Nervous System

- It is responsible for the stimulus-response interaction between the environment and the organism and for regulation and co-ordination of other body systems.
- It acts with and so controlled by the endocrine, immune and sensory organs.
- Topographically the nervous system divide into:

1. **Central Nervous System (CNS) consisting of:**
   a. **Brain**
   b. **Spinal cord**
2. **Peripheral Nervous System (PNS) consisting of:**
   a. **Cranial nerves**
   b. **Spinal nerves**

- The brain continues as the spinal cord between the occipital bone and the atlas: the exact limit is drawn between the last pair of cranial nerves and the first pair of cervical nerves.

Development of nervous system

Neural tube becomes central nervous system (CNS), which consists of the brain and spinal cord.

The cavity of the tube (neural cavity) becomes the ventricles of the brain and central canal of the spinal cord.

Neural crest cells become those neurons of peripheral nervous system (PNS) that have their cell bodies located in ganglia.

They also become neurolemmocytes (Schwann cells) of the PNS.

Additionally, neural crest cells become adrenal medulla cells, melanocytes of skin and a variety of structures in the face

Embryonic development

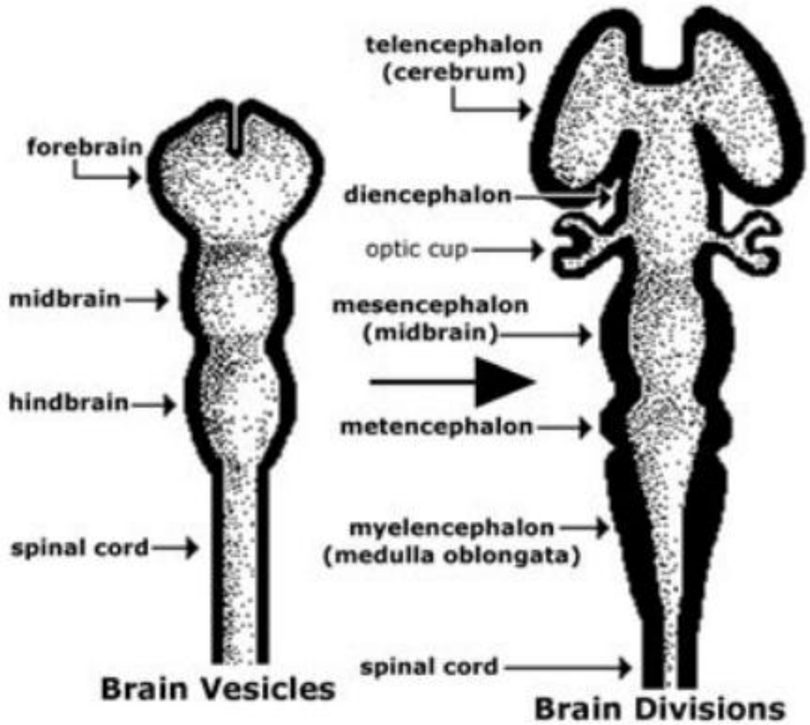
1. The CNS is derived from the ectoderm. During gastrulation, the notochord develops from the chordamesodermal tissue. The notochord, in a process called primary induction, sends a signal to the overlying ectoderm to thicken, thus forming theneural plate. The inducing signal is a protein called noggin.

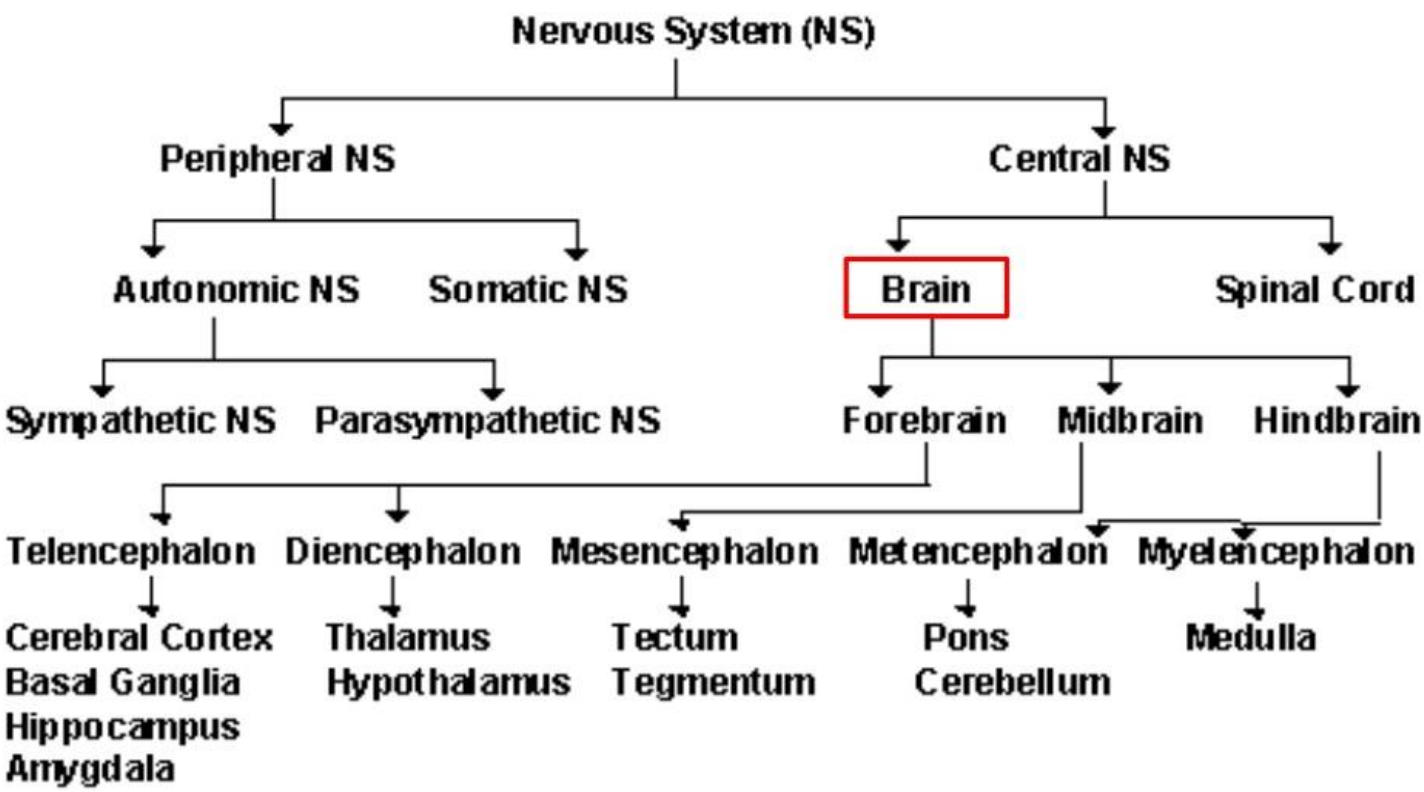
2. After formation of the neural plate, its lateral edges become elevated forming the neural folds which flank the neural groove. As the neural plate begins to invaginate, the neural folds surround it. The lateral edges of the neural folds eventually migrate toward the longitudinal midline of the embryo, thus forming the neural tube.

3. Failure of the tube to close at different sites results in various birth defects. Spina bifida occurs if the posterior neural tube does not close, whereas anencephaly is a lethal condition that results when the anterior neural tube fails to close. Craniorachischisis is a failure of the entire tube to close.

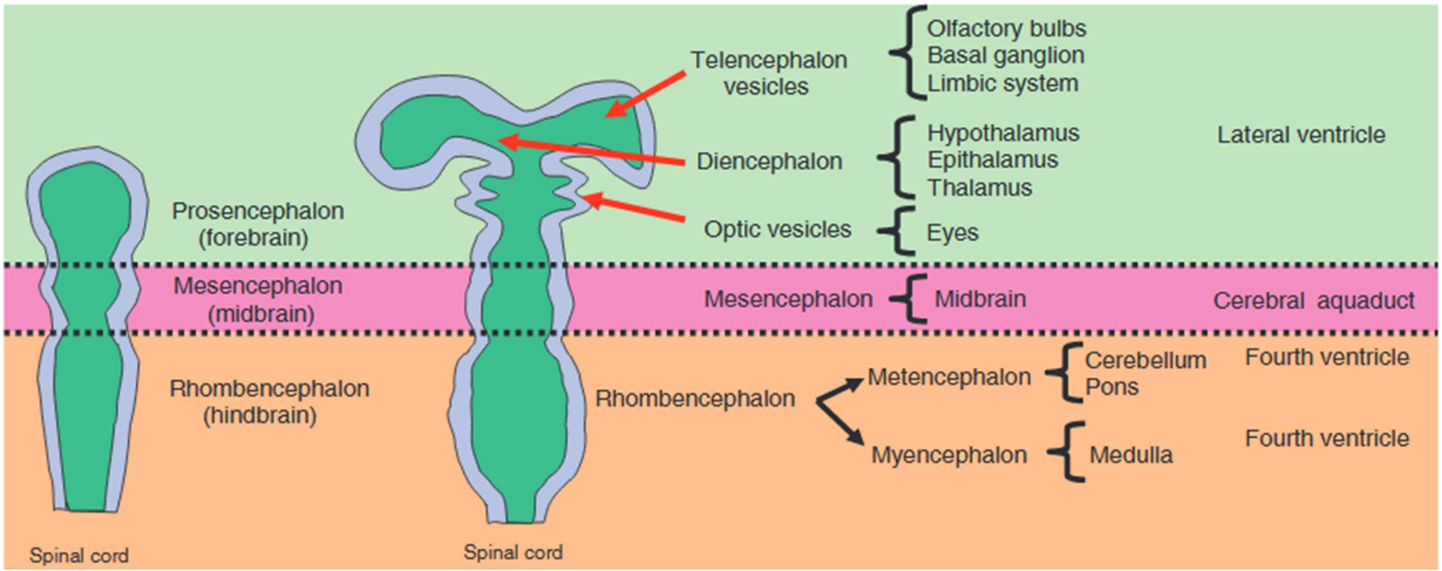
Adult CNS Structures Derived From Embyonic Brain Divisions

Embryonic Brain Division	Derived Brain Structures	Definitive Brain Cavities	Associated Cranial Nerves
FOREBRAIN			
Telencephalon	Cerebrum	Lateral ventricles	Olfactory (I)
Diencephalon	Thalamus; hypothalamus; etc.	Third Ventricle	Optic (II)
MIDBRAIN			
Mesencephalon	Midbrain	Mesencephalic aqueduct	III & IV
HINDBRAIN			
Metencephalon	Pons and Cerebellum	Fourth ventricle	V
Myelencephalon	Medulla Oblongata		VI—XII


forebrain
midbrain
hindbrain
spinal cord
Brain Vesicles
telencephalon
(cerebrum)
diencephalon
optic cup
mesencephalon
(midbrain)
metencephalon
myelencephalon
(medulla oblongata)
spinal cord
Brain Divisions

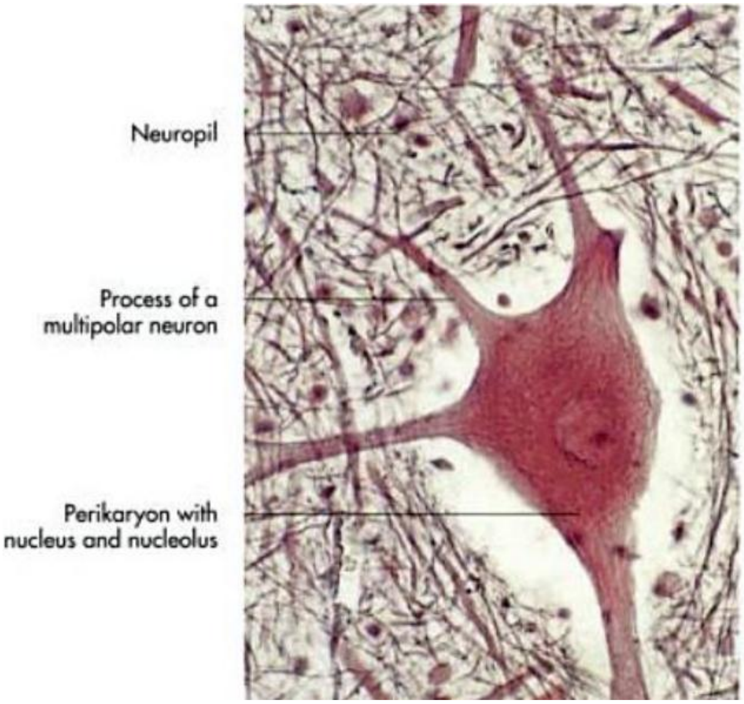

Nervous System (NS)
Peripheral NS
Central NS
Autonomic NS
Somatic NS
Brain
Spinal Cord
Sympathetic NS
Parasympathetic NS
Forebrain
Midbrain
Hindbrain
Telencephalon
Diencephalon
Mesencephalon
Metencephalon
Myelencephalon
Cerebral Cortex
Basal Ganglia
Hippocampus
Amygdala
Thalamus
Hypothalamus
Tectum
Tegmentum
Pons
Cerebellum
Medulla

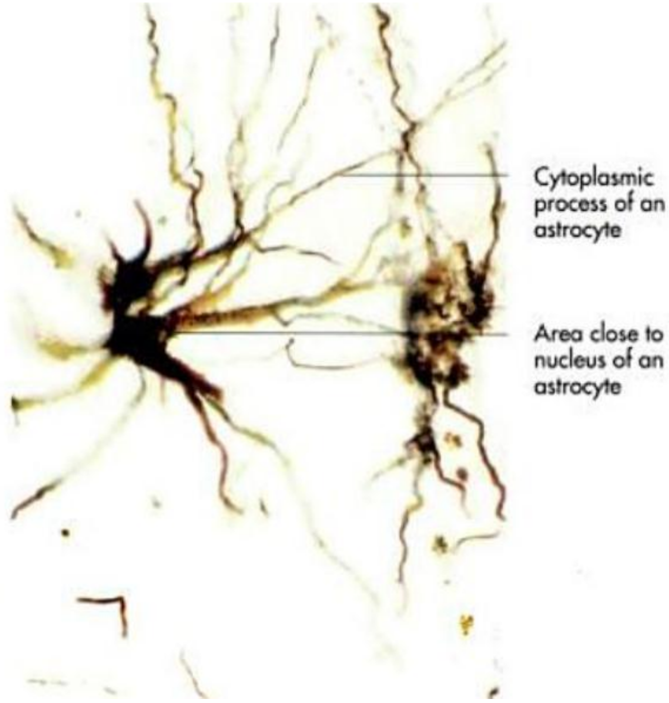
Schematic showing brain development

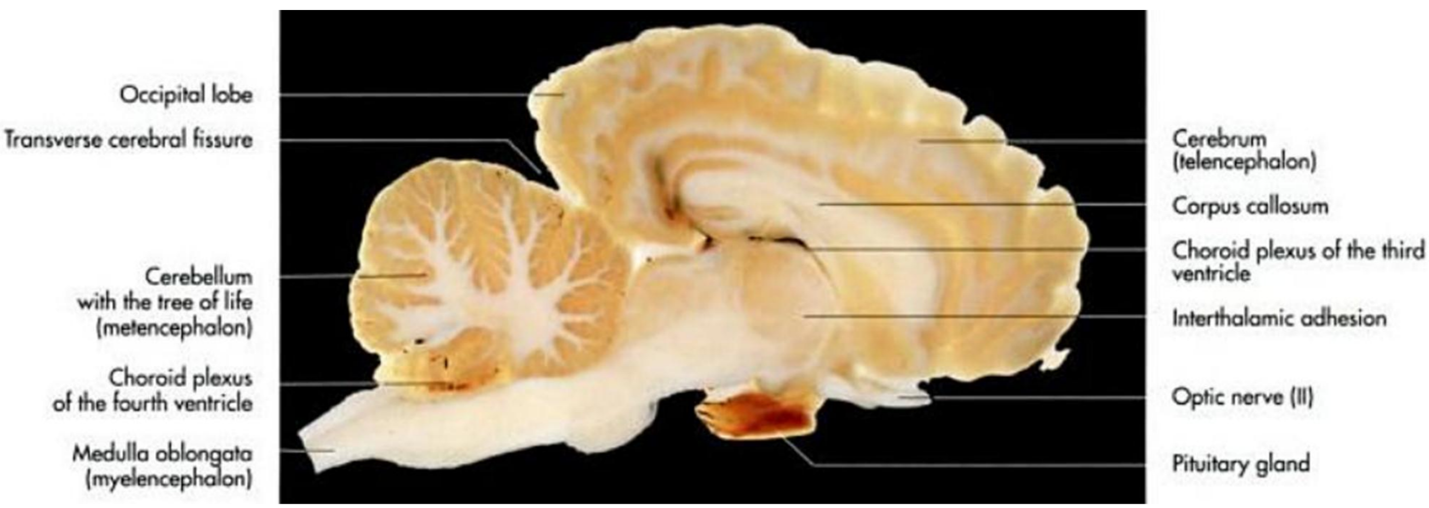


Some notes on CNS

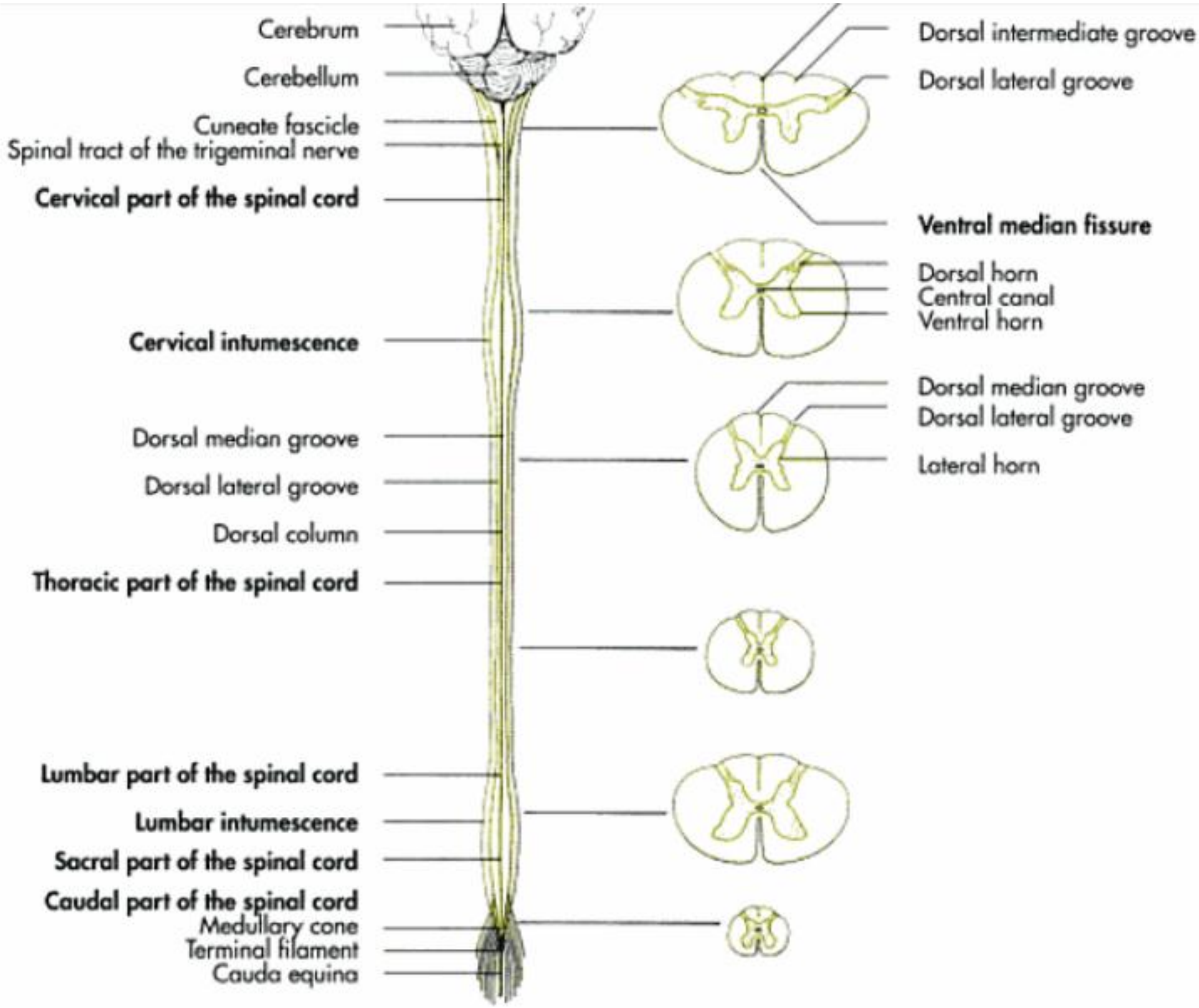
- The brain encloses a system of connected cavities consisting of four ventricles and a central canal
- These cavities within the brain filled with cerebrospinal fluid
- Approximately 100 billion neurons are present in the CNS, including the interneurons and the perikaryons of the motor neurons from the body's cerebrospinal nerve system.
- New neurons develop from the precursor cells, the neuroblast
- Once a neuron no longer functional, it can't be replaced.
- The loss of neuronal function due to small injuries could be partly be regained by the neogenesis of neuron net work
- It is estimated that one neuron can have as many as 10,000 interneuronal connections with other neurons







Paramedian section of the brain of a horse



Grey matter and white matter

- .Grey matter is mainly made up of cell bodies and dendrites. It is called grey matter because it has a grey appearance in fresh material.
- The other region is called white matter, and has a white appearance in fresh tissue. White matter is mainly composed of axons, which give it its white color because of a membrane around the axons known as a myelin sheath.

- ## Comparison between gray and white matter

White Matter	Gray Matter
Made up of bundles of myelinated axons	Made up of neutrophils, glial cells, neuronal cell bodies, capillaries, synapses, and a few myelinated axons
Color: white	Color: pinkish gray
Mostly located in the superficial areas of the spinal cord and in the internal areas of the brain	Mostly located in the internal areas of the spinal cord and on the superficial areas of the brain
Fully develops once a person reaches middle age	Fully develops once a person reaches his/her twenties
Makes up 60% of the brain	Makes up 40% of the brain
Responsible for learning and cognition	Responsible for sensory perception, muscle control, self-control, decision-making, memory, and data processing

Interactions between the central and peripheral nervous systems

- The peripheral nervous system (PNS) is made up of nerves and ganglia (clusters of nerve cells).
- The PNS and CNS work together to send information between the brain and the rest of the body.
- Nerves emerge from the CNS through the skull and vertebral column, using the PNS to carry information to the rest of the body.
- The PNS is made up of two divisions – sensory and motor. The sensory division carries signals from all over the body back to the CNS to be translated, while the motor division carries signals from the CNS to cells all over the body to carry out the body's responses to this information.

Brain (Encephalon)

- The brain is the control organ of the body, for the regulation, co-ordination and integration of the rest of the nervous system.
- Based on the ontogenetic (genes) and phylogenetic development from the rostral part of the neural tube, the brain can be subdivided into five majors parts:

A. **Prosencephalon (forebrain): 1. Telencephalon**

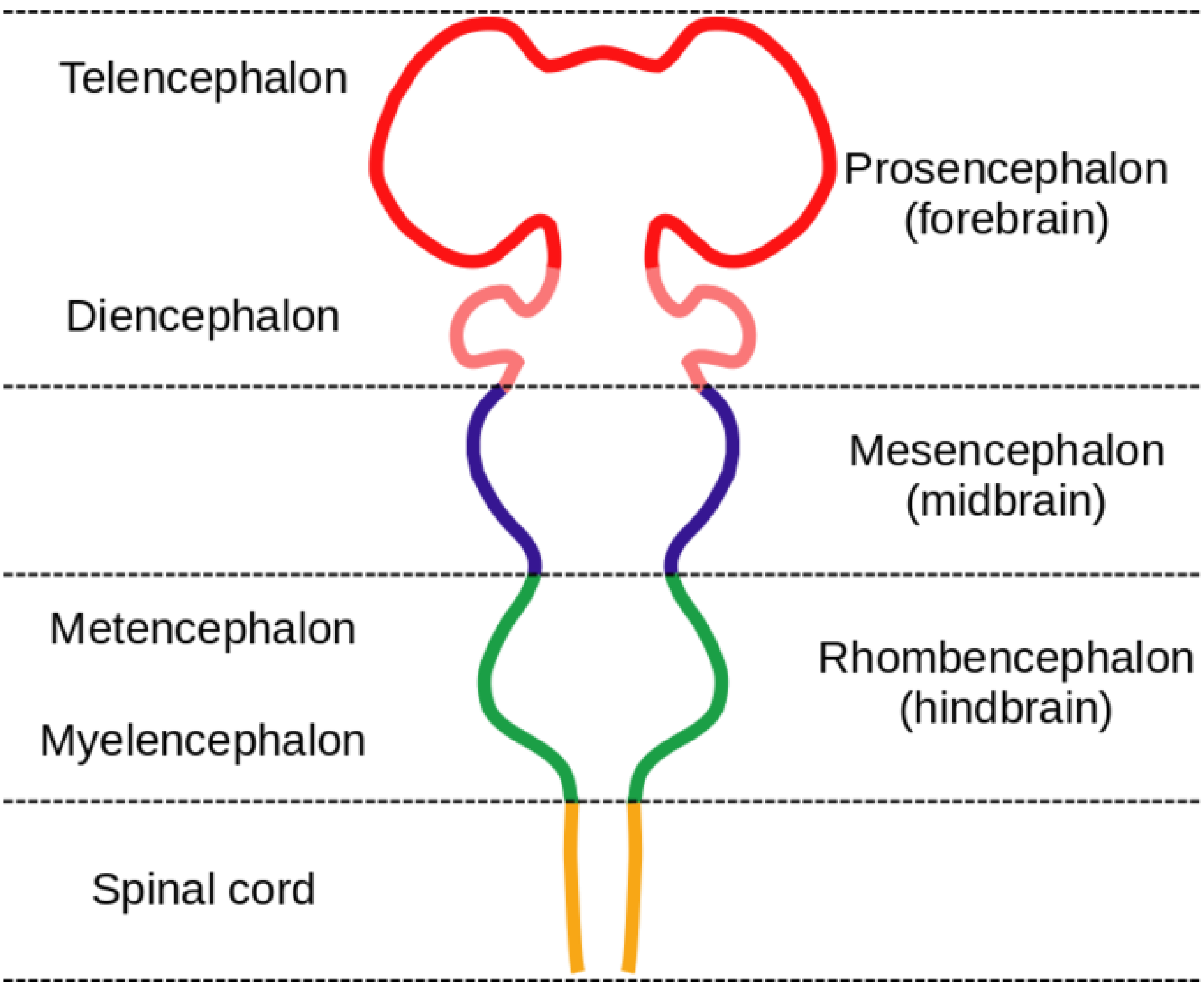
2. Diencephalon

B. Mesencephalon: 3. Midbrain

C. Rhomencephalon (hindbrain) :

4. Metencephalon (pons and cerebellum)

5. Myelencephalon (medulla oblongata)



A. Prosencephalon (forebrain):

1. **Telencephalon**

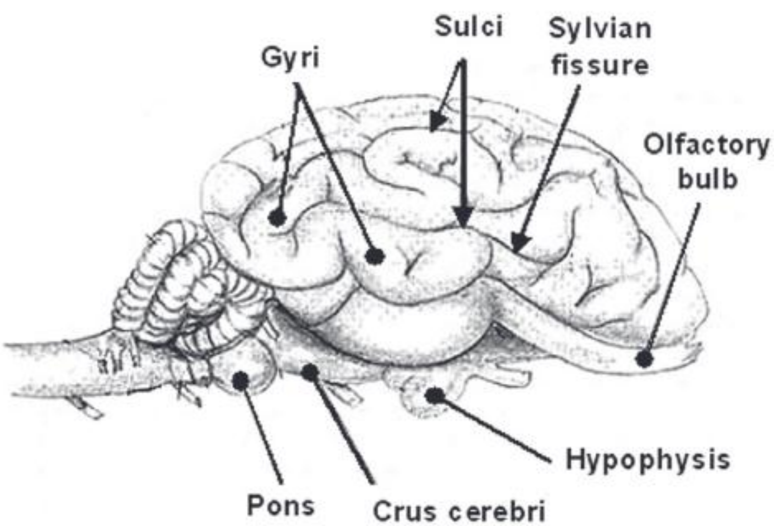
2. **Diencephalon**

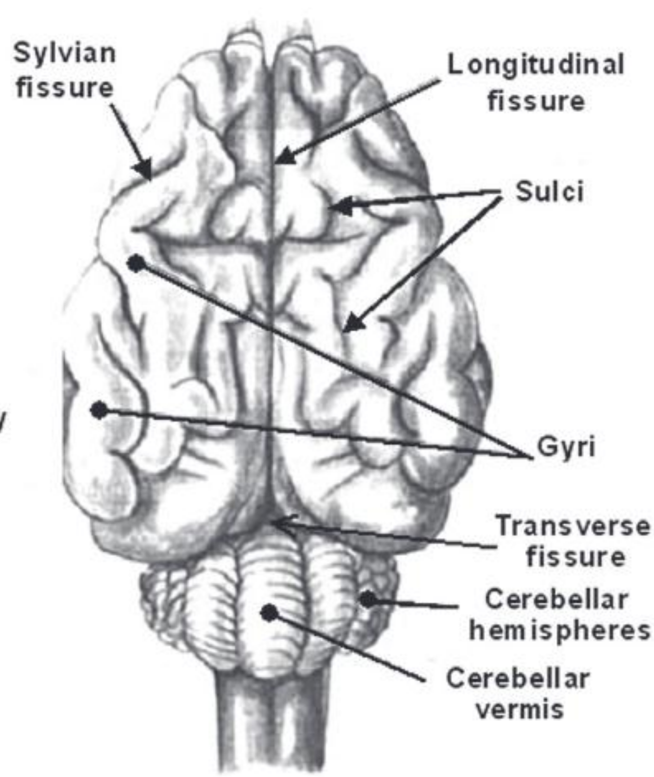
- The telencephalon and diencephalon make up the forebrain and are derived from the rostral-most vesicle called the **prosencephalon**. Surrounded by the cerebral hemispheres, the diencephalons consist of the epithalamus, thalamus, and hypothalamus.

Telencephalon

- The telencephalic vesicles form the telencephalon, which consists of two cerebral hemispheres. As the brain develops, the telencephalic vesicles grow posteriorly and laterally until they encase the diencephalon.
- The surface of the brain is marked by many convolutions. The grooves are called sulci (singular: sulcus), while the ridges are called gyri (singular: gyrus).
- The larger grooves that separate brain regions are called fissures. The longitudinal fissure separates the two cerebral hemispheres, whereas the cerebral hemispheres are separated from the cerebellum by the transverse fissure, which runs perpendicular to the longitudinal fissure.

When viewing the cerebral hemisphere, four lobes—frontal, parietal, temporal, and occipital—are visible.





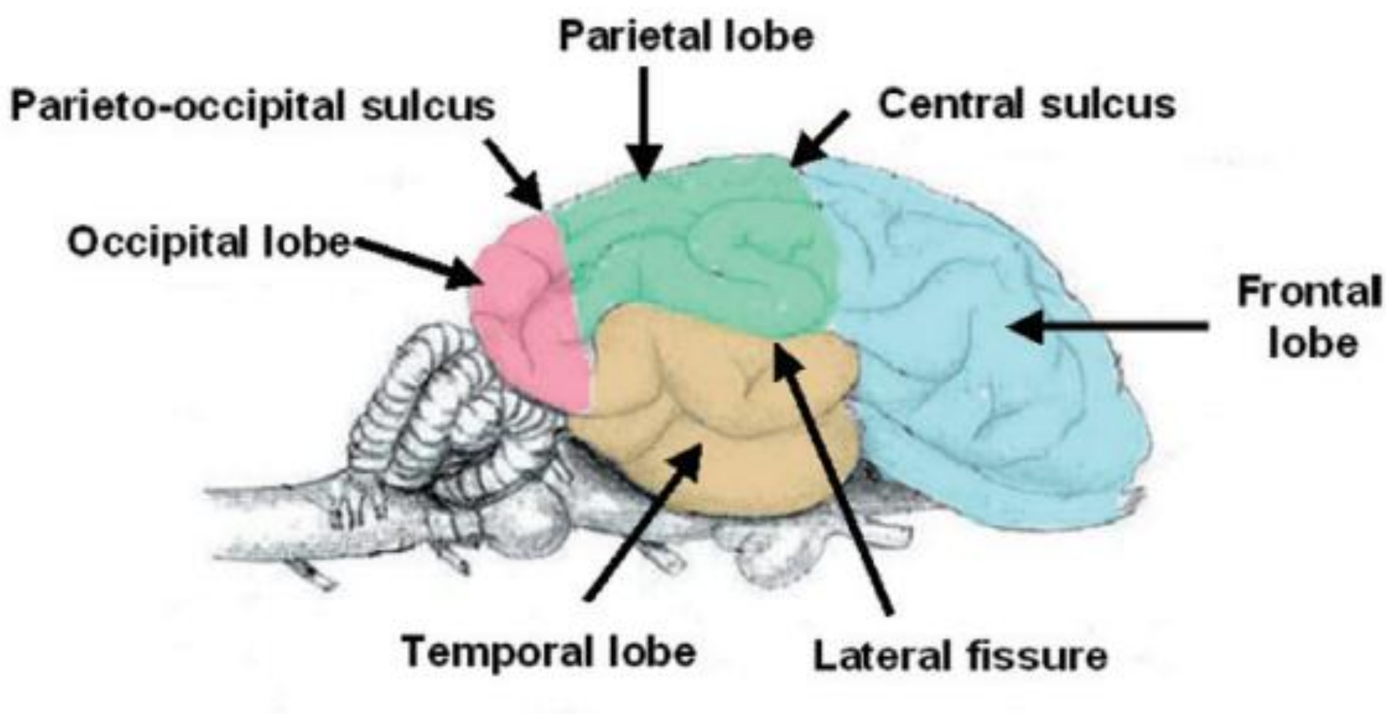
Cerebral hemispheres

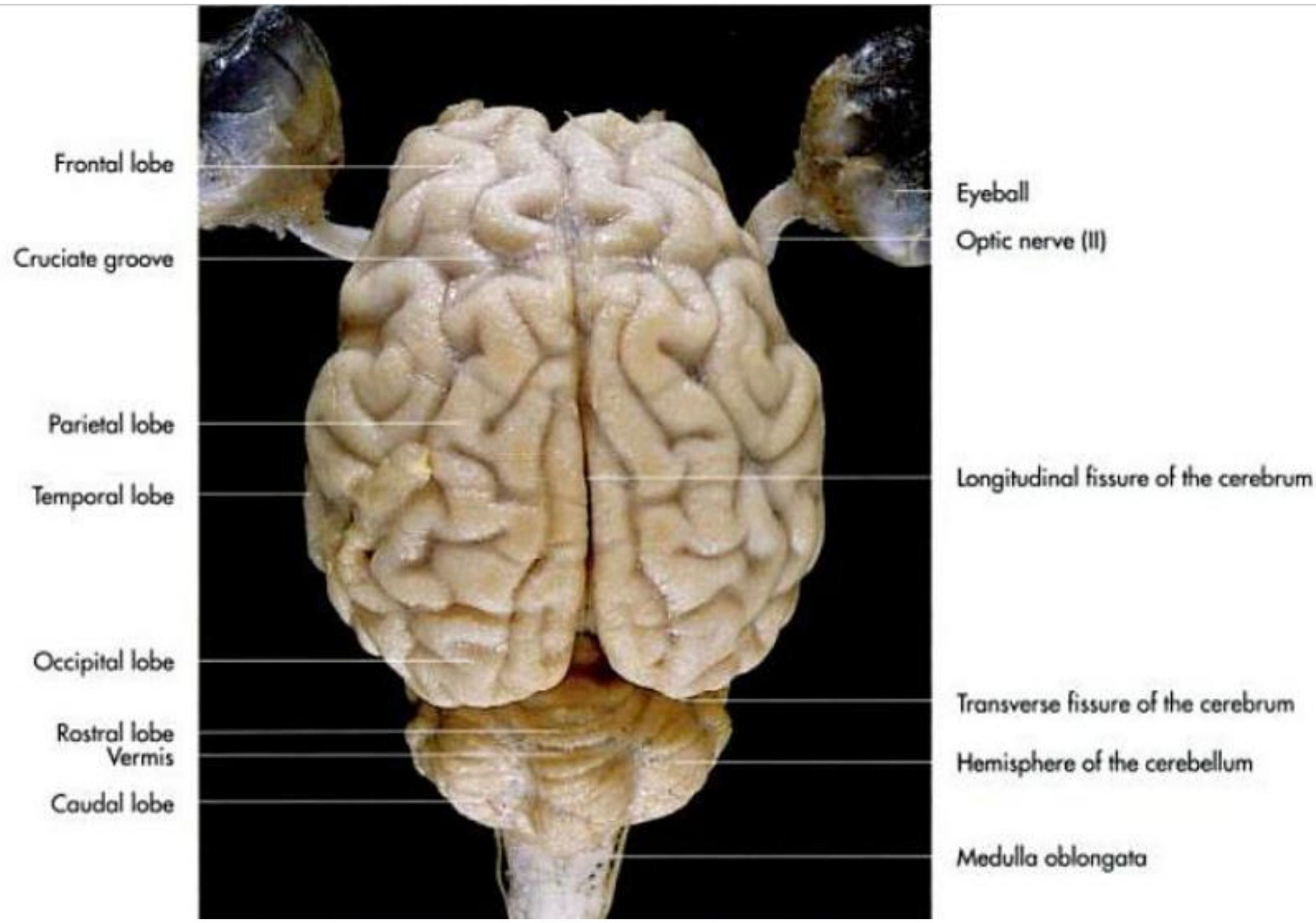
The cerebral hemispheres are made up of four major parts:

1. Cerebral cortex 2. Basal ganglia 3. Hippocampus 4. Amydala

Cerebral cortex:

- The cerebral cortex is located on the surface of the cerebral hemispheres.
- It is highly convoluted and folded. This allows a large surface area to fit inside the confined space of the skull.
- The cerebral cortex is divided into four lobes called the frontal lobe (front lobe), the parietal lobe (between front and back lobes), the occipital lobe (back lobe) and the temporal lobe (side lobes).





Cerebral cortex

1. The cerebral cortex is arranged as layers of cells that lie parallel to the surface of the brain.
2. The neocortex, which is found only in mammals and is associated with higher brain functions such as conscious behavior, is found over most of the surface of the cerebral hemisphere and consists of six layers of cells.
3. Medial to the lateral ventricles is an area of cortex named for its unique shape called the hippocampus (Greek for "seahorse"). It is only a single cell layer.
4. Ventral and lateral to the hippocampus is the third area of cortex called the olfactory cortex (piriform, or pyriform cortex) that consists of two cell layers.
5. The primary motor cortex is the final site for cortical processing of motor commands before messages are then sent to the somatic muscles. In mammals, this area lays in the rostral region of the frontal lobes.
6. The extrapyramidal system includes all the descending somatic motor pathways excluding those described previously that constitute the pyramidal system.

Cerebral white matter

1. There are deep subcortical nuclei called the basal ganglia or nuclei. While the definition of the structures included in the basal ganglion varies, it generally includes the caudate nucleus, putamen, globus pallidus, substantia nigra (consisting of the pars reticulata and pars compacts), and subtha-lamic nucleus
2. The limbic system consists of a group of structures located in the medial region of each cerebral hemisphere. These structures encircle (limbus =ring or border) the brain stem.
3. The limbic lobe of the cerebral hemisphere includes gyri surrounding the diencephalon, as well as other underlying structures. Specifically, it consists of three gyri.
4. The cingulate gyrus is dorsal to the corpus callosum.
5. The dentate gyrus and
6. parahippocampal gyrus form the inferior and posterior portions of the limbic lobe.
7. The limbic system is involved in emotional and behavioral patterns

Basal ganglia:

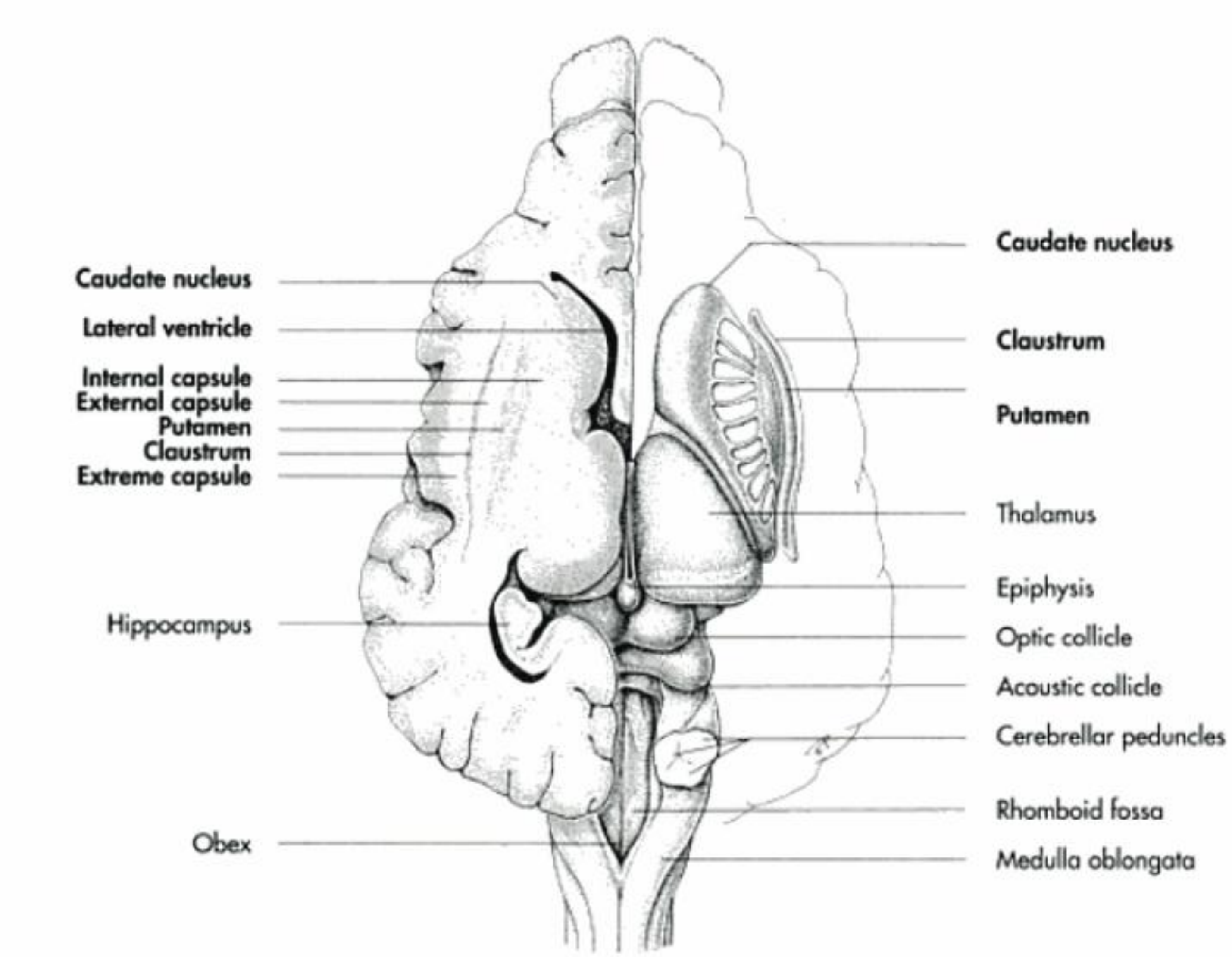
- They are collections of cells that are located deep inside the brain and have important roles in many higher brain functions.
- One function in which they play an important part is the control of movement.
- In Parkinson's disease, the basal ganglia are damaged. Patients with Parkinson's disease experience tremors and a slowing of movement as a result.
- Basal ganglia also influence other aspects of behaviors such as cognition and emotion.

Hippocampus:

- It has an important role in the formation of memories.
- It is also part of the limbic system, which influences thought and mood.

Amydala:

- It coordinates the release of hormones and the actions of the autonomic nervous system
- It is also part of the limbic system, and has a role in emotion.



Diencephalon

The diencephalon is made up of the thalamus and the hypothalamus. Also, epithalmus and thalamus

Thalamus

1. The thalamus lies dorsal to the hypothalamus and is bordered by the caudate nucleus dorsally and the internal capsule laterally. Its two halves are separated by the third ventricle.
2. The thalamus is the major relay station for sensory information generated in the periphery
3. The thalamus has an important role in transferring information to the cerebral hemispheres. In turn, it receives information from areas in the cerebrum.
4. Signals from all over the body are also sent to the thalamus, which directs this information to the cerebrum to be processed.

5. The thalamus is closely interconnected with the system responsible for emotion and memory – the limbic system.
6. Eye movements, taste, smell, hearing and balance are also linked to the thalamus.

Hypothalamus

- The hypothalamus is found ventral to the thalamus and forms the inferolateral walls of the third ventricle. It extends from the optic chiasm to the posterior border of the mammillary bodies. The infundibulum, which connects the hypothalamus to the pituitary, lies between the optic chiasm and mammillary bodies.
- The hypothalamus controls the autonomic nervous system, and thereby controls growth, feeding, drinking, circadian rhythms, and maternal behavior. Specifically, the hypothalamus plays a key role in six physiological areas.

The hypothalamus is the major control center of the autonomic nervous system, therefore playing important roles in ensuring all the systems in the body function smoothly. It is also involved in the release of hormones from the pituitary. The hypothalamus is involved in many body functions including the following:

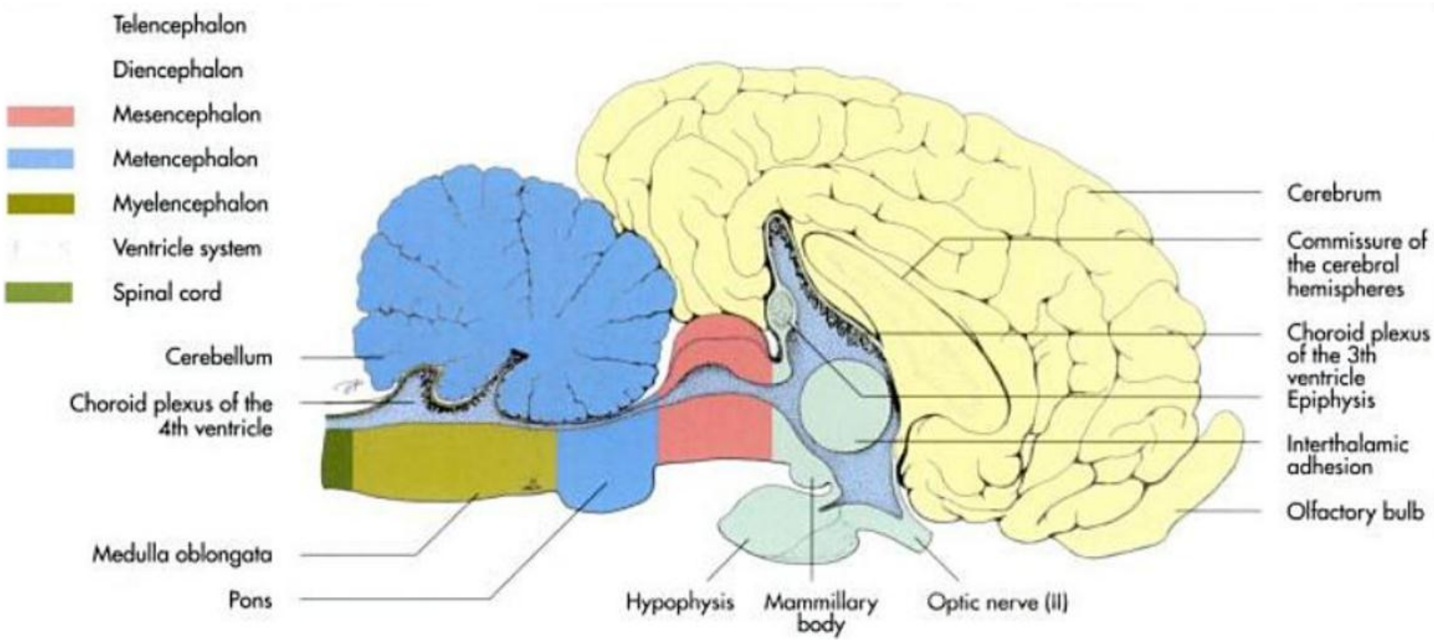
1. Hormone secretion
2. Autonomic effects (acting as a control system for the body)
3. Regulating body temperature
4. Detecting food and water intake (making you feel hungry or thirsty)
5. Sleep and waking
6. Memory
7. Emotion and behavior

Epithalamus

It comprises the pineal gland and the habenula with its associated tracts.

The pineal gland is a small median body that projects dorsally. It is an endocrine gland that secretes melatonin and other compounds which affect sexual activity.

The habenula consists of habenular nuclei and it is an important part of the olfactory pathway.



B. Mesencephalon (Midbrain)

- The midbrain connects the hindbrain and the forebrain to each other.
- The mesencephalon lies between the diencephalons and pons.
- The tectum forms the roof of the mesencephalon and contains two pairs of prominent bulges known as the corpora quadrigemina. Consisting of the superior and inferior colliculi, these nuclei process visual and auditory stimuli, respectively.
- The tegmentum forms the floor of the midbrain.

C. Rhomencephalon (hindbrain) or brain stem

4. Metencephalon (pons and cerebellum)

5. Myelencephalon (medulla oblongata)

Brain stem

The brain stem is made up of the medulla, pons and cerebellum. It has the following functions:

1. Receive incoming information from structures in the skull.

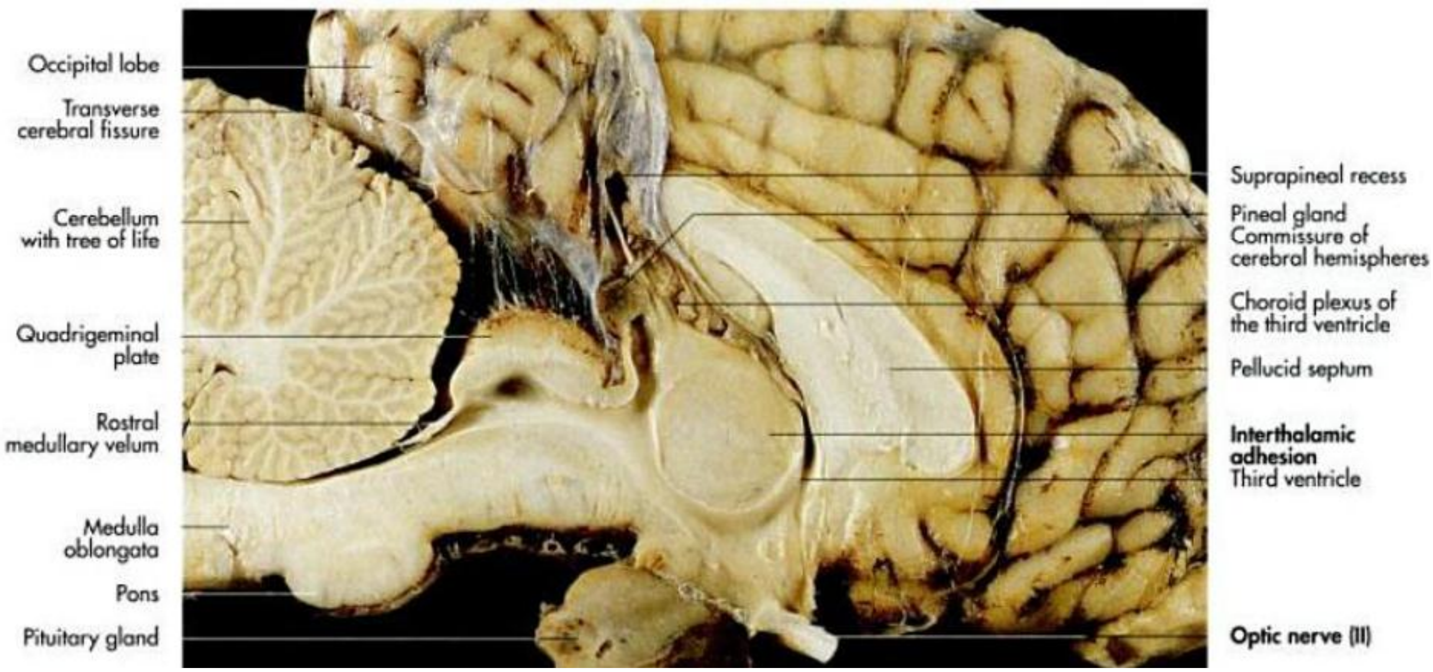
2. Transmit information between the spinal cord and higher brain regions.

3. Put together the actions of the different parts of the brain stem to regulate levels of stimulation.

Pons and cerebellum

- The pons is a bulge at the front of the brainstem, while the cerebellum is located underneath the cerebrum.
- The pons transfers information from the cerebrum to the cerebellum, and is also involved in sleeping, hearing, balance, facial sensation/expression, breathing, and swallowing.
- The cerebellum has roles in muscle coordination, emotion, and cognitive processes such as judgment.

1. The cerebellum is the second largest region of the brain accounting for 10% of its total mass, but containing half of all neurons in the brain.
2. The cerebellum is important in coordinating muscle movement and maintaining balance.
3. The cerebellum monitors all proprioceptive, visual, tactile, balance, and auditory sensory information



Medulla oblongata

The medulla is located just above the spinal cord. It contains structures known as pyramids that carry signals from the cerebrum to the spinal cord. This stimulates the skeletal muscles in the body, which are generally the muscles used to create movement.

- Originating from the myelencephalon, the medulla oblongata is continuous with the spinal cord.

- The rostral portion of the medulla contains part of the fourth ventricle, while the caudad portion contains a central canal.
- The medulla also receives information from the spinal cord and other parts of the brain, and transfers it to the cerebellum.
- Parts of the medulla also receive information from the taste buds, the pharynx, as well as the chest and abdominal cavities.
- The cell structures that receive this information have several functions, including:

1. Controlling heart rate and how hard the heart pumps
2. Controlling blood pressure
3. Controlling how fast and how hard breathing is

- The medulla also plays important roles in speaking, swallowing, coughing, sneezing, vomiting, sweating, salivation, and tongue and head movements.

Meningeal layers

- The meningeal layers are sometimes referred to as meninges.
- They are three separate layers that enclose the brain and spinal cord.
- Their roles are mainly to protect the brain and to circulate blood to and from the brain.
- The three layers are: 1. Dura mater

2. Arachnoid mater

3. Pia mater

Dura mater:

- Dura mater is the outermost of the meningeal layers.
- It is the thickest membrane.
- The dura around the cerebral hemispheres and the brainstem is actually made up of two layers.
- The outer of these layers is attached to the inside of the skull.

Arachnoid mater:

- The arachnoid mater is the middle meningeal layer.
- It lies next to the dura mater, but is not tightly bound to it.
- The space existing between the two layers is known as the subdural space.
- Breaking of a blood vessel in the dura mater can cause bleeding and a formation of a blood clot in this subdural space, resulting in a subdural haematoma.
- This is dangerous because the blood clot can push the arachnoid and dura layers apart, compressing the brain tissues.

Pia mater:

- The pia mater is the innermost meningeal layer, adhering to the brain and the spinal cord.
- It is a delicate layer and is separated from the arachnoid mater by a space known as the subarachnoid space.
- The space is filled with cerebrospinal fluid (CSF) and contains the veins and arteries overlaying the surface of the CNS.

Cerebrospinal fluid (CSF)

- Cerebrospinal fluid (CSF) bathes the inside of the brain through a network of cavities within the CNS known as the ventricular system. CSF has the following functions:
- A clear and colorless fluid, CSF has many functions:

1) It maintains a constant external environment for cells in the brain;

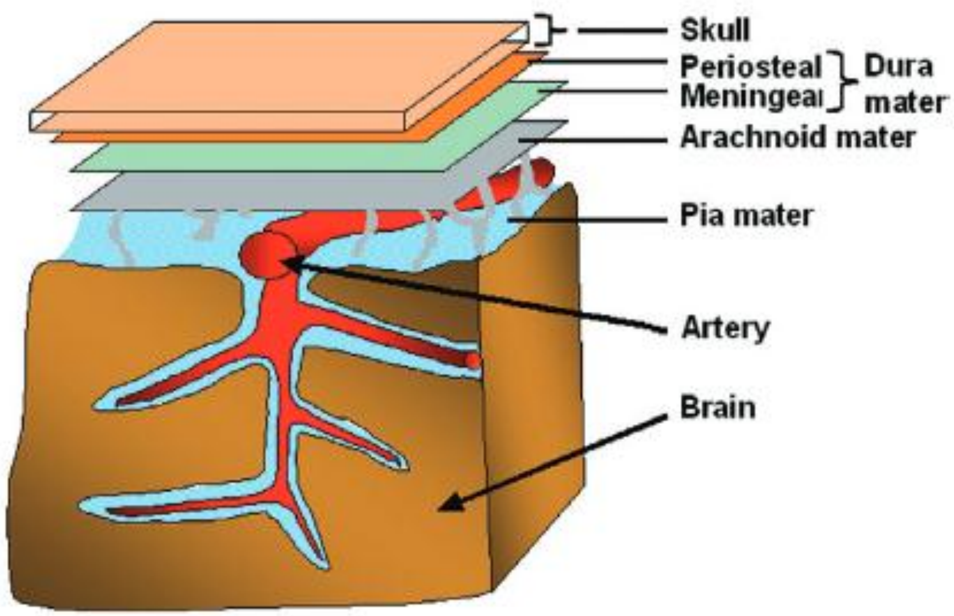
2) Provides a route for removing harmful metabolites from the brain;

3) Provides a cushion to protect the brain from trauma;

4) Acts as the lymphatic system for the brain;

5) Provides a route for peptides that are released at one site and act at a distant site in the brain.

- CSF is produced mostly from the choroid plexus. The remaining CSF is formed from the ependymal cells.

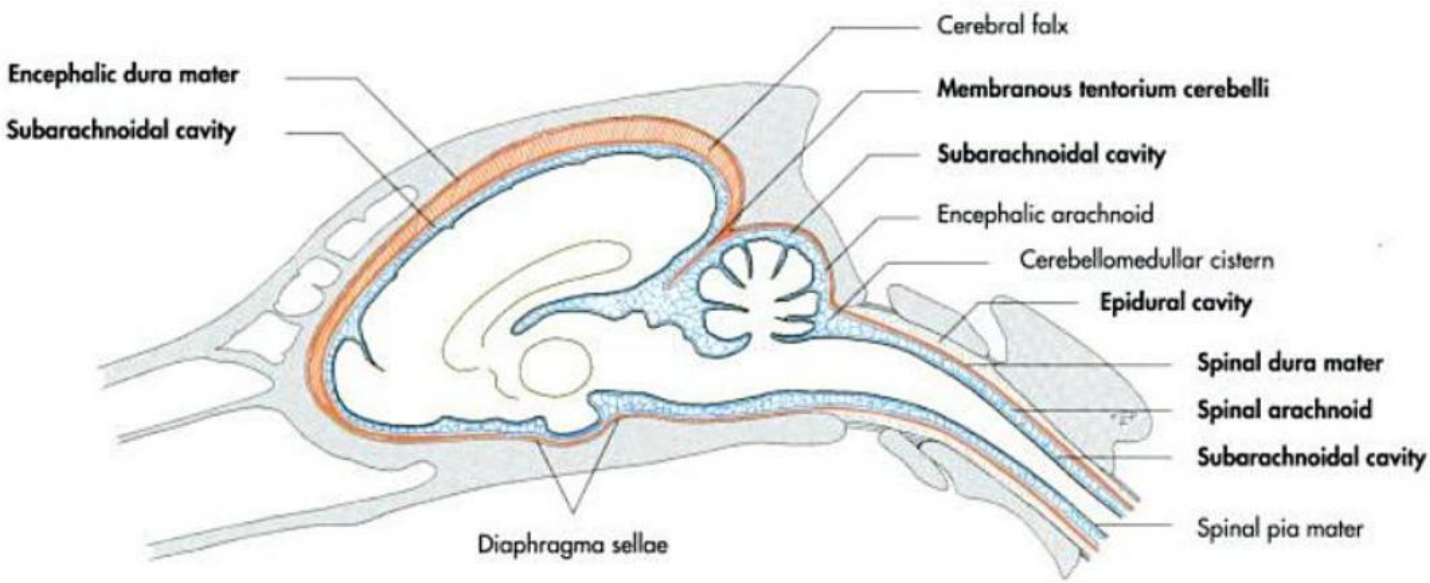


CSF

- CSF is produced mostly from the choroid plexus, a tuft of capillaries found at the top of the third and fourth ventricles, as well as the floor of the lateral ventricles.
- The remaining CSF is formed from the ependymal cells. Although CSF originates as an ultrafiltration of blood, its composition differs from that of plasma in several important ways.
- It contains less protein, calcium, and potassium, and more sodium, chloride, and hydrogen ions than plasma.

Blood–cerebrospinal fluid barrier

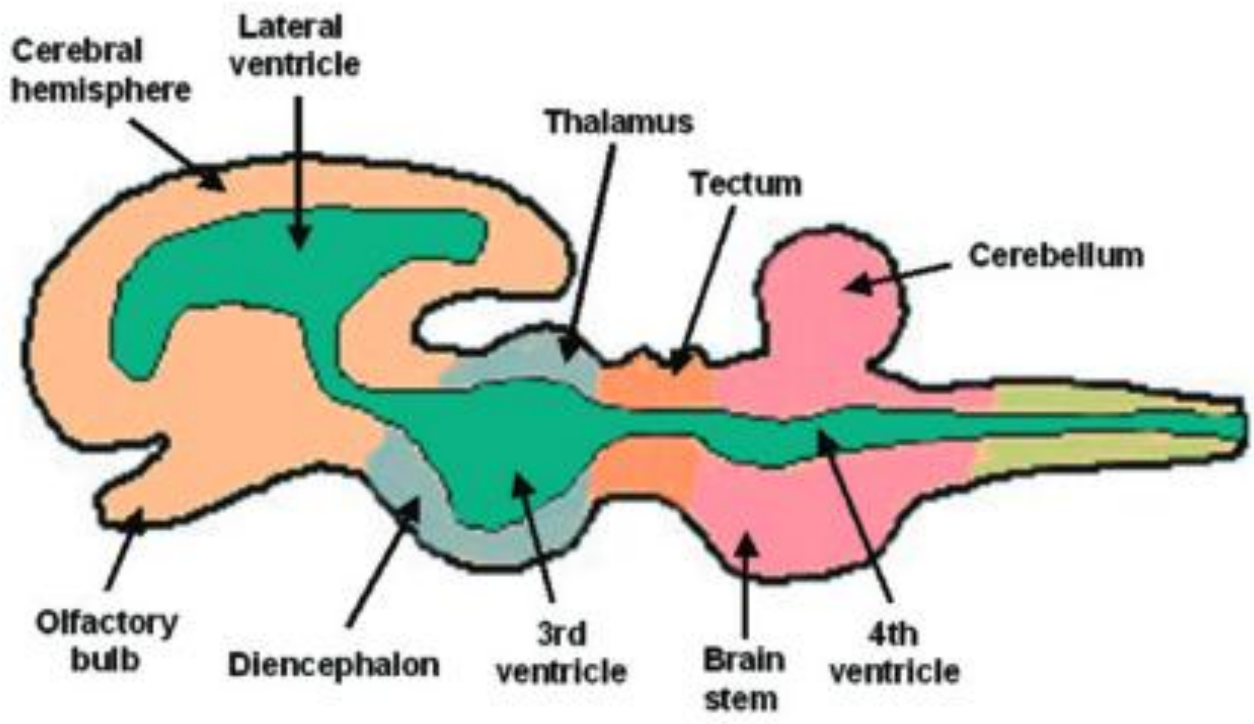
- Although the choroid plexus is located within the ventricles, embryologically, it is derived from mesodermal tissue that is outside of the CNS.
- Therefore, unlike the endothelial cells in most brain capillaries, those in the choroid plexus do not have tight junctions.
- Instead, the ependymal cells lining the cerebroventricles overlying the choroid plexus have tight junctions, thus forming a barrier between the blood and CSF.

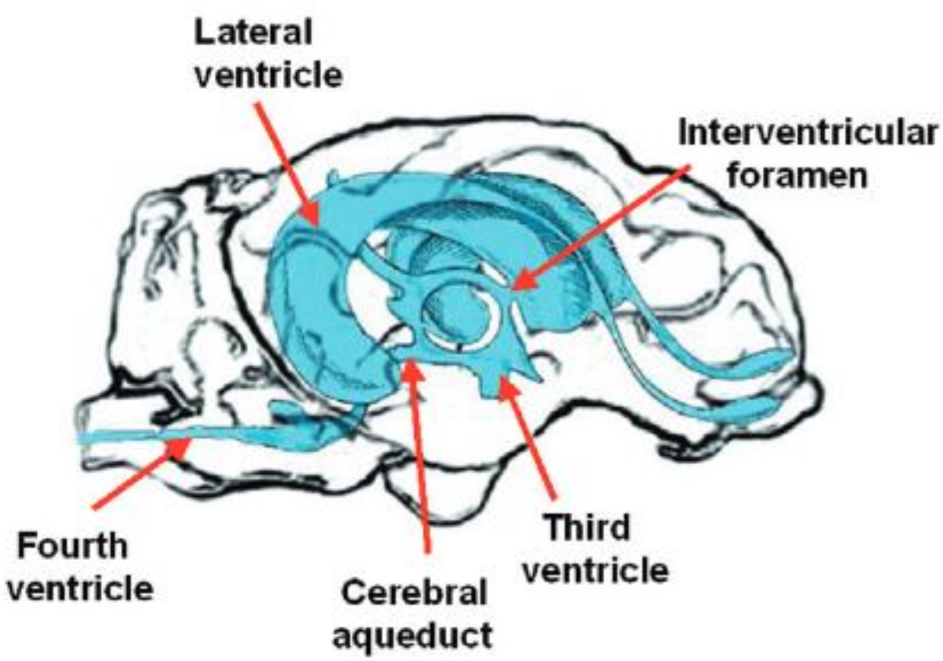


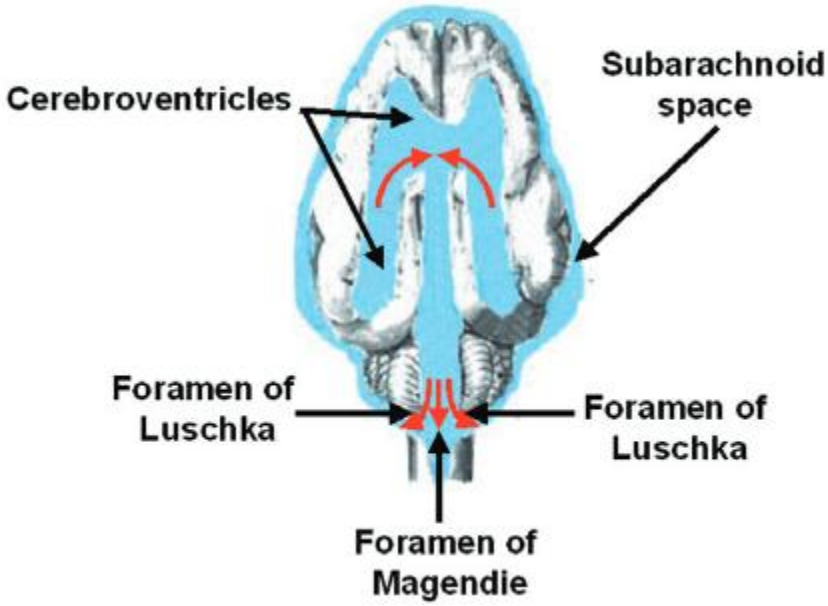
Ventricles of the brain

- Each cerebral hemisphere contains a lateral ventricle, also called the first and second ventricle.
- A thin layer of tissue called the septum pellucidum separates the two lateral ventricles from each other.
- The third ventricle is found in the diencephalon
- The fourth ventricle extends from the posterior surface of the pons and the anterior surface of the cerebellum to the superior portion of the medulla oblongata, The fourth ventricle is continuous with the central canal of the spinal cord.
- The lateral ventricles are connected to the third ventricle via the interventricular foramen of Monroe
- The third ventricle connects to the fourth ventricle via the mesencephalic aqueduct, also called the aqueduct of Sylvius or cerebral aqueduct.
- CSF flows by bulk flow from the lateral ventricles to the third ventricle to the fourth ventricle.
- CSF can leave the fourth ventricle through the medial aperture called the foramen of Magendie and the two lateral apertures called the foramina of Luschka and enter the subarachnoid space.

- This space is found between the arachnoid and pia mater, which, along with the dura mater, form the three meningeal layers covering the brain. The fluid in the subarachnoid space bathes the surface of the brain and spinal cord.







Blood–brain barrier (BBB)

- Neurons of the brain and spinal cord are very sensitive to alterations in their environment. As such, they are isolated from the systemic circulation by the BBB, which prevents the movement of many molecules into the CNS.
- The BBB is formed by the endothelial cells lining the blood capillaries. In the periphery, these cells are fenestrated; in the CNS, these cells form tight junctions.
- The tight junctions are induced by factors produced by astrocytes whose end feet surround the endothelial cells of brain capillaries.
- To cross the BBB, a molecule either must be lipid soluble or must cross via a carrier mediated transport system.
- Lipidsoluble compounds readily cross cell membranes and are thereby readily able to enter the CNS. Such compounds include carbon dioxide, oxygen, steroids, prostaglandins, and alcohol.
- In contrast, nonlipidsoluble compounds, such as peptides and various antibiotics, do not readily cross the BBB. However, since many essential nutrients for the brain are not lipid soluble, the BBB also possesses many carrier mediated transport systems that allow such compounds to enter the brain at a rate far greater than that explained by their lipid solubility.

Cranial nerves

Cranial nerves connect directly to the brain rather than the spinal cord. Most are part of the periph-eral nervous system, although the first two (olfactory nerve and optic nerve) are considered part of the CNS.

There are 12 pairs of cranial nerves, and they arise from the ventrolateral surface of the brain. These nerves mostly innervate the head. The cranial nerves attach to the brain near their associated sensory and/or motor nuclei.

The cranial nerves can be classified as sensory, special sensory, motor, or mixed. Sensory nerves carry somatic sensory information such as touch, pressure, vibration, temperature, and pain input to the brain.

Special sensory nerves carry signals associated with special senses including smell, sight, hearing, taste, or balance. Motor nerves carry somatic motor input to their respective muscles, while mixed nerves are both afferent and efferent, carrying sensory and motor information.

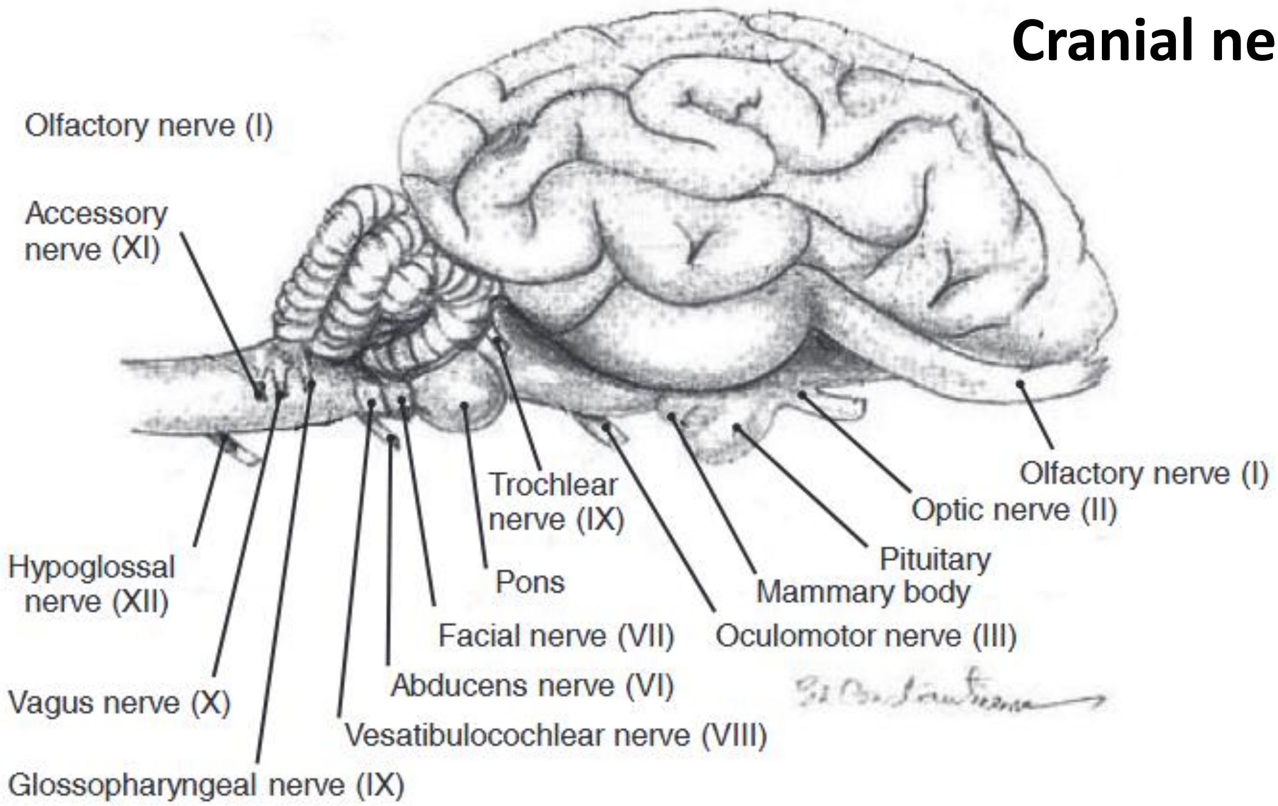
Cranial nerves III, VII, IX, and X are associated with the parasympathetic nervous system. They carry autonomic signals to preganglionic fibers located in the periphery.

Cranial nerves are involved in cranial reflexes.

These are reflexes involving sensory and motor fibers of the cranial nerves

Number	*Name*	*Types of Axons*	*Function*
I	Olfactory	Special sensory	Smell
II	Optic	Special sensory	Vision
III	Oculomotor	Somatic motor	Movements of eye and eyelid
		Visceral motor	Parasympathetic control of pupil size
IV	Trochear	Somatic motor	Movement of the eye
V	Trigenimal	Somatic sensory	Sensation of touch to the face
		Somatic motor	Motor control of mastication
VI	Abducens	Somatic motor	Movement of the eye
VII	Facial	Somatic motor	Facial expressions
		Special sensory	Taste in anterior two-thirds of the tongue
VIII	Vestibulocochlear	Special sensory	Hearing and balance
IX	Glossopharyngeal	Somatic motor	Movements in the throat
		Special sensory	Taste in posterior two-thirds of the tongue
		Visceral sensory	Detection of blood pressure (BP) changes in aorta
		Visceral motor	Parasympathetic control of salivary glands
X	Vagus	Visceral sensory	Sense of pain in viscera
		Visceral motor	Movement in the throat
		Somatic motor	Parasympathetic control of heart, lungs and abdominal organs
XI	Spinal accessory	Somatic motor	Movement in throat and neck
XII	Hypoglossal	Somatic motor	Movement of the tongue

Cranial nerves



Cranial reflex

Reflex	*Stimulus*	*Afferent Cranial Nerve*	*Central Synapse*	*Efferent Cranial Nerves*	*Response*
Somatic					
Corneal reflex	Touching corneal surface	V	Motor nucleus for facial nerve	VII	Blinking eyelids
Tympanic reflex	Loud noise	VIII	Inferior colliculus	VII	Reduced movement of auditory ossicles
Auditory reflex	Loud noise	VIII	Motor nuclei of brain stem and spinal cord	III, IV, VI, VII, X, and cervical nerves	Eye and/or head movements triggered by sudden sounds
Vestibulo-ocular reflex	Rotation of head	VIII	Motor nuclei controlling eye muscles	III, IV, VI	Opposite movement of eyes to stabilize field of vision
Visceral					
Direct light reflex	Light stimulating photoreceptors	II	Superior colliculus	III	Constriction of ipsilateral pupil
Consensual light reflex	Light stimulating photoreceptors	II	Superior colliculus	III	Constriction of contralateral pupil