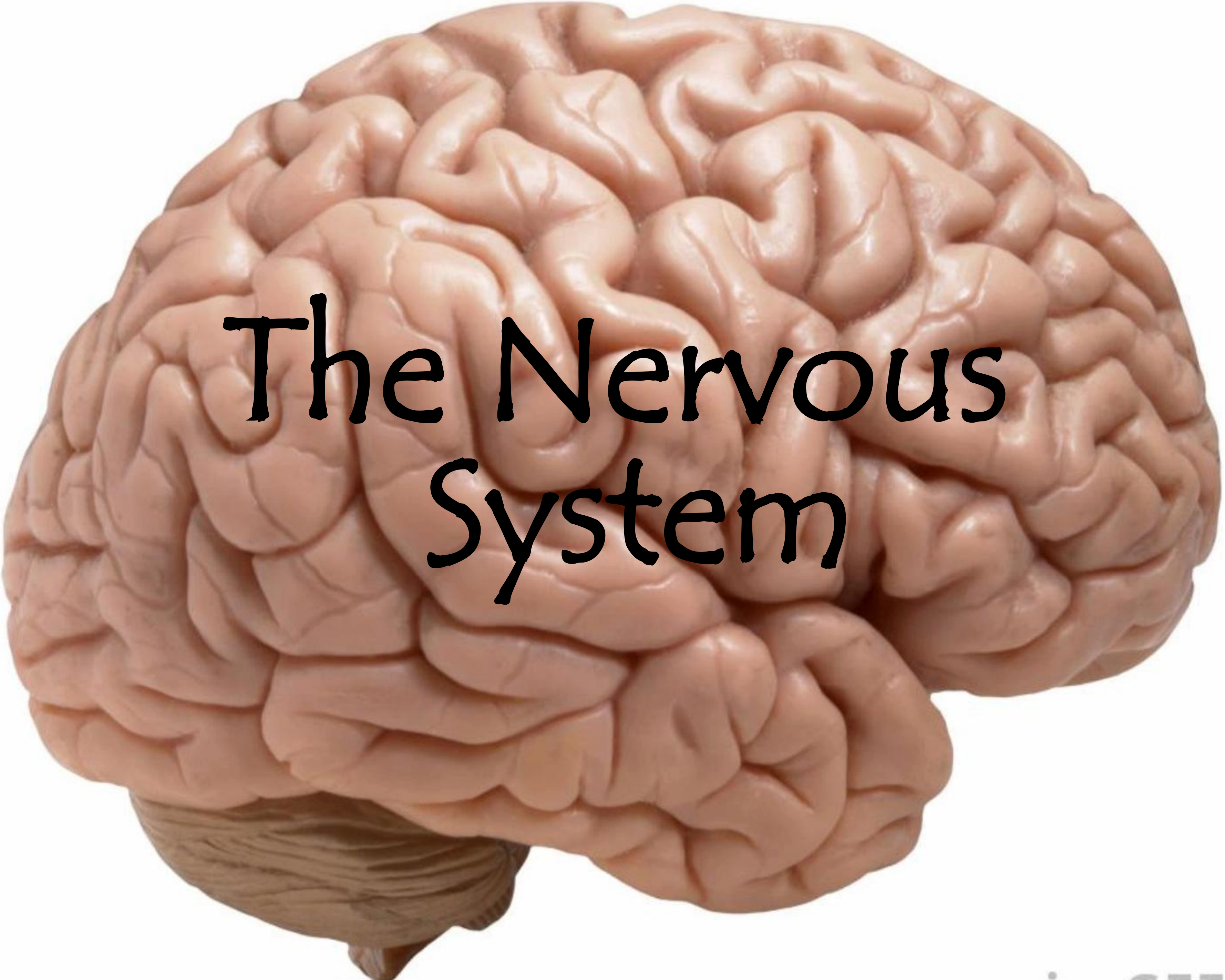
The Nervous System



General Functions of the Nervous System

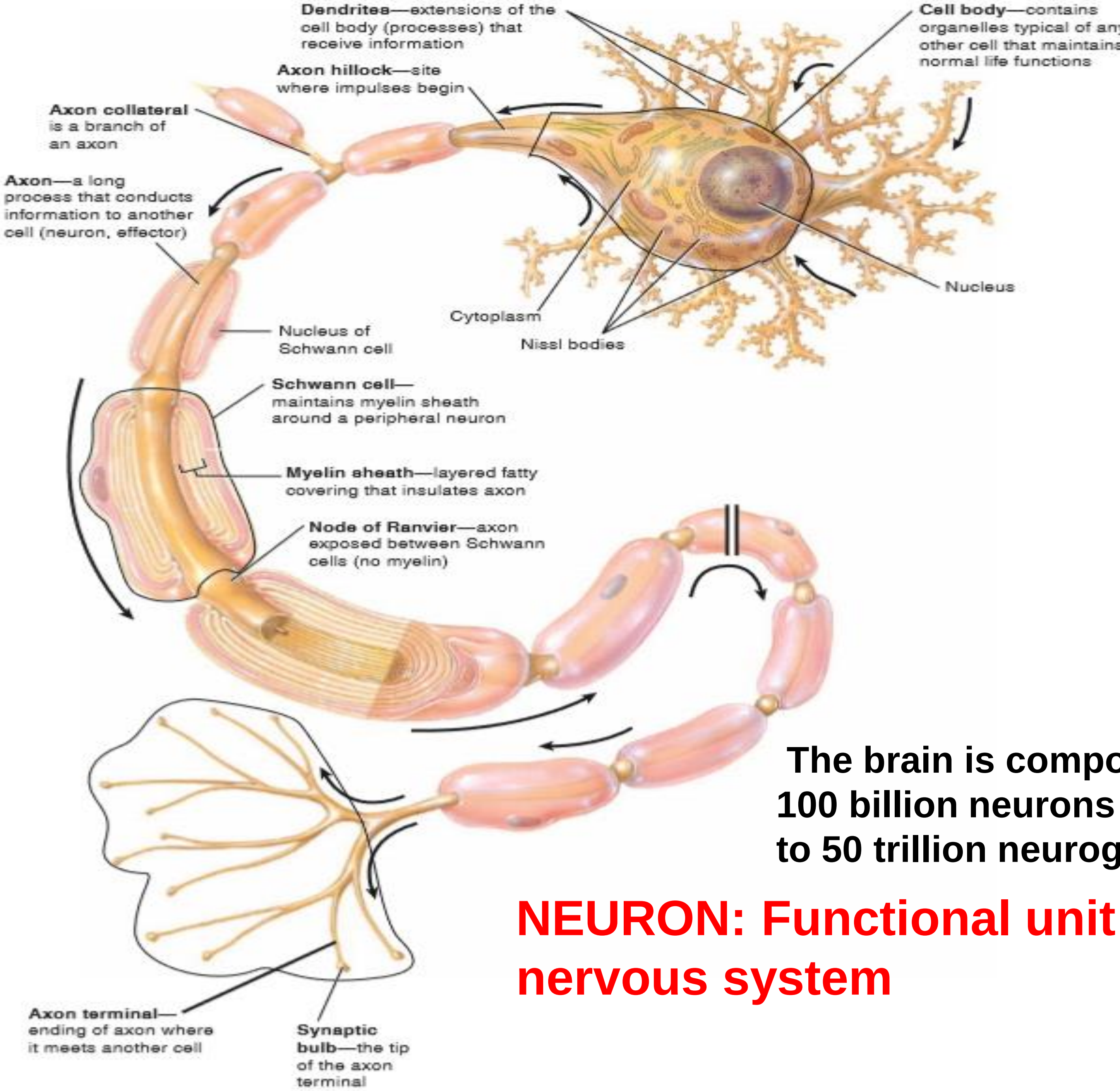
- Sensory: gathers info about changes occurring within and around the body; sensory receptors, at ends of peripheral nerves, send signals to CNS

  examples – light, oxygen levels, body temperature

- Integrative: information is "brought together," interpreted, to create sensations, create thoughts, add to memory, make decisions, etc.

- Motor: sending of signals to muscles and/or glands to elicit a response

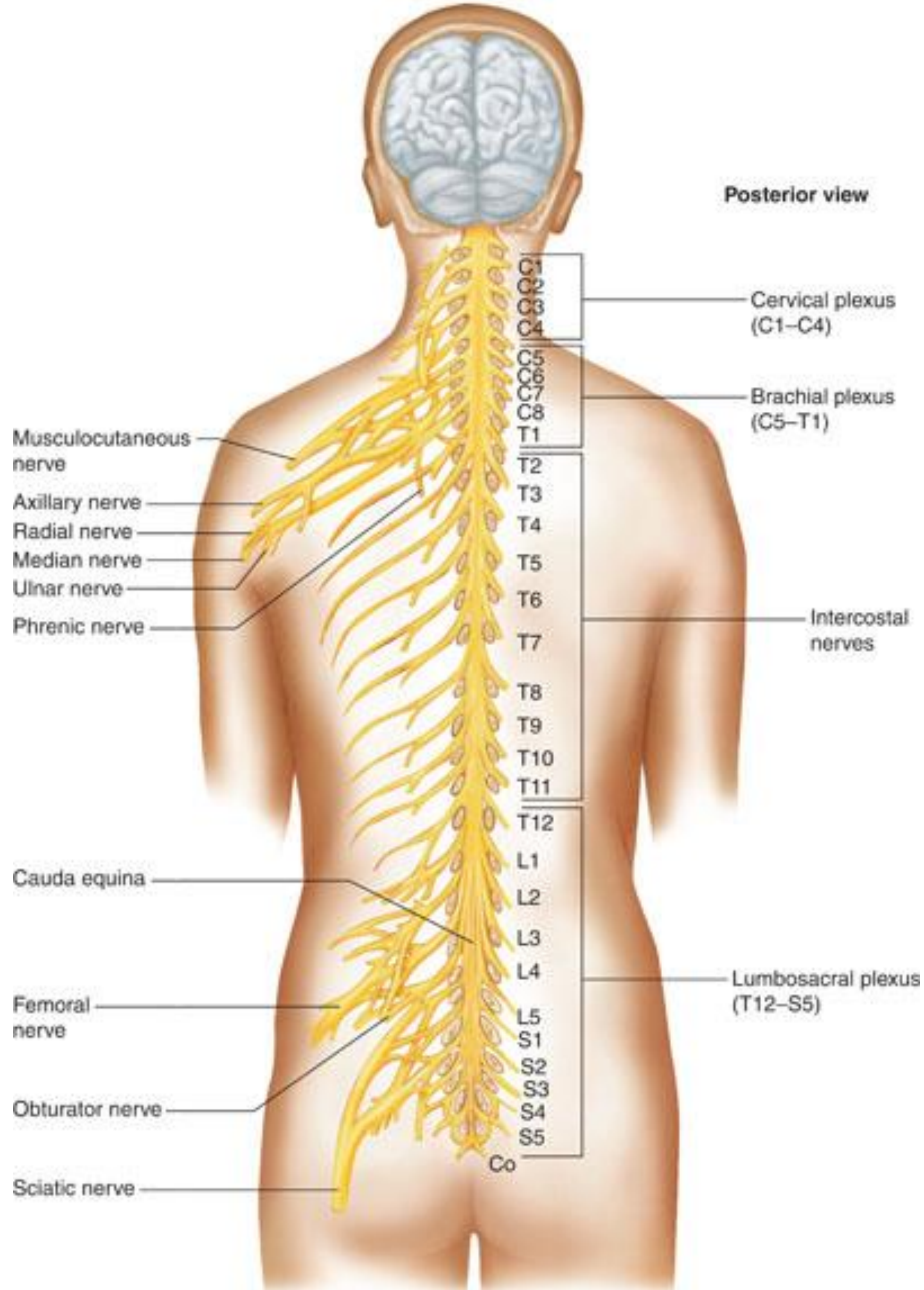
Bottom Line = Maintenance of Homeostasis



The brain is composed of 100 billion neurons and 10 to 50 trillion neuroglia

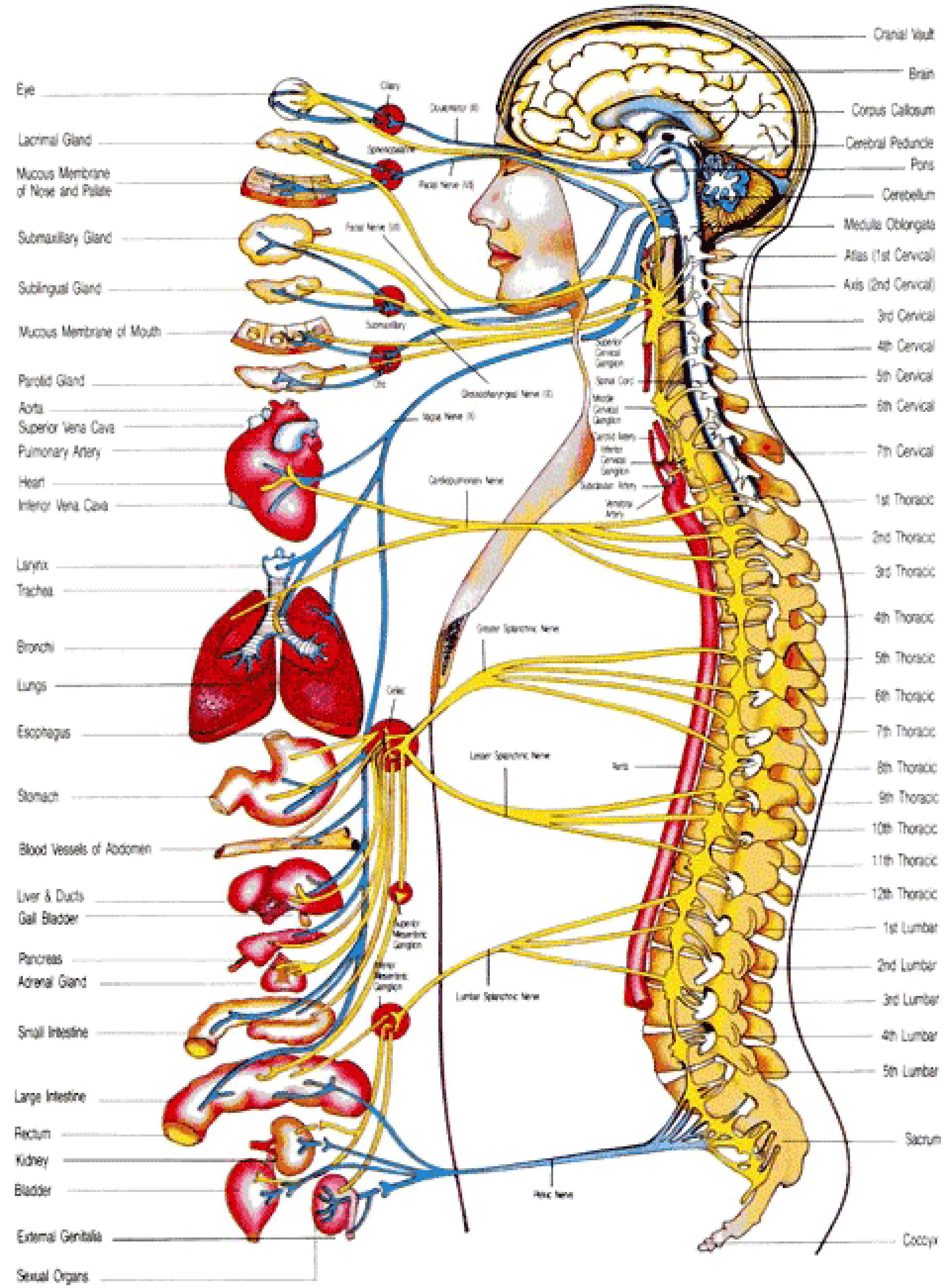
NEURON: Functional unit of nervous system

- The peripheral nervous system (PNS) is made up of peripheral nerves that connect the CNS to the rest of the body. These neurons can regenerate if damaged.
- 31 pairs of spinal nerves
- 12 pairs of cranial nerves

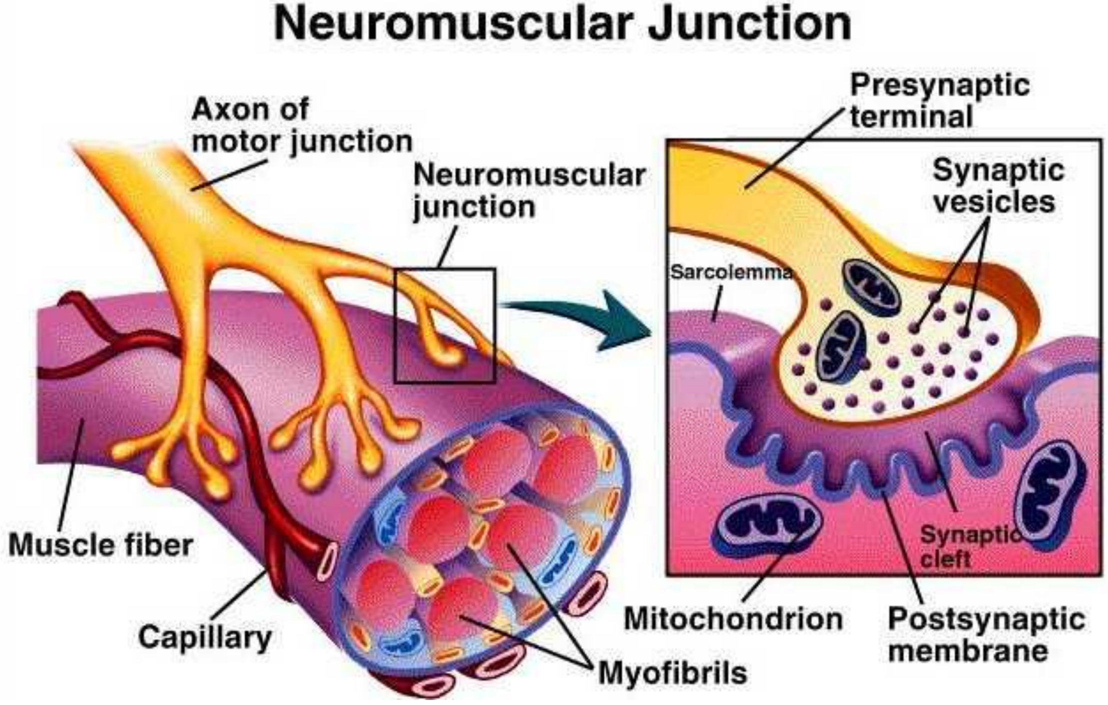


Peripheral Nervous System

- PNS can be subdivided into 2 divisions:
- (1) <u>Autonomic</u>
  - Cranial & spinal nerves connecting <u>CNS</u> to heart, stomach, intestines, glands
  - Controls <u>unconscious</u> activities



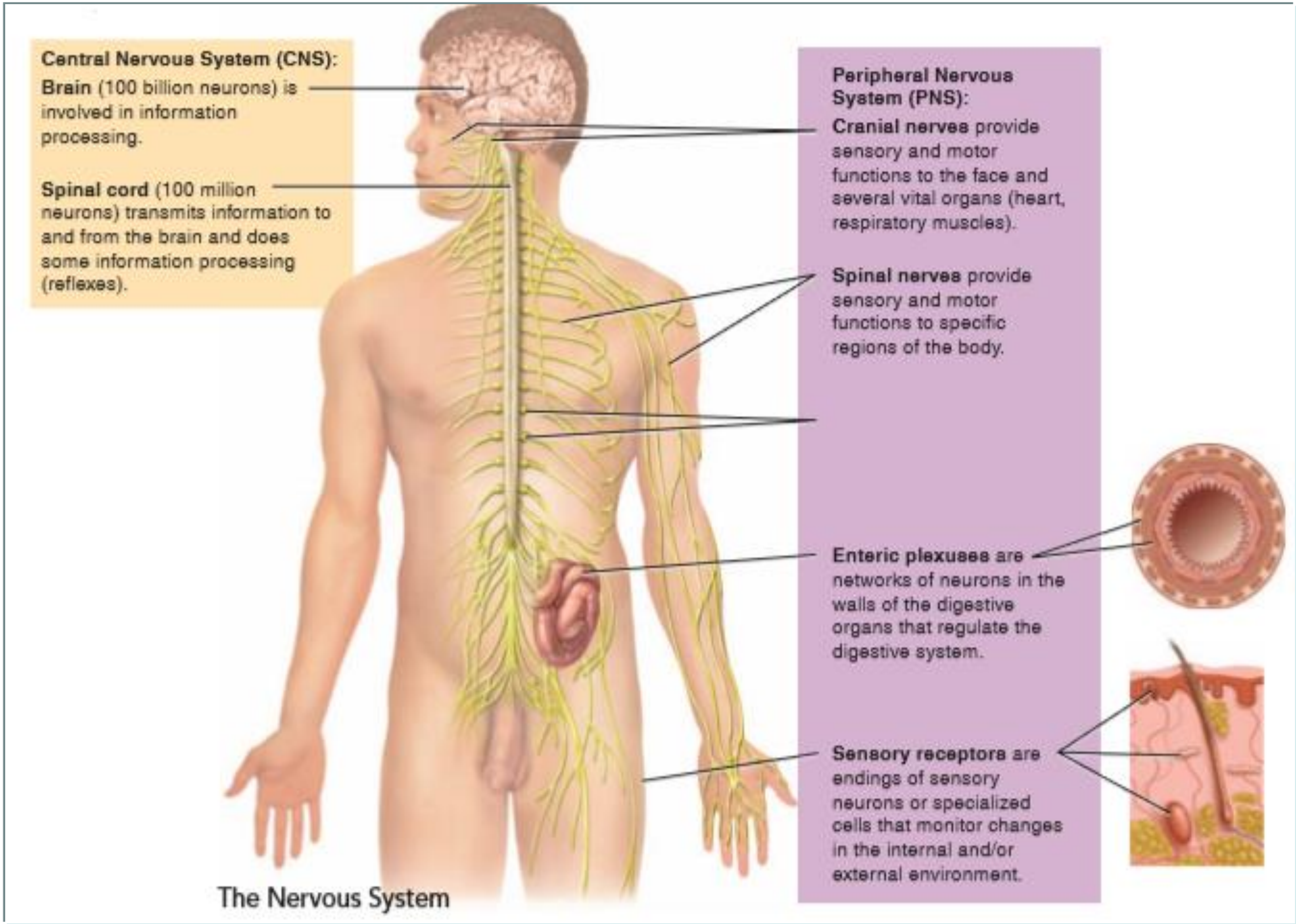
- (2) Somatic
  - Cranial & spinal nerves connecting CNS to skin & skeletal muscles
  - Oversees conscious activities



Organization of Nervous System

Nervous System

- Central Nervous System
  - Brain & spinal cord
- Peripheral Nervous System
  - Autonomic N.S.
  - Somatic N.S.



The Nervous System

General Design of the Nervous System

1. Central Nervous system:

a) Brain or encephalon; higher governing center

b) Spinal cord: upper two thirds of vertebral canal, reflex centers.

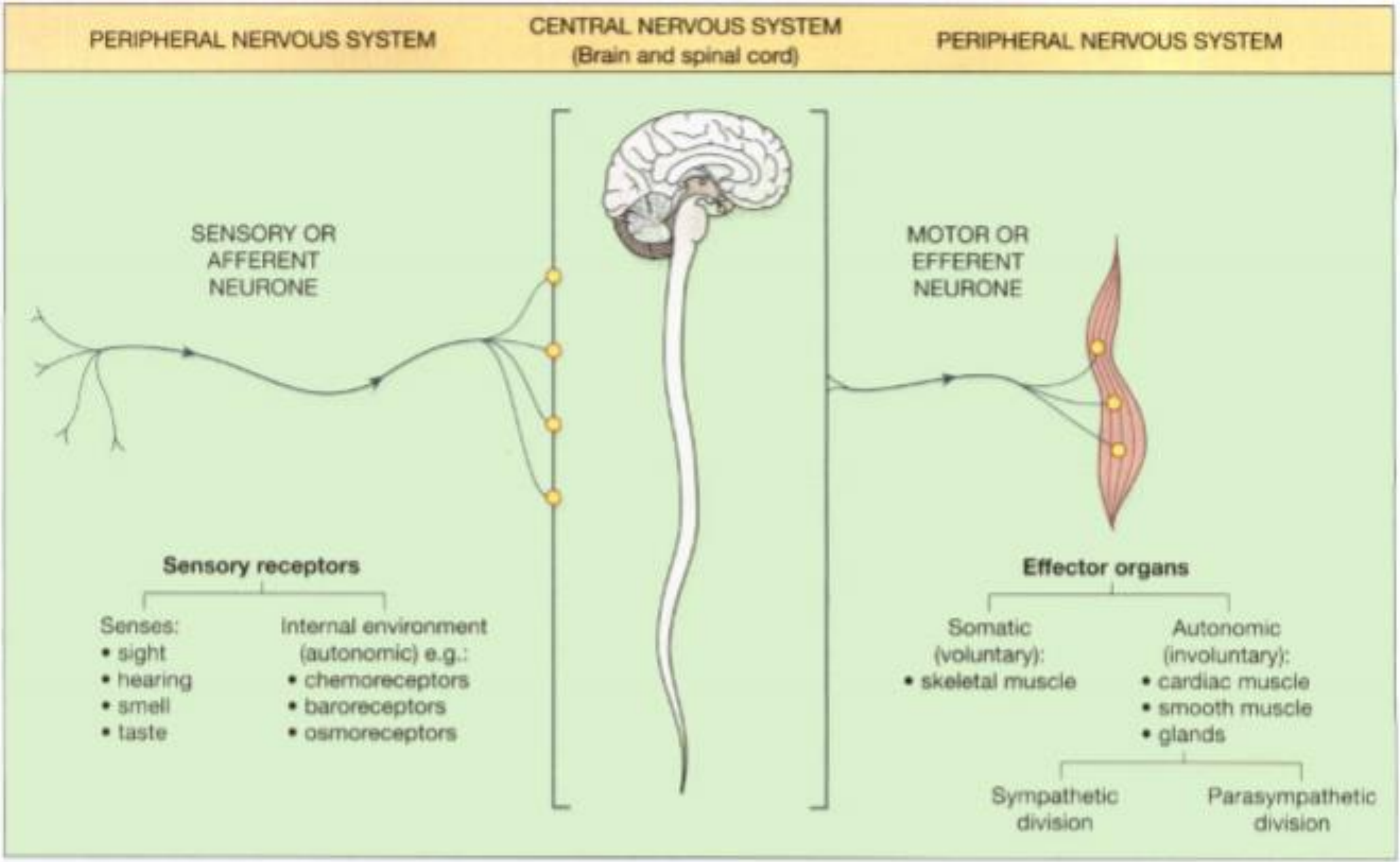
2. Peripheral nervous system

a) Cerebrospinal NS:

- ❖ **Somatic component** of PNS, **12 pairs** of cranial nerves & **31 pairs** of spinal nerves.
- ❖ Somatic structure of head, neck, limbs, body wall (Skeletal muscle).
- ❖ Somatic sensory & motor functions
- ❖ Somatic efferent pathway; only one neuron directly to effector organ

b) Peripheral autonomic NS:

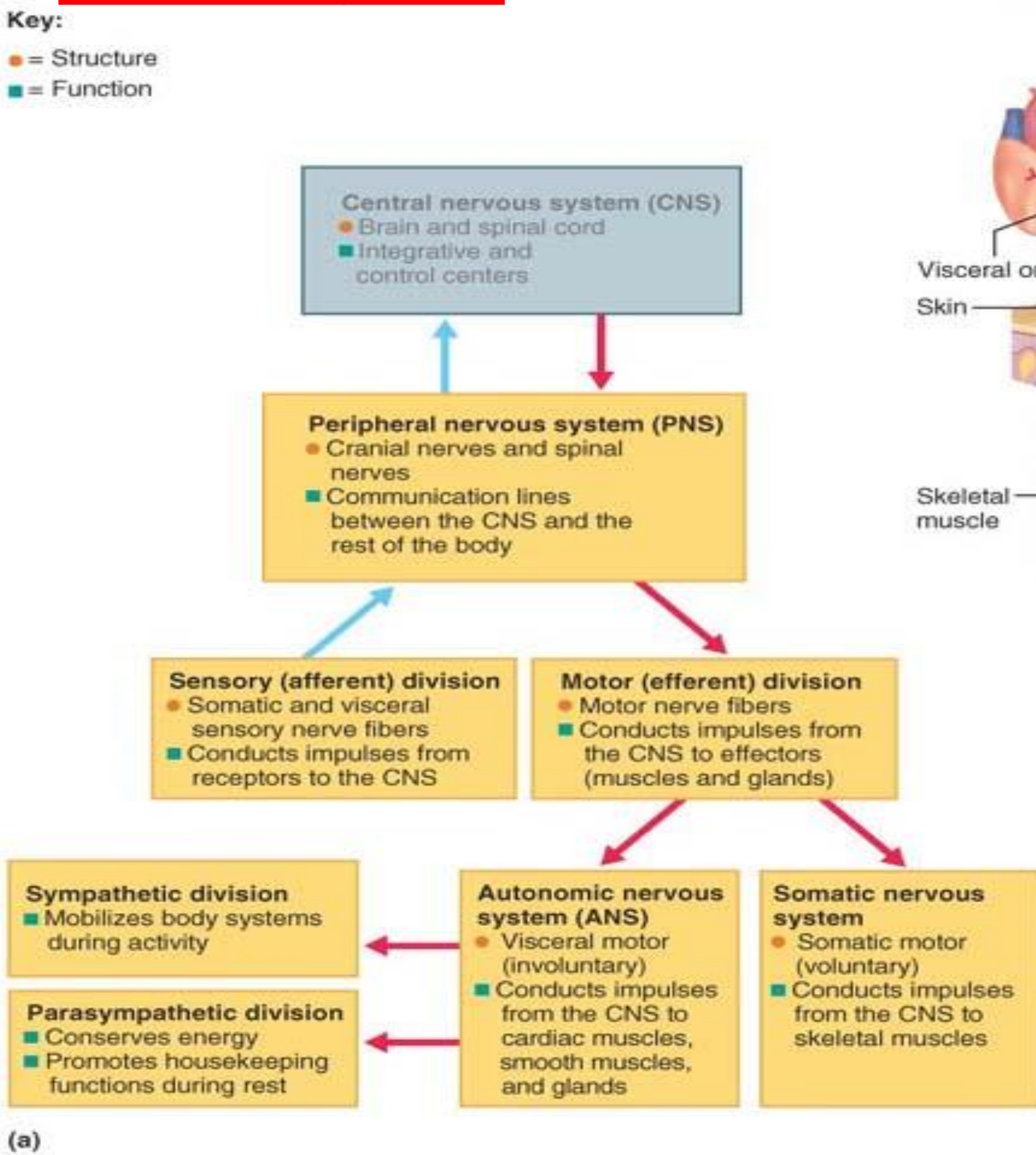
- ❖ **Visceral component** of PNS
- ❖ Innervate viscera, glands, blood vessels & non-striated muscles (smooth) & cardiac muscles
- ❖ Autonomic efferent pathway; two neurons (preganglionic & post-ganglionic)

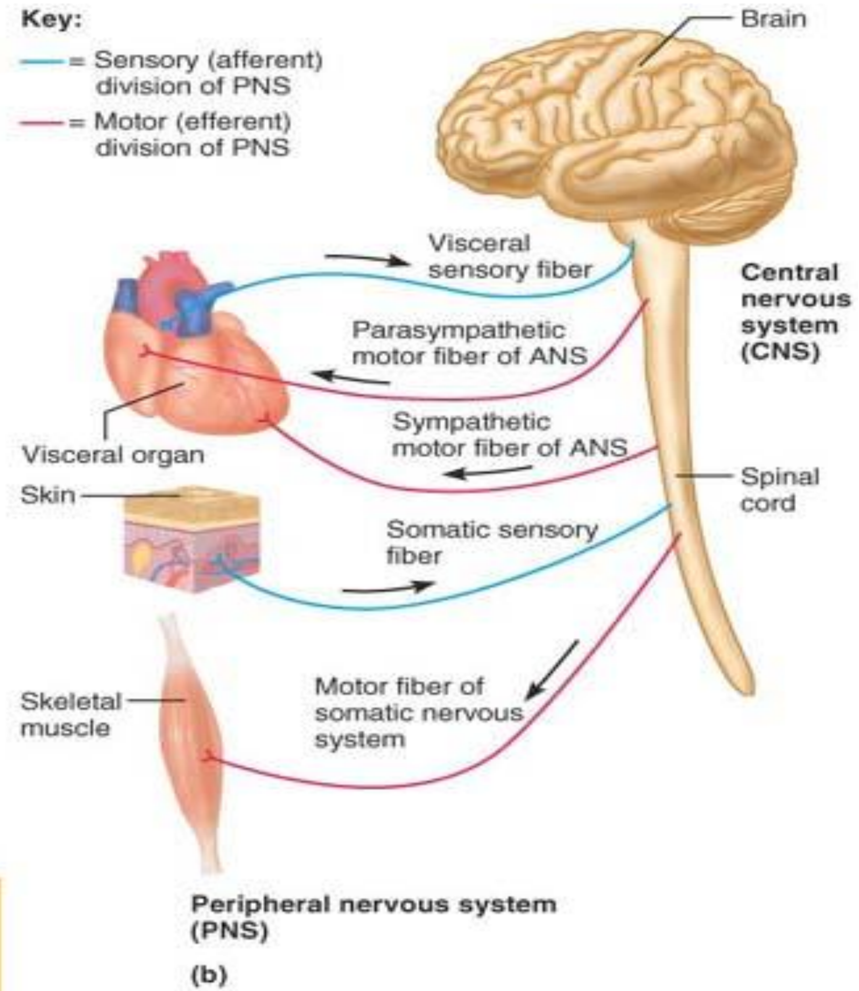


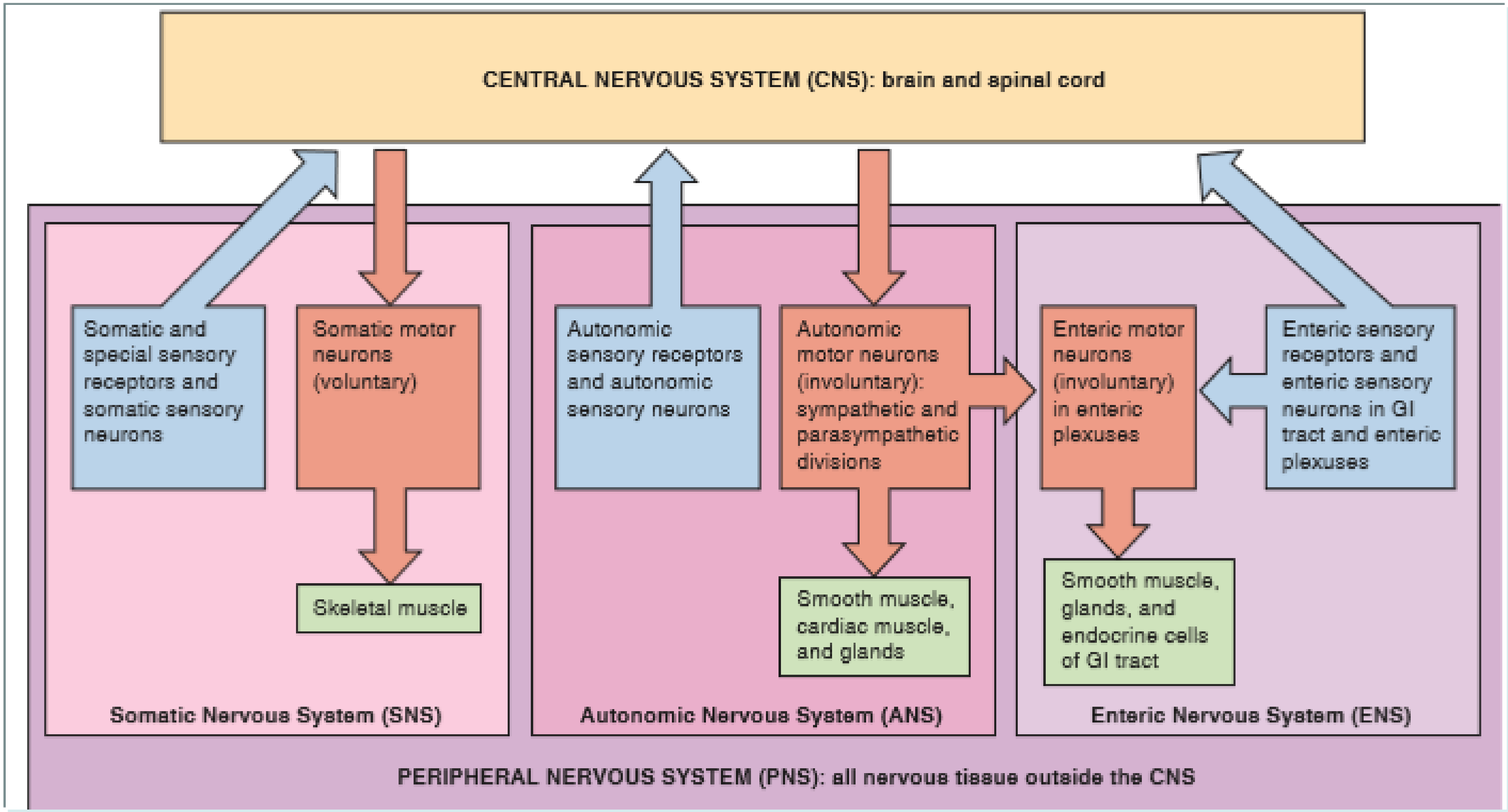
Functional components of the nervous system.

Functional components of nervous system

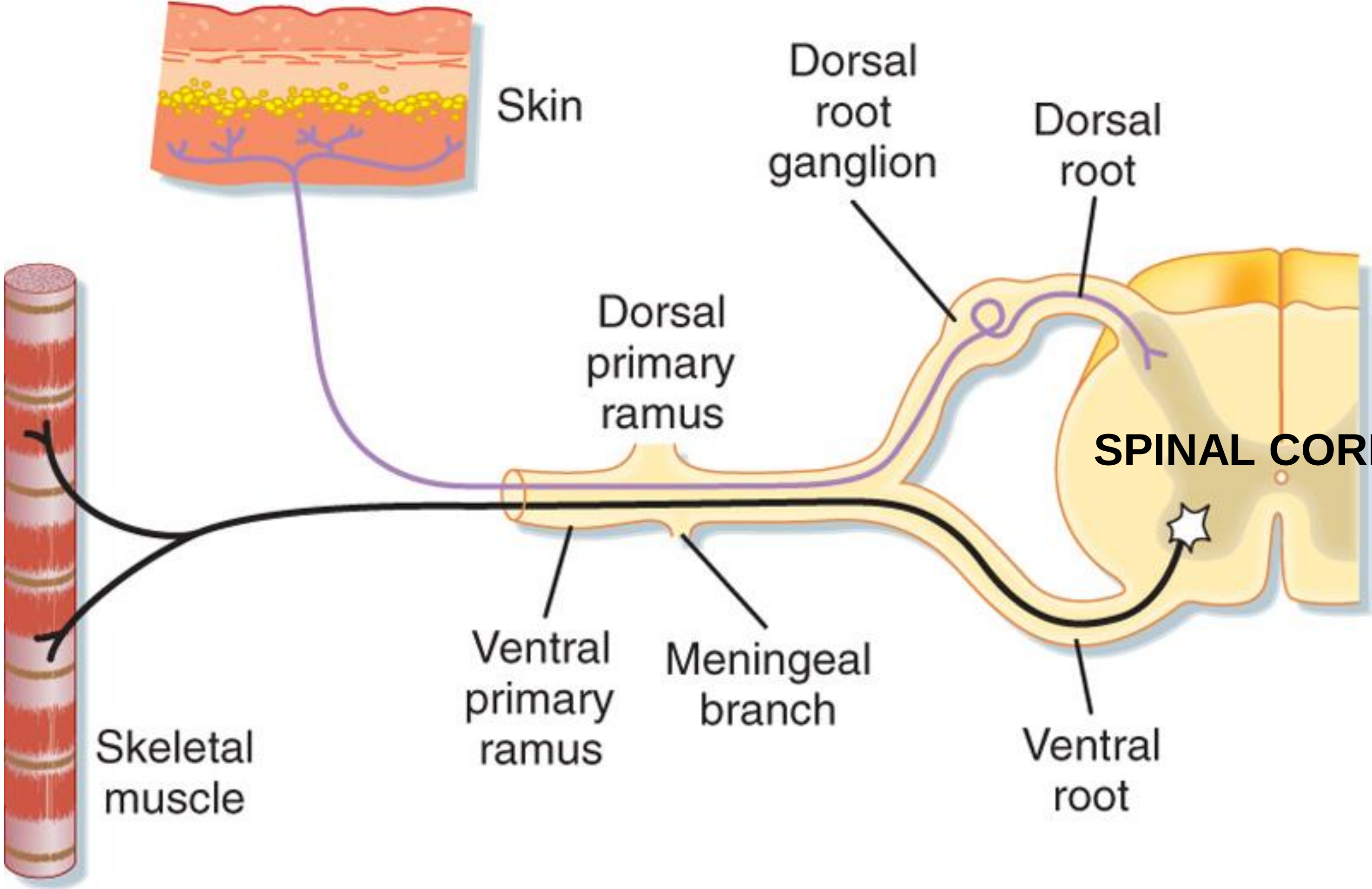
General organization of nervous system







CENTRAL NERVOUS SYSTEM (CNS): brain and spinal cord
Somatic and special sensory receptors and somatic sensory neurons
Somatic motor neurons (voluntary)
Skeletal muscle
Somatic Nervous System (SNS)
Autonomic sensory receptors and autonomic sensory neurons
Autonomic motor neurons (involuntary): sympathetic and parasympathetic divisions
Smooth muscle, cardiac muscle, and glands
Autonomic Nervous System (ANS)
Enteric motor neurons (involuntary) in enteric plexuses
Enteric sensory receptors and enteric sensory neurons in GI tract and enteric plexuses
Smooth muscle, glands, and endocrine cells of GI tract
Enteric Nervous System (ENS)
PERIPHERAL NERVOUS SYSTEM (PNS): all nervous tissue outside the CNS



Bell-Magendie Law

In the spinal cord, ventral (anterior) nerve roots are entirely motor and dorsal (posterior) nerve roots are entirely sensory

Terminologies

Nerve: group of many nerve fibers that are traveling together to the same general location in the peripheral nervous system. There are no nerves in the central nervous system

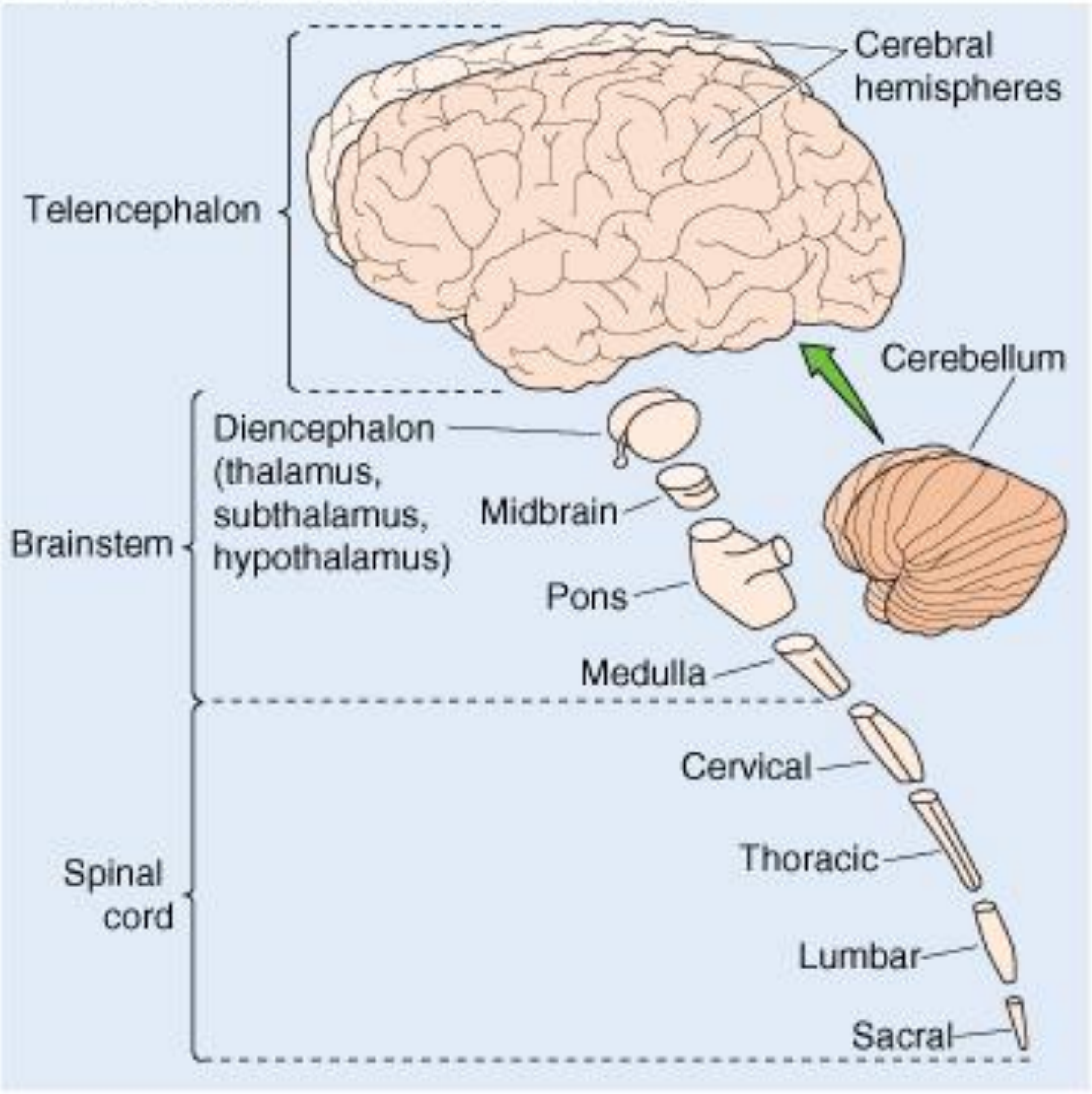
Pathway or tract: a group of nerve fibers traveling together in the central nervous system. Commissure is the special tract linking the right and left halves of the central nervous system (brain).

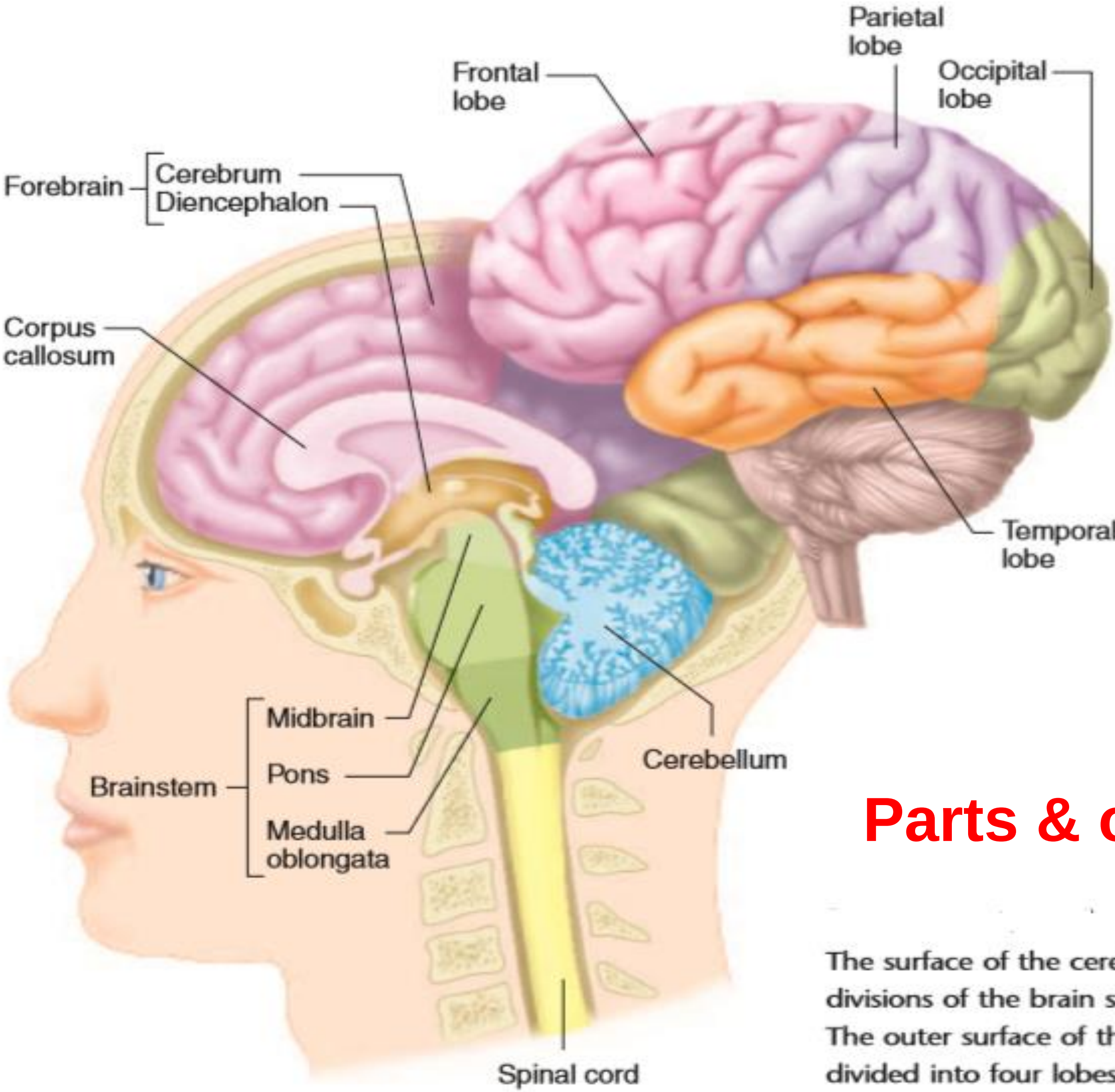
Ganglia: Groups of neuron cell bodies in the peripheral nervous system.

Nuclei: Groups of neuron cell bodies in the central nervous system, not to be confused with cell nuclei.

Parts & organs of CNS

B MAJOR COMPONENTS OF THE CNS





Parts & organs of CN

The surface of the cerebral cortex and the divisions of the brain shown in sagittal section. The outer surface of the cerebrum (cortex) is divided into four lobes as shown.

- Four subdivisions of the brain: cerebrum, diencephalon, brainstem, and cerebellum.
- The cerebrum and diencephalon together constitute the **forebrain.**
- **The brainstem** consists of the midbrain, pons, and medulla oblongata.
- Cerebellum is called as **hind brain**
- The brain also contains **four interconnected cavities**, the cerebral **ventricles**, which are filled with fluid.

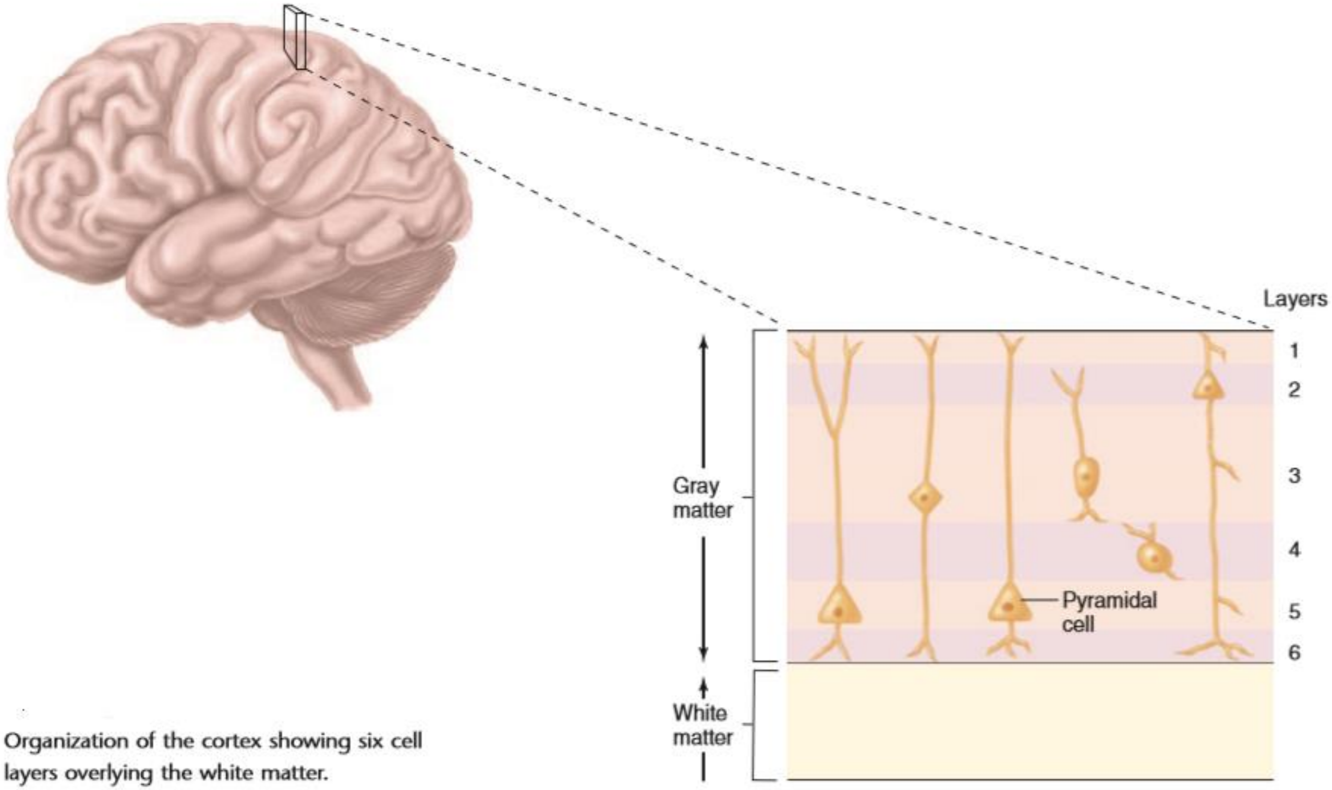
1. Forebrain (cerebrum + diencephalon)

Cerebrum consists of the **right and left cerebral hemispheres** separated by a deep **longitudinal division**, are connected by a massive bundle of nerve fibers known as the **corpus callosum. Cerebrum also contain** other structures on the underside of the brain.

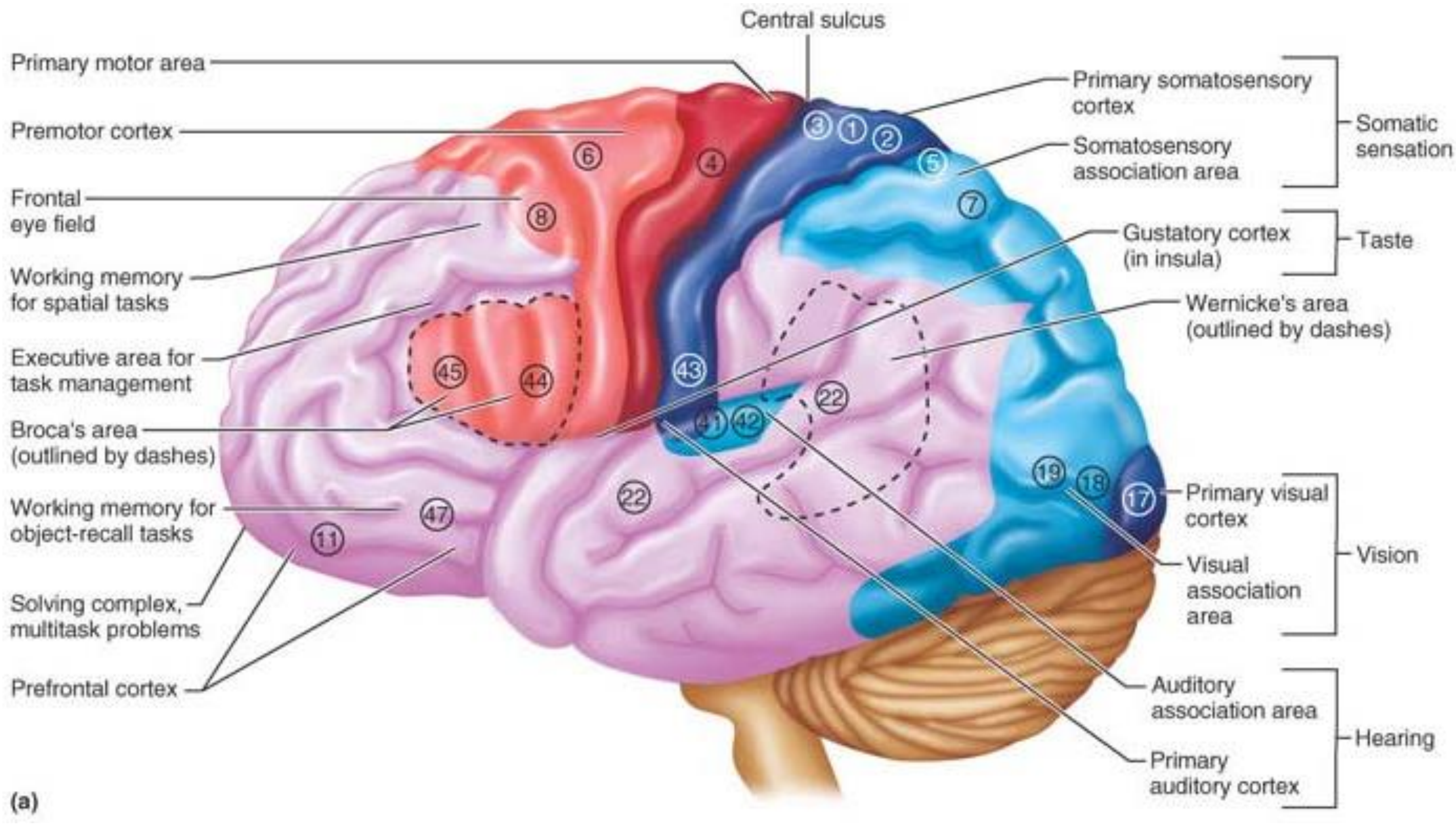
The central core of the forebrain is formed by the **diencephalon.**

Cerebrum

- The cerebral hemispheres consist of the **cerebral cortex**, an outer **shell of gray matter** composed primarily of **cell bodies** that give the area a gray appearance, and an inner layer of **white matter**, composed primarily of **myelinated fiber tracts**.
- This in turn overlies cell clusters, which are also gray matter and are collectively termed the **subcortical nuclei**



Organization of the cortex showing six cell layers overlying the white matter.



<u>Functional and structural areas of the cerebral cortex</u>

Summary of Functions of the Major Parts of the Brain

I. Forebrain

A. Cerebral hemispheres

1. Contain the cerebral cortex, which participates in perception the generation of skilled movements , reasoning, learning, and memory
2. Contain subcortical nuclei, including those that participate in coordination of skeletal muscle activity
3. Contain interconnecting fiber pathways

B. Thalamus

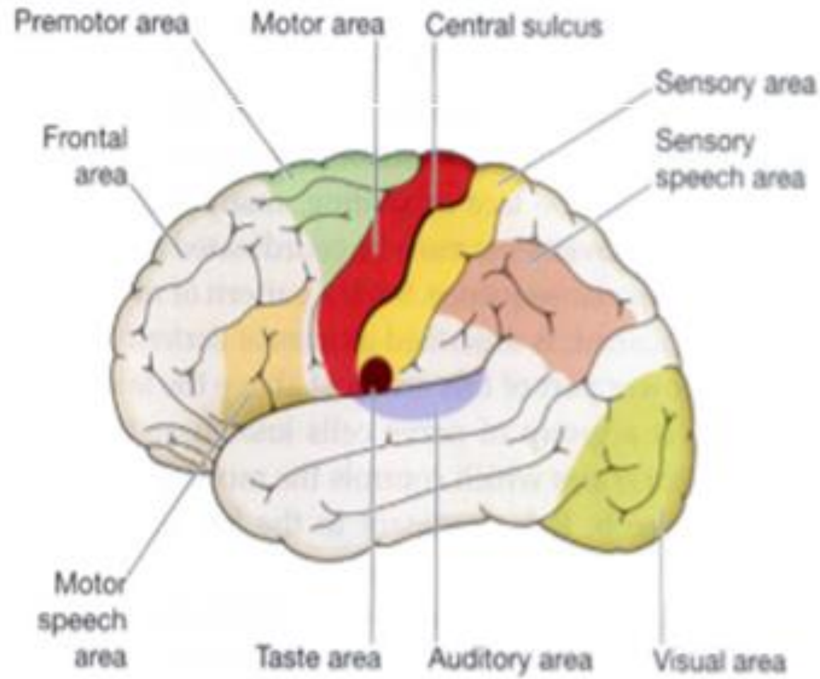
1. Is a synaptic relay station for sensory pathways on their way to the cerebral cortex
2. Participates in control of skeletal muscle coordination
3. Plays a key role in awareness

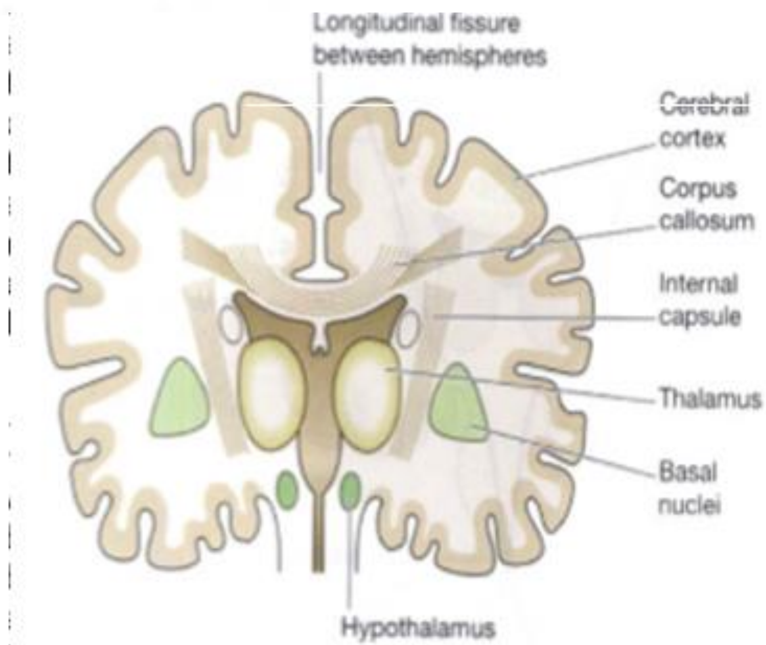
C. Hypothalamus

1. Regulates anterior pituitary gland function
2. Regulates water balance
3. Participates in regulation of autonomic nervous system
4. Regulates eating and drinking behavior
5. Regulates reproductive system
6. Reinforces certain behaviors
7. Generates and regulates circadian rhythms
8. Regulates body temperature
9. Participates in generation of emotional behavior

D. Limbic system

1. Participates in generation of emotions and emotional behavior
2. Plays essential role in most kinds of learning





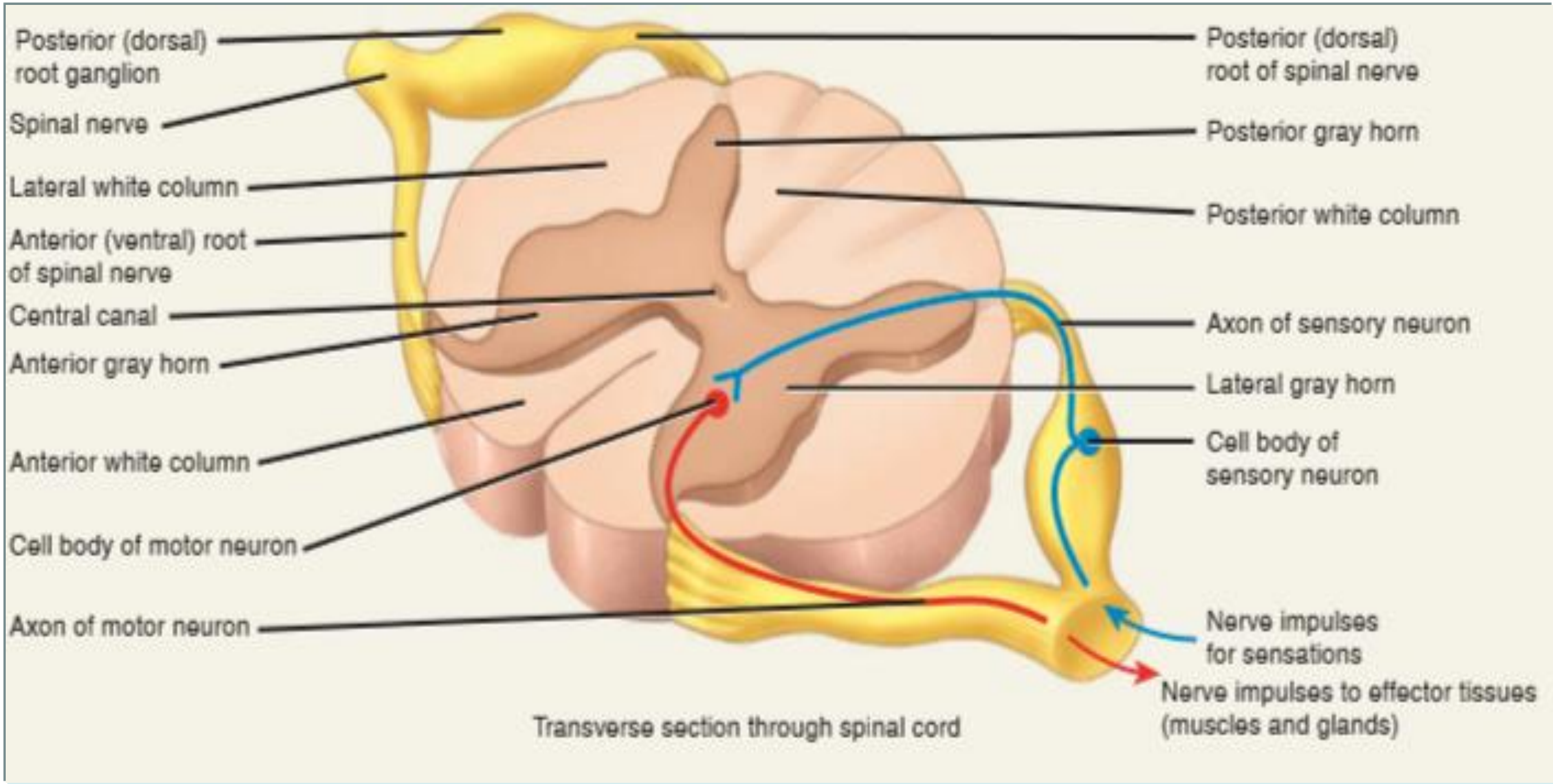
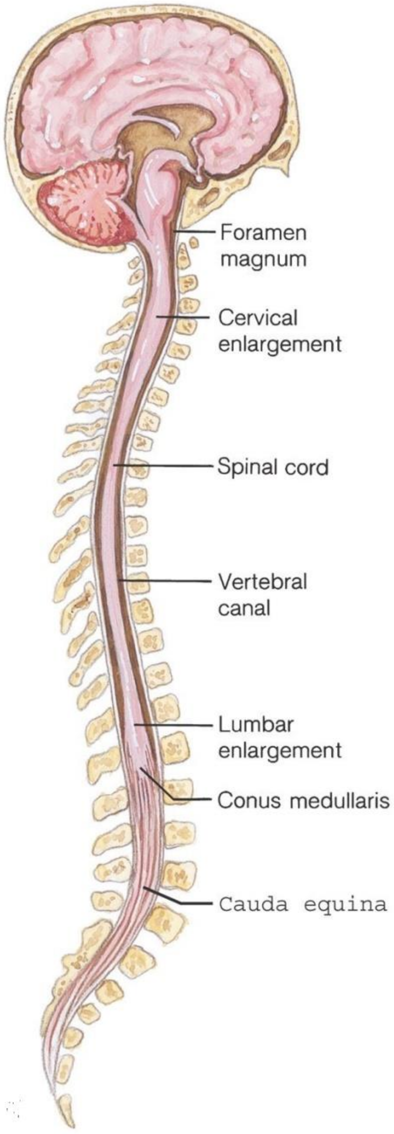


Fig. Detail structure of spinal cord (Transverse section)

Spinal Cord

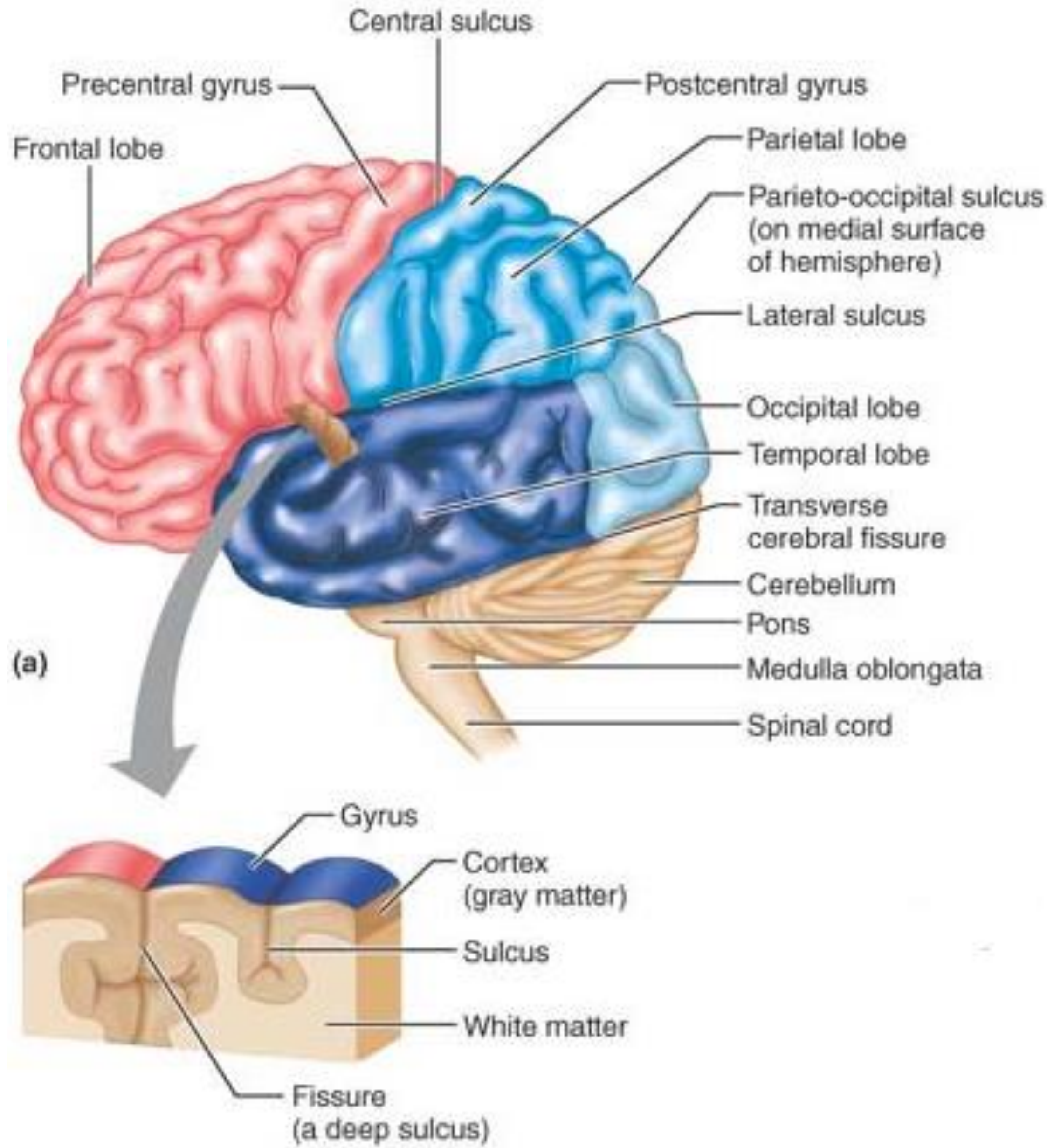
Name the spinal segments and tell how many of each segment are present on the spinal cord.

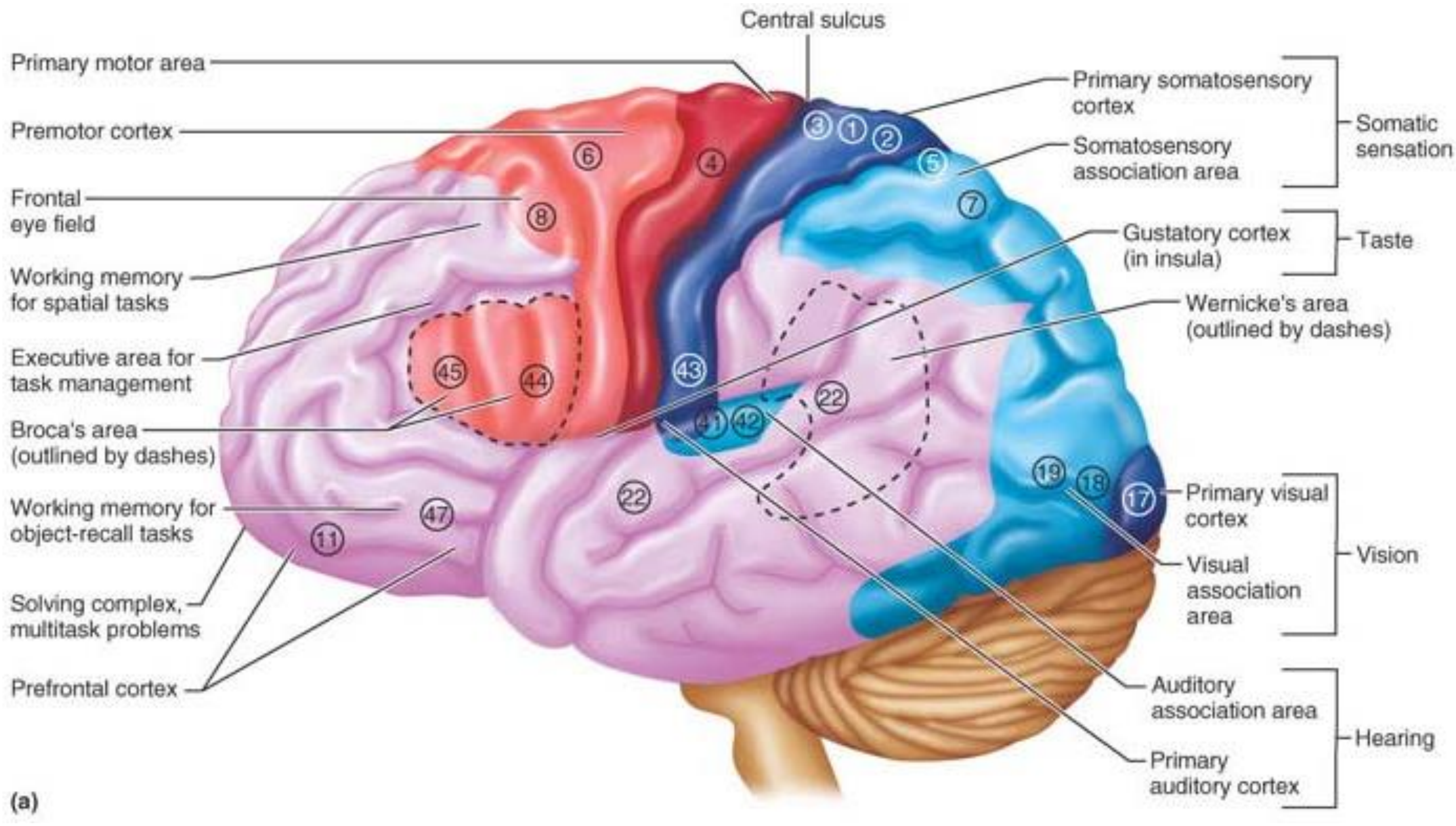
- 8 cervical segments
- 12 thoracic segments
- 5 lumbar segments
- 5 sacral segments
- 1 coccygeal segment



Cerebral Hemispheres

- Paired cerebral hemispheres cover and obscure the diencephalon and the top of the brain stem
- 83% of total brain mass.

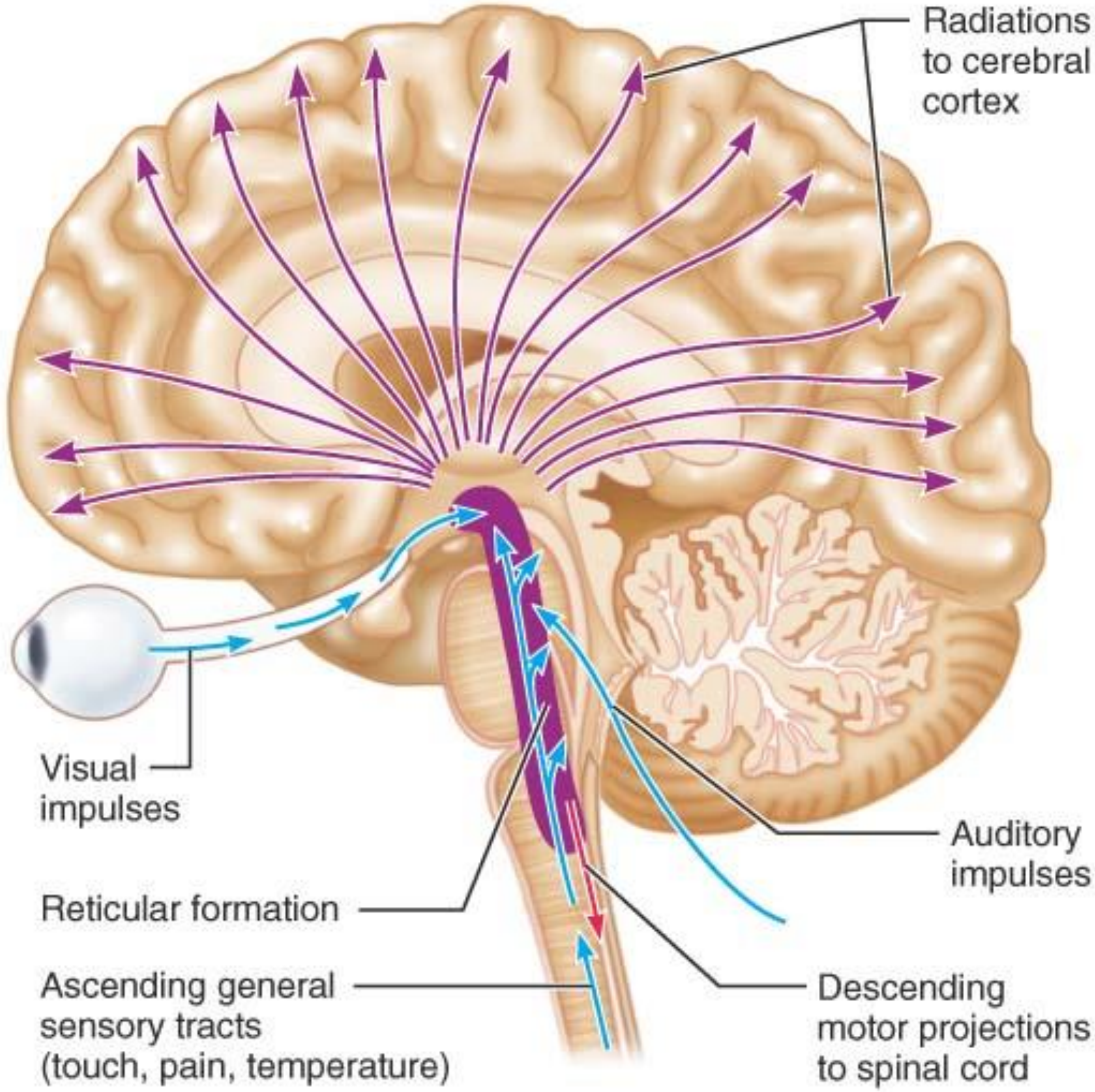




Functional and structural areas of the cerebral cortex

Diencephalon

- Central core of the forebrain and surrounded by the cerebral hemispheres.
- Consists largely of three paired structures**—the thalamus, hypothalamus, and epithalamus**.
- These all are gray matter (collection of cell bodies of neurons) areas which collectively enclose the third ventricle



1.Thalamus

- It is a Greek word meaning “inner room,” deep, well-hidden brain region that makes up 80% of the diencephalon.
- contains a large number of nuclei (collection of cell bodies in CNS) primarily visual and auditory relay centers.
- Within the thalamus, information is sorted out and “edited.
- virtually all other inputs ascending to the cerebral cortex funnel through thalamic nuclei.
- It is truly the gateway to the cerebral cortex.

2.Hypothalamus

- Caps the brain stem.
- Functions are:

1. Autonomic control center.
2. Center for emotional response
3. Body temperature regulation
4. Regulation of food intake
5. Regulation of water balance and thirst
6. Regulation of sleep-wake cycles
7. Control of endocrine system functioning

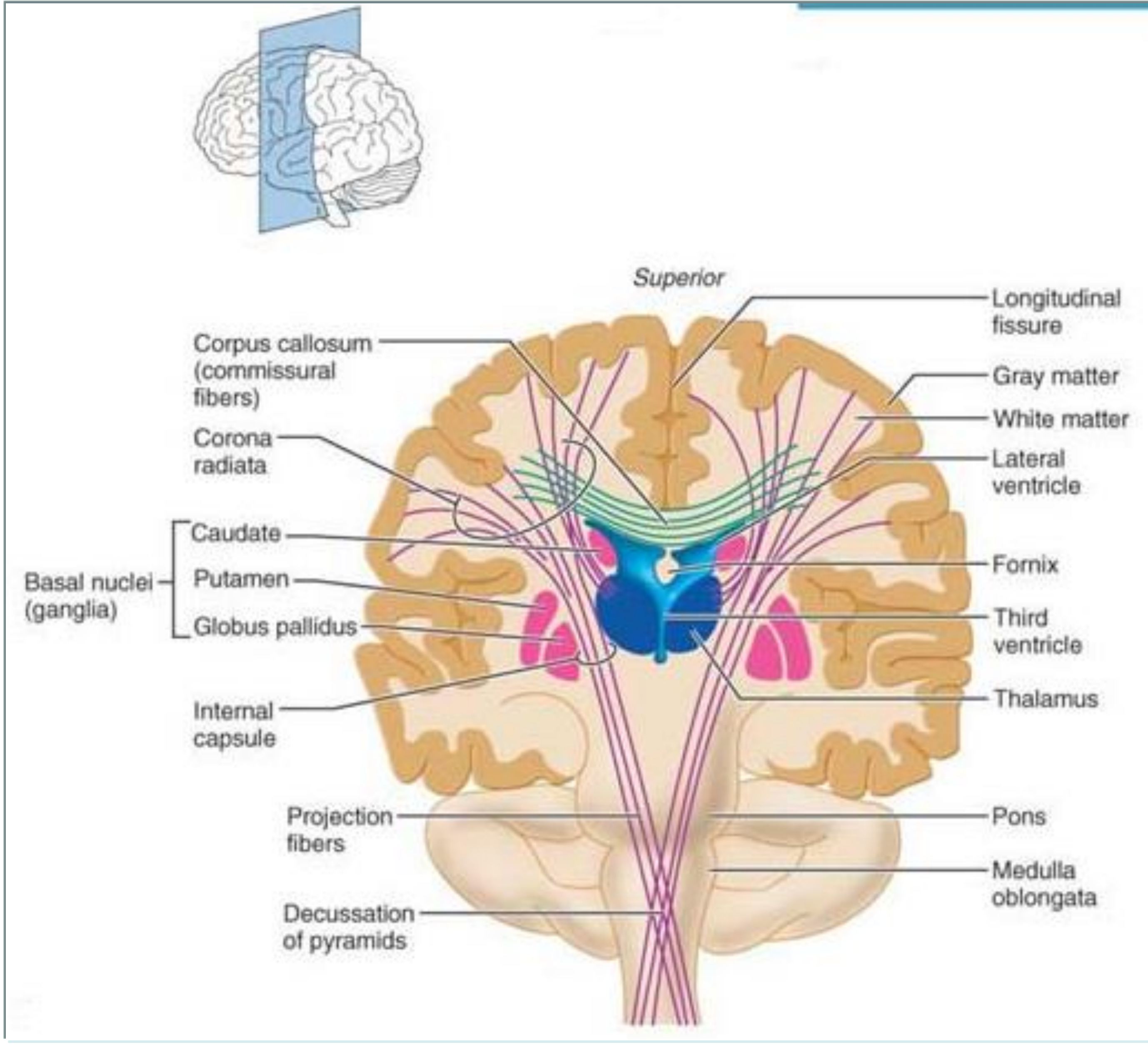
3. The epithalamus is the most dorsal portion of the diencephalon and forms the roof of the third ventricle.

- **The pineal gland (part of epithalamus)** secretes the hormone melatonin (a sleep-inducing signal and antioxidant

Brain Stem

Brain stem regions are midbrain, pons, and medulla oblongata.

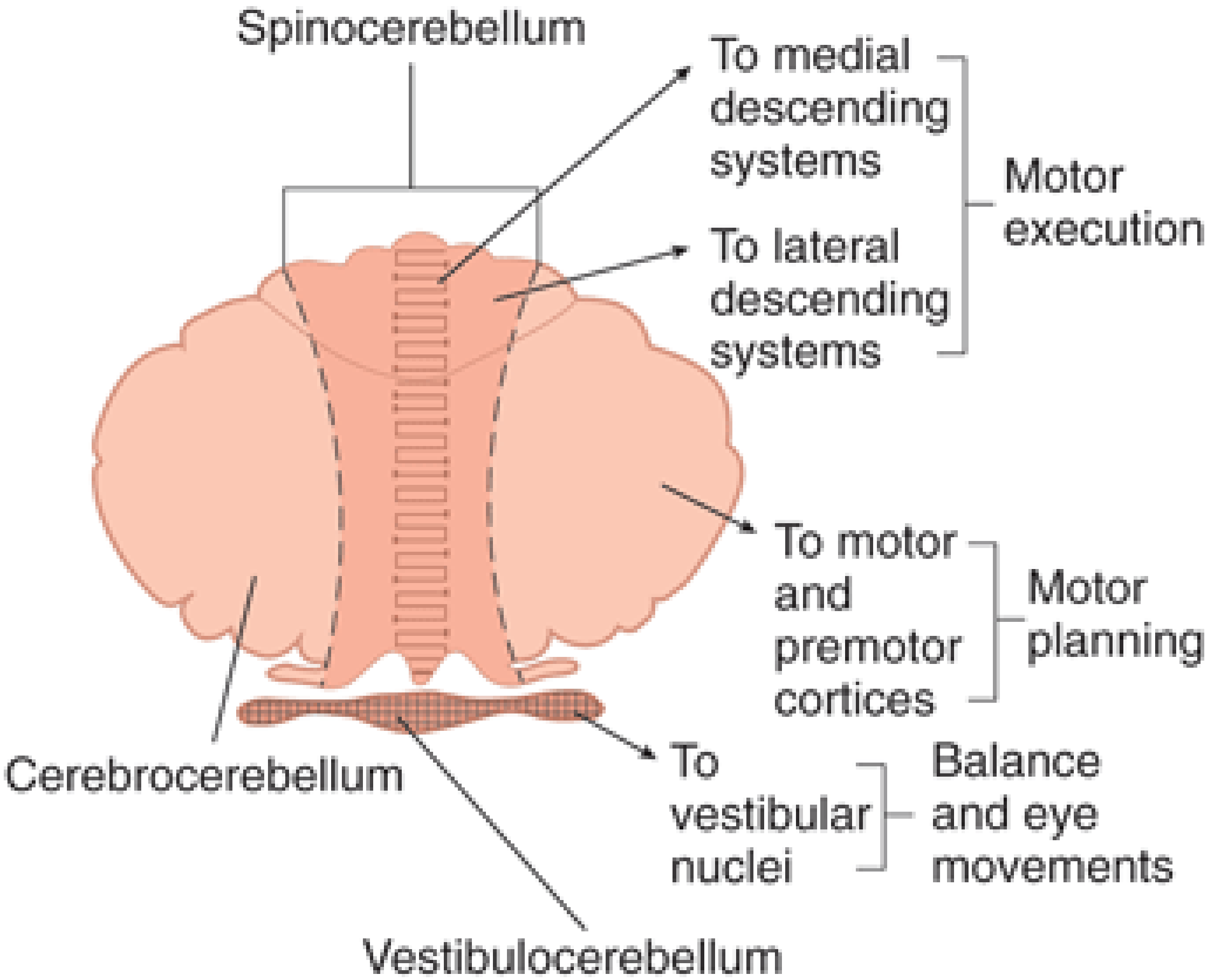
Fig. Frontal section showing commissural fibers and projection fibers running between the cerebrum and lower CNS centers. Notice the tight band of projection fibers called the <u>internal capsule</u> that passes between the thalamus and the basal nuclei, and then fans out as the corona radiata.



Cerebellum

- The cauliflower-like **cerebellum** (“small brain”), accounts for about **11% of total brain mass.**
- The cerebellum is located dorsal to the pons and medulla.
- It protrudes under the occipital lobes of the cerebral hemispheres, from which it is separated by the transverse cerebral fissure.
- It process the inputs received from the cerebral motor cortex, various brain stem nuclei, and sensory receptors and provides the precise timing and appropriate patterns of skeletal muscle contraction for smooth, coordinated movements and agility needed for our daily living—driving, typing.
- Cerebellar activity occurs subconsciously; that is, we have no awareness of its functioning.

- The cerebellum is bilaterally symmetrical; its two apple-sized cerebellar hemispheres are connected **medially by the wormlike vermis**.
- Deep fissures subdivide each hemisphere into **anterior, posterior, and flocculonodular** lobe.
- F**locculonodular** lobe is situated deep to the vermis and posterior lobe which cannot be seen in a surface view.
- Like the cerebrum, the cerebellum has a thin outer cortex of gray matter, internal white matter, and small, deeply situated, paired masses of gray matter.
- Several types of neurons populate the cerebellar cortex, including **stellate, basket, granule, and Purkinje cells.**



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

FUNCTIONAL DIVISIONS OF CEREBELLUM

- The anterior and posterior lobes of the cerebellum have completely **overlapping sensory and motor maps of the entire body** thus **coordinating body movements.**
- The **medial portions** influence the **motor activities of the trunk and girdle muscles.**
- The **intermediate parts of each hemisphere** are more concerned with the **distal parts of the limbs and skilled movements.**
- The **lateralmost parts** of each hemisphere integrate information from the association areas of the cerebral cortex and appear to play a **role in planning rather than executing movements.**
- **The flocculonodular lobes** receive inputs from the equilibrium apparatus of the **inner ears, and adjust posture to maintain balance**

Functions of cerebellum

1. The motor areas of the cerebral cortex, **via relay nuclei in the brain stem**, notify the cerebellum of their intent **to initiate voluntary muscle contractions.**

2. At the same time, the **cerebellum receives information from proprioceptors throughout the body** (regarding tension in the muscles and tendons, and joint position) and **from visual and equilibrium pathways**.

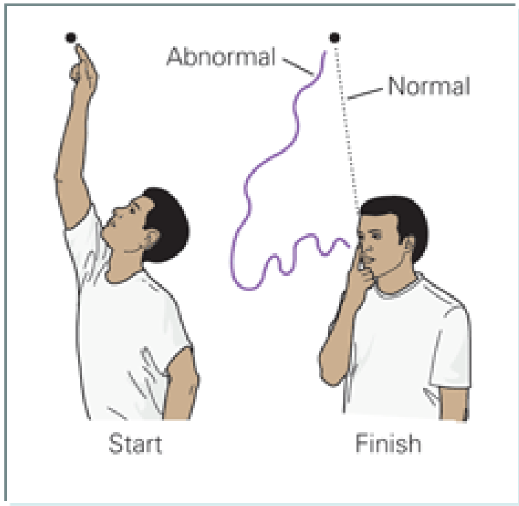
3. The cerebellar cortex calculates the best way to **coordinate the force, direction, and extent of muscle contraction** to prevent overshoot, maintain posture, and ensure smooth, coordinated movements.

4. Then, **via the superior peduncles**, the cerebellum dispatches to the cerebral motor cortex its “blueprint” **for coordinating movement**

- Hence **cerebellum continually compares the higher brain's intention with the body's performance** and sends out messages to initiate the appropriate corrective measures.
- The cerebellum **recognizes and predicts sequences of events** so that it may adjust for the multiple forces exerted on a limb during complex movements involving several joints.
- Some **nonmotor functions**, including **word association and puzzle solving**, also appear to involve the cerebellum.
- Cerebellar injury results in loss of muscle tone and clumsy, unsure movements.

Cerebellar disease

- **Hypotonia:** Decreased muscle tone
- **Ataxia:** incoordination due to errors in the rate, range, force, and direction of movement. unsteady, "**drunken" gait**
- **Intention tremor:** Voluntary movements are also highly abnormal for example, attempting to touch an object with a finger results in overshooting to one side or the other (**dysmetria or past-pointing),** promptly initiates a gross corrective action, but the correction overshoots to the other side. Consequently, the finger oscillates back and forth. This oscillation is the **intention tremor** of cerebellar disease.



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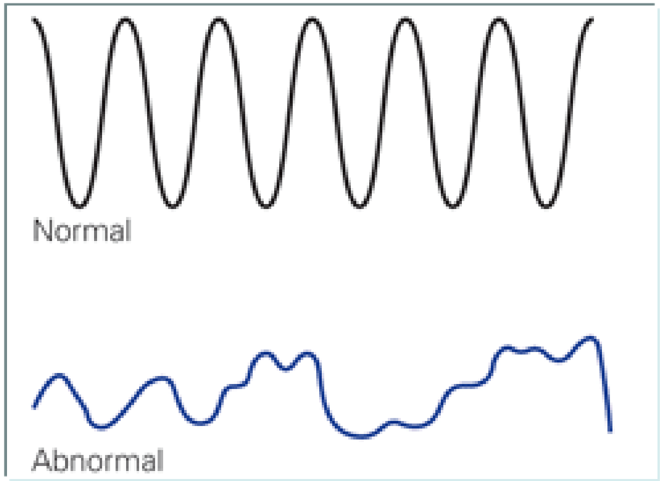
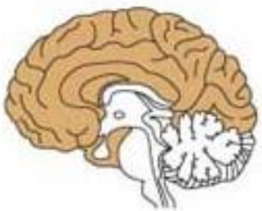
Cerebellar disease

- **Dysdiadochokinesia:** the inability to perform rapidly alternating opposite movements such as repeated pronation and supination of the hands

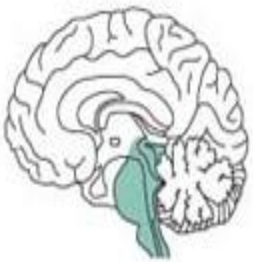
- Defects of the skilled movements involved in the production of speech, so that slurred, **scanning speech** results.



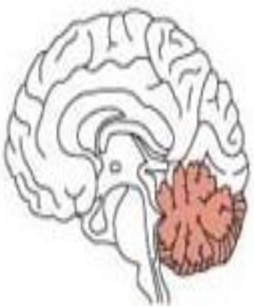
Functions of Major Brain Regions

REGION	FUNCTION
CEREBRAL HEMISPHERES (pp. 434–443)	
	Cortical gray matter localizes and interprets sensory inputs, controls voluntary and skilled skeletal muscle activity, and functions in intellectual and emotional processing; basal nuclei (ganglia) are subcortical motor centers important in initiation of skeletal muscle movements
DIENCEPHALON	
	Thalamic nuclei are relay stations in conduction of (1) sensory impulses to cerebral cortex for interpretation, and (2) impulses to and from cerebral motor cortex and lower (subcortical) motor centers, including cerebellum; thalamus is also involved in memory processing Hypothalamus is chief integration center of autonomic (involuntary) nervous system; it functions in regulation of body temperature, food intake, water balance, thirst, and biological rhythms and drives; regulates hormonal output of anterior pituitary gland and is an endocrine organ in its own right (produces ADH and oxytocin); part of limbic system
Limbic system	A functional system involving cerebral and diencephalon structures that mediates emotional response; also involved in memory processing

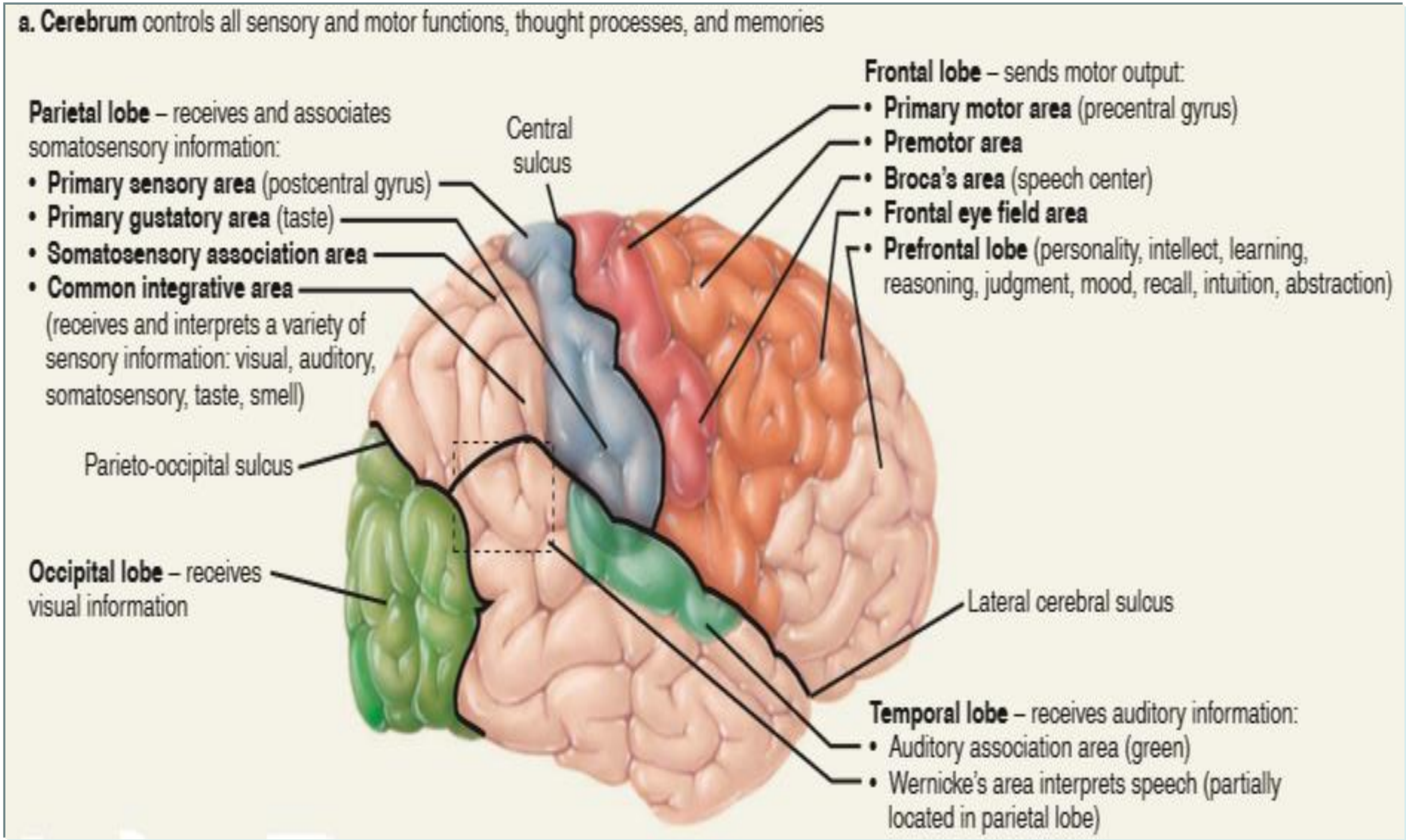
BRAIN STEM

	Midbrain: Conduction pathway between higher and lower brain centers (e.g., cerebral peduncles contain the fibers of the pyramidal tracts); its superior and inferior colliculi are visual and auditory reflex centers; substantia nigra and red nuclei are subcortical motor centers; contains nuclei for cranial nerves III and IV
	Pons: Conduction pathway between higher and lower brain centers; pontine nuclei relay information from the cerebrum to the cerebellum; its respiratory nuclei cooperate with the medullary respiratory centers to control respiratory rate and depth; houses nuclei of cranial nerves V–VII
	Medulla oblongata: Conduction pathway between higher brain centers and spinal cord; site of decussation of the pyramidal tracts; houses nuclei of cranial nerves VIII–XII; contains nuclei cuneatus and gracilis (synapse points of ascending sensory pathways transmitting sensory impulses from skin and proprioceptors), and visceral nuclei controlling heart rate, blood vessel diameter, respiratory rate, vomiting, coughing, etc.; its inferior olivary nuclei provide the sensory relay to the cerebellum
Reticular formation	A functional brain stem system that maintains cerebral cortical alertness (reticular activating system) and filters out repetitive stimuli; its motor nuclei help regulate skeletal and visceral muscle activity

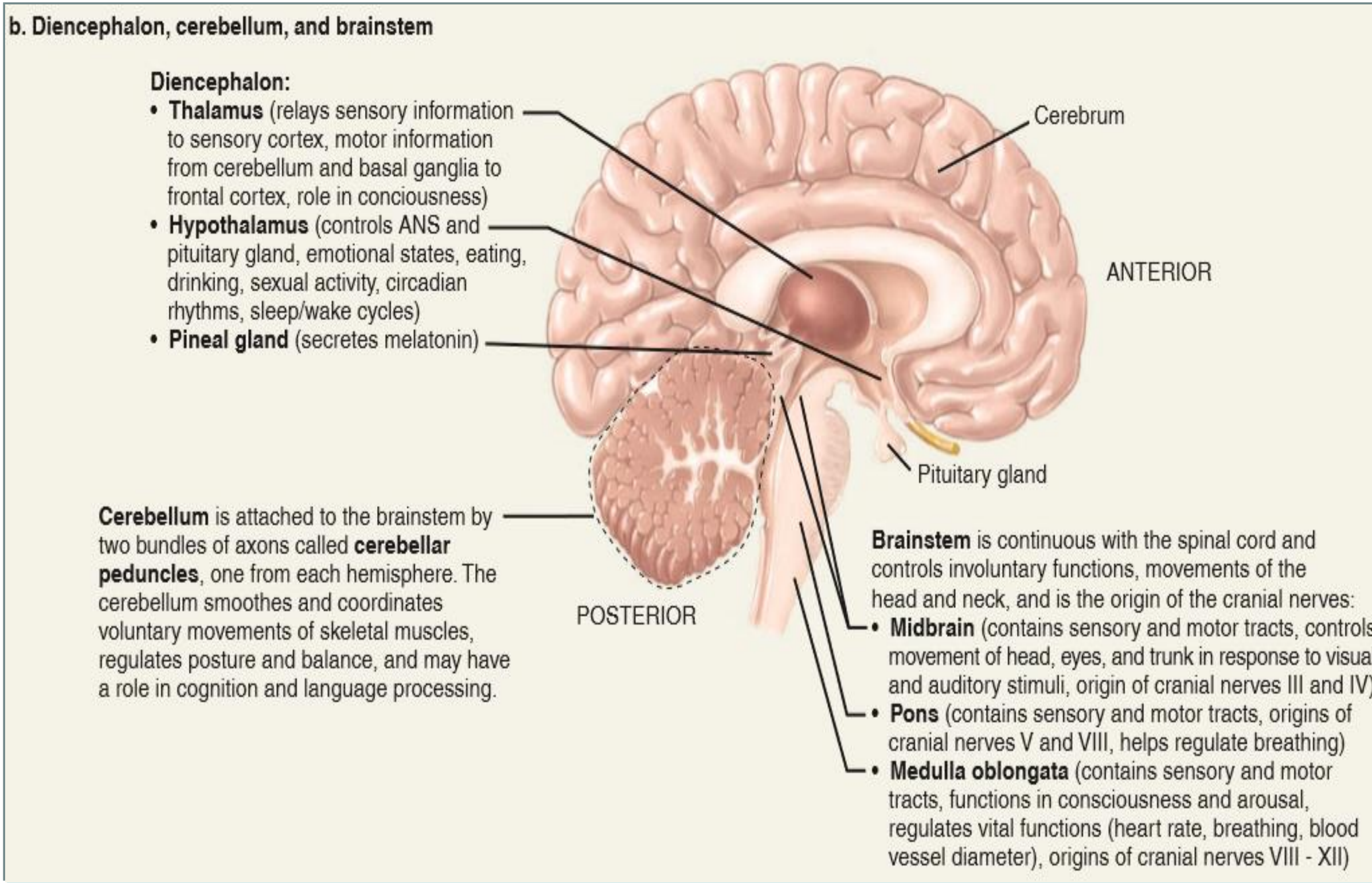
CEREBELLUM



Processes information from cerebral motor cortex and from proprioceptors and visual and equilibrium pathways, and provides "instructions" to cerebral motor cortex and subcortical motor centers that result in proper balance and posture and smooth, coordinated skeletal muscle movements



a. Cerebrum controls all sensory and motor functions, thought processes, and memories
Parietal lobe – receives and associates somatosensory information:
• Primary sensory area (postcentral gyrus)
• Primary gustatory area (taste)
• Somatosensory association area
• Common integrative area (receives and interprets a variety of sensory information: visual, auditory, somatosensory, taste, smell)
Central sulcus
Frontal lobe – sends motor output:
• Primary motor area (precentral gyrus)
• Premotor area
• Broca's area (speech center)
• Frontal eye field area
• Prefrontal lobe (personality, intellect, learning, reasoning, judgment, mood, recall, intuition, abstraction)
Parieto-occipital sulcus
Occipital lobe – receives visual information
Lateral cerebral sulcus
Temporal lobe – receives auditory information:
• Auditory association area (green)
• Wernicke's area interprets speech (partially located in parietal lobe)

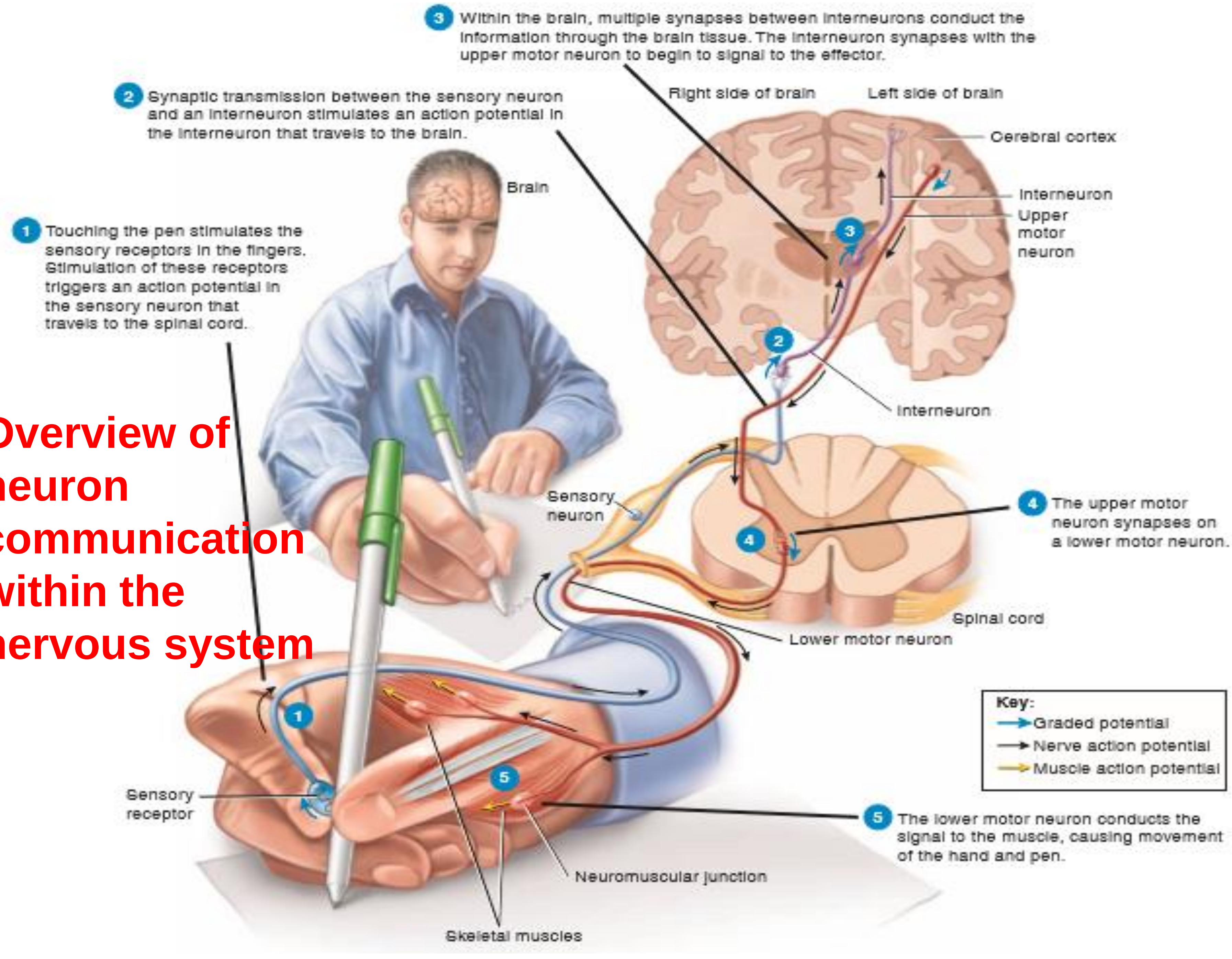

b. Diencephalon, cerebellum, and brainstem
Diencephalon:
• **Thalamus** (relays sensory information to sensory cortex, motor information from cerebellum and basal ganglia to frontal cortex, role in conciousness)
• **Hypothalamus** (controls ANS and pituitary gland, emotional states, eating, drinking, sexual activity, circadian rhythms, sleep/wake cycles)
• **Pineal gland** (secretes melatonin)
Cerebrum
ANTERIOR
Pituitary gland
Cerebellum is attached to the brainstem by two bundles of axons called **cerebellar peduncles**, one from each hemisphere. The cerebellum smoothes and coordinates voluntary movements of skeletal muscles, regulates posture and balance, and may have a role in cognition and language processing.
POSTERIOR
Brainstem is continuous with the spinal cord and controls involuntary functions, movements of the head and neck, and is the origin of the cranial nerves:
• **Midbrain** (contains sensory and motor tracts, controls movement of head, eyes, and trunk in response to visual and auditory stimuli, origin of cranial nerves III and IV)
• **Pons** (contains sensory and motor tracts, origins of cranial nerves V and VIII, helps regulate breathing)
• **Medulla oblongata** (contains sensory and motor tracts, functions in consciousness and arousal, regulates vital functions (heart rate, breathing, blood vessel diameter), origins of cranial nerves VIII - XII)

Summary of parts & function of CNS

Parts and Functions of the Central Nervous System

Region	Nerves (Input/Output)	General Functions
Spinal cord	Dorsal/ventral roots	Sensory input, reflex circuits, somatic and autonomic motor output
Medulla	Cranial nerves VIII-XII	Cardiovascular and respiratory control, auditory and vestibular input, brainstem reflexes
Pons	Cranial nerves V-VIII	Respiratory/urinary control, control of eye movement, facial sensation/motor control
Cerebellum	Cranial nerve VIII	Motor coordination, motor learning, equilibrium
Midbrain	Cranial nerves III-IV	Acoustic relay and mapping, control of the eye (including movement, lens and pupillary reflexes), pain modulation
Thalamus	Cranial nerve II	Sensory and motor relay to the cerebral cortex, regulation of cortical activation, visual input
Hypothalamus		Autonomic and endocrine control, motivated behavior
Basal ganglia		Coordinated movement
Cerebral cortex	Cranial nerve I	Sensory perception, cognition, learning and memory, motor planning and voluntary movement, language

Overview of neuron communication within the nervous system

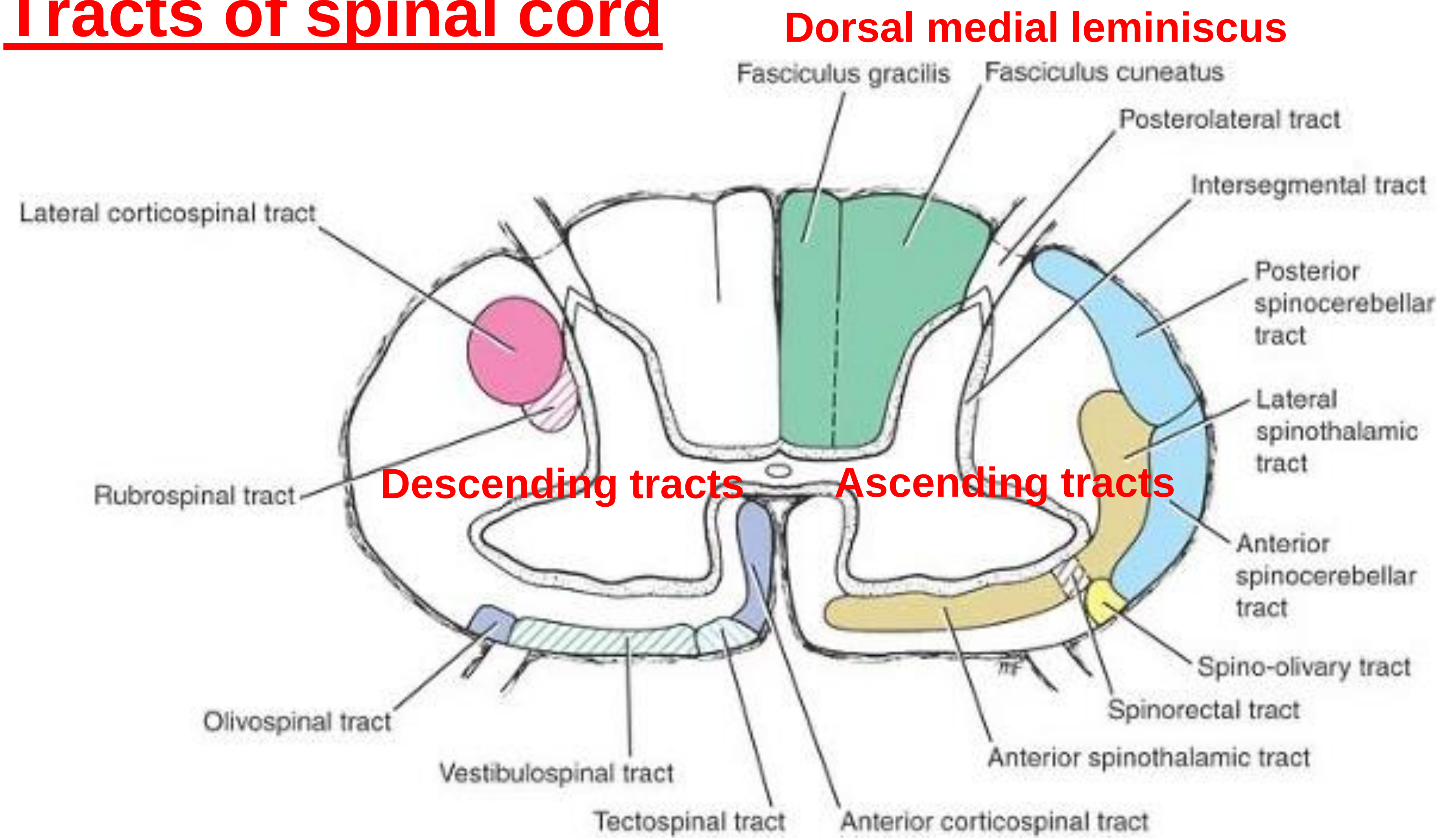


Tracts of spinal cord

There are primarily two major tracts in CNS, passing through the spinal cord.

1. **Ascending tract or sensory pathway**: carry the sensory impulses from different parts of the body to the specific regions of cerebrum .
2. **Descending tract or motor pathway**: carry impulses from the specific regions of cerebrum or other nuclei of brain to the different muscles & glands.

Tracts of spinal cord



Transverse section of the spinal cord at the midcervical level showing the general arrangement of the ascending tracts on the right and the descending tracts on the left.

Types of Sensory Receptors and the Stimuli They Detect

(1) ***Mechanoreceptors****:* detect mechanical compression or stretching of the receptor or of tissues adjacent to the receptor.

(2) ***Thermoreceptors****:* detect changes in temperature, with some receptors detecting cold and others warmth.

(3) ***Nociceptors*** **(pain receptors**): detect damage occurring in the tissues, whether physical damage or chemical damage.

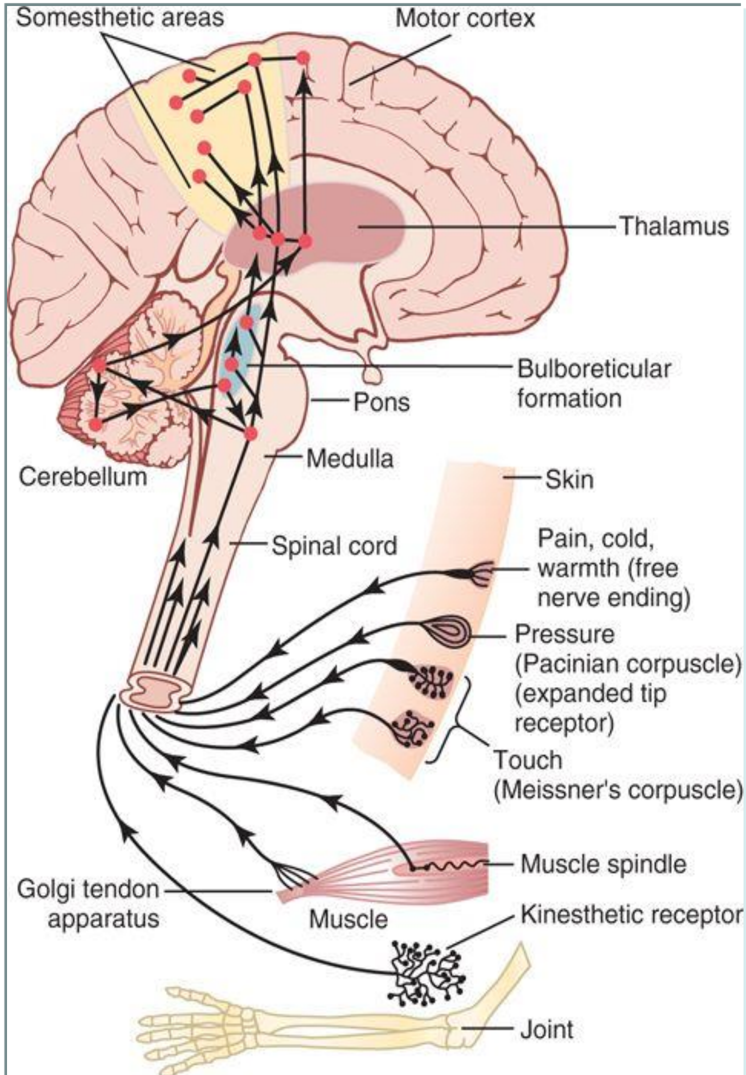
(4) ***Electromagnetic receptors****:* detect light on the retina of the eye.

(5) ***Chemoreceptors****:* detect taste in the mouth, smell in the nose, oxygen level in the arterial blood, osmolality of the body fluids, carbon dioxide concentration

Each type of receptor is highly sensitive to one type of stimulus for which it is designed and yet is almost nonresponsive to other types of sensory stimuli

Modality of Sensation-The "Labeled Line" Principle

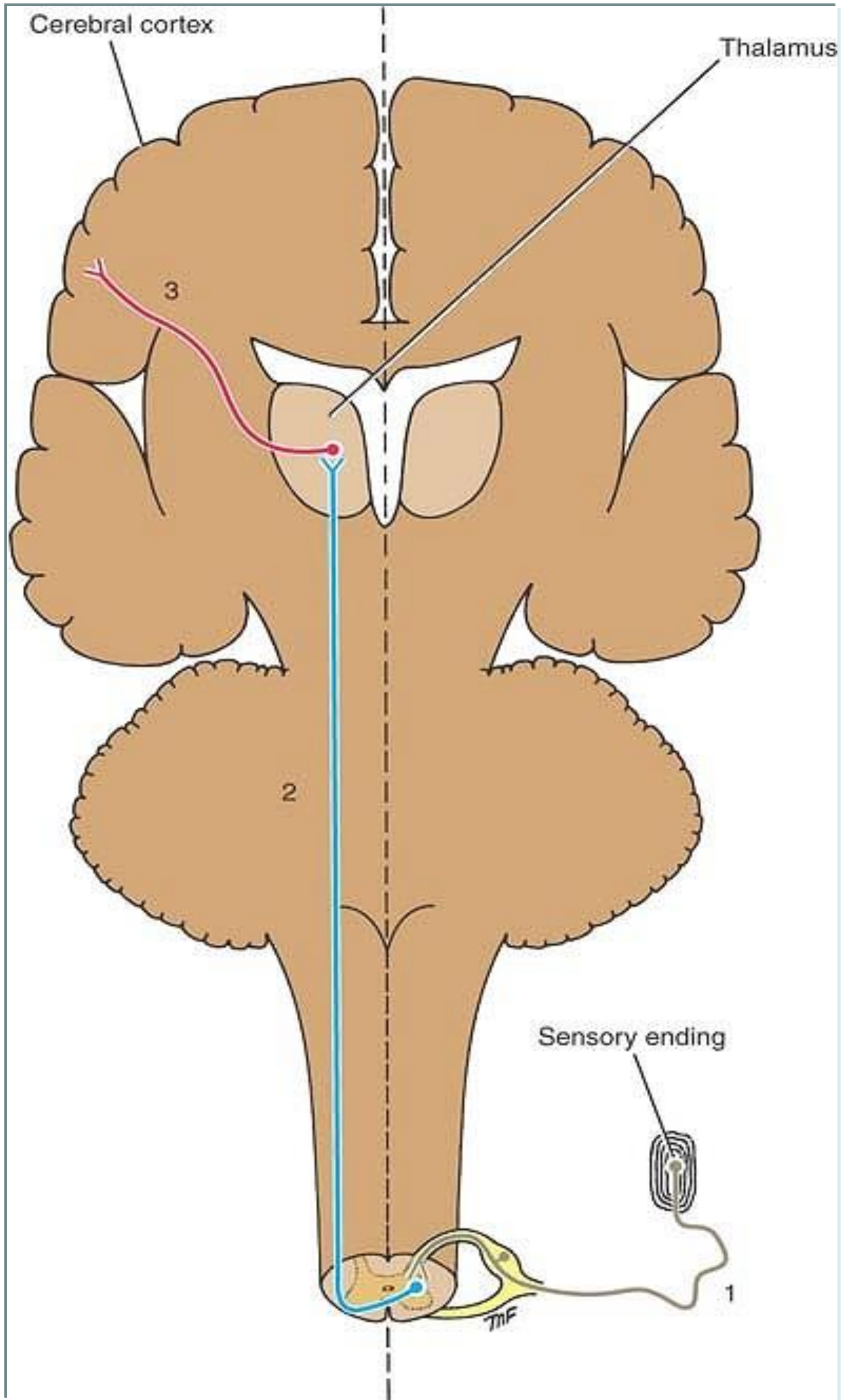
- Each of the principal types of sensation that we can experience-pain, touch, sight, sound, and so forth-is called a ***modality* of sensation**
- Each nerve tract terminates at a specific point in the central nervous system. Fibers from the retina of the eye terminate in the vision areas of the brain, fibers from the ear terminate in the auditory areas of the brain, and temperature fibers terminate in the temperature areas.
- This specificity of nerve fibers for transmitting only one modality of sensation is called the ***labeled line principle.***



Hall: Guyton and Hall Textbook of Medical Physiology, 12th Edition

Fig. General organization of ascending tract.

the ascending pathway to consciousness consists of three neurons



Sensory Pathways for Transmitting Somatic Signals into the Central Nervous System (ASCENDING PATHWAY)

(1) *Dorsal column*-medial lemniscal system: composed of large, myelinated nerve fibers that transmit signals to the brain at velocities of 30 to 110 m/sec

– Touch sensations requiring a high degree of localization of the stimulus

– Touch sensations requiring transmission of fine gradations of intensity (Two point disrimination)

– Phasic sensations, such as vibratory sensations

– Sensations that signal movement against the skin

– Position sensations from the joints

– Pressure sensations related to fine degrees of judgment of pressure intensity

2) Anterolateral system: composed of smaller myelinated fibers that transmit signals at velocities ranging from a few meters per second up to 40 m/sec.

- Pain
- Thermal sensations, including both warmth and cold sensations
- Crude touch and pressure sensations capable only of crude localizing ability on the surface of the body
- Tickle and itch sensations
- Sexual sensations

- Note that all ascending pathways send branches to the reticular activating system (for alertness)

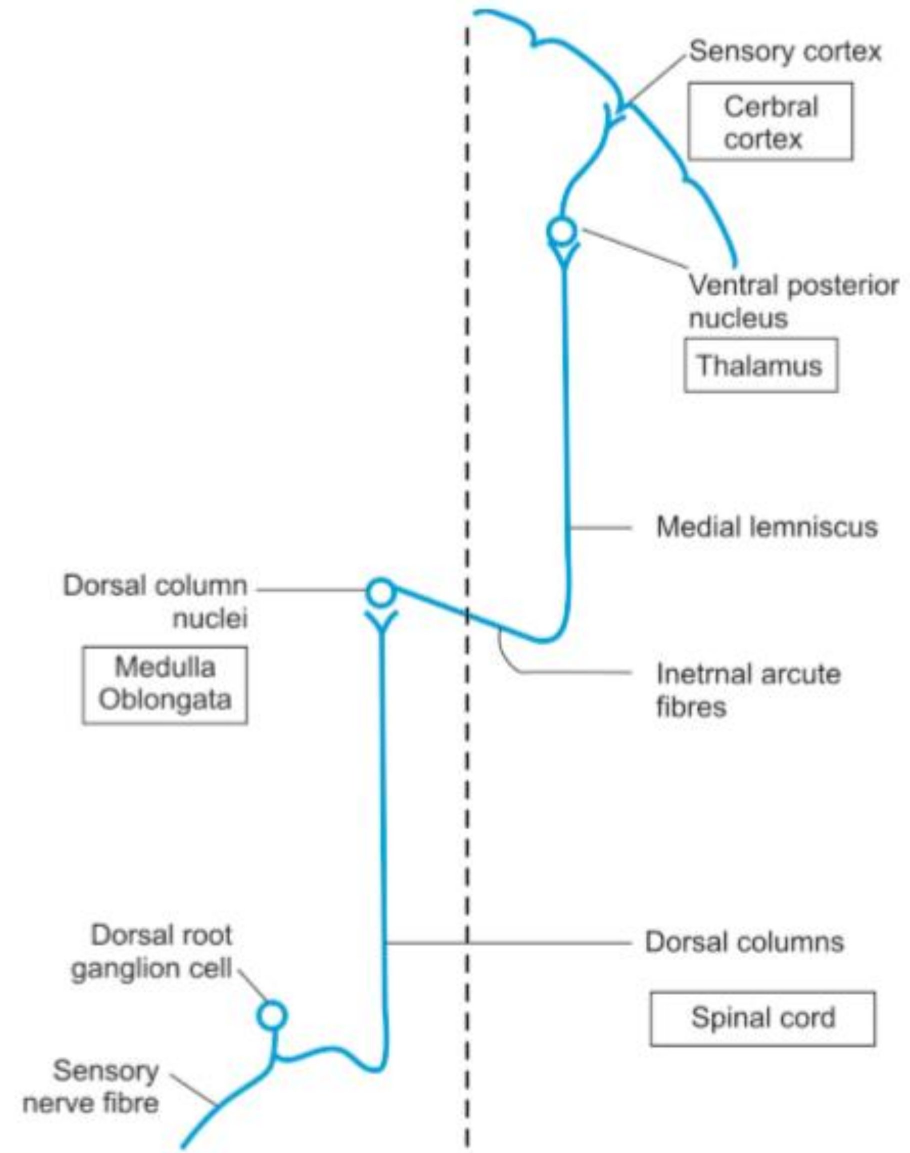
Sesory pathway or ascending tract of spinal cord

1.Dorsal column-medial lemniscal system

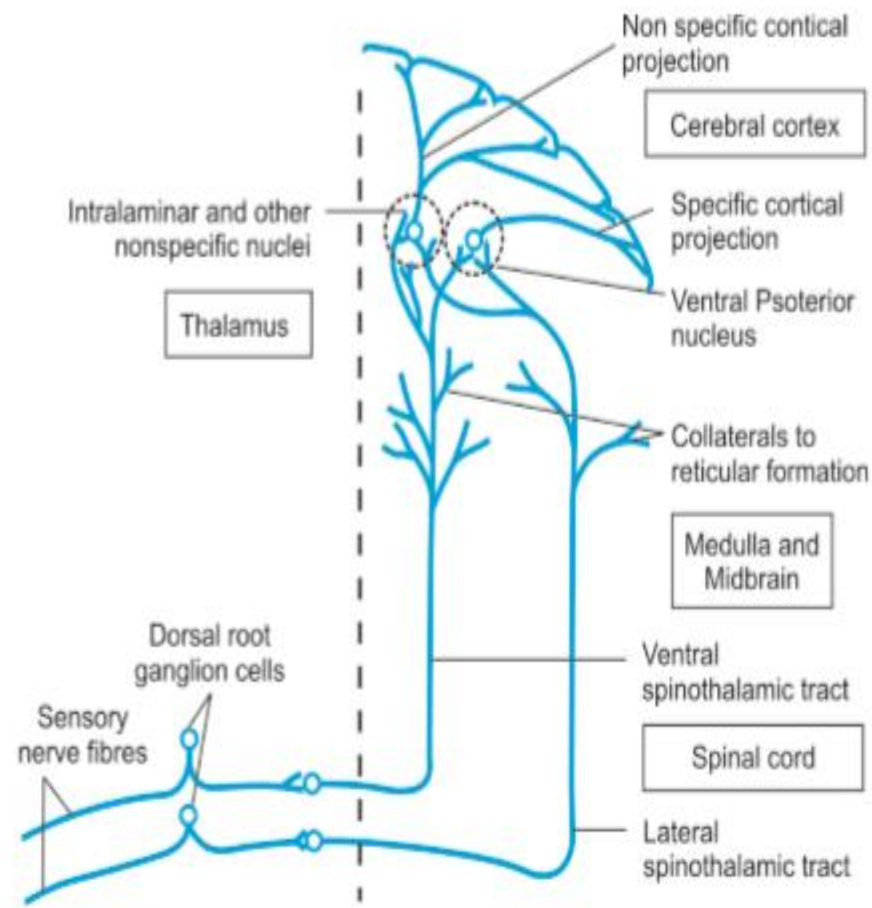
Carries signals upward to the medulla of the brain mainly in the dorsal columns of the cord. Then, after the signals synapse and cross to the opposite side in the medulla, they continue upward through the brain stem to the thalamus by way of the medial lemniscus.

2. Anterolateral system

After entering the spinal cord from the dorsal spinal nerve roots, synapse in the dorsal horns of the spinal gray matter, then cross to the opposite side of the cord and ascend through the anterior and lateral white columns of the cord.

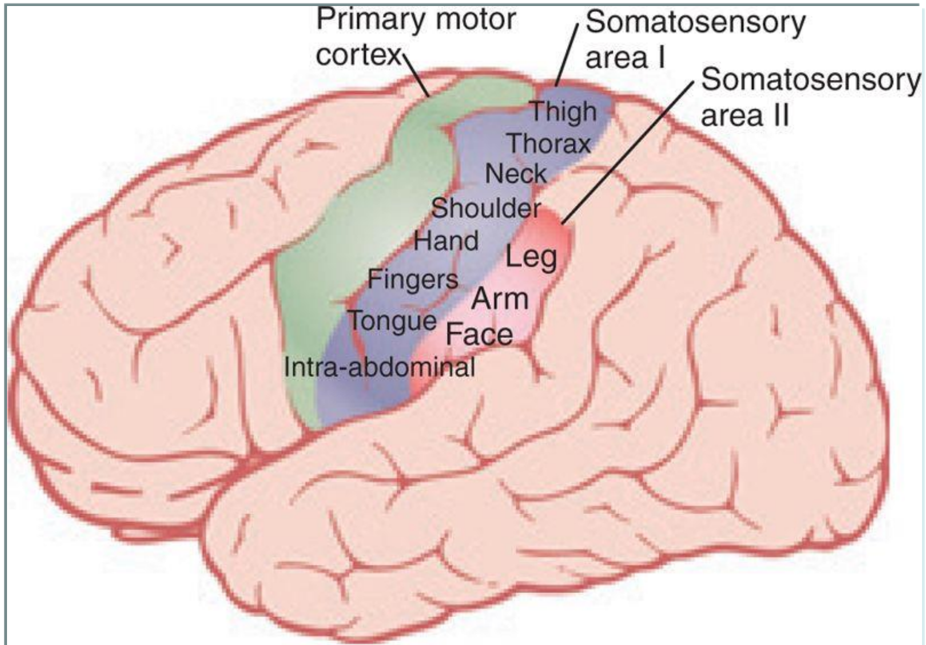


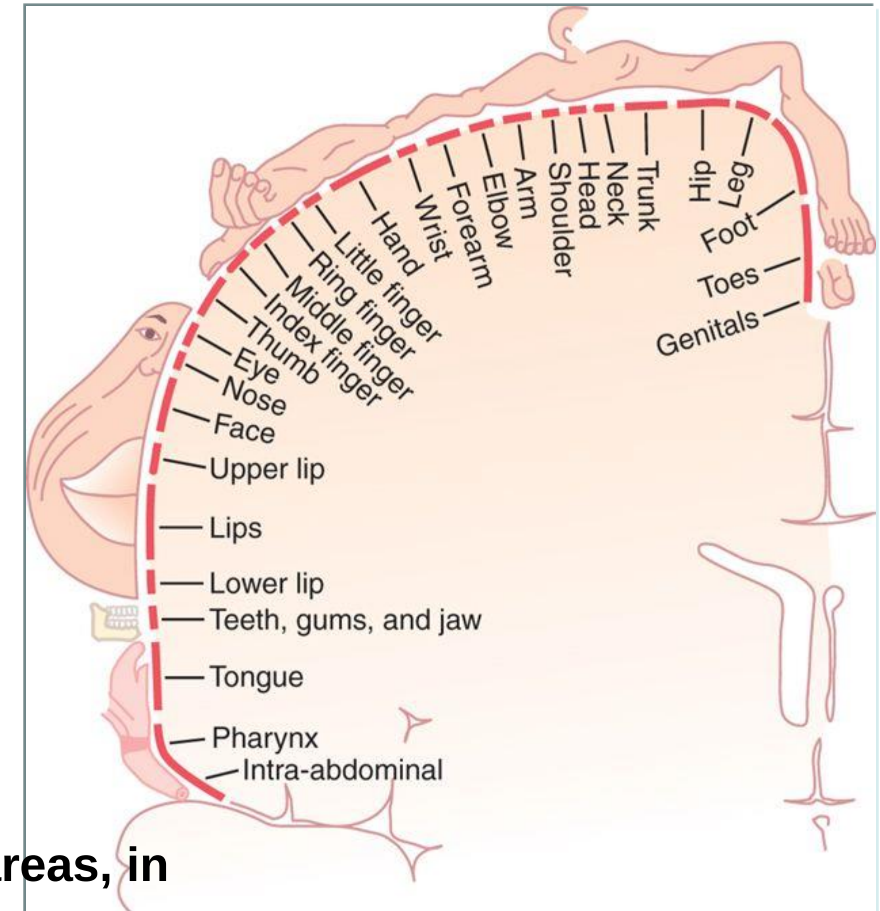
The dorsal column system for transmitting sensory signals. The dotted line represents the midline.



: The anterolateral system for transmitting sensory signals. The dotted line represents the midline.

Two types of ascending tract





The relative sizes of the cortical receiving areas, in which the proportions of the homunculus have been distorted to correspond to the size of the cortical receiving areas for each.

Note that the *cortical areas for sensation from the trunk and back are small*, whereas very large areas are concerned with impulses from the hand and the parts of the mouth concerned with speech

Sensory homunculus

Regions in the cerebrum to which the ascending tract from different parts of body reach

Descending tract or motor pathway

- Starts from the cortical motor area of brain (primary motor cortex, premotor cortex; area no. 4,6) and course through the different nuclei of brain like basal ganglia (subcortical nuclei like caudate, putaman, globus pallidus, substantia nigra form basal ganglia), red nucleus, nuclei of pons, medulla & terminate in the anterior horn cells of spinal cord (excludes this cell)

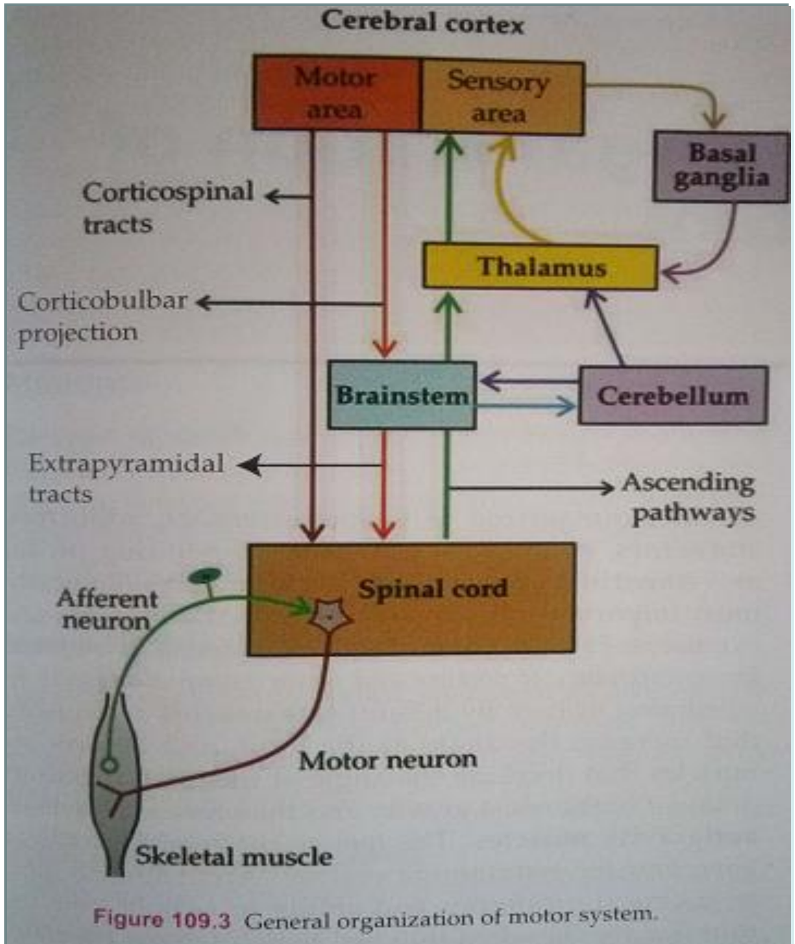
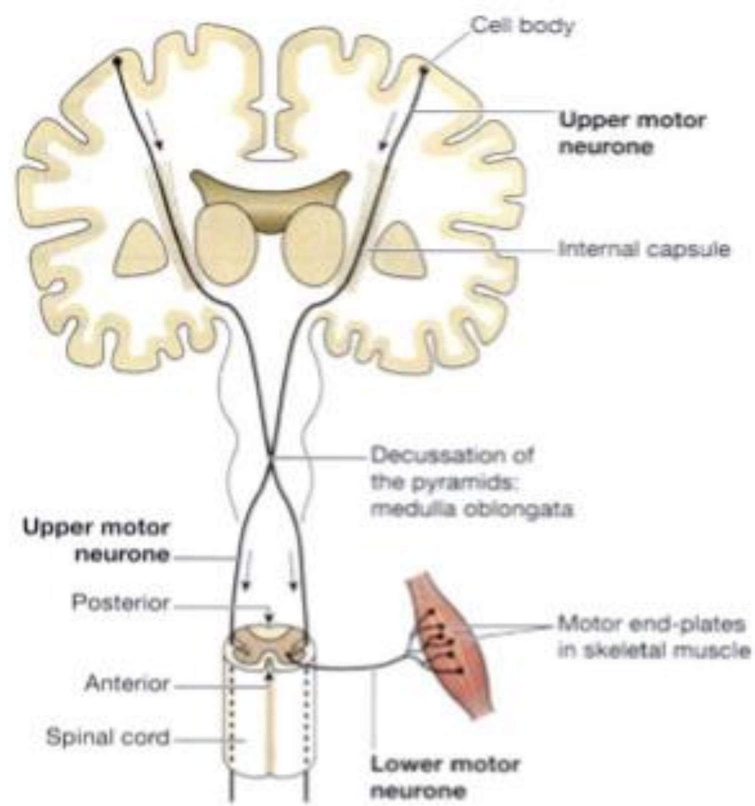


Figure 109.3 General organization of motor system.



The motor nerve pathways: upper and lower motor neurones.

- The nerve fibers that descend in the white matter from different supraspinal nerve centers are segregated into nerve bundles called the descending tracts.
- These supraspinal neurons and their tracts are sometimes referred to as the upper motor neurons, and they provide numerous separate pathways that can influence motor activity.

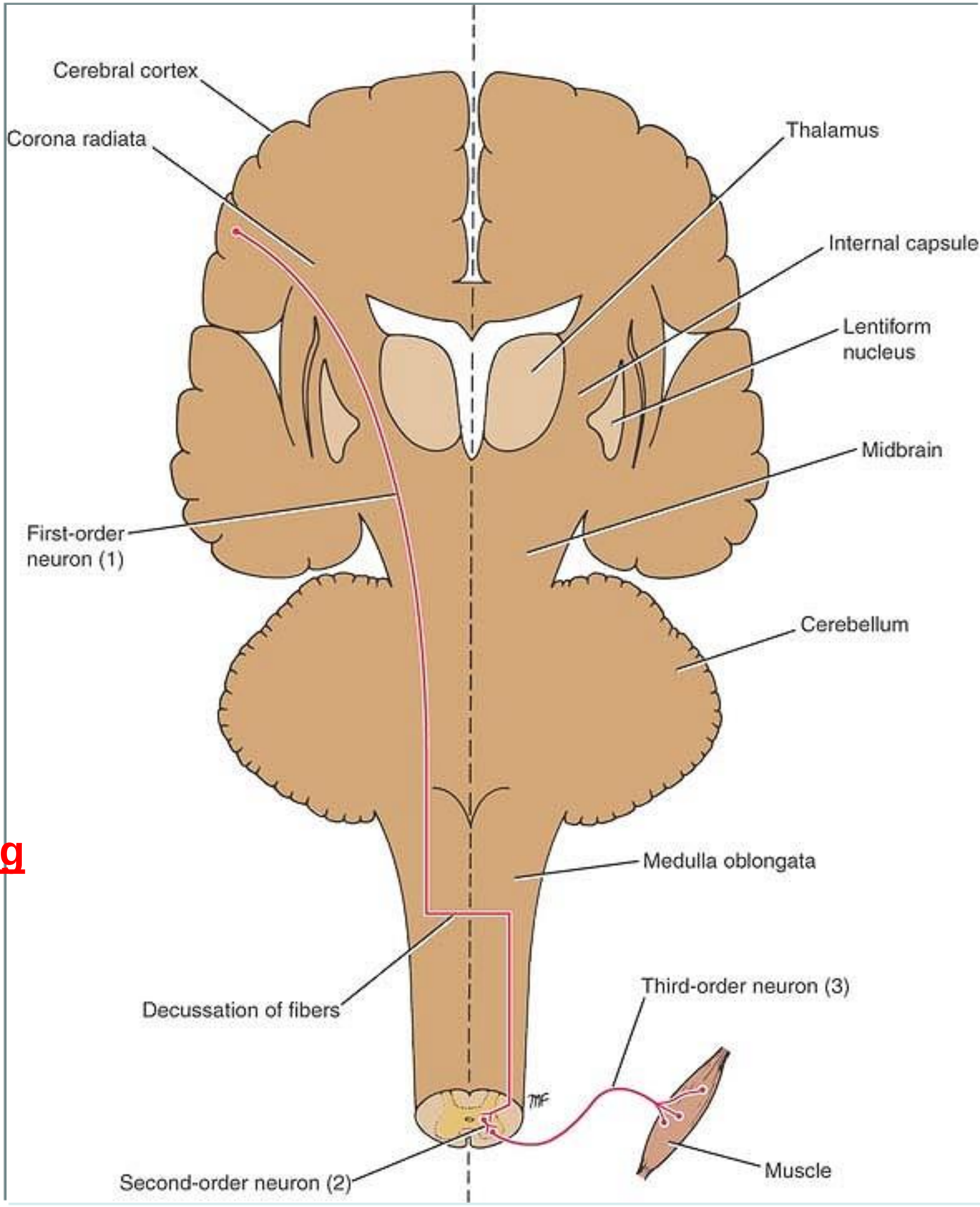
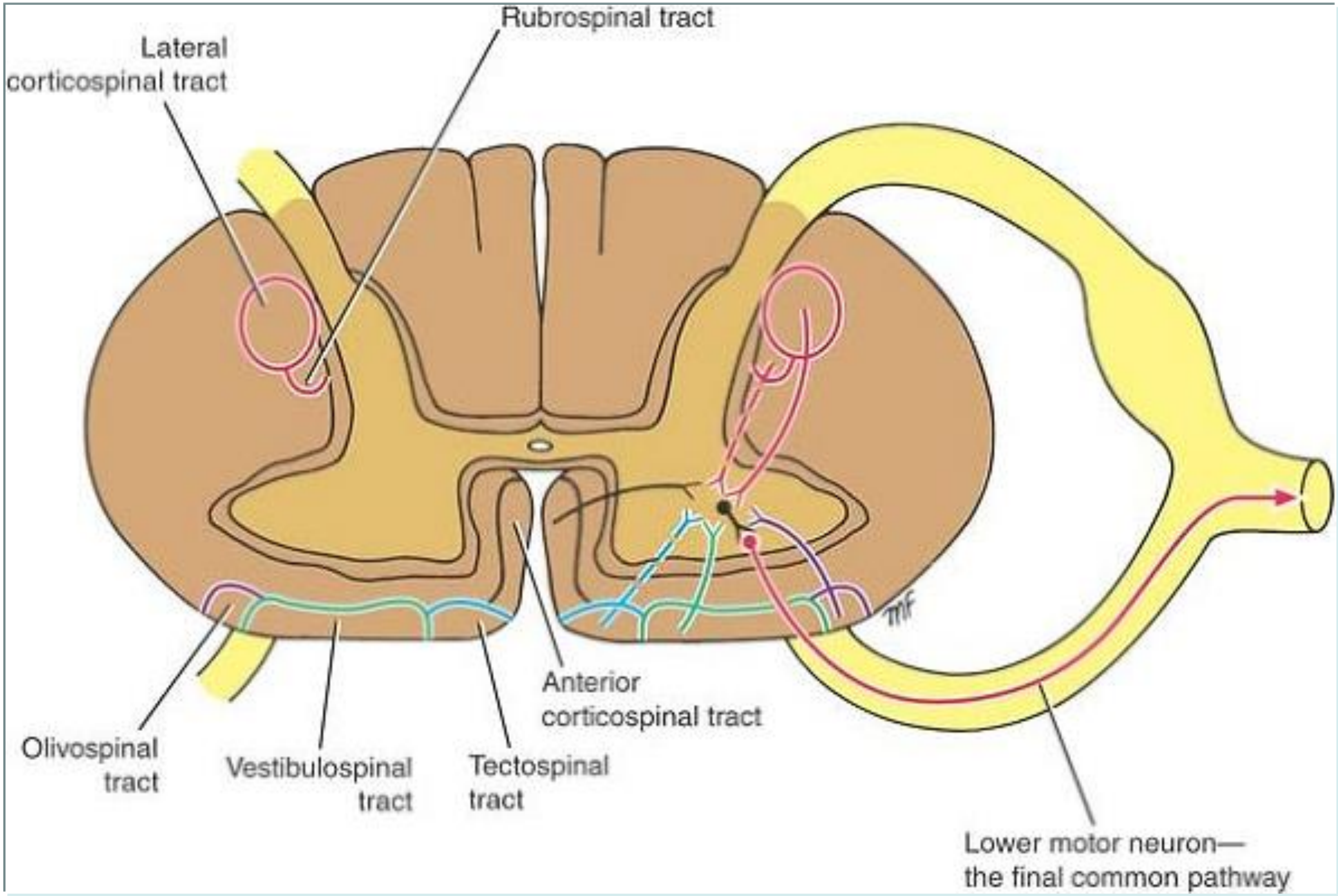


Fig. Simple form of the descending motor pathway from the cerebral cortex to the skeletal muscle



Transverse section of the spinal cord showing the termination of the descending motor tracts

From the functional point of view descending tract can be of two types:

1. **Lateral system** that governs finely coordinated movements of the extremities.
2. **Medial system** that controls coarse trunk and whole limb movements & controlling tone and posture.

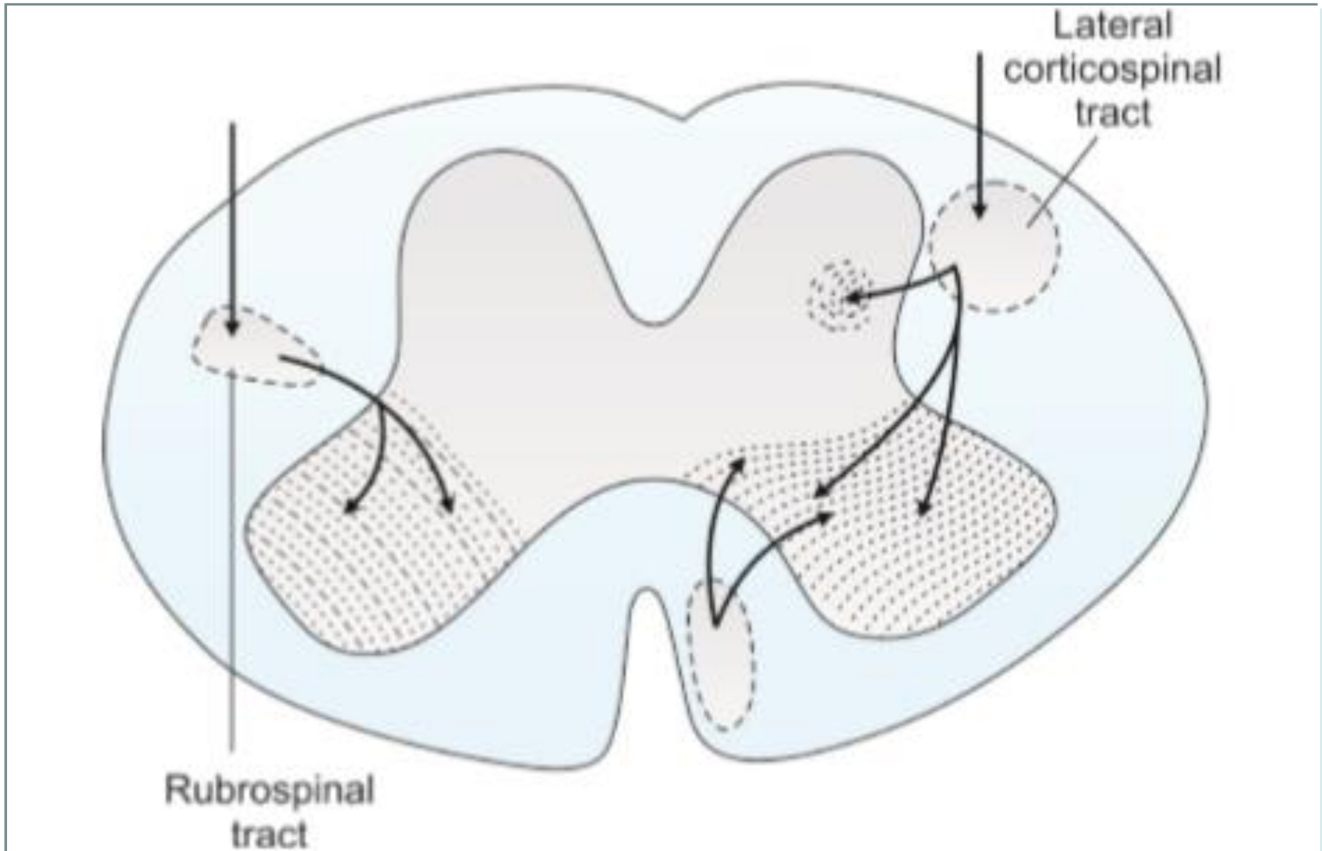
1.Lateral System Pathways: Two major motor pathways terminate on the lateral system of neurons:

a) **Lateral corticospinal tract:**

- ❖ originate from motor cortex (area 4), premotor cortex (area 6) and supplementary motor area.
- ❖ Most of the fibers **decussate at the junction of medulla oblongata and spinal cord** and descend in the lateral funiculus of the spinal cord where they form the **lateral corticospinal tract.**
- ❖ A small number of fibers **do not cross and descend down in the ipsilateral ventral funiculus** as the ventral (also called **anterior) corticospinal tract.**

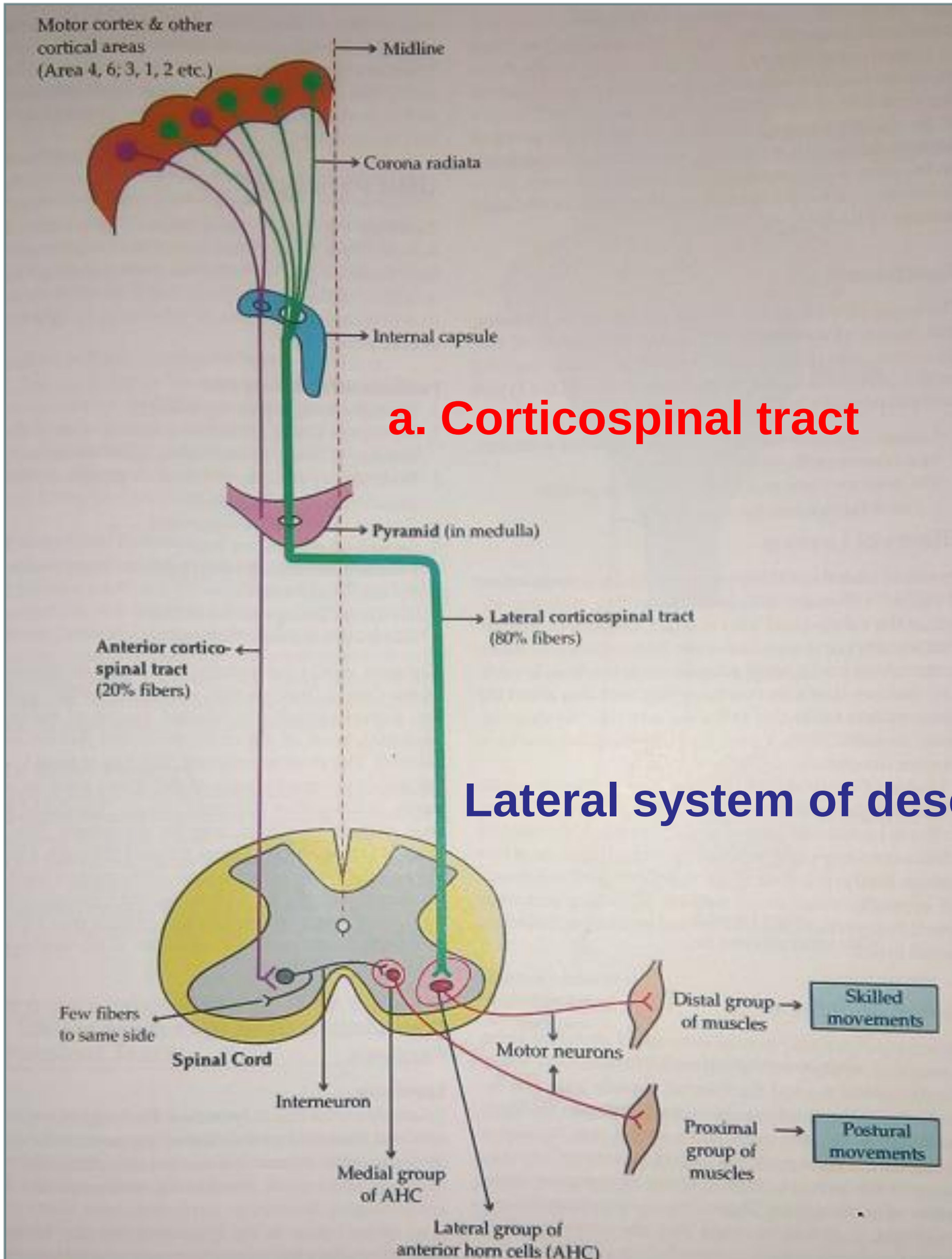
b) **Rubrospinal tract:** This tract arises from both large and small cells of the **red nucleus present in the midbrain**

- These tracts of lateral system terminate most prominently on the motorneurons innervating the muscles of extremities; that governs finely coordinated movements.eg. Digits muscles, typing

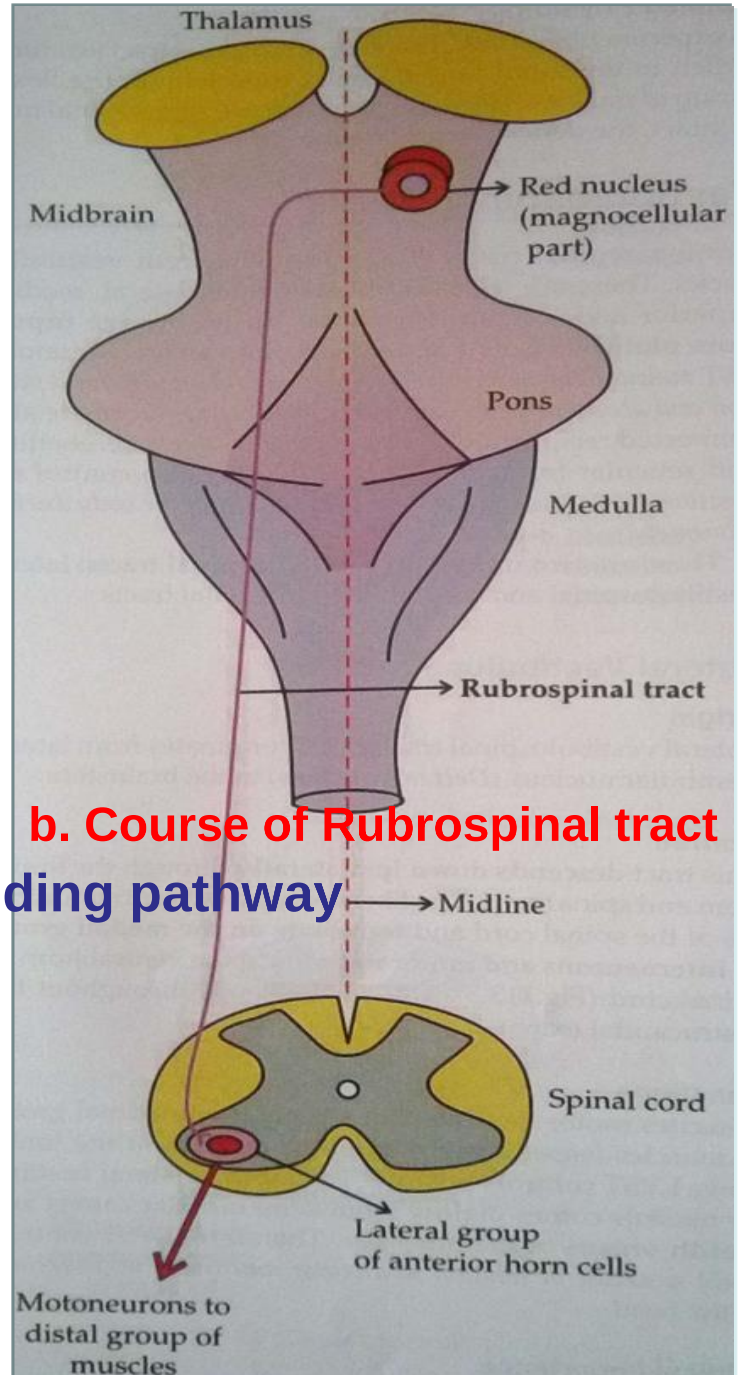


: Sites of termination of the two major tracts of the lateral system, lateral corticospinal tract and the rubrospinal tract.

Lateral system of descending pathway



a. Corticospinal tract



b. Course of Rubrospinal tract

2. Medial System Pathways: Vestibulospinal & Reticulospinal

a) vestibulospinal (medial and lateral):

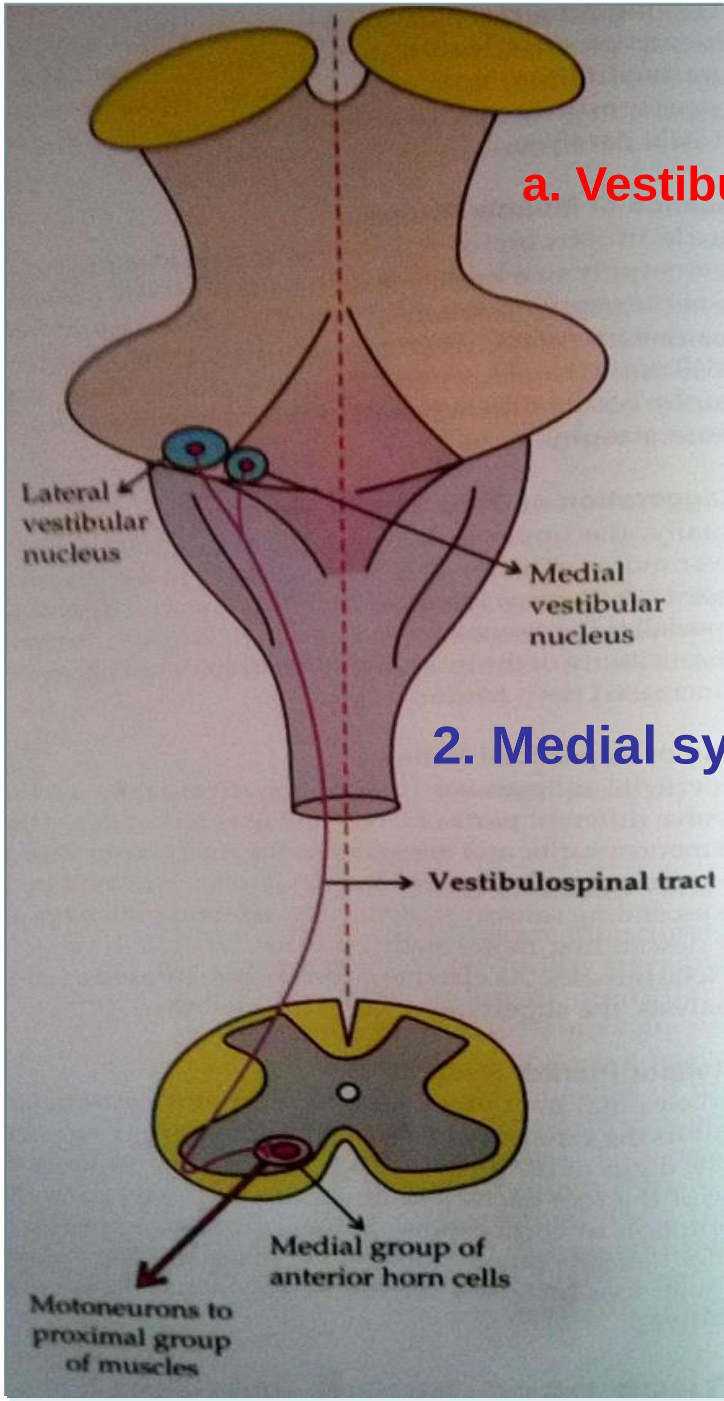
- ❖ They arise from vestibular nuclei of the brain stem, travel uncrossed in the ventral funiculus and make monosynaptic connections with the ventromedial extensor motoneurons.
- ❖ These tracts are probably principally concerned with adjustment of body posture in response to linear accelerating displacement of the head, and adjustments of the position of neck and limbs

b) Reticulospinal (pontine and medullary) tracts:

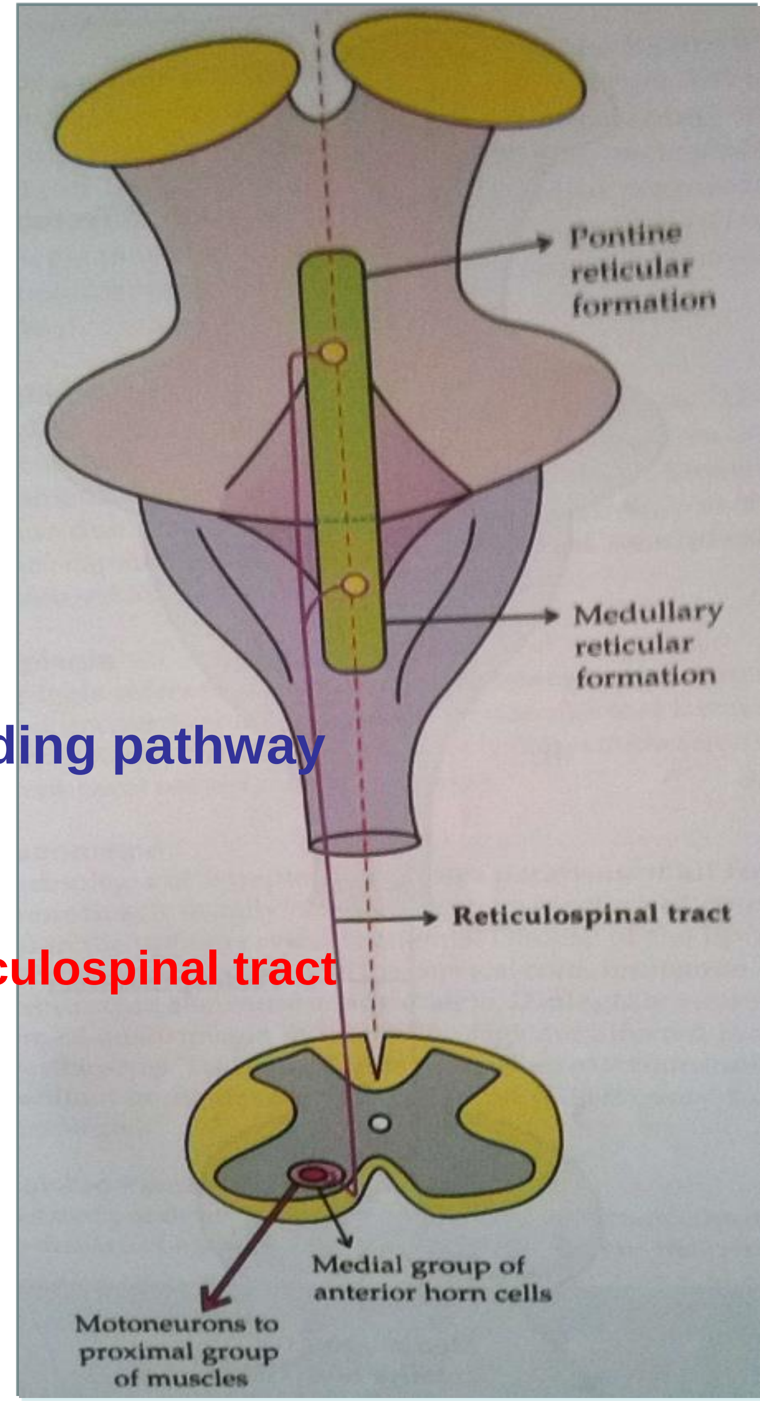
- ❖ They arise from the reticular nuclei of the pons and medulla.
- ❖ Like the vestibulospinal tracts, they descend ipsilaterally in the ventral funiculus and terminate in the more ventromedial gray matter of the spinal cord.
- ❖ mediate excitatory influences to the proximal extensor muscles, primarily through interneurons

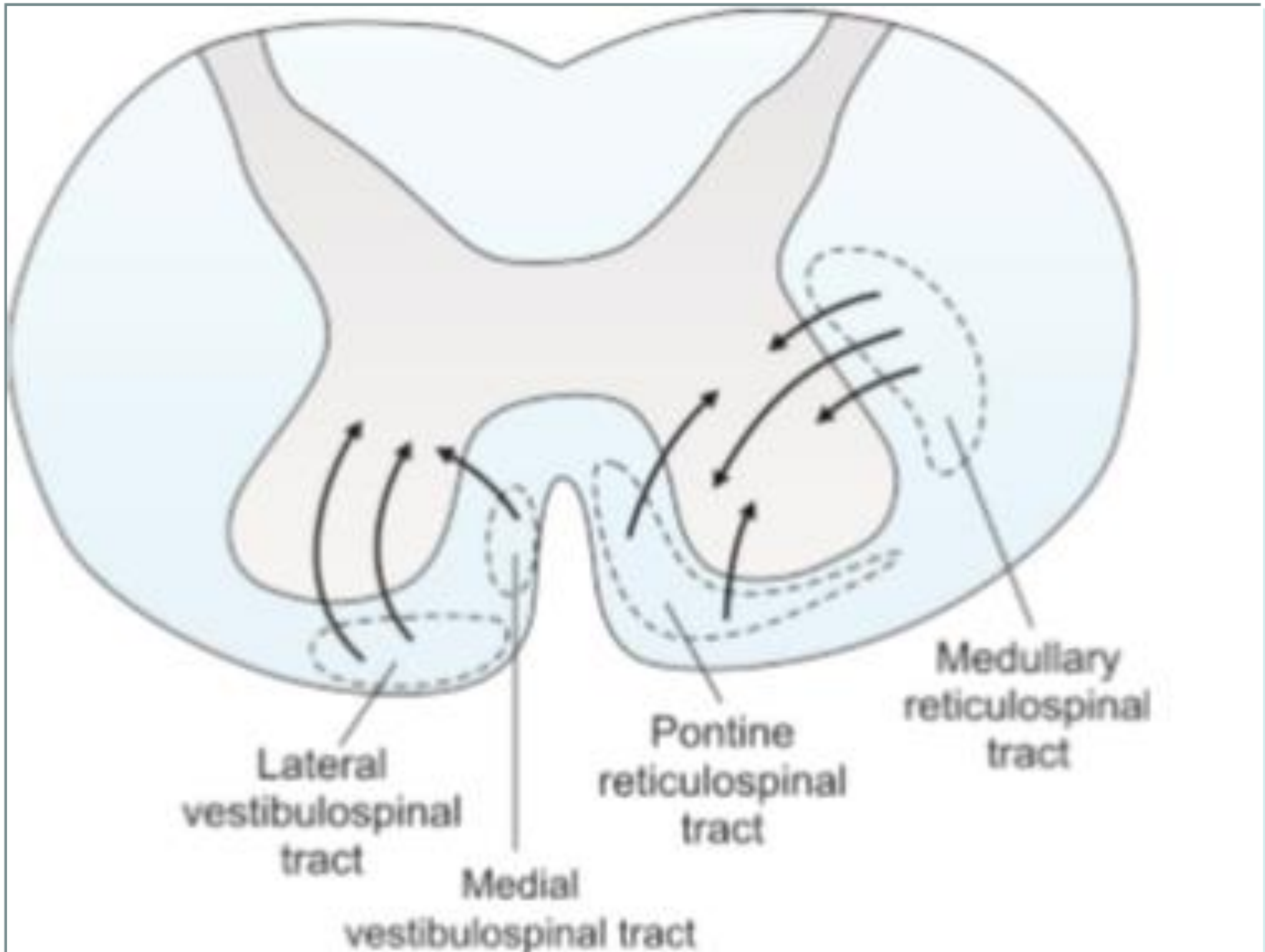
2. Medial system of descending pathway

a. Vestibulospinal tract

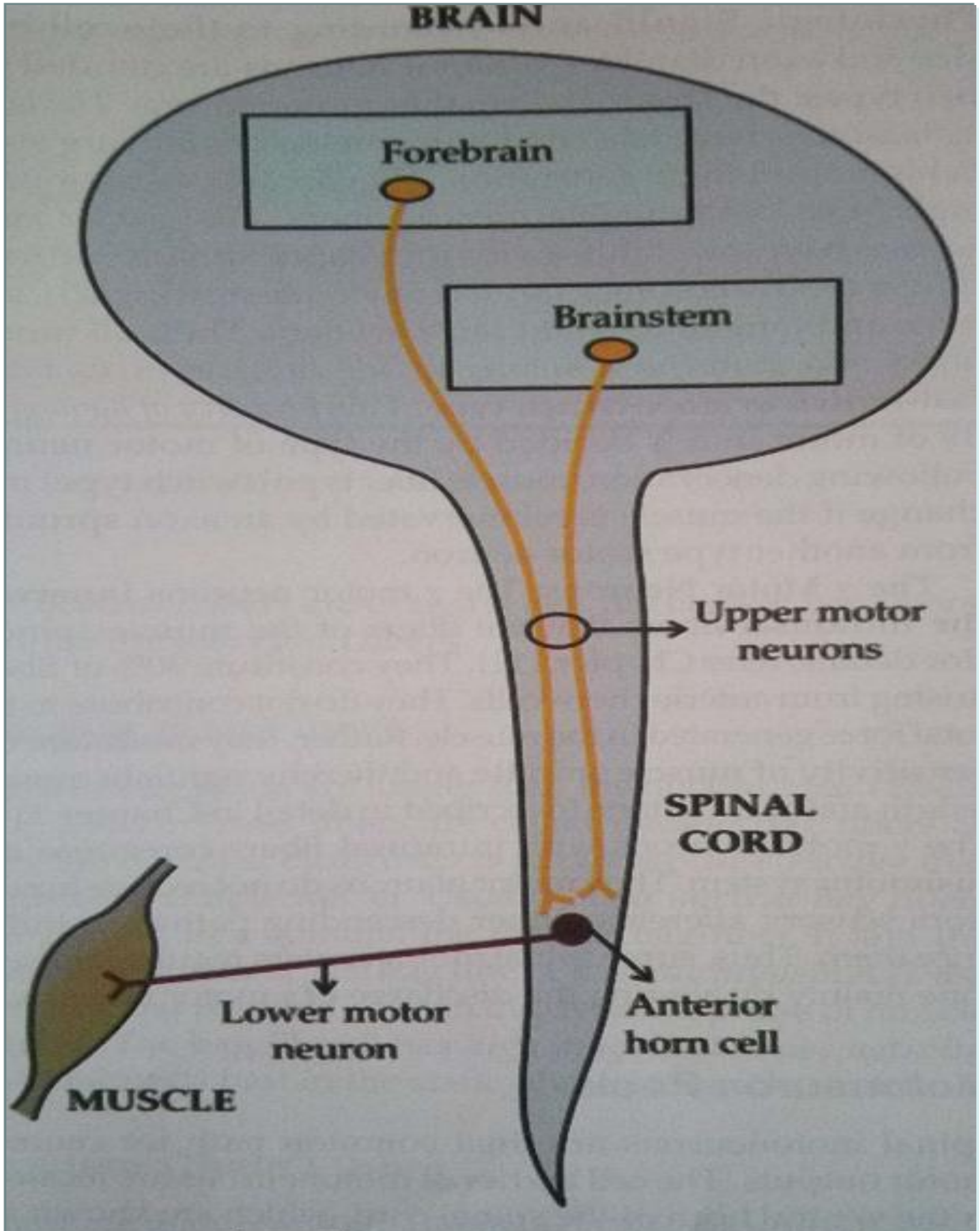


b. Reticulospinal tract





Sites of termination of major medial system pathways.



Upper and lower motor neurons.

The pontine Reticular Formation is relatively medial and has a facilitatory influence on motor neurons.

The medullary Reticular Formation is relatively lateral and has a predominantly inhibitory influence on motor neurons.

Upper Motor Neuron Paralysis Vs Lower Motor Neuron Paralysis

Differences between the UMN and LMN paralysis

	UMN Paralysis	LMN Paralysis
1. Muscles affected	In groups (not individual muscles)	Individual muscles are affected
2. Size of the muscles	No atrophy	Atrophy is a pronounced feature
3. Type of paralysis	Spastic paralysis (hypertonia)	Flaccid paralysis (hypotonia)
4. Tendon reflexes	Exaggerated	Diminished or absent
5. Superficial reflexes	Absent	Absent
6. Babinski's sign	Extensor planter response	Flexor planter response
7. Involuntary movements	Absent	Present (in the form of fascicular twitches)
8. EMG changes	No denervation potential	Denervation potential seen in EMG
9. Nerve conduction study	No abnormalities	Decreased nerve conduction

Peripheral Nervous System

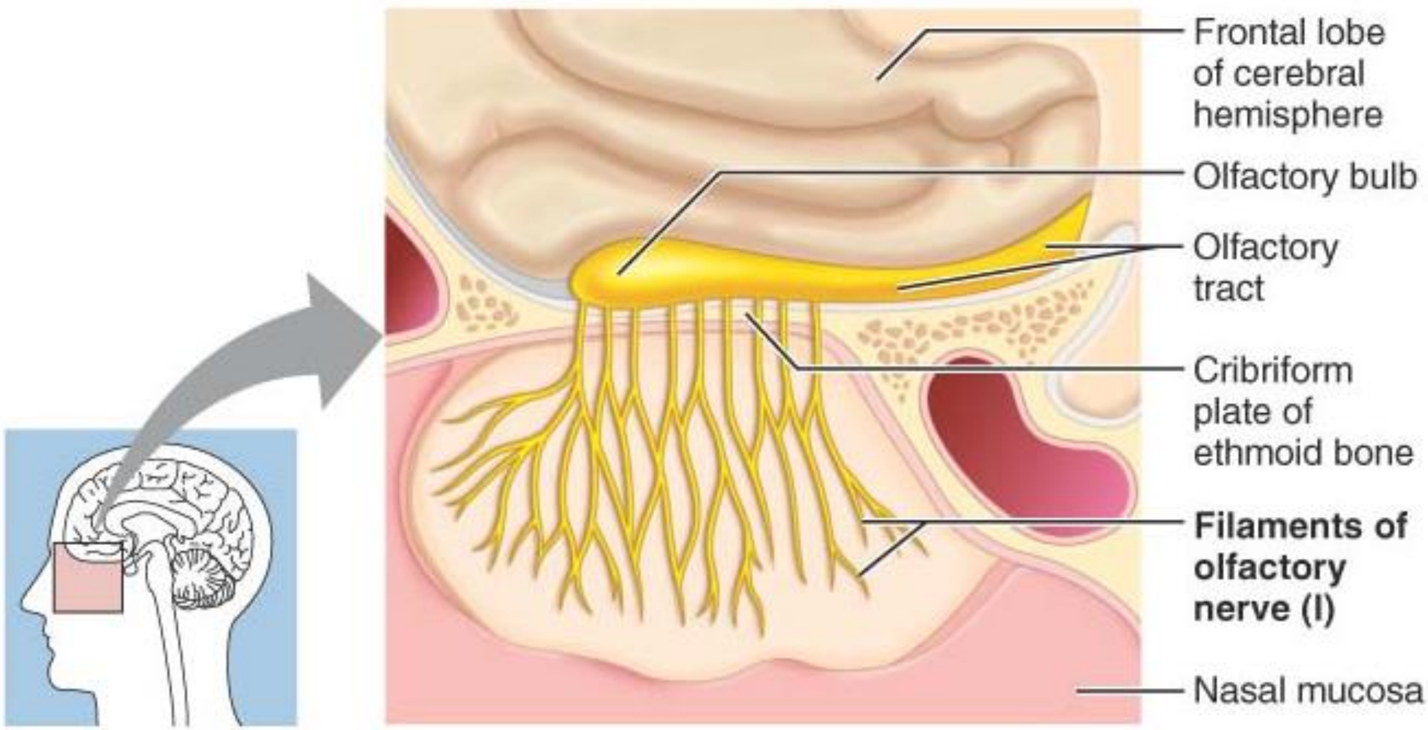
- **Consists of nerves that branch off the CNS.**
- **These nerves are called peripheral nerves and are classified in 2 types:**
  - Cranial nerves
  - Spinal nerves

Cranial Nerves

- Twelve pairs of **cranial nerves** are associated with the brain.
- The first two pairs attach to the forebrain; the rest originate from the brain stem.
- Other than the vagus nerves, which extend into the abdomen, cranial nerves serve only head and neck structures.

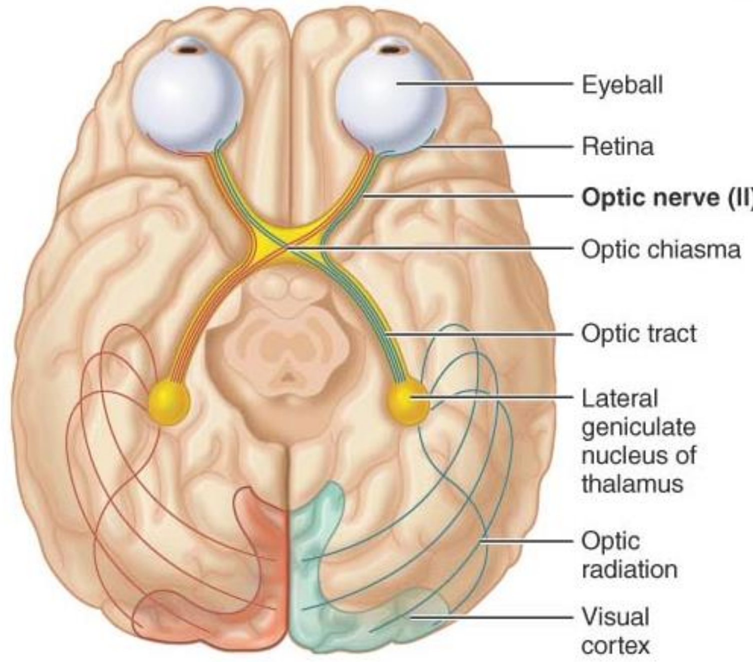
I THE OLFACTORY NERVES

Function: Purely sensory; carry afferent impulses for sense of smell



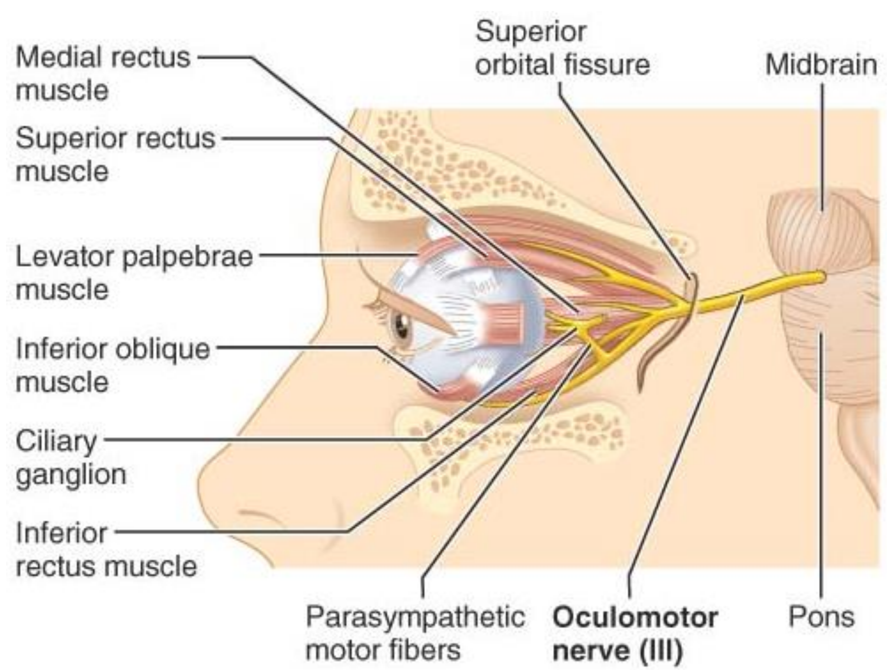
II THE OPTIC NERVES

Function: Purely sensory; carry afferent impulses for vision



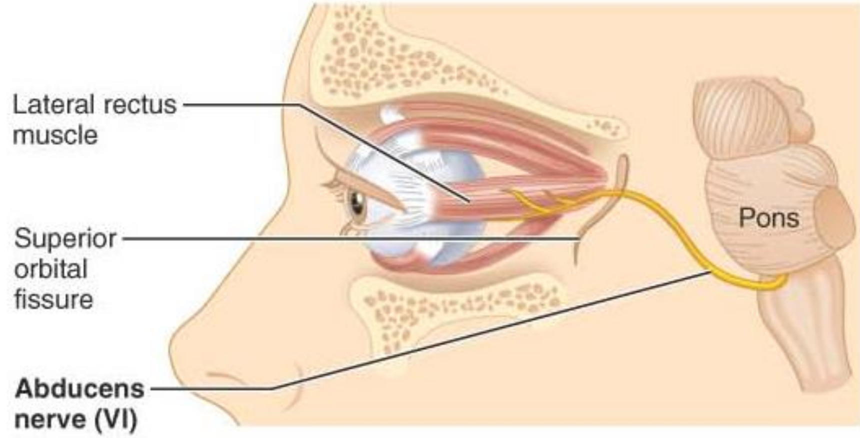
III THE OCULOMOTOR NERVES

Function: Chiefly motor nerves (*oculomotor* = motor to the eye);



Movement of extraoccular muscles

VI THE ABDUCENS NERVES



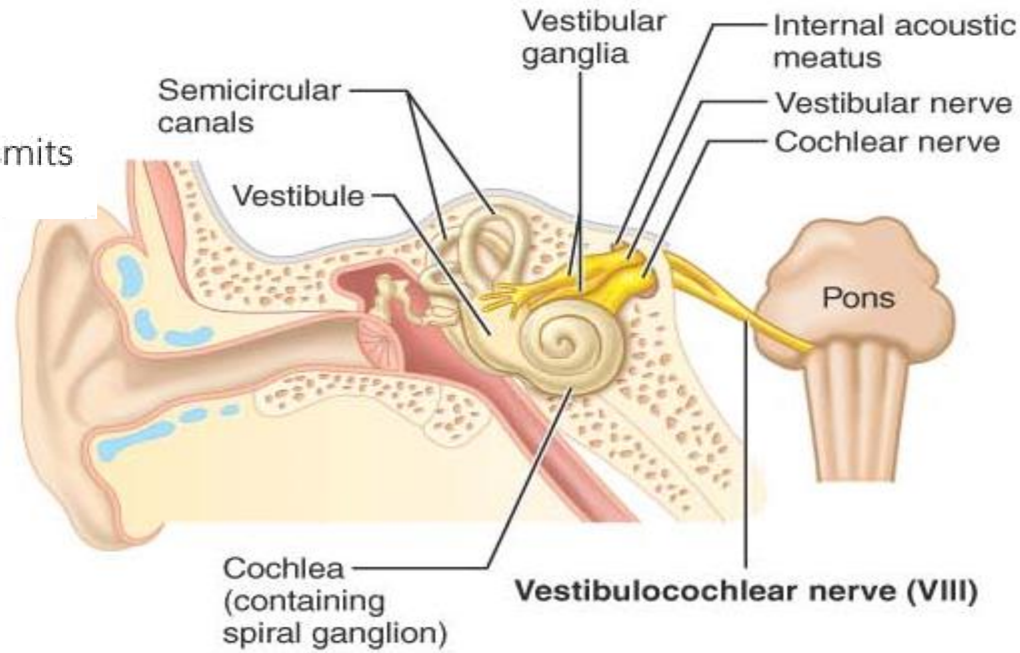
Function: Primarily motor; supply somatic motor fibers to lateral rectus muscle, an extrinsic muscle of the eye; convey proprioceptor impulses from same muscle to brain.

VII THE FACIAL NERVES

Function: Mixed nerves that are the chief motor nerves of face; have five major branches: temporal, zygomatic, buccal, mandibular, and cervical

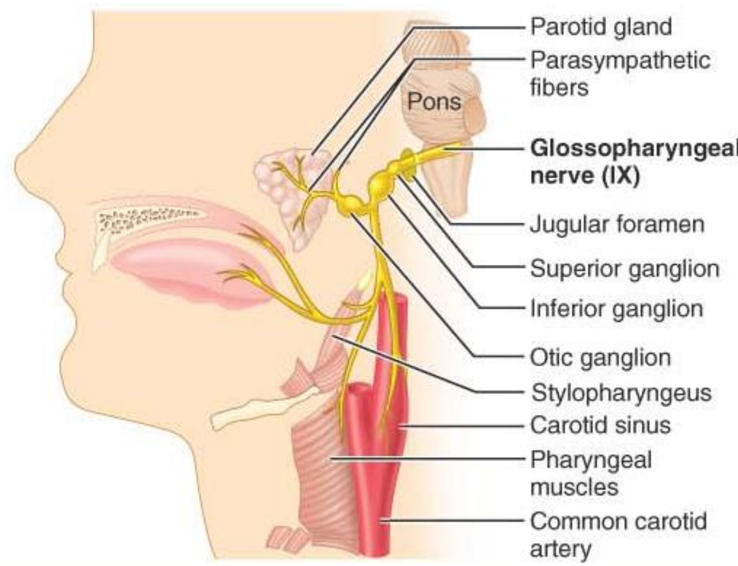
VIII THE VESTIBULOCOCHLEAR NERVES

Function: Mostly sensory. Vestibular branch transmits afferent impulses for sense of equilibrium

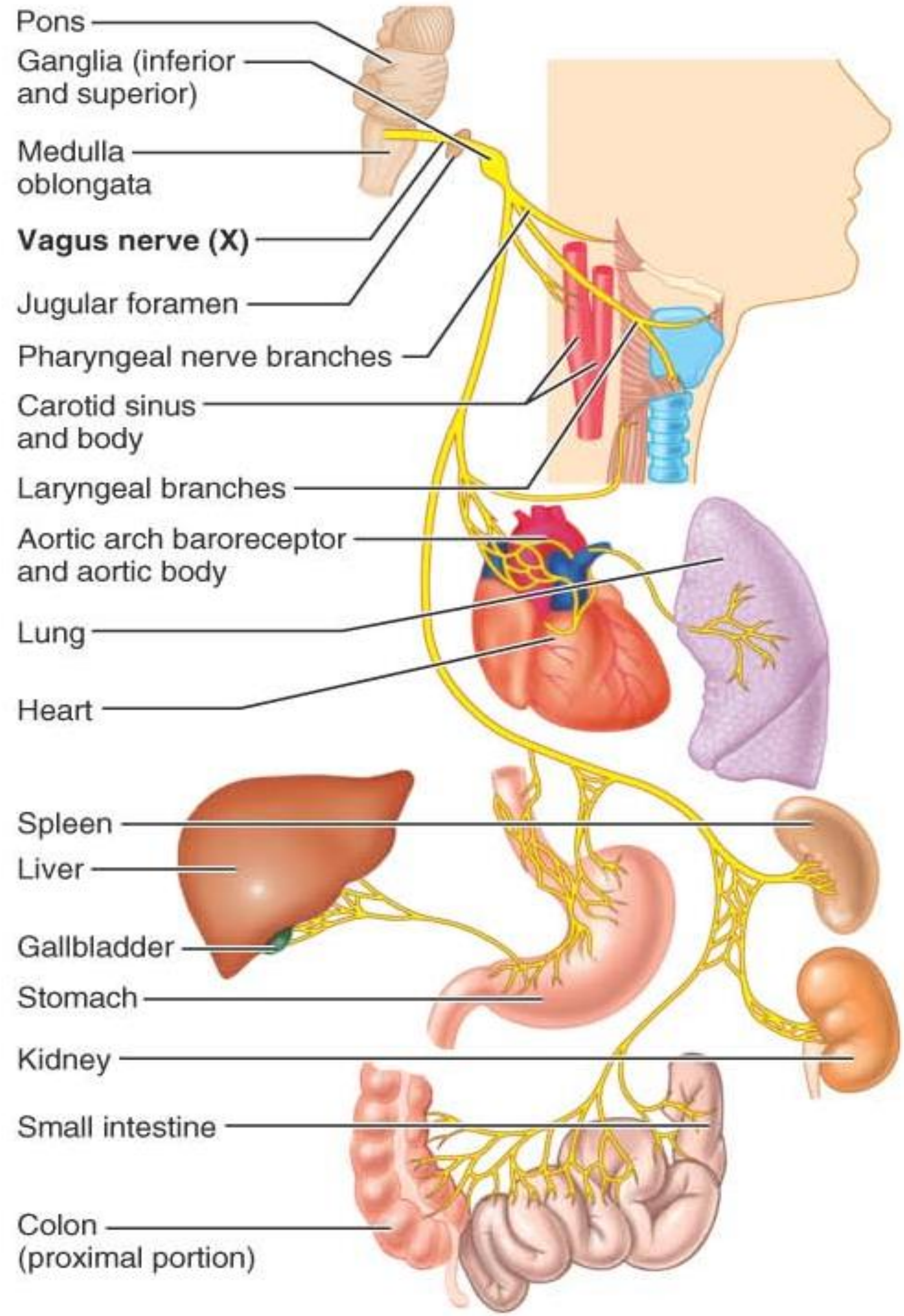


IX THE GLOSSOPHARYNGEAL NERVES

Function: Mixed nerves that innervate part of tongue and pharynx. Provide somatic motor fibers to, and carry proprioceptor fibers from, a superior pharyngeal muscle



X THE VAGUS NERVES

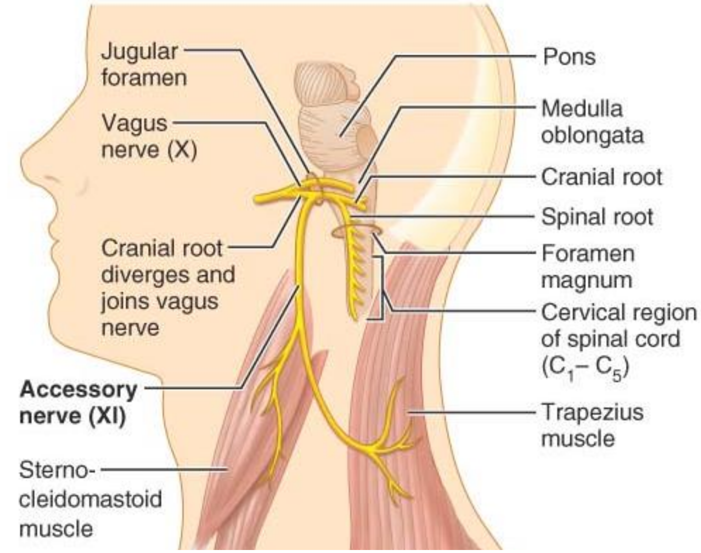


FUNCTIONS OF VAGUS NERVE (X)

Function: Mixed nerves; nearly all motor fibers are parasympathetic efferents, except those serving skeletal muscles of pharynx and larynx (involved in swallowing). Parasympathetic motor fibers supply heart, lungs, and abdominal viscera and are involved in regulation of heart rate, breathing, and digestive system activity. Transmit sensory impulses from thoracic and abdominal viscera, from the aortic arch baroreceptors (for blood pressure) and the carotid and aortic bodies (chemoreceptors for respiration), and taste buds of posterior tongue and pharynx. Carry proprioceptor fibers from muscles of larynx and pharynx.

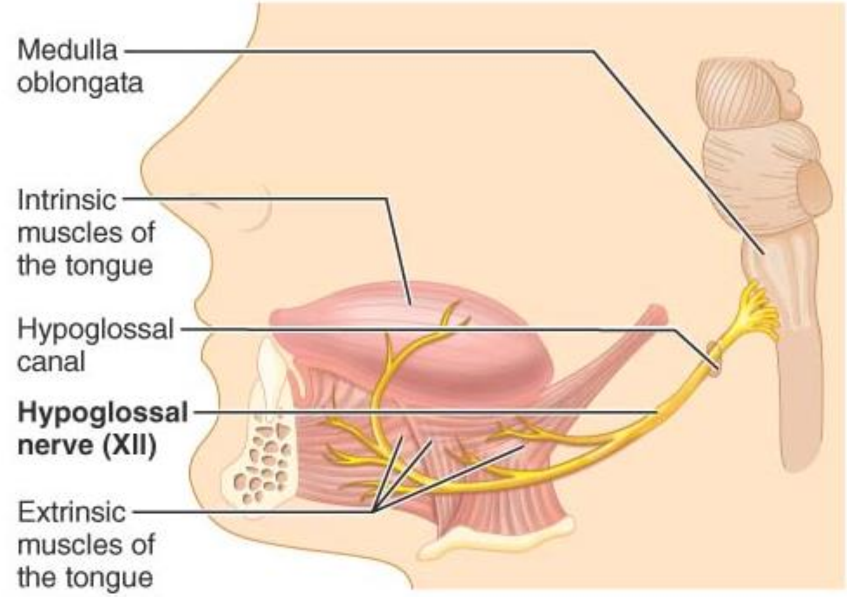
XI THE ACCESSORY NERVES

Function: Mixed nerves, but primarily motor in function. Cranial division joins with fibers of vagus nerve (X) to supply motor fibers to larynx, pharynx, and soft palate. Spinal root supplies motor fibers to trapezius and sternocleidomastoid muscles, which together move head and neck, and conveys proprioceptor impulses from same muscles.



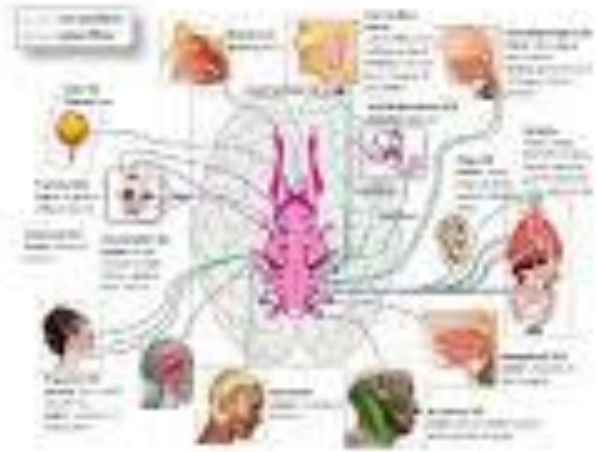
XII THE HYPOGLOSSAL NERVES

Function: Mixed nerves, but primarily motor in function. Carry somatic motor fibers to intrinsic and extrinsic muscles of tongue, and proprioceptor fibers from same muscles to brain stem. Hypoglossal nerve control allows not only food mixing and manipulation by tongue during chewing, but also tongue movements that contribute to swallowing and speech.



Oh, **O**h, **O**h, **T**o
Touch **A**nd
Feel **V**ery **G**ood
Velvet, **A**h
Heaven.

Learning the 12 cranial nerves in a minute ☺



Spinal Nerves

- Spinal nerves are peripheral nerves that originate from the spinal cord.
- 31 pairs of spinal nerves:
  - 8 pairs of cervical nerves (C1 through C8)
  - 12 pairs of thoracic nerves (T1 through T12)
  - 5 pairs of lumbar nerves (L1 through L5)
  - 5 pairs of sacral nerves (S1 through S5)
  - One pair of coccygeal nerves (Co)

13.5 Spinal Nerves

- 31 pairs of **spinal nerves**
- All are mixed nerves named for point of issue from spinal cord
- Supply all body parts except head and part of neck
  - 8 pairs of cervical nerves (C_1–C_8)
  - 12 pairs of thoracic nerves (T_1–T_{12})
  - 5 pairs of lumbar nerves (L_1–L_5)
  - 5 pairs of sacral nerves (S_1–S_5)
  - 1 pair of tiny coccygeal nerves (C_0)

The Spinal Nerves

- All of the spinal nerves **contain both sensory and motor neurons.**
- Each spinal nerve divides into several branches. Some of these branches form networks called a **plexus.**
  - A PLEXUS is a tangled network of fibers from all the spinal nerves involved that serves the area of the body from which the nerves originate.
    - Examples: C-1 through C-4 form the cervical plexus. L-1 thru L-4 form the lumbar plexus

Nerve Plexuses: The nerves branching off the spinal cord can branch some more and also merge together. As the nerves merge together, they form a braided network called a plexus. Major nerve plexuses are:

1. Cervical plexus: plexus emerging from the cervical region eventually forms a single nerve that innervates the diaphragm muscle; *phrenic nerve*.

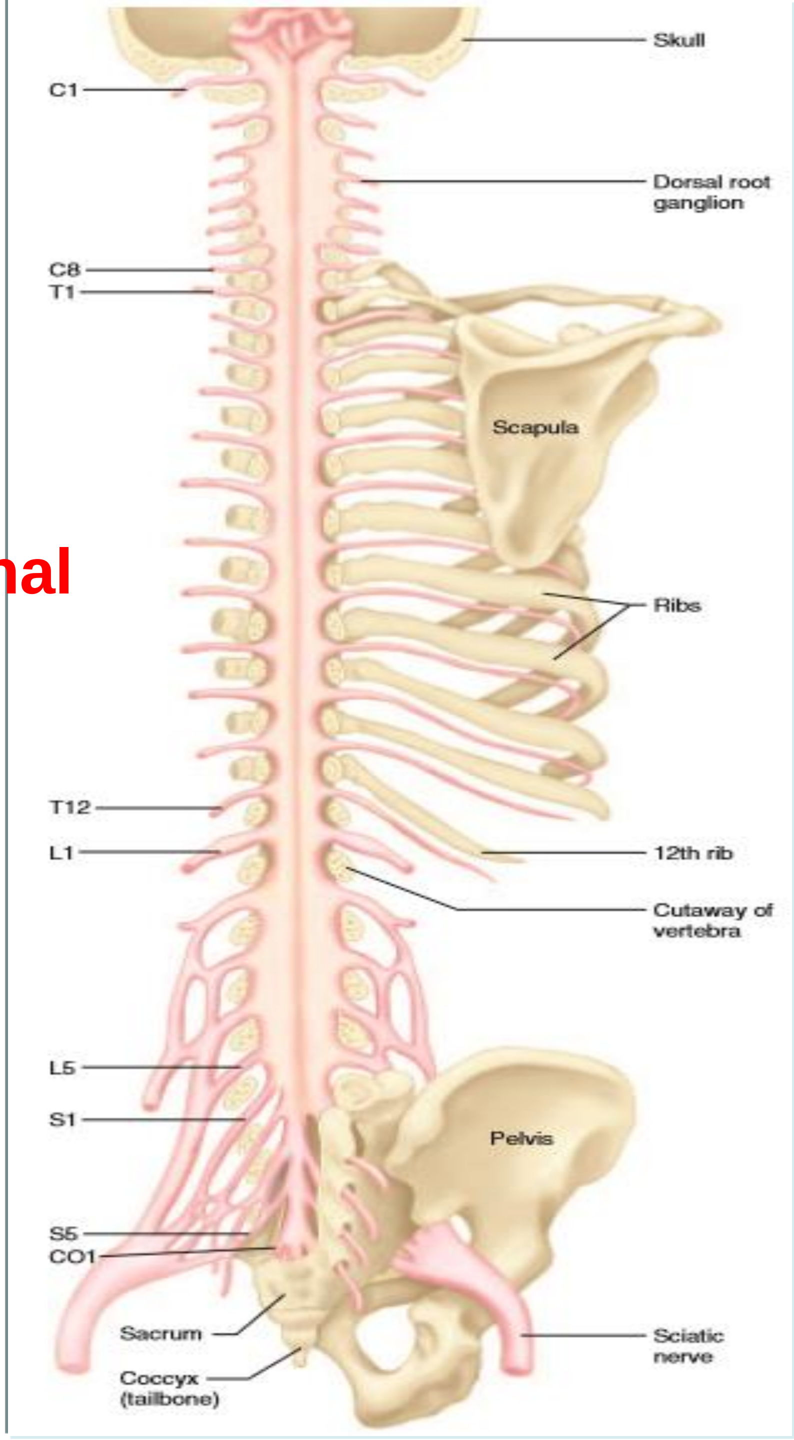
2. Brachial plexus: arises from the lower cervical and upper thoracic region. This plexus will eventually form a single nerve that innervates the medial side of the arm; *ulnar nerve*.

3. Lumbar plexus: arises from the lumbar region. One major nerve that develops from this plexus controls some of the muscles of the upper thigh; *femoral nerve.*

4. Sacral plexus: arises from the sacral region. One major nerve that develops from this plexus is the *sciatic nerve* which controls some of the posterior thigh muscles and foot muscles

NOTE :Thoracic region does not form a plexus. All of the nerves emerging from the thoracic region form single nerves, not plexuses.

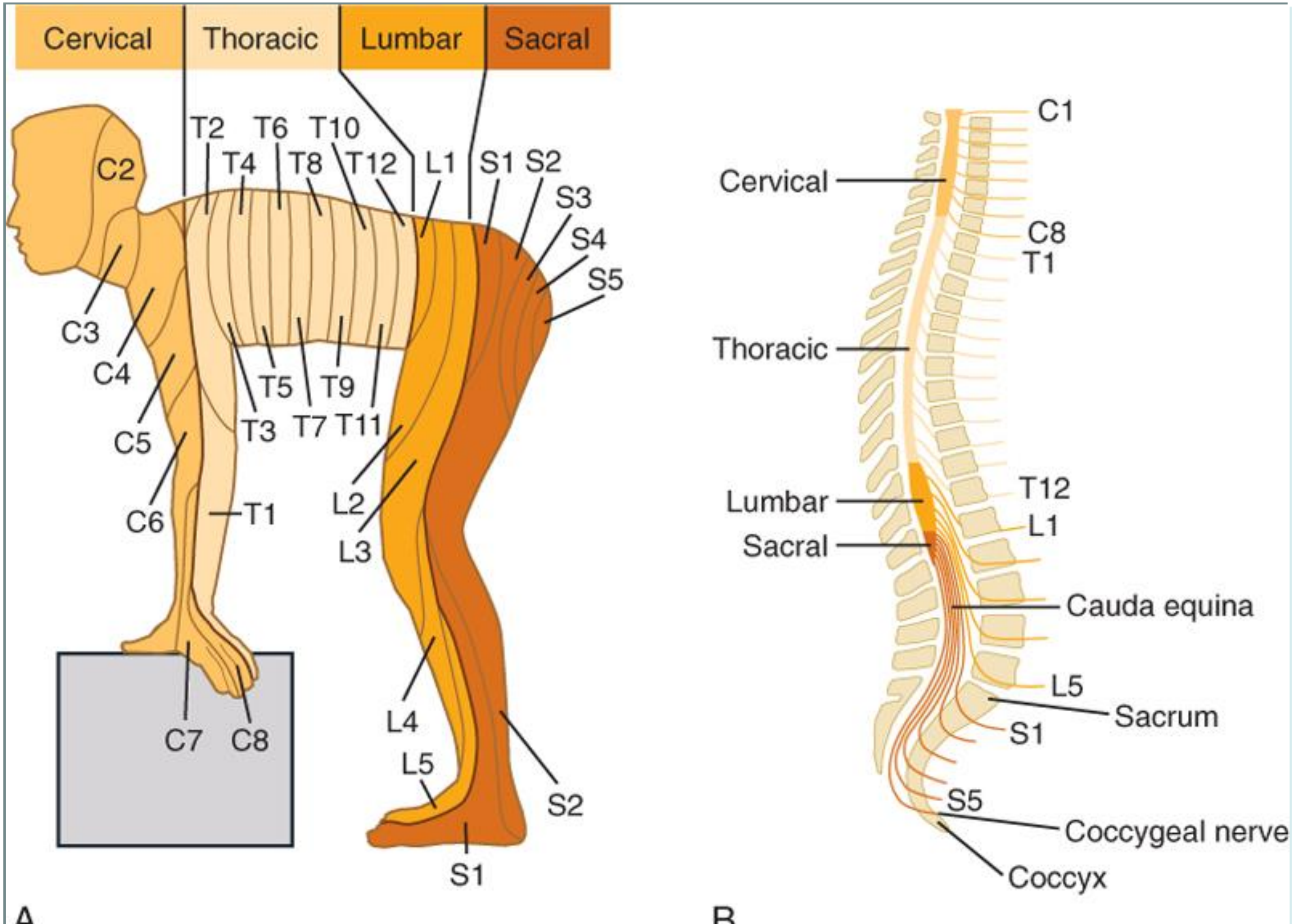
Dorsal view of the spinal cord.



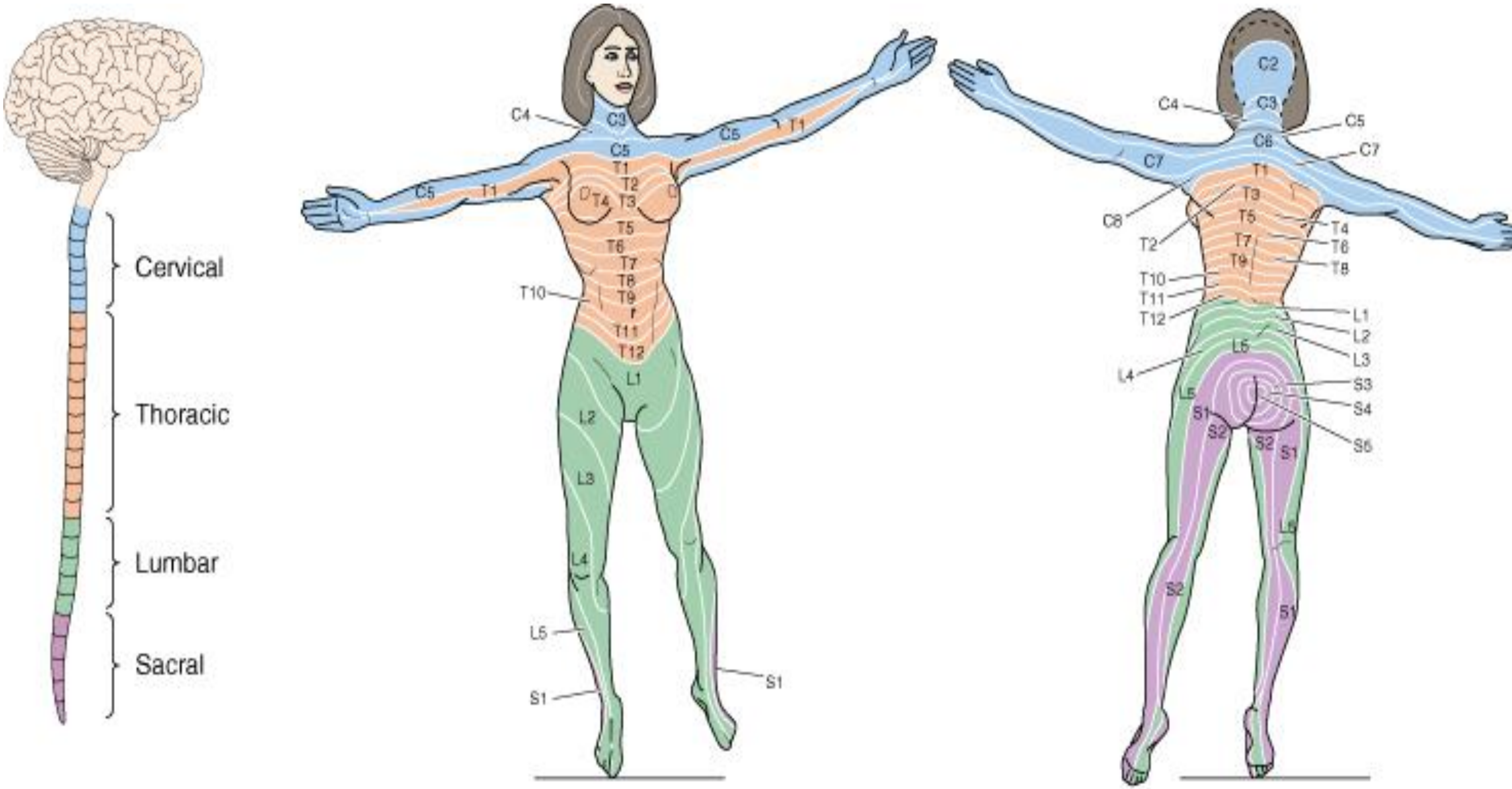
- Axons of the spinal nerves enter or leave the CNS through the **spinal roots**: 2 roots; dorsal & ventral roots.
- **Dorsal root** composed entirely of the central processes of dorsal root ganglion cells & **ventral root** consists chiefly of motor axons, including α motor axons, γ motor axons.
- The pattern of innervation is determined during embryological development. In adults, a given dorsal root ganglion supplies a specific cutaneous region, which is called a **dermatome.**
- Dermatome receives its densest innervation from the corresponding spinal cord segment

Spinal Nerve Plexuses

PLEXUS	SPINAL ROOTS (ORIGIN)	BODY AREA SERVED	IMBALANCE
Cervical	C_1-C_5	Skin of neck, shoulder and clavicle region Diaphragm (phrenic nerve) and muscles of shoulder and neck	Irritation of the phrenic nerve causes spasms of the diaphragm - hiccups
Brachial	C_5– C_8 and T_1	All nerves that innervate upper limb Arm muscles – deltoid, triceps, biceps, flexor, extensor, wrist and hands Cutaneous sensation of the upper limb	Weakness or paralysis of entire upper limb Carpal tunnel syndrome the median nerve is compressed “The funny bone” results from an injury to the ulnar nerve



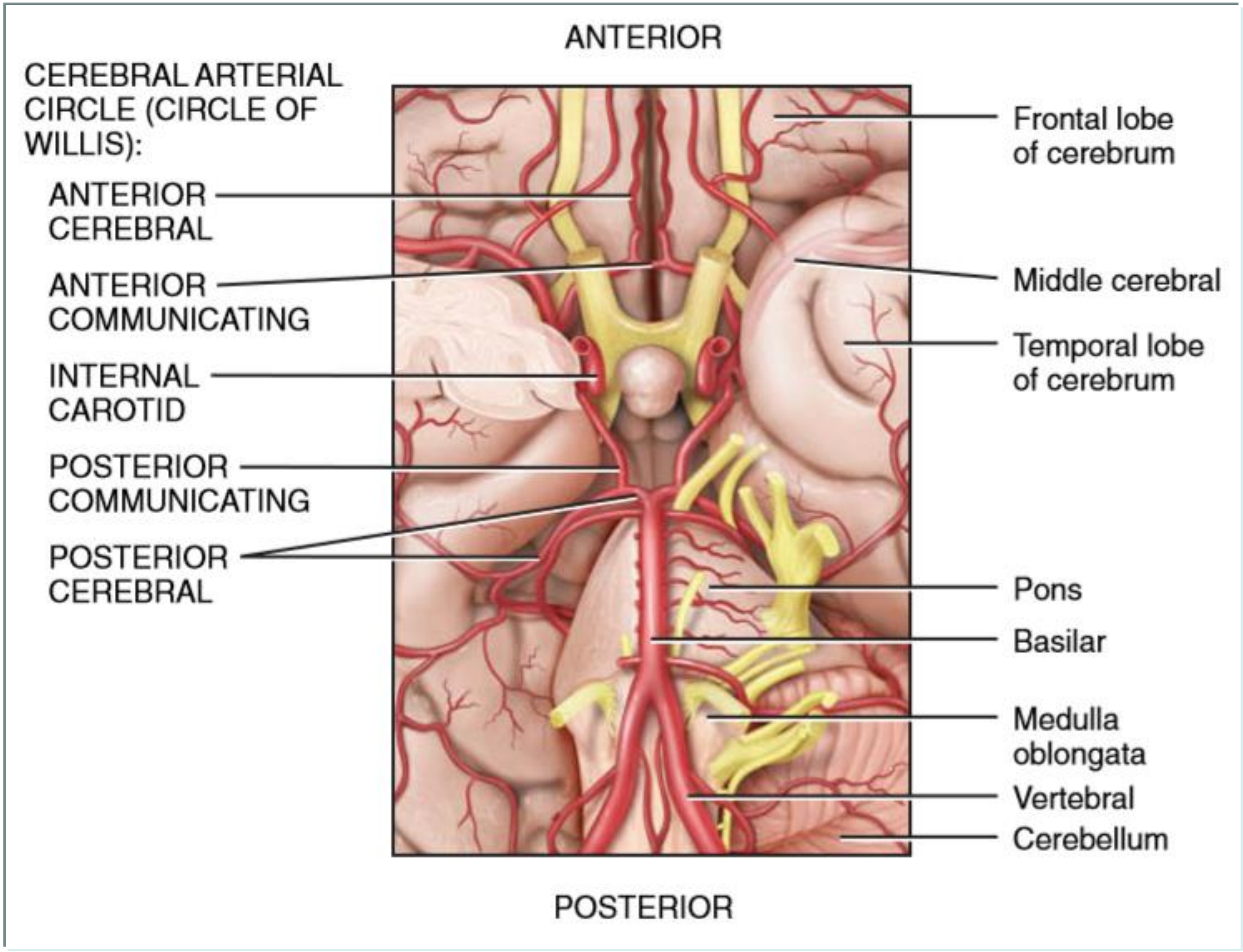
Dermatomes represented on a drawing of a person assuming a quadrupedal position



Cervical
Thoracic
Lumbar
Sacral
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
S1
S2
S3
S4
S5

VERTEBRAL LEVEL	NERVE ROOT	INNERVATION	POSSIBLE SYMPTOMS
C1, C2, C3, C4	C1, C2, C3, C4	Intracranial Blood Vessels • Eyes • Lacrimal Gland • Parotid Gland • Scalp • Base of Skull • Neck Muscles • Diaphragm	Headaches • Migraine Headaches • Dizziness • Sinus Problems • Allergies • Head Colds • Fatigue • Vision Problems • Runny Nose • Sore Throat • Stiff Neck • Cough • Croup • Arm Pain • Hand and Finger Numbness or Tingling • Asthma • Heart Conditions • High Blood Pressure
C5, C6, C7	C5, C6, C7, C8	• Neck Muscles • Shoulders • Elbows • Arms • Wrists • Hands • Fingers • Esophagus • Heart • Lungs • Chest	
T1, T2, T3, T4	T1, T2, T3, T4	Arms • Esophagus • Heart • Lungs • Chest • Larynx • Trachea	Wrist, Hand and Finger Numbness or Pain • Middle Back Pain • Congestion • Difficulty Breathing • Asthma • High Blood Pressure • Heart Conditions • Bronchitis • Pneumonia • Gallbladder Conditions • Jaundice • Liver Conditions • Stomach Problems • Ulcers • Gastritis • Kidney Problems
T5, T6, T7, T8, T9, T10	T5, T6, T7, T8, T9, T10	Gallbladder • Liver • Diaphragm • Stomach • Pancreas • Spleen • Kidneys • Small Intestine • Appendix • Adrenals	
T11	T11	Small Intestines • Colon • Uterus	
T12	T12	Uterus • Colon • Buttocks	
L1, L2, L3, L4, L5	L1, L2, L3, L4, L5	Large Intestines • Buttocks • Groin • Reproductive Organs • Colon • Thighs • Knees • Legs • Feet	Constipation • Colitis • Diarrhea • Gas Pain • Irritable Bowel • Bladder Problems • Menstrual Problems • Low Back Pain • Pain or Numbness in Legs
	SACRAL	Buttocks • Reproductive Organs • Bladder • Prostate Gland • Legs • Ankles • Feet • Toes	Constipation • Diarrhea • Bladder Problems • Menstrual Problems • Lower Back Pain • Pain or Numbness in Legs

Cerebral arterial circle (Circle of Willis)

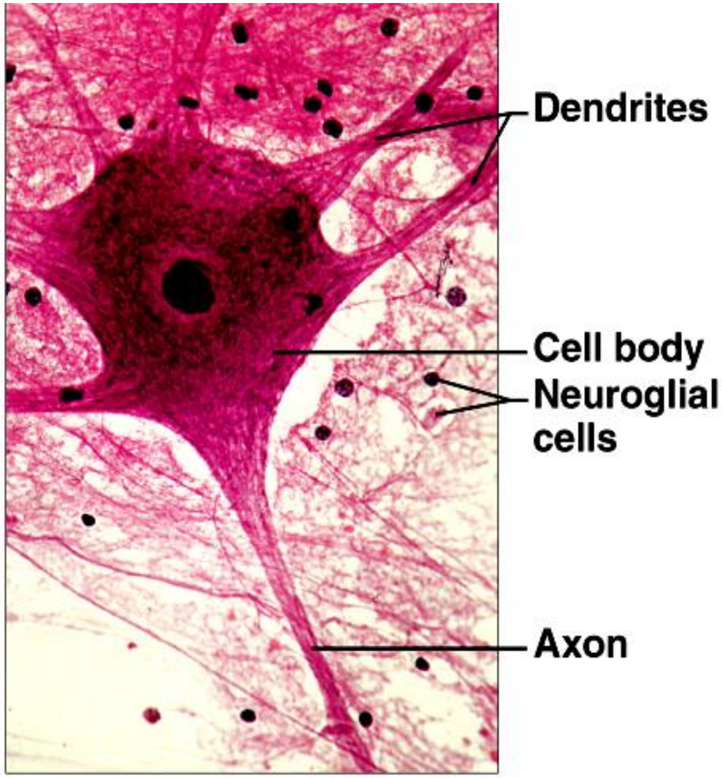


Anastomoses of left and right internal carotid arteries via anterior communicating artery between two anterior cerebral arteries, along with internal carotid–basilar artery anastomoses, form an arrangement of blood vessels at base of brain called cerebral arterial circle (<u>circle of Willis</u>)

Anastomoses give the two way blood flow which is important if one of the way of blood flow is distrubed; so that second pathway still can supply the blood to the vital organs (brai)

NEURONS & SUPPORTING CELLS

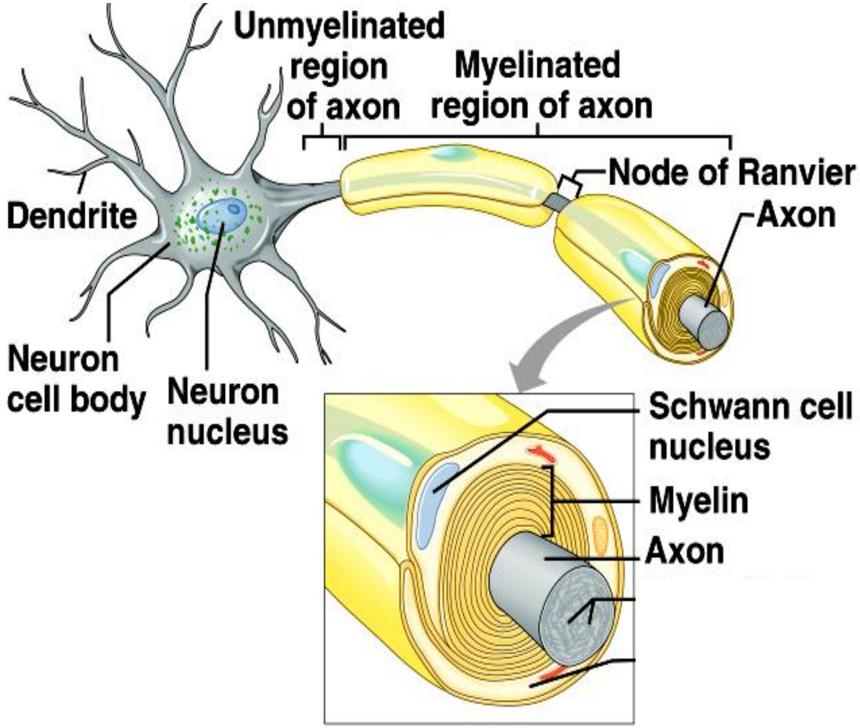
Nervous Tissue is composed of two major cell types: neurons and neuroglial cells.



Neurons are made up of a cell body, dendrites, and axons.

Dendrites receive information.

Axons send information.

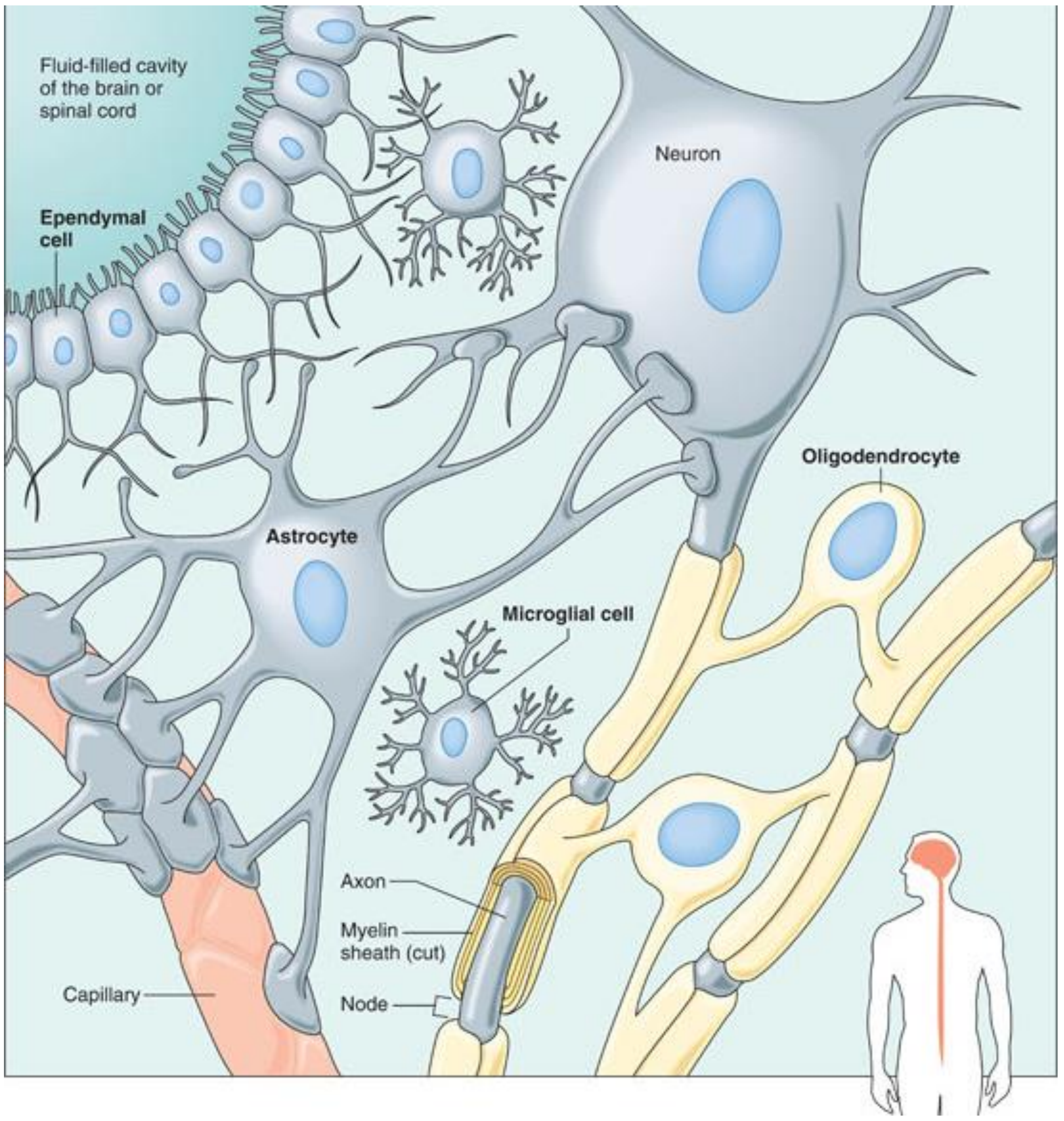


Larger axons are enclosed by sheaths of myelin produced by Schwann cells.

Narrow gaps in the myelin sheath between Schwann cells are called nodes of Ranvier.

Nerves are cable-like bundles of <u>axons</u>.

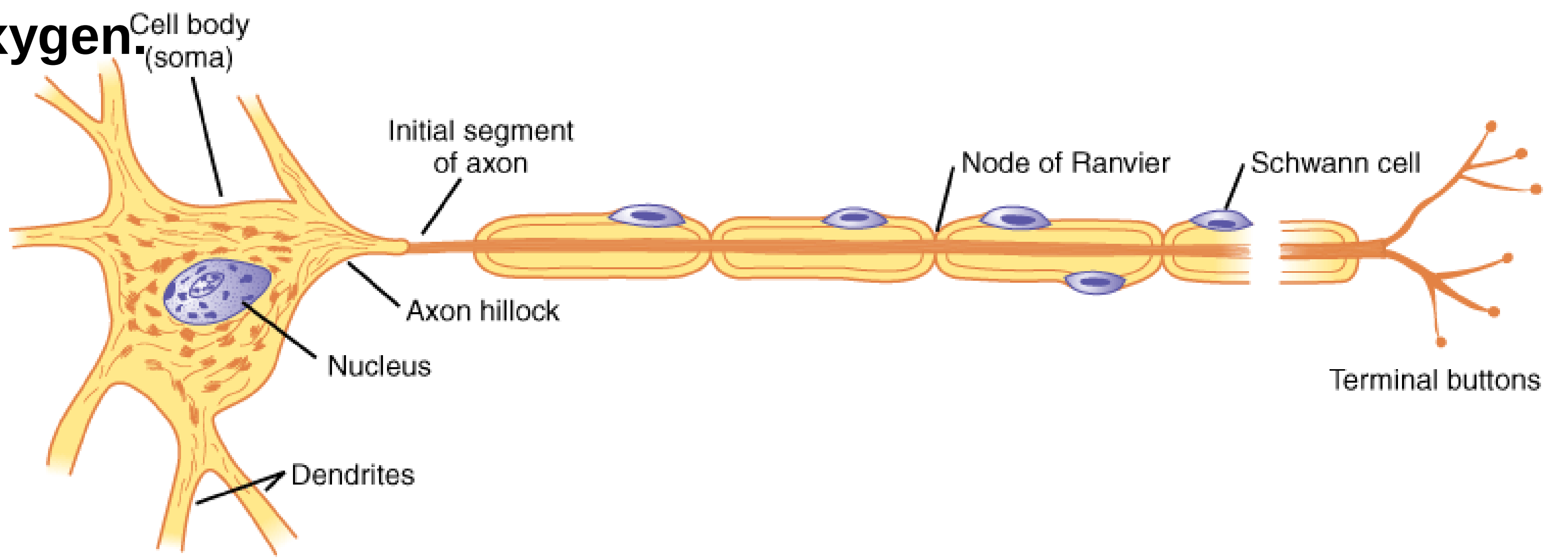
Neuroglial cells provide physical <u>support</u>, <u>insulation</u> (myelin), and <u>nutrients</u> for neurons.



- **nervous tissue consists of only two types of cells**: **neurons and neuroglia .**
- The basic unit of the nervous system is the individual nerve cell, or neuron. **Neurons** operate by generating electrical signals that move from one part of the cell to another part of the same cell or to neighboring cells.
- Neurons, or nerve cells, are specialized cells that are sensitive to various **stimuli (pain, temp, sound, heat, light).** They convert stimuli into nerve impulses and conduct these impulses to other neurons, to muscle fibers, or to glands.
- Neurons can be small or large. For example, some neurons within the brain may extend only a few inches, while a spinal neuron from the spinal cord to a muscle in your foot may extend well over a foot.
- **Neuroglia** are supporting cells that do not generate or conduct nerve impulses but have many other important **supportive functions.** For many years following their discovery, **glial cells (or glia)** were viewed as **CNS connective tissue**. In fact, the word *glia* is Greek for *glue*. However, today theses cells are recognized for their role in communication within the CNS in **partnership with neurons**.

NEURONS

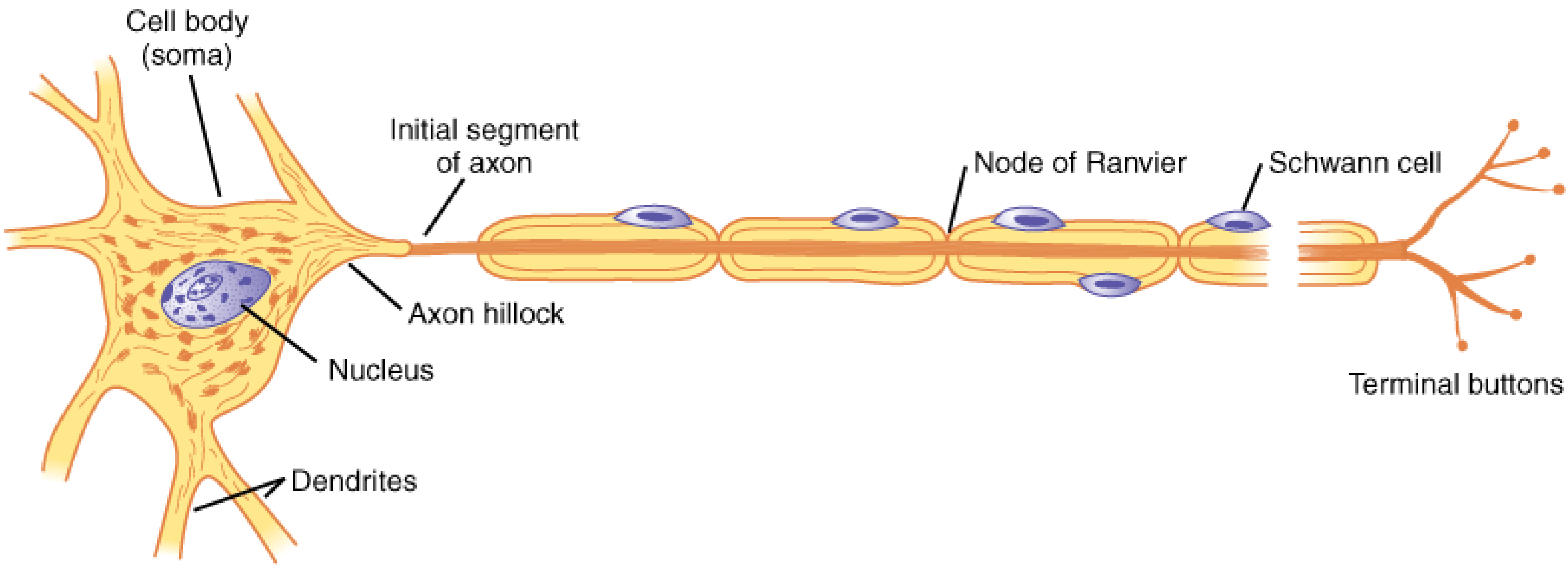
- The billions of neurons, also called nerve cells, are the structural units of the nervous system. They are highly specialized cells that conduct messages in the form of nerve impulses from one part of the body to another.
- They have extreme longevity. Given good nutrition, neurons can function optimally for a lifetime (over 100 years).
- They are amitotic (no division of neuron).
- They have an exceptionally high metabolic rate and require continuous and abundant supplies of oxygen and glucose. Neurons cannot survive for more than a few minutes without oxygen.



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

Nerve cell of nervous tissue (neurons): never dividing cells

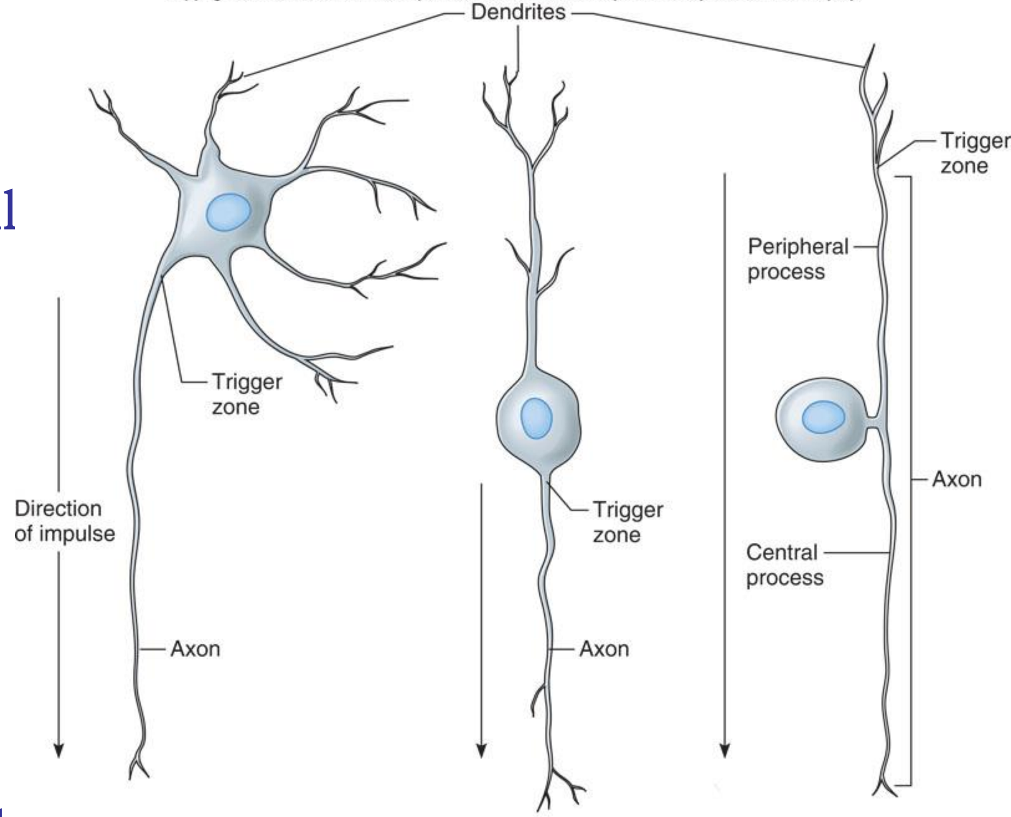
Numerous projections of the cell body of the neuron called dendrites receive nerve impulses from other cells.
Increase a cell's capacity to receive signals from many other neurons.
A long projection of the neuron cell body called an axon/ called a nerve fiber conducts each impulse away from the cell body to other cel



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

Classification of Neurons

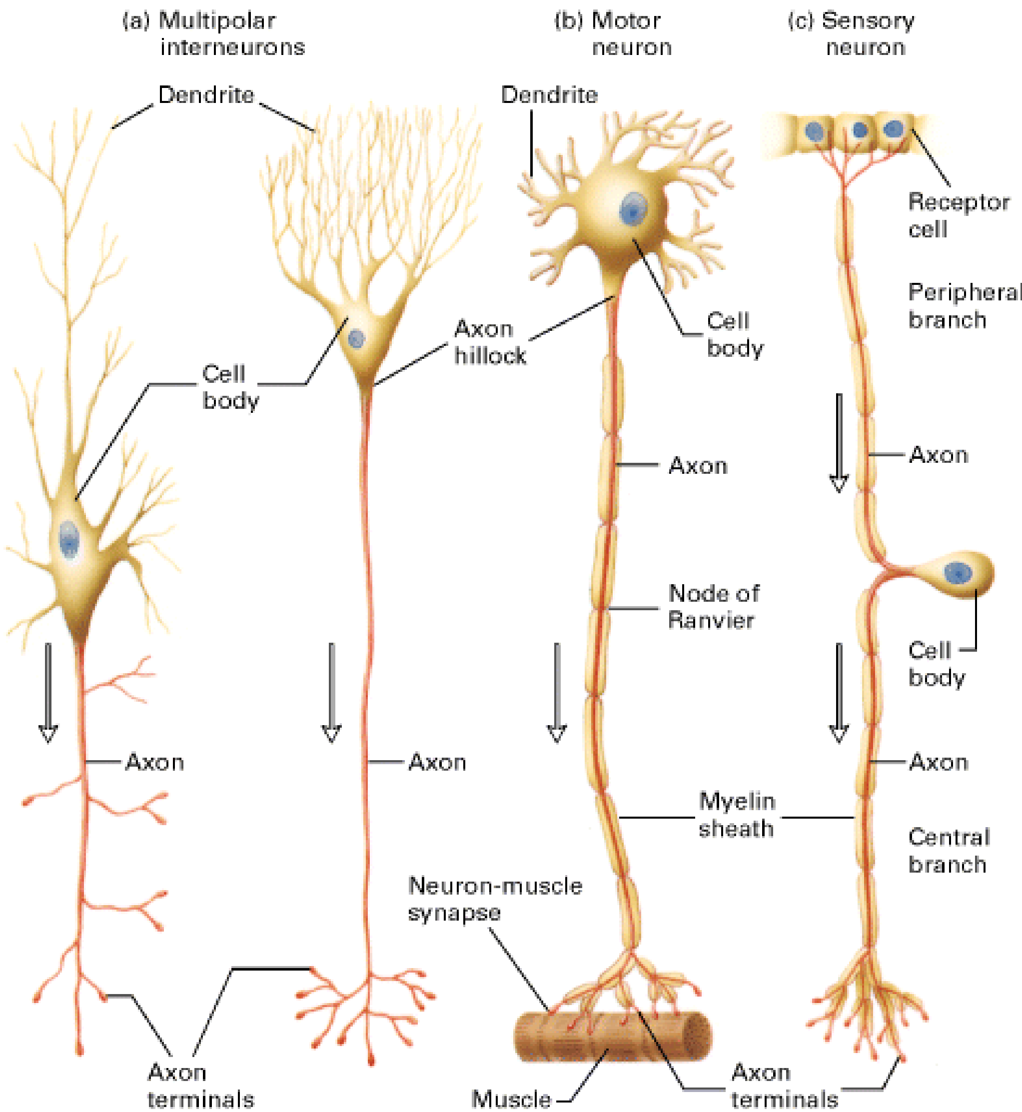
- Neurons can be classified based on function or by structure.
- Structure:
- (1) Multipolar
- Many processes arising from cell body
- Brain or spinal cord
- (2) Bipolar
- 2 processes (1 from each end of cell body)
- Ear, eyes, nose
- (3) Unipolar
- Single process extends from cell body
- Outside of brain & spinal cord



(a) Multipolar (b) Bipolar (c) Unipolar

Classification of Neurons

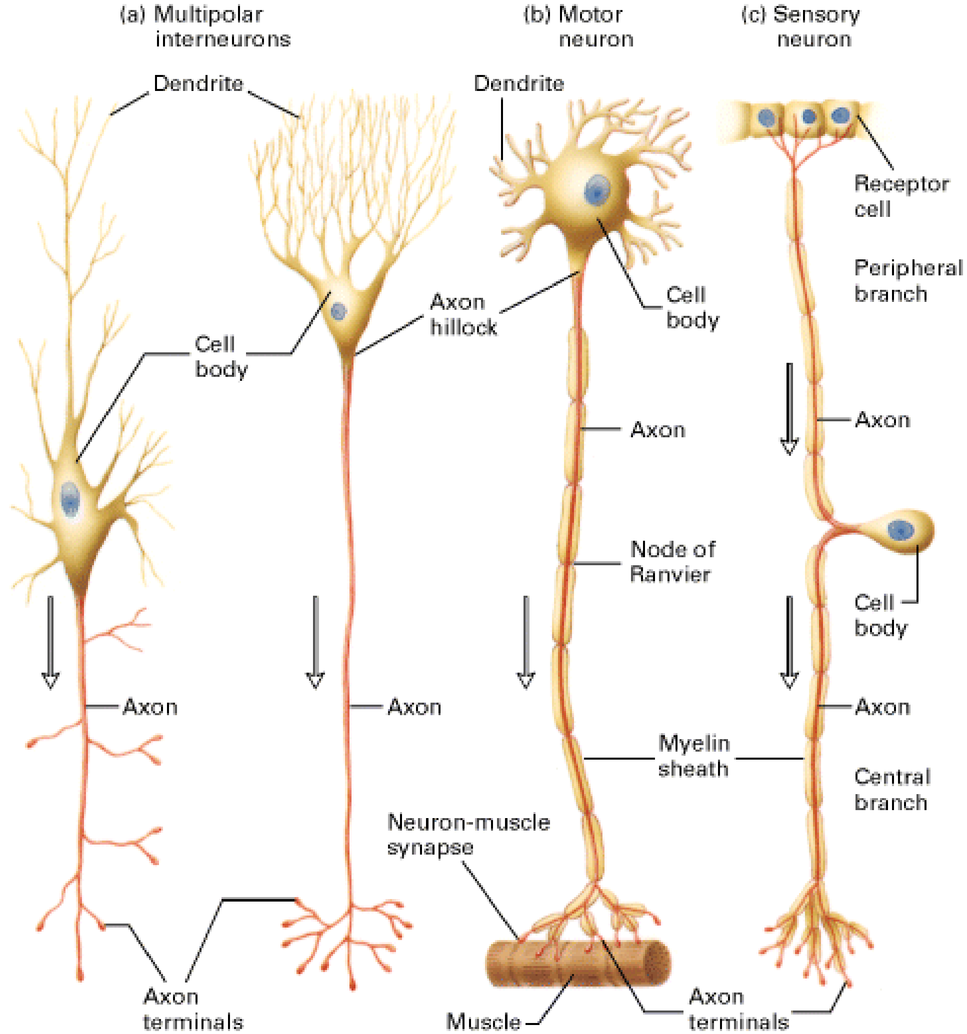
- **Classifying by Function:**



Classification of Neurons (by function)

Sensory Neurons – (afferent) have specialized receptor ends that sense stimuli and then carry impulses from peripheral body parts to brain or spinal cord.

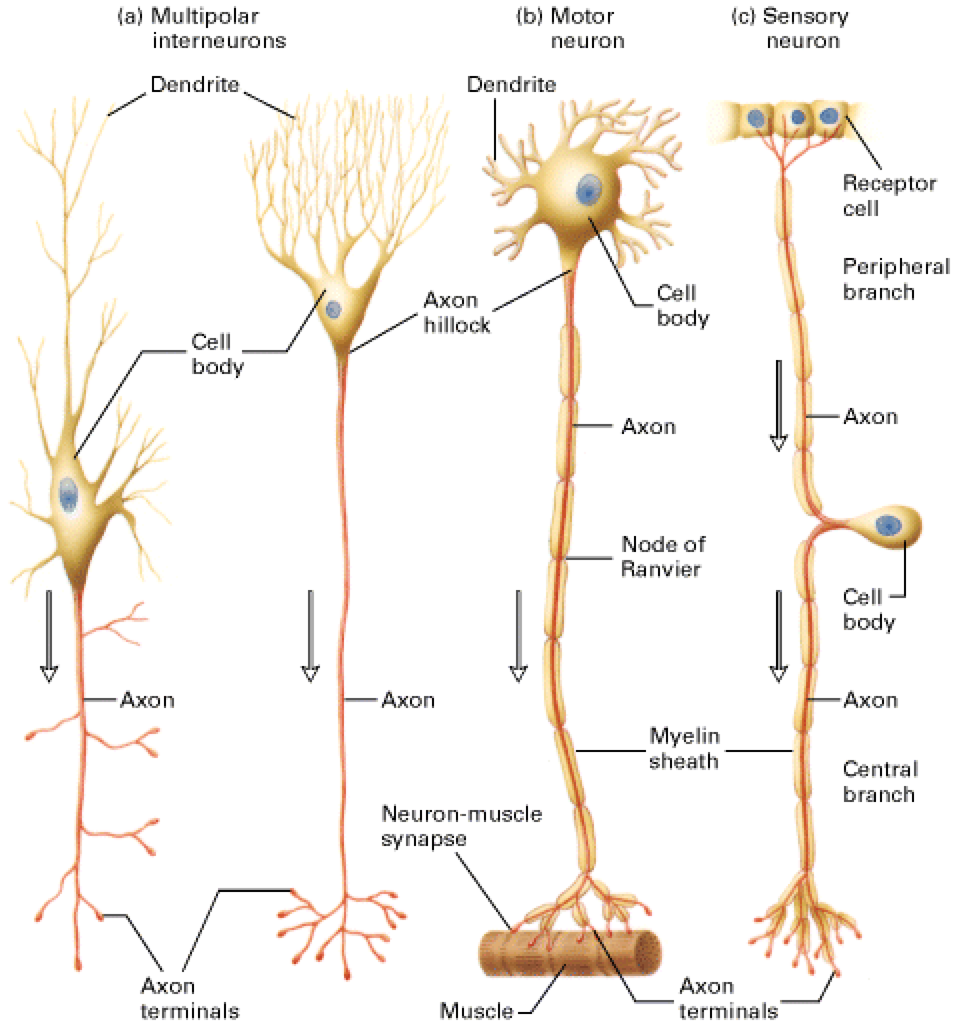
Can be unipolar or bipolar.



Interneurons – lie entirely within the brain or spinal cord; direct incoming sensory impulses to appropriate parts for processing and interpreting.

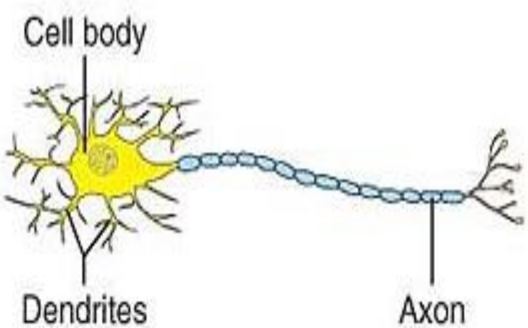
Motor Neurons – (efferent) carry impulses out of the brain or spinal cord to effectors (muscles, glands).

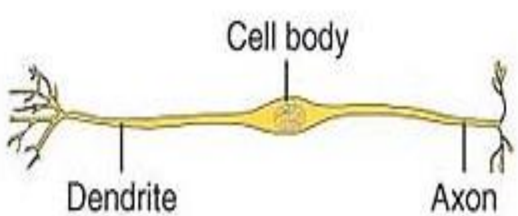
Interneurons and motor neurons are multipolar.

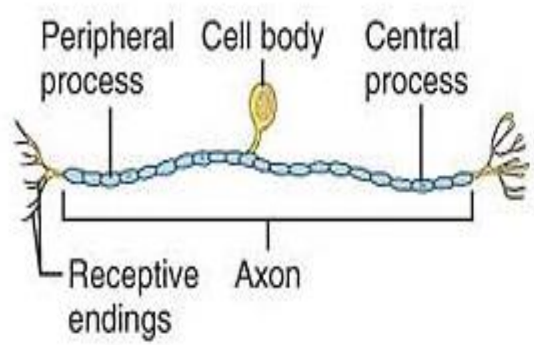


Comparison of Structural Classes of Neurons

NEURON TYPE		
MULTIPOLAR	**BIPOLAR**	**UNIPOLAR (PSEUDOUNIPOLAR)**
STRUCTURAL CLASS: NEURON TYPE ACCORDING TO THE NUMBER OF PROCESSES EXTENDING FROM THE CELL BODY		
Many processes extend from the cell body; all are dendrites except for a single axon.	Two processes extend from the cell body: one is a fused dendrite, the other is an axon.	One process extends from the cell body and forms central and peripheral processes, which together comprise an axon.





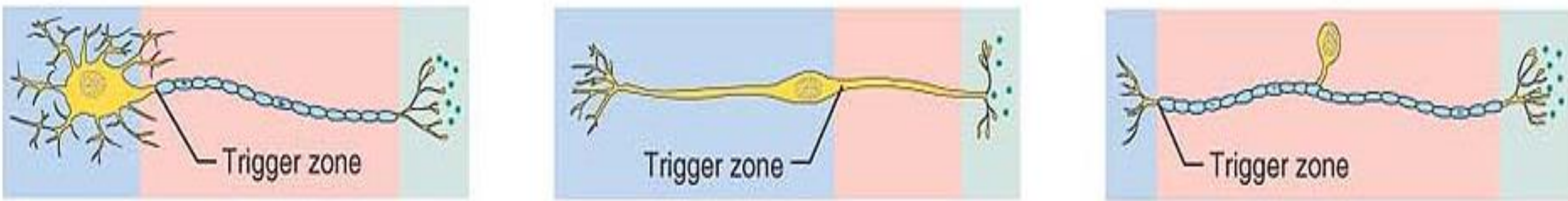


RELATIONSHIP OF ANATOMY TO THE THREE FUNCTIONAL REGIONS

= Receptive region (receives stimulus). Plasma membrane exhibits chemically gated ion channels.

= Conducting region (generates/ transmits action potential). Plasma membrane exhibits voltage-gated Na^+ and K^+ channels.

= Secretory region (axon terminals release neurotransmitters). Plasma membrane exhibits voltage-gated Ca^+ channels.



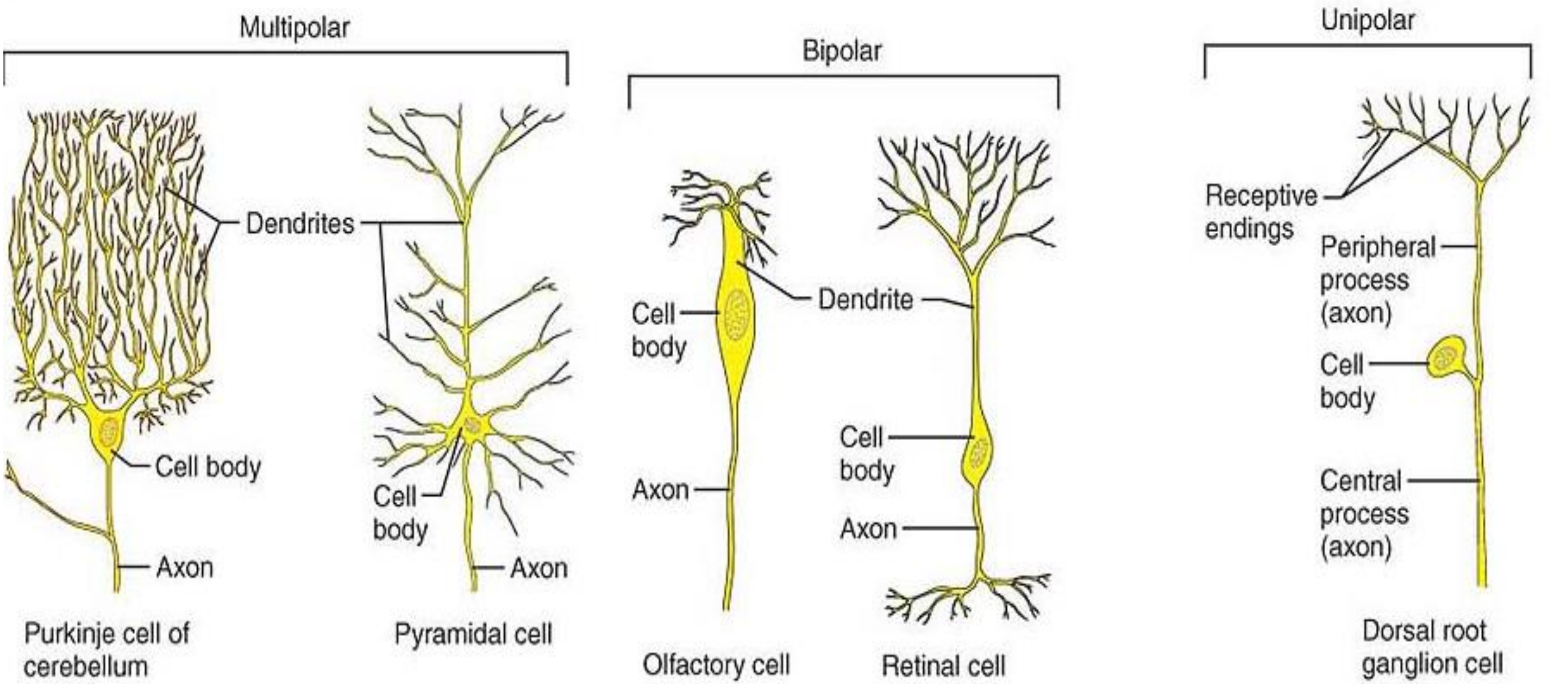
(Many bipolar neurons do not generate action potentials and, in those that do, the location of the trigger zone is not universal.)

RELATIVE ABUNDANCE AND LOCATION IN HUMAN BODY

RELATIVE ABUNDANCE AND LOCATION IN HUMAN BODY

Most abundant in body. Major neuron type in the CNS.	Rare. Found in some special sensory organs (olfactory mucosa, eye, ear).	Found mainly in the PNS. Common only in dorsal root ganglia of the spinal cord and sensory ganglia of cranial nerves.

STRUCTURAL VARIATIONS



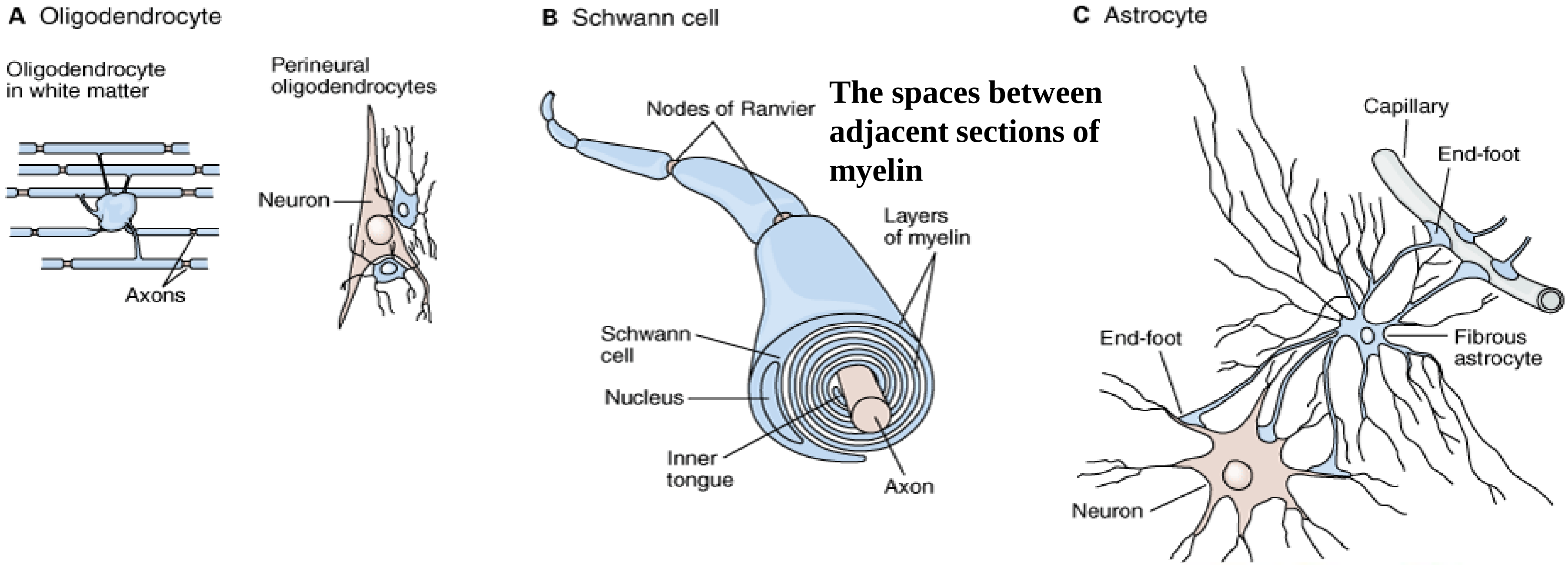
Neuroglial Cells (supporting cells of nervous tissue)

The neurons of the central nervous system are **supported b**y several varieties of **nonexcitable cells**, which together are called neuroglia. Neuroglial cells are generally **smaller than neurons** and **more than five to ten times than neurons**; they comprise about **half the total volume of the brain and spinal cord.**

- glial cells (*glia* is Greek for *glue)* unlike neurons, continue to undergo **cell division**
- There are **two major types of glial cells** in the vertebrate nervous system: **microglia** and **macroglia**

1. **Microglia** are scavenger (hunter) cells that resemble tissue macrophages and remove debris resulting from injury, infection, and disease (eg, multiple sclerosis, AIDS-related dementia, Parkinson disease, and Alzheimer disease). Microglia arse from macrophages outside of the nervous system.

2. **Macroglia**: 3 types
   a) oligodendrocytes,
   b) Schwann cells, and
   c) astrocytes

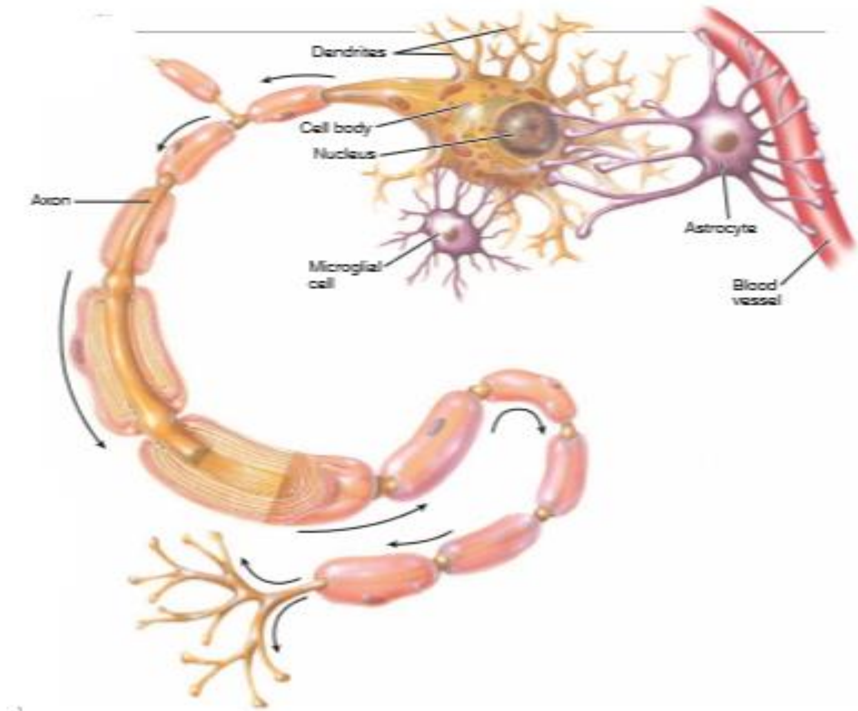


The spaces between adjacent sections of myelin

Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

Astrocytes induce capillaries to form the tight junctions making up the blood–brain barrier.

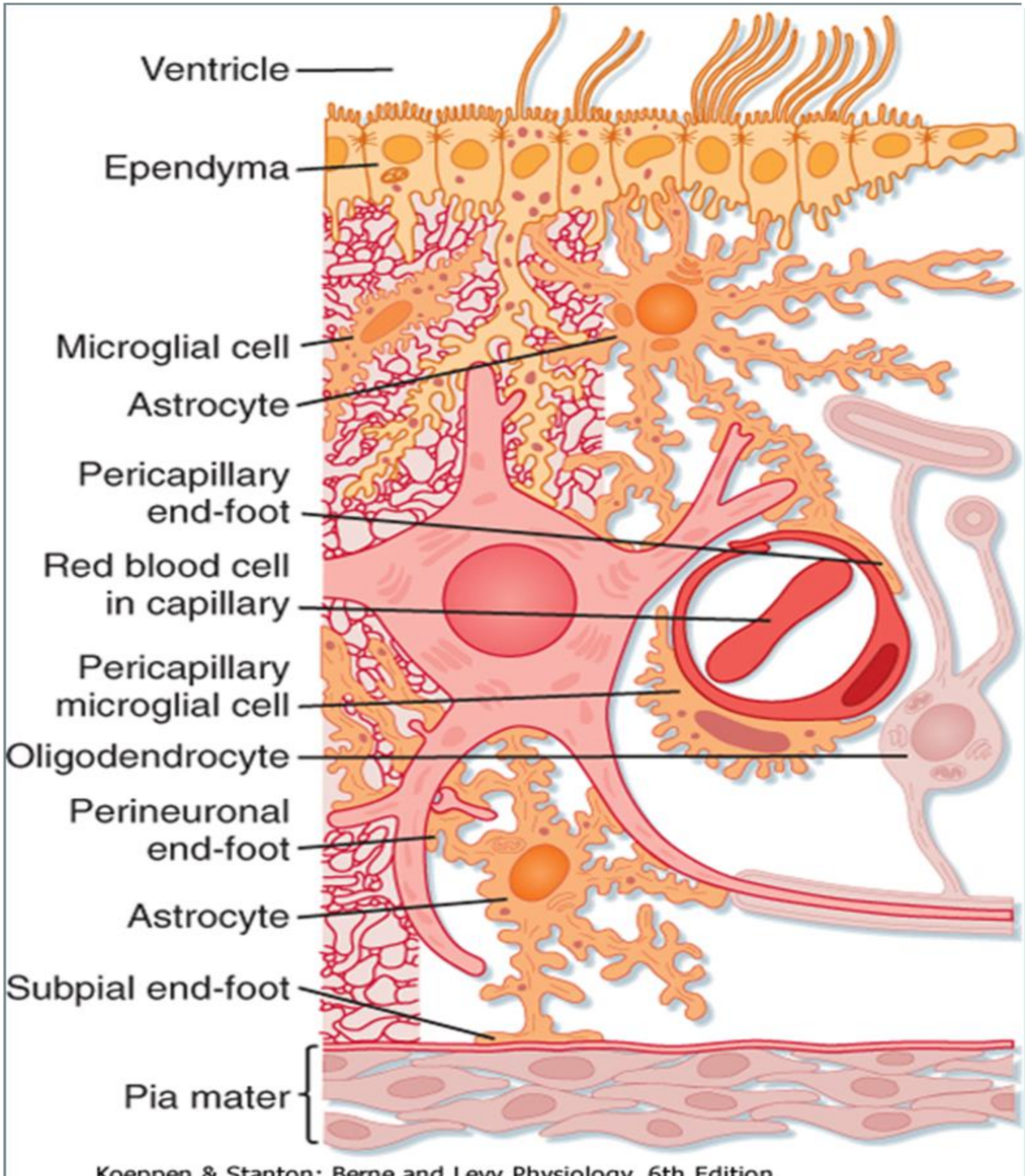
Oligodendrocites and schwan cells form Myelin sheath around axon. The myelin sheath speeds up conduction of the electrical signals along the axon and conserves energy



Supporting cells of nervous system

Origin and Principal Functions of Neuroglial Cells.

Glial Cell Type	Origin	Location	Main Functions
Oligodendrocyte	Neural tube	Central nervous system	Myelin production, electric insulation
Schwann cell	Neural tube	Peripheral nerves	Myelin production, electric insulation
Astrocyte	Neural tube	Central nervous system	Structural support, repair processes
			Blood–brain barrier, metabolic exchanges
Ependymal cell	Neural tube	Central nervous system	Lining cavities of central nervous system
Microglia	Bone marrow	Central nervous system	Macrophagic activity



Koeppen & Stanton: Berne and Levy Physiology, 6th Edition.

Fig: Location of various neuroglial cells (non-neuronal cells) in brain

Classification of nerve fibres

Nerve fibers may be classified based on diameter, degree of myelination, and conduction speed:

1. Group A fibers are mostly **somatic sensory and motor fibers (α motor neuron) serving the skin, skeletal muscles, and joints**. They have **the largest diameter and thick myelin sheath**s, and conduct impulses at speeds ranging up to **150 m/s**.

2. Group B fibers, **lightly myelinated fibers** of intermediate diameter, transmit impulses at an average rate of **15 m/s.**

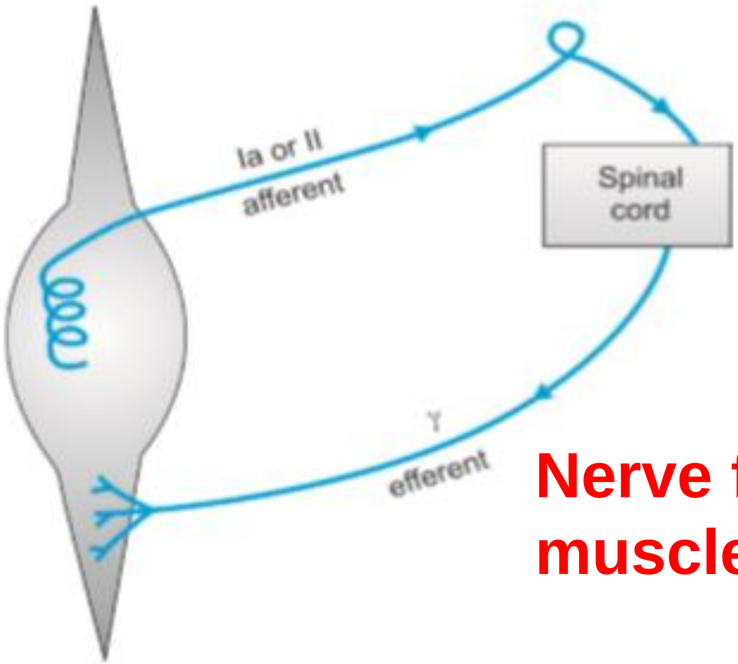
3. Group C fibers have the **smallest diameter and are unmyelinated**. Hence, they are **incapable of saltatory conduction** and conduct impulses at a pace **1 m/s.**

Autonomic nervous system **motor fibers** serving the **visceral organs; visceral sensory fibers**; and the **smaller somatic sensory fibers** transmitting afferent impulses from the skin (such as **pain and small touch fibers)** belong in the **B and C fiber groups**

Classification of nerve fibres

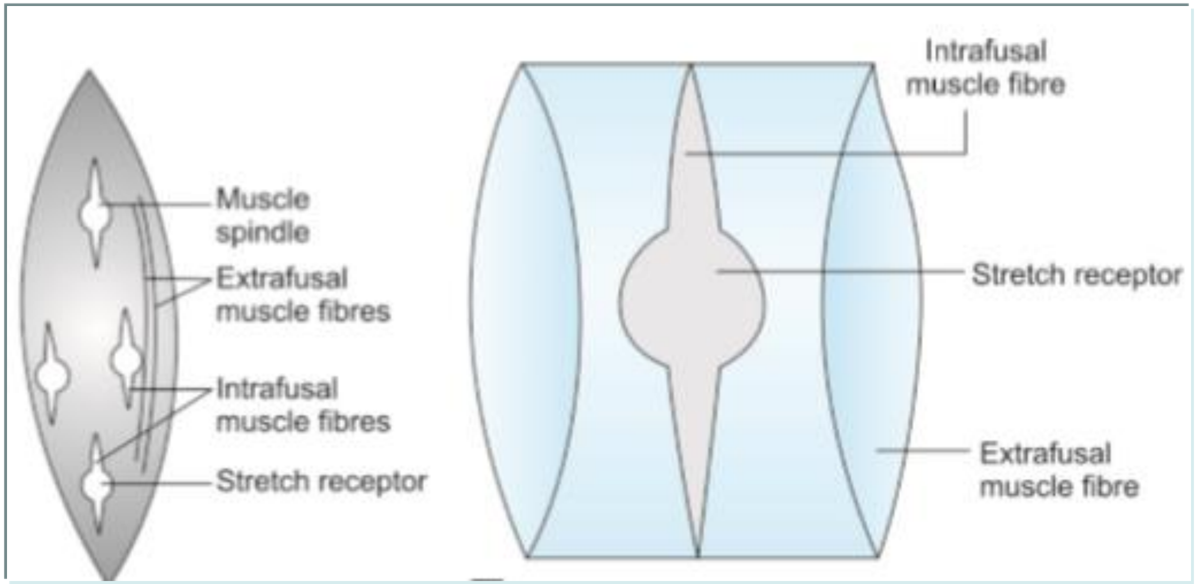
Classification of Mammalian Nerve Fibres						
Group						
Erlanger and Gasser	*Lloyd & Hunt**	*Myelination***	*Diameter (microns)*	*Conduction velocity (m/s)*	*Function*	*Agent to which conduction is most susceptible*
A alpha	I	M	13-20	70-120	Proprioception Motor supply to skeletal muscles	Pressure
A beta	II	M	4-13	25-70	Touch, kinesthetic sense, pressure	Pressure
A gamma	-	M	3-6	15-30	Motor supply to intrafusal muscle fibres	Pressure
A delta	III	M	1-5	5-30	Pain, temperature, pressure, touch	Pressure
B	-	M	1-3	3-14	Preganglionic autonomic fibres	Hypoxia
C	IV	UM	0.2-1.0	0.2-2	Pain, temperature, pressure Postganglionic autonomic fibres	Local anaesthetics

*Considers only sensory fibres
**M, myelinated; UM, ummyelinated



Nerve fibres: sensory & motor to muscles

Diagrammatic representation of the afferent and efferent nerve supply of muscle spindles.



Blood-Brain Barrier

- If the brain were exposed to all chemical variations **(**hormones, amino acids, and ions)**,** the neurons would fire uncontrollably. so special protective mechanism come into play to maintain a stable environment for the brain, called as Blood Brain Barrier.
- Brain's capillaries are separated from the extracellular space and neurons by i.e BBB is formed by

(1) Continuous endothelium of the capillary wall (capillary endothelial cells are almost seamlessly joined all around by tight junctions)

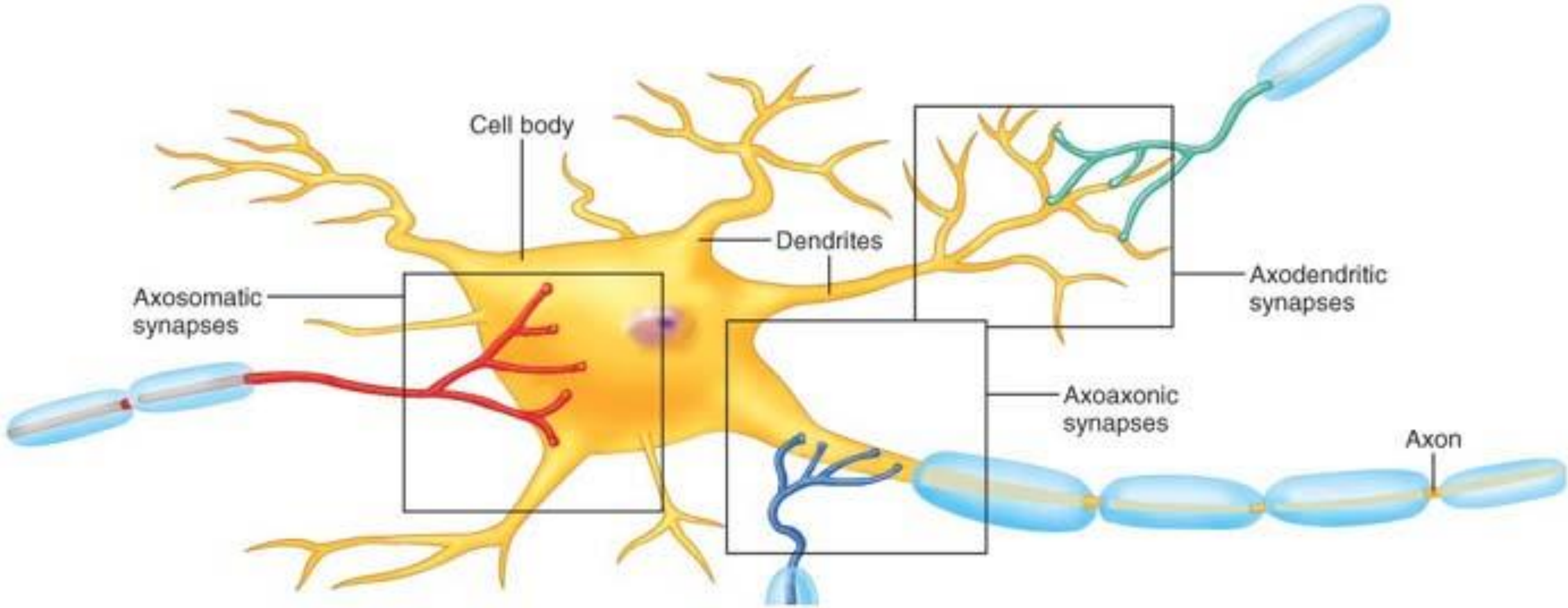
(2) Relatively thick basal lamina surrounding the external face of each capillary, and

(3) the bulging "feet" of the astrocytes adhering to the capillaries.

- The blood-brain barrier is **selective**, rather than absolute.
- Nutrients such as glucose, essential amino acids, and some electrolytes **move passively** by facilitated diffusion through the endothelial cell membranes.
- Bloodborne metabolic wastes, proteins, certain toxins, and most drugs are **denied entry to brain tissue**.
- The barrier is **ineffective against fats, fatty acids, oxygen, carbon dioxide, and other fat-soluble molecules** that diffuse easily through all plasma membranes.
- This explains why blood borne **alcohol, nicotine, and anesthetics can affect the brain.**
- Blood-brain barrier is **entirely absent and the capillary endothelium is quite permeable in vomiting center** of the brain stem (monitors the blood for poisonous substances) & **hypothalamus**, which regulates water balance, body temperature, and many other metabolic activities; lack of a blood-brain barrier here is essential to allow the hypothalamus to detect the chemical composition of the blood.
- The barrier is incomplete in newborn and premature infants, and potentially toxic substances can enter the CNS and cause problems not seen in adults.

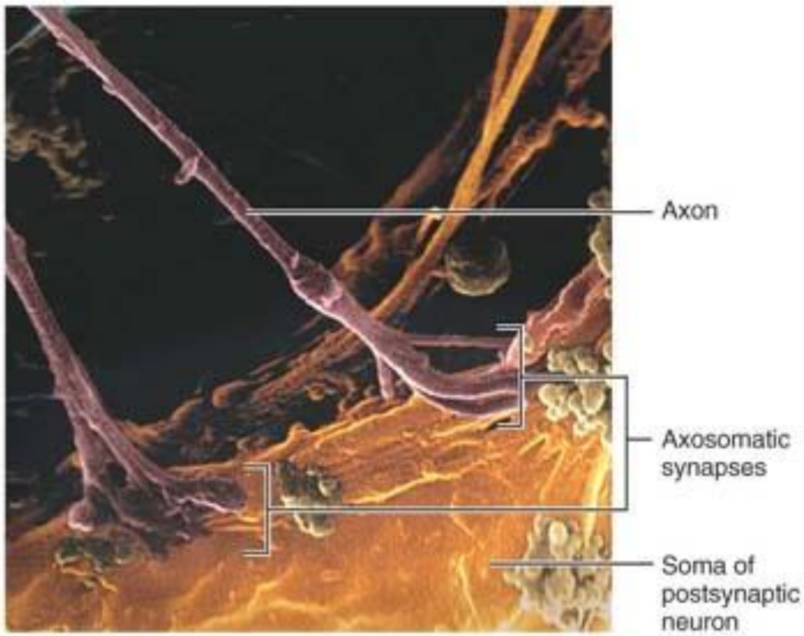
Synapses (Greek syn, “to clasp or join)

- It is a **junction** that mediates **information transfer from one neuron to the next or from a neuron to an effector cell**—(a muscle cell or gland cell)
- **The neuron** conducting impulses **toward the synapse** is the **presynaptic neuron**, and the neuron transmitting the electrical signal **away from the synapse is the postsynaptic neuron**.
- At a given synapse, the **presynaptic neuron is the information sender**, and the **postsynaptic neuron is the information receiver**.
- Neurons have anywhere from **1000 to 10,000 axon terminals making synapses** and are stimulated by an equal number of other neurons.


Cell body
Dendrites
Axosomatic synapses
Axodendritic synapses
Axoaxonic synapses
Axon

(a)

Synapse


Axon
Axosomatic synapses
Soma of postsynaptic neuron

(b)

Structural classification of synapses

1.**Axodendritic** synapses: Synapses between the axon endings of one neuron and the dendrites of other neurons.

2.**Axosomatic** synapses: synapse between axon endings of one neuron and cell bodies of other neurons.

3.**Axoaxonic** Synapse: Less common (and far less understood) are synapses between axons.

4.**Dendrodendritic** synapse: between dendrites

5.**Dendrosomatic** synapse: between dendrites and cell bodies

Functional classification of synapse: electrical and chemical

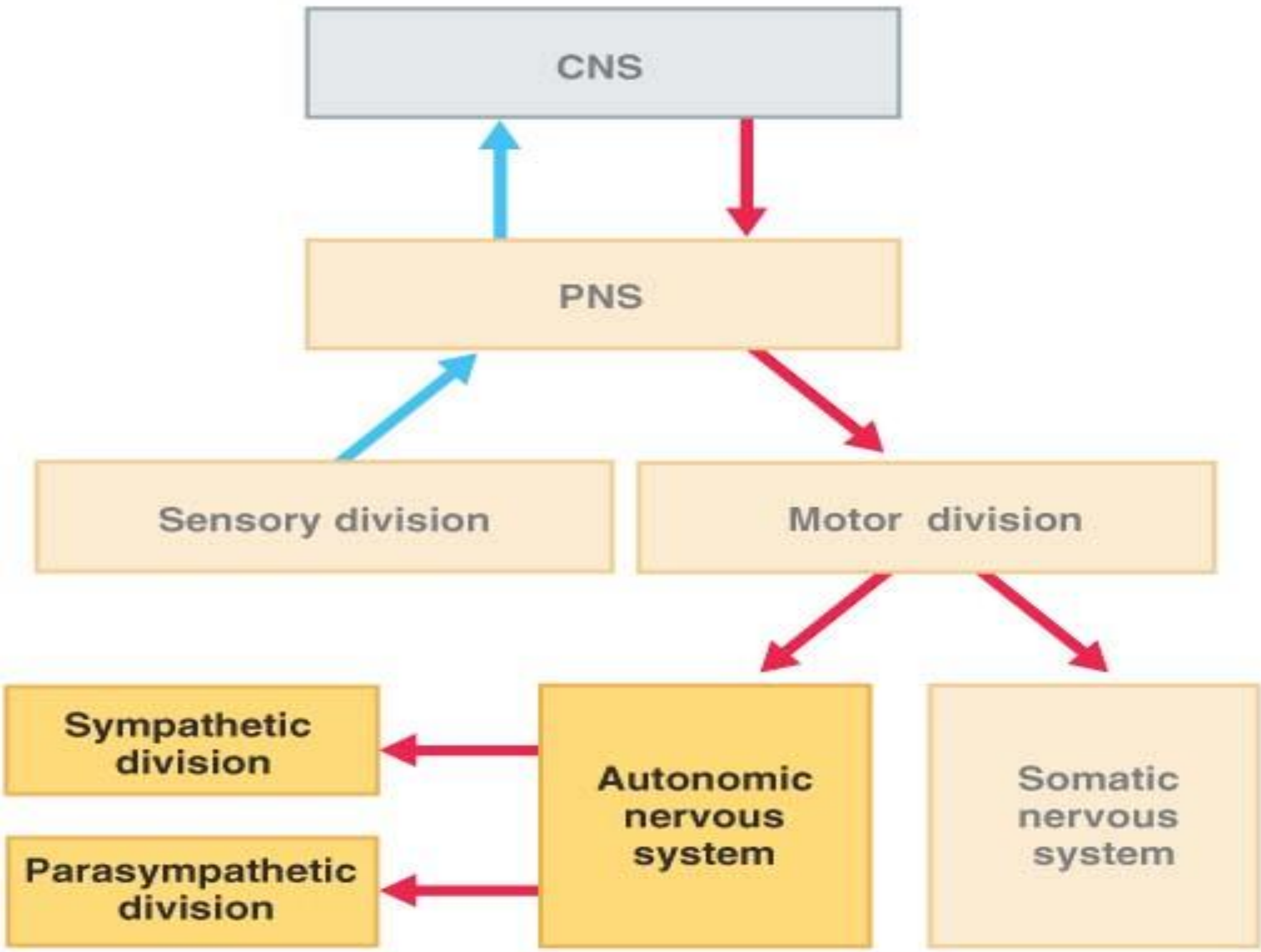
Electrical synapses:

- Less common variety, gap junctions found between cells.
- They contain **protein channels**, made of **connexin subunits**, that intimately Connect the cytoplasm of adjacent neurons and allow ions and small molecules to **flow directly from one neuron to the next**.
- Transmission across these synapses is **very rapid.**
- Communication may be **unidirectional or bidirectional.**
- More **abundant in embryonic nervous tissue**, between **glial cells of the CNS**

Chemical Synapses

- Release and reception of chemical neurotransmitters.
- A knoblike axon terminal of the presynaptic neuron + a neurotransmitter receptor region on the membrane of a dendrite or the cell body of the postsynaptic neuron

Structural organization of the nervous system. SUMMARY



The Nervous System

Central Nervous System (CNS)

- brain and spinal cord
- receives sensory input via PNS sensory nerves
- processes/interprets sensory input (interneurons)
- sends response to effectors (muscles and glands) via motor nerves

Peripheral Nervous System (PNS)

- cranial and spinal nerves extending from brain and spinal cord
- connects CNS to entire body

Autonomic

- cranial and spinal nerves connecting CNS to heart, stomach, intestines, and glands
- controls unconscious activities

Somatic

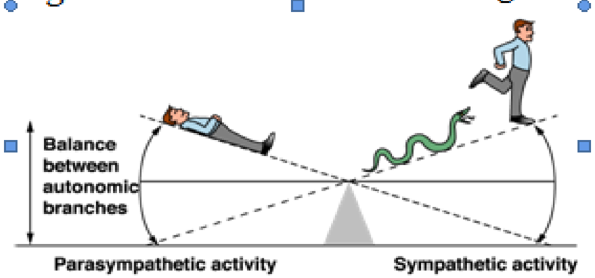
- cranial and spinal nerves connecting CNS to skin and skeletal muscles
- oversees conscious activities

Parasympathetic

- decreases heart rate, bronchiole dilation, blood glucose, blood to skeletal muscle, bladder
- increases digestion, pupil size, urinary output
- "rest and digest"

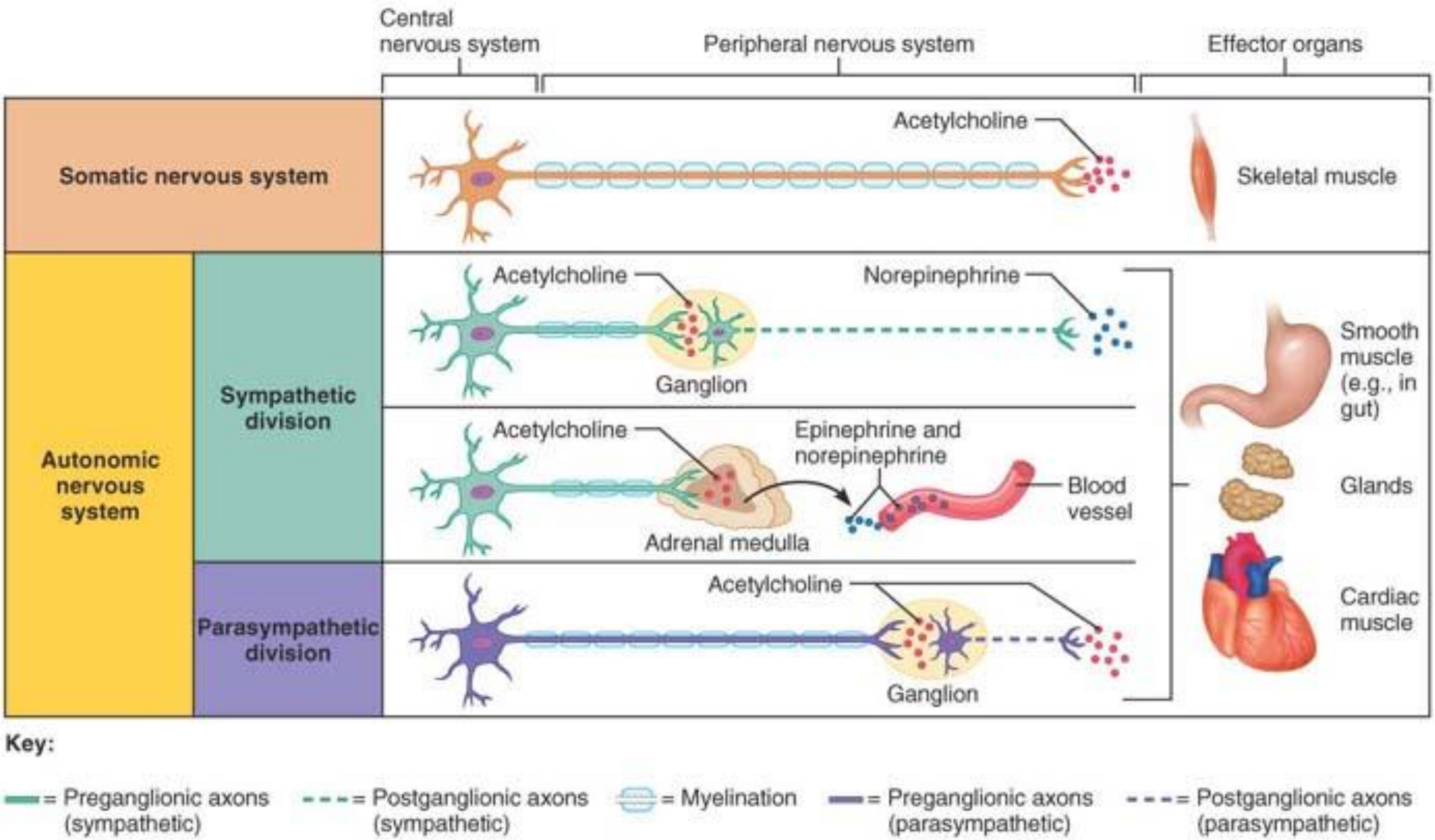
Sympathetic

- decreases digestion, pupil size, urinary output
- increases heart rate, bronchiole dilation, blood glucose, blood to skeletal muscle, pupil size
- "fight or flight"

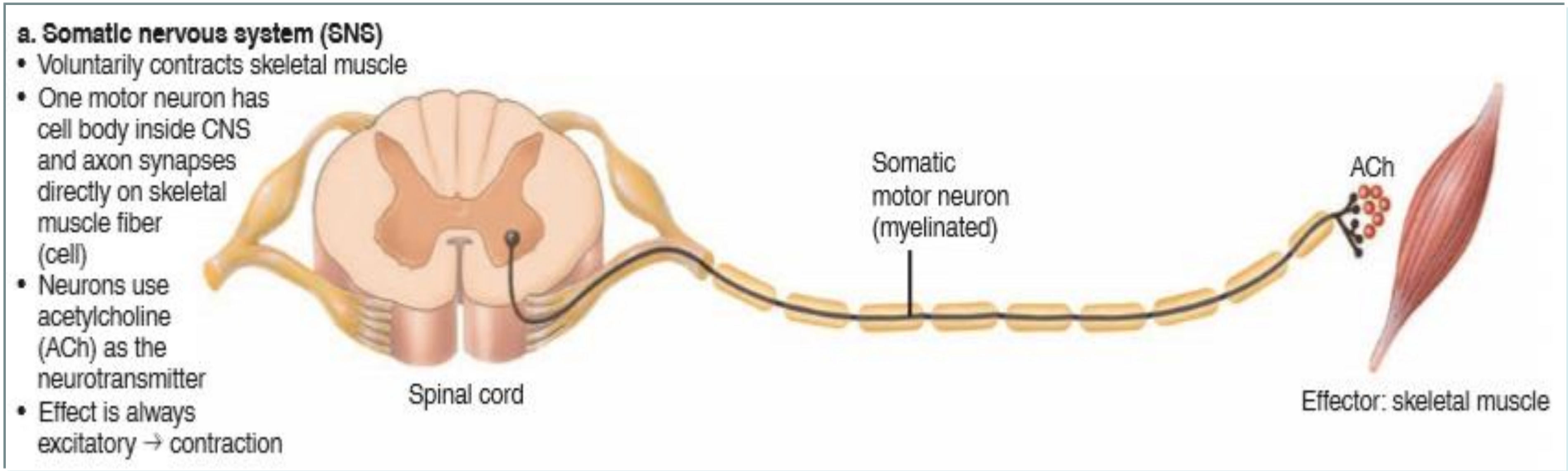


Structural organization of the nervous system

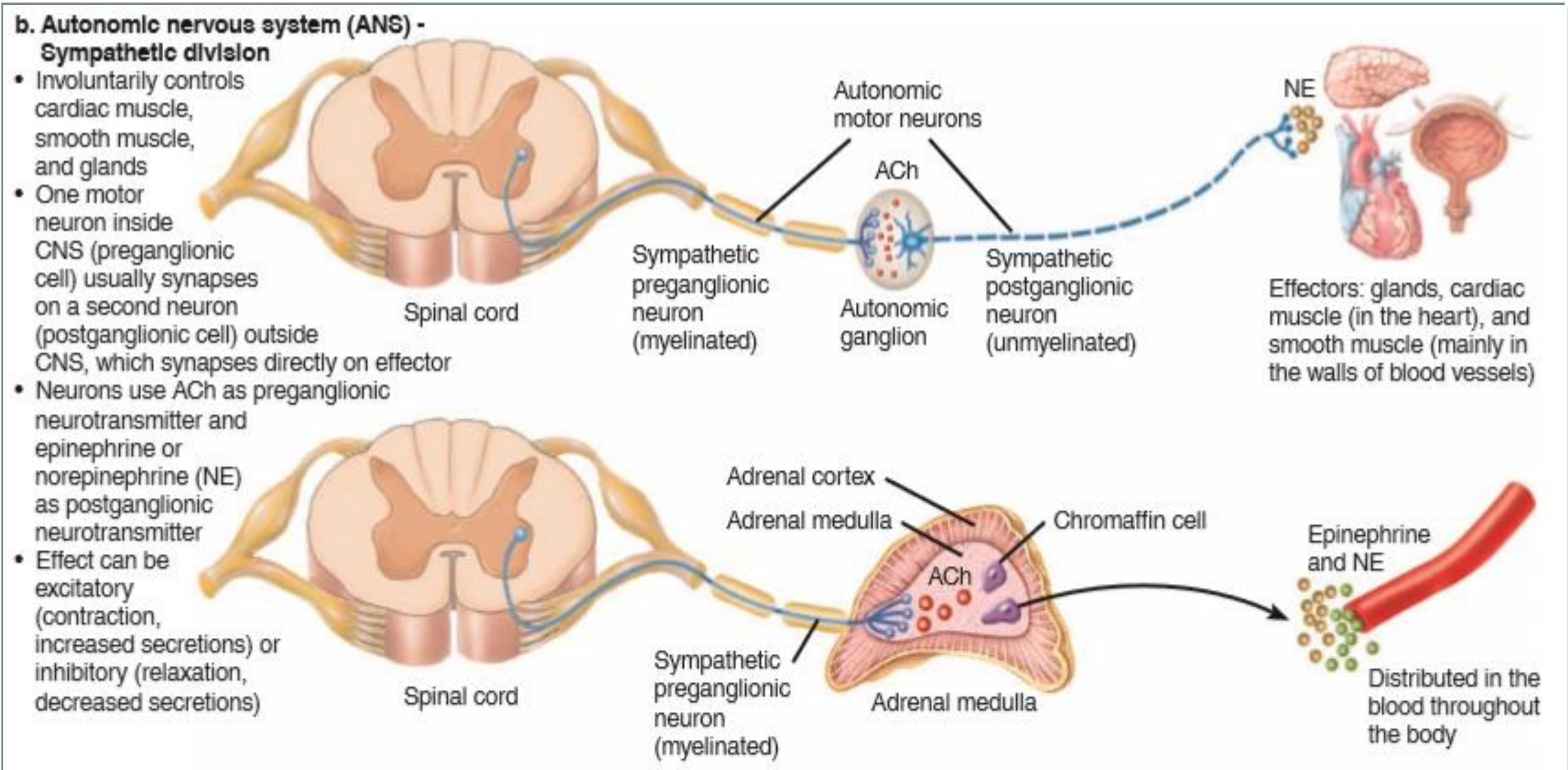
Comparison of the Somatic and Autonomic Nervous Systems



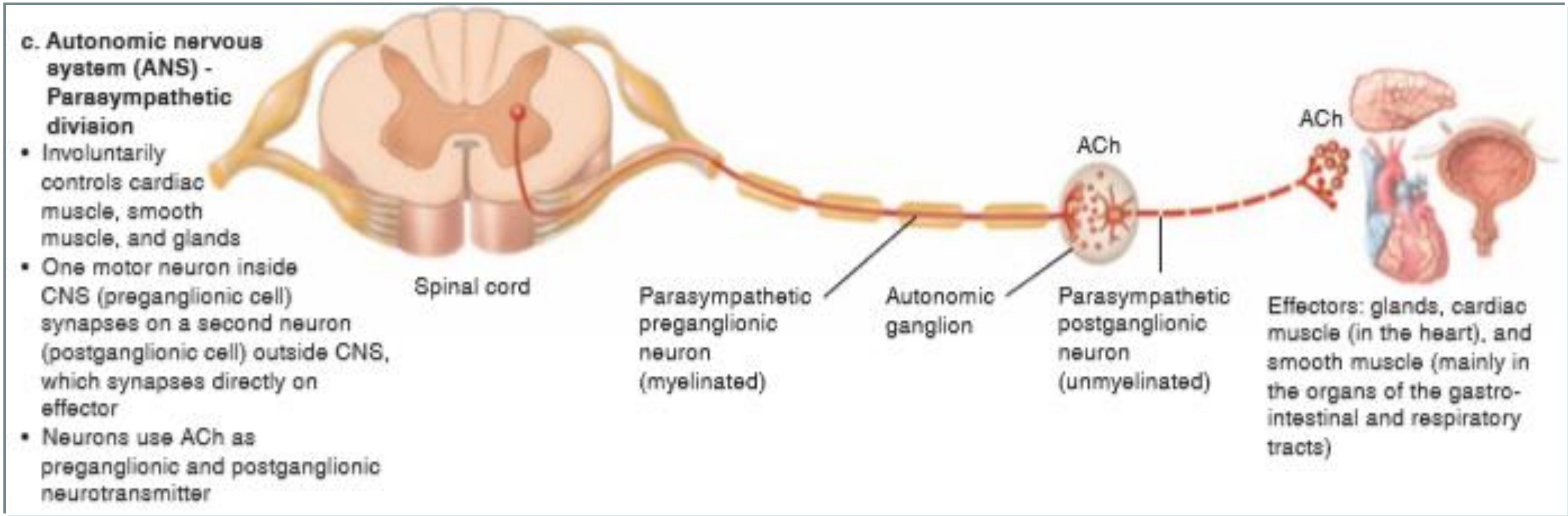
SOMATIC NERVOUS SYSTEM



Autonomic Nervous System: Sympathetic division



Autonomic Nervous System: Parasympathetic division



Peripheral Nervous System

- Autonomic division of the nervous system can be subdivided into 2 divisions:
- (1) <u>Parasympathetic</u>
  - Decreases heart rate, bronchiole dilation, blood glucose, blood to skeletal muscle
  - Increases digestion, pupil size, urinary output
  - "rest and digest"
- (2) <u>Sympathetic</u>
  - Decreases digestion, pupil size, urinary output
  - Increases heart rate, bronchiole dilation, blood glucose, blood to skeletal muscle
  - "fight or flight"

Comparison between sympathetic and parasympathetic nervous systems

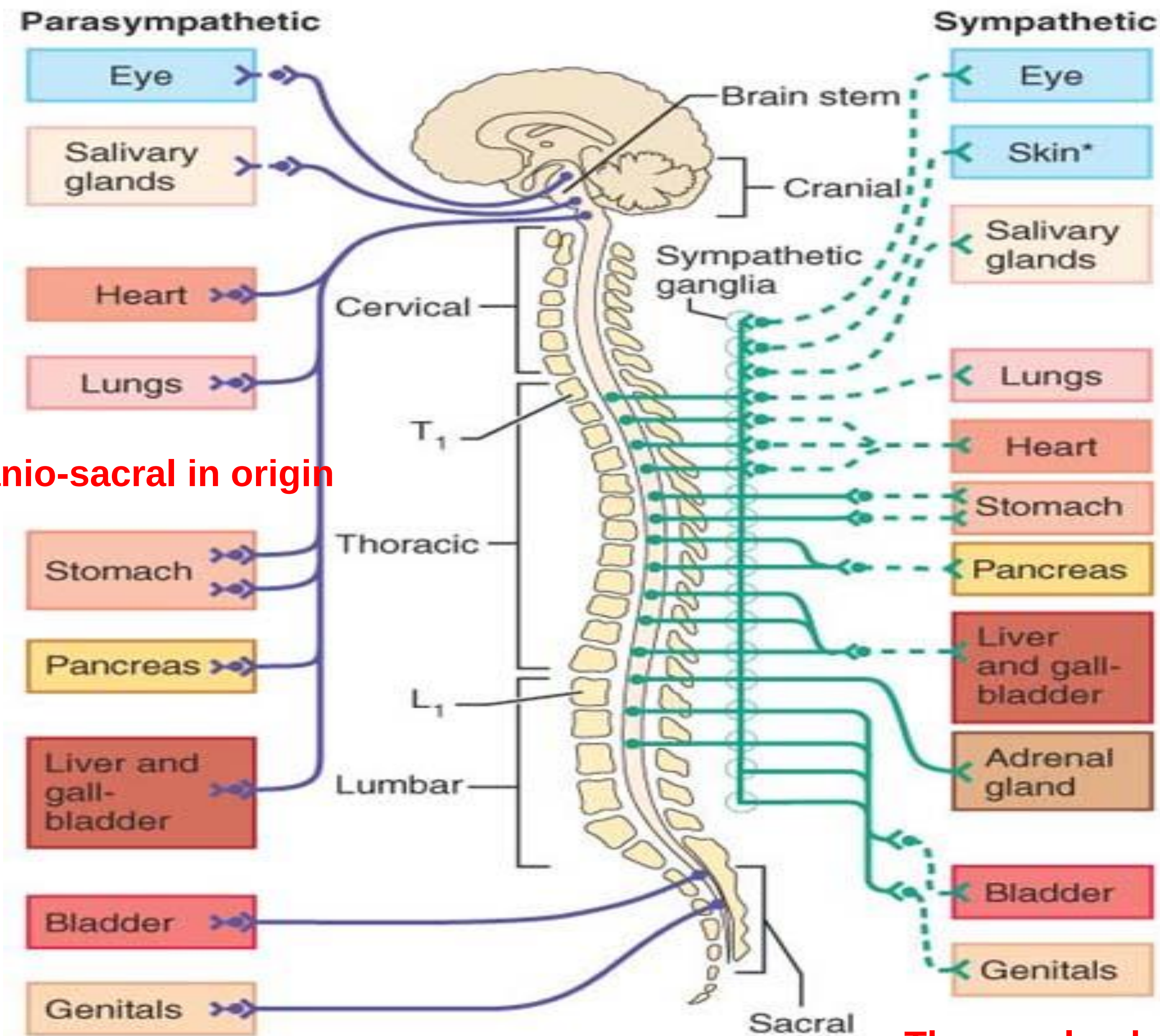
	Sympathetic	*Parasympathetic*
Site of preganglionic neurons	Thoracolumbar (Segments T1-L3)	Craniosacral (Nuclei of cranial nerves III, VII, IX and X; segments S2-4)
Site of ganglia	Paravertebral and prevertebral ganglia	Within or very close to the organ innervated
Preganglionic neurons	Cholinergic	Cholinergic
Postganglionic neurons	Adrenergic (Exceptions: In sweat glands and skeletal muscle, cholinergic)	Cholinergic
Activation	In emergencies, and in REM sleep	When relaxed, and in slow wave sleep
Effects	Useful in emergencies Substrates mobilised for providing energy Catabolic and thermogenic	Useful at rest Substrates deposited for storage Anabolic

The sympathetic and parasympathetic divisions are distinguished by

1. **Their unique origin sites:**
   - Parasympathetic fibers emerge from the brain and sacral spinal cord (are craniosacral)
   - Sympathetic fibers originate in the thoracolumbar region of the spinal cord.
2. **The relative lengths of their fibers:**
   - The parasympathetic division has long preganglionic and short postganglionic fibers
   - The sympathetic division has the opposite condition.
3. **The location of their ganglia:**
   - Most parasympathetic ganglia are located in the visceral effector organs
   - Sympathetic ganglia lie close to the spinal cord.

Anatomical and Physiological Differences Between the Parasympathetic and Sympathetic Divisions

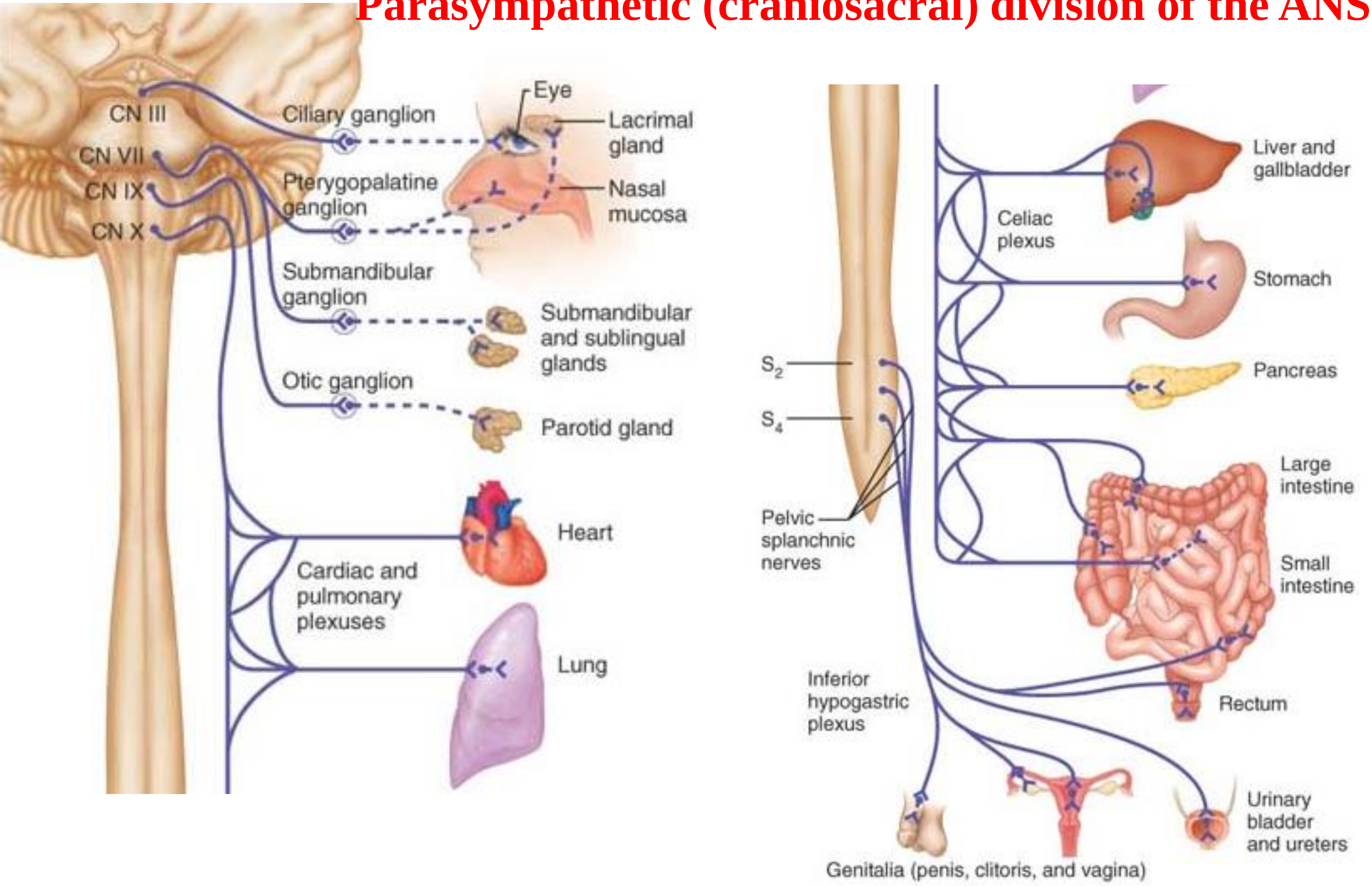
CHARACTERISTIC	PARASYMPATHETIC	SYMPATHETIC
Origin	Craniosacral outflow: brain stem nuclei of cranial nerves III, VII, IX, and X; spinal cord segments S_2–S_4	Thoracolumbar outflow: lateral horn of gray matter of spinal cord segments T_1–L_2
Location of ganglia	Ganglia in (intramural) or close to visceral organ served	Ganglia within a few centimeters of CNS: alongside vertebral column (sympathetic trunk, or chain, ganglia) and anterior to vertebral column (collateral, or prevertebral, ganglia)
Relative length of pre- and postganglionic fibers	Long preganglionic; short postganglionic	Short preganglionic; long postganglionic
Degree of branching of preganglionic fibers	Minimal	Extensive
Functional role	Maintenance functions; conserves and stores energy	Prepares body for activity
Neurotransmitters	All fibers release ACh (cholinergic fibers)	All preganglionic fibers release ACh; most postganglionic fibers release norepinephrine (adrenergic fibers); postganglionic fibers serving sweat glands and some blood vessels of skeletal muscles release ACh; neurotransmitter activity augmented by release of adrenal medullary hormones (norepinephrine and epinephrine)



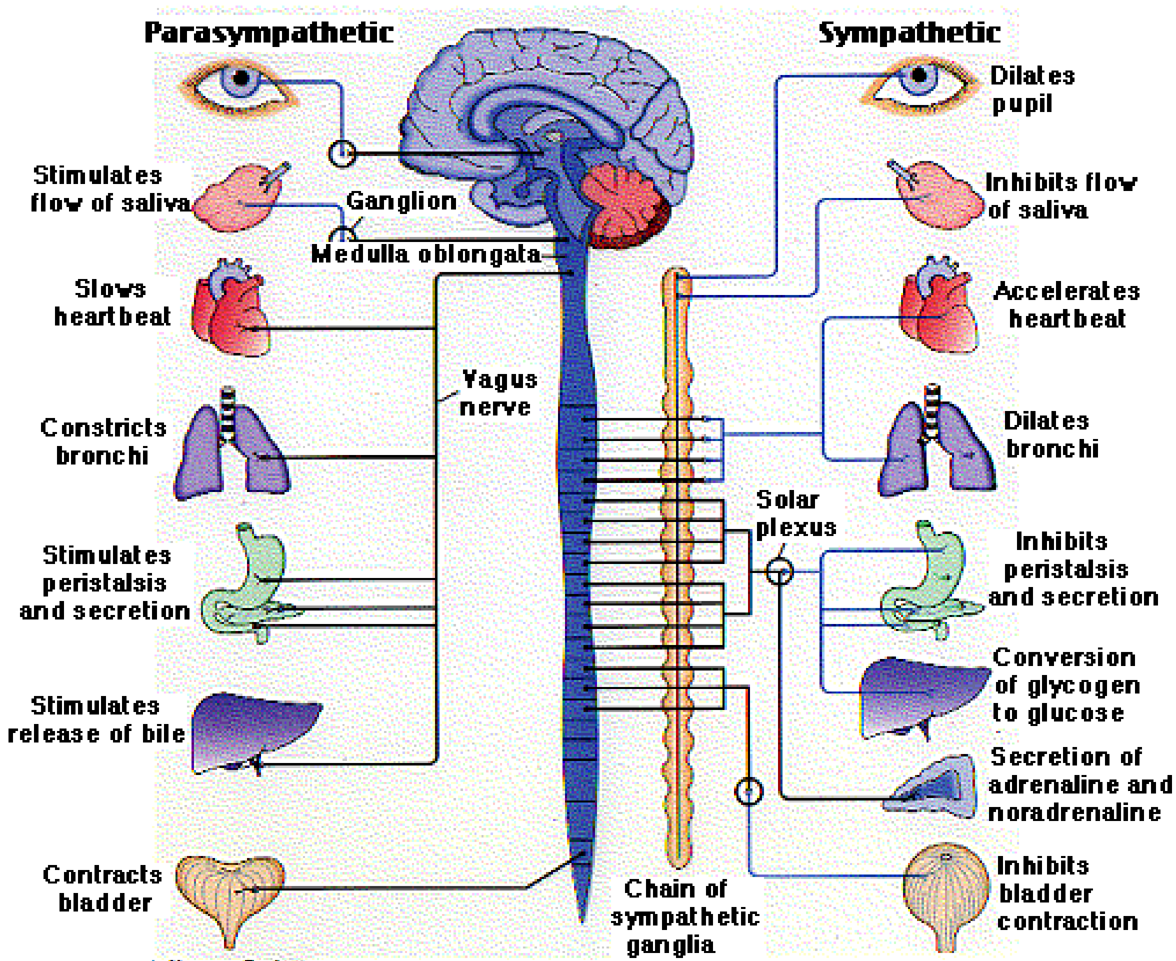
Cranio-sacral in origin

Thoraco-lumbar in origin

Parasympathetic (craniosacral) division of the ANS



Parasympathetic vs. Sympathetic Divisions

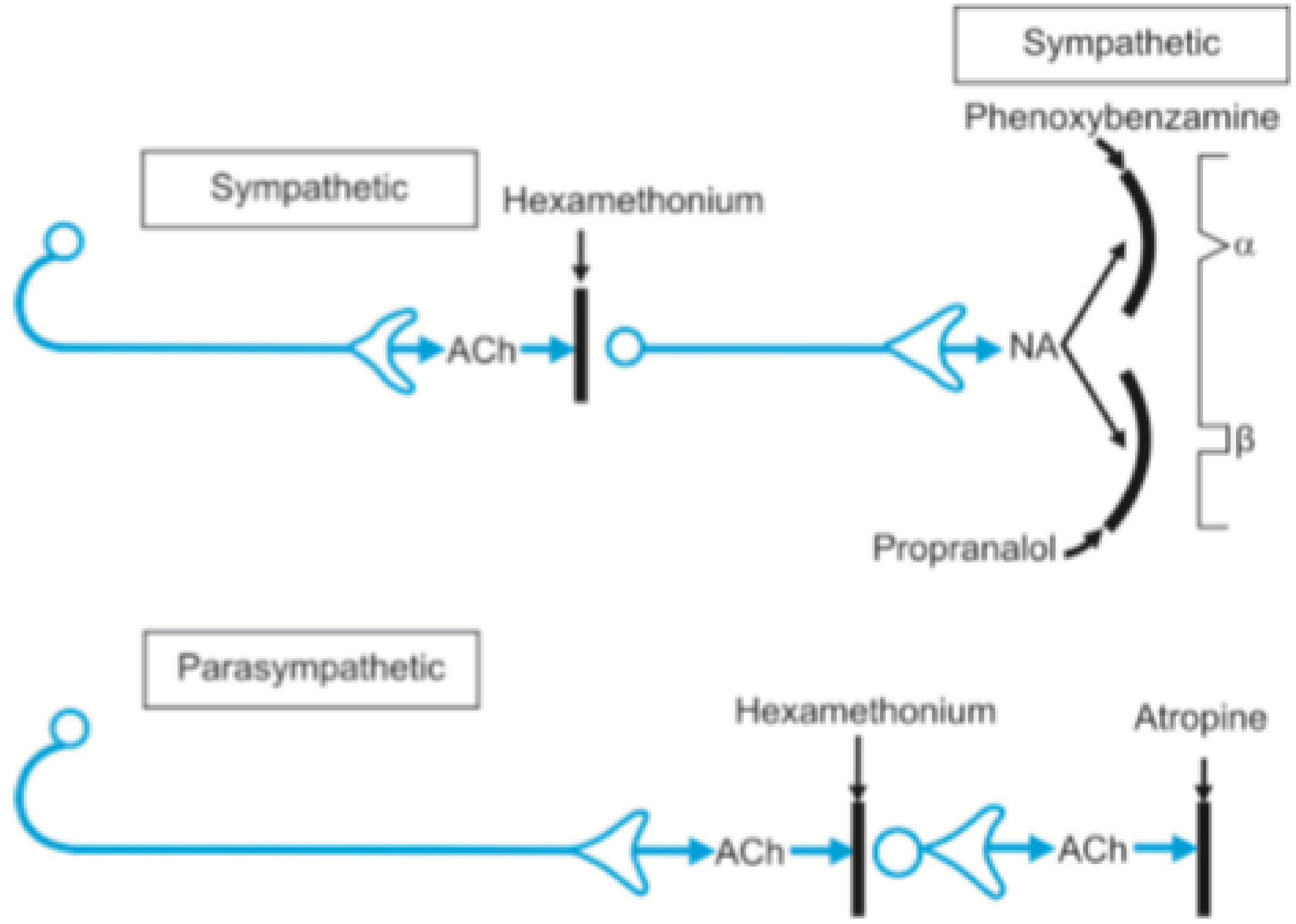


Effects of ANS to various organs & system

Autonomic effects on various organs

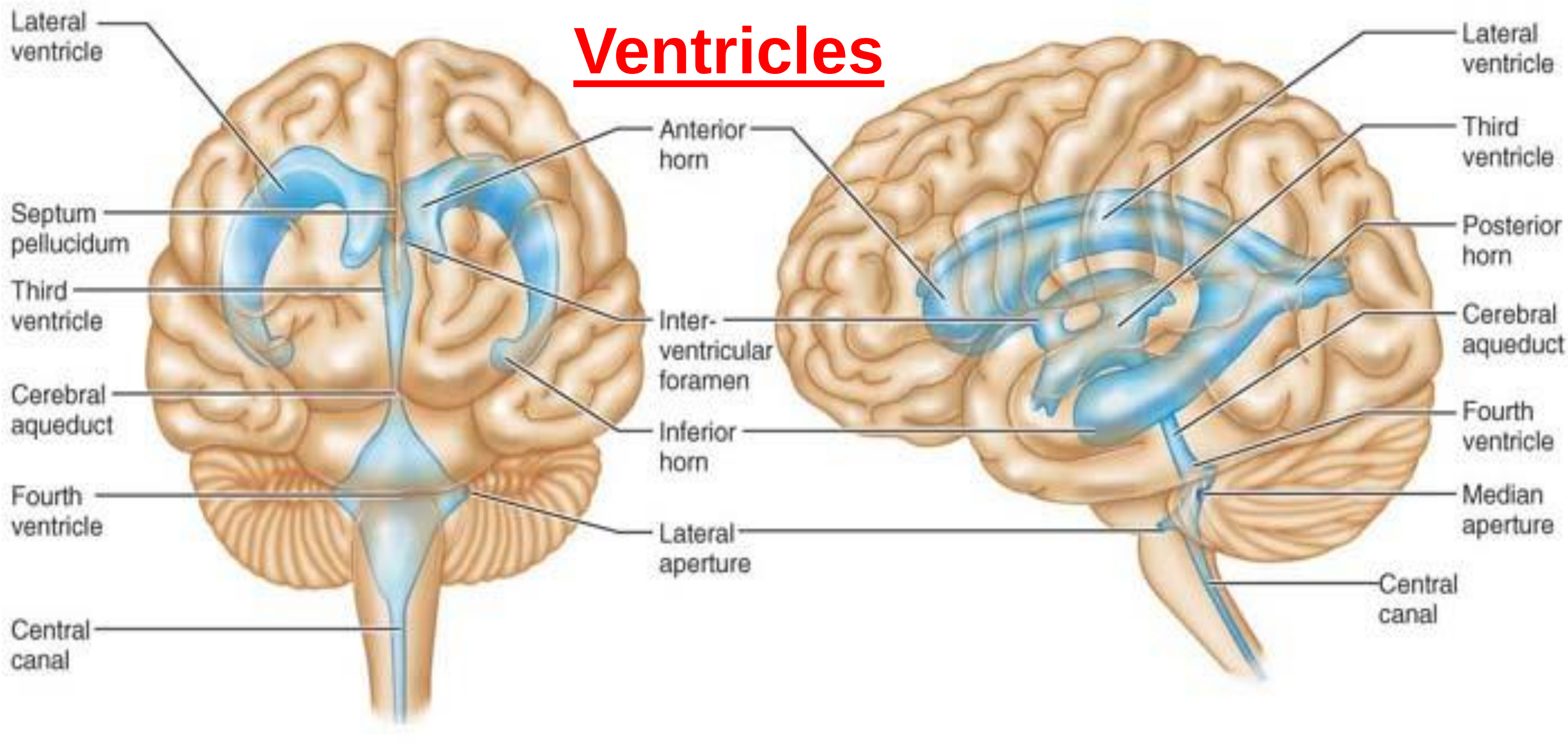
Organ	*Effects of*	
	Sympathetic stimulation	*Parasympathetic stimulation*
Heart	Increase in rate, increase in force of contraction	Decrease in rate. Decrease in force of contraction
Lungs	Bronchodilation	Bronchoconstriction
Gastrointestinal tract	Decrease in motility, tone and secretion	Increase in motility, tone and secretion
	Contraction of sphincters	Relaxation of sphincters
Bladder	Relaxation of detrusor	Contraction of detrusor
	Contraction of sphincter	Relaxation of sphincter
Blood vessels	Splanchnic and cutaneous vasoconstriction	None
	Skeletal muscles: Constriction (adrenergic alpha), dilatation (adrenergic beta-2), dilatation (cholinergic)	None
Eyes	Pupillary dilatation, Relaxation of ciliary muscles	Pupillary constriction. Contraction of ciliary muscles
Sweat glands	Sweating (cholinergic)	Sweating on palms only
Metabolic effects	Glycogenolysis. Lipolysis	Not significant

ANS Blocker



: Agents which may be employed to block the action of autonomic nerves at the level of the ganglia or the postganglionic fibres. ACh, acetylcholine; NA, noradrenaline.

Ventricles



(a) Anterior view (b) Left lateral view

- Ventricles (hollow chambers of brain) are continuous with one another and with the central canal of the spinal cord.
- The hollow ventricular chambers are **filled with cerebrospinal fluid and lined by ependymal cells**, a type of neuroglia which are responsible for producing **csf.**

Protection of the Brain

The Skull

Cranial

Meninges

Cerebrospinal Fluid

Blood-Brain

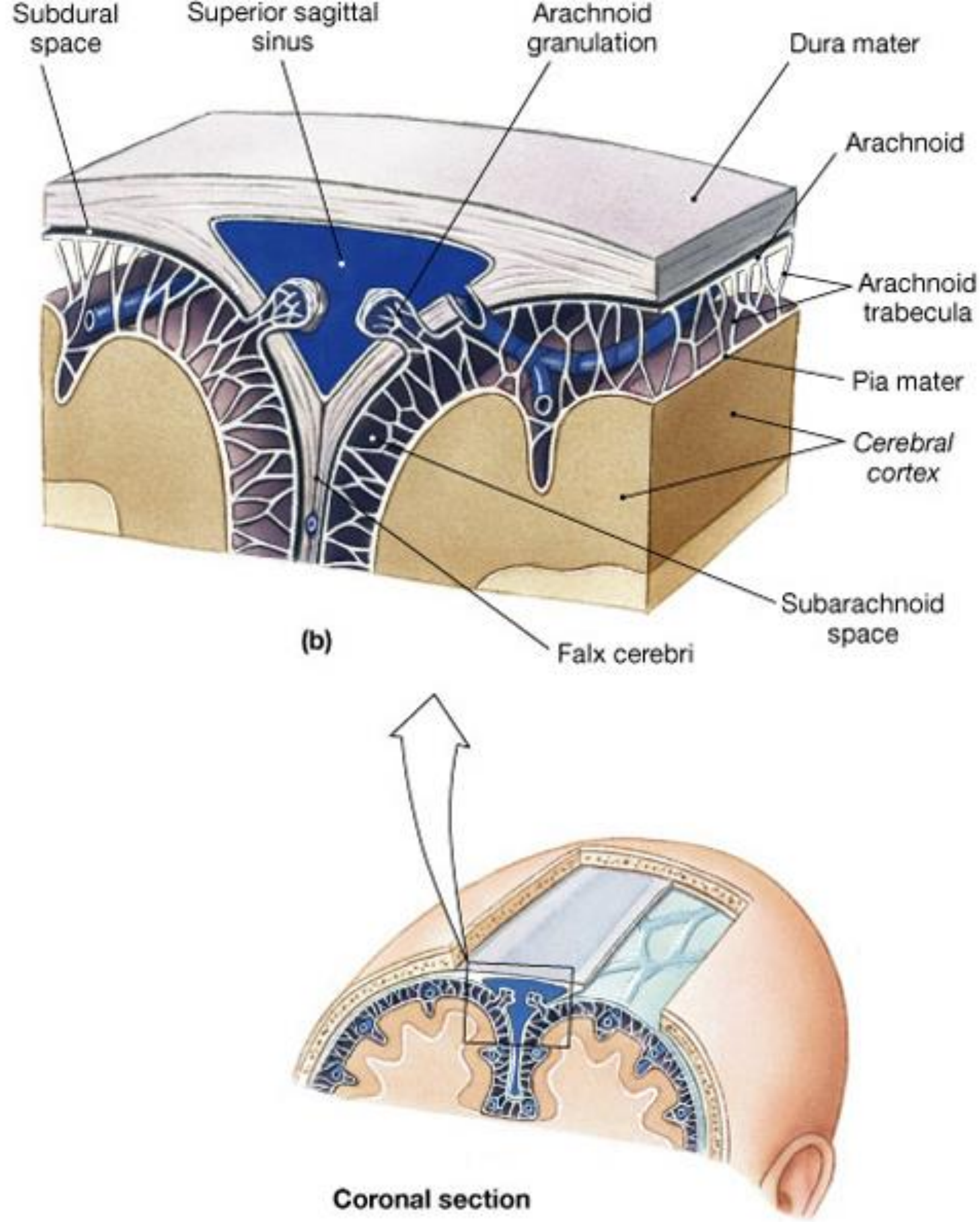
Barrier

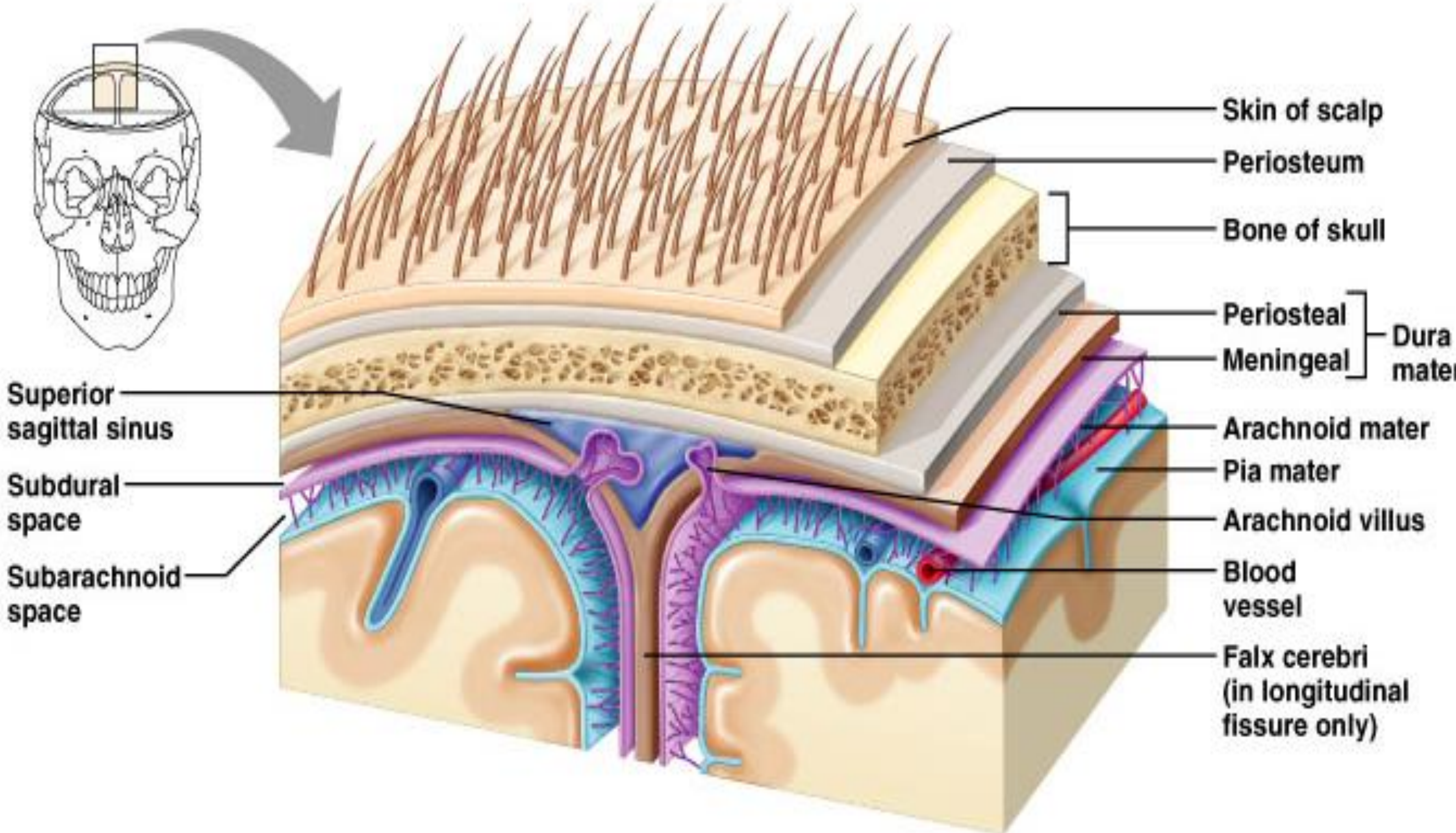
Cranial Meninges - 3 layer protective membrane

1. **Dura Mater - Composed of two layers:**
   a) **Periosteal – outer layer, attaches to bone.**
   b) **Meningeal – inner layer, closer to brain.**
   Two layers fused, except to enclose the dural sinuses

2. **Arachnoid Layer - ‘spider’ web like.**

3. **Pia Mater - delicate, follows convolutions.**


Subdural space
Superior sagittal sinus
Arachnoid granulation
Dura mater
Arachnoid
Arachnoid trabecula
Pia mater
Cerebral cortex
Subarachnoid space
Falx cerebri
(b)
Coronal section



Skin of scalp
Periosteum
Bone of skull
Periosteal
Meningeal
Dura mater
Superior sagittal sinus
Subdural space
Subarachnoid space
Arachnoid mater
Pia mater
Arachnoid villus
Blood vessel
Falx cerebri (in longitudinal fissure only)

(a)

Cranial Meningeal Spaces

<u>Epidural space</u>

Potential space superior to dura.

<u>Subdural space</u>

Potential space between dura and arachnoid mater.

<u>Subarachnoid space</u>

Filled with CSF

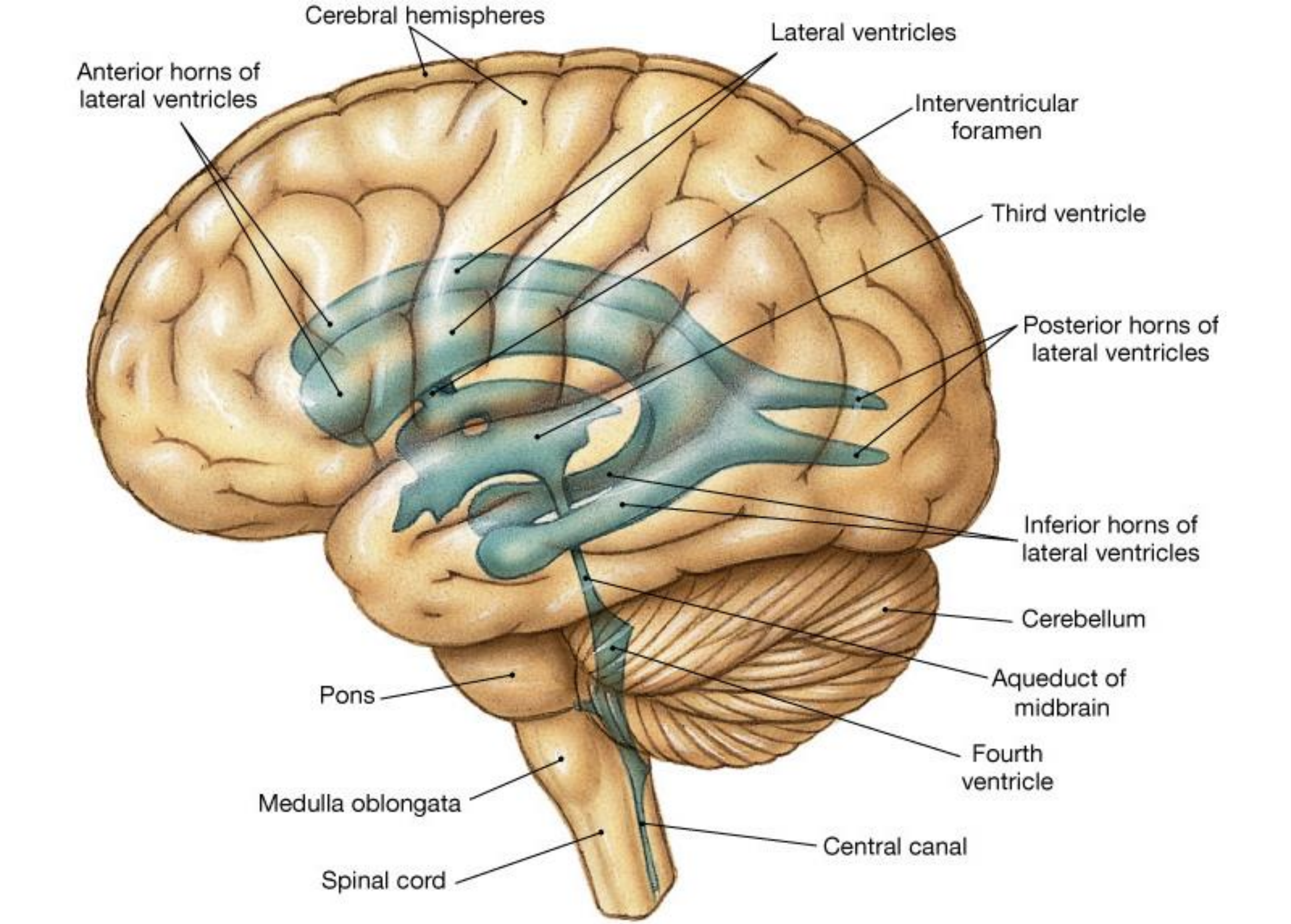
Contains the blood vessels supplying brain.

Cerebrospinal Fluid (CSF)

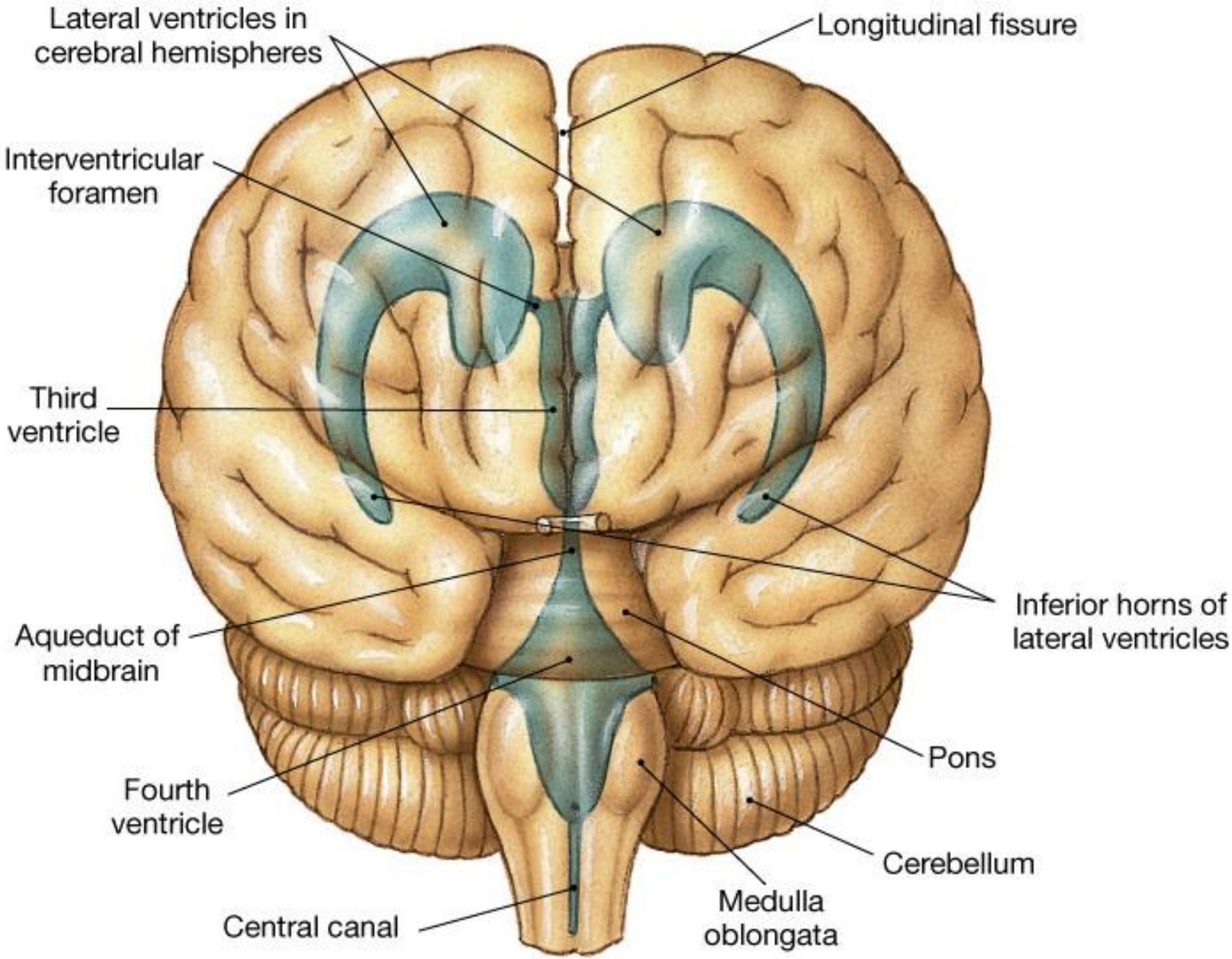
<u>Roles of CSF</u>:

1. Cushions and insulates delicate nervous tissue.
2. Gives Buoyancy to the brain ("floats" in CSF).
3. Exchange of gases (O_2 and CO_2), nutrients and wastes.

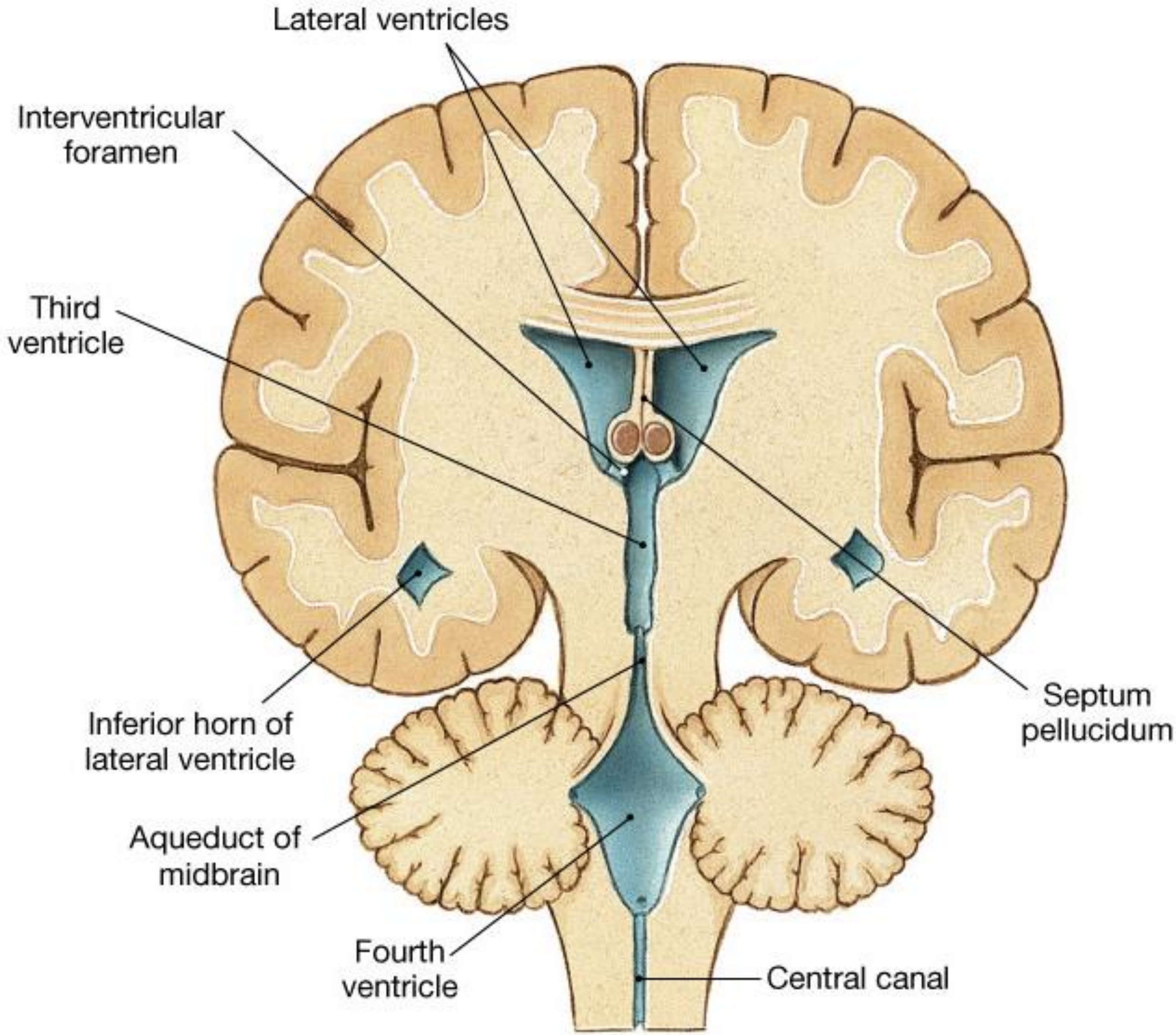
* CSF formed in the choroid plexuses in ventricles of brai



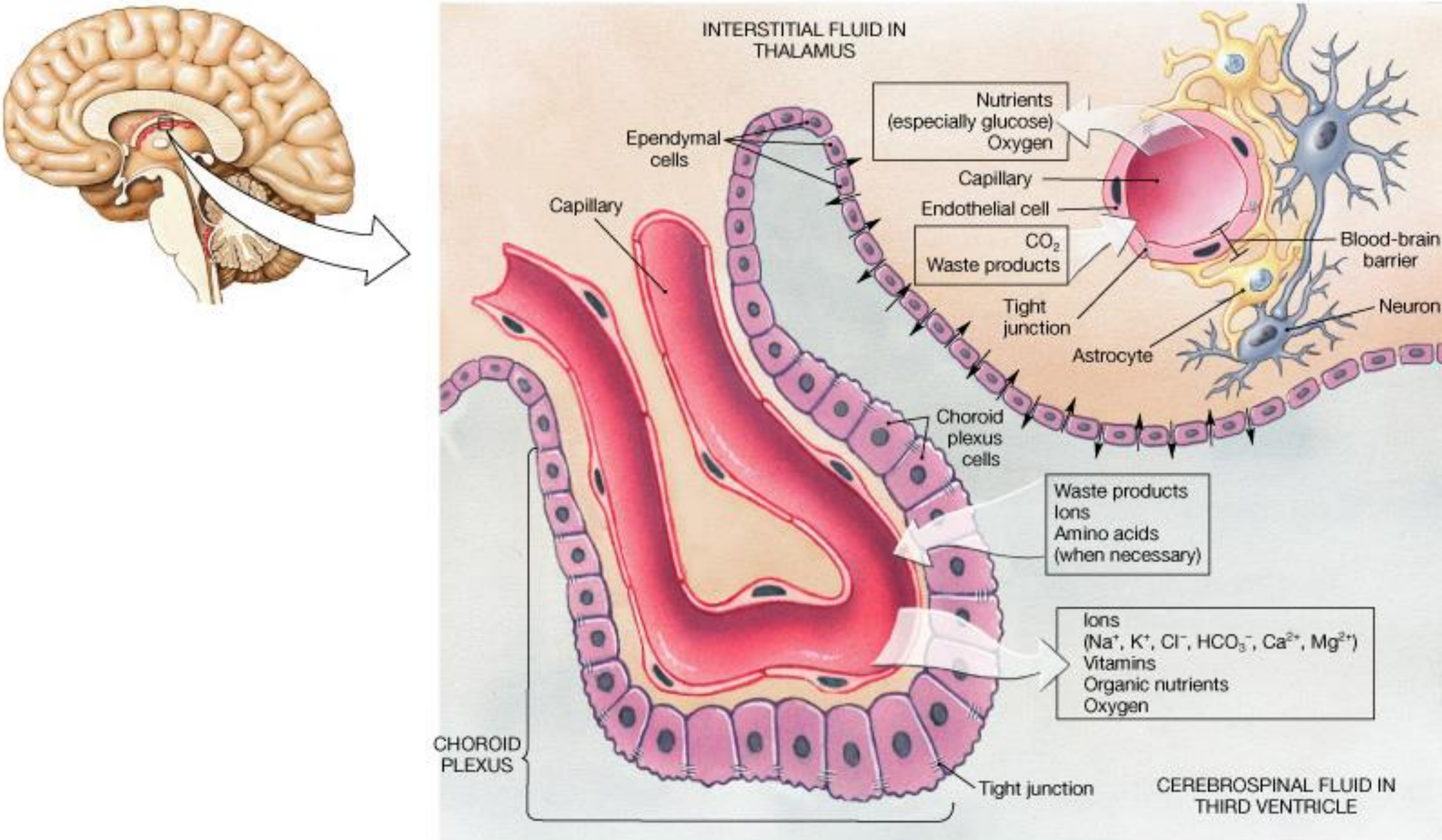
(a) Lateral view



(c) Anterior view



(d) Coronal section



INTERSTITIAL FLUID IN THALAMUS
Nutrients (especially glucose) Oxygen
Ependymal cells
Capillary
Capillary
Endothelial cell
CO_2 Waste products
Blood-brain barrier
Tight junction
Neuron
Astrocyte
Choroid plexus cells
Waste products
Ions
Amino acids
(when necessary)
Ions
(Na^+, K^+, Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+})
Vitamins
Organic nutrients
Oxygen
CHOROID PLEXUS
Tight junction
CEREBROSPINAL FLUID IN THIRD VENTRICLE

Blood Brain Barrier (BBB)

A restrictive barrier around blood vessels in the brain (created by astrocytes).

Prevents most blood-borne toxins from entering the brain but not an *absolute* barrier.

Nutrients such as O_2, and glucose can pass. Plus CO_2, alcohol, nicotine, and anesthetics.

Dopamine? L-Dopa?

Meninges

The **meninges** (mening = membrane) are three connective tissue membranes that lie just external to the CNS organs.

(1) cover and protect the CNS

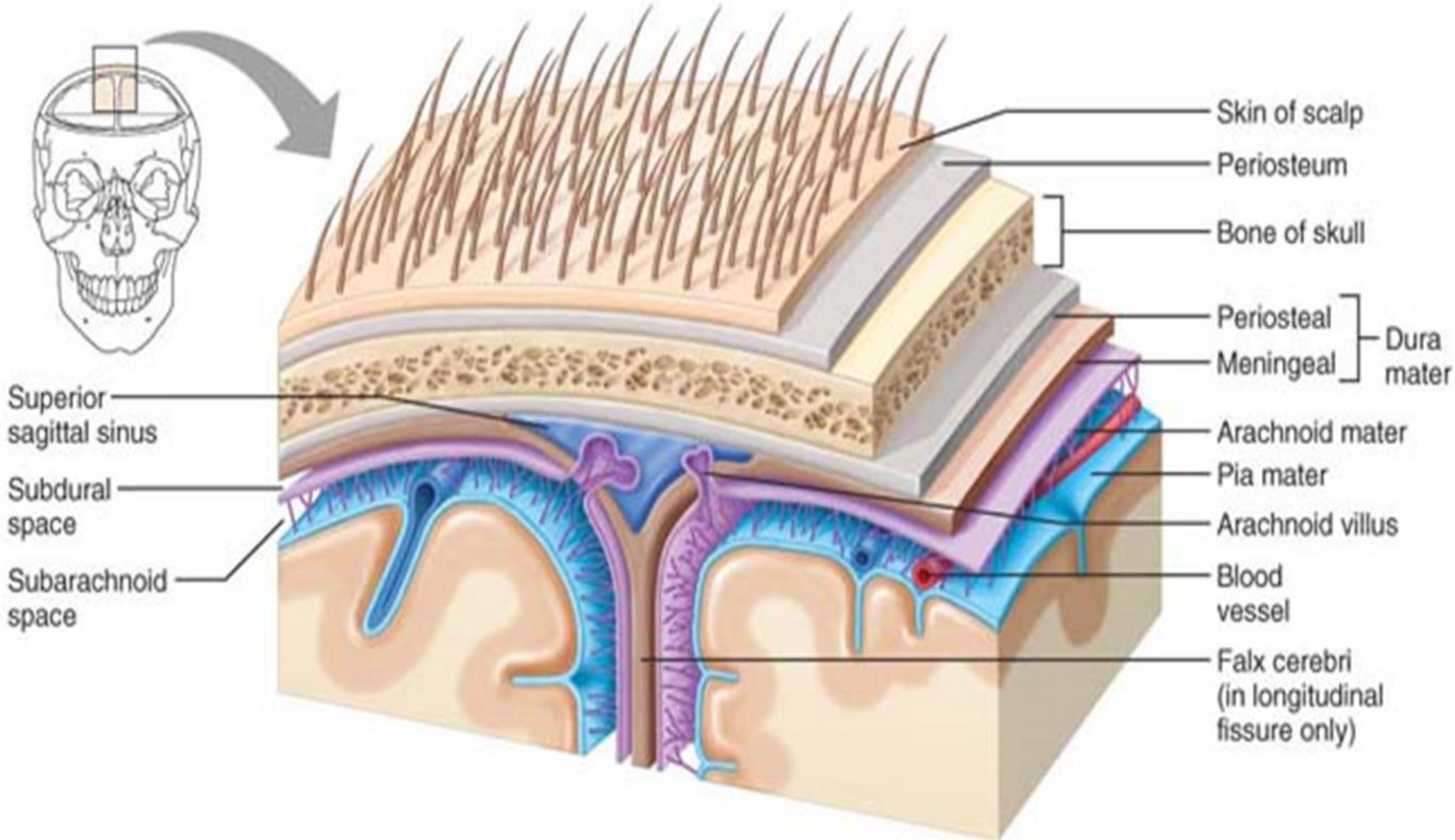
(2) protect blood vessels and enclose venous sinuses.

(3) contain cerebrospinal fluid, and

(4) form partitions in the skull

From **external to internal,** the meninges (singular: meninx) are

- Dura mater,
- Arachnoid mater, and
- Pia mater



Skin of scalp
Periosteum
Bone of skull
Periosteal
Meningeal
Dura mater
Superior sagittal sinus
Subdural space
Subarachnoid space
Arachnoid mater
Pia mater
Arachnoid villus
Blood vessel
Falx cerebri (in longitudinal fissure only)

1. Dura Mater (tough mother)

- The strongest meninx
- It is a two-layered sheet of fibrous connective tissue (not in spinal cord region).
- The more superficial periosteal layer is attached to the inner surface of the skull (the periosteum).
- The deeper meningeal layer forms the true external covering of the brain.
- In several places, the meningeal dura mater extends inward (dural septa) to form flat partitions that subdivide the cranial cavity
- These dural septa, which limit excessive movement of the brain within the cranium

2. Arachnoid Mater (“spider,”weblike extensions)

- Middle meninx, forms a loose brain covering, never dipping into the sulci at the cerebral surface.
- It is separated from the dura mater by a narrow serous cavity, the subdural space, which contains a film of fluid.
- Beneath the arachnoid membrane is the wide subarachnoid space.
- Weblike extensions span this space and lock the arachnoid mater to the underlying pia mater.
- The subarachnoid space is filled with cerebrospinal fluid and also contains the largest blood vessels serving the brain.

3. Pia Mater (gentle mother)

- Composed of delicate connective tissue and is richly invested with tiny blood vessels.
- It is the only meninx that clings tightly to the brain, following its every convolution.
- Small arteries entering the brain tissue carry ragged sheaths of pia mater inward with them for short distances.

Meningitis, inflammation of the meninges, is a serious threat to the brain because a bacterial or viral meningitis may spread to the CNS

Cerebrospinal Fluid (CSF)

- CSF is a watery “broth” similar in composition to blood plasma formed by **choroid plexuses** that hang from the roof of each ventricle .
- However, it contains less protein than plasma.
- CSF contains more Na^+, Cl^-, and H^+ than does blood plasma, and less Ca^{2+} and K^+.
- Found in and around the brain and spinal cord, forms a **liquid cushion that gives buoyancy to the CNS structures**
- CSF effectively **reduces brain weight by 97%** and prevents the brain from crushing under its own weight.
- CSF also **protects the brain and spinal cord from blows and other trauma**.
- Although the brain has a rich blood supply, CSF helps **nourish the brain**.
- It also **carries chemical signals** (such as hormones and sleep- and appetite-inducing molecules) from one part of the

First few drops…

- Emanuel Swedenborg who discovered CSF, referred to it as “highly gifted juice” that is dispensed from the roof of the fourth ventricle to the medulla oblongata, and the spinal cord.
- Albrecht von Haller found that that the “water” in the brain, in case of excess secretion, descends to the base of the skull resulting in hydrocephalus

Introduction

- CSF → flows via macroscopic & ECF spaces

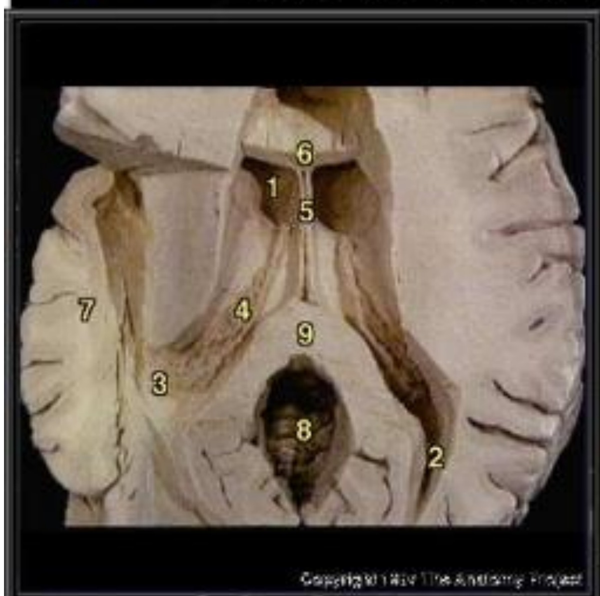
PRESSURES AND VOLUMES	
CSF PRESSURE [mm of Hg]	
CHILDREN	3.0-7.5
ADULTS	4.5-13.5
CSF VOLUME [mL]	
INFANTS	40-60
YOUNG CHILDREN	60-100
OLDER CHILDREN	80-120
ADULTS	100-160

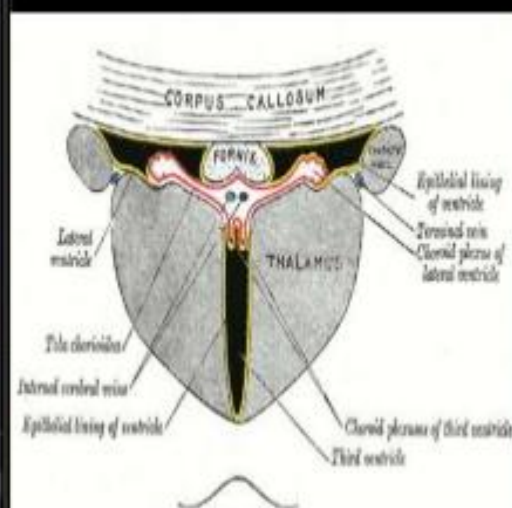
CHOROID PLEXUS

- Invagination of blood vessels & leptomeninges covered by a layer of modified ependyma
- Epithelium is the blood-CSF barrier
- Carbonic anhydrase present in the epithelium & Na-K pump in luminal plasma membrane play major role in CSF formation

Anatomy

- **<u>Choroid plexus projects into</u>**
- The temporal horn of each lateral ventricle,
- the posterior portion of the third ventricle &
- the roof of the fourth ventricle.





Circulation of CSF

Site of formation

Choroid plexus of the lateral ventricle

1. Lateral ventricle

↓ *Interventricular foramina*

2. Third ventricle

↓ *Cerebral aqueduct*

3. Fourth ventricle

3.2 Lateral foramina (Luschka) | 3.1 Median foramen (Magendie) | 3.2 Lateral foramina (Luschka)

↓

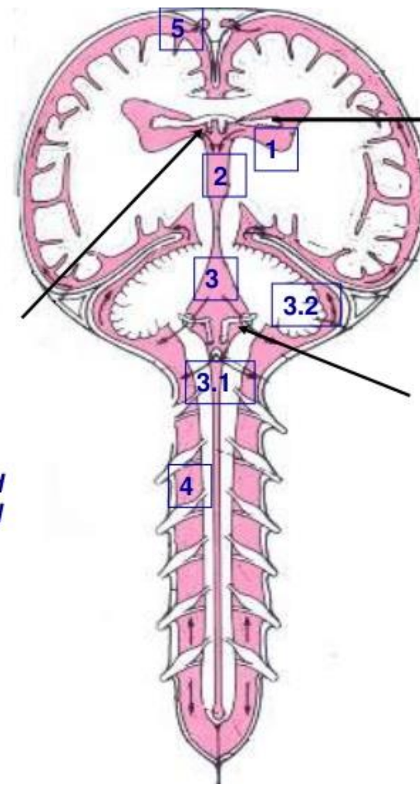
4. Subarachnoid space

↓

Inferiorly

Absorbed — Superiorly

Absorbed — Superiorly



Superiorly = lateral aspect of each cerebral hemisphere

Choroid plexus of the lateral ventricle

Choroid plexus of the 3rd ventricle

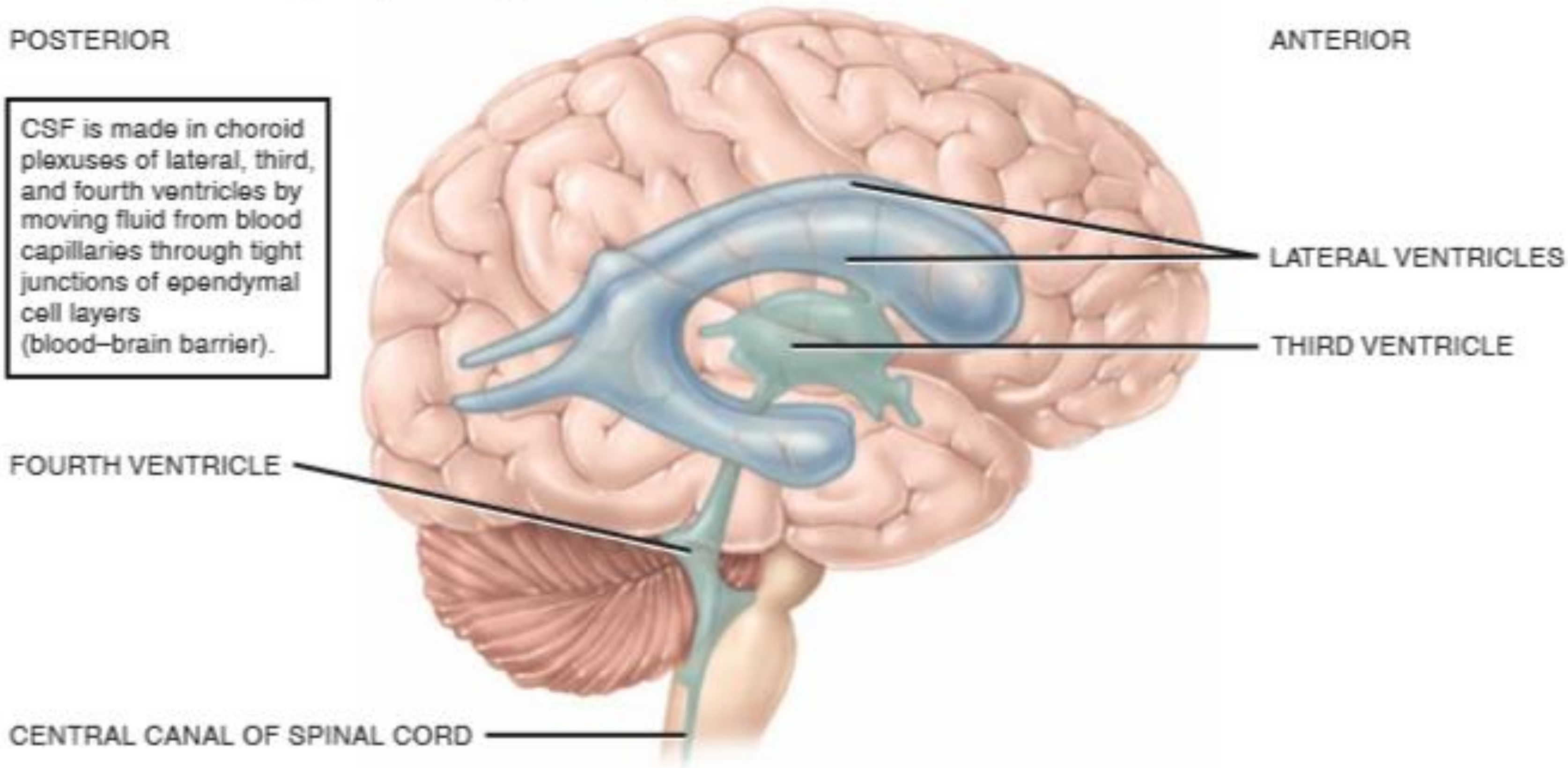
Choroid plexus of the 4th ventricle

Inferiorly = subarachnoid space around the brain & spinal cord

Circulation of the cerebrospinal fluid

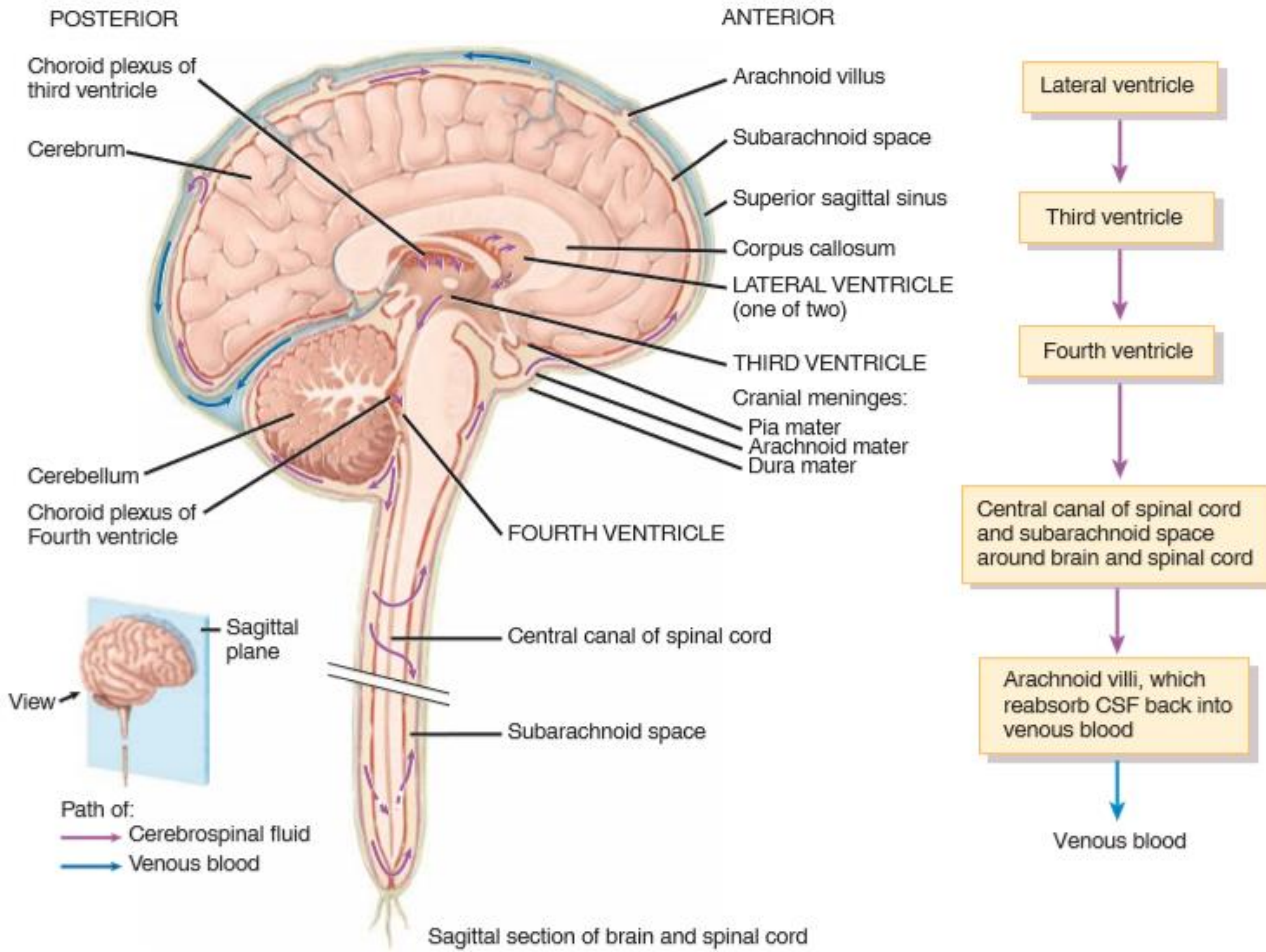
CSF is produced in the ventricles and circulates through the ventricles and around the brain and spinal cord.

a. View of the ventricles (through a transparent brain)



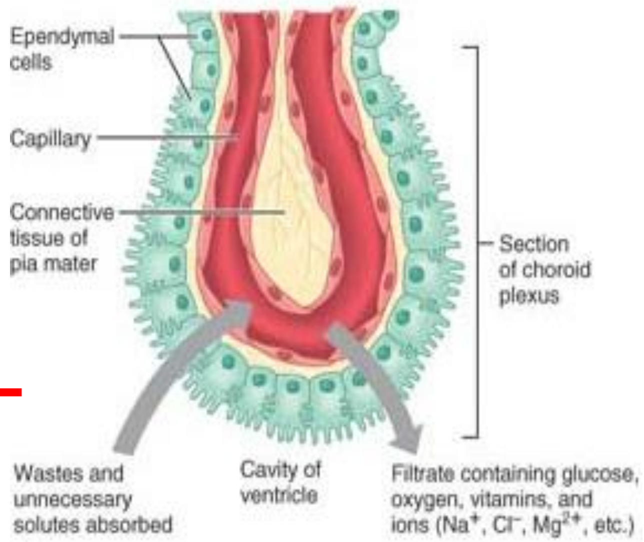
Right lateral view of brain

Flow of CSF through the brain and spinal cord



- In adults, the total CSF volume of about 150 ml (about half a cup) is replaced every 8 hours.
- About 500 ml of CSF is formed daily.
- Choroid plexuses (csf forming regions) are clusters of broad, thin-walled capillaries (plex = interwoven) enclosed first by pia mater and then by a layer of ependymal cells lining the ventricles.
- These capillaries are fairly permeable, and tissue fluid filters continuously from the bloodstream to form the csf.
- The choroid plexuses also help cleanse the CSF by removing waste products and unnecessary solutes.

choroid plexus



FUNCTIONS OF CSF-support,nutrition

- The low specific gravity of CSF (1.007) relative to that of the brain(1.040) reduces the effective mass of a 1400g brain to only 47g
- *Stable supply of nutrients ,primarily glucose; also vitamins /eicosanoids/monosaccharides/neutral & basic Amino acids*

Control of the chemical environment

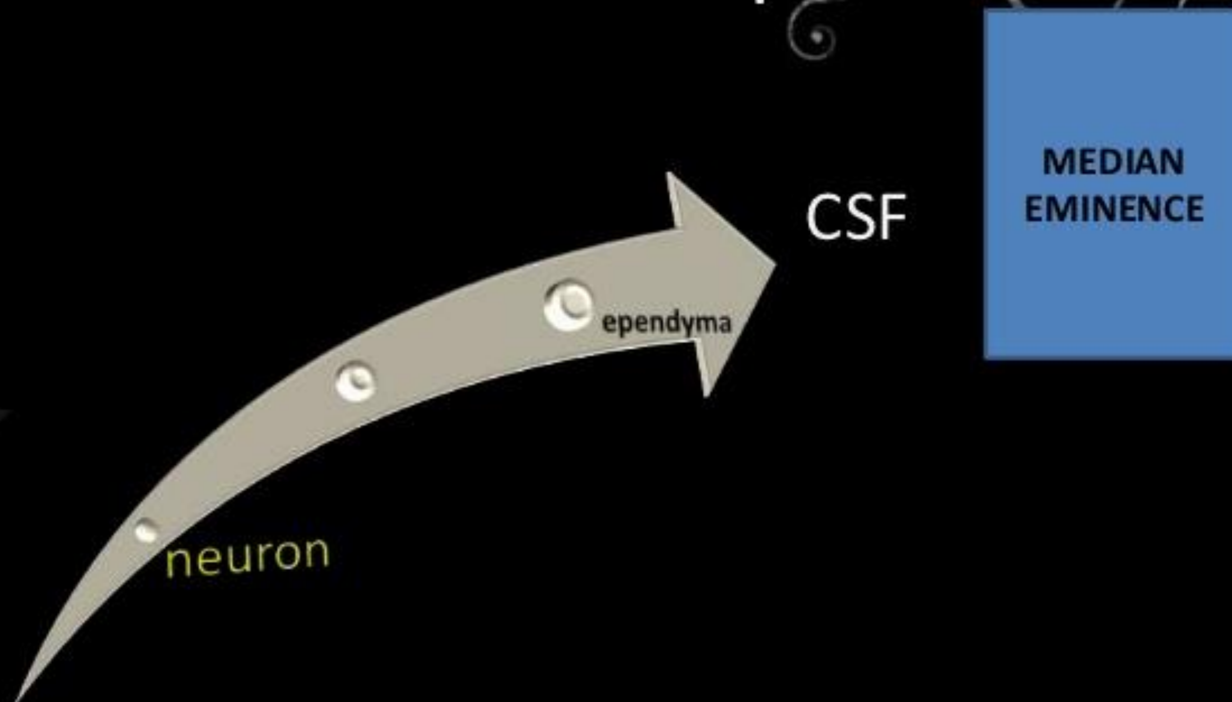
- Exchange between neural tissue & CSF is easy diffusion distance 15mm (max) & ISF space and CSF spaces are continuous

Control of the chemical environment

Excretion

- Removes metabolic products,unwanted drugs
- BBB excludes out toxic large,polar and lipid insoluble drugs, humoral agents etc

Intracerebral transport



- Neurohormone releasing factors formed in hypothalamus

- Ordinarily, CSF is produced and drained at a constant rate.
- However, if something (such as a **tumor) obstructs its circulation or drainage,** it accumulates and exerts pressure on the brain.
- This condition is called **hydrocephalus ("water on the brain**"). Hydrocephalus in a newborn baby

Meningitis

- An **inflammatory process of the meninges and CSF within the subarachnoid space** presents with a characteristic combination of **pyrexia, headache and meningism**.
- **Meningism,** which can occur in other situations (e.g. subarachnoid haemorrhage), consists of **stiffness of the neck**, often with other signs of meningeal irritation: **Kernig's sign** (with the hip joint flexed, extension at the knee causes spasm in the hamstring muscles) and **Brudzinski's sign** (passive flexion of the neck causes flexion of the thighs and knees).
- Meningitis is usually caused by an infection, **but *chemical meningitis*** may also occur in response to a nonbacterial irritant **introduced into the subarachnoid space**.

- On the basis of the characteristics of inflammatory exudate on CSF examination and the clinical evolution of the illness, **Infectious meningitis is broadly classified into**
  1. **acute pyogenic** (usually bacterial meningitis),
  2. **Aseptic** (usually acute viral meningitis), and
  3. **Chronic** (usually tuberculous, spirochetal, or cryptococcal)

1. Acute Pyogenic (Bacterial) Meningitis

BACTERIAL CAUSES OF MENINGITIS

Age of onset	Common	Less common
Neonate	Gram-negative bacilli (*Escherichia coli*, *Proteus* etc.) Group B streptococci	*Listeria monocytogenes*
Pre-school child	*Haemophilus influenzae*	*Mycobacterium tuberculosis* *Neisseria meningitidis* *Streptococcus pneumoniae*
Older child and adult	*Neisseria meningitidis* *Streptococcus pneumoniae*	*Listeria monocytogenes* *Mycobacterium tuberculosis* *taphylococcus aureus* (skull fracture) *Haemophilus influenzae*

- Listeria monocytogenes has recently emerged as an increasing cause of meningitis in the immunosuppressed, diabetics, alcoholics and pregnant women.

Pathology

- The **pia-arachnoid is congested** and **infiltrated with inflammatory cells.**
- A thin layer of **pus forms** and this may later **organise to form adhesions.**
- These may cause **obstruction to the free flow of CSF** leading to **hydrocephalus**, or they may **damage the cranial nerves at the base of the brain.**
- The **CSF pressure rises rapidly**, the **protein content increases**.
- **Pneumococcal meningitis** is often associated with a **very purulent CSF and a high mortality**, especially in older adults.

Clinical features

- Headache,
- Drowsiness,
- Fever and
- Neck stiffness are the usual presenting features.
- In severe bacterial meningitis the patient may be **comatose and later there may be focal neurological signs**.
- Meningococcal meningitis is associated with a **purpuric rash** in 70% of cases

Investigations

- **Lumbar puncture** is mandatory unless there are contra-indications
- Drowsy patient with focal neurological signs or seizures, it is wise to obtain a **CT scan.**
- In bacterial meningitis the **CSF is cloudy** (turbid) due to the presence of many **neutrophils (often > 10^9 cells/litre**), the **protein content is significantly elevated and the glucose reduced.**
- Polymerase chain reaction (PCR) techniques can be used on both blood and CSF to identify bacterial DNA

2. Acute Aseptic (Viral) Meningitis

- Aseptic meningitis is a **misnomer,** but it is a clinical term referring to the **absence of recognizable organisms in an illness** with **meningeal irritation, fever, and alterations of consciousness of relatively acute onset**.
- The disease is generally of **viral**, and rarely of bacterial or other etiology.
- ***In CSF*** *there is a lymphocytic, the protein elevation is only moderate, and the sugar content is nearly always normal.*
- The viral aseptic meningitides are **usually self-limiting** and are treated symptomatically.
- In approximately 70% of cases, a pathogen can be identified, most commonly an **enterovirus**.
- **Echovirus, coxsackievirus, and nonparalytic poliomyelitis are responsible for up to 80% of these cases**

3. TUBERCULOUS MENINGITIS

More frequently as a **secondary infection in patients with AIDS**.

The usual local source of infection is a **caseous focus in the meninges or brain substance adjacent to the CSF pathway**. The brain is covered by a greenish, gelatinous exudate, especially around the base.

CLINICAL FEATURES OF TUBERCULOUS MENINGITIS

- Headache
- Vomiting
- Low-grade fever
- Lassitude
- Depression
- Confusion
- Behaviour changes
- Papilloedema

Investigations

- The CSF is under increased pressure.
- It is usually clear but, when allowed to stand, a fine clot (**'spider web'**) may form.
- The fluid contains up to **5 × 10^8 cells/litre**, predominantly **lymphocytes.**
- There is a **rise in protein and a marked fall in glucose**.
- Brain imaging may show hydrocephalus

- **Fungal meningitis** (especially cryptococcosis) usually occurs in patients who are immunosuppressed and is a recognised **complication of HIV infection**. The CSF findings are similar to those of tuberculous meningitis, but the diagnosis can be confirmed by microscopy or specific serological tests.
- In some areas, meningitis may be caused by **spirochaetes** (leptospirosis, **Lyme disease and syphilis**), **rickettsiae** (typhus fever) or **protozoa** (amoebiasis).

CSF analysis in different types of meningitis

CEREBROSPINAL FLUID INDICES IN MENINGITIS*

Condition	Cell type	Cell count	Glucose	Protein	Gram stain
Normal	Lymphocytes	$0\text{-}4 \times 10^6/l$	> 60% of blood glucose	Up to 0.45 g/l	-
Viral	Lymphocytes	10-2000	Normal	Normal	-
Bacterial	Polymorphs	1000-5000	Low	Normal/elevated	+
Tuberculous	Polymorphs/lymphocytes/mixed	50-5000	Low	Elevated	Often -
Fungal	Lymphocytes	50-500	Low	Elevated	±
Malignant	Lymphocytes	0-100	Low	Normal/elevated	-

Special Sense	***Select Function***
Smell	The process of smelling is called **olfaction.** The nerves associated with olfaction pass through the olfactory foramina. Olfactory nerves are the only cranial nerves that go directly to the cerebrum and do not have to be relayed by the thalamus. These nerves are identified as cranial nerve I.
Taste	The process of tasting is called **gustation.** The cells involved are called gustatory cells. These cells are clustered inside taste buds. Taste buds line the papillae of the tongue. The papillae are the bumps on the surface of the tongue. Dissolved food particles stimulate the gustatory cells and a signal is sent via the facial nerve (cranial nerve VII) to the brain for interpretation.
Vision	Light enters the pupil of the eye and stimulates special cells that make up the retina of the eye. Once these cells are stimulated, they send an impulse along the optic nerve and then the impulse is relayed to the occipital lobe of the brain. The special cells of the retina are called rods and cones. The rods function during dim light conditions. They do not sense color. The cones function only during bright light conditions. They sense color.
Special Sense	***Select Function***
Hearing	Sound waves create vibrations in the cochlear region of the ear. These vibrations stimulate special cells that send an impulse via the cochlear nerve (of the vestibulocochlear nerve, cranial nerve VIII) to the brain for interpretation.
Balance	The movement of the body causes movement of fluid within the semicircular canals of the internal ear. This fluid movement stimulates special cells that send an impulse via the vestibular nerve (of the vestibulocochlear nerve, cranial nerve VIII) to the brain for interpretation.

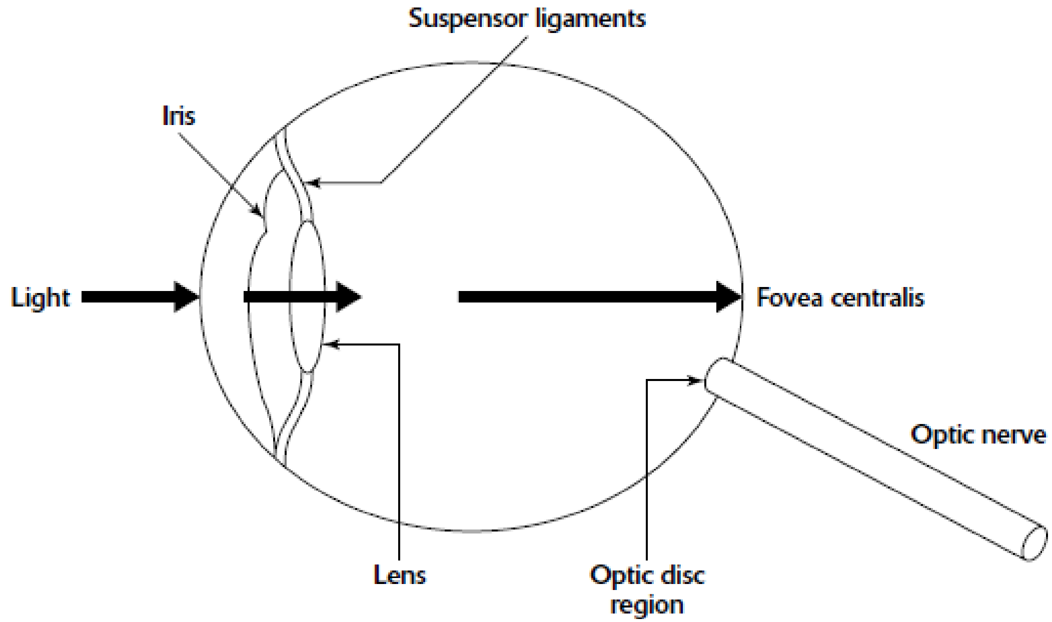
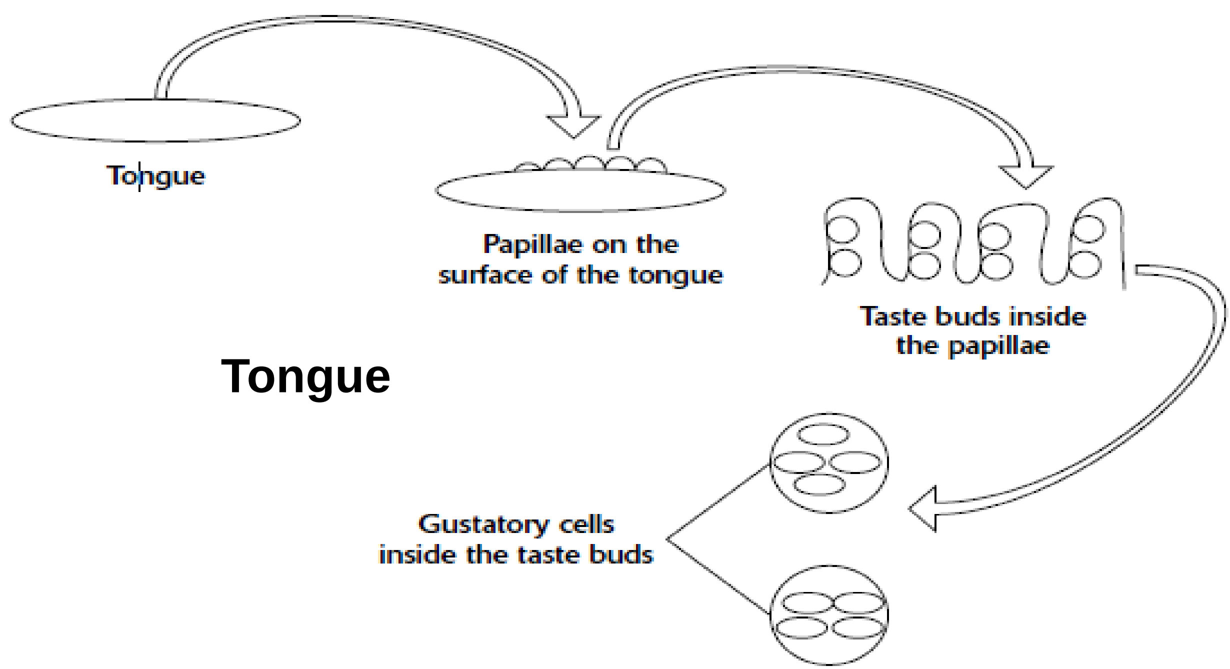


Figure 12-2: Internal eye.



Tongue

Middle ear:

1. M, I, S: sound amplification, impedence matching
2. Tympanic membrane: vibration of sound.
3. Eustachian/ pharyngotympanic tube: Equalise the pressure across the tympanic membrane i.e pressure balance in middle ear respevtive to external ear

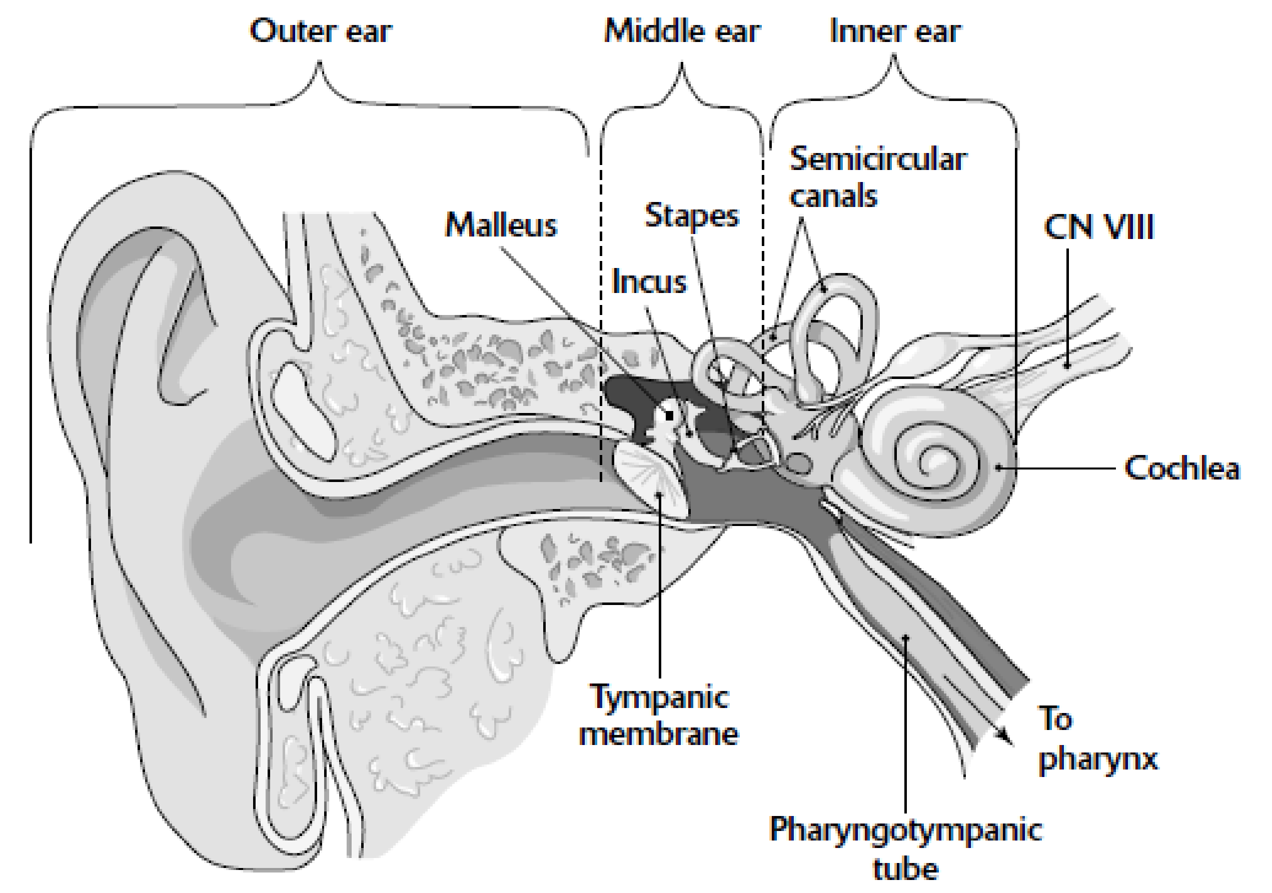


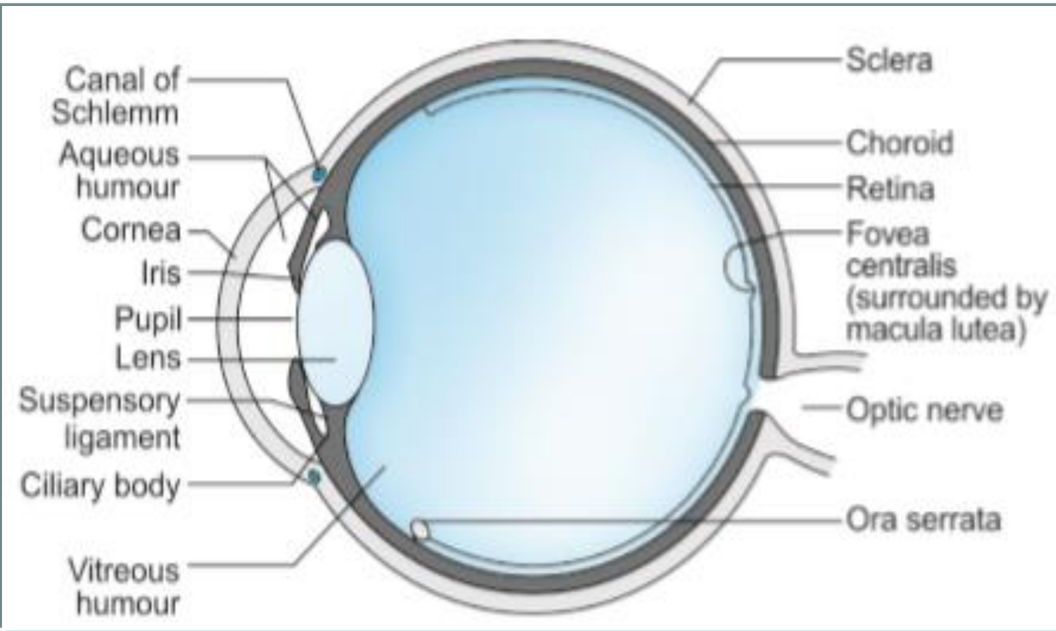
Figure 12-4: The pathway of sound waves.

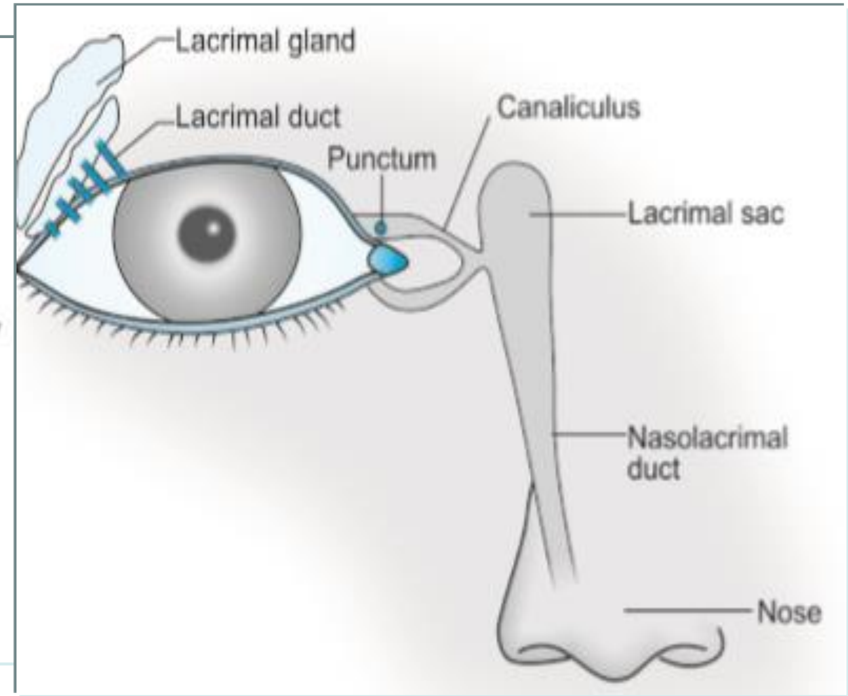
External ear:

1. Pinna; funneling of sound
2. Wax production; protective

INNER EAR:

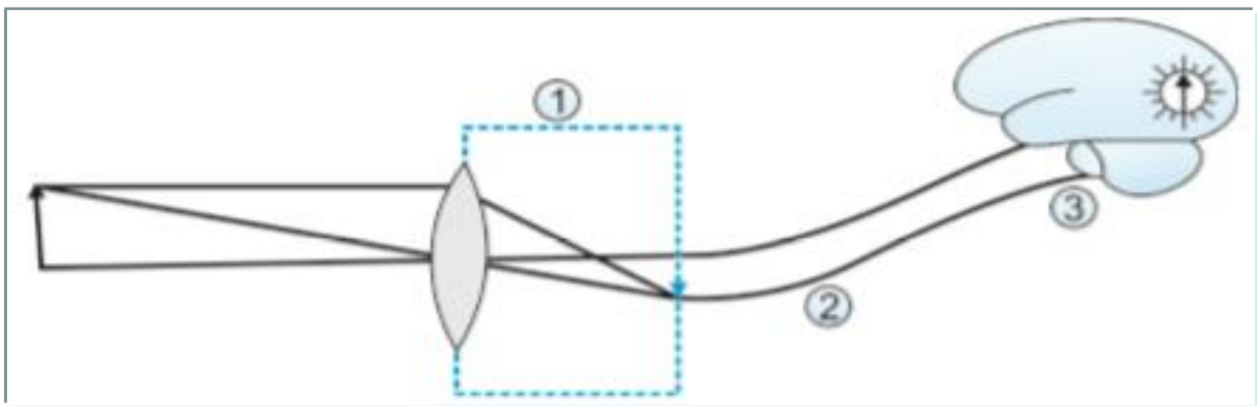
1. Cochlea: hearing apparatus
2. Semicircular canal: balancing apparatus





EYE

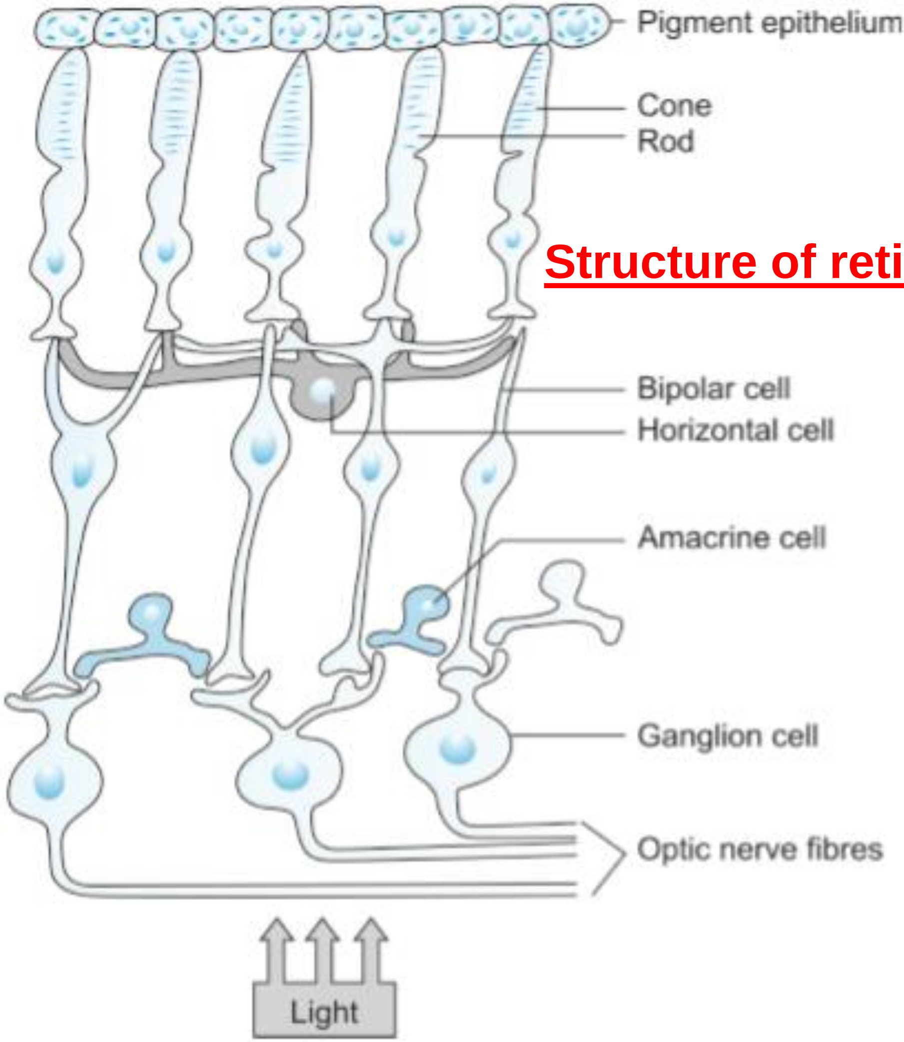
The lacrimal apparatus



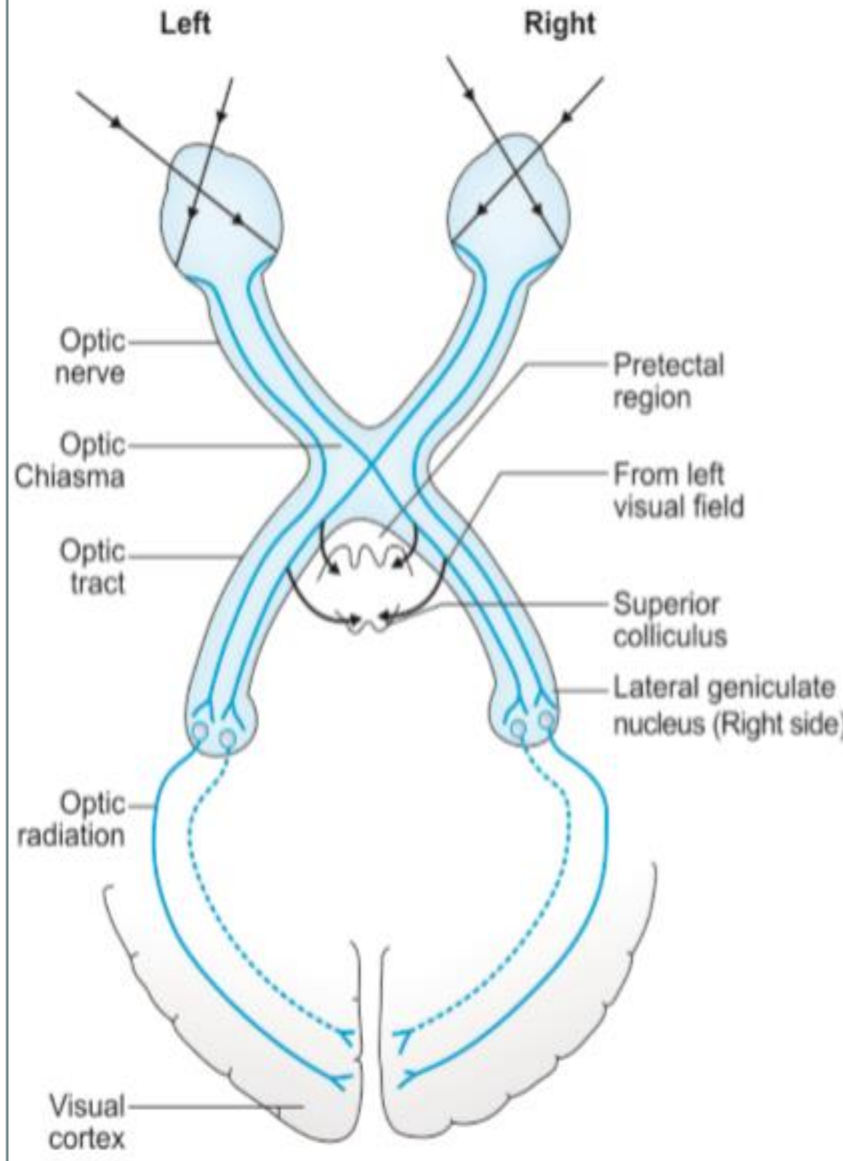
The visual process involves formation of an image (1: Eye) and its transmission (2: visual pathway) to the brain (3: occipital lobe of cerebrum).

- **The wall of the eyeball is made up of three layers**:
  - **Outer sclera**, which continues anteriorly as the transparent and more convex cornea.
  - Middle layer is the **vascular choroid**, which forms the iris and ciliary body anteriorly. The colour of the eye depends on the colour of the iris.
  - **Innermost layer is light-sensitive retina** (3 major types of cells form sublayers within retina; rods & cons form the outer sublayer, bipolar cells form middle sublayer & ganglion cells form inner sublayer of retina). The most peripheral part of the retina is called ora serrata. The central part of the retina is responsible for more sharp vision and is called the macula lutea.
- **The function of the eye** is to form an image of the surroundings and transmit it to the brain.
- Tears are secreted by the lacrimal glands; important protective functions; contain bactericidal enzymes lysozyme.
- Tears also reduce friction between the eyelids and the eyeball during blinking
- Tears also express emotions, perhaps only in human beings, specially women.

Structure of retina



Schematic diagram of the structure of the retina. Note that the chain essentially consists of rods/cones, bipolar cells and ganglion cells. Horizontal cells and amacrine cells possibly achieve horizontal integration of information.



The principal visual pathways.

Visual pathway from eye to brain

ERRORS OF REFRACTION