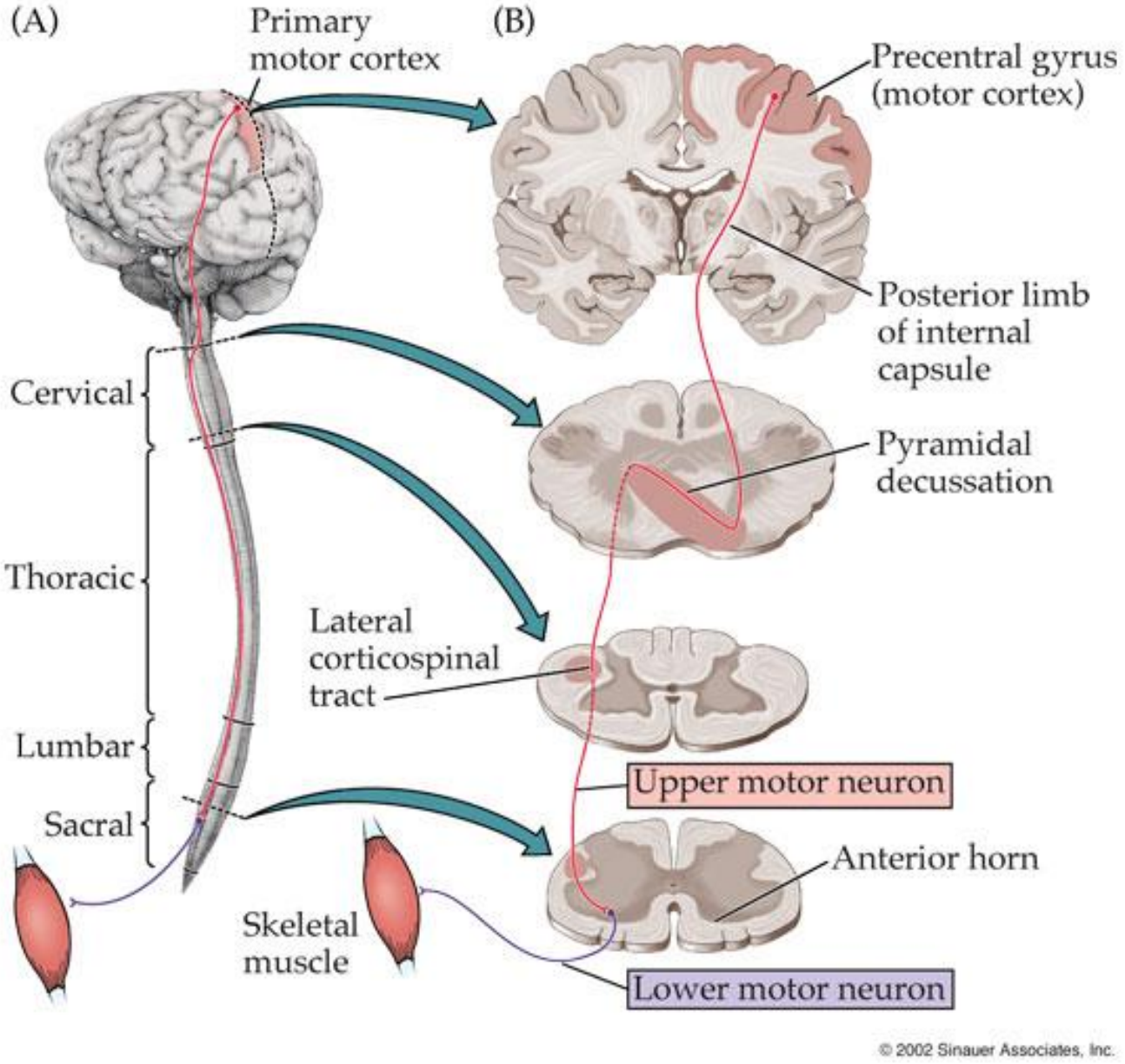


# Ratunculus



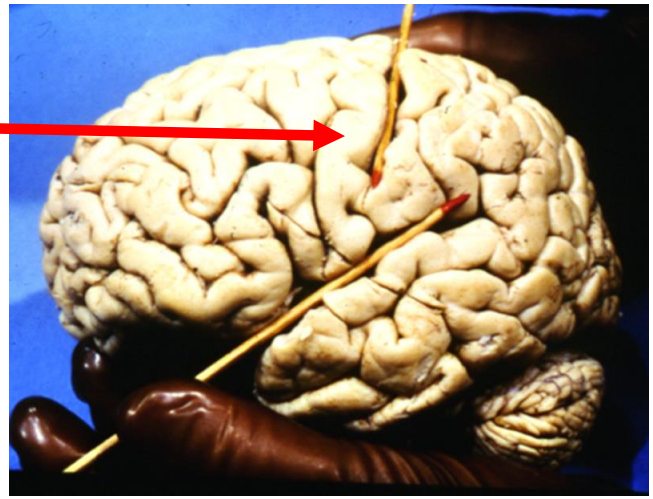

| BODY REGION | Sm1 SURFACE AREA ($mm^2$) | % of Sm1 |
|---|---|---|
| MYSTACIAL VIBRISSAE | 9.0 | 20.0 |
| HEAD and NECK (less mystacial vibrissae) | 20.9 | 46.4 |
| FORELIMB | 7.1 | 15.8 |
| HINDLIMB | 4.9 | 10.9 |
| TRUNK and TAIL | 3.1 | 6.9 |
| TOTAL: | 45.0$mm^2$ | 100.0% |

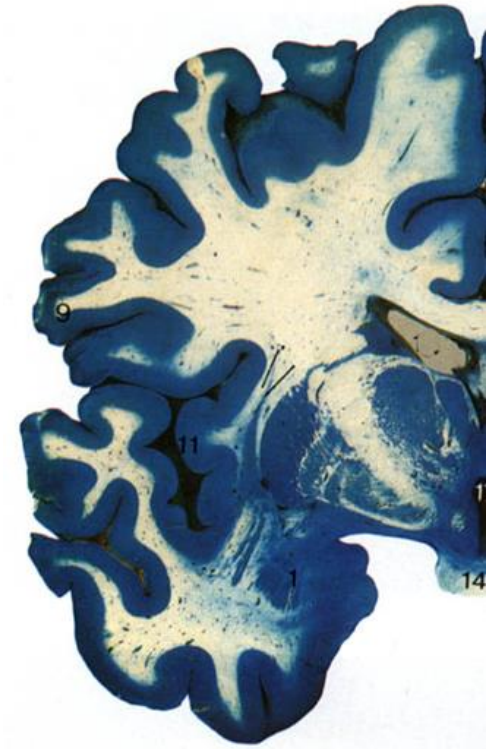
# Motor pathways

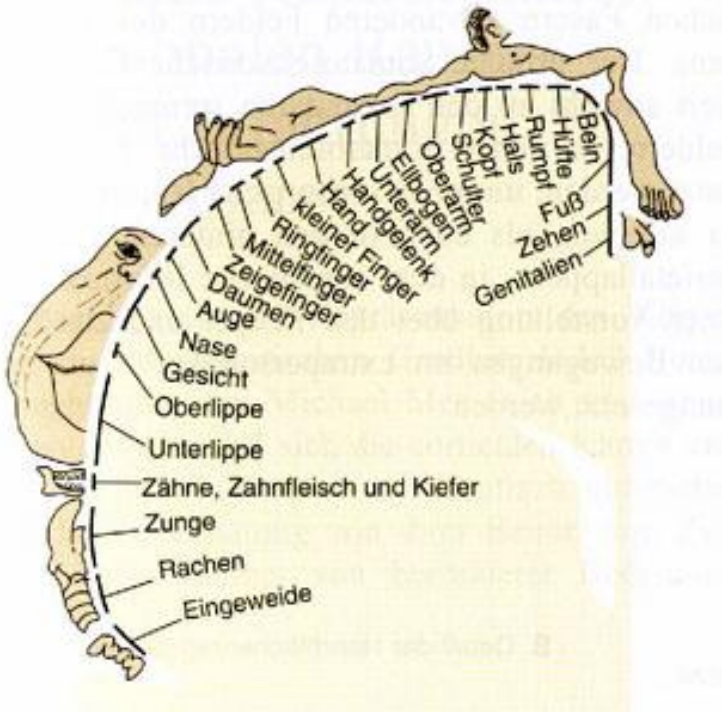


# Topographic organization of primary motor cortex

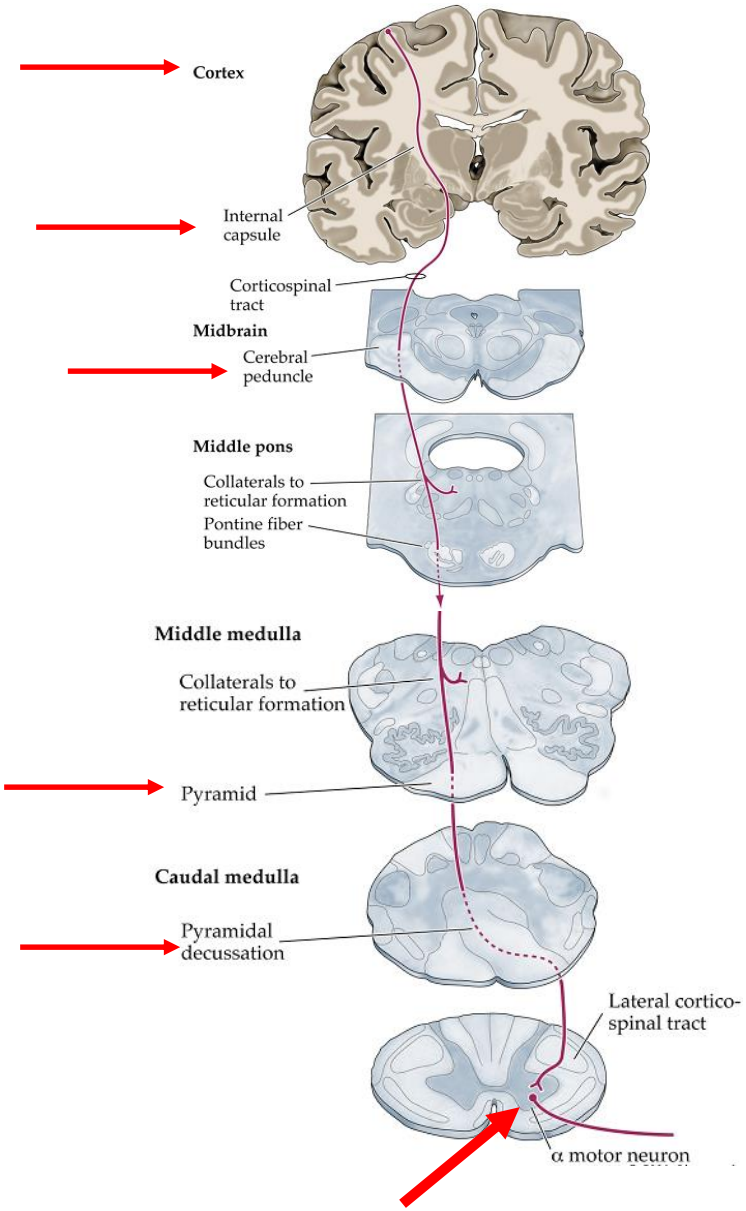
Primary motor cortex



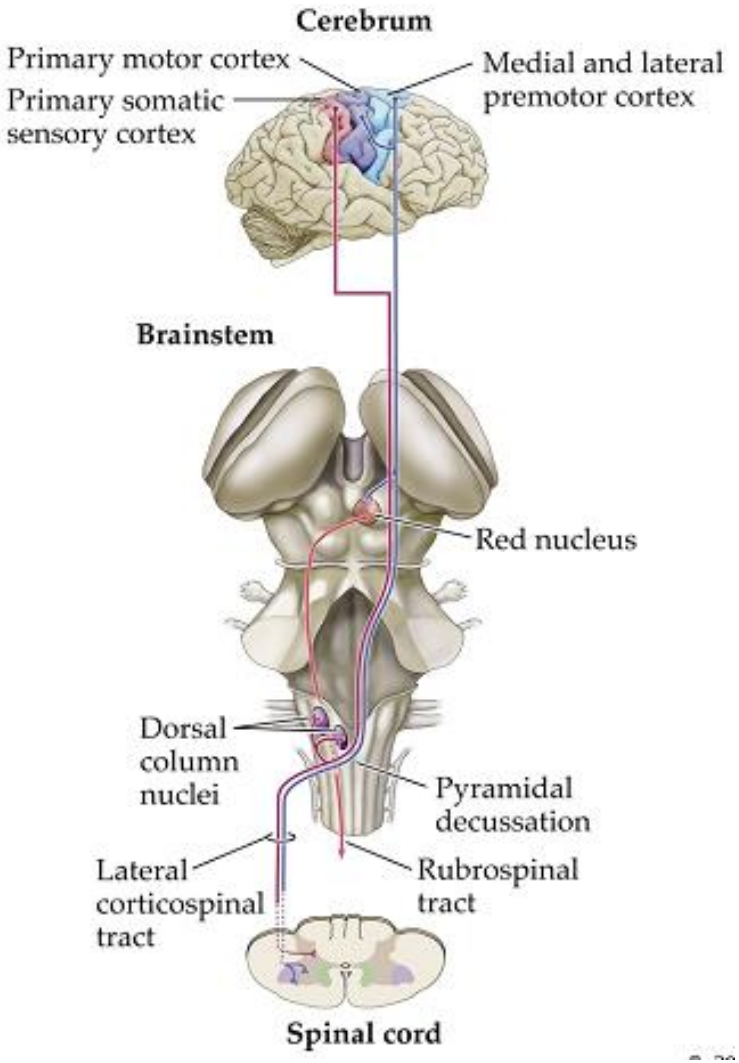




# Corticospinal tract

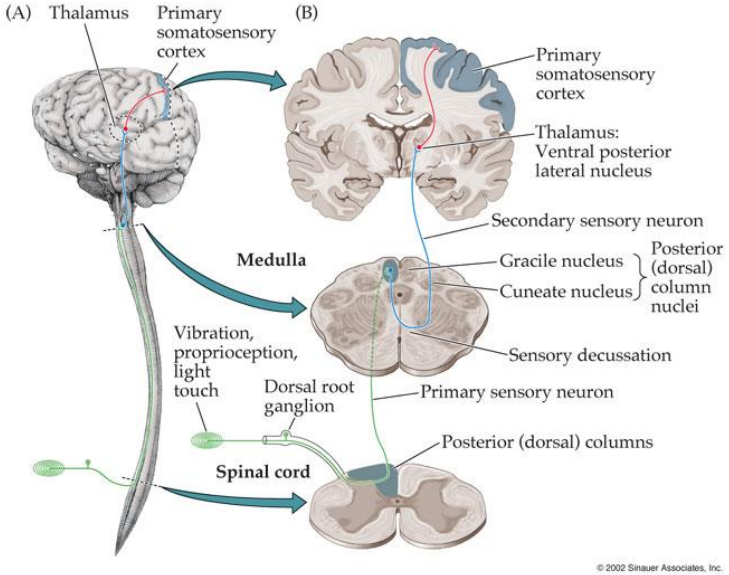


# Corticospinal tracts (Lateral and Ventral)

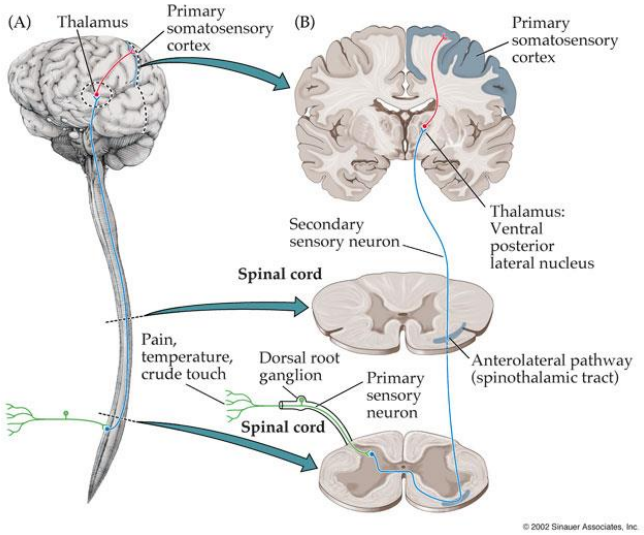


# The somatosensory and motor pathways

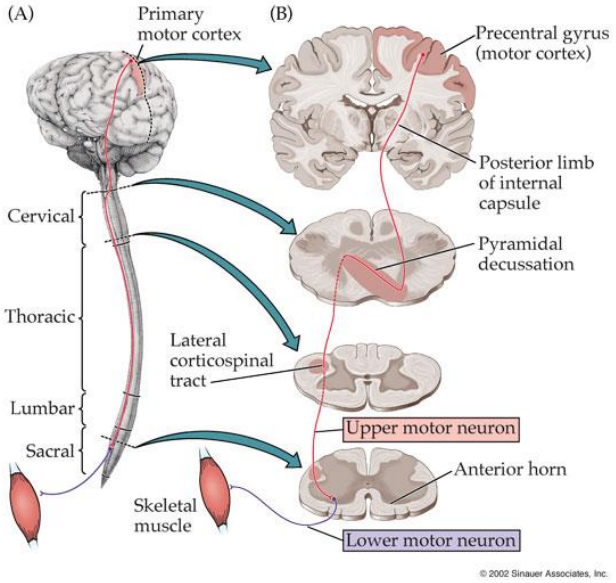
## Fine touch pathway




## Nociceptive pathway

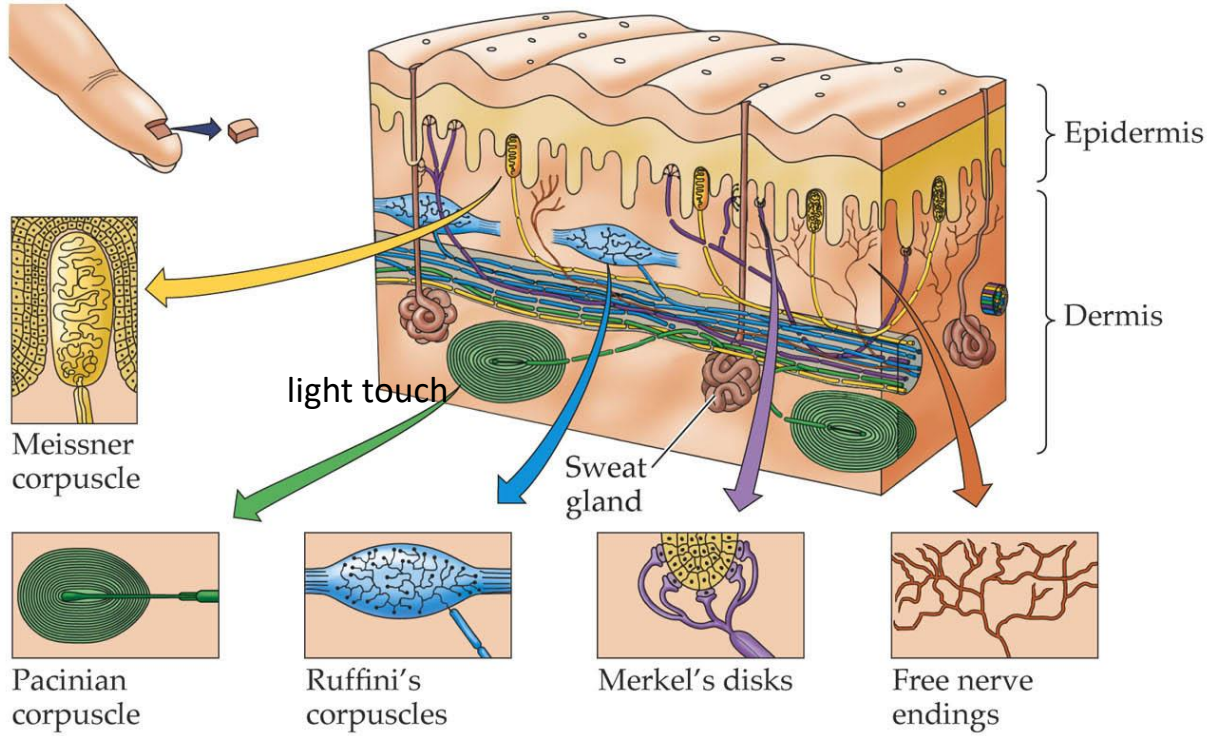



## Motor pathway



# Receptors

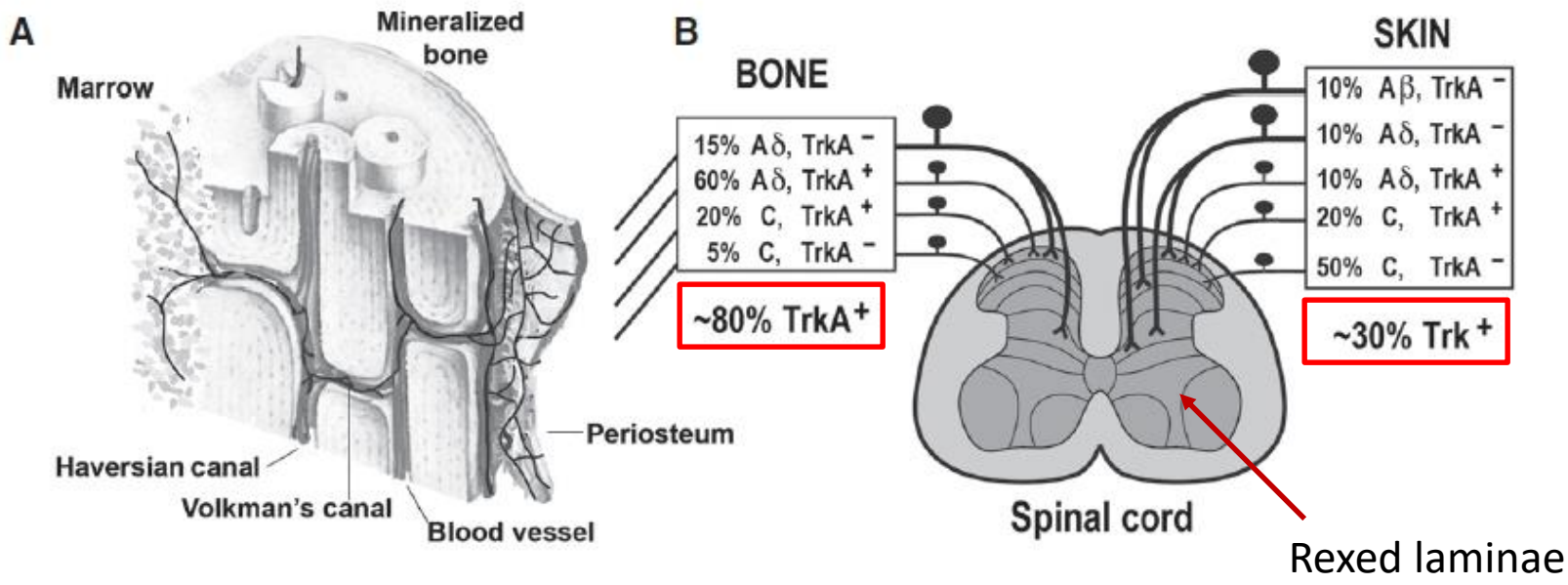
Sensations begin with the stimulation of receptors that are specialized parts of the axon and are located throughout the body. Each sensory modality is associated with a particular receptor.




pressure/vibration light touch Low freq vibration "pain" and temp receptors

NEUROSCIENCE, Third Edition, Figure 8.3 © 2004 Sinauer Associates, Inc.

# C-fiber variation



# Peripheral nerve axons

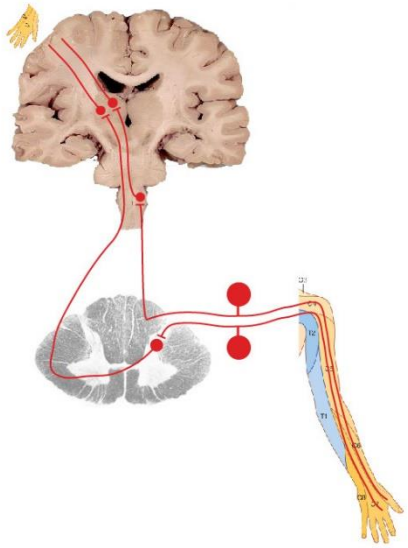
Axons (nerve fibers) have a range of sizes and conduct electrical impulses at different speeds.

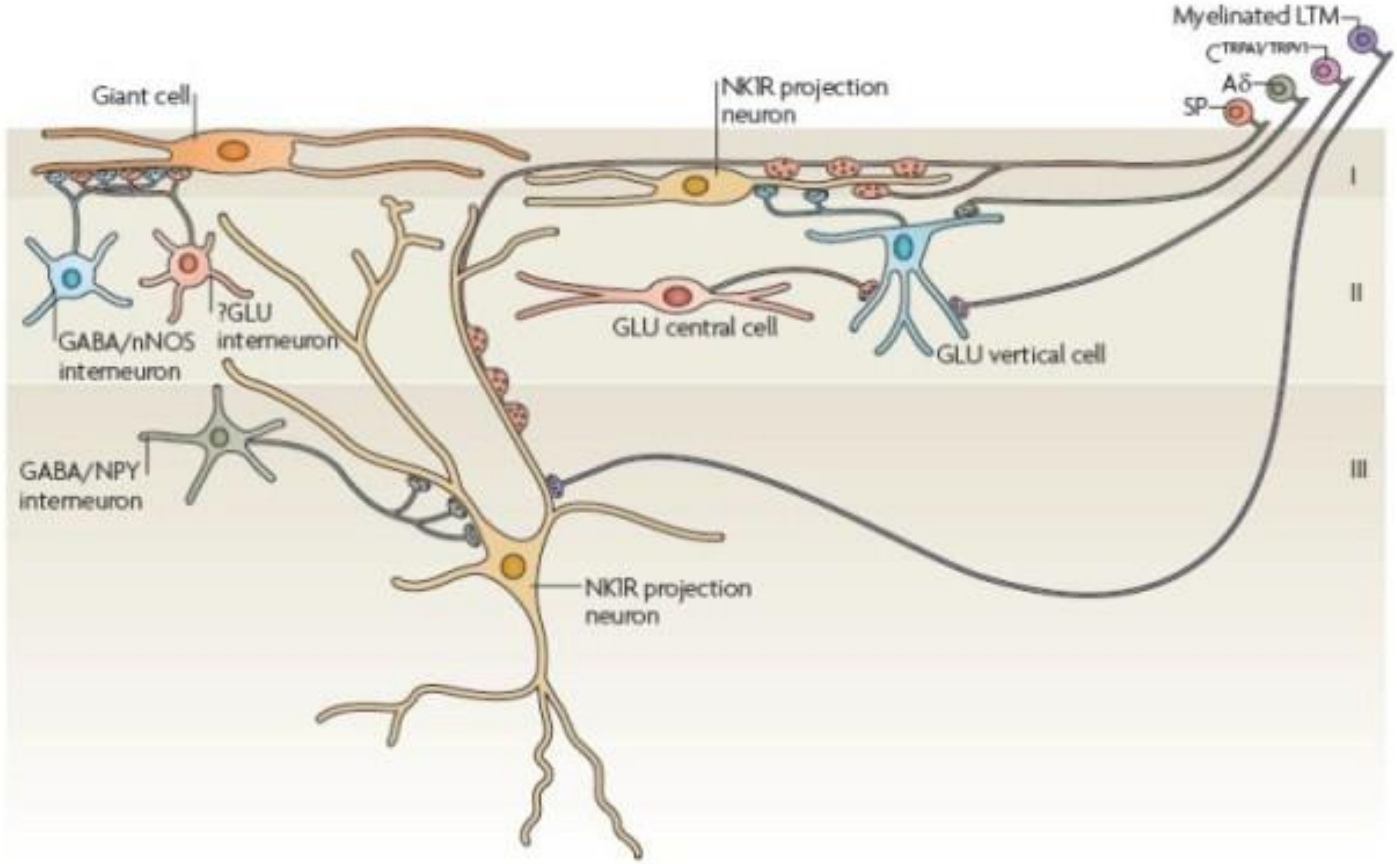
**TABLE 9.1 Somatic Sensory Afferents that Link Receptors to the Central Nervous System**

| Sensory function | Receptor type | Afferent axon type[a] | Axon diameter | Conduction velocity |
|---|---|---|---|---|
| Proprioception | Muscle spindle |   Ia, II | 13–20 µm | 80–120 m/s |
| Touch | Merkel, Meissner, Pacinian, and Ruffini cells |  Aβ | 6–12 µm | 35–75 m/s |
| Pain, temperature | Free nerve endings |  Aδ | 1–5 µm | 5–30 m/s |
| Pain, temperature, itch | Free nerve endings |  C | 0.2–1.5 µm | 0.5–2 m/s |

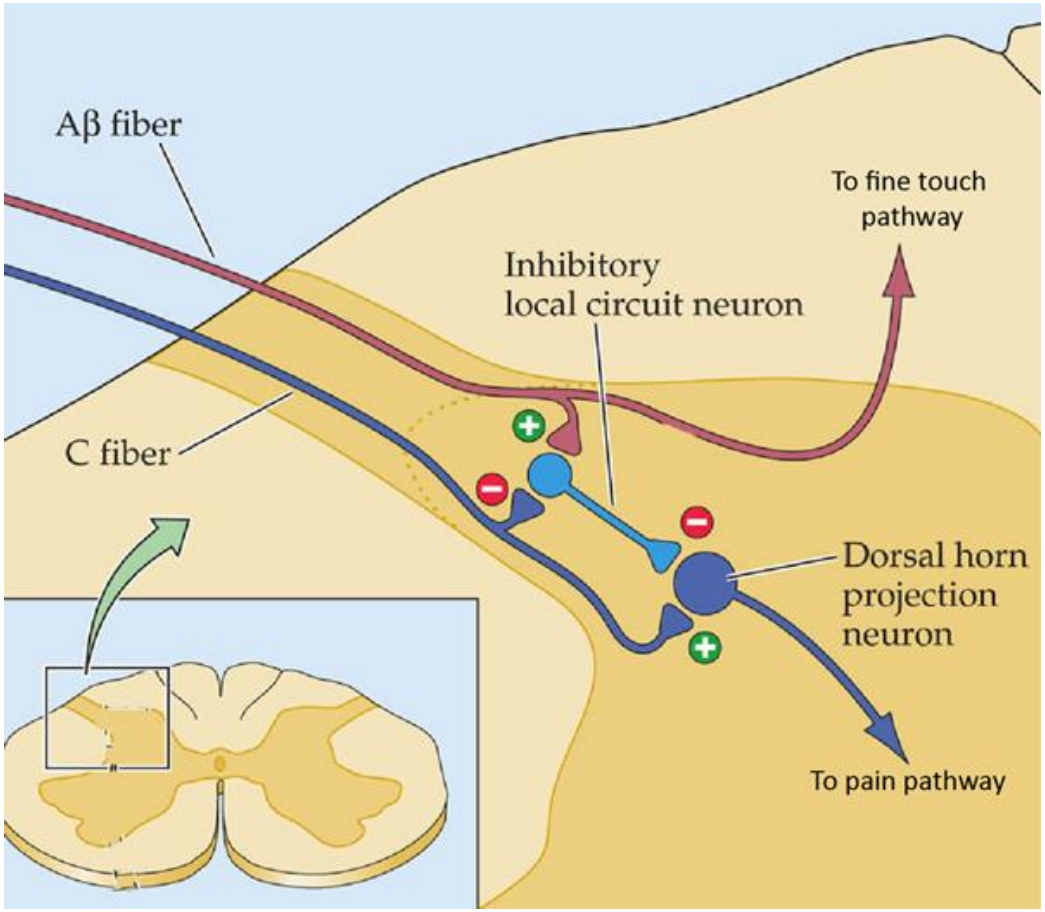
***NEUROSCIENCE, Fourth Edition*, Table 9.1**

# Neurotransmitters/neuromodulators/circuits in the dorsal horn



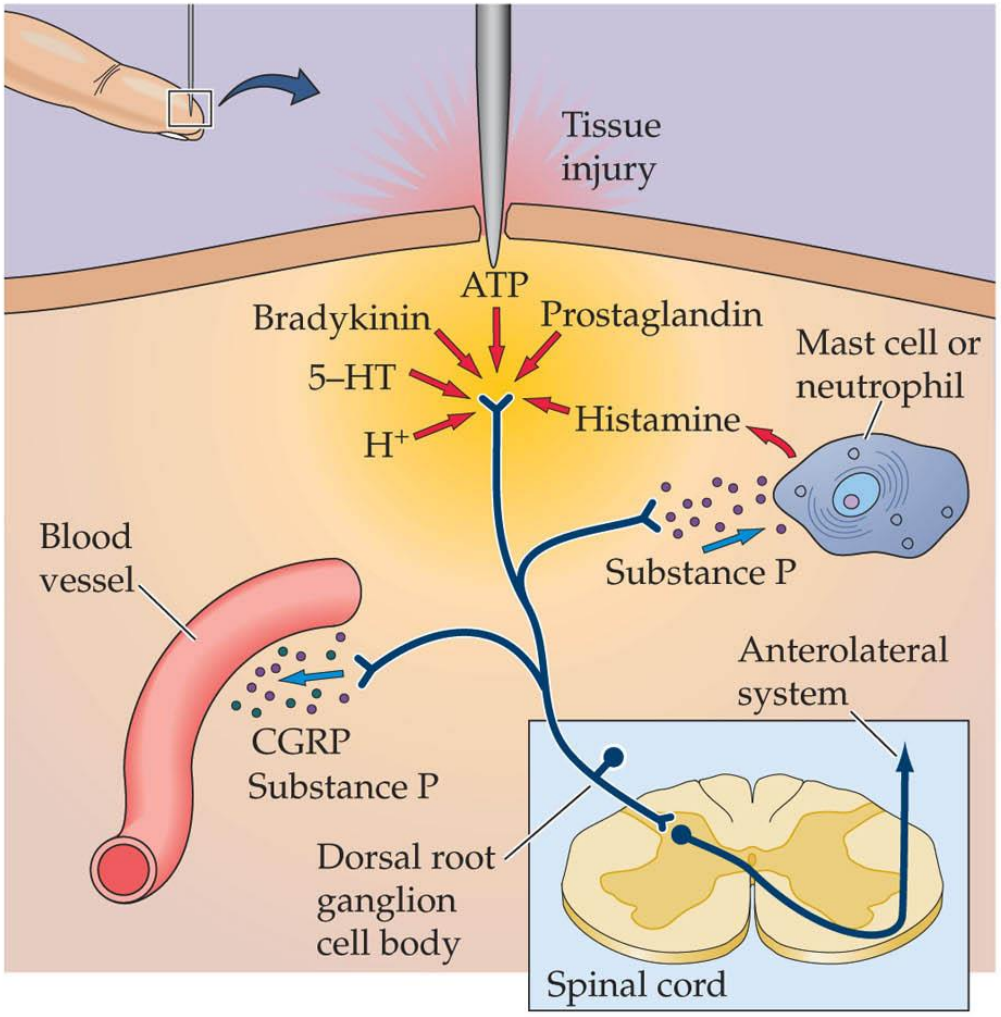


# The gate theory



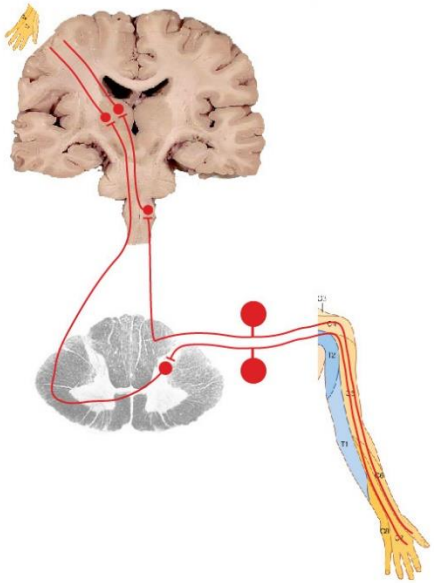

Dorsal horn spinal cord

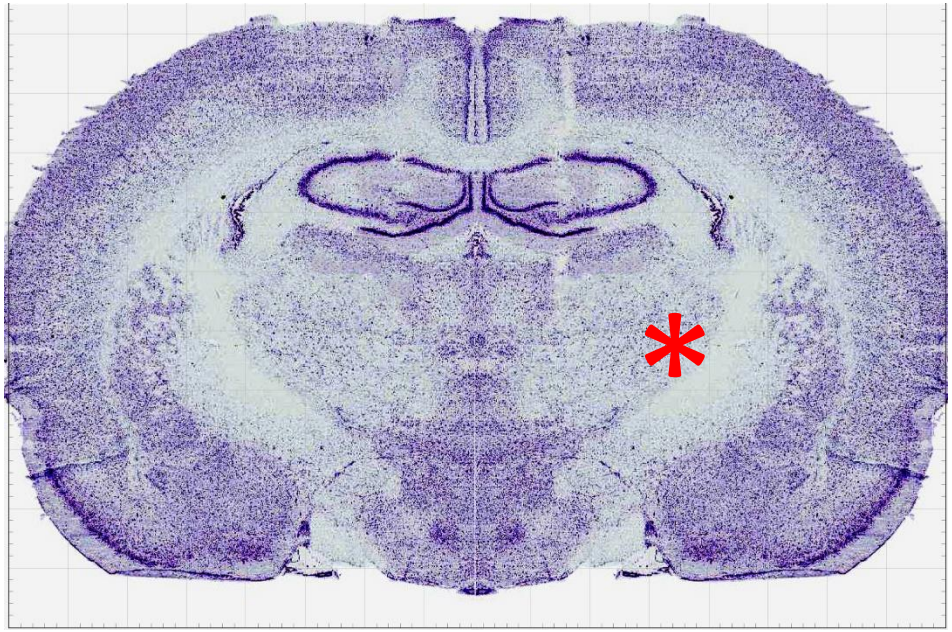
# Mediators of inflammation



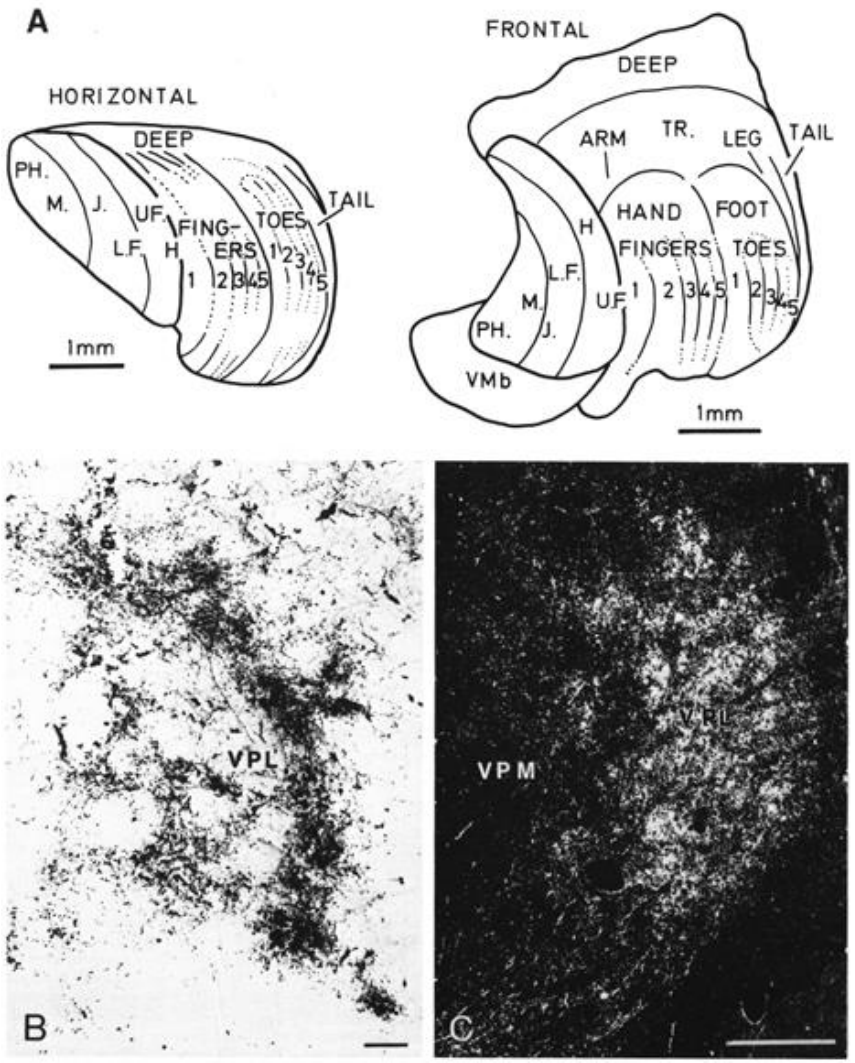

NEUROSCIENCE, Third Edition, Figure 9.6 © 2004 Sinauer Associates, Inc.

# The somatosensory thalamus

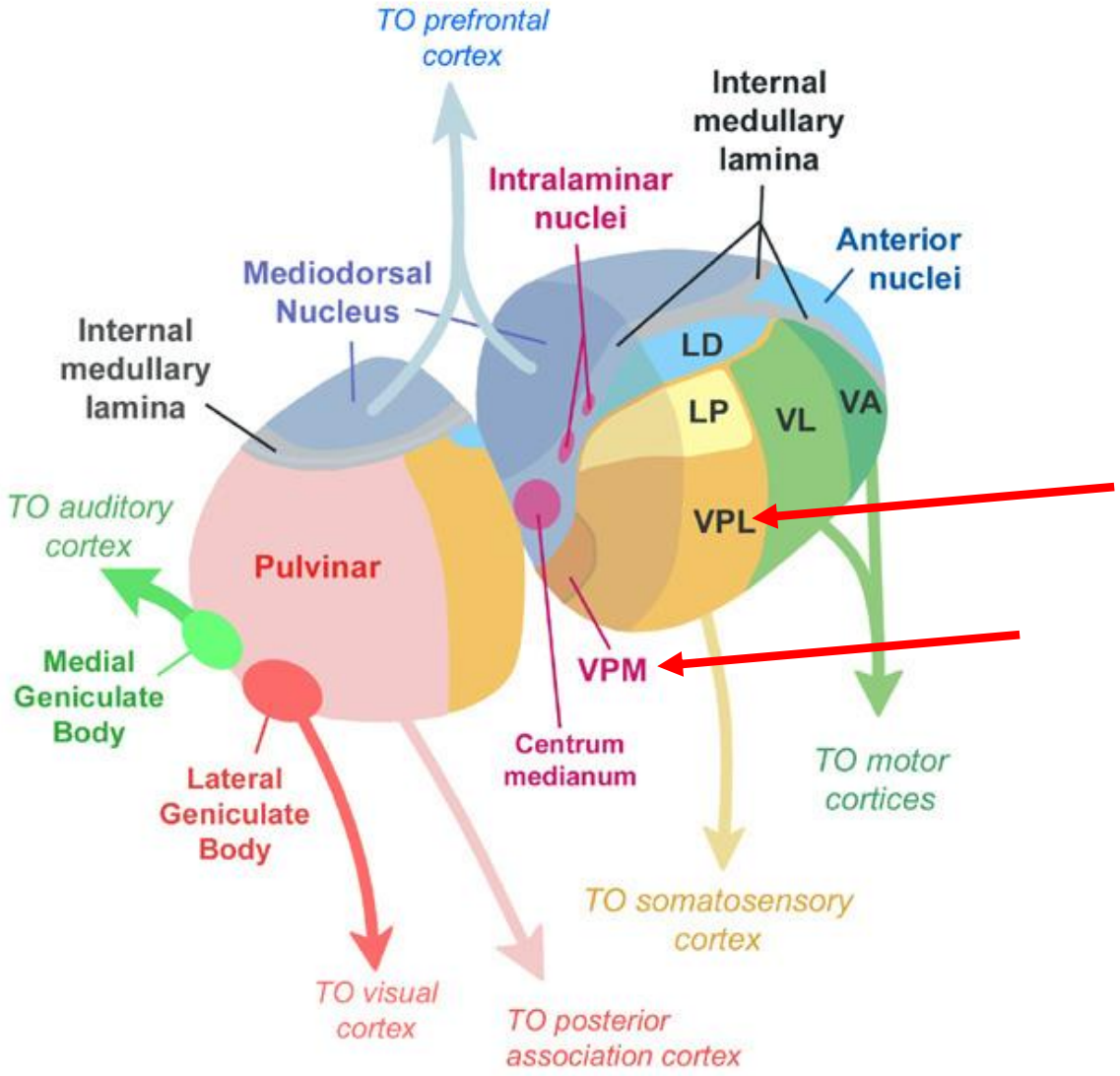





# Somatosensory thalamus topography

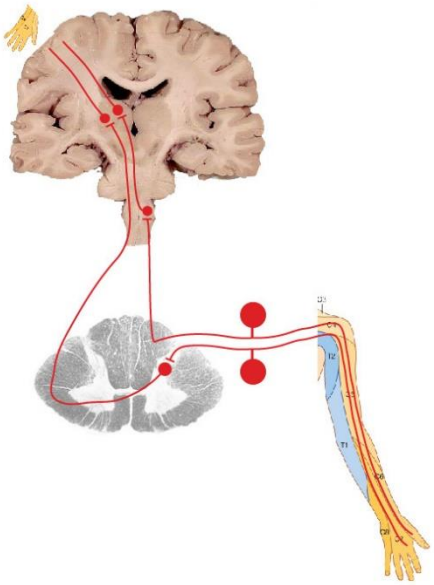


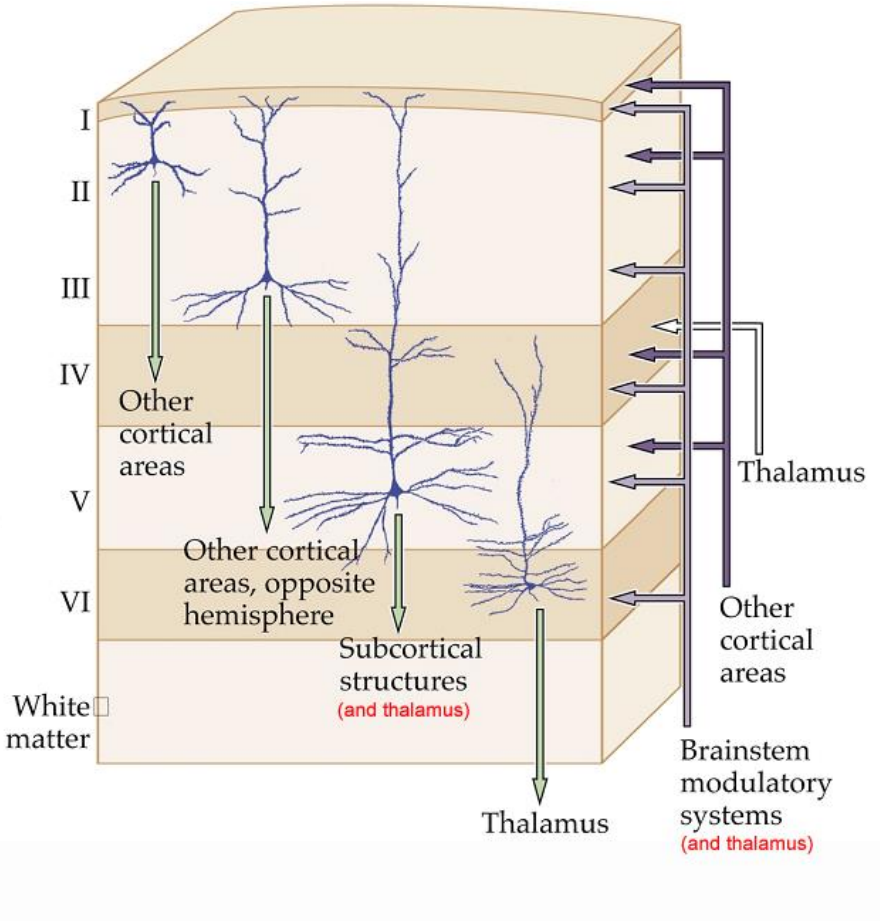

Somatotopy (VPL)




thalamic nuclei can be categorized on their location within the thalamus or according to function

# Thalamo-cortical termination

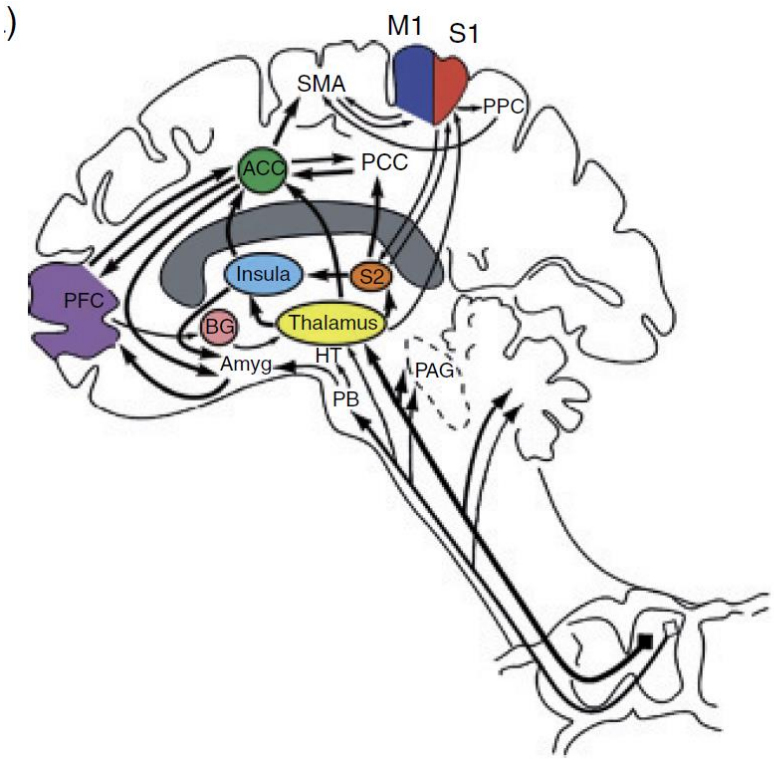




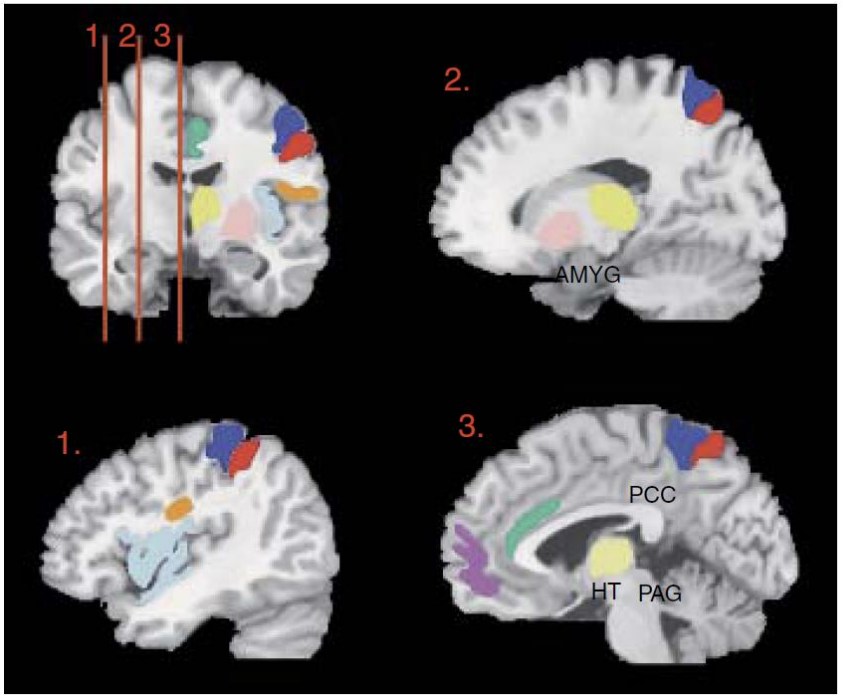

Corticothalamic afferents terminate in:

- Layer 4 but some 3 and 5
- Layer 6
- Layer 1 and sometimes 2

# Cortical regions involved in pain perception

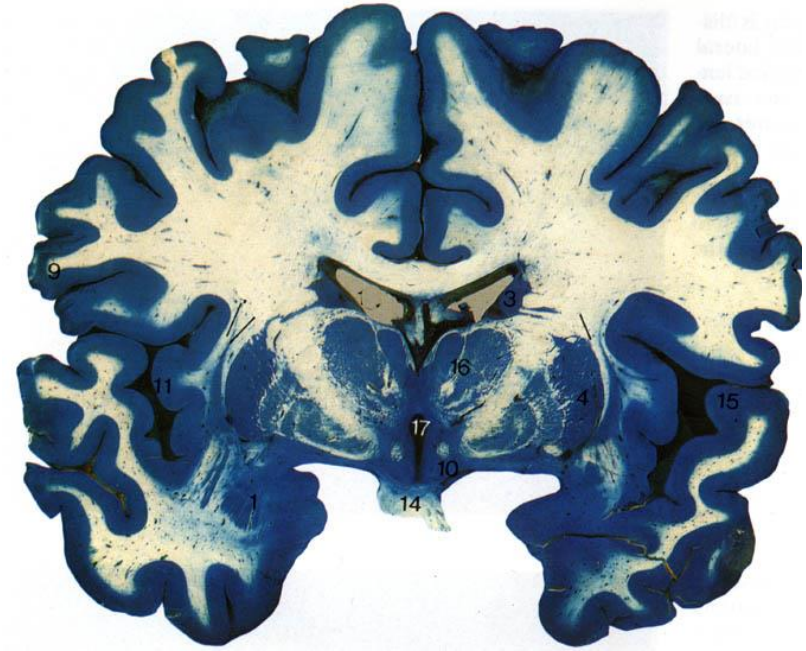


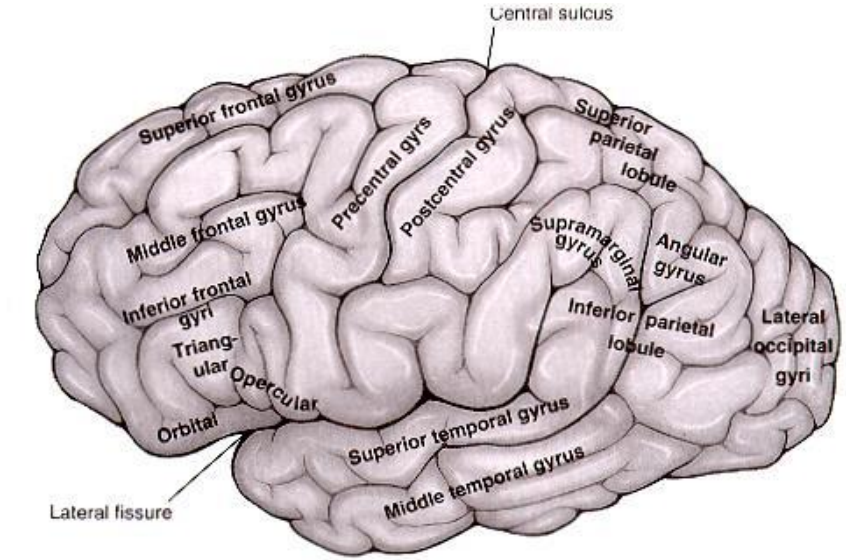

(b)

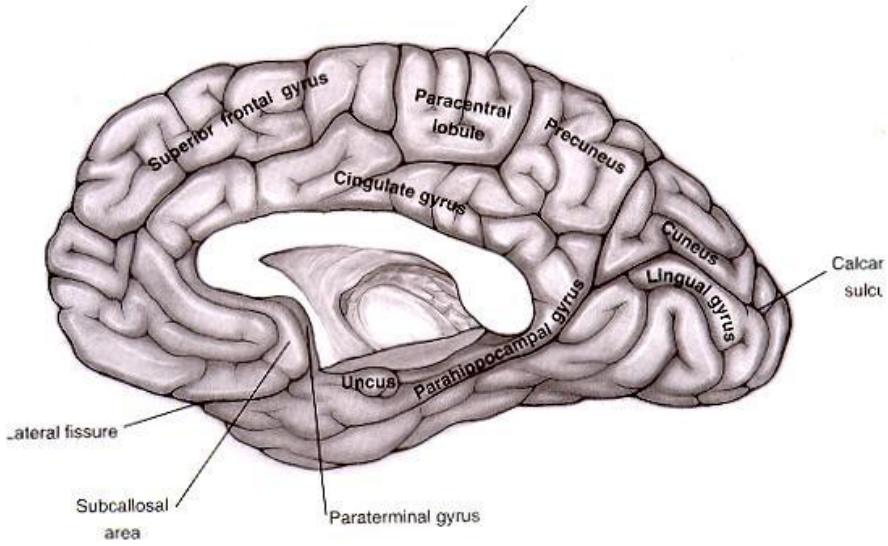


# Affective and Discriminative aspects of pain

- Localization and Intensity
  - Primary somatosensory Cortex
- Affective Component
  - Cingulate Cortex
  - Insular cortex

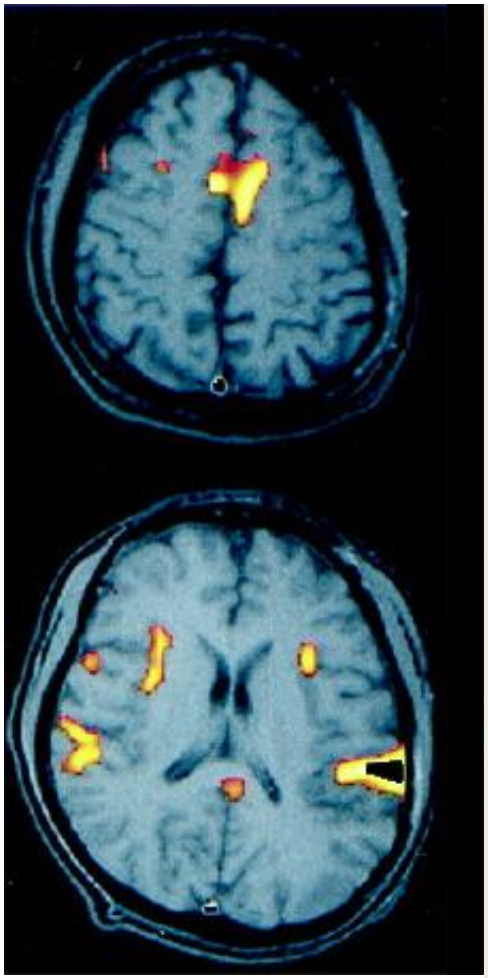




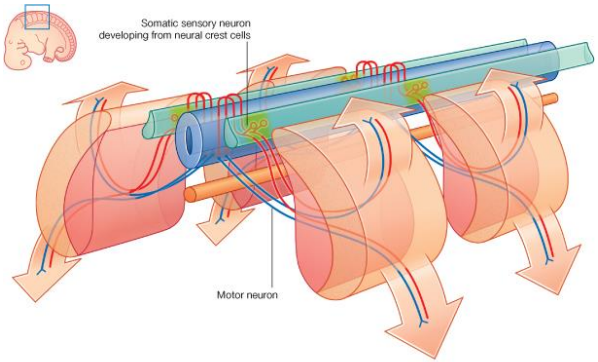
# Expectance can alter pain

| Pain (expect pain) | Warm (expect pain) | Warm (expect warm) |
| --- | --- | --- |

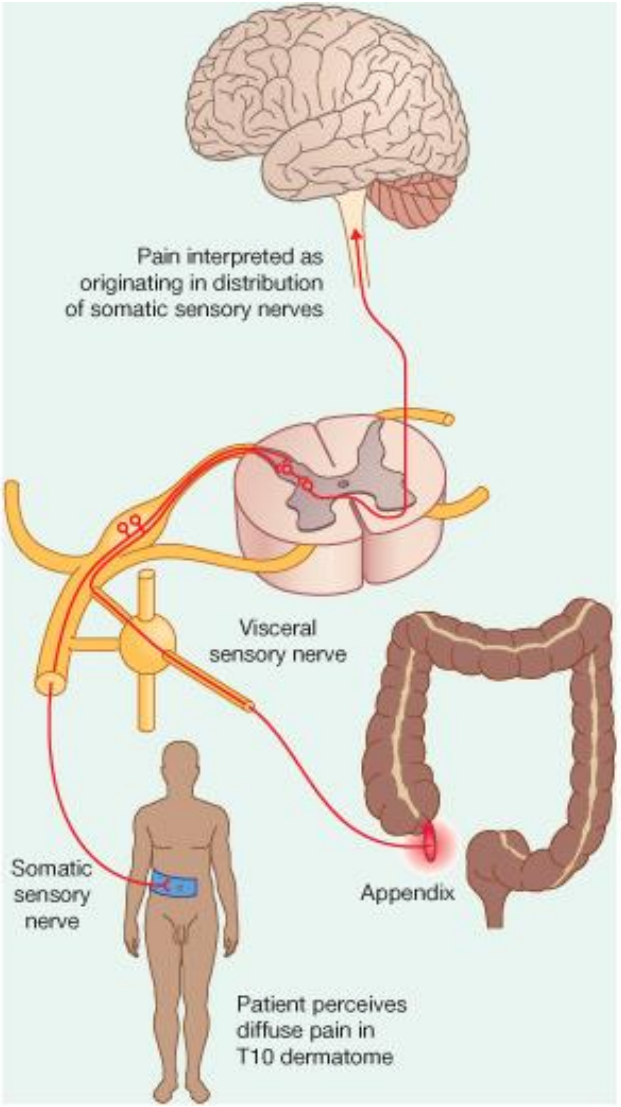


Sawamoto et al. 2000

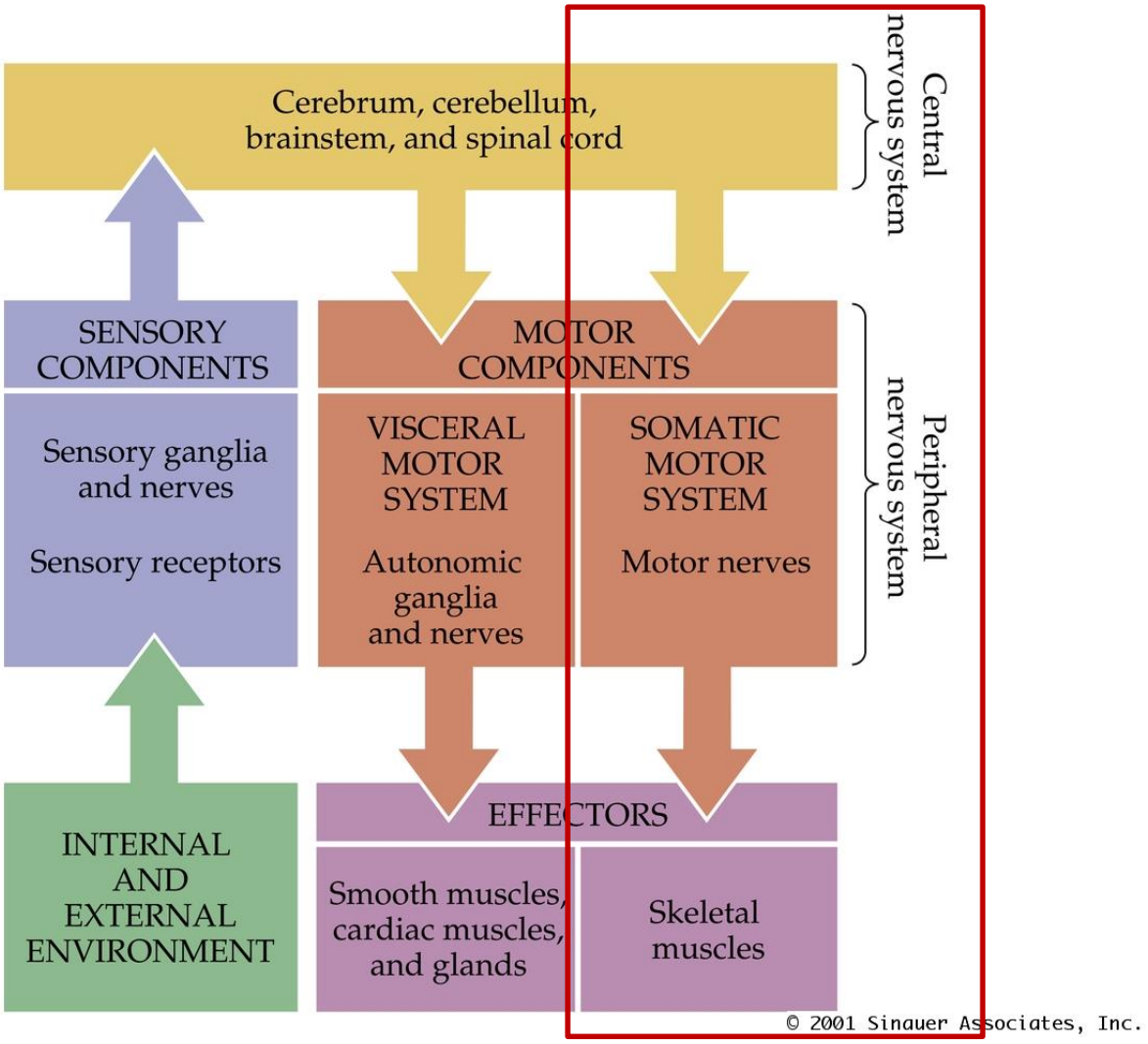
# Referred pain



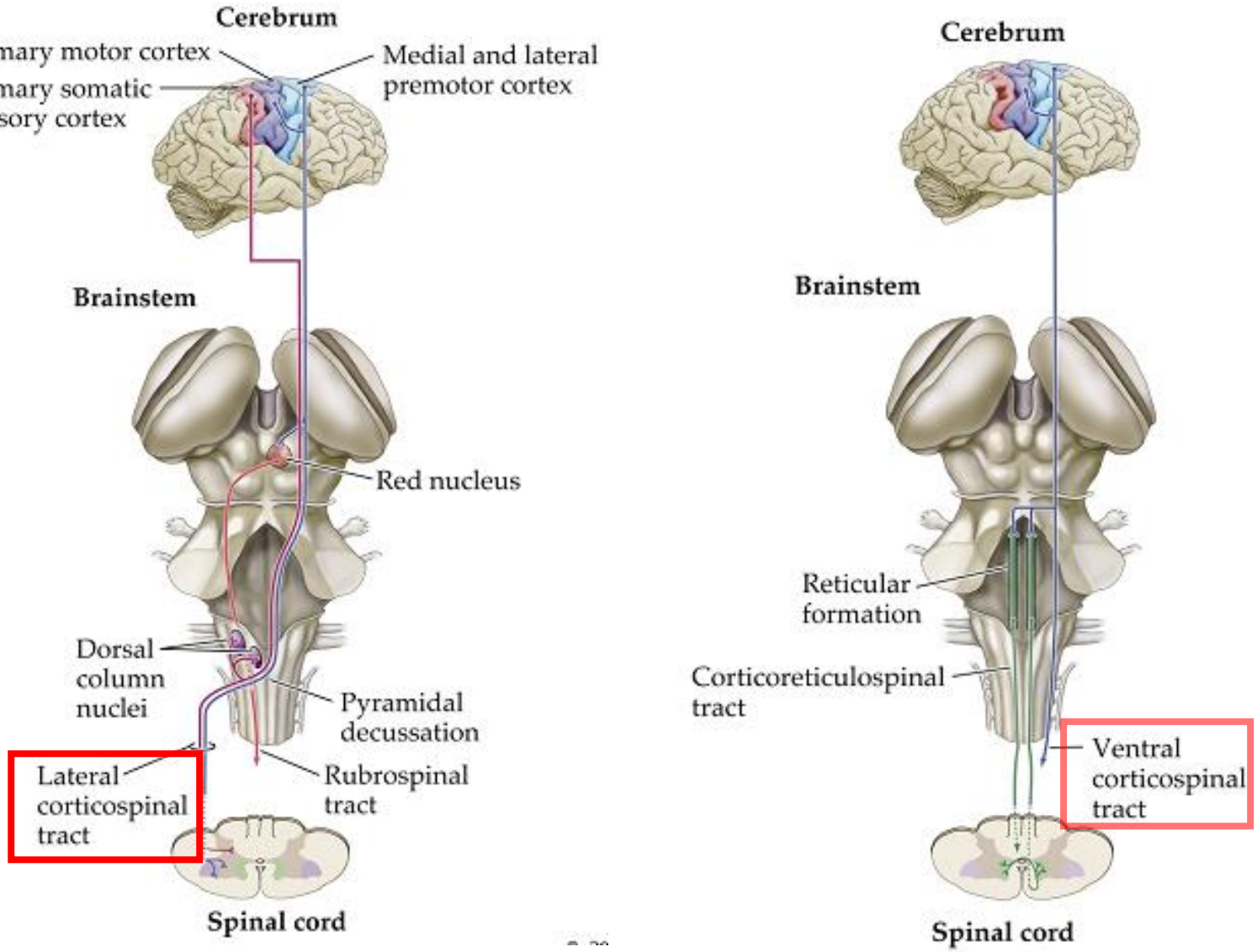


# Motor systems

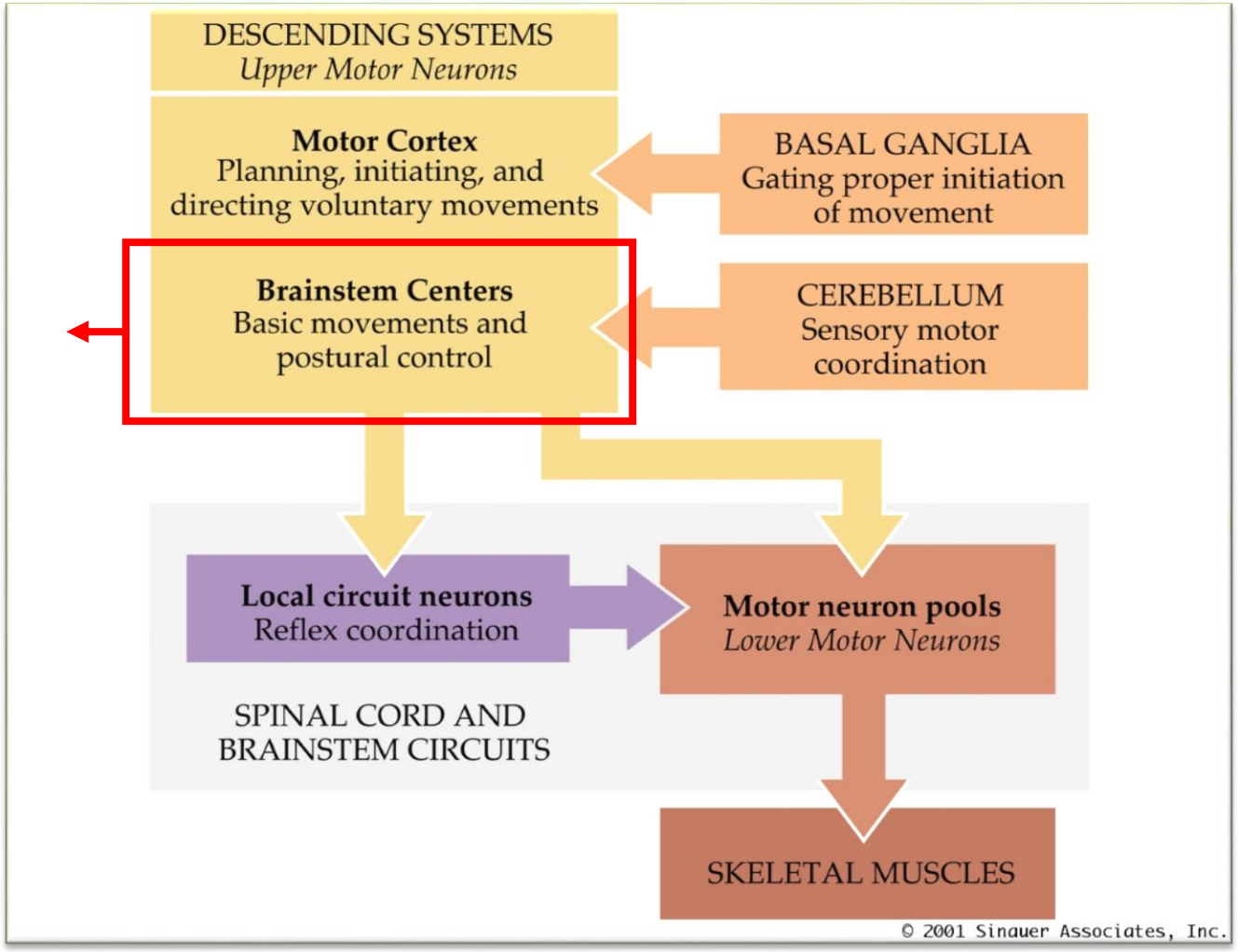


# Corticospinal tract

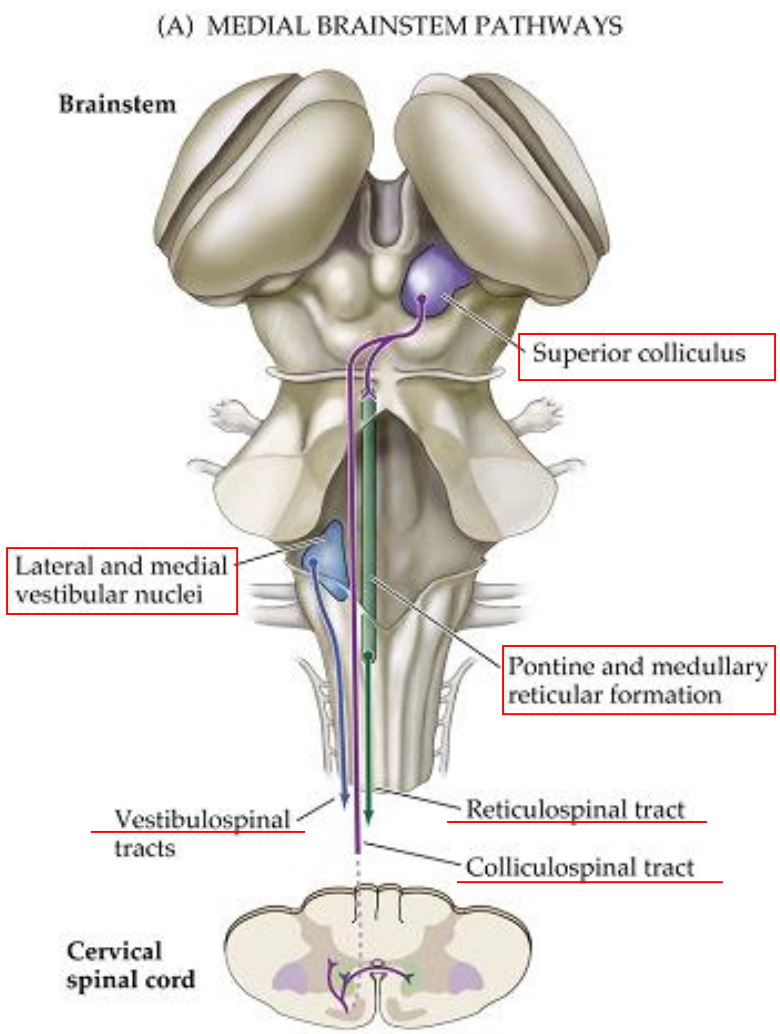


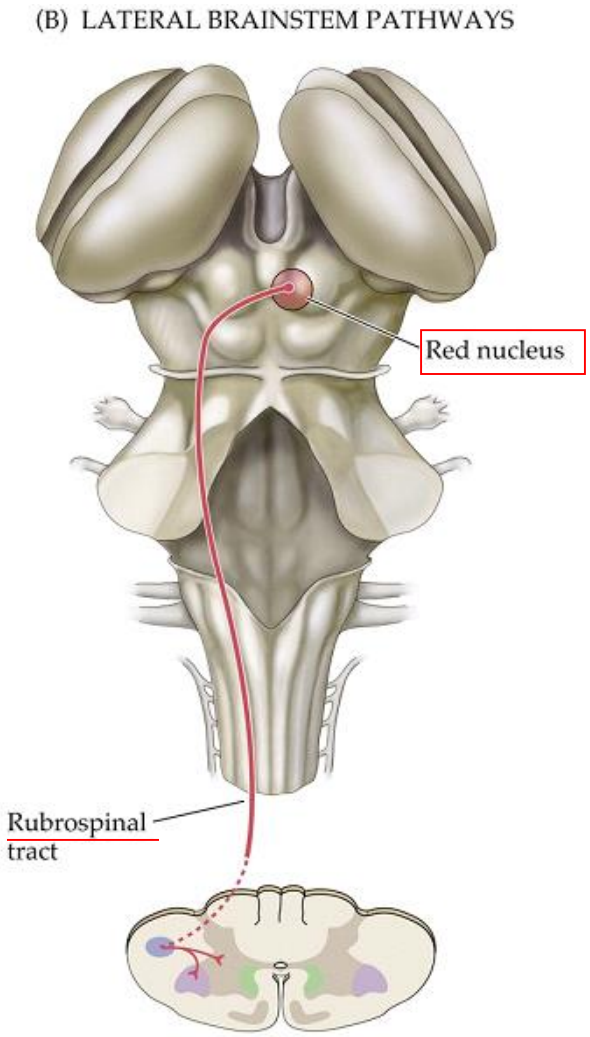
# Descending pathways - 1

Vestibular nucleus
Reticular formation
Red nucleus
Superior colliculus



# Descending Projections from the Brainstem

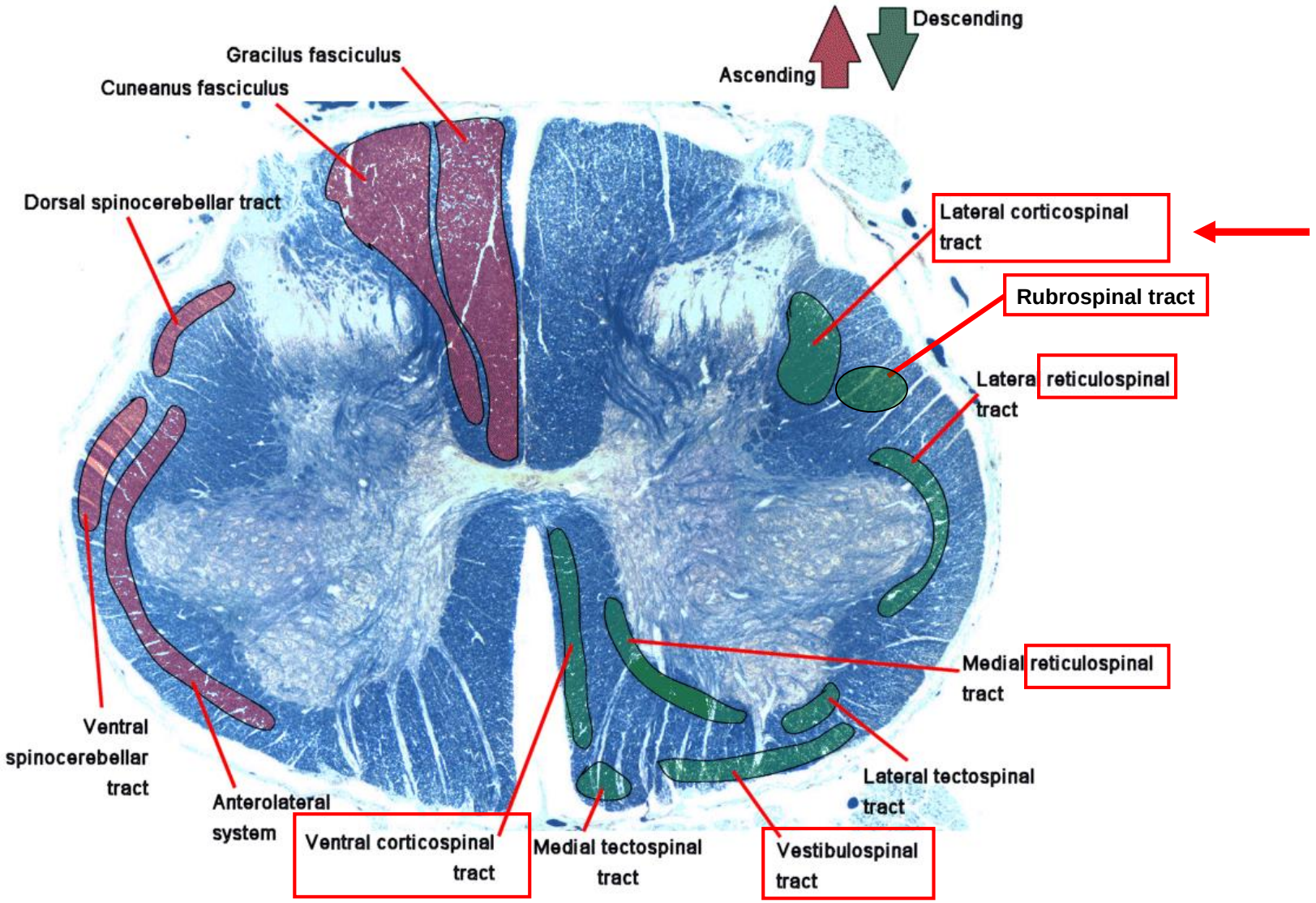


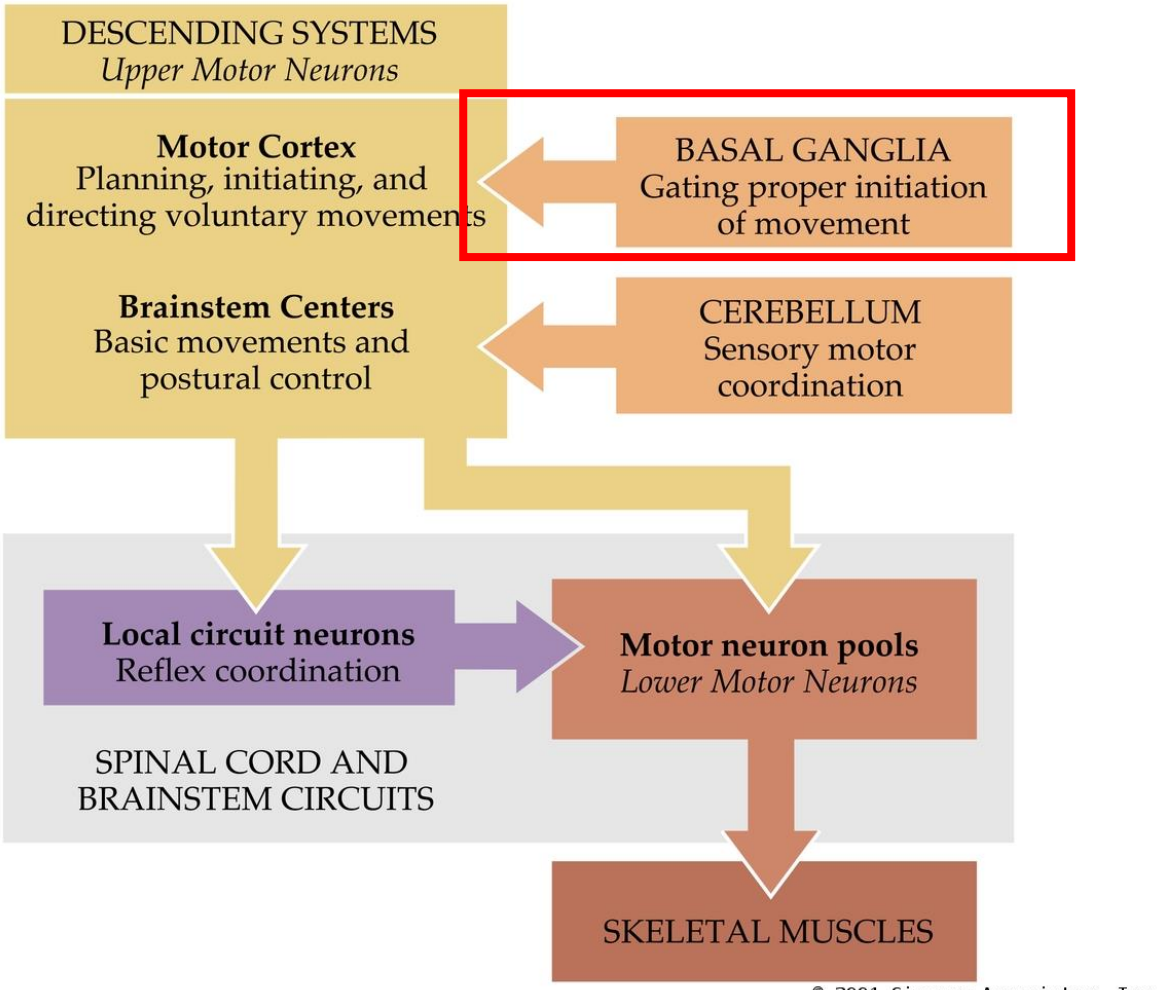

Vestibular nucleus – maintenance of posture
Reticular formation – integration of muscle groups
Superior colliculus – movement of head and neck with visual input.

Red nucleus – similar function to motor cortex

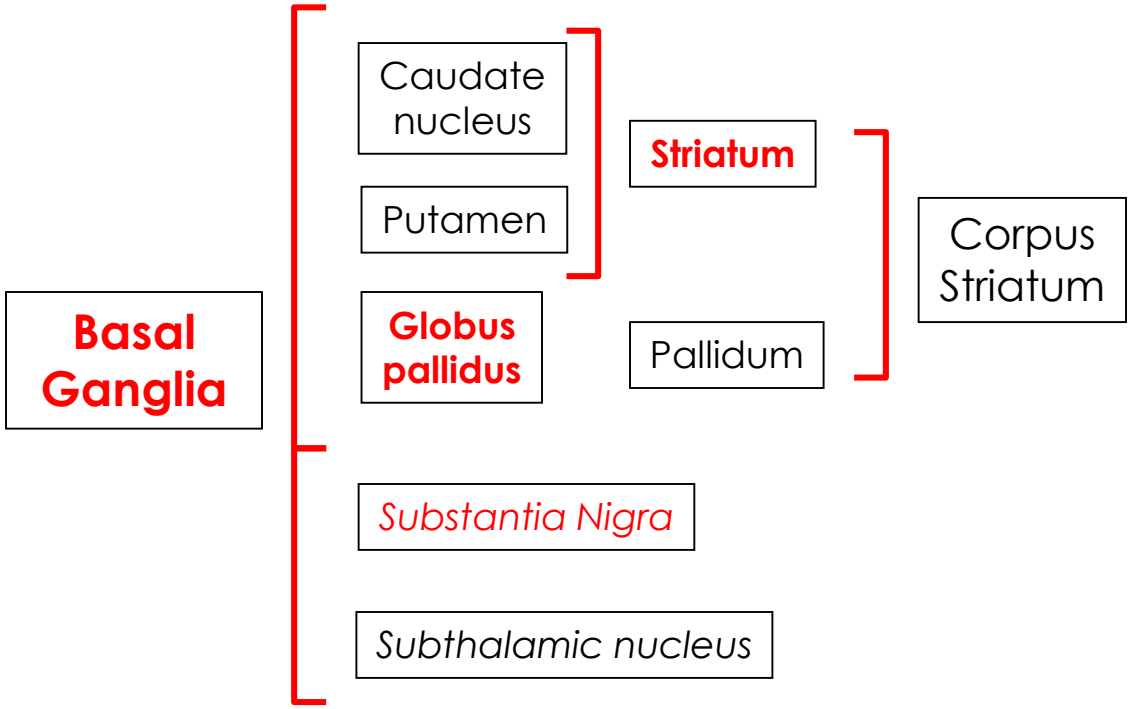
# The motor tracts in the spinal white matter



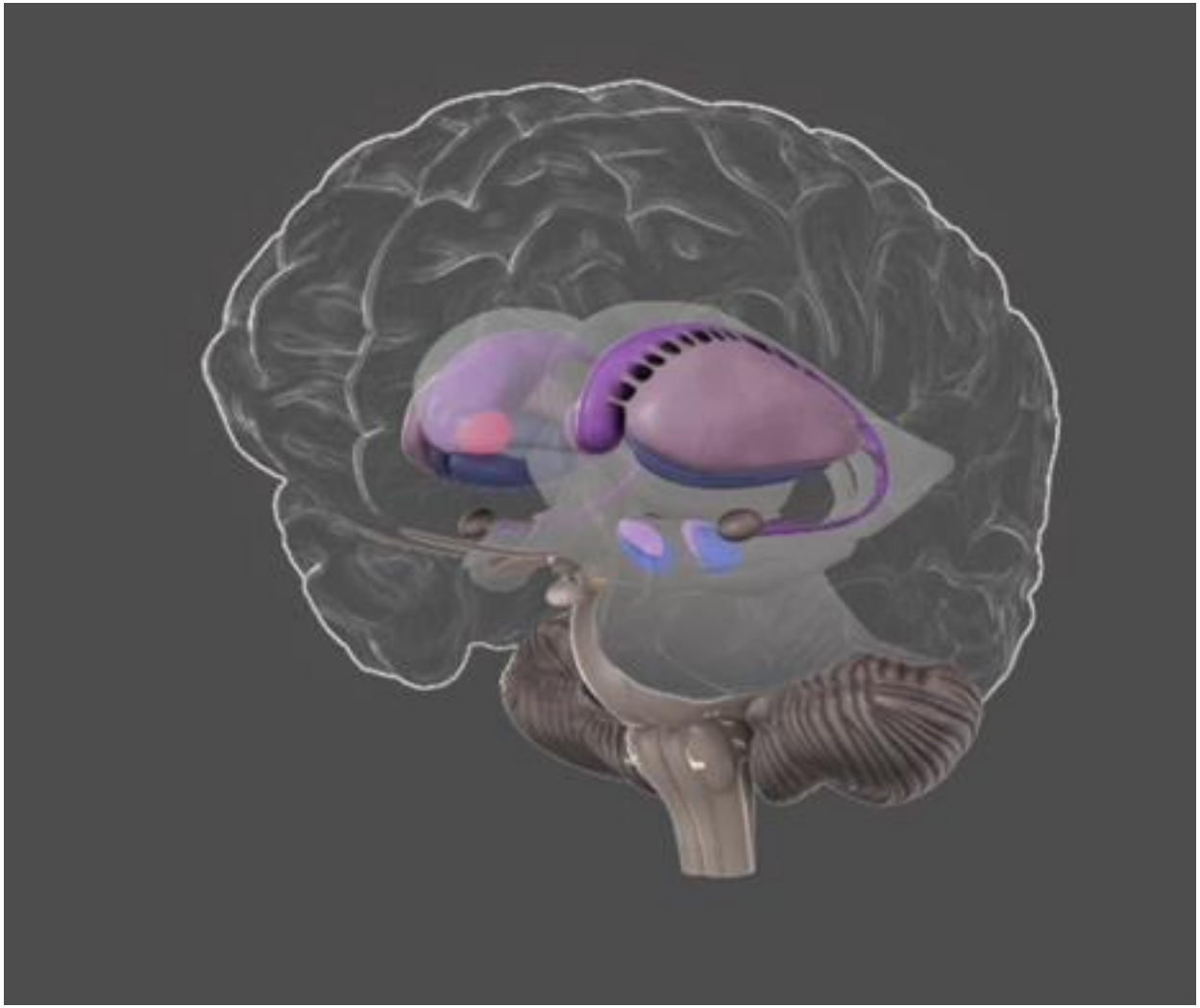
# Overall scheme



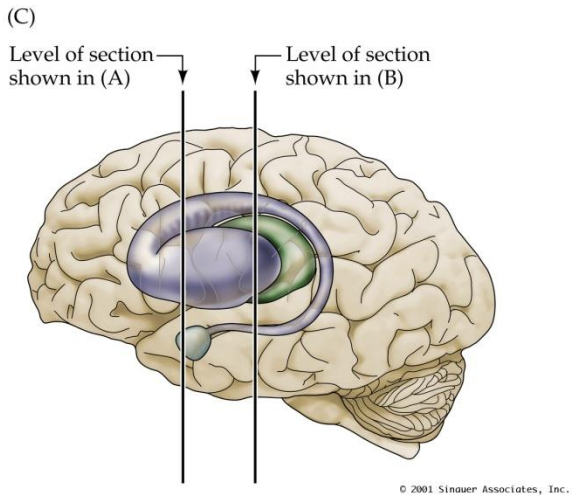
# Basal Ganglia nomenclature

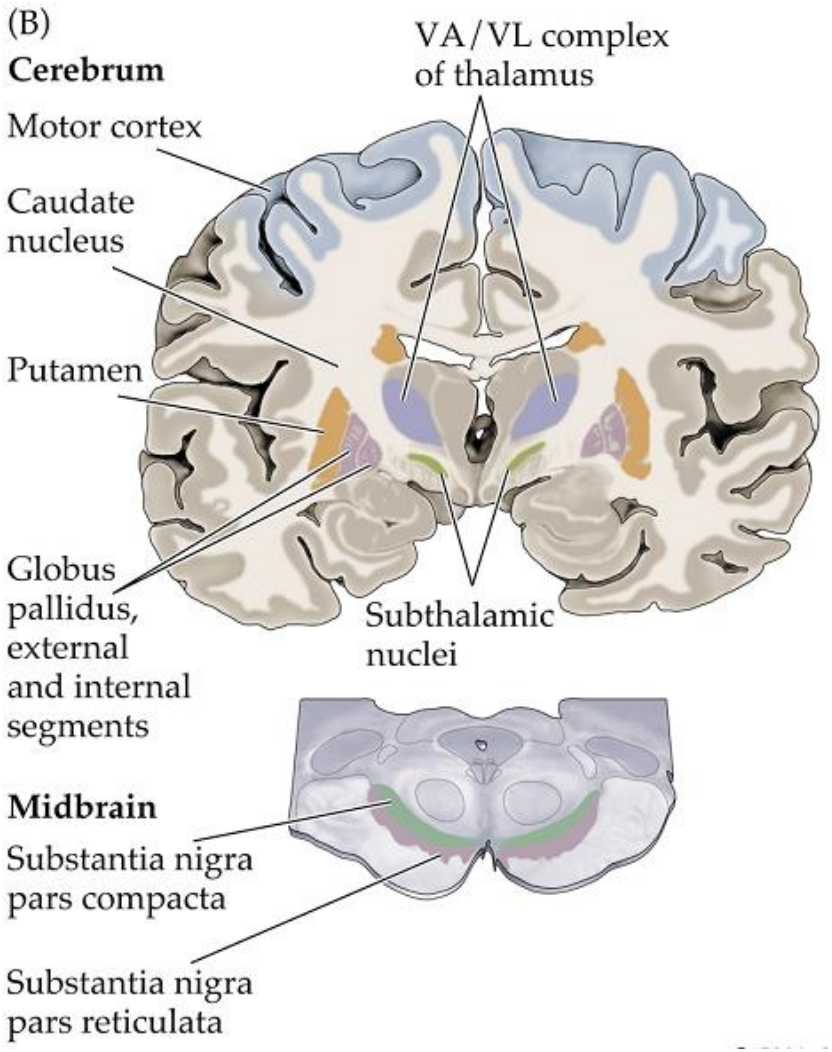


# Basal ganglia: Anatomy



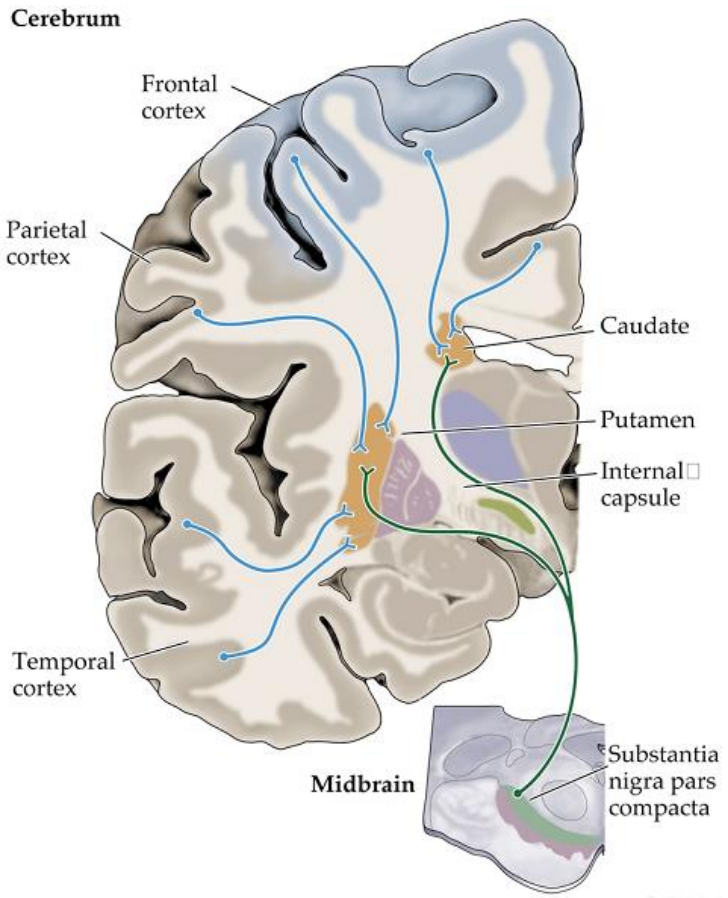
# Basal ganglia: Anatomy



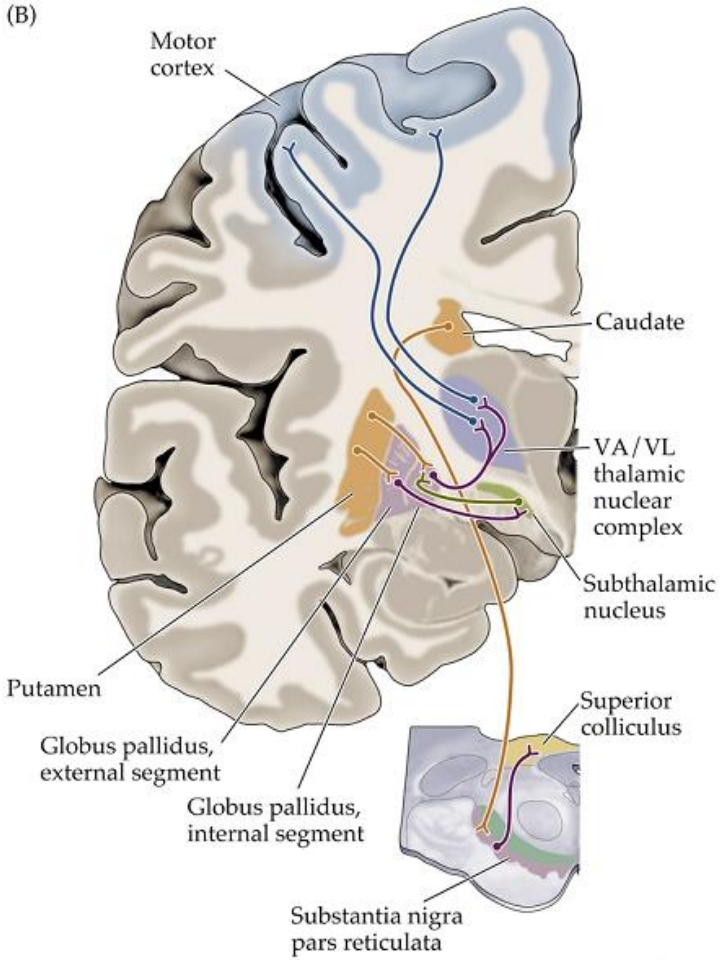



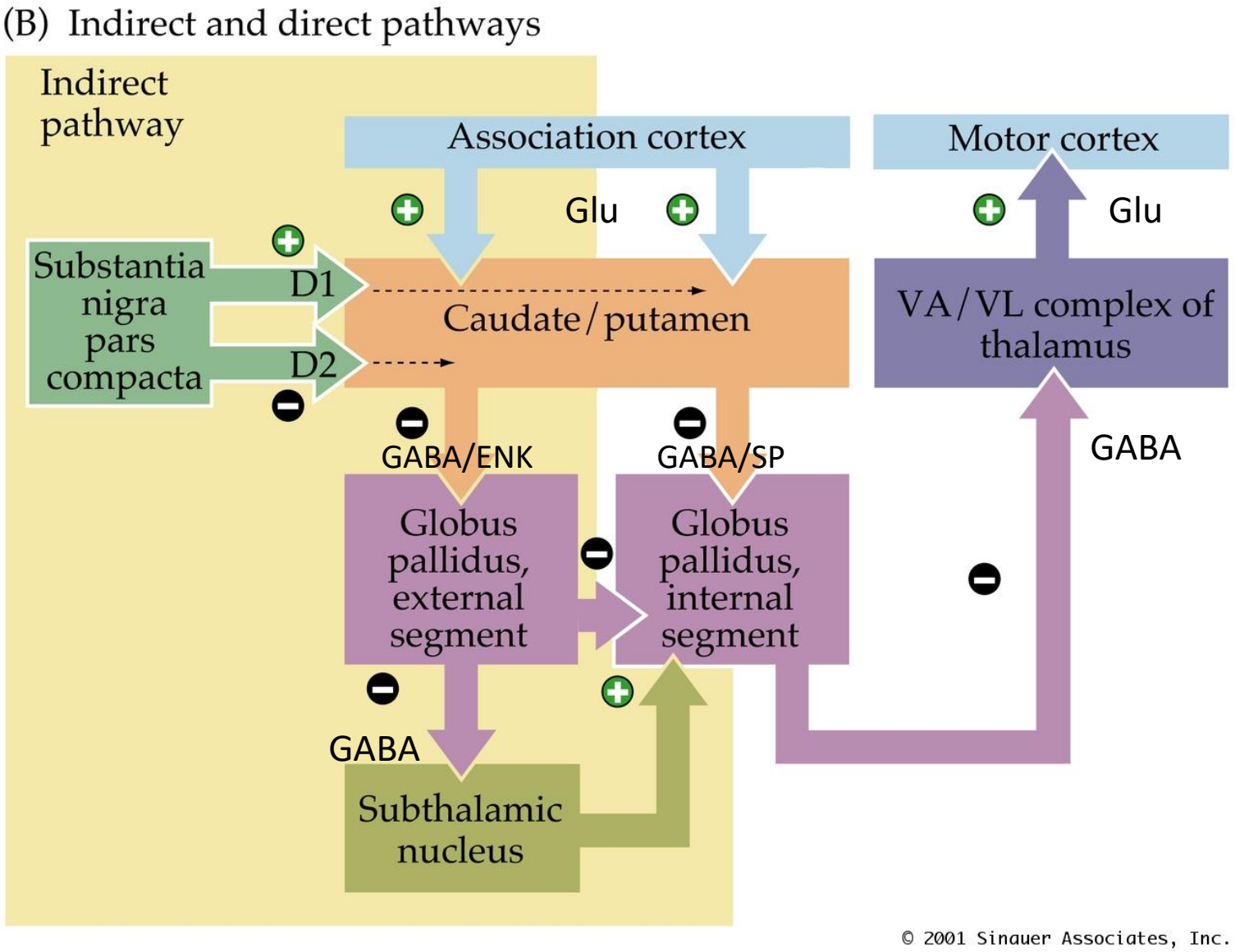
# Basal Ganglia connections

## input

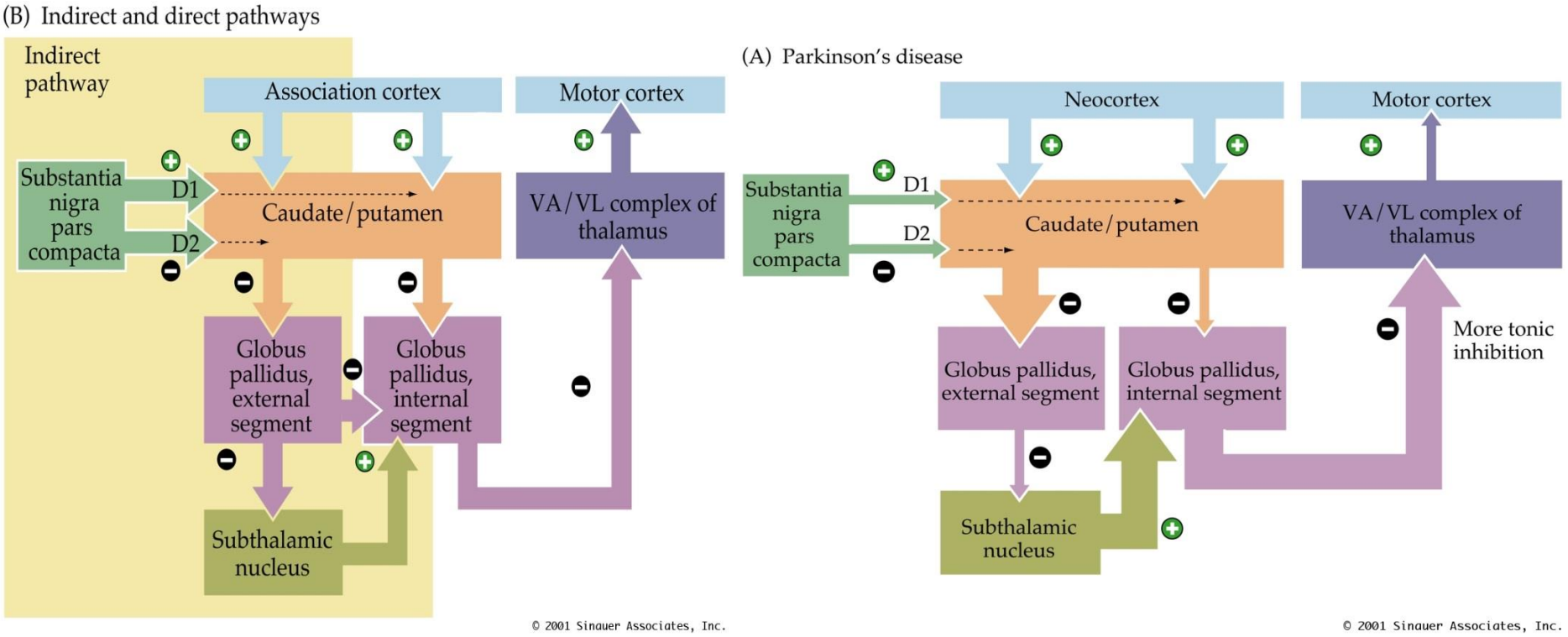



## output

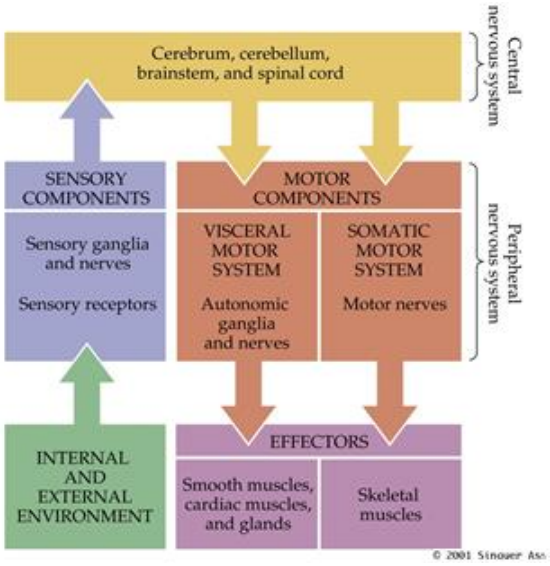


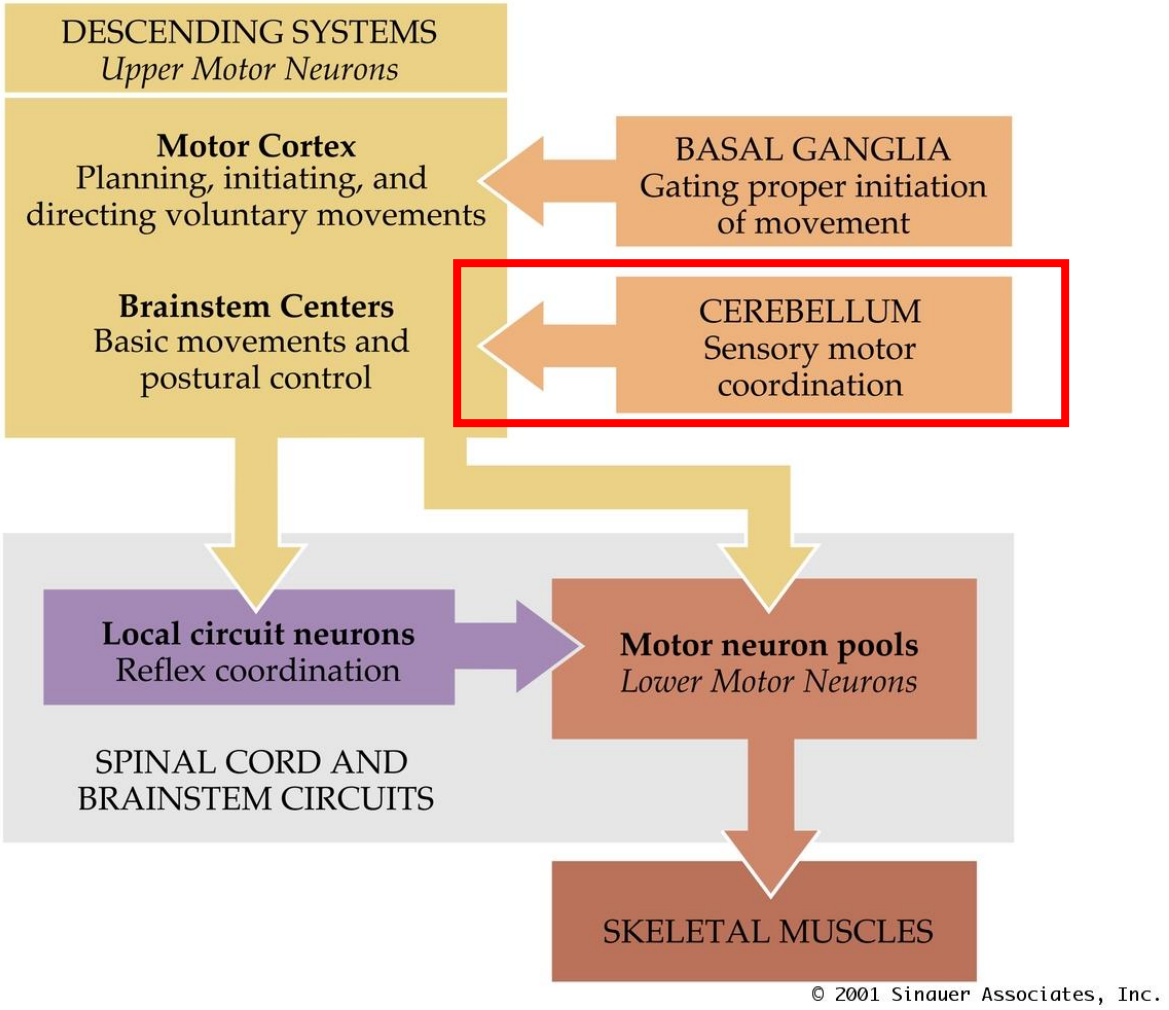

(B) Indirect and direct pathways
Indirect pathway
Association cortex
Motor cortex
Glu
Glu
Substantia nigra pars compacta
D1
D2
Caudate/putamen
VA/VL complex of thalamus
GABA/ENK
GABA/SP
GABA
Globus pallidus, external segment
Globus pallidus, internal segment
GABA
Subthalamic nucleus
© 2001 Sinauer Associates, Inc.

# Parkinson's: basal ganglia circuitry



# Relationship of Cerebellum to descending motor pathways

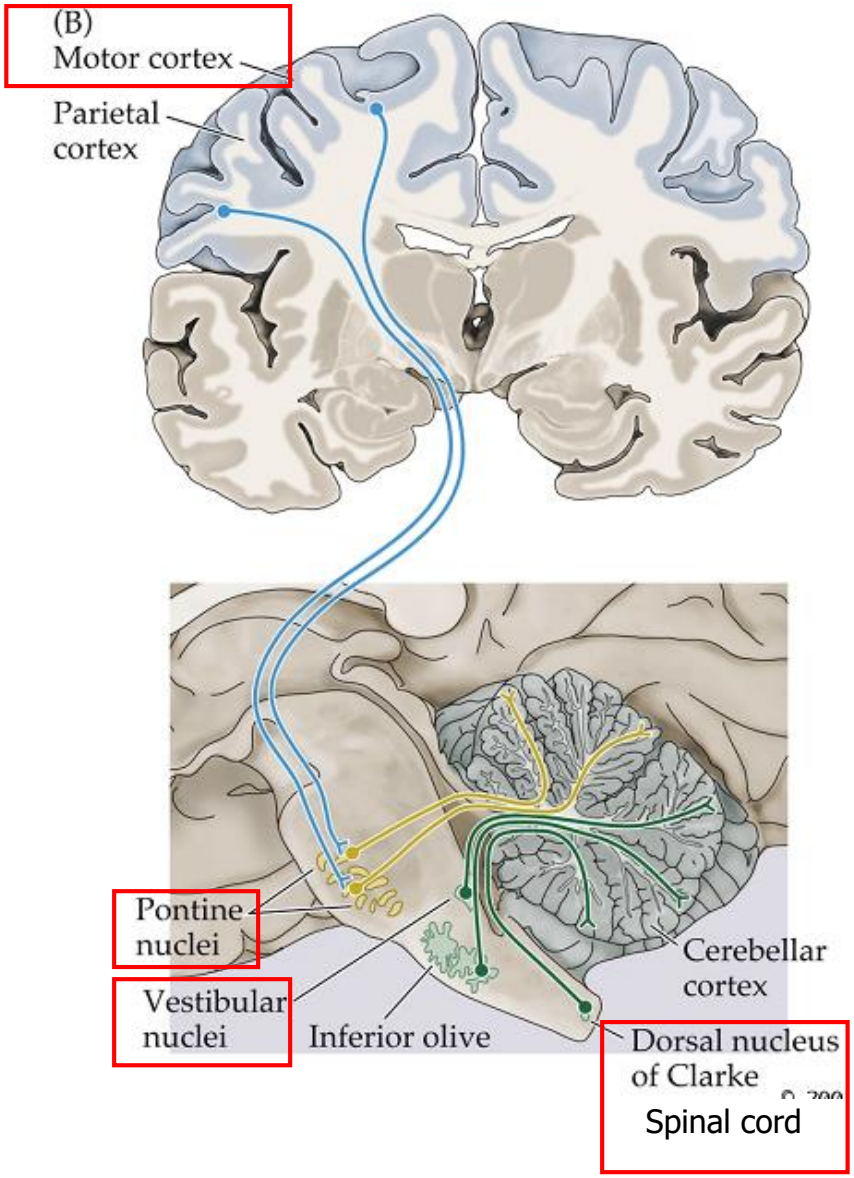


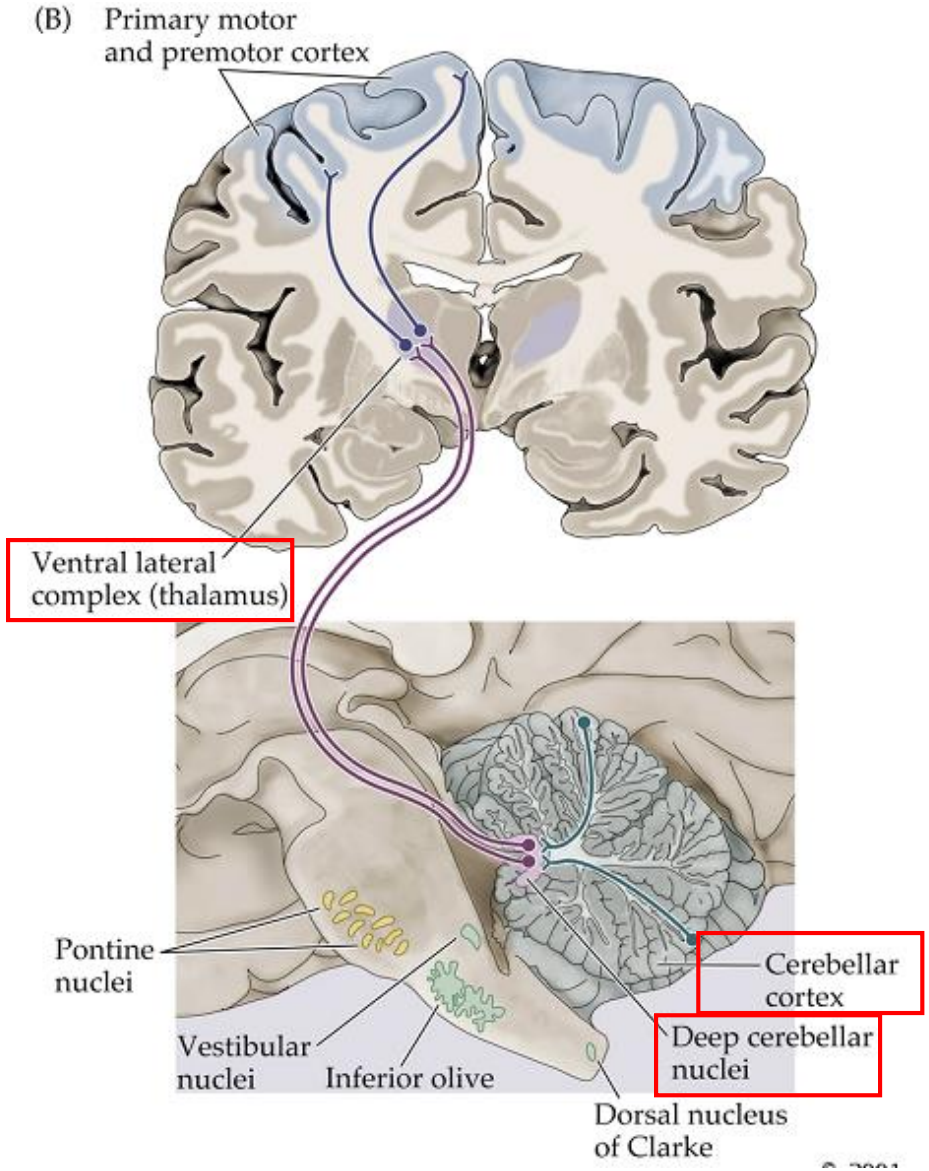
# Cerebellum


# The Cerebellum: Connections

## input

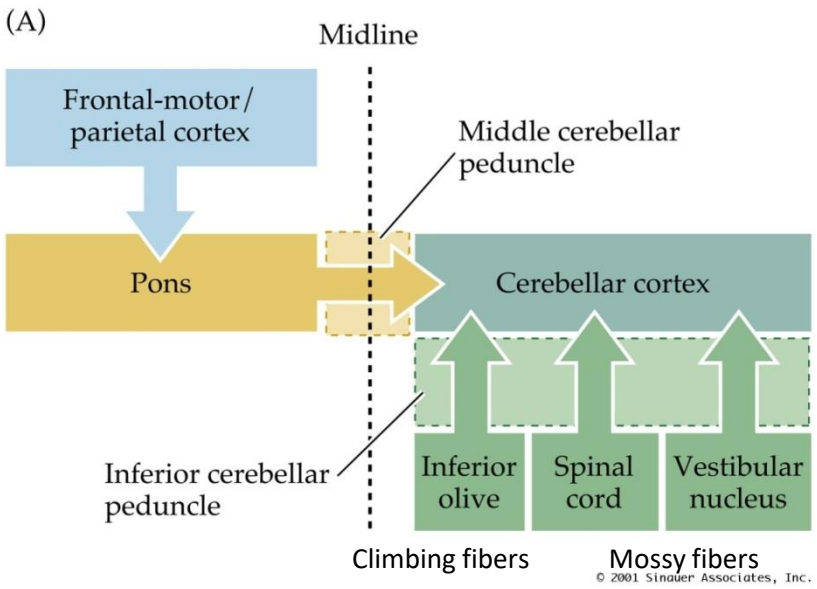



## output

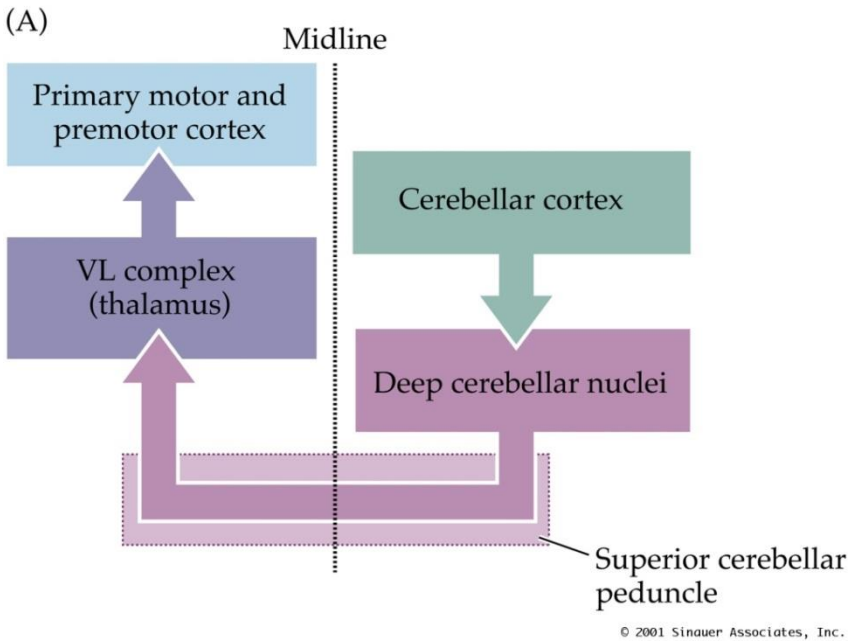


# Cerebellum: Connections

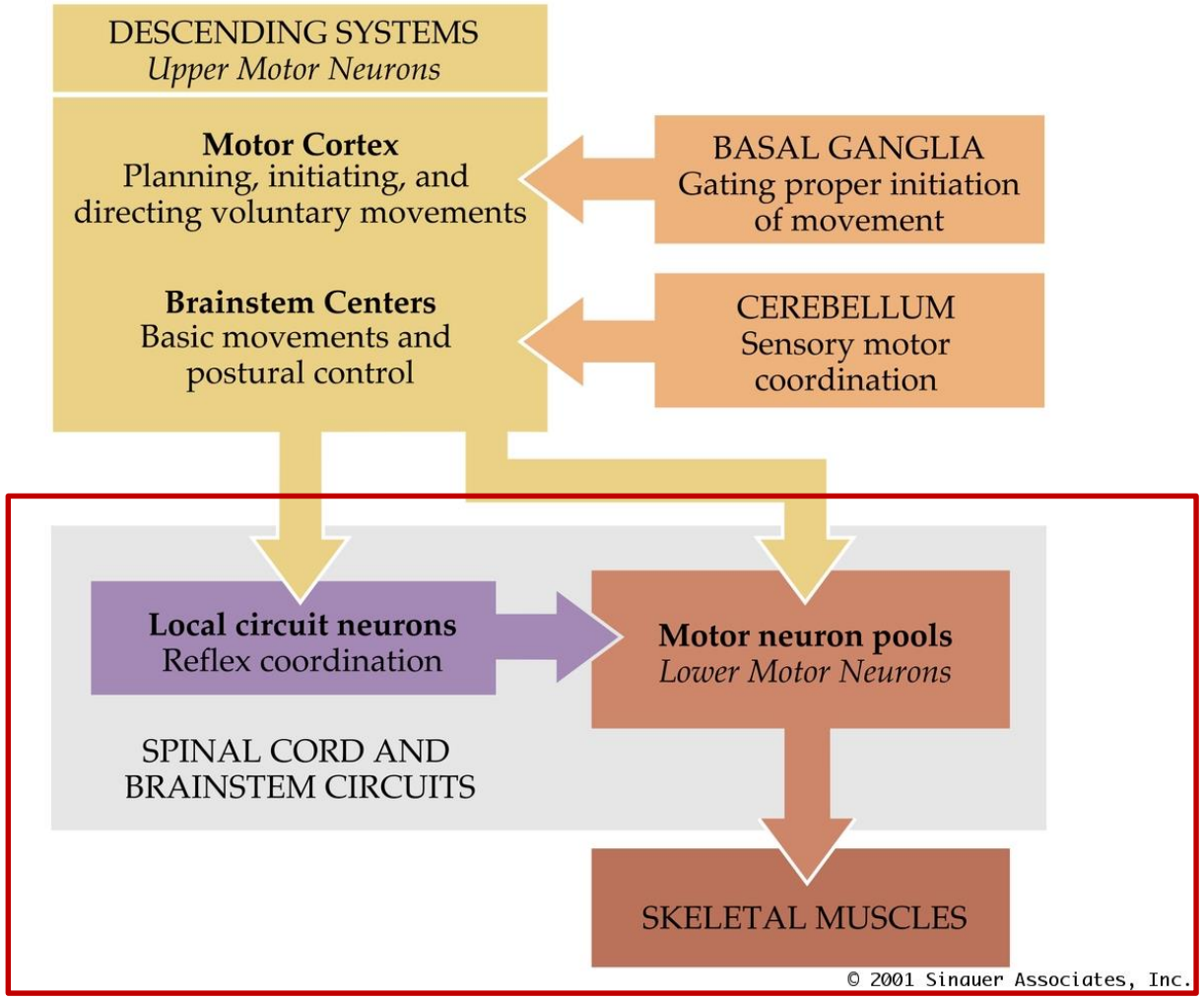
## input



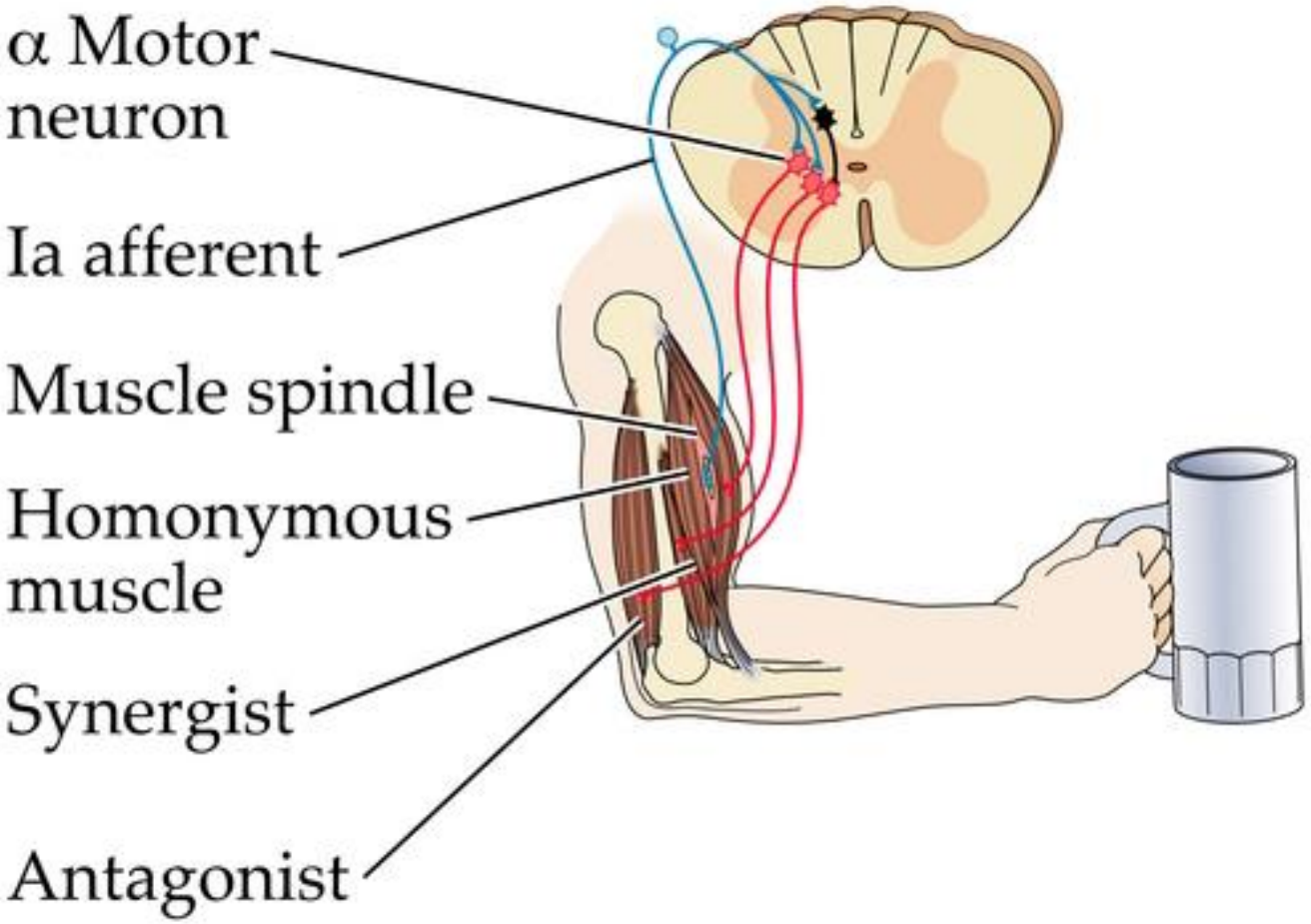

## output



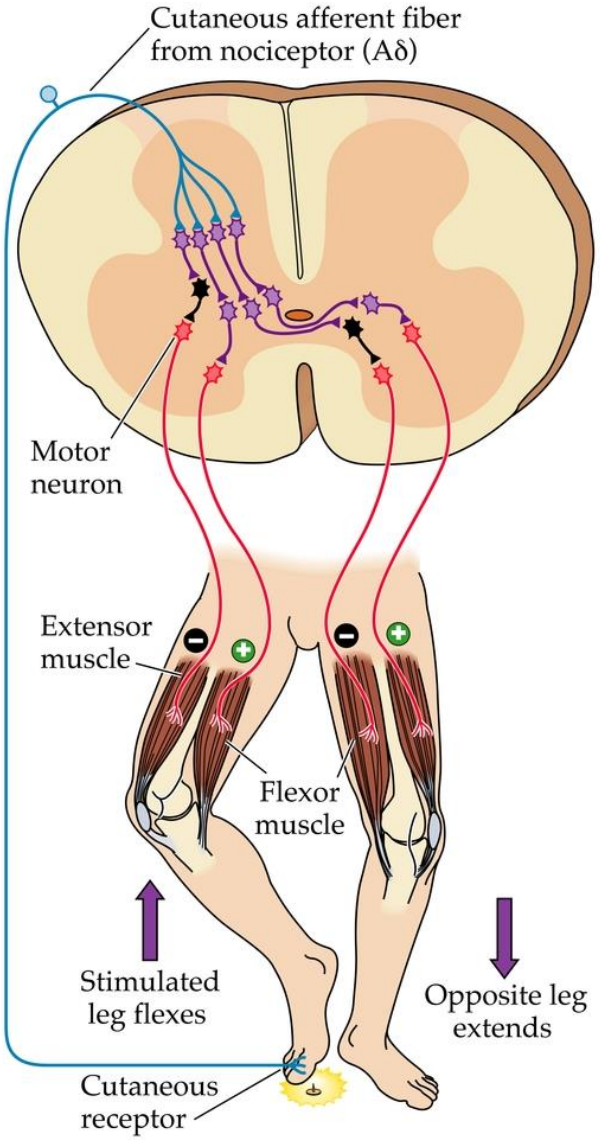
# The motor system



# Stretch reflex



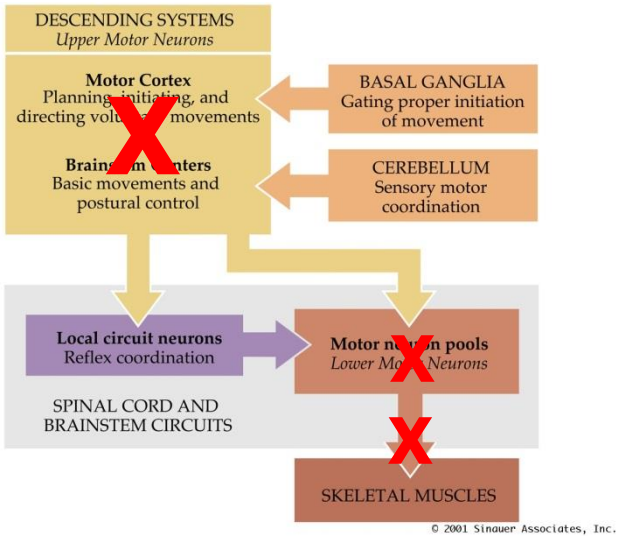
# Spinal reflexes




Spindle afferents
Segmental connections
Interneurons (excitatory and inhibitory)
Corticospinal tract
Rubrospinal tract
Tectospinal tract
Vestibulospinal tract

# Upper vs. lower motoneuron lesion

An **upper motor neuron lesion (cortical lesion)**
Causes **paralysis**,
Reflexes becomes **spastic** (muscle tone increases),
The muscle does **not atrophy**.
If the sole of the foot is stroked, the toe dorsiflexes.
This is the **Babinski response**.

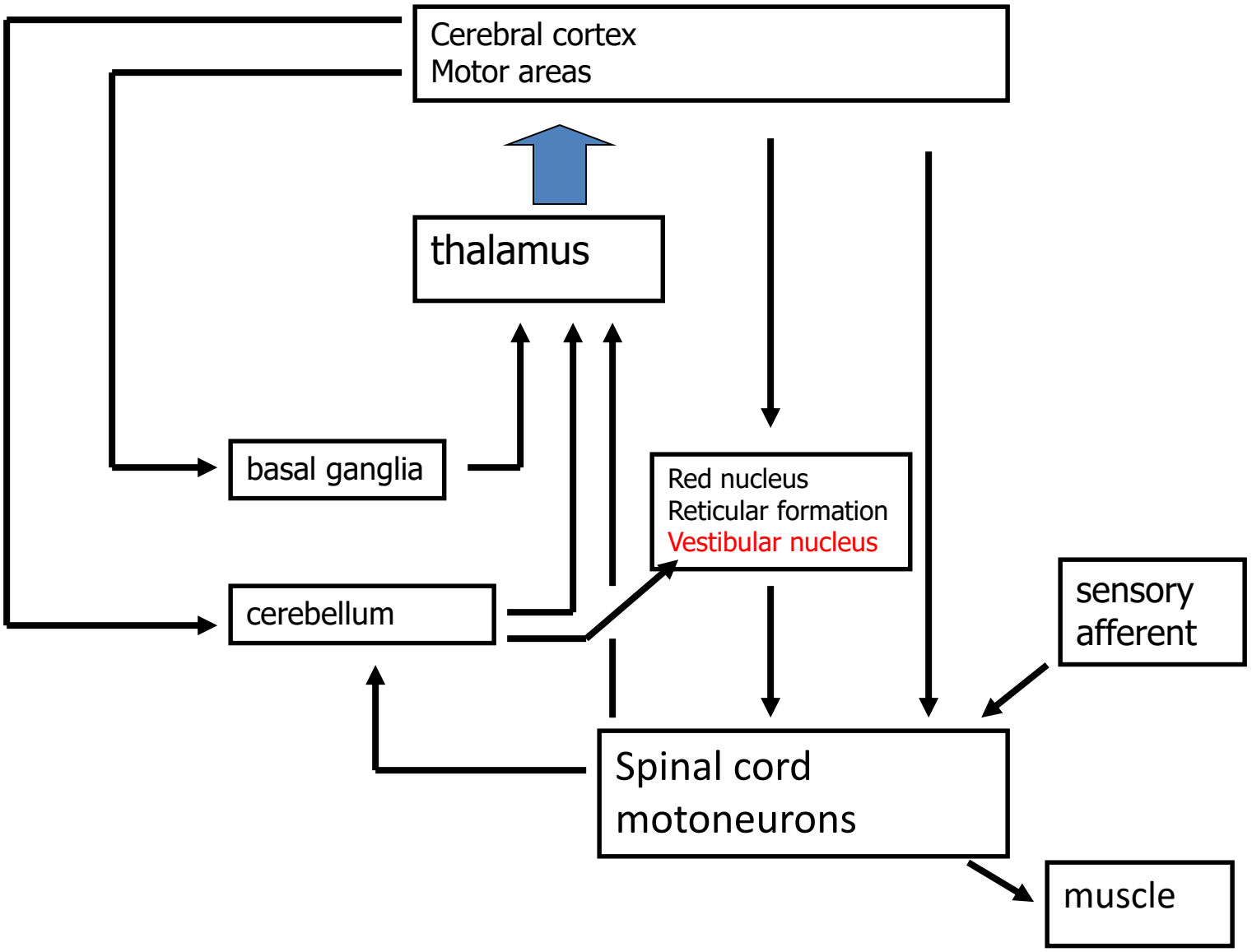



A **lower motor neuron lesion**
All excitation of the muscle is lost
the muscle becomes **paralyzed** (unable to move)
**flaccid** (muscle tone decreases).
the muscle will eventually **atrophy**.

Lesions of the basal ganglia generally lead to hyper- or hypo-kinetic movement and **resting tremors.**

Lesions of the cerebellum lead to errors in accuracy and coordination of movements and **intention tremors**

# Summary


Cerebral cortex
Motor areas
thalamus
basal ganglia
Red nucleus
Reticular formation
Vestibular nucleus
cerebellum
sensory afferent
Spinal cord motoneurons
muscle

# Clinical case

A 68 year old woman with hypertension and diabetes develops abrupt onset numbness and tingling on the right half of the face and head and the entire right hemitrunk, right arm and right leg. She does not experience any weakness or incoordination.

Physical Examination:
Vitals: T 37.0° C; BP 168/87; P 86; RR 16
Cardiovascular, pulmonary, and abdominal exam are within normal limits.

Neurological Examination:
**Mental Status:** Alert and oriented x 3, 3/3 recall in 3 minutes, language fluent.
**Cranial nerves:** CN II-XII intact except for objective loss of all sensation (including fine touch, two point discrimination, pain and temperature) on the right side of the face.
**Motor:** Normal bulk and tone. Strength and reflexes are as follows:

**Reflexes:**

| | Deltoids | Biceps | Triceps | Wrist Ext. | Wrist Flex. | Finger Ext. | Finger Flex. |
|---|---|---|---|---|---|---|---|
| R | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 |
| L | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 |
| | illiopsoas | Hams | Quads | Tibialis ant. | Gastroc. | | |
| R | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | | |
| L | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 | | |

**Sensation**: Intact fine touch, two point discrimination, vibration, joint position sense, pain and temperature sensation in the left arm, left leg and left hemitrunk. Complete sensory loss of all modalities in the right arm, right hemitrunk and right leg.
**Coordination:** Normal rapid alternating movements in the upper and lower extremities, and normal finger-to-nose and heel-knee-shin testing.
**Gait:** Normal

Where is the most likely location of the lesion that gives rise to these symptoms?

# Clinical Case

As a volunteer working for Doctors Without Borders in a clinic in Jordan, you are asked to evaluate a 14 year-old Iraqi refugee who was injured by a sniper's bullet 7 weeks ago. The bullet entry hole is obliterated by an apparent attempt at exploratory surgery in the mid-back, and plain x-rays show that the bullet was lodged somewhere in the bony spine.

Physical Examination:

Vitals: T 37.6° C; BP 112/60; P 64; RR 12

Cardiovascular and abdominal exam are within normal limits. Pulmonary exam reveals mild crackles in the upper right lung field.

Neurological Examination:

**Mental Status:** AO x 3, 3/3 recall in 3 minutes, language fluent.

**Cranial nerves:** CN II-XII intact.

**Motor:** Normal bulk. Increased tone (spasticity) in the left lower extremity. No pronator drift.

**Sensation**: Markedly decreased pain and temperature sensation on the right side only from the level of the umbilicus down to and including the entire right leg. Vibration and joint position sense normal bilaterally in the upper and lower extremities.

**Coordination:** Normal rapid alternating movements and finger-to-nose in the upper extremities. Slow foot tap in the left leg.

**Gait:** Spastic with impaired movement of the left leg (circumduction of the left leg during swing-through phase of gait).

***Q – Diagram a single continuous lesion that can explain these findings.***