Review of anatomy and physiology

Structural Divisions

- The **central nervous system** (CNS) includes the brain and spinal cord.
- The **peripheral nervous system** (PNS) is made up of all the nerves outside the CNS. It includes all the **cranial nerves** and all the **spinal nerves**.

Functional Divisions

Functionally, the nervous system is divided according to whether control is *voluntary or involuntary* and according to what *type of tissue* is stimulated

- The **somatic nervous system** is controlled *voluntarily* , and all its effectors are *skeletal muscles* .

- The *involuntary* division of the nervous system is called the **autonomic nervous system** (ANS). It is also called the **visceral nervous system** because it controls *smooth muscle, cardiac muscle, and glands*, much of which make up the soft body organs, the viscera.

The ANS is further subdivided into a **sympathetic nervous system** and a **parasympathetic nervous system** based on organization and how each affects specific organs.

The human central nervous system (CNS) contains about 10^{11} (100 billion) **neurons.** It also contains 10–50 times this number of **glial cells.**

Glial Cells

Unlike neurons, glial cells continue to undergo cell division in adulthood .

The four types of CNS neuroglia are astrocytes, oligodendrocytes, microglia, and ependyma:

1.Oligodendrocytes and **Schwann cells:** are involved in myelin formation around axons in the CNS and peripheral nervous system, respectively.

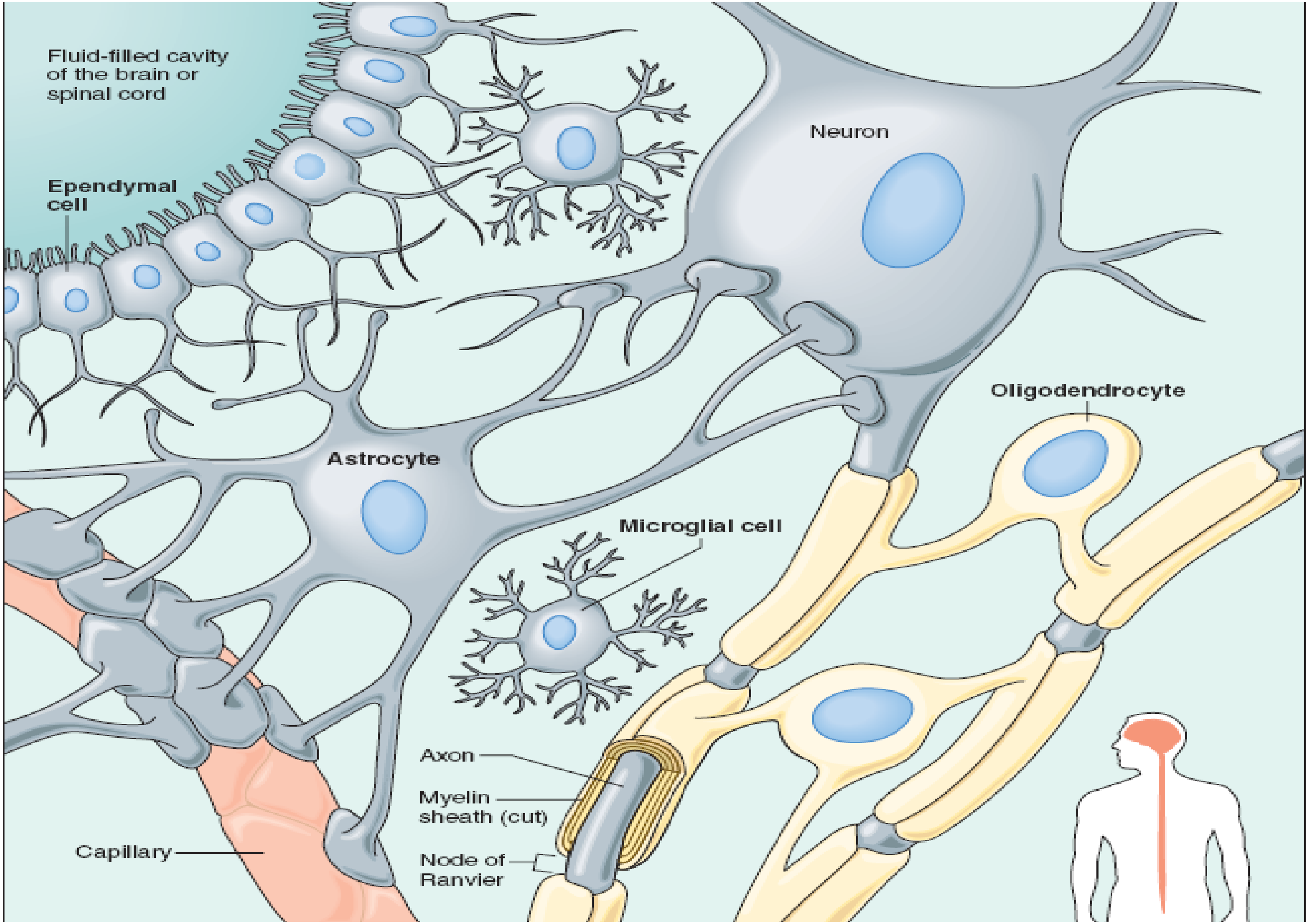
2. Astrocytes: which are found throughout the brain, are of two subtypes.

***Fibrous astrocytes*,** found primarily in white matter, are concerned with repair of damaged tissue (scaring).

Protoplasmic astrocytes are found in gray matter, they may serve as a metabolic intermediary for nerve cells. Both types are involved in the formation of **blood–brain barrier.**

3. Microglia: are cells that resemble tissue macrophages and remove debris resulting from injury, infection, and disease .

4. Ependyma: They form the inner lining of the *central canal* that extends downward through the spinal cord. These cells also cover the inside of spaces in the brain called *ventricles*. Ependymal cells also cover the specialized capillaries called *choroid plexuses* associated with the ventricles of the brain. Here they help regulate the composition of the cerebrospinal fluid.


Fluid-filled cavity of the brain or spinal cord
Ependymal cell
Neuron
Oligodendrocyte
Astrocyte
Microglial cell
Axon
Myelin sheath (cut)
Node of Ranvier
Capillary

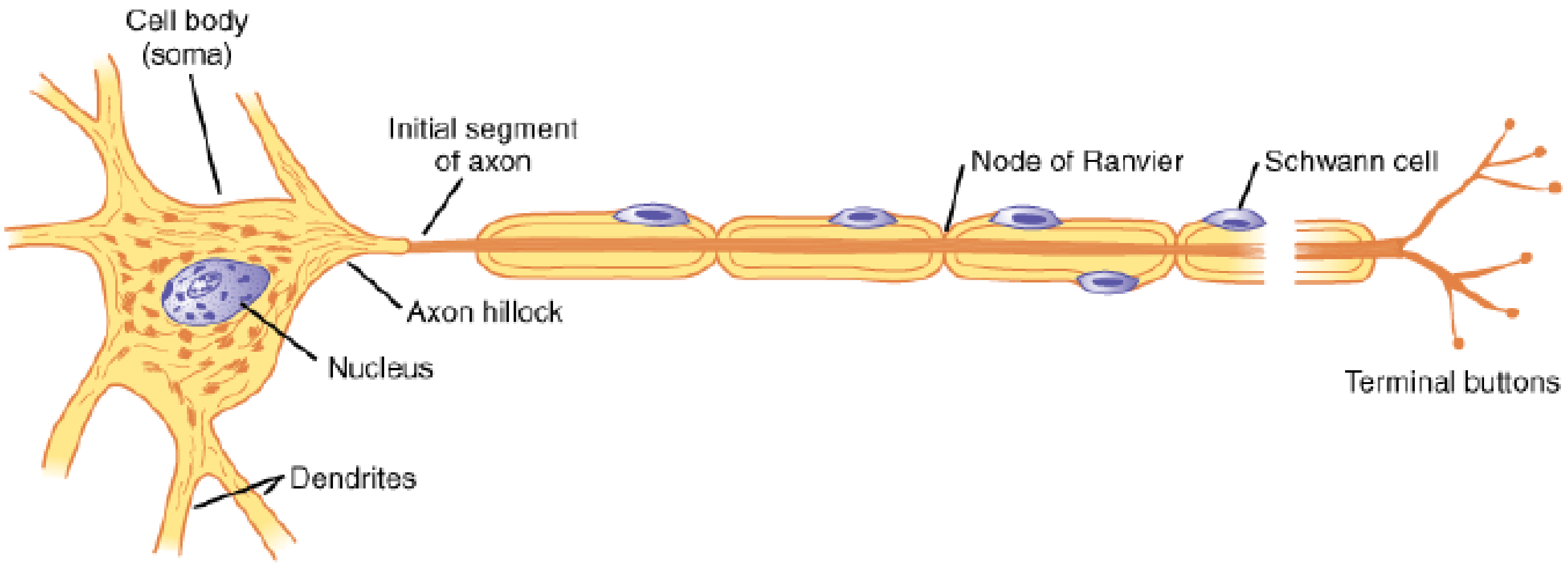
Neurons

Neurons or nerve cells are comsist of:

- Cell body **(soma)** contains the nucleus and is the metabolic center of the neuron.

- Several processes called **dendrites** that extend outward from the cell body and arborize extensively.

- Long fibrous **axon** that originates from a somewhat thickened area of the cell body, the **axon hillock.** The axon divides into **presynaptic terminals,** each ending in a number of **synaptic knobs** which are also called **terminal buttons** or **boutons.** They contain granules or vesicles in which the synaptic transmitters secreted by the nerves are stored.



Cell body
(soma)
Initial segment
of axon
Node of Ranvier
Schwann cell
Axon hillock
Nucleus
Terminal buttons
Dendrites

Resting Membrane Potential

- An electrical potential difference, or ***membrane potential*,** can be recorded across the plasma membrane of living cells.
- The potential of unstimulated muscle and nerve cells, or ***resting potential*,** amounts to – 70mV (polarized with the cell interior is negative).
- A resting potential is caused by a slightly unbalanced distribution of ions between the intracellular fluid (ICF) and extracellular fluid (ECF).

Action Potential

- **Excitation** of a neuron occurs if the membrane potential on the axon hillock of neuron, changes from its resting value (polarized – 70) to a less negative value (*slow depolarization*). This depolarization may be caused by electrical, chemical, or mechanical stimulus .
- If the membrane potential of a stimulated cell comes close to the **threshold Potential** “rapid” voltage-gated Na+ channels are activated. This results in *increased Na+ conductance* and the entry of Na+ into the cell. If the threshold potential is not reached, this process remains a **local (non-propagated) potential.**

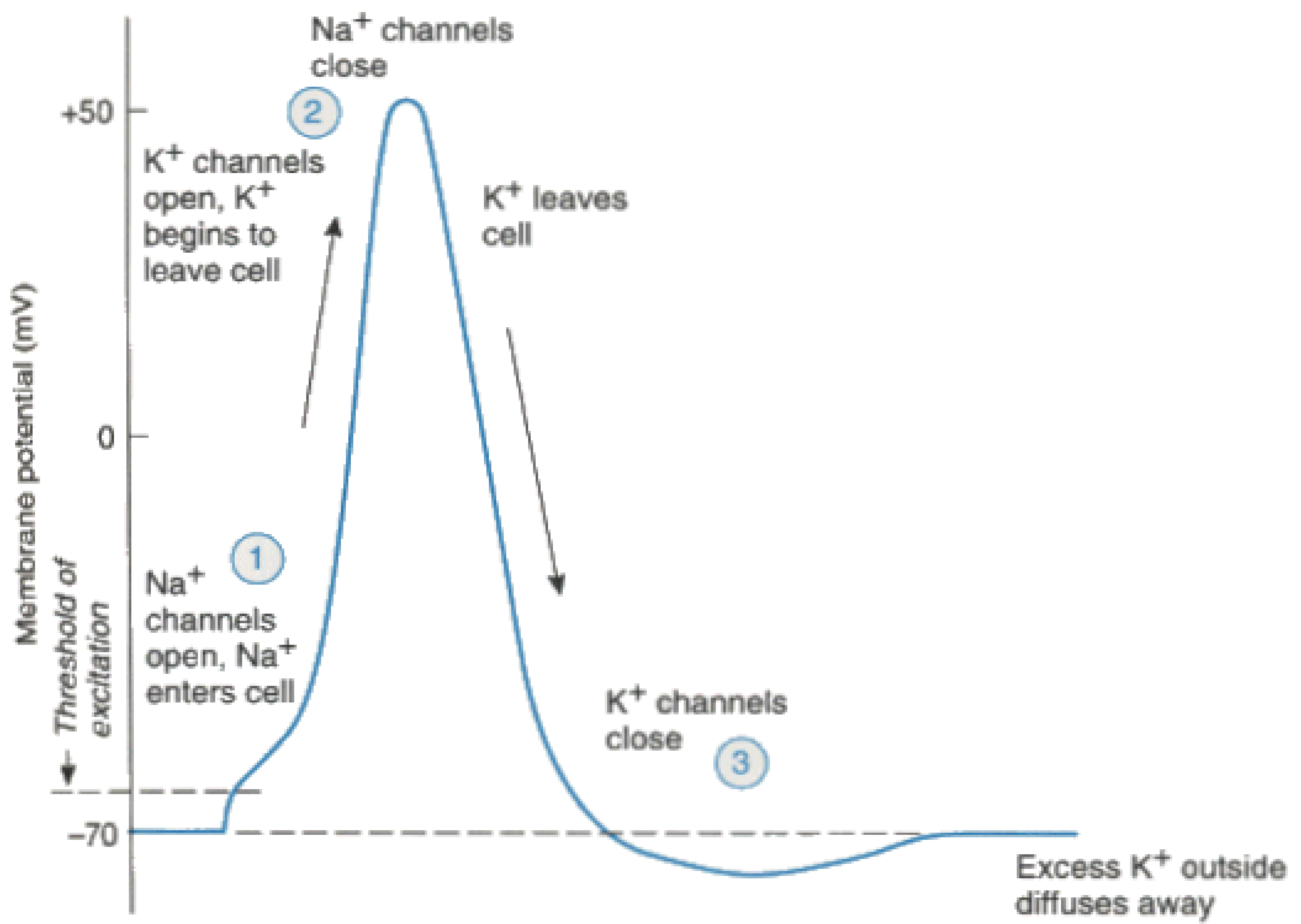
- Once the threshold potential is reached, the cell responds with a fast depolarization called an **action potential**.

- Large numbers of Na+ channels are activated, and the influxing Na+ accelerates depolarization.

- As a result, the membrane potential rapidly depolarized (*fast depolarization phase*) and temporarily reaches positive levels (*overshooting*, + 20 to + 30 mV).

- The Na conductance drops before overshooting occurs, because the Na+ channels are *inactivated* within 0.1ms. The potential therefore reverses, and restoration of the resting potential, the **repolarization phase** of the action potential, begins. Depolarization increases (relatively slowly) the open-probability of voltage-gated K+ channels. This increases the potassium conductance, thereby accelerating repolarization.

- In many cases, potassium conductance, is still increased after the original resting potential has been restored, resulting in a hyperpolarizing **afterpotential**.



Na+ channels close
2
+50
K+ channels open, K+ begins to leave cell
K+ leaves cell
0
Membrane potential (mV)
1
Na+ channels open, Na+ enters cell
Threshold of excitation
K+ channels close
3
−70
Excess K+ outside diffuses away

THE SYNAPSE

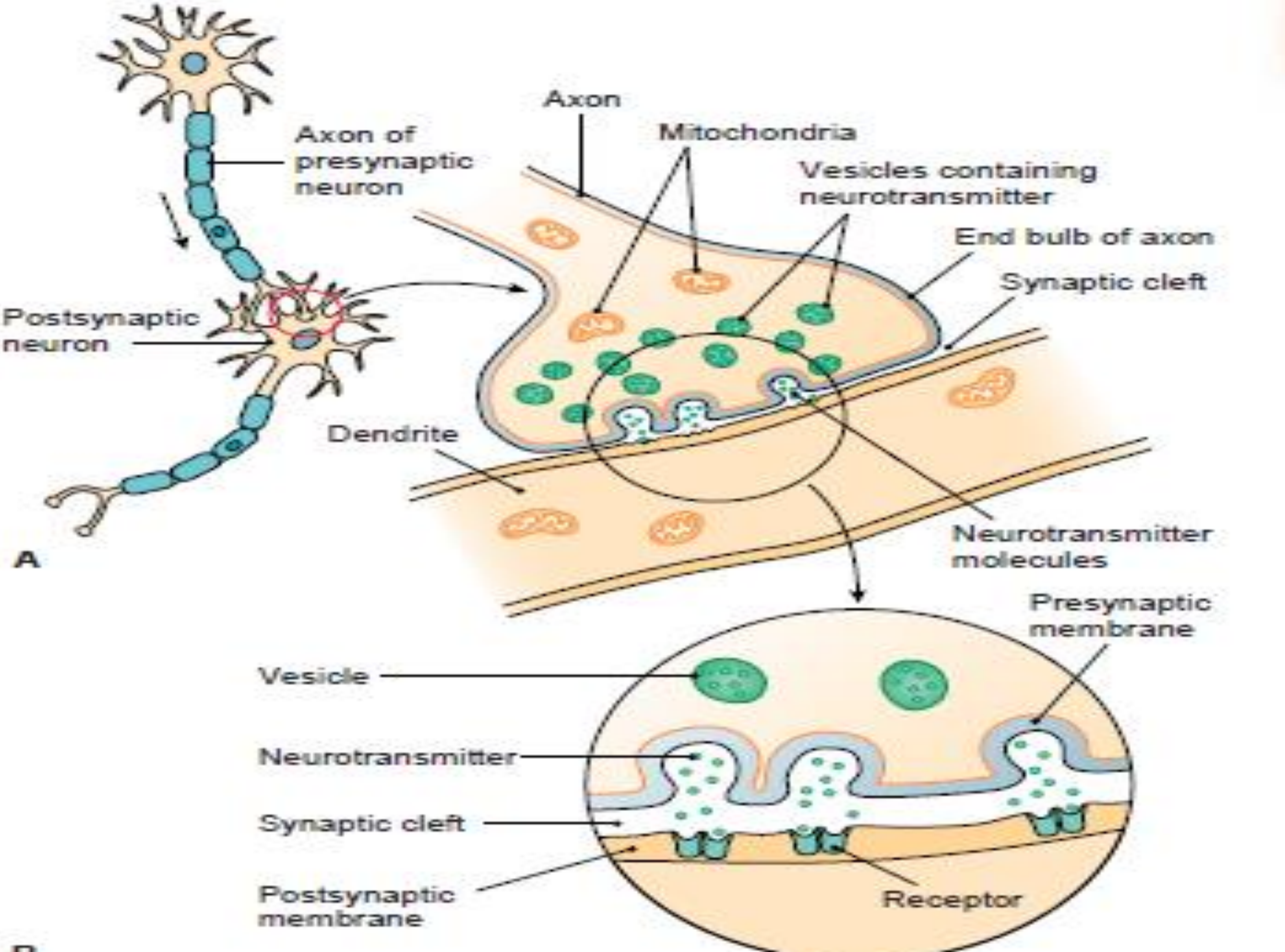
Nerve impulses pass from neuron to neuron (or to other cells) at synapses. A ***presynaptic neuron*** brings the impulse to the synapse and, as a result, stimulates or inhibits a ***postsynaptic neuron*** (or a muscle or gland). **A*synaptic cleft*,** or gap, separates the two cells.

Synaptic transmission

- A nerve impulse travels along the axon to the axon terminal. When a nerve impulse reaches a synaptic knob, *voltage-sensitive calcium channels* open and calcium diffuses inward from the extracellular fluid.

- The increased calcium concentration inside the cell initiates a series of events that fuses the synaptic vesicles with the cell membrane, where they release their neurotransmitter by exocytosis.

- Once the neurotransmitter binds to receptors on a postsynaptic cell, the action of neurotransmitter on the postsynaptic cell is either excitatory (turning a process on) or inhibitory (turning a process off).



Axon of
presynaptic
neuron
Postsynaptic
neuron
A
Axon
Mitochondria
Vesicles containing
neurotransmitter
End bulb of axon
Synaptic cleft
Dendrite
Neurotransmitter
molecules
Presynaptic
membrane
Vesicle
Neurotransmitter
Synaptic cleft
Postsynaptic
membrane
Receptor

Spinal cord

The **spinal cord** is a slender column of nervous tissue that is continuous with the brain and extends downward through the vertebral canal.

It originates at the level of the *foramen magnum*. And terminates near the intervertebral disc that separates the first and second lumbar vertebrae.

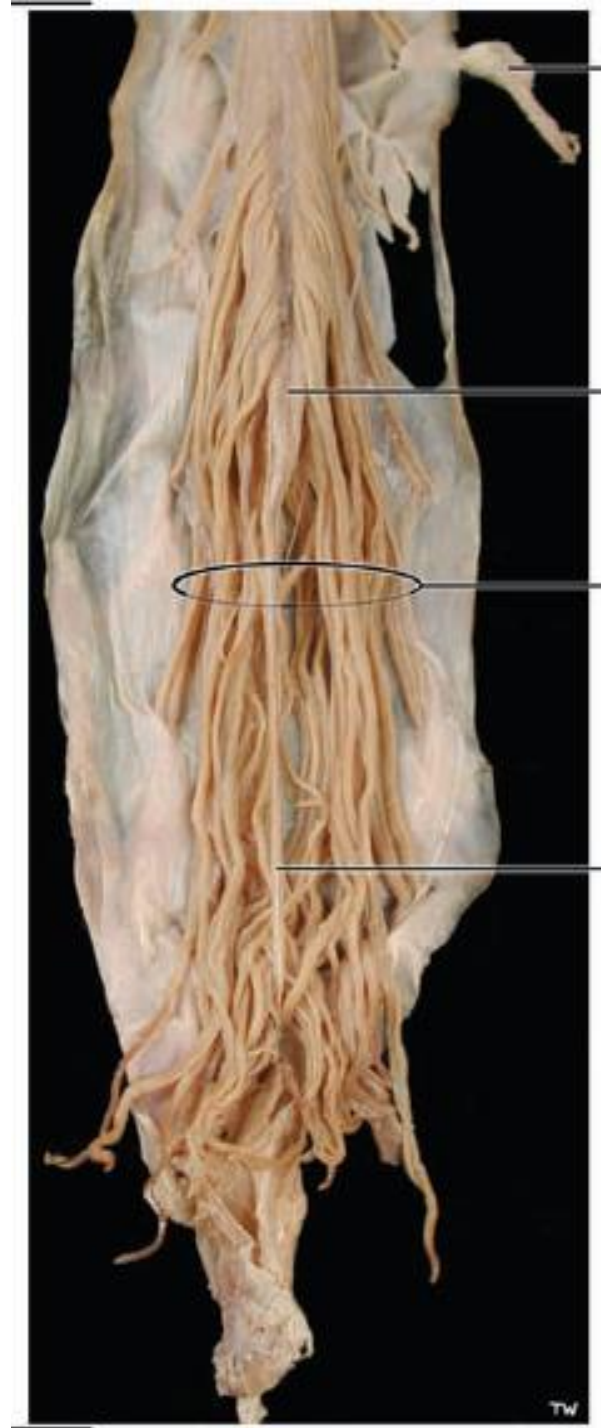
Structure of the Spinal Cord

- The spinal cord consists of thirty-one segments, each of which gives rise to a pair of **spinal nerves.**
- It has tow **enlargments (*cervical enlargement*** and ***lumbar enlargement*)** *which* gives off nerves to the upper and lower limbs respectivly.
- Just inferior to the lumbar enlargement, the spinal cord tapers to a structure called the ***conus medullaris,*** from which a pia-glial filament the ***filum terminale***, extend to the coccyx to anchor the spinal cord.

- Because of the differential rate of growth of the spinal cord and the vertebral column, spinal cord segment do not correspond to those of the vertebral column.

- Because of this the root filaments of the spinal cord segments have to travel progressively longer distance from cervical to sacral segments to reach the corresponding intervertebral foramina from which the spinal nerves emerge.

- The crowding of the lumbosacral roots around the filum terminale is known as the ***cauda equine*** (resembles a horse's tail).

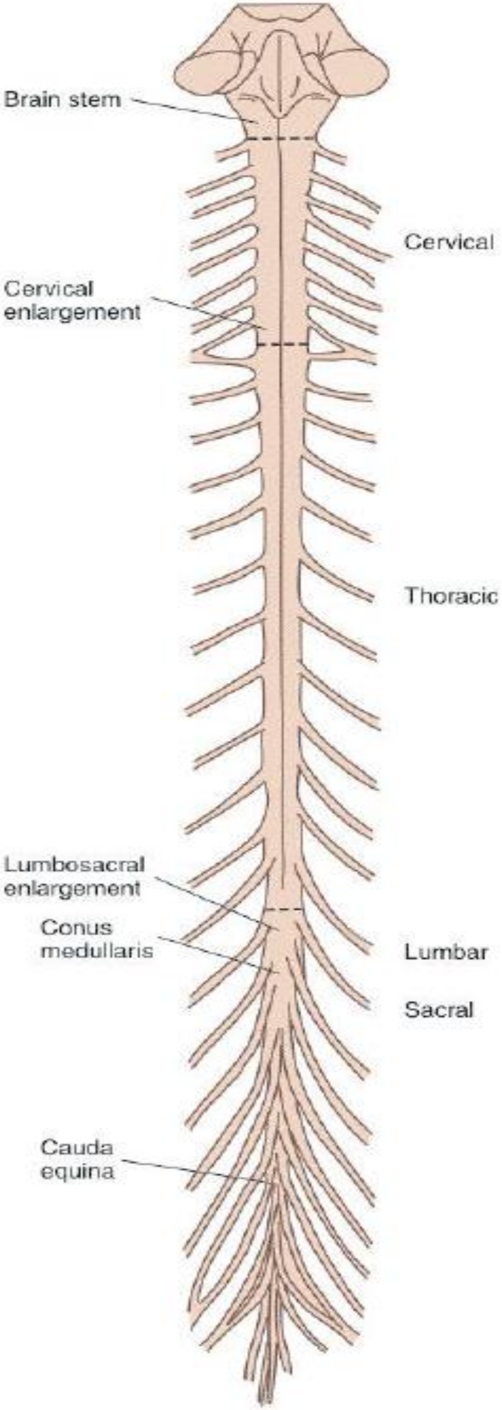

Dorsal root ganglion
Conus medullaris
(sacral spinal cord)
Cauda equina
(L3 - S5 nerve roots)
Filum terminale
TW

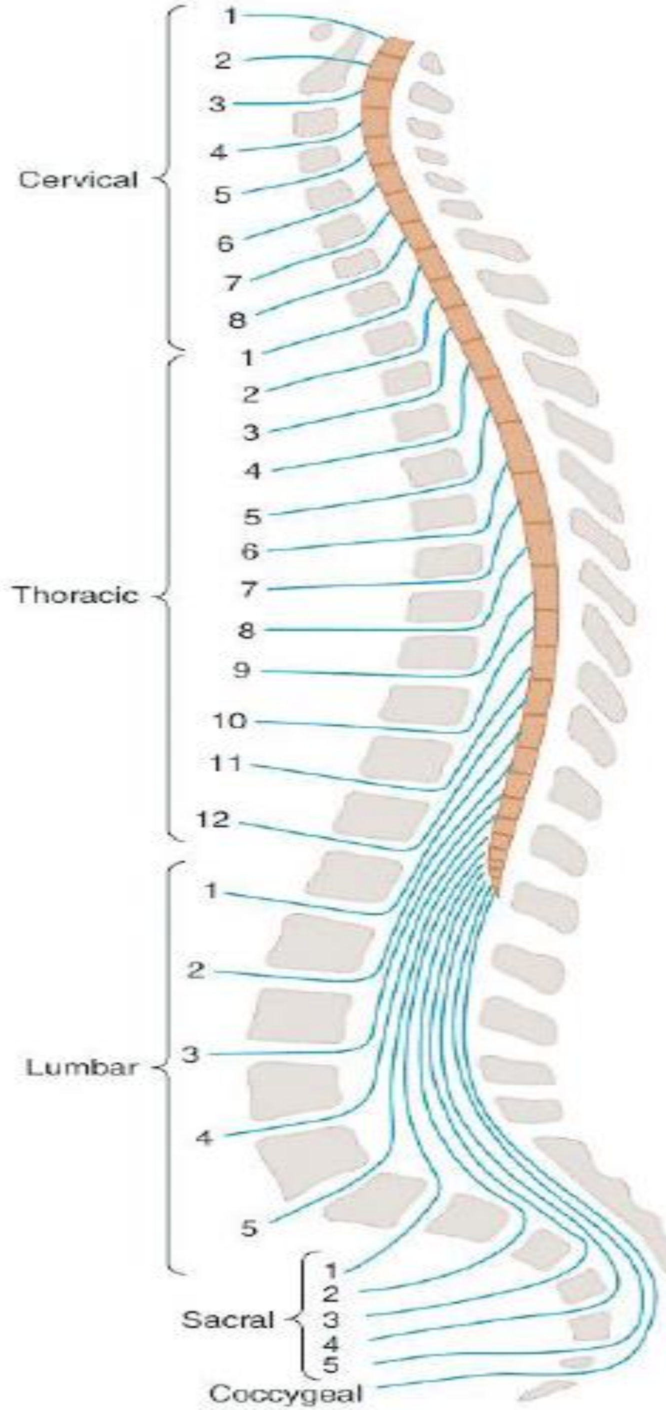
- The spinal cord is covered by three meningial coats; these are the *pia, arachnoids, and dura mater*.

- The spinal cord terminates at the level of L1-L2 vertebrae whereas the dura mater extends down to the level of S1-S2 vertebrae.

- A sac filled with CSF and devoid of the spinal cord is formed in the subarachnoid space; this sac is a favorable site for ***LP.***

- Two grooves, a deep ***anterior median fissure*** and a shallow ***posterior median sulcus,*** extend the length of the spinal cord, dividing it into right and left halves.


Brain stem
Cervical
Cervical enlargement
Thoracic
Lumbosacral enlargement
Conus medullaris
Lumbar
Sacral
Cauda equina


Cervical
1
2
3
4
5
6
7
8
Thoracic
1
2
3
4
5
6
7
8
9
10
11
12
Lumbar
1
2
3
4
5
Sacral
1
2
3
4
5
Coccygeal

- In cross-section, the spinal cord is composed of centrally placed, *butterfly or H-shaped core of gray matter surrounded by white matter*.

- The gray matter of the cord contains primarily cell bodies of neurons and glia, while the white part of the cord contains primarily ascending and descending tracts (axons).

- The white matter divided in each side of the spinal cord into; ventral, lateral, and dorsal funiculus.

- The gray matter is also divided into ventral and dorsal horn.

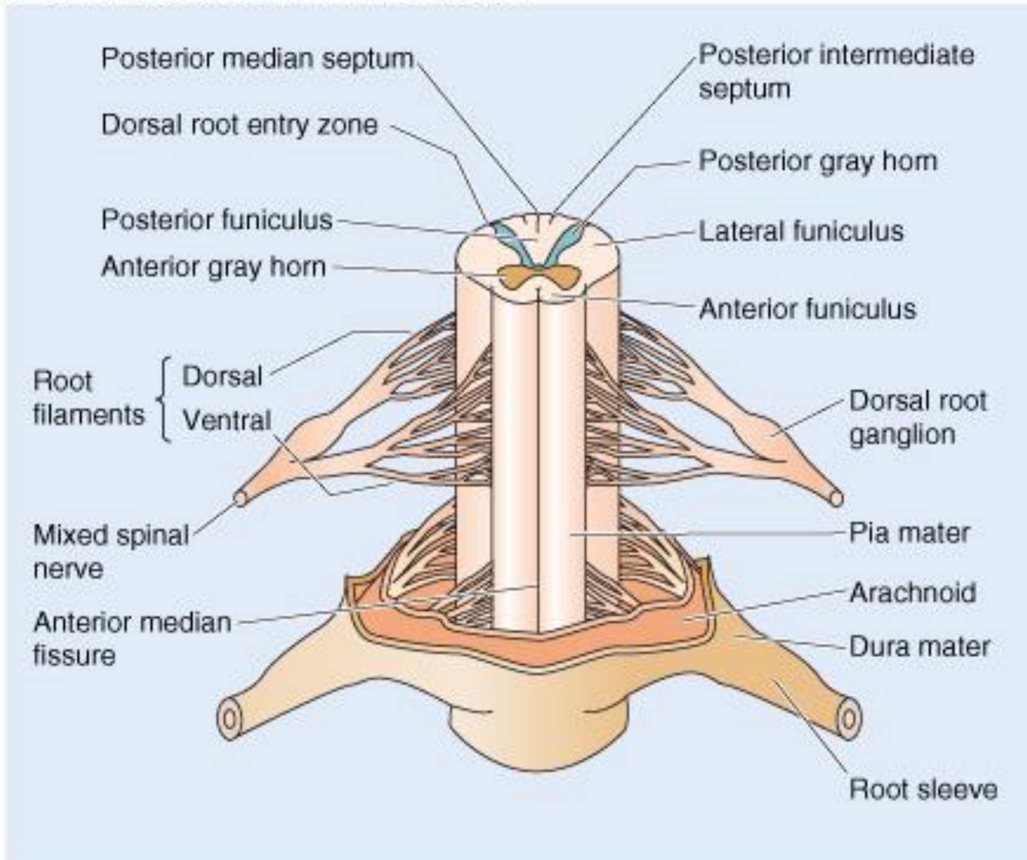
- Sensory information from the skin, muscle, and visceral organs enters the spinal cord via axons called *dorsal roots*.

- Dorsal root axons have their cell bodies of origin in the spinal ganglia (i.e., *dorsal root ganglia*) associated with that spinal segment.

- *Ventral roots* contain strictly efferent fibers. These fibers arise from motor neurons whose cell bodies are located in the ventral (or anterior) gray horns of the spinal cord .

- Most of the efferent fibers innervate skeletal muscle to mediate voluntary movement. The other fibers are visceral efferents innervate visceral smooth muscle or glandular tissue.

A SPINAL CORD AND NERVE ROOTS



Blood Supply of the Spinal Cord

The spinal cord receives its arterial supply from three small arteries: the two posterior spinal arteries and the anterior spinal artery.

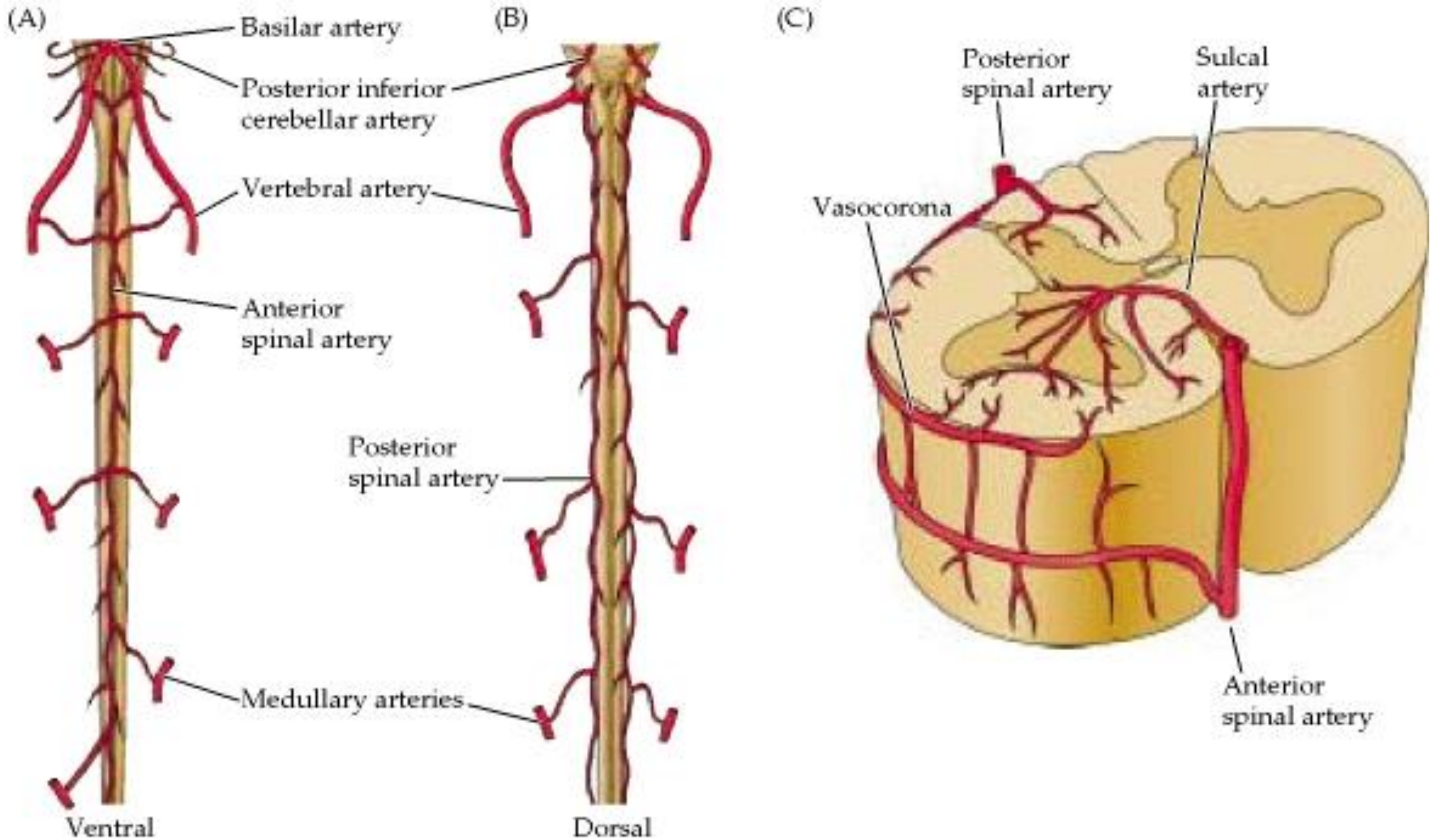
Posterior Spinal Arteries

- The posterior spinal arteries arise either directly from the *vertebral arteries* inside the skull or indirectly from the *posterior inferior cerebellar arteries*.

- Each artery descends on the posterior surface of the spinal cord and gives off branches that enter the substance of the cord. The posterior spinal arteries supply the posterior one-third of the spinal cord.

Anterior Spinal Artery

- The anterior spinal artery is formed by the union of two arteries, each of which arises from the vertebral artery inside the skull.
- The anterior spinal artery then descends on the anterior surface of the spinal cord within the *anterior median fissure*.
- Branches from the anterior spinal artery enter the substance of the cord and *supply the anterior two-thirds of the spinal cord.*



(A)
Basilar artery
Posterior inferior cerebellar artery
Vertebral artery
Anterior spinal artery
Medullary arteries
Ventral
(B)
Posterior spinal artery
Dorsal
(C)
Posterior spinal artery
Sulcal artery
Vasocorona
Anterior spinal artery

Segmental Spinal Arteries

At each intervertebral foramen, the longitudinally running posterior and anterior spinal arteries are reinforced by small segmental arteries on both sides.

The arteries are branches of arteries outside the vertebral column *(deep cervical, intercostal, and lumbar arteries)..*

Functions of the Spinal Cord

The spinal cord has two main functions.

- First, it is a center for spinal reflexes.

- Second, it is a conduit for nerve impulses to and from the brain.

TABLE 11.3 | Nerve Tracts of the Spinal Cord

Tract	Location	Function
Ascending Tracts		
1. Fasciculus gracilis and fasciculus cuneatus	Posterior funiculi	Conduct sensory impulses associated with the senses of touch, pressure, and body movement from skin, muscles, tendons, and joints to the brain
2. Spinothalamic tracts (lateral and anterior)	Lateral and anterior funiculi	Conduct sensory impulses associated with the senses of pain, temperature, touch, and pressure from various body regions to the brain
3. Spinocerebellar tracts (posterior and anterior)	Lateral funiculi	Conduct sensory impulses required for the coordination of muscle movements from muscles of the lower limbs and trunk to the cerebellum
Descending Tracts		
1. Corticospinal tracts (lateral and anterior)	Lateral and anterior funiculi	Conduct motor impulses associated with voluntary movements from the brain to skeletal muscles
2. Reticulospinal tracts (lateral, anterior, and medial)	Lateral and anterior funiculi	Conduct motor impulses associated with the maintenance of muscle tone and the activity of sweat glands from the brain
3. Rubrospinal tracts	Lateral funiculi	Conduct motor impulses associated with muscular coordination and the maintenance of posture from the brain

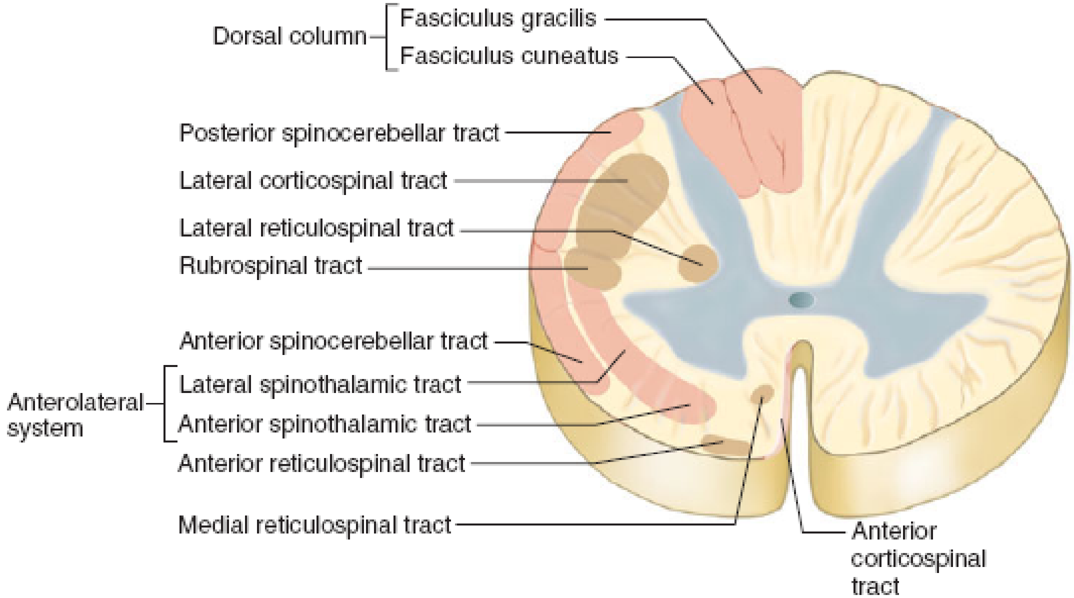
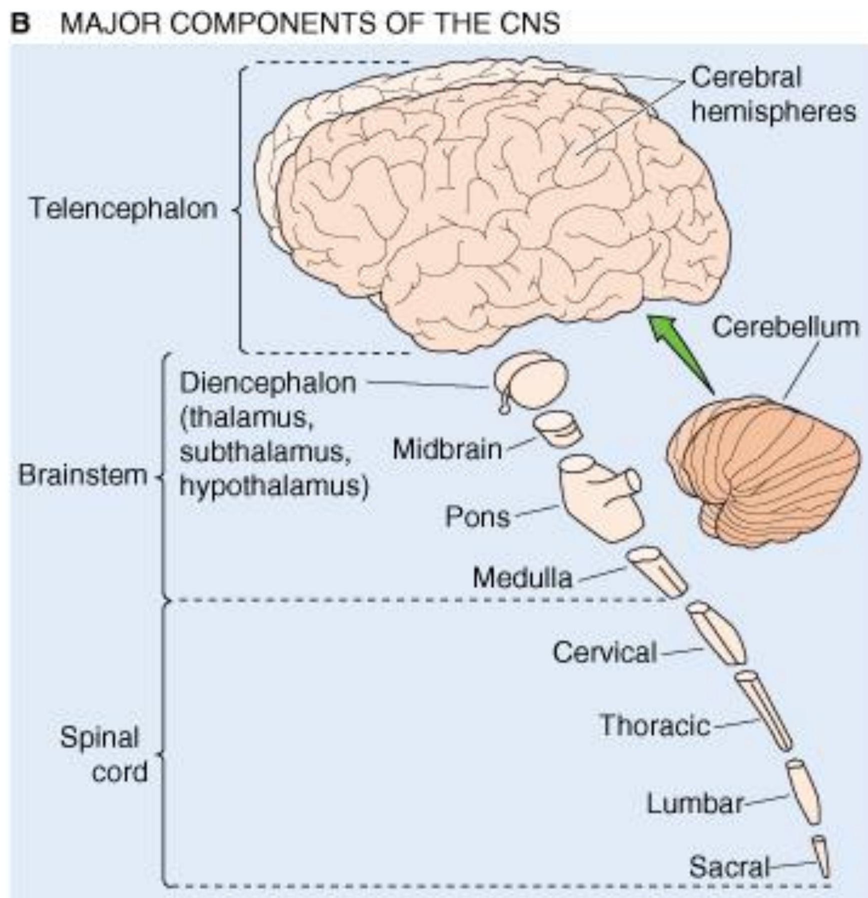


FIGURE 11.11 Major ascending and descending tracts in a cross section of the spinal cord. Ascending tracts are in pink, descending tracts in light brown. (Tracts are shown only on one side.) The pattern varies with the level of the spinal cord. This pattern is representative of the midcervical region.

Central nervous system

The CNS is usually considered to have two major divisions, the brain and the spinal cord the brain is subdivided into the following structures.

- *Telencephalon* consists of bilateral symmetrical cerebral hemispheres.
- *The brain stem* consists of diencephalon (*thalamus, subthalamus, and hypothalamus*), mesencephalon (*midbrain*), pons and medulla oblongata.
- *The cerebellum*.


B MAJOR COMPONENTS OF THE CNS
Cerebral hemispheres
Telencephalon
Cerebellum
Diencephalon (thalamus, subthalamus, hypothalamus)
Midbrain
Brainstem
Pons
Medulla
Cervical
Thoracic
Spinal cord
Lumbar
Sacral

Cerebral cortex

- The cerebral cortex is the layer of gray matter capping the white matter core of the cerebral hemispheres .
- The number of neurons in the cerebral cortex is about 50 bilion.
- 5% of the area of the cortex is specialized for receiving sensory input from the eyes, ears, and skin and for projecting motor output down the pyramidal tract to bring about movement.
- Over 90% of the cortex serves an association function specially related to integrative and cognitive activities.

Anatomy of the Cerebral Hemispheres

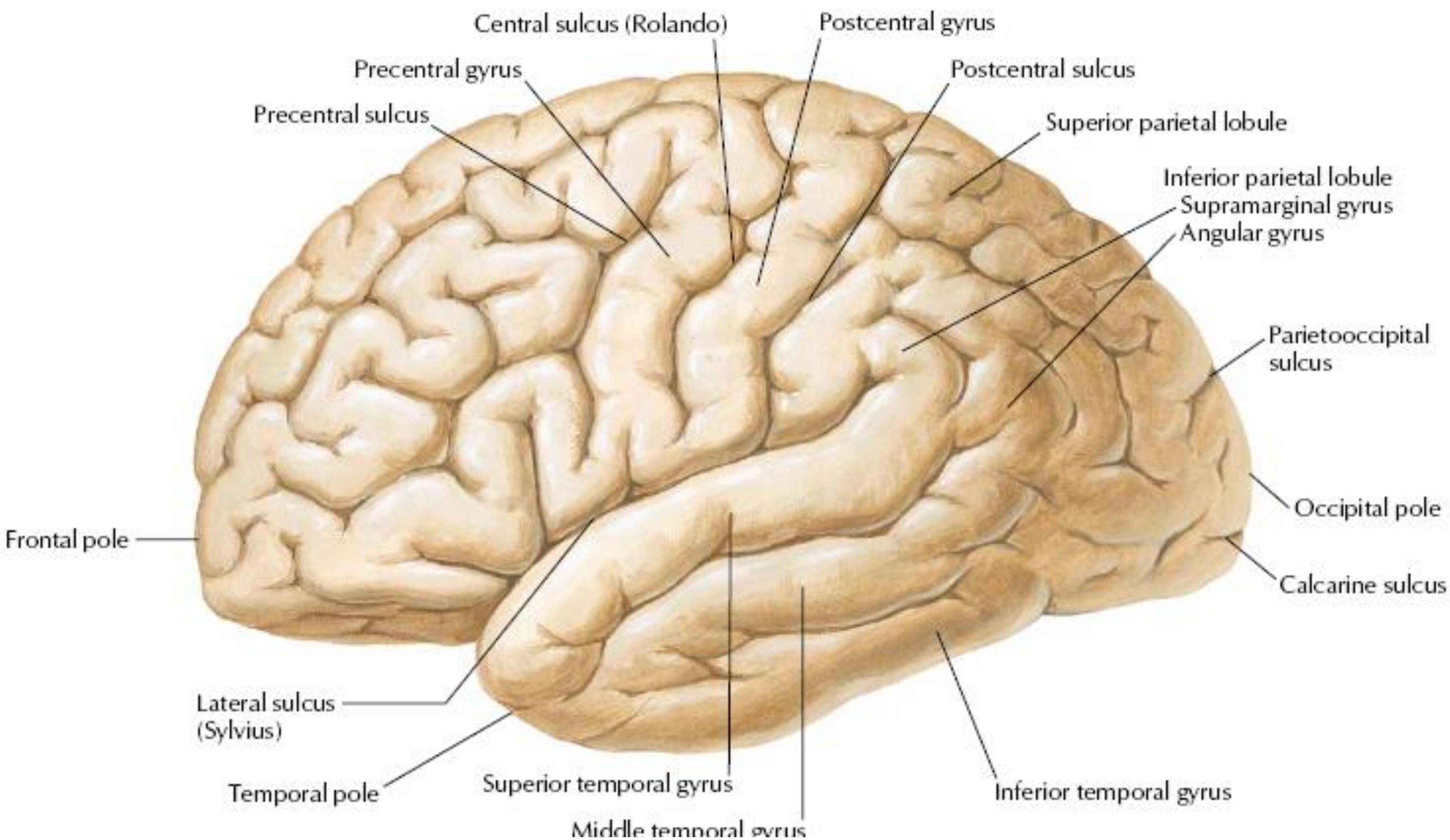
- The cerebral hemispheres appear as highly convoluted masses of gray matter that are organized into a folded structure.

- The crests of the cortical folds ***(gyri)*** are separated by furrows ***(sulci)*** or deeper ***fissures.***

Main Sulci & Fissures

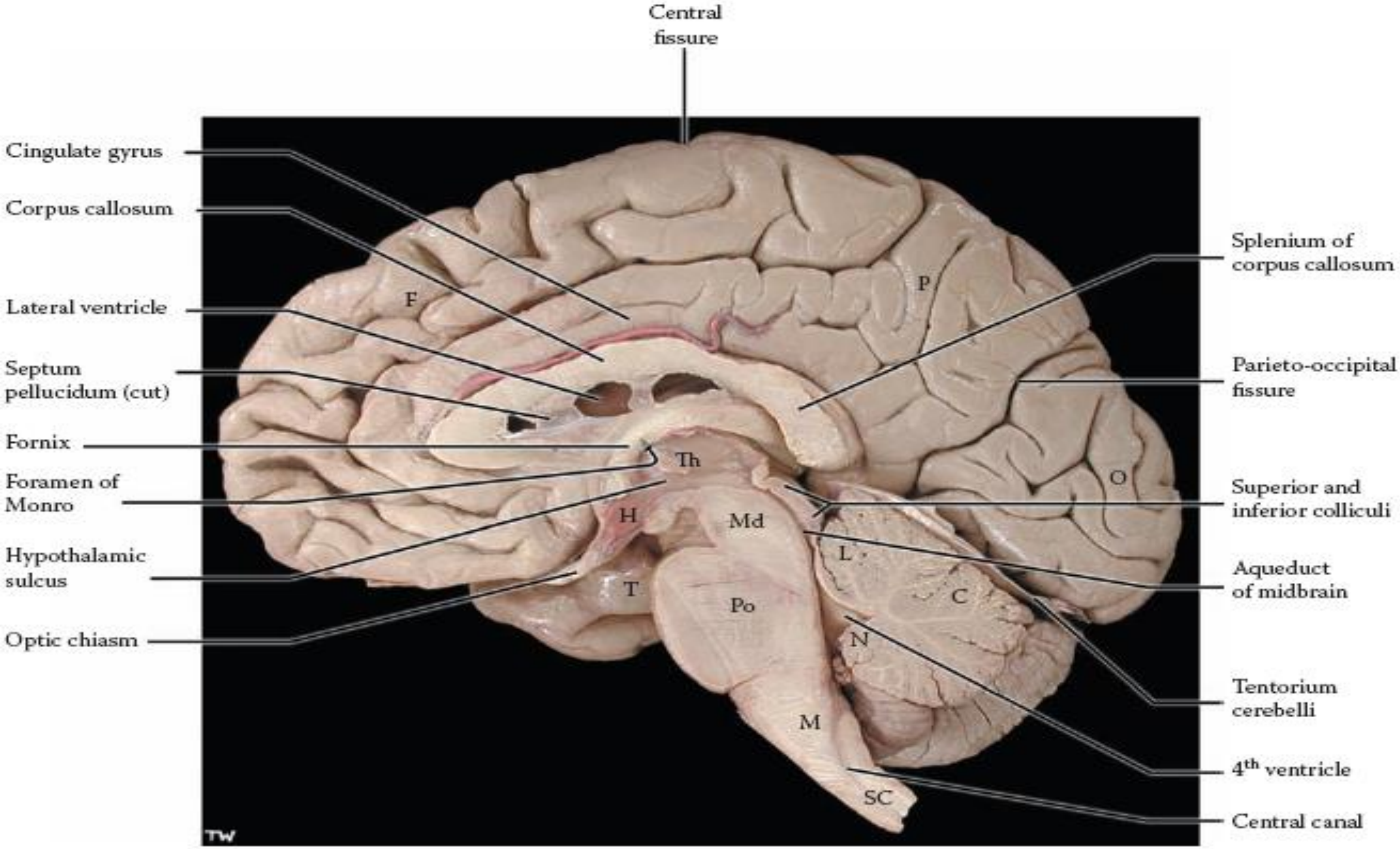
The surfaces of the cerebral hemispheres contain many fissures and sulci that separate the *frontal, parietal, occipital, and temporal lobes from each other.*

- The **lateral cerebral fissure (Sylvian fissure)** separates the *temporal lobe from the frontal and parietal lobes.*
- The hemispheres are separated by a deep median fissure, the **longitudinal cerebral fissure.**
- The **central sulcus** (the **fissure of Rolando**) separates the *frontal lobe from the parietal lobe.*
- The **parieto-occipital fissure**, separates the parietal lobe from the occipital lobe.


Central sulcus (Rolando)
Postcentral gyrus
Precentral gyrus
Postcentral sulcus
Precentral sulcus
Superior parietal lobule
Inferior parietal lobule
Supramarginal gyrus
Angular gyrus
Parietooccipital sulcus
Occipital pole
Frontal pole
Calcarine sulcus
Lateral sulcus (Sylvius)
Temporal pole
Superior temporal gyrus
Inferior temporal gyrus
Middle temporal gyrus

Corpus Callosum

The corpus callosum is a large bundle of myelinated and nonmyelinated fibers, serves to integrate the activity of the two hemispheres and permits them to communicate with each other.



F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Th = Thalamus
H = Hypothalamus

Md = Midbrain
Po = Pons
M = Medulla
SC = Spinal cord

C = Cerebellum
L = Lingula
N = Nodulus

- **Frontal lobe** which contain the main motor areas; *primary motor area, premotor area, and in the dominant hemisphere; the motor speech area(Broca).*

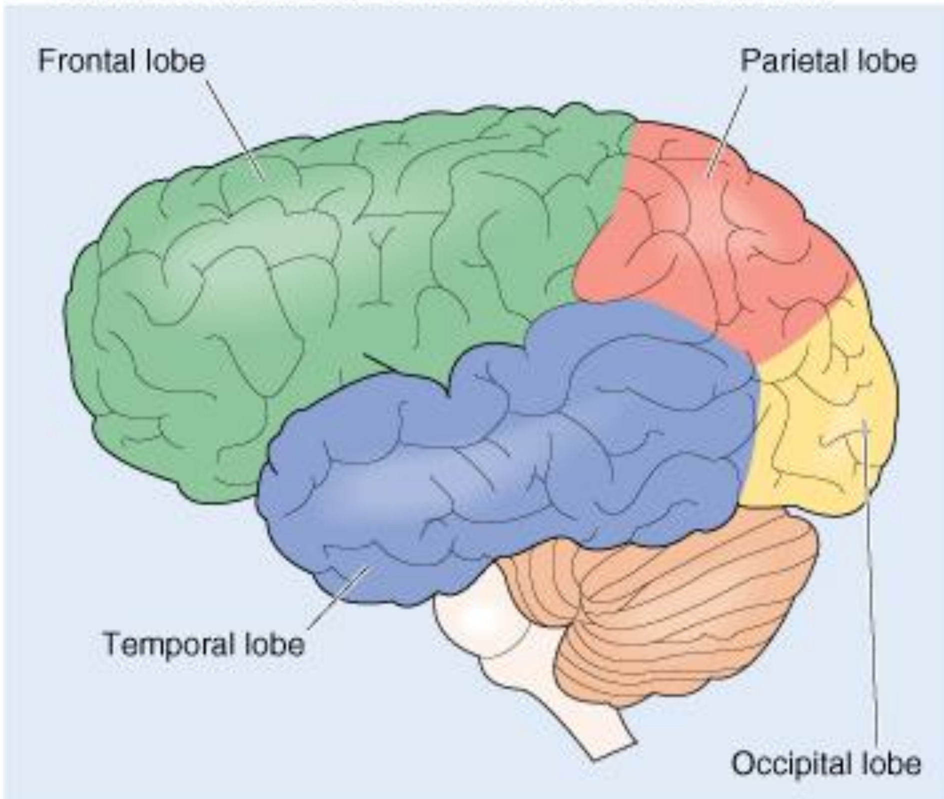
In the primary motor area, all parts of the body are represented *in upside down arrangement* and the areas of the body *is proportional to the functional status* of the part(in the face area the lip representation is large compared to its actual size in the face.

- Parietal lobe have the *primary sensory* area which is concerned with general body sensations (body representation in the primary sensory area is similar to that described for the primary motor area), *primary gustatory (taste) area,* and in the dominant hemisphere the *area of language comprehension (Wernike).*

- Temporal lobe which have the *primary auditory area, primary olfactory (smell) area, and the primary vestibular area.*

- Occipital lobe which concern primarily with *vision*.

C SURFACE ANATOMY OF THE CEREBRAL CORTEX



- Other parts of the telencephalon are the **basal ganglia,** which consist of; the *caudate nucleus, globus pallidus and putamen*.

- the basal ganglia have many connections with other brain stem nuclei forming the **exrtapyramidal system** which play an important role in motor control.

Diencephalon

Thalamus is the largest component of the diencephalon and considered as the gateway to the cortex, its main functions are:

- Integration of motor and sensory activities.
- Play a role in arousal and consciousness.
- Play a role in affective behavior.

Subthalamus is important for regulation of movement by its connections with the extrapyramidal system.

Hypothalamus plays an important role in the following:

- Control of the pituitary gland.
- Autonomic regulation.
- Temperature regulation.
- Feeding behavior.

Midbrain, Pons, and Medulla.

This caudal portion of the brainstem lies immediately above, or rostral to, the spinal cord.

The main functions of the brainstem include the followings:

- The brainstem plays a role in conduction. That is, all information relayed from the body to the cerebrum and cerebellum and vice versa must traverse the brainstem.
- The cranial nerves III-XII emerge from the brainstem. These cranial nerves supply the face, head, and viscera.
- It also contain important control centers for the ANS .

- Additionally, this portion of the brainstem contains a loosely organized interconnected collection of neurons and fibers called the *reticular- formation*. This neuronal network has diffuse connections with the cortex and other brain regions and affects the level of consciousness or arousal.

- The brainstem has integrative functions being involved in cardiovascular system control and respiratory control.

Thus, brainstem damage is a very serious and often life-threatening problem.

Cerebellum

- The cerebellum lies immediately dorsal to the brainstem, it consist of a midline *vermis* and two laterally placed *hemispheres .*
- The cerebellum is *principally a motor organ*.
- it is responsible for the regulation and control of muscular tone, the coordination of movement, especially skilled voluntary movements; and the control of posture and gait

Ventricular System

is a communicating system of cavities that are lined with ependyma and filled with cerebrospinal fluid (CSF):

There are:

- two lateral ventricles,
- the third ventricle (between the halves of the diencephalon),
- the cerebral aqueduct,
- and the fourth ventricle within the brain stem .

Lateral Ventricles

- The lateral ventricles are the largest of the ventricles. They each include two central portions (body and atrium) and three extensions (horns).

Third Ventricle

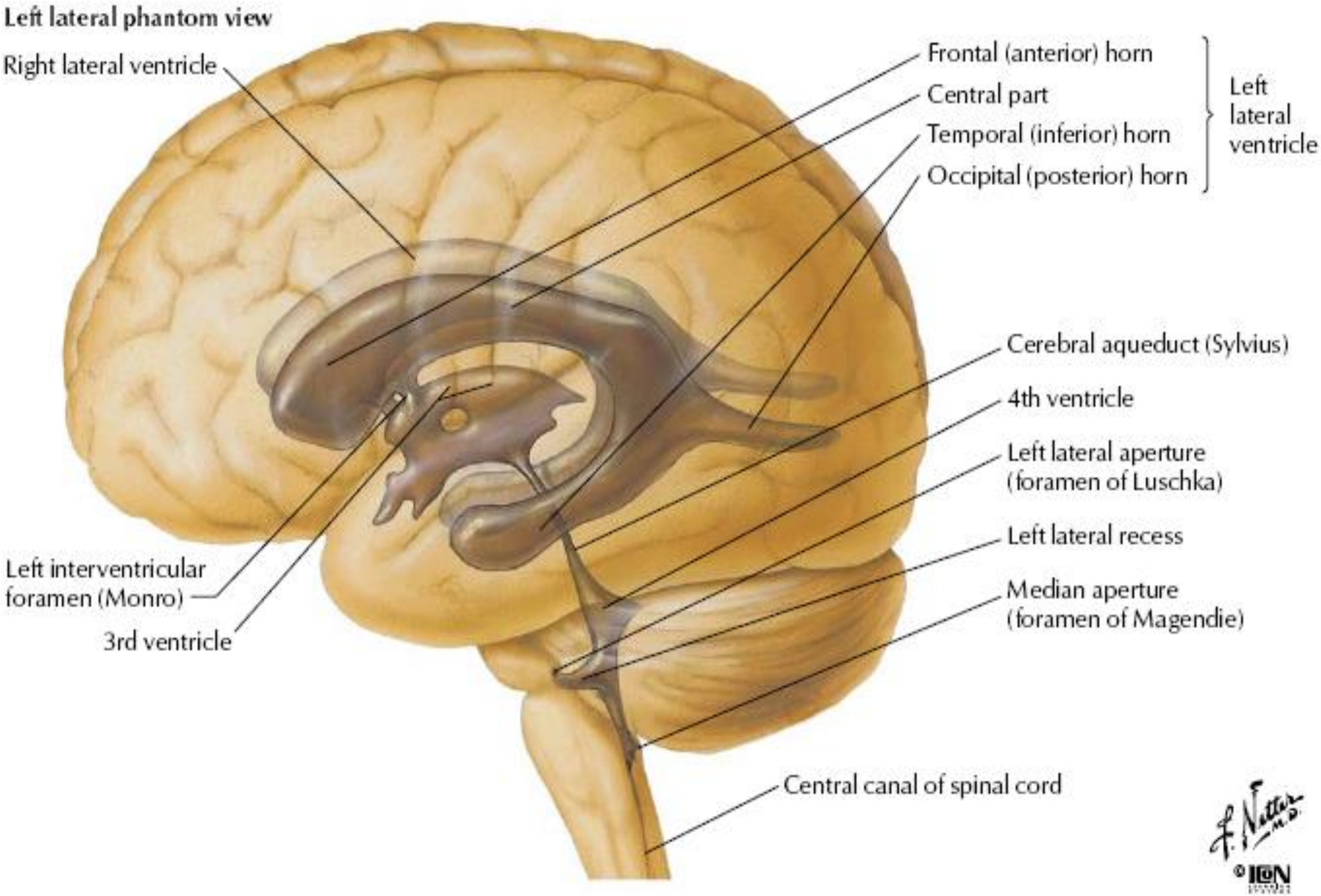
- The third ventricle is a narrow vertical cleft between the two halves of the diencephalon

Cerebral Aqueduct

- The cerebral aqueduct is a narrow, curved channel running from the posterior third ventricle into the fourth.

Fourth Ventricle

- The fourth ventricle is a pyramid-shaped cavity bounded ventrally by the pons and medulla oblongata, The position of the cerebellum, just above the roof of the fourth ventricle.


Left lateral phantom view
Right lateral ventricle
Frontal (anterior) horn
Central part
Temporal (inferior) horn
Occipital (posterior) horn
Left lateral ventricle
Cerebral aqueduct (Sylvius)
4th ventricle
Left lateral aperture (foramen of Luschka)
Left lateral recess
Median aperture (foramen of Magendie)
Left interventricular foramen (Monro)
3rd ventricle
Central canal of spinal cord
F. Netter M.D.
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CSF

Function

- provides mechanical support of the brain and acts like a protective water jacket.
- It controls brain excitability by regulating the ionic composition, carries away metabolites (because the brain has no lymphatic vessels)
- provides protection from pressure changes (venous volume versus CSF volume).

The CSF is present in a system that comprises two communicating parts.

- *The internal portion of the system* consists of two lateral ventricles, the interventricular foramens, the third ventricle, the cerebral aqueduct, and the fourth ventricle.
- *The external part* consists of the subarachnoid spaces and cisterns.

Communication between the internal and external portions occurs through the two lateral apertures of the fourth ventricle *(foramens of Luschka*) and the median aperture of the fourth ventricle *(foramens of Magendie*).

In adults, the total volume of CSF in all the spaces is about 150 mL. Between 400 and 500 mL of CSF is produced and reabsorbed daily.

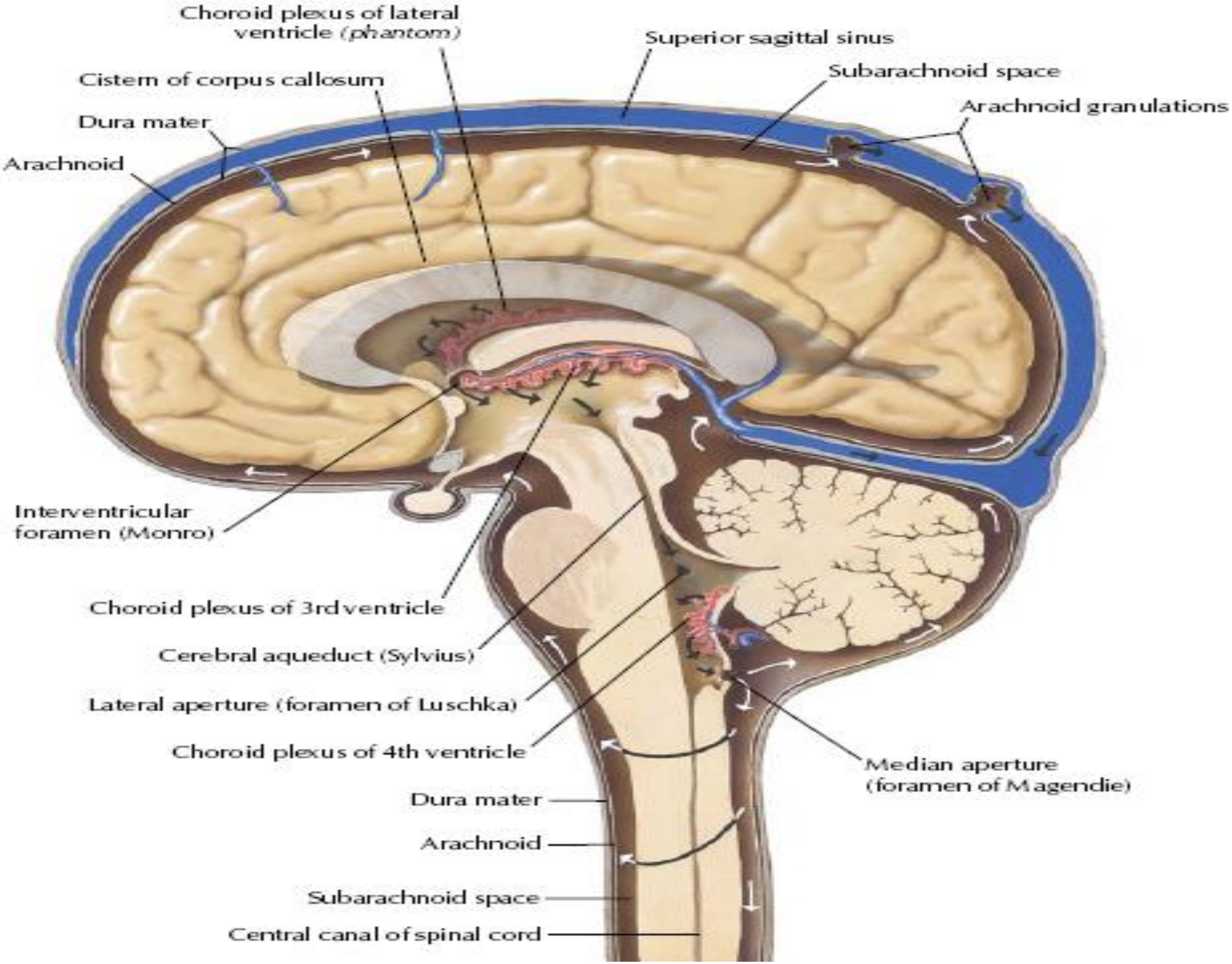
Circulation

- Much of the CSF originates from the choroid plexuses within the lateral ventricles.
- The fluid passes through the interventricular foramens *(foramens of Monro)* into the midline third ventricle; more CSF is produced here by the choroid plexus in the ventricle's roof.
- The fluid then moves through the cerebral aqueduct within the midbrain and passes into the fourth ventricle, where the choroid plexus adds more fluid.

- The fluid leaves the ventricular system through the midline and lateral apertures of the fourth ventricle and enters the subarachnoid space.

- From here it may flow over the cerebral convexities or into the spinal subarachnoid spaces.

- Some of it is reabsorbed (by diffusion) into the small vessels in the pia or ventricular walls. The remainder passes via the **arachnoid villi** into the venous blood (of sinuses or veins) in various areas, primarily over the superior convexity.


Choroid plexus of lateral ventricle (phantom)
Superior sagittal sinus
Cistern of corpus callosum
Subarachnoid space
Arachnoid granulations
Dura mater
Arachnoid
Interventricular foramen (Monro)
Choroid plexus of 3rd ventricle
Cerebral aqueduct (Sylvius)
Lateral aperture (foramen of Luschka)
Choroid plexus of 4th ventricle
Median aperture (foramen of Magendie)
Dura mater
Arachnoid
Subarachnoid space
Central canal of spinal cord

Vascular Supply: Introduction

- About 18% of the total blood volume in the body circulates in the brain.

- The blood transports oxygen, nutrients, and other substances necessary for proper functioning of the brain tissues and carries away metabolites.

- Loss of consciousness occurs in less than 15 seconds after blood flow to the brain has stopped, and irreparable damage to the brain tissue occurs within 5 minutes.

Arterial Supply of the Brain

- The ***circle of Willis*** is a confluence of vessels that gives rise to all of the major cerebral arteries.

- It is fed by the paired internal carotid arteries and the basilar artery.

- When the circle is complete, it contains a posterior communicating artery on each side and an anterior communicating artery.

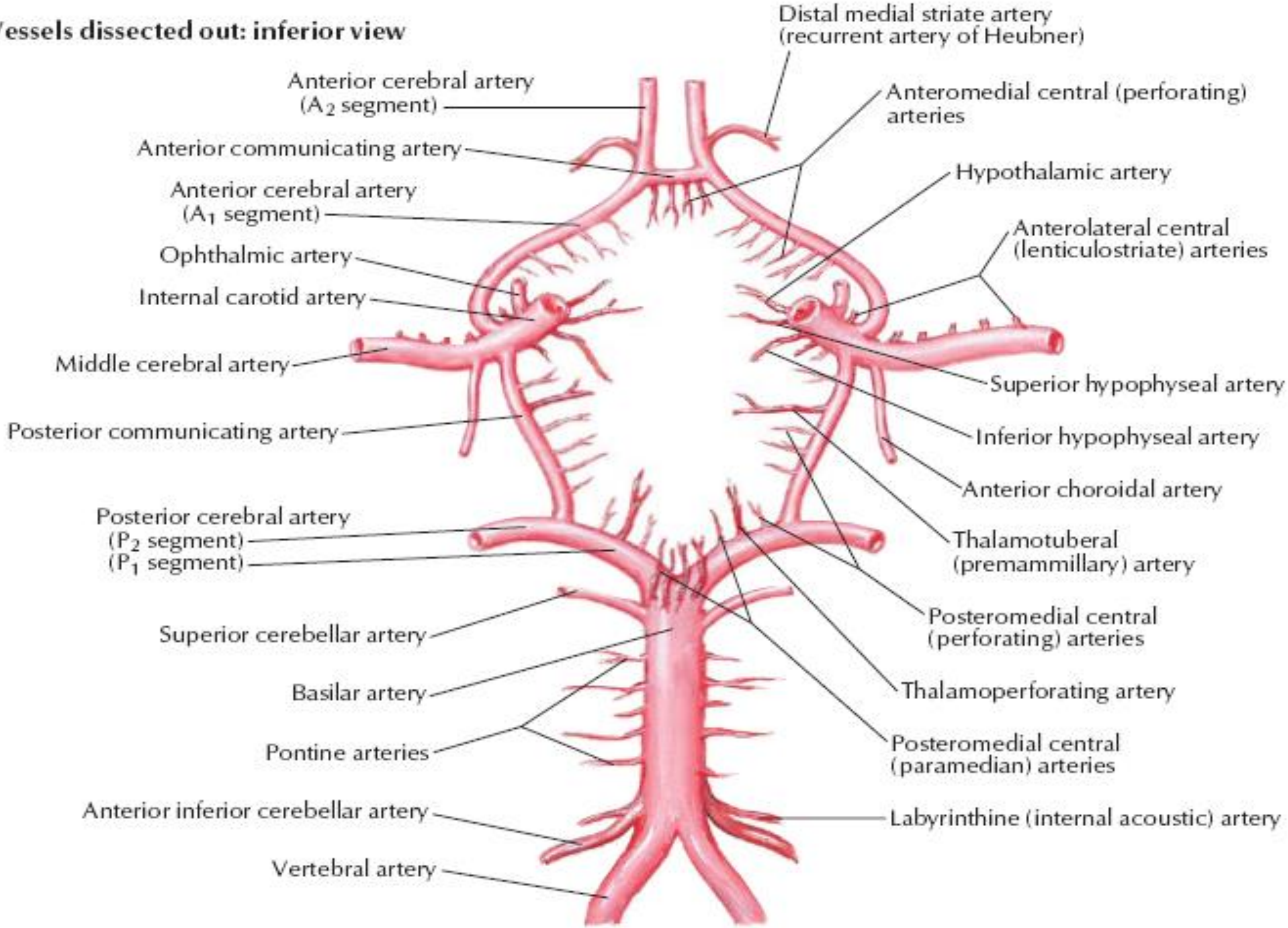
Principal Arteries

The arterial blood for the brain enters the cranial cavity by way of two pairs of large vessels:

- the ***internal carotid arteries,*** which branch off the common carotids, and the ***vertebral arteries*****,** which arise from the subclavian arteries.
- The vertebral arterial system supplies the *brain stem, cerebellum, occipital lobe, and parts of the thalamus*.
- the carotids supply *the remainder of the forebrain.*

- The carotids are interconnected via the **anterior cerebral arteries** and the **anterior communicating artery;** the carotids are also connected to the **posterior cerebral arteries** of the vertebral system by way of two **posterior communicating arteries,** part of the circle of Willis

Vessels dissected out: inferior view



Vertebrobasilar Territory

- After passing through the foramen magnum in the base of the skull, the two vertebral arteries form a single midline vessel, *the **basilar artery***.

- This vessel terminates in the interpeduncular cistern in a bifurcation as the left and right posterior cerebral arteries.

- Several pairs of small circumferential arteries arise from the vertebral arteries and their fused continuation, the basilar arteryThese are:

- the ***posterior*** *and* ***anterior inferior cerebellar arteries,***
- *the* ***superior cerebellar arteries*****,**
- The small ***penetrating arteries*****,** which branch off the basilar artery, supply vital centers in the brain stem.

Carotid Territory

- The **internal carotid artery** passes through the **carotid canal** of the skull and then curves forward within the cavernous sinus.

- The first branch is usually the *ophthalmic artery.*

- the carotids branch into a *large middle and a smaller anterior cerebral artery* on each side.

- The two anterior cerebral arteries usually meet over a short distance in midplane to form a short but functionally important **anterior communicating artery.**

- This vessel forms an anastomosis between the left and right hemispheres, which is especially important when one internal carotid becomes occluded.

Cortical Supply

- The **middle cerebral artery** supplies many deep structures and much of the lateral aspect of the cerebrum.

- The **anterior cerebral artery** supply the anterior frontal lobe and the medial aspect of the hemisphere.

- The **posterior cerebral artery** supply mainly the occipital lobe lower surface of the temporal lobe