Excitability is defined as the **physiochemical change** that occurs in a tissue when stimulus is applied. Nerve fibers have a low threshold for excitation than the other cells.

Response Due to Stimulation of Nerve Fiber

When a nerve fiber is stimulated, based on the strength of stimulus, two types of response develop:
1. *Action potential or nerve impulse:* Action potential develops in a nerve fiber when it is stimulated by a stimulus with adequate strength. Adequate strength of stimulus, necessary for producing the action potential in a nerve fiber is known as **threshold** or **minimal stimulus.** Action potential is propagated.
2. *Electrotonic potential or local potential:* When the stimulus with **subliminal strength** is applied, only electrotonic potential develops and the action potential does not develop. Electrotonic potential is nonpropagated.

A. RESTING MEMBRANE POTENTIAL

Resting membrane potential is defined as the electrical potential difference (voltage) across the cell membrane (between inside and outside of the cell) under resting condition.
It is also called membrane potential, transmembrane potential, transmembrane potential difference or transmembrane potential gradient.
When two electrodes are connected to a cathode ray oscilloscope through a suitable amplifier and placed over the surface of the muscle fiber, there is no potential difference, i.e. there is zero potential difference. But, if one of the electrodes is inserted into the interior of muscle fiber, potential difference is observed across the sarcolemma (cell membrane). There is negativity inside and positivity outside the muscle fiber. This potential difference is constant and is called resting membrane potential. The condition of the muscle during resting membrane potential is called **polarized state.** In human skeletal muscle, the resting membrane potential is –90 mV.

Ionic Basis of Resting Membrane Potential

Development and maintenance of resting membrane potential in a muscle fiber or a neuron are carried out by movement of ions, which produce ionic imbalance across the cell membrane. This results in the development of more positivity outside and more negativity inside the cell. Ionic imbalance is produced by two factors:
1. Sodiumpotassium pump
2. Selective permeability of cell membrane.

B. ACTION POTENTIAL OR NERVE IMPULSE

Action potential is defined as a series of electrical changes that occur in the membrane potential when the muscle or nerve is stimulated. Action potential in a nerve fiber is similar to that in a muscle, except for some minor differences. Resting membrane potential in the nerve fiber is –70 mV. The firing level is at –55 mV. Depolarization ends at +35 mV (Fig. 136.1). Usually, the action potential starts in the initial segment of nerve fiber.

ACTION POTENTIAL

Action potential occurs in two phases:
1. Depolarization
2. Repolarization.

Depolarization

Depolarization is the initial phase of action potential in which inside of the muscle becomes positive and outside becomes negative. That is, the polarized state (resting membrane potential) is abolished resulting in depolarization.

Repolarization

Repolarization is the phase of action potential in which the muscle reverses back to the resting membrane potential. That is, within a short time after depolarization the inside of muscle becomes negative and outside becomes positive. So, the polarized state of the muscle is reestablished.

Properties of Action Potential

i. Action potentials follow an **all-or-none law.** If a stimulus depolarizes the neuron to threshold, the neuron fires at its maximum voltage (such as +35 mV); if threshold is not reached, the neuron doesn't fire at all. Above threshold, stronger stimuli don't produce stronger action potentials. Thus, action potentials are not graded (proportional to stimulus strength).
ii. Action potentials are **non-decremental. The**y do not get weaker with distance. The last action potential at the end of a nerve fiber is just as strong as the first one in the trigger zone, no matter how far away— even in a pain fiber that extends your toes to your brainstem.
iii. Action potentials are **irreversible.** If a neuron reaches threshold, the action potential goes to completion; it cannot be stopped once it begins.

C. ELECTROTONIC POTENTIAL OR LOCAL POTENTIAL

Electrotonic potential or local potential is a non-propagated **local response** that develops in the nerve fiber when a subliminal stimulus is applied. Subliminal or subthreshold stimulus does not produce action potential. But, it alters the resting membrane potential and produces **slight depolarization** for about 7 mV. This slight depolarized state is called electrotonic potential. Firing level is reached only if depolarization occurs up to 15 mV. Then only action potential can develop.

Electrotonic potential is a **graded potential** meaning they vary in magnitude (voltage) according to the strength of the stimulus. An intense or prolonged stimulus opens more gated ion channels than a weaker stimulus, and they stay open longer. Thus, more Na+ enters the cell and the voltage changes more than it does with a weaker stimulus.

Properties of Electrotonic Potential

1. Electrotonic potential is **non-propagated**
2. It does not obey **all-or-none law.** If the intensity of the stimulus is increased gradually every time, there is increase in the amplitude till the firing level is reached, i.e. at 15 mV.

Neurotransmitter is a chemical substance that acts as a **mediator** for the transmission of nerve impulse from one neuron to another neuron through a synapse.

A. CLASSIFICATION OF NEUROTRANSMITTERS

1) „ DEPENDING UPON CHEMICAL NATURE

Many substances of different chemical nature are identified as neurotransmitters. Depending upon their chemical nature, neurotransmitters are classified into three groups.

1. *Amino Acids*

Neurotransmitters of this group are involved in **fast synaptic transmission** and are inhibitory and excitatory in action. GABA, glycine, glutamate (glutamic acid) and aspartate (aspartic acid) belong to this group.

2. *Amines*

Amines are the modified amino acids. These neurotransmitters involve in **slow synaptic transmission.** These neurotransmitters are also inhibitory and excitatory in action. Noradrenaline, adrenaline, dopamine, serotonin and histamine belong to this group.

3. *Others*

Some neurotransmitters do not fit into any of these categories. One such substance is acetylcholine. It is formed from the choline and acetyl coenzyme A in the presence of the enzyme called choline acetyltransferase. Another substance included in this category is the soluble gas nitric oxide (NO).

2) DEPENDING UPON FUNCTION

Some of the neurotransmitters cause excitation of postsynaptic neuron while others cause inhibition.

Thus, neurotransmitters are classified into two types:

1. Excitatory neurotransmitters
2. Inhibitory neurotransmitters.

1. *Excitatory Neurotransmitters*

Excitatory neurotransmitter is a chemical substance, which is responsible for the conduction of impulse from presynaptic neuron to postsynaptic neuron.

Common excitatory neurotransmitters are **acetylcholine** and **noradrenaline.**

2. *Inhibitory Neurotransmitters*

Inhibitory neurotransmitter is a chemical substance, which inhibits the conduction of impulse from the presynaptic neuron to the postsynaptic neuron.

Common inhibitory neurotransmitters are **gamma-aminobutyric acid (GABA)** and dopamine.

B. SOME IMPORTANT NEUROTRANSMITTERS

a. ACETYLCHOLINE

Acetylcholine is a **cholinergic neurotransmitter.** It possesses excitatory function. It produces the excitatory function by opening the ligand-gated sodium channels.

Source

Acetylcholine is the transmitter substance at the neuromuscular junction and synapse. It is also released by the following nerve endings:

1. Preganglionic parasympathetic nerve
2. Postganglionic parasympathetic nerve
3. Preganglionic sympathetic nerve
4. Postganglionic sympathetic cholinergic nerves:

i. Nerves supplying eccrine sweat glands
ii. Sympathetic vasodilator nerves in skeletal muscle

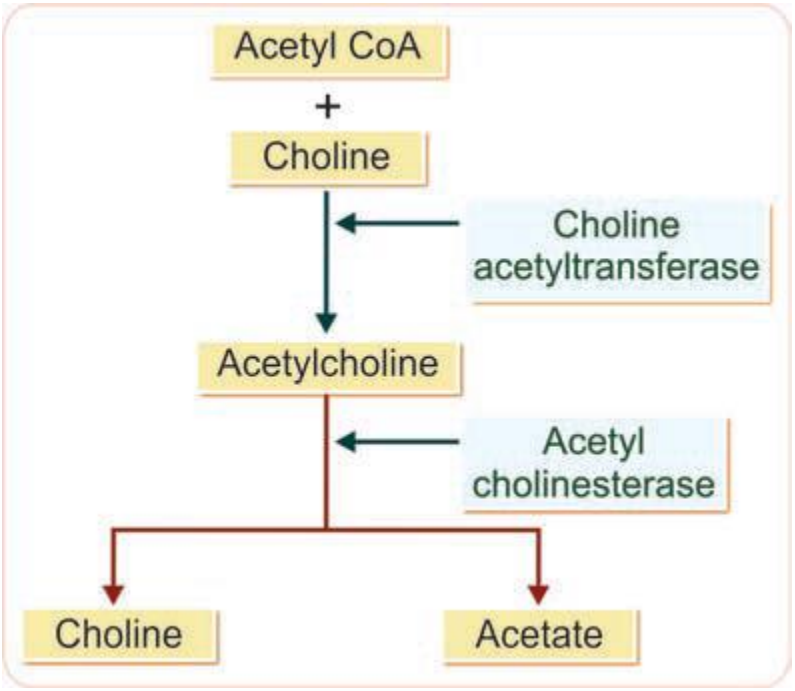
5. Nerves in amacrine cells of retina
6. Many regions of brain.

Synthesis

Ach is synthesized in the cholinergic nerve endings. Synthesis takes place in axoplasm and Ach is stored in the vesicles. It is synthesized from acetyl coenzyme A (acetyl CoA). It combines with choline in the presence of the enzyme choline acetyltransferase to form Ach.

Fate

Action of Ach is short lived. Within one millisecond after the release from the vesicles, it is hydrolyzed into acetate and choline by the enzyme **acetylcholinesterase**. This enzyme is present in basal lamina of the synaptic cleft.



b. NORADRENALINE

Noradrenaline is the neurotransmitter in adrenergic nerve fibers. It is released from the following structures:

1. Postganglionic sympathetic nerve endings
2. Cerebral cortex
3. Hypothalamus
4. Basal ganglia
5. Brainstem
6. Locus ceruleus in pons
7. Spinal cord.

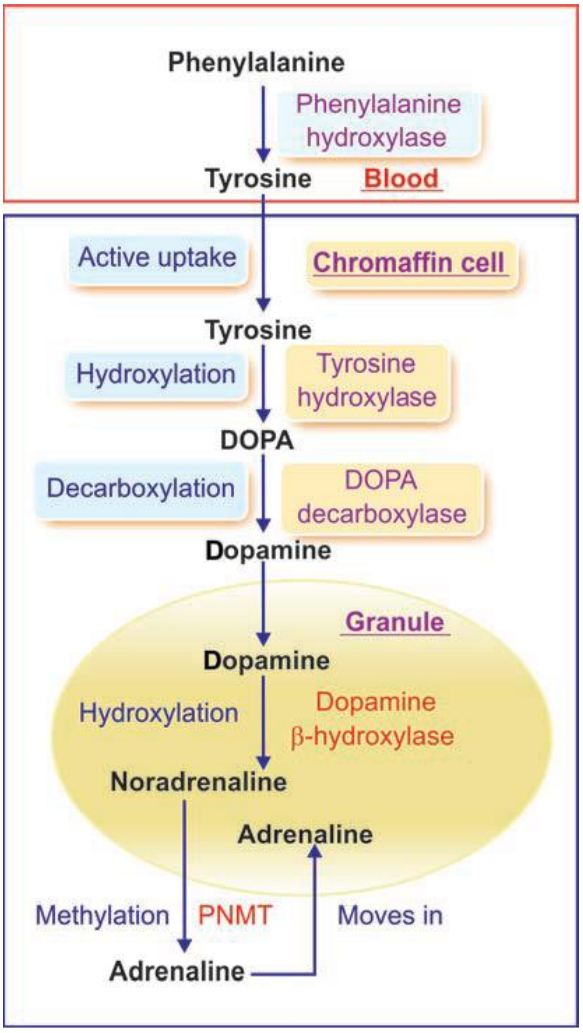
In many places, noradrenaline is the **excitatory** chemical mediator and in very few places, it causes **inhibition.** It is believed to be involved in dreams, arousal and elevation of moods.

c. DOPAMINE

Dopamine is secreted by nerve endings in the following areas:

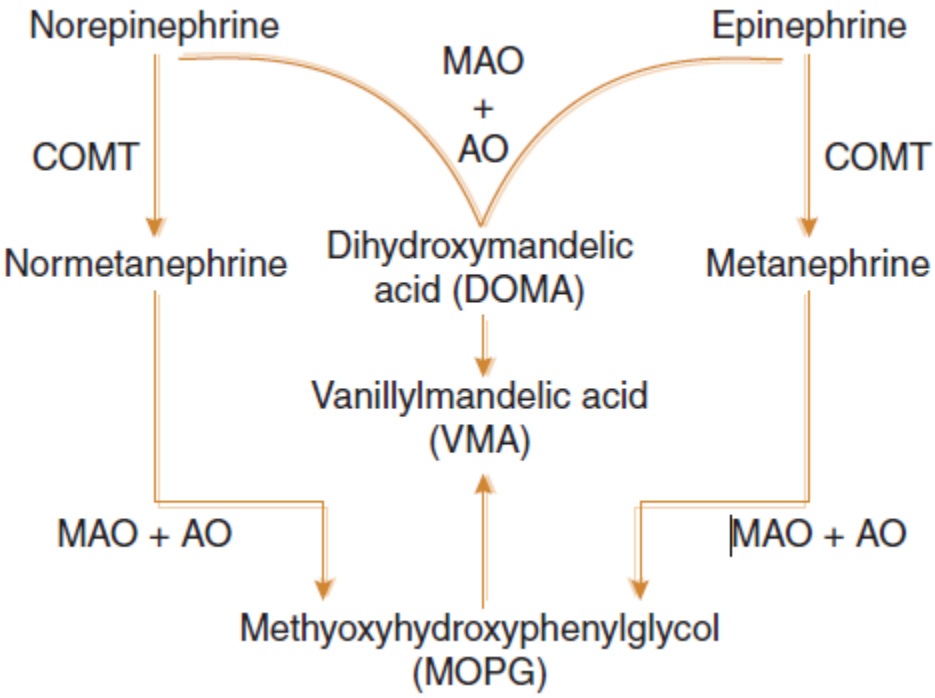
1. Basal ganglia
2. Hypothalamus
3. Limbic system
4. Neocortex
5. Retina
6. Small, intensely fluorescent cells in sympathetic ganglia.

Dopamine possesses **inhibitory** action. Prolactin inhibitory hormone secreted by hypothalamus is considered to be dopamine.



Removal and metabolism of NE. Norepinephrine is removed from the synapse by *reuptake* or is *metabolized* in the pre-synaptic terminal by monoamine oxidase (MAO) and catechol-O-methyl transferase (COMT). The metabolites are: dihydroxymandelic acid, normetanephrine and 3-methoxy-4-hydroxy-phenyl-glycol.

Metabolism of dopamine. Dopamine is metabolized by MAO and COMT



d. SEROTONIN

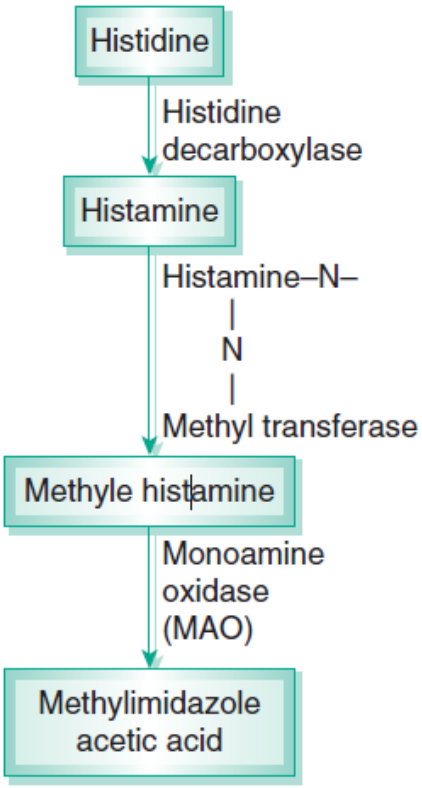
Serotonin is otherwise known as **5hydroxytryptamine** (5-HT). It is synthesized from tryptophan by hydroxylation and decarboxylation. Large amount of serotonin (90%) is found in enterochromatin cells of GI tract. Small amount is found in platelets and nervous system. It is secreted in the following structures:

1. Hypothalamus
2. Limbic system
3. Cerebellum
4. Dorsal raphe nucleus of midbrain
5. Spinal cord
6. Retina
7. GI tract
8. Lungs
9. Platelets.

It is an **inhibitory** substance. It inhibits impulses of pain sensation in posterior gray horn of spinal cord. It is supposed to cause depression of mood and sleep. Serotonin causes vasoconstriction, platelet aggregation and smooth muscle contraction. It also controls food intake.

e. HISTAMINE

Histamine is secreted in nerve endings of hypothalamus, limbic cortex and other parts of cerebral cortex. It is also secreted by gastric mucosa and mast cells. Histamine is an **excitatory** neurotransmitter. It is believed to play an important role in arousal mechanism. Histamine is formed by the decarboxylation of the amino acid histidine.



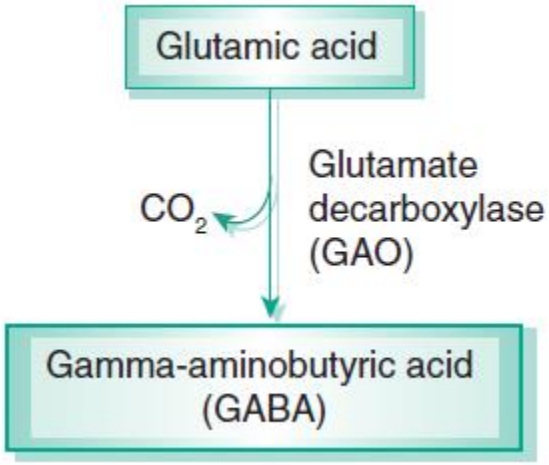


Fig. Formation of gamma-aminobutyric acid (GABA).

Fig. Synthesis and catabolism of histamine.

f. GAMMAAMINOBUTYRIC ACID

Gamma-aminobutyric acid (GABA) is an **inhibitory** neurotransmitter in synapses particularly in CNS. It is responsible for presynaptic inhibition. ***Synthesis.*** It is formed by decarboxylation of glutamic acid by the enzyme glutamate decarboxylase (GAD) pyridoxal phosphate, a vitamin B complex derivative is co-factor for GAD. It is secreted by nerve endings in the following structures:

1. Cerebral cortex
2. Cerebellum
3. Basal ganglia
4. Spinal cord
5. Retina.

GABA causes synaptic inhibition by opening potassium channels and chloride channels. So, potassium comes out of synapse and chloride enters in. This leads to hyperpolarization, which is known as inhibitory postsynaptic potential (IPSP).

g. SUBSTANCE P

Substance P is a neuropeptide that acts as a neurotransmitter and as a neuromodulator (see below). Substance P is a polypeptide with 11 amino acid residues. It belongs to a family of 3 related peptides called **neurokinins** or **tachykinins.** The other peptides of this family are neurokinin A and neurokinin B which are not well known like substance P.

Substance P is secreted by the nerve endings (first order neurons) of pain pathway in spinal cord. It is also found in many peripheral nerves, different parts of brain particularly hypothalamus, retina and intestine (Chapter 44).

It mediates **pain sensation.** It is a potent vasodilator in CNS. It is responsible for regulation of anxiety, stress, mood disorders, neurotoxicity, nausea and vomiting.

h. NITRIC OXIDE

Nitric oxide (NO) is a neurotransmitter in the CNS. It is also the important neurotransmitter in the neuromuscular junctions between the inhibitory motor fibers of intrinsic nerve plexus and the smooth muscle fibers of GI tract.

Nitric oxide acts as a mediator for the **dilator effect** of Ach on small arteries. In the smooth muscle fibers of arterioles, NO activates the enzyme guanylyl cyclase, which in turn causes formation of cyclic guanosine monophosphate (cGMP) from GMP. The cGMP is a smooth muscle relaxant and it causes dilatation of arterioles. Thus, NO indirectly causes dilatation of arterioles. Peculiarity of NO is that it is neither produced by the neuronal cells nor stored in the vesicles. It is produced by **nonneuronal cells** like the endothelial cells of blood vessels. From the site of production, it diffuses into the neuronal and non-neuronal cells where it exerts its action.

UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

Almost all neurons are generated by early postnatal life and are not generally replaced by new ones during a lifetime. The cardiovascular system and the nervous system are the first organ systems to function during embryonic life. Before the heart begins to beat, the nervous system commences to differentiate and change in shape. Growth in size occurs after the heart commences to pulsate and blood slowly circulates to bring oxygen and essential nutrients to the developing nervous system.

From a relatively few primordial cells present several weeks after fertilization of the ovum, the nervous system undergoes a remarkable change to attain its complex and intricate organization. Once a neuroblast leaves the ventricular layer of the neural tube, not only is it committed to differentiate into a neuron but also it will never divide again. To generate the estimated 100–200 billion neurons in the mature brain requires a calculated production of more than 2500 neurons per minute during the entire prenatal period. The brain of a 1-year-old child has as many neurons as it will ever have. Throughout life, cells are continuously lost at an estimated rate of 200,000 per day in humans.

Differentiation and growth continue postnatally, attaining the organized complexity of the entire nervous system. It continues throughout life as the nervous system is remodeled through plasticity. The normal development of a neuron and its subsequent integration into neuronal circuits result from activities at both (1) the *genetic level* and (2) the *epigenetic level*. The former (genetic) comprises (a) transcription or the transfer of information from DNA molecules into RNA molecules and (b) translation or the transfer of information from the RNA molecules into polypeptides. The latter (epigenetic) includes many environmental and extracellular factors that can modify, regulate, or channel subsequent development. Epigenesis involves neurotropic and neurotrophic molecules that have critical roles in the structural changes occurring during ontogeny of the nervous system. Tropic factors are molecules to which, for example, growth cones are attracted. Trophic (relating to nutrition for survival) factors are molecules secreted by their targets (target-derived neurotrophic factors) and are essential for the differentiation, growth, and survival of neurons. Neurons in part depend on one another for trophic factors, which affect their signaling efficiency and even their survival.

A. ORIGIN OF THE NERVOUS SYSTEM

The nervous system develops from the **neural plate**, which is an ectodermal thickening in the floor of the amniotic sac. Development of the central nervous system commences on day 18, with the formation of the **neural plate** in the ectoderm anterior to the **primitive pit**. During the third week, the plate forms paired neural folds that fuse to form the neural tube and neural canal. The neural plate first appears at the cranial end, and develops in a cranio-caudal direction. The plate is broad at the cranial end, and narrows caudally. The cranial end will expand into the brain, and even at this primitive stage can be differentiated visually into the fore-, mid-, and hindbrain. The caudal end of the neural plate, which lies above the notochord, develops into the spinal cord. By the end of the fourth week, the open ends, the neuropores, become fused at both end and close. The formation of the neural tube is termed neurulation.
During the third week, the neural folds begin the process of neurulation. On day 22, the neural folds rise, their edges move in towards the midline and they fuse together to form the **neural tube**. Closure of the folds does not occur at the same time along the midline, but begins cranially, and subsequently continues in both cranial and caudal directions. When the two neural folds have almost completely fused with each

other, there remain two openings of the neural tube where the fusing is delayed. These cervical and caudal openings of the neural tube are called **neuropores**. Formation of the neural tube creates a neural canal, which communicates directly with the amniotic cavity at either end. As neurulation proceeds, the cranial and caudal neuropores gradually shrink in size and finally close on the twenty-fifth and twenty-seventh days respectively. Closure of the caudal end is caused by a secondary neurulation that involves the mesoderm as well. As the tube is closing, **neural crest** cells migrate from their origin at the lateral lips of the folds, and move in both lateral and medial paths. Those moving in a medial direction pass in between the neural tube and the somites and form the peripheral autonomic nervous system, dorsal root ganglia and the Schwann cells of spinal nerves. Those moving in a lateral direction form melanoblasts in the skin. The neural crest also gives rise to the ganglia of the peripheral nervous system. The neural tube itself moves and sinks deeper into the embryo as it differentiates into the brain and the spinal cord.

Even before neurulation begins, the brain starts to develop from the rostral (front) end of the tube, which expands to form three vesicles termed the forebrain, or **prosencephalon**, the midbrain or **mesencephalon**, and the hindbrain, or **rhombencephalon**. These three form the embryonic **brain stem**. During the fifth week, the prosencephalon divides further to form the **telencephalon** and **diencephalon**. The telencephalon is comprised of the cerebral hemispheres. The rhombencephalon also divides to form the **metencephalon** and **myelencephalon**. After these divisions, the embryonic brain now consists of five vesicles. Towards the end of the fourth week, the neuroepithelium of the neural tube begins to differentiate into the neuroblasts, glioblasts, and ependymal cells of the central nervous system. The neuroblasts will migrate to form the mantle zone, which will ultimately form the gray matter. The neuroepithelium proliferates beneath the mantle zone in the region of the brain stem and the spinal cord to form a ventricular zone, while migrating neuroepithelial fibers begin to form the marginal zone, which will become the white matter.

As development proceeds, between the fourth and eighth weeks, the embryonic brain undergoes flexion, or bending, at three points. The prosencephalon folds under the brain at the cranial (mesencephalic) flexure. A **pontine flexure** occurs in the area of the future pons, and a cervical flexure occurs between the spinal cord and the hindbrain. The myelencephalon will give rise to the medulla oblongata, the brain area most similar to the spinal cord in structure, while the metencephalon will give rise to the **pons**. The cerebellum develops from the end of the sixth week from the rhombic lips of the metencephalon. By the middle of the third month the cerebellum starts to bulge dorsally, forming a swelling at the cranial end of the rhombencephalon.
Within each of the brain vesicles the neural canal expands into a cavity termed the primitive ventricle. In the rhombencephalon this will become the fourth ventricle and in the mesencephalic cavity becomes the cerebral aqueduct (aqueduct of Sylvius). The third ventricle forms within the diencephalon, while paired lateral ventricles form within the cerebral hemispheres.
At 14 weeks the **lobes** of the cerebral hemispheres are defined; they are the **frontal**, **parietal**, **temporal**, and **occipital** lobes. The structures within the hemispheres, too, are forming. At 16 weeks, the **corpus callosum** is formed, as is the **optic chiasm**, where the optic nerves decussate on their way to the occipital lobe from the eyes. The basal ganglia are defined, as are the thalamus, hippocampus, **anterior commissure**, and fornix. At 28 weeks, the three major cortical **sulc**i are visible. These are the **central**, **lateral**, and **calcarine sulci**.

UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

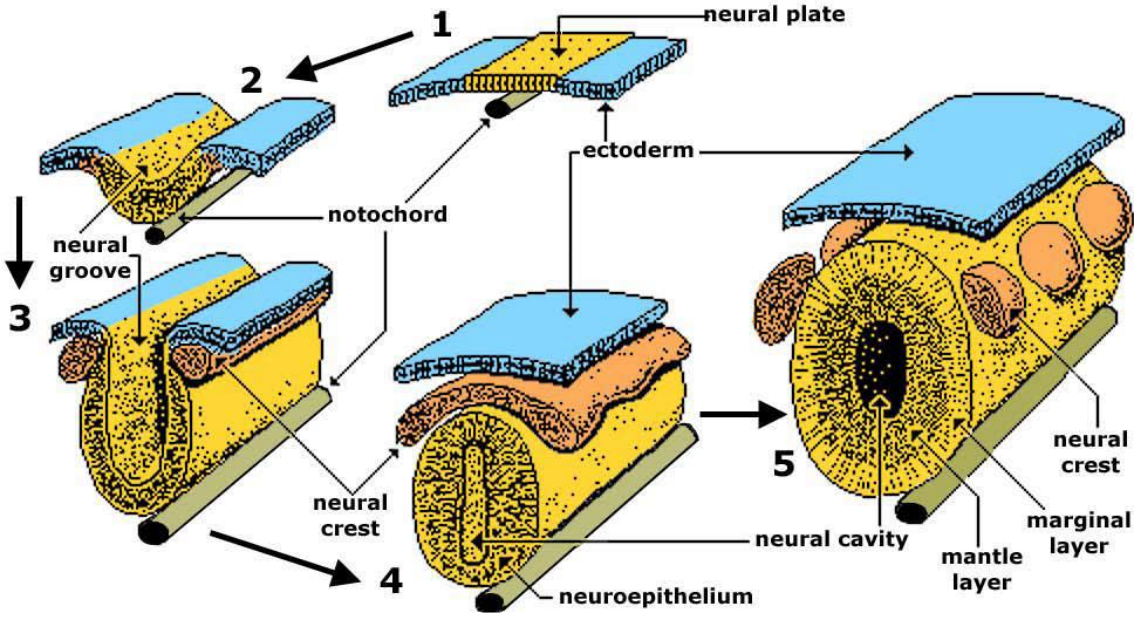


Fig. Cross section through the developing neural tube. (1) Neural plate. (2-3) Neural fold & groove. (4) Neural folds apposing. (D) Neural tube complete. (Neural crest before and after its exit from the neural epithelium is shown in orange.)

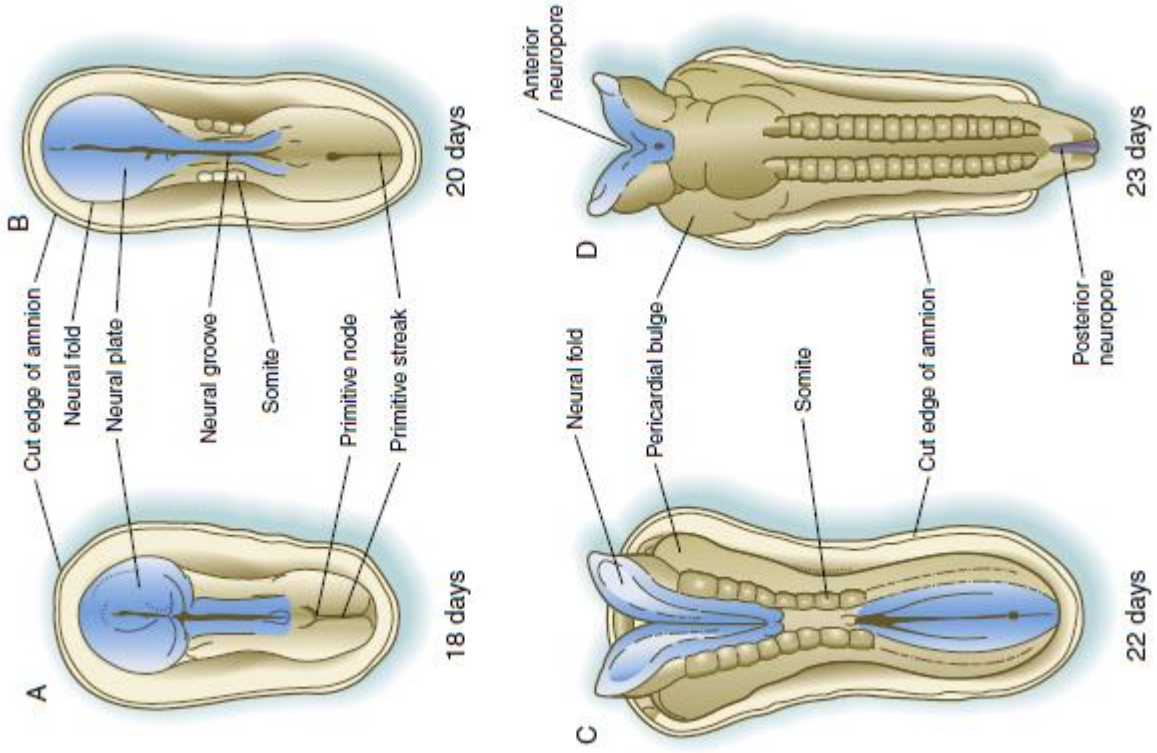


Fig. Early stages in the formation of the human central nervous system. (A) At 18 days. (B) At 20 days. (C) At 22 days. (D) At 23 days.

UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

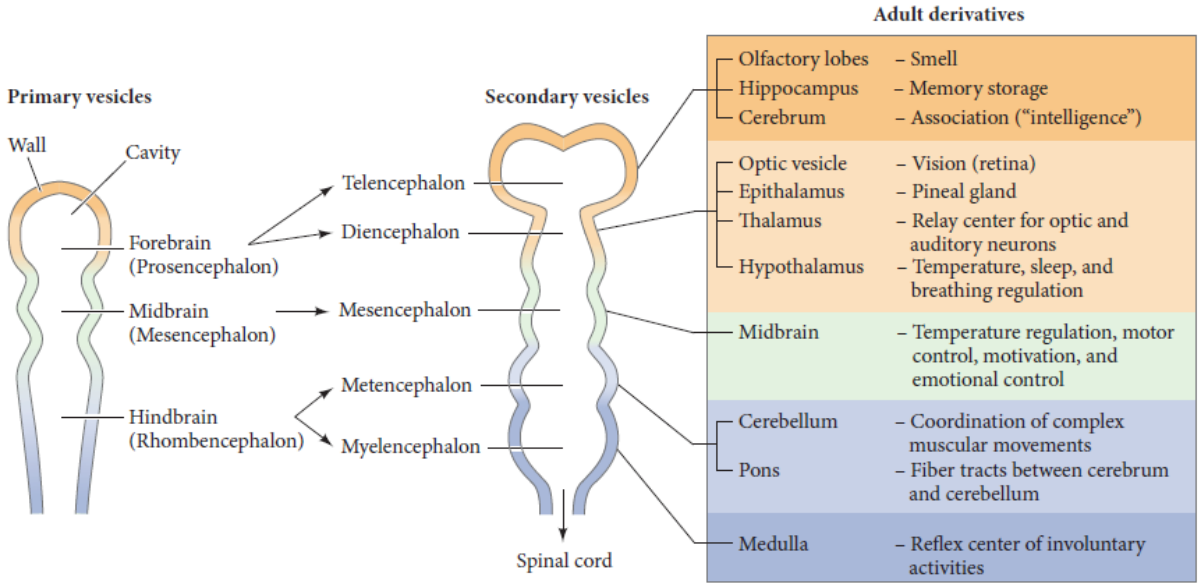


Fig. - Early brain development and formation of the first brain chambers (In humans) - the three primary brain vesicles become further subdivided into 5 secondary brain vesicles. At the right is a list of the adult derivatives formed by the walls and cavities of the brain along with some of their functions.

UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

B. Organization of the nervous system

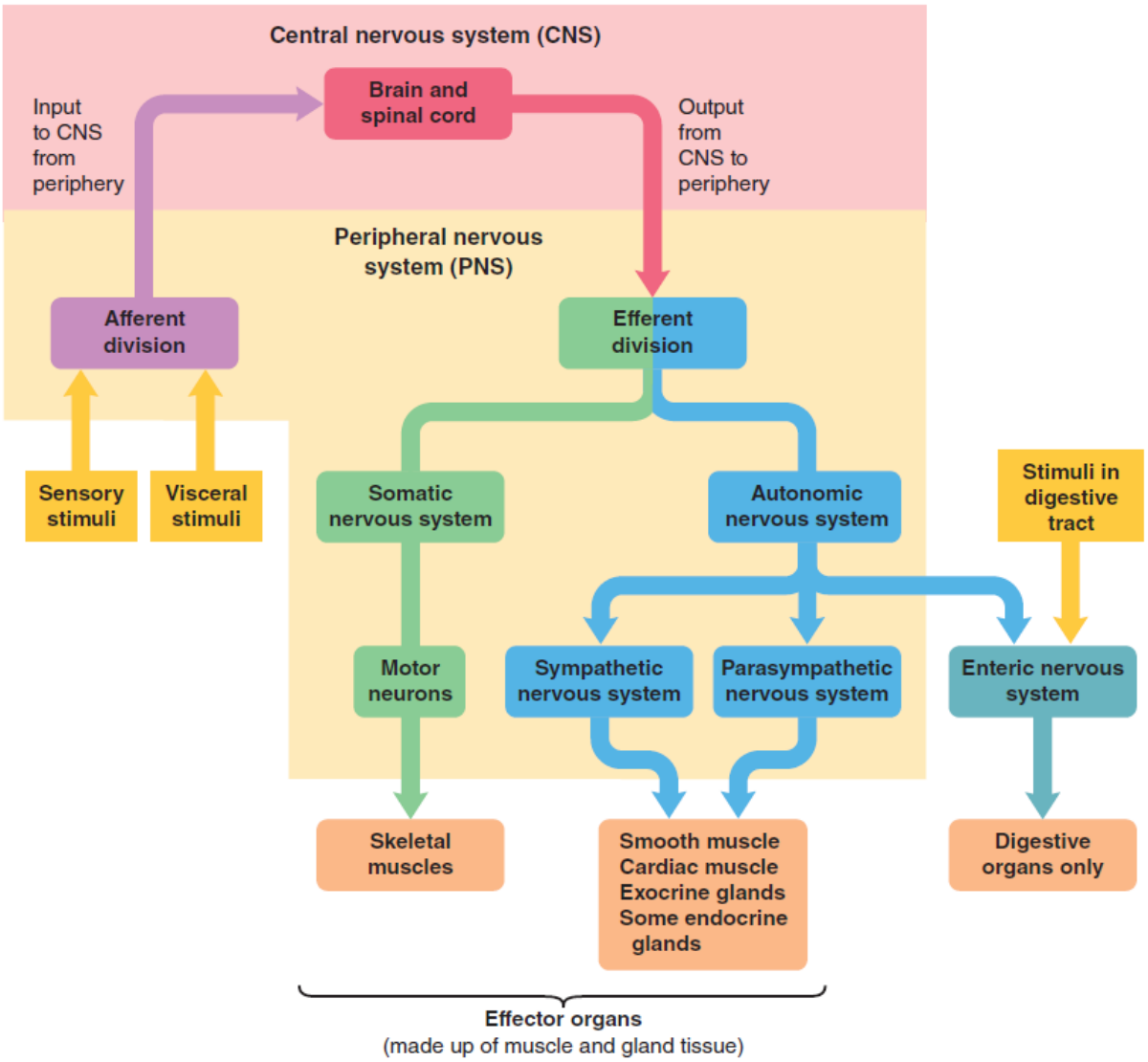


Fig. Organization of the nervous system

The subdivisions of the nervous system are based on differences in the structure, location, and functions of the various diverse parts of the whole nervous system.

The nervous system is organized into the **central nervous system (CNS)** and the **peripheral nervous system (PNS).**

1. The **CNS** consists of the **brain** and **spinal cord,** which are covered by three membranous layers known collectively as the **meninges.**

a) The **dura mater** is the outermost layer and consists of tough connective tissue.

UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

b) The **arachnoid mater** is the middle layer and lies beneath the dura, which it closely follows. The **subarachnoid space** lies beneath the arachnoid membrane and is filled with **cerebrospinal fluid (CSF).**

c) The **pia mater** is the innermost layer. It is a delicate vascular membrane that closely follows the surface of the brain and spinal cord.

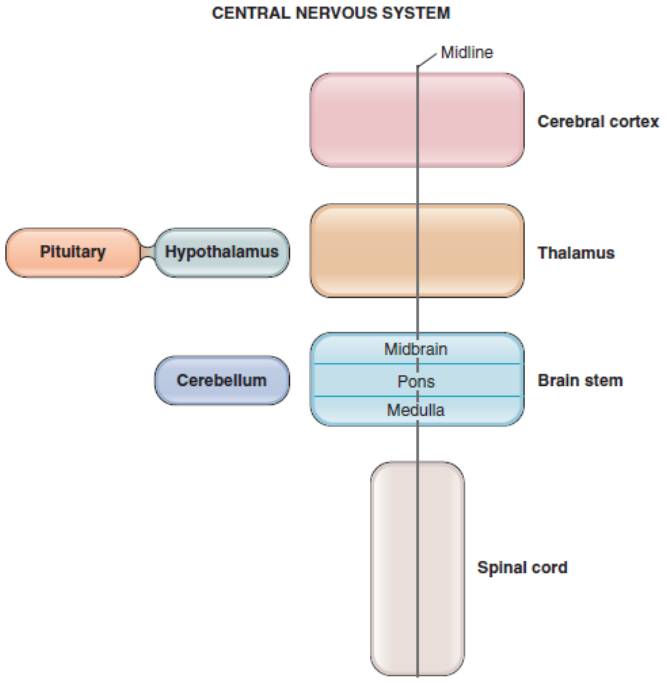
2. The **PNS** consists of neurons and glia, which are located outside the meninges. Structures in the PNS include spinal nerves, cranial nerves, and sensory receptors. **Sensory nerves** that convey information from the periphery to the CNS are called **afferent nerves.** Nerves that carry information from the CNS to the periphery are called **efferent nerves;** the efferent nerves that carry information to skeletal muscle are called **motor nerves** and are involved in muscle control. The **autonomic nervous system (ANS)** is concerned with control of visceral functions such as digestion, blood flow, temperature regulation, and reproduction. The ANS has three divisions:

a) The **sympathetic nervous system** is generally excitatory and is associated with "fight or flight" responses.

b) The **parasympathetic nervous system** is generally antagonist to the sympathetic nervous system and is associated with "rest and digest" functions.

c) The **enteric nervous system** is a large system of neural networks within the walls of the gastrointestinal tract.

1. The **major divisions of the CNS** are the spinal cord; brain stem (medulla, pons, and midbrain); cerebellum; diencephalon (thalamus and hypothalamus); and cerebral hemispheres (cerebral cortex, white matter, basal ganglia, hippocampal formation, and amygdala).



UNIT 1- ORGANIZATION OF NERVOUS SYSTEM: ORIGIN AND DIFFERENTIATION OF NEURONS

I. Spinal Cord

The spinal cord is the most caudal portion of the CNS, extending from the base of the skull to the first lumbar vertebra. The spinal cord is segmented, with 31 pairs of spinal nerves that contain both **sensory** (afferent) nerves and **motor** (efferent) nerves. Sensory nerves carry information *to* the spinal cord from the skin, joints, muscles, and visceral organs in the periphery via dorsal root and cranial nerve ganglia. Motor nerves carry information *from* the spinal cord to the periphery and include both somatic motor nerves, which innervate skeletal muscle, and motor nerves of the autonomic nervous system, which innervate cardiac muscle, smooth muscle, glands, and secretory cells.

Information also travels up and down within the spinal cord. **Ascending pathways** in the spinal cord carry sensory information from the periphery to higher levels of the CNS. **Descending pathways** in the spinal cord carry motor information from higher levels of the CNS to the motor nerves that innervate the periphery.

II. Brain Stem

The medulla, pons, and midbrain are collectively called the brain stem. Ten of the 12 cranial nerves (CNs III–XII) arise in the brain stem. They carry sensory information to the brain stem and motor information away from it. The components of the brain stem are as follows:

1. The **medulla** is the rostral extension of the spinal cord. It contains autonomic centers that regulate breathing and blood pressure, as well as the centers that coordinate swallowing, coughing, and vomiting reflexes.
2. The **pons** is rostral to the medulla and, together with centers in the medulla, participates in balance and maintenance of posture and in regulation of breathing. In addition, the pons relays information from the cerebral hemispheres to the cerebellum.The **midbrain** is rostral to the pons and participates in control of eye movements. It also contains relay nuclei of the auditory and visual systems.

III. Cerebellum

The cerebellum is a foliated (“leafy”) structure that is attached to the brain stem and lies dorsal to the pons and medulla. The functions of the cerebellum are coordination of movement, planning and execution of movement, maintenance of posture, and coordination of head and eye movements. Thus the cerebellum, conveniently positioned between the cerebral cortex and the spinal cord, integrates sensory information about position from the spinal cord, motor information from the cerebral cortex, and information about balance from the vestibular organs of the inner ear.

IV. Thalamus and Hypothalamus

Together, the thalamus and hypothalamus form the **diencephalon,** which means “between brain.” The term refers to the location of the thalamus and hypothalamus between the cerebral hemispheres and the brain stem.

1. The **thalamus** processes almost all sensory information *going to* the cerebral cortex and almost all motor information *coming from* the cerebral cortex to the brain stem and spinal cord.
2. The **hypothalamus** lies ventral to the thalamus and contains centers that regulate body temperature, food intake, and water balance. The hypothalamus is also an endocrine gland that controls the hormone secretions of the pituitary gland. The hypothalamus secretes releasing hormones and release-inhibiting

3. hormones into hypophysial portal blood that cause release (or inhibition of release) of the anterior pituitary hormones. The hypothalamus also contains the cell bodies of neurons of the posterior pituitary gland that secrete antidiuretic hormone (ADH) and oxytocin.

V. Cerebral Hemispheres

The cerebral hemispheres consist of the cerebral cortex, an underlying white matter, and three deep nuclei (basal ganglia, hippocampus, and amygdala). The functions of the cerebral hemispheres are perception, higher motor functions, cognition, memory, and emotion.

1. **Cerebral cortex.** The cerebral cortex is the convoluted surface of the cerebral hemispheres and consists of four lobes: **frontal, parietal, temporal,** and **occipital.** These lobes are separated by sulci or grooves. The cerebral cortex receives and processes sensory information and integrates motor functions. These sensory and motor areas of the cortex are further designated as **"primary," "secondary,"** and **"tertiary,"** depending on how directly they deal with sensory or motor processing. The primary areas are the most direct and involve the fewest synapses; the tertiary areas require the most complex processing and involve the greatest number of synapses. **Association areas** integrate diverse information for purposeful actions. For example, the limbic association area is involved in motivation, memory, and emotions. The following examples illustrate the nomenclature: (1) The *primary* motor cortex contains the upper motoneurons, which project directly to the spinal cord and activate lower motoneurons that innervate skeletal muscle. (2) The *primary* sensory cortices consist of the primary visual cortex, primary auditory cortex, and primary somatosensory cortex and receive information from sensory receptors in the periphery, with only a few intervening synapses. (3) *Secondary* and *tertiary* sensory and motor areas surround the primary areas and are involved with more complex processing by connecting to association areas.

2. **Basal ganglia, hippocampus, and amygdala.** There are three deep nuclei of the cerebral hemispheres. The **basal ganglia** consist of the caudate nucleus, the putamen, and the globus pallidus. The basal ganglia receive input from all lobes of the cerebral cortex and have projections, via the thalamus, to the frontal cortex to assist in regulating movement. The **hippocampus** and **amygdala** are part of the limbic system. The hippocampus is involved in memory; the amygdala is involved with the emotions and communicates with the autonomic nervous system via the hypothalamus (e.g., effect of the emotions on heart rate, pupil size, and hypothalamic hormone secretion).

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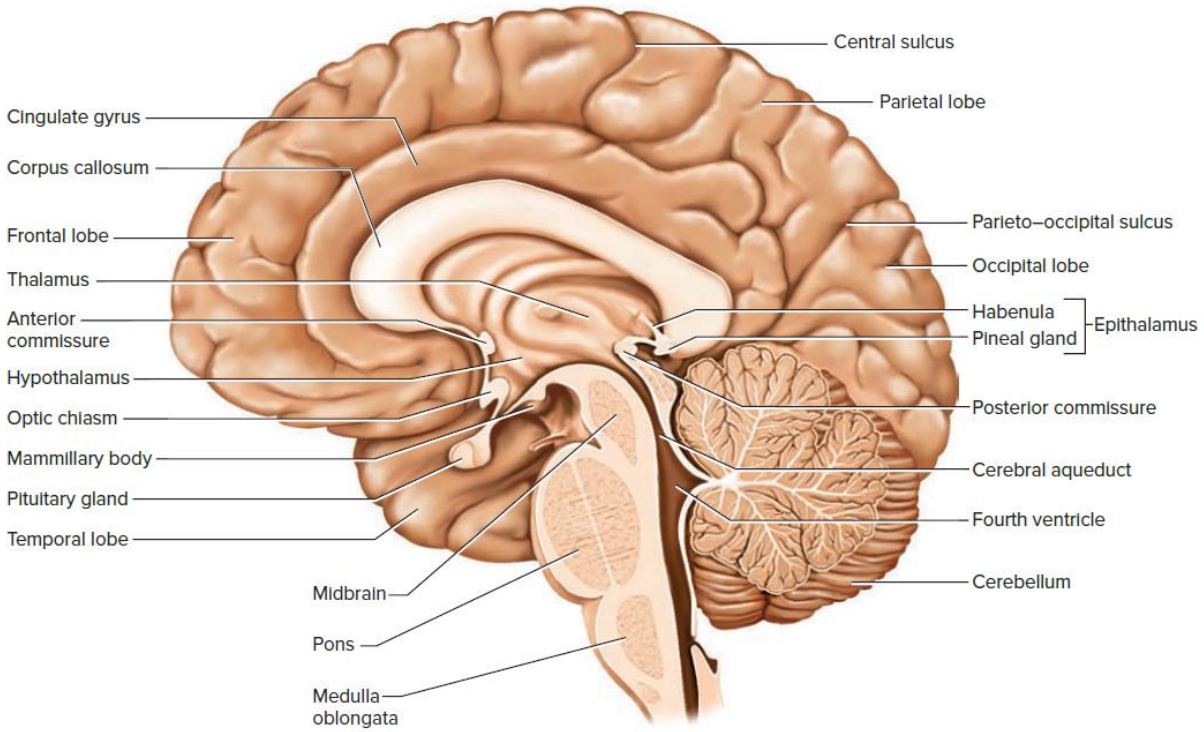

Fig. Major anatomical landmarks of the medial surface of the brain

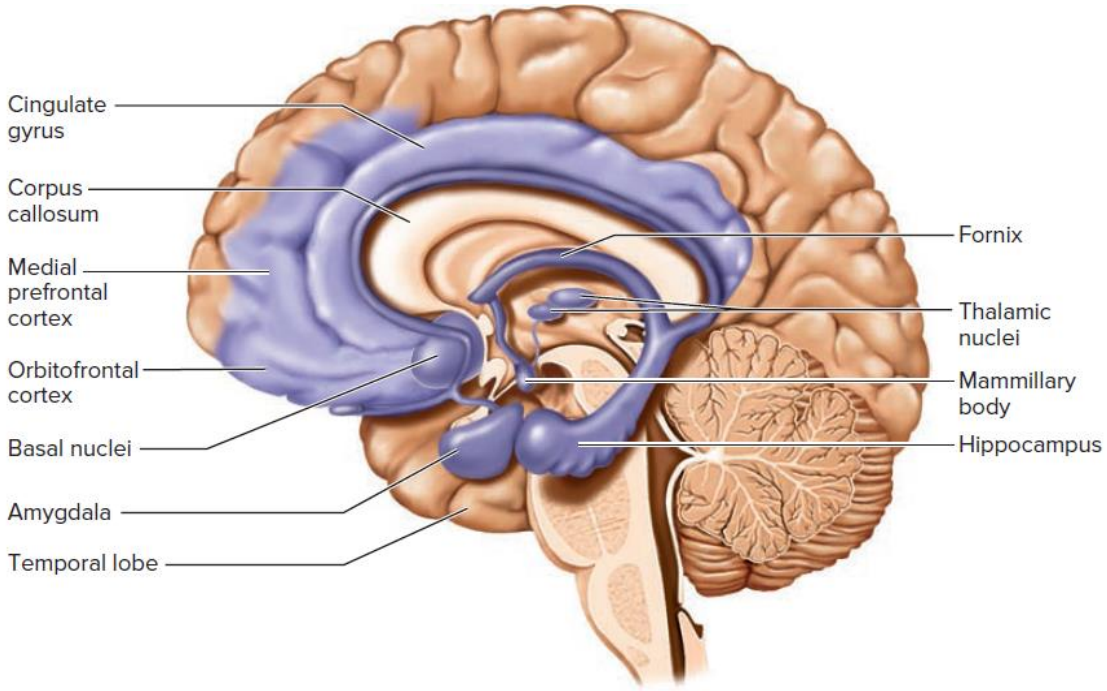

Fig. The Limbic System showing basal ganglia, hippocampus, and amygdala

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