NEUROBIOLÓGIA 1. FOGALOMTÁR

KÉSZÍTETTE:

TIBORI KINGA

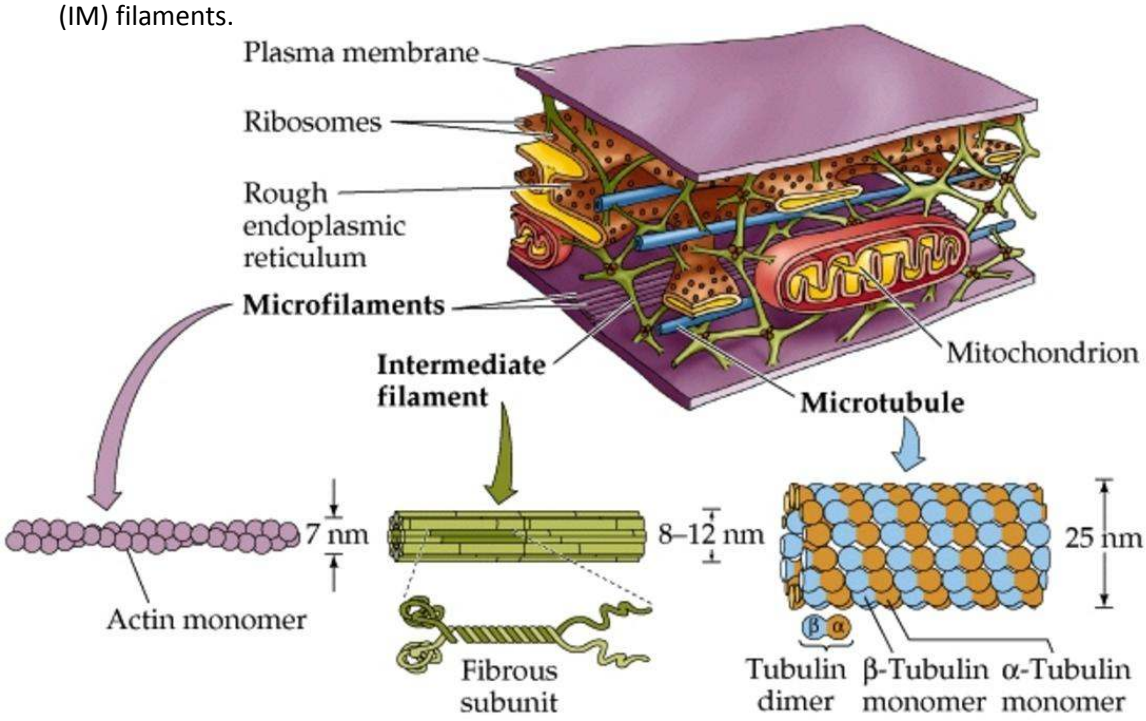
Cell organelles

Centriole 9 mikrotubulus-tripletből áll. Egy pár centriólum alkotja a sejtmag közelében elhelyezkedő centroszómát, amely a mikrotubulusok növekedését szervezi.

Cilium Egy membránnal körülvett, ujj-szerű nyúlványa a citoplazmának, ami a basal bodyból ered. (A membrane-covered, finger-like projection of the cytoplasm which originates from the basal body)

Cytoplasm A gel that makes up 70% of the whole cell volume, and gives a plastic character to it. Contains water, inorganic salts and organic molecules.

Cytoskeleton Fehérje-struktúrák hálózata, mely egy belső vázat ad a sejtnek. (Network of protein structures forming an inner skeleton for the cell. Composed of microfilaments, microtubules and intermediate (IM) filaments.



Endocytosis 2 fajtája: fagocitózis (részecskék, nem oldott anyag felvétele, specializált sejtek (fagociták) funkciója, az immunválasz egyik lépése); pinocitózis (oldott anyagok felvétele)

Glycolipid Lipids with a carbohydrate attached. Their role is to provide energy and also serve as markers for cellular recognition. (The carbohydrates are found on the outer surface of all eukaryotic cell membranes. They extend from the phospholipid bilayer into the aqueous (vizes) environment outside the cell where it acts as a recognition site for specific chemicals as well as helping to maintain the stability of the membrane and attaching cells to one another to form tissues.)

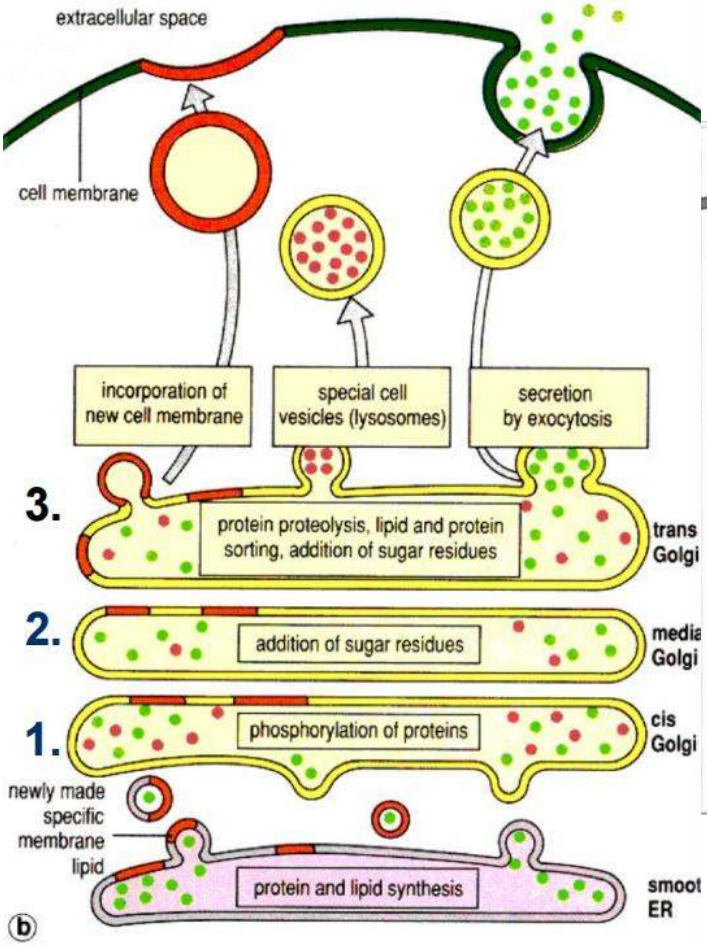
Glycoprotein Important integral membrane proteins – they play a role in cell-cell interactions.

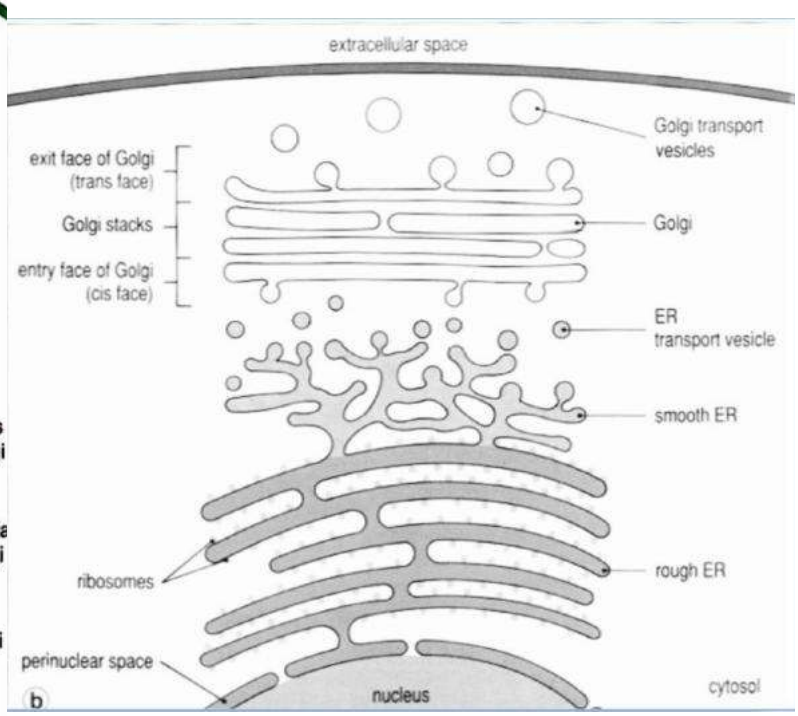
Golgi complex A cell organelle which consists of stacked saucer-shaped flattened cisternae.

Structure: convex-concave 3D structure → the convex part faces the ER system (cis face); the concave part is called trans face.

Function: it communicates via membrane bound vesicles with the rest of the cell organelles (most notably with the ER). Liposomal vesicles born here and also proteoglycans (components of the extracellular matrix) originate from Golgi complex.

Functioning: Transfer vesicles budding off the ER, fuse with the cis face and transport macromolecules for maturation, which involves glycosilation and phosphorylation. The tagging of macromolecules enables their sorting for domestic use, secretion for external utilization or local degradation.

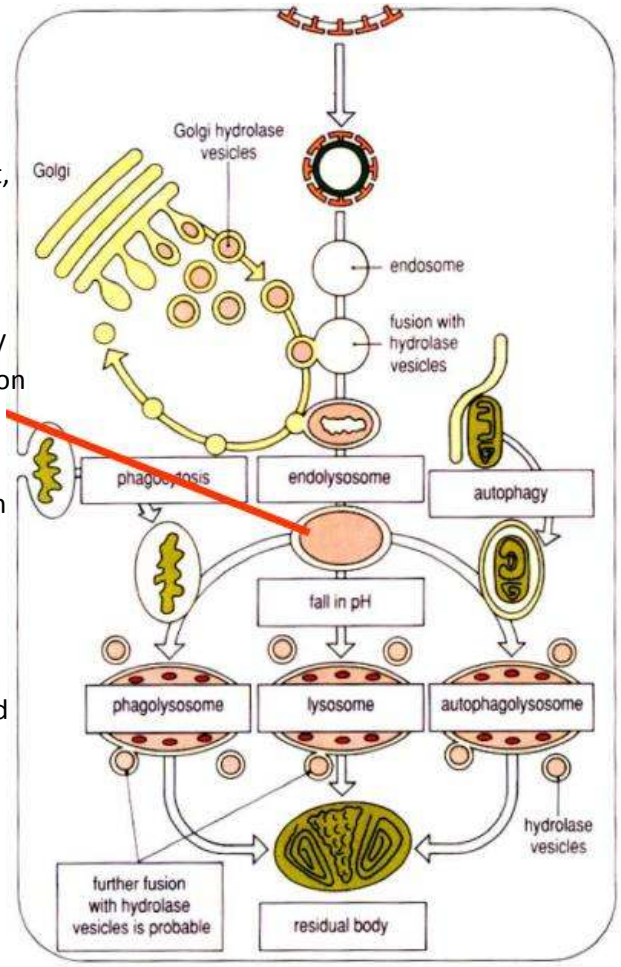




IM filaments Intermediate filaments are protein filaments with 10-12 nm diameter. They form a relatively stable, fibrous network in cell. Their composition is tissue-specific.

Lysosome Membránhatárolt, gömbölyű, 0.1-1 mikrométer átmérőjű vezikula. Hidrolizáló enzimeket tartalmaz, melyek a sejtbe fagocitózis által került részecskéket, valamint elöregedett sejtalkotókat emésztenek. A hidrolizáló enzimek az ER-ben keletkeznek, onnan vezikulák segítségével a Golgiba szállítódnak.
A lizoszóma belső környezete savas (pH: 4.8), amely a citoplazmából, ioncsatornákon és protonpumpákon keresztül beérkező H^+ ionoknak köszönhető.

Membrane-bound, spherical (gömbölyű) vesicle with a diameter of 0.1-1 micrometer. It contains hydrolytic enzymes that digest particles taken into the cell by phagocytosis. They also digest old organelles such as mitochondria. The hydrolytic enzymes are formed in the ER and then transported into the Golgi apparatus by transport vesicles.
The lysosomes internal milieu is acidic (pH: 4.8) which is maintained by pumping H^+ ions from the cytoplasm via chloride ion channels and proton pumps.



Microfilaments 5 nm compartment of the cytoskeleton. Made of actin. Each filament contains 2 twisted protein strings that bind ATP. ***Function***: in muscle tissue they interact with myosin that results in contraction.

Microtubules 10-14 nm compartment of the cytoskeleton. Composed of α and β tubulins. The units polymerize to build up the hollow (üreges) tube. Microtubule-associated proteins (MAP) stabilize the structure. Dynein and kynesin attachment proteins act as motors in delivery along the microtubules. They are vital structures in cell division.

Mitochondrion Elongated, double membrane composed, tubular structure which undergo self-replication. ***Length***: in range of 0.5-10 micrometers. The cavity is filled with the matrix substance which contains a circular DNA, RNA, ribosomes, and a wide array of enzymes. ***Function***: provides ATP to the cell as a source of chemical energy.

Nissl-bodies The RER patches in neurons.

Nuclear envelope Double membrane layer, continuous with rough endoplasmic reticulum.

Nuclear matrix The network of fibers found throughout the inside of a cell nucleus, and is somewhat analogous to the cell cytoskeleton.

Nuclear pores Holes in the double membrane. They form the nuclear pore complex, which regulates trafficking between the nucleus and the cytoplasm (macromolecules, RNA).

Nucleoli A small body in the nucleus of a cell that contains protein and RNA and is the site for the synthesis of ribosomal RNA and for the formation of ribosomal subunits.

RER Rough Endoplasmic Reticulum. A labyrinthine complex membrane structure composed by tubules, vesicles and flattened sacks. ***Function***: ribosomes are attached to the outer surface of the paralleling sacs → protein synthesis takes place at the ribosomes than the newly synthesized proteins get into the lumen of the membrane sacks.

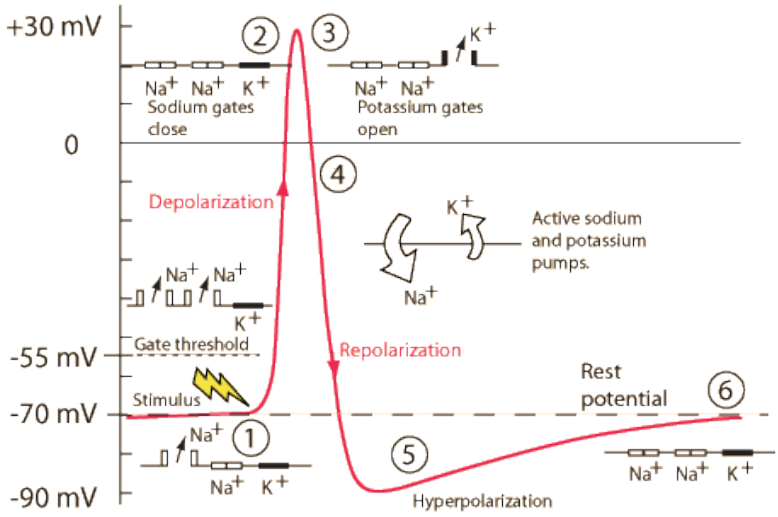
SER Smooth Endoplasmic Reticulum. Irregular network of membranous tubules and vesicles which doesn't carry ribosomes. It is continuous with the RER system and linked to the Golgi system. ***Functions***: it takes part in lipid synthesis, glycogen metabolism, break down of metabolites and detoxification + it stores and releases Calcium in excitable tissues (muscle, nervous tissue). ***Location***: it is abundant in liver cells and steroid synthesizing endocrine cells.

Transport vesicles Vesicles budding off the Golgi complex → they can be classified into 3 categories:

1. Secretory vesicles: they store proteins for extracellular use – triggered by release signals they move to and fuse with the plasma membrane
2. Exocytic vesicles: constitutive secretion maintaining a continuous supply of proteins to the extracellular space by exocytosis
3. Lysosomal vesicles: they contain proteins and degrading enzymes, include acid hydrolase. They get incorporated into the lysosomal digestive machinery.

Nervous tissue

Action potential Transmits signals from the cell body toward the axon terminal.



1. A stimulus is received by the dendrites of a nerve cell. This causes the Na^+ channels to open. If the opening is sufficient to drive the interior potential from -70 mV up to 55 mV, the process continues.

2. Having reached the action threshold, more Na^+ channels (sometimes called voltage gated channels) open. The Na^+ influx drives the interior of the cell membrane up to about +30 mV. The process to this point is called depolarization.

3. The Na^+ channels close and the K^+ channels open. Since the K^+ channels are much slower to open, the depolarization has time to be completed. Having both Na^+ and K^+ channels open at the same time would drive the system toward neutrality and prevent the creation of the action potential.

4. With the K^+ channels open, the membrane begins to repolarize back toward its resting potential

5. The repolarization typically overshoots the rest potential to about -90 mV. This is called hyperpolarization and would seem to be counterproductive, but it is actually important in the transmission of information. Hyperpolarization prevents the neuron from receiving another stimulus during this time, or at least raises the threshold for any new stimulus. Part of the importance of hyperpolarization is in preventing any stimulus already sent up an axon from triggering another action potential in the opposite direction. In other words, hyperpolarization assures that the signal is proceeding in one direction.

6. After hyperpolarization, the Na^+/K^+ pump eventually brings the membrane back to its resting state of -70 mV.

Axon Efferent process of neuron. Propagates action potentials and ensures transport mechanisms. In light microscope (LM) it seems denser than dendrites.

Naked axon The thinnest axons in the nervous system ($d \in [0.1 - 0.3]$ micrometer). They don't have any insulating sheath → their conductor velocity is low: 0.5 – 2 m/sec. They occur in axon bundles within the CNS, and also the initial and the terminal segments of neurons are naked.

Non-myelinated axon Consists of a group of small axons (150-200 micrometer segments) that have invaginated separately a single Schwann cell (in series) without any spiraling of the *mesaxon* (=duplicate of the Schwann cell membrane). ***Location***: sensory fibers carrying temperature and pain sensations.

Axon myelinated by Schwann cell In the PNS the Schwann cells rotate around the axon, their mesaxons wrap around the axon process resulting in the formation of a concentric, multi-laminar, membrane structure called myelin. At the Ranvier nodes, the axolemma has access to the extracellular fluid compartment. At these sites, ion movements take place between the intra- and extracellular compartments. The myelin sheath speeds up the propagation of the information in the axon.

Axon myelinated by oligo-dendrocyte In the CNS myelin is formed by the processes of special glial cells, so-called oligodendrocytes. Their processes wrap around axons. A single oligodendrocyte can insulate about 50 axons. Ranvier nodes also exist between the adjacent myelin insulations. Myelinated axons propagate action potentials in a saltatory manner from one Ranvier node to the other.

Axon collateral Branch of the axon process. Takes part in local neuronal networks.

Axon hillock Site for axon origin. Shows high density of voltage-dependent sodium channels. Action potential initiation place.

Axon terminal The final segment of the axon splitting into fine-caliber (vékony belső átmérőjű) processes that communicate with other elements. It contains microtubules, neurofilament bundles, mitochondria and pools of synaptic vesicles. Releases neuro-messengers.

Dendritic tree Collection of dendrites, extensive branching. Exhibits dendritic spines. Receives afferent axon terminals from other neurons. Takes part in neural plasticity and remodeling.

Dendrites Egy neuron elágazó nyúlványai. Mikrotubulusokat, RER-t, poliszómákat és mRNS-eket tartalmaznak; speciális peptid és transzmitter receptorokban gazdagok. A beérkező információ nagy részét a citoplazma kidudorodásai – az úgynevezett dendritikus tüskék (dendritic spines) fogadják.

Growth cone Dinamikus, aktin-támogatott meghosszabbodása egy fejlődő neuritnak (= a neuron sejttestének bármilyen nyúlványa). Az axonok és dendritek legvégén található. A növekvő axonok és dendritek összes funkcióját magában foglalja.
A dynamic, actin-supported extension of a developing neurite (= any projection from the cell body of a neuron). They are situated on the very tips of nerve cells on axons and dendrites. The sensory, motor, integrative, and adaptive functions of growing axons and dendrites are all contained within this specialized structure.

Hystodynamic polarization The preferred way of conducting [vezetés] information in the axon is from the direction of the cell body toward the axon terminal.

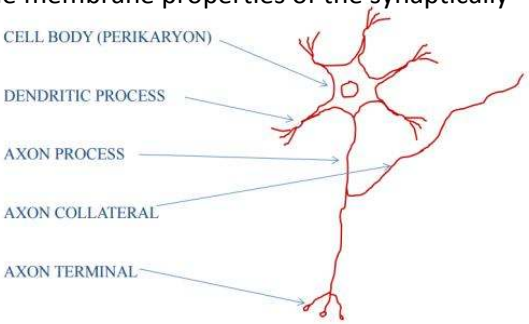
Nervous tissue Receive information from the environment, processes the data and dispatches executive commands (végrehajtandó parancsokat küld) that regulate the basic functions of the body. It is composed of 2 major cell types: neurons and glial cells.

Neural cell body Perikaryon is 10-100 micrometer wide in diameter, the nucleus has a central location and contains 1-2 prominent nucleoli. The cytoplasm around the nucleus contains well-developed RER system units, called Nissl bodies. High RNA content in cytoplasm → strong basophilia (= egyes sejteknek, illetve sejtrészeknek az a tulajdonsága, hogy bázikus [lúgos] anyagokkal jól festhetők). Free ribosomes, RER and Golgi complexes take part in the production and storing of proteins.

Neural units

1. Structural unit: neurons are individual entities, totally covered by cell membrane, 15-20 nm wide interneuronal space separates them.
2. Developmental unit: neurons develop from spherical or columnar neuroepithelial cells of the neural tube, neural crest and the placode plates. Differentiated, mature neurons do not divide.
3. Trophic unit: The cell body provides the genetic code and the diverse biochemical machineries that maintain the trophic needs of the long processes. Nissl bodies are indicative of the active protein synthesis in neurons.
4. Functional unit: The inhibitory and excitatory currents spread in all directions in the neural membrane. Once the all-or-none type of action potential is generated it spreads in the direction of the axon terminal.
5. Pathological unit: Neurons give a different response to pathological causes.

Neuron Exhibits processes that are used for networking and communication. Neurons are excitable cells that maintain a -70mV resting potential due to the uneven distribution of K^+, Na^+ and Cl^- ions across the plasma membrane. Increase in the K^+ and Na^+ conductance evokes action potential that results in electric or chemical signaling affecting the membrane properties of the synaptically coupled neurons.



Neuron functions

1. belső aktivitást generál
2. külső szinaptikus inputokat fogad
3. egységesíti a külső és belső jeleket
4. kódolja a kimenet mintázatát (pattern of output)
5. szinapszisokon keresztül terjeszti az információt

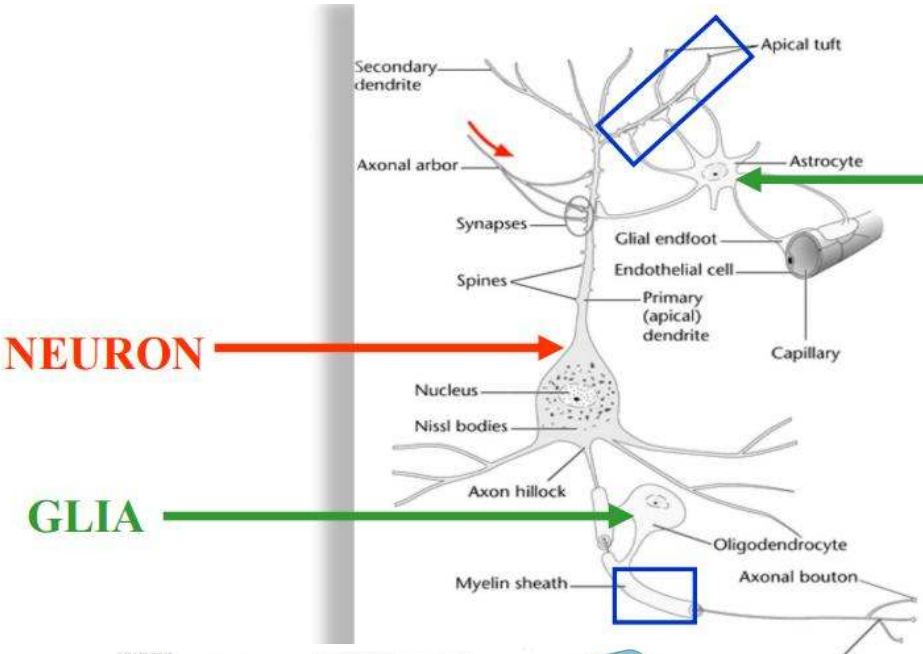
Neuron types

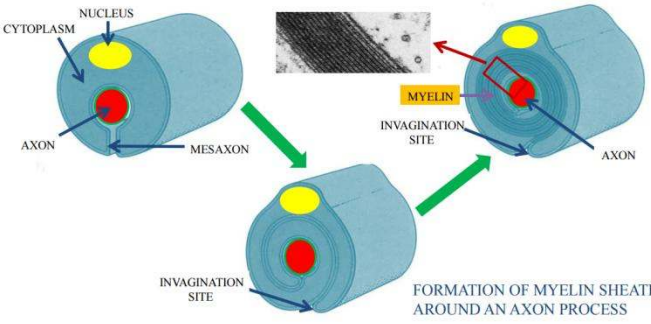
1. Multipolar Neurons: most common type with an extended, branching dendritic tree. E.g. motorneurons in the spinal cord.
2. Bipolar Neurons: possess a dendritic process (nyúlvány) and an axon, originating from the opposite poles of the cell. E.g. sensory neurons of the vestibular ganglion.
3. Pseudo-unipolar Neurons: the dendrite and the axon arise from a common stem of the neuron. E.g. sensory neurons of the spinal ganglion.

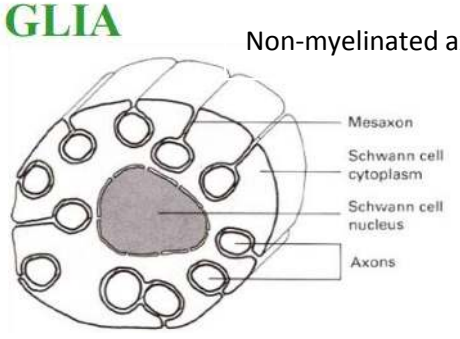
Neuropil Any area in the nervous system composed of mostly unmyelinated axons, dendrites and glial cell processes that form a synaptically dense region containing a relatively low number of cell bodies.

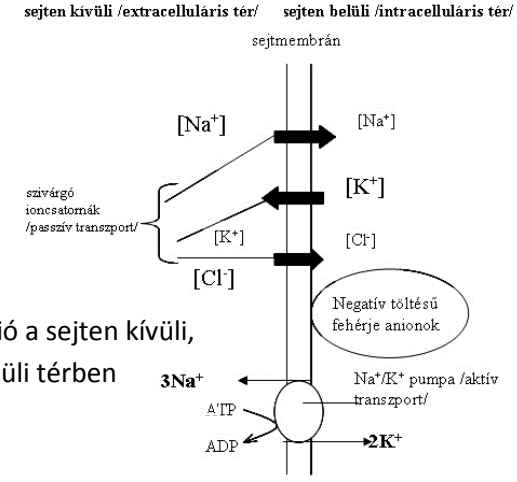
Peripheral nerves Establish connections with receptor and effector structures. Structurally they are composed of Schwann cells, fibroblasts and axons. Connective tissue fibers support and hold tightly this cable like structure.

Pyramidal cell A type of neuron found in areas of the brain including the cerebral cortex, the hippocampus, and the amygdala. It is named after its triangular-shaped cell body. ***Function***: They are the primary excitation units (gerjesztési egységek) of the mammalian prefrontal cortex and the corticospinal tract.









ionkoncentráció a sejten kívüli, illetve belüli térben

Glial cells

Astrocytes Star-shaped glial cells in the CNS: the white matter is rich in *fibrous*, the gray matter is rich in *protoplasmic astrocytes*. Their thin processes contain Glial Fibrillary Acidic Protein (***GFAP***) made filaments and glycogen. ***Functions***: their processes fill the gaps among neurons, project to blood vessels to form the blood-brain barrier, surround and isolate synapsing neuronal elements and form the internal and external glial laminae. They are coupled by gap junctions → they generate spreading calcium waves.

BBB Blood-Brain Barrier is a highly selective permeability barrier (válaszfal) that separates the circulating blood from the brain extracellular fluid (BECF) in the CNS. Transporter for sodium (Na^+), amino acids and glucose.

Ependyma Neural tissue that facing the cavities of the brain and spinal cord. Cuboidal or columnar glial cells that carrying microvilli (used for absorption) and kinocilia (support the flow of CSF) on their ventricular, apical surface. ***Location***: at the border of the cerebrospinal fluid and the extracellular space liquid compartments. Tight and gap junctions occur between ependyma cells.

Glial cell Exists in structural and functional symbiosis with neurons.

CLASSIFICATION OF NEUROGLIA

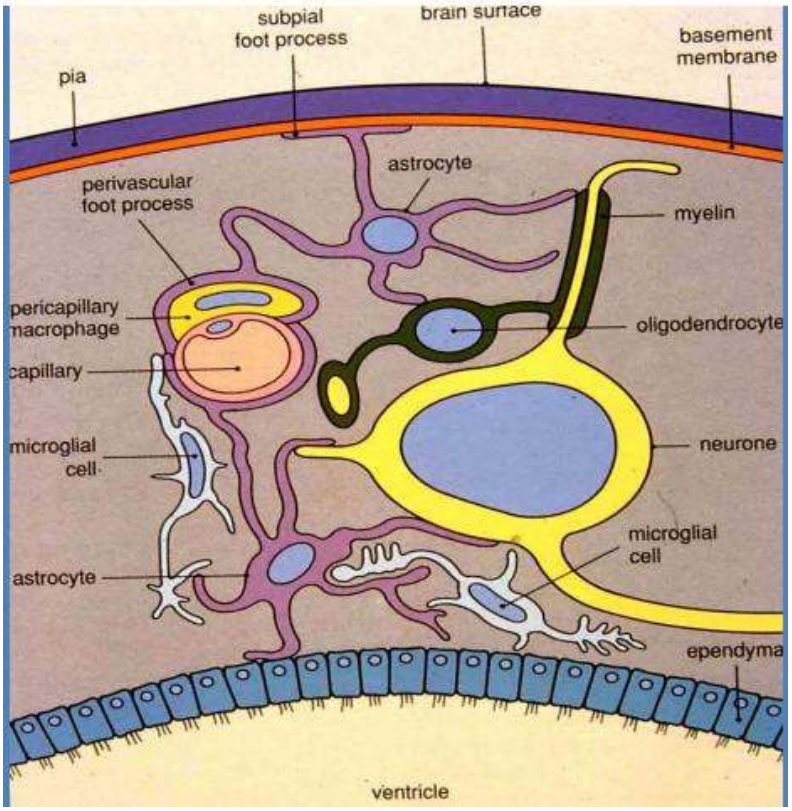
ASTORGLIA
1. PROTOPLASMIC ASTROCYTE
2. FIBROUS ASTROCYTE

OLIGODENDROGLIA
1. INTRAFASCICULAR OLIGODENDROCYTE
2. SATELLITE OLIGODENDROCYTE

MICROGLIA
1. RESTING
2. ACTIVATED

EPENDYMA
1. EPENDYMOCYTE
2. TANYCYTE

SCHWANN CELL



Glial cell functions
1. provide support and structure for neurons
2. provide insulation (elszigeteltség) for groups of neurons (e.g. insulation from electrical activity)
3. form myelin (Schwann cells in PNS, oligodendroglia in CNS)
4. remove debris after neuron injury or death
5. buffer (csökkenti) K^+ concentration and remove transmitters from ECF (extracellular fluid)
6. during brain development act as guides for neuron migration and outgrowth of axons
7. BBB
8. nutritive (tápláló) function for neurons

Microglia Sejtek nagy százalékát (5-20%) képezi az agyban: a CNS rezidens immunsejtjeiként működnek. Képesek fagocitálni, így eltávolítják a sérült neuronokat, plakkokat és egyéb fertőző képződményeket. A nyugalmi mikrogliának számos elágazó nyúlványa van, melyek konstans módon mozogva felmérik a szomszédos területeket. Az aktív mikrogliának nagyobb a sejtteste és vastagabbak a nyúlványai; bizonyos ingerek hatására pedig makrofággá válik.
Microglia constitutes a large percentage (5-20%) of cells in the brain: they operate as resident immune cells of the CNS. They are capable of phagocytosis and removal of damaged neurons, degenerative plaques, and infectious agents. The resting microglia has several ramifying processes that move constantly and survey the neighboring area. The reactive microglia differs from the resting type: it has a larger cell body and thicker processes. The triggers of activation: glutamate receptor activation, changes in extracellular potassium level, lipopolysaccharides, pro inflammatory cytokines and necrosis factors.

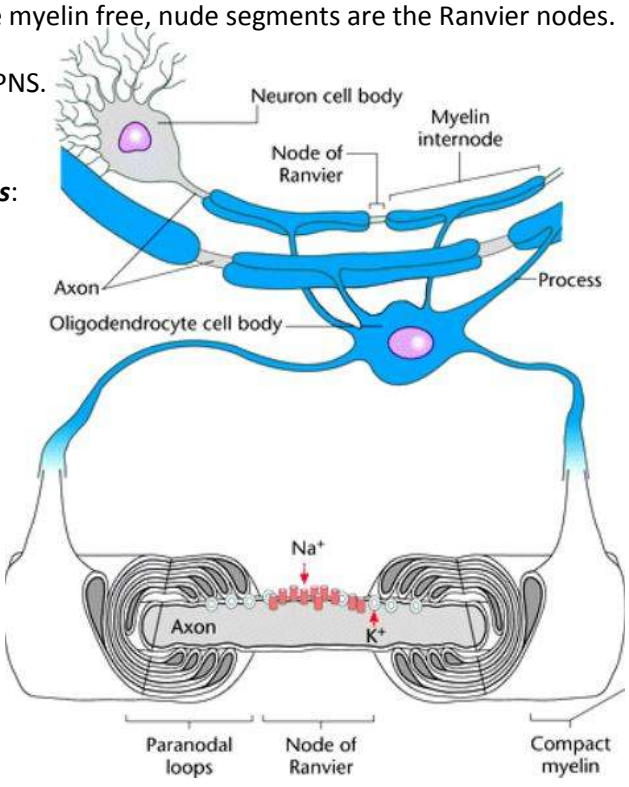
Neuroglia Astroglia, oligodendroglia, microglia, ependyma and Schwann cells. They develop from neuroepithel cells.
Main roles: – guidance of neuron migration in early development
– establishment of the blood brain barrier (BBB)
– formation of myelin
– participation in brain energy metabolism
– production of extracellular matrix
– neurotransmitter uptake, the glutamate-glutamine shuttle
– synthesis of growth factors and cytokines
– phagocytosis, neuroprotection, aging

Oligodendrocytes Apró sejtek számos elágazó nyúlvánnyal. Sok RER-t és poliriboszómát tartalmaznak. 2 fajtája van: a szatellit oligodendrociták a neuronokat támogatják, míg az intrafascikuláris oligodendrociták a CNS axonkötegeiben jelennek meg, ahol kialakítják az axonok mielinhüvelyét.
Small cells with numerous branching processes. They have a large quantity of RER and polyribosomes. **2 types**: *satellite oligodendrocytes* are juxtaposed to neurons and support them; *intrafascicular oligodendrocytes* occur in axon bundles of the CNS where they interact with axons and form the myelin sheath for them.

Ranvier nodes The myelin insulation of axons is not continuous, there are gaps between myelin enclosures belonging to neighboring Schwann cells. These myelin free, nude segments are the Ranvier nodes.

Schwann cell Derives from the neural crest. It occurs in the PNS.

Tanycytes Specialized ependymal cells covering the floor region of the third cerebral ventricle. ***Functions***: they transport substances from the CSF to the circulation; plus they contain an enzyme that activate the thyroid hormone.



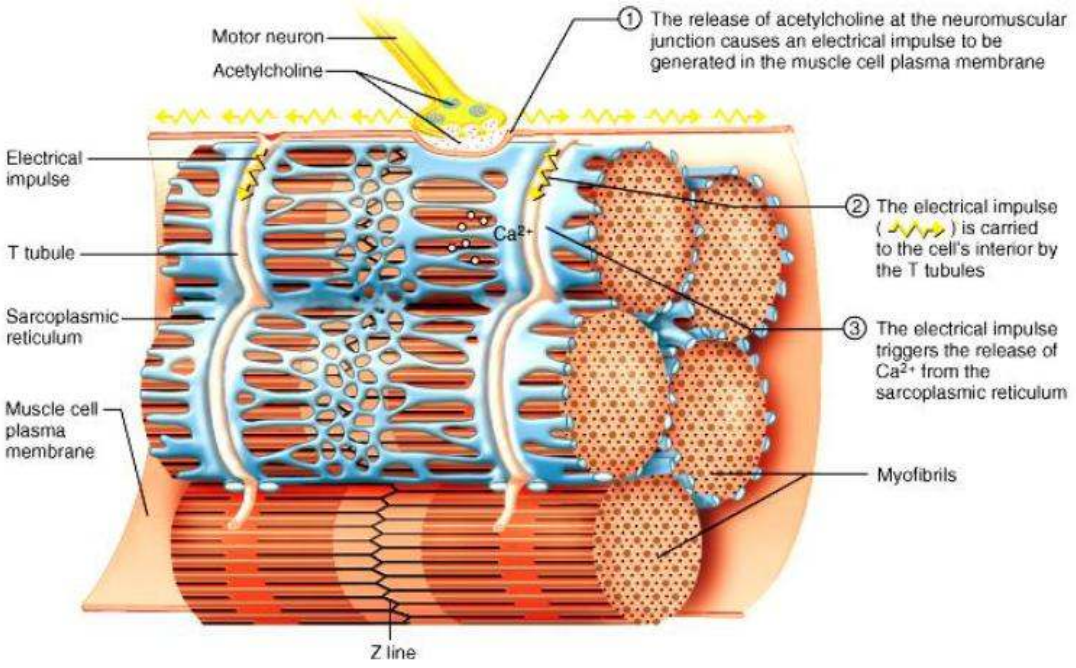
Nerve endings

Autonomic plexus Postganglionic nerve fibers of the sympathetic and parasympathetic branches of autonomic nervous system innervate the cardiac muscle, smooth muscle bundles of visceral organs and glands. These axons do NOT establish synapses with the target cells. They release the transmitter into the extracellular space from their axons. Specific receptors of the target cells pick up the transmitters and initiate the cellular responses.

Chemoreceptors Sensory receptors that monitor changes in the chemical composition of the circulating blood. They sense oxygen, carbon dioxide saturation and pH. They contribute to the regulation of respiration and circulation.

Mechanoreceptors Sensory receptors that respond to pressure and distorsion. Mechanoreceptors are numerous in the superficial and deep layers of the skin. They are either free or encapsulated nerve endings.

Motor end plate The joint units of the nerve terminals and muscle fibers. Synonym: *neuromuscular junction*. Motoneurons (projecting from the brain stem and spinal cord) send axons to the striated muscle fibers for innervations. The terminal axon loses its myelin sheath and the terminal boutons juxtapose to the sarcolemma, the membrane of the muscle fiber. The axon terminal contains synaptic vesicles filled with the neurotransmitter acetylcholine. Activation of the nerve terminal leads to the release of the transmitter that binds to its receptors embedded into the muscle membrane. The receptor activation evokes cascade events resulting in the contraction of the muscle fibers



Muscle spindle Capsulated receptor composed of special, thin striated muscle fibers. The structure is embedded among *extrafusal muscle fibers*. The stretching of the extrafusal muscle fibers activates the receptor that informs the CNS and evokes the compensatory action, the contraction.

Pain receptors Sensory receptors that respond to tissue damaging stimuli. They play a key role in avoiding the harmful insults of the environment and help to preserve the integrity of the body. The activation of these so called nociceptors alarms the body. They have fast and slow conducting systems. They are integrated within the nociceptor reflex arc.

Sarcolemma The membrane of the muscle fiber.

Sarcomere The smallest functional unit of a myofibril (izomrost).

Sensory epithelial cell They are capable of sensing special stimuli (odor, flavor, liquid movement). They are related to the special sense organ system. Primary sensory cells convey the information to the CNS by their own processes, secondary sensory cells forward the information by the peripheral processes of sensory ganglion neurons.

Thermoreceptors Sensory receptors that code absolute and relative changes in temperature. They are free-nerve endings of unmyelinated and thin myelinated fibers. There are cold and warm sensitive types.

NERVE ENDINGS

NEURONS COMMUNICATE WITH NON-NEURONAL ELEMENTS VIA SPECIALIZED NERVE ENDINGS BELONGING TO EFFECTOR AND RECEPTOR CATEGORIES

I. EFFECTORS

1. MOTOR END-PLATE
2. AUTONOMIC FIBER PLEXUS

II. RECEPTORS

1. MUSCLE RECEPTORS
2. SENSORY EPITHELIAL CELLS
3. MECHANORECEPTORS
4. THERMORECEPTORS
5. PAIN RECEPTORS
6. CHEMORECEPTORS

NEURONS COMMUNICATE WITH OTHER NEURONAL ELEMENTS VIA SPECIALIZED STRUCTURAL AND FUNCTIONAL UNITS

I. SYNAPSES

1. CHEMICAL SYNAPSE
2. ELECTRICAL SYNAPSE

Synaptic communication

Basket-like synapse The terminating axons form basket-like structures around the base of the cell at the axon hillock region. Innervation of Purkinje cells happens by basket neurons.

Bouton-type synapse The axon exhibits significantly enlarged, spherical axon terminals, so called boutons. Innervation of spinal motoneurons represents this connection type.

Chemical synapse The dominant form of communication in the CNS of humans. Chemical substances called neurotransmitters mediate the information from one cell to the other. The synapsing elements are separated by the synaptic cleft. It's a one way conduction. The human brain possesses about 10^{14} to 5×10^{14} synapses.

Main characteristics of chemical neurotransmission:

1. The synthesis of the classic neurotransmitters takes place in the presynaptic axon terminal
2. The classic and peptide neurotransmitters are stored in synaptic vesicles and granules forming a releasable pool of bioactive messenger substances
3. Upon activation of the presynaptic element, the neurotransmitters are released into the synaptic cleft
4. Binding and recognition of neuromessengers by specific receptors of target structure
5. Termination of the synaptic events, inactivation of transmitters

Electrical synapse The extracellular space narrows (20 nm → 2.7 nm) and the interacting membranes get coupled by gap junctions. At the gaps, the interacting elements are in continuous, although the opening of the pores is regulated: they are composed of connexons which close if the calcium concentration is high. There's no synaptic delay; and the transmission is bidirectional. It can be detected by intracellular delivery of the dye, Lucifer yellow.

FEATURE	ELECTRICAL SYNAPSES	CHEMICAL SYNAPSES
➢ Distance between pre- and postsynaptic cell membranes	3.5 nm	30-50 nm
➢ Cytoplasmic continuity between pre- and postsynaptic cells	Yes	No
➢ Ultrastructural components	Gap junction channels	Presynaptic active zones and vesicles; postsynaptic receptors
➢ Agent of transmission	Ionic current	Chemical transmitter
➢ Synaptic delay	Virtually absent	Significant: at least 0.3 ms, usually 1-5 ms or longer
➢ Direction of transmission	Usually bidirectional	Unidirectional

En passant synapse The axon establishes several synapses along its course without branching into axon terminals. Dendritic spines of Purkinje cells receive information from granule cells this way.
(jelentés: menet közbeni)

Excitatory synapses They release excitatory neurotransmitters like acetylcholine, serotonin, dopamine, noradrenaline and histamine which increase the membrane's permeability to Na^+. The sodium influx results in the increase of the resting membrane potential: excitatory postsynaptic potential (EPSP). The EPSPs are subjects of spatial and temporal summation mechanisms that increase the probability of evoking action potential firing in the postsynaptic neuron. Excitatory synapses generally carry spherical synaptic vesicles with 30-40 nm diameter.

Fatigue of synaptic transmission Overstimulation of excitatory synapses repetitively at a rapid rate induces a compensatory mechanism manifested in a gradual decline of discharges of the postsynaptic neuron.

Glomerular synapse Has a complex architecture in which multiple dendrites receive information from the same, terminating large-sized axon. The interacting structures fit each other like cogwheels. Synapses formed by mossy fibers and granule cell dendrites in cerebellum.

Inhibitory synapse The axons release inhibitory neurotransmitters like gamma-aminobutyric acid (GABA) and glycine. They open potassium and/or chloride channels the effluence of potassium and/or the influence of chloride ions results in the decrease of the resting membrane (hyperpolarization). The voltage is called inhibitory postsynaptic potential (IPSP). Inhibitory synapses generally carry flattened synaptic vesicles. The pre- and postsynaptic membrane regions are equal in thickness.

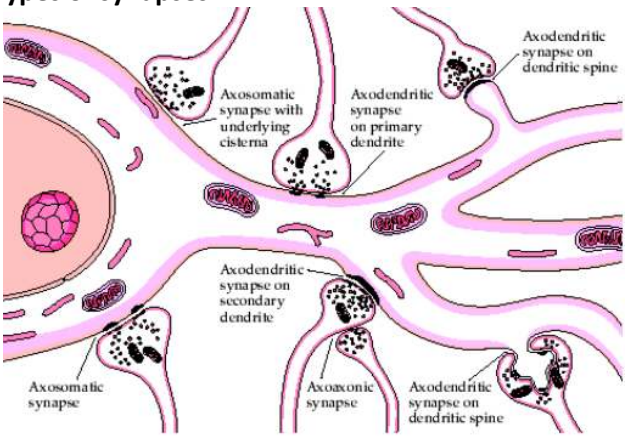
Parallel contacts Synaptic type in the CNS. The axons climb and wind around the innervated cell. Climbing fibers terminate this way on Purkinje cells.

Post-tetanic facilitation In the rest period after a repetitive, tetanic stimulation the synapse might become even more responsive to subsequent stimulation than normally. It may last for seconds or minutes. This mechanism contributes to short term memory storage.

Synaptic delay Delay in the transfer of information from one neuron to the other. It is about 0.5 millisecond. Primarily due to the duration of actions in the synaptic cleft and at the postsynaptic membrane.

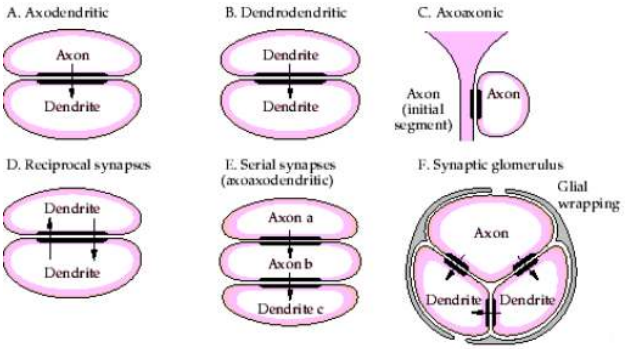
Synaptic strength It is defined by the change in transmembrane potential resulting from activation of the postsynaptic neurotransmitter receptors.

Types of synapses

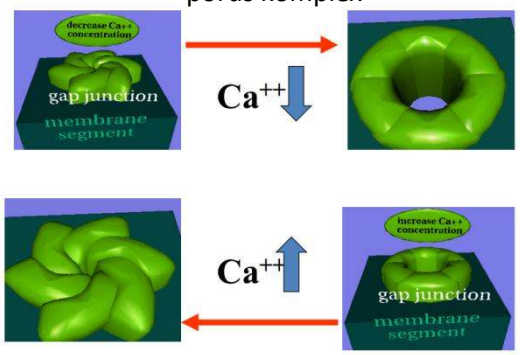


1. axo-dendritic: axon terminating on the dendritic shaft
2. axo-spinous: axon terminating on the dendritic spine
3. axo-somatic: axon terminating on cell body
4. axo-axonic axon terminating on another axon
5. dendro-dendritic: dendrite communicating with dendrite

: *(b)*



Elektromos szinapszis: pórus komplex



Neurotransmitters

DEFINITION AND CRITERIA OF NEUROTRANSMITTERS

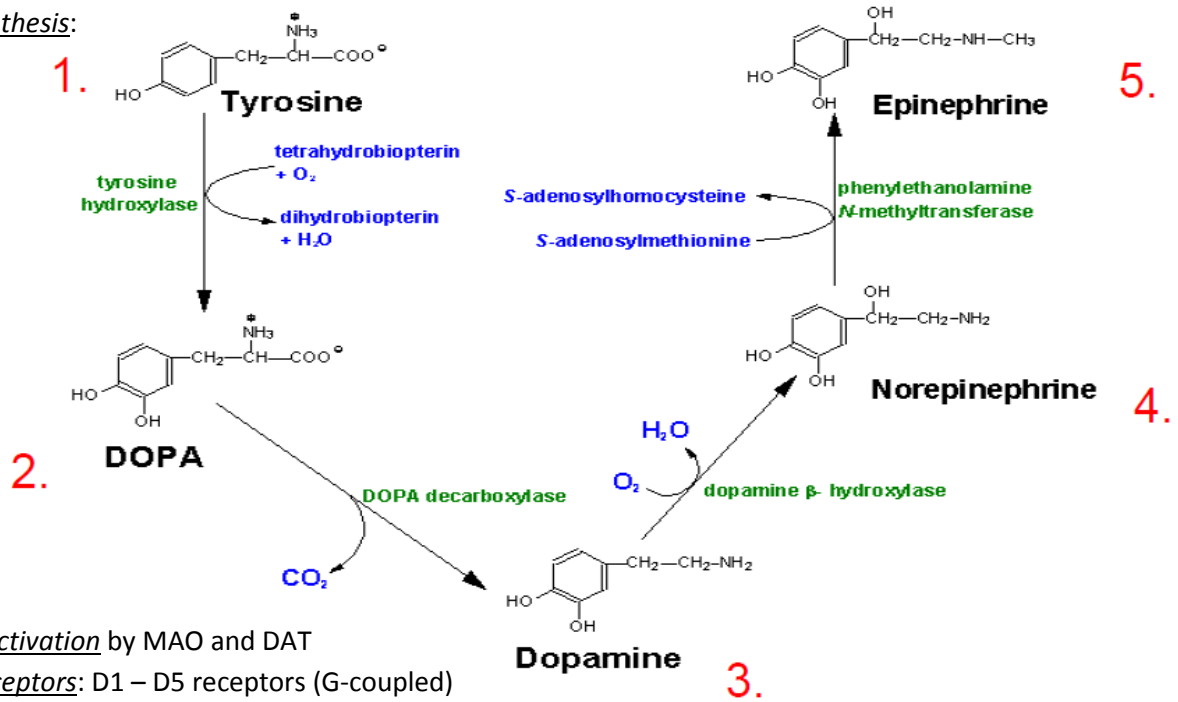
NEUROTRANSMITTERS ARE ENDOGENOUS BIOACTIVE SUBSTANCES SYNTHESIZED BY NEURONS. THEY ARE RELEASED FROM THE CELLS, ACT VIA SPECIFIC RECEPTORS COUPLED TO THE MEMBRANE OF POSTSYNAPTIC TARGET STRUCTURES AND MODIFY THE ELECTRIC AND METABOLIC CONDITIONS OF THE AFFECTED CELLS.

CRITERIA OF CHEMICAL NEUROTRANSMITTERS:

1. THE SYNTHESIS OF THE CHEMICAL TRANSMITTER TAKES PLACE IN THE PRESYNAPTIC NEURON
2. THE SYNTHESIZED TRANSMITTER OR IT PRECURSOR IS STORED IN THE RELEASE COMPARTMENT OF THE CELL, MOST FREQUENTLY IN AXON TERMINALS
3. RELEASE OF THE NEUROTRANSMITTER INTO THE SYNAPTIC CLEFT UPON EXCITATION OF THE PRESYNAPTIC ELEMENT
4. BINDING OF THE TRANSMITTER TO ITS RECEPTOR/S/ THAT BELONG TO IONOTROPIC AND METABOTROPIC CLASSES
5. TERMINATION OF THE ACTION OF TRANSMITTERS AND ITS TRIGGERED MECHANISMS

Dopamine

Synthesis:



Inactivation by MAO and DAT

Receptors: D1 – D5 receptors (G-coupled)

Expression in brain: brain stem, hypothalamus

Significance: attention, memory; Parkinson disease, schizophrenia

Norepinephrine

Synthesis (up)

Inactivation by MAO, re-uptake by NET (norepinephrine transporter)

Receptors: G protein-coupled receptors

Expression in brain: brainstem

Significance: attention, feeding regulation, stress

Serotonin

Synthesis: Tryptophan → Tryptophan hydroxylase → aromatic L-amino acid decarboxylase
Inactivation: by MAO, re-uptake by serotonin transporter
Receptors: ligand-gated ion channel, G-coupled receptors
Expression in brain: brainstem
Significance: feeding regulation, obesity, aggression

Acetylcholine

Synthesis: Acetyl CoA + Choline → Choline Acetyltransferase
Inactivation: Acetylcholinesterase, choline transporter
Receptors: nicotinic, ionotropic, ligand-gated ion channels, muscarinic, G-coupled receptors
Expression in brain: forebrain, brainstem
Significance: memory, attention; Alzheimer disease

Glutamate

Synthesis: α-ketoglutamate → aminotransferase OR
glutamine → glutaminase
Inactivation: neural and glial uptake by glutamate transporters
Receptors: ionotropic, metabotropic, G-coupled receptors
Expression in brain: throughout the brain
Significance: plasticity, learning, long term potentiating, neurotoxicity

Histamine

Synthesis: histidine → L-histidine decarboxylase
Inactivation: MAO-B, histamine-N-methyl transferase
Receptors: histamine receptors 1-4
Expression in brain: hypothalamus
Significance: sleep-waking cycle, psychomotor performance

GABA

Synthesis: L-glutamate →glutamate decarboxylase (GAD)
Inactivation: GABA aminotransferase
Receptors: GABA A, chloride channel, GABA B
Expression in brain: in the entire neuroaxis (a CNS teljes tengelye mentén)
Significance: inhibition of excitatory actions, epilepsy, anxiety (szorongás)

Glycine

Synthesis: serine → serine hydroxymethyltransferase
Inactivation: glycine transporters
Receptors: chloride channel
Expression in brain: spinal cord
Significance: inhibition of excitatory actions

Anterograde transport

A cellular process responsible for movement of mitochondria, lipids, synaptic vesicles, proteins, and other cell organelles to and from a neuron's cell body, through the cytoplasm of its axon.

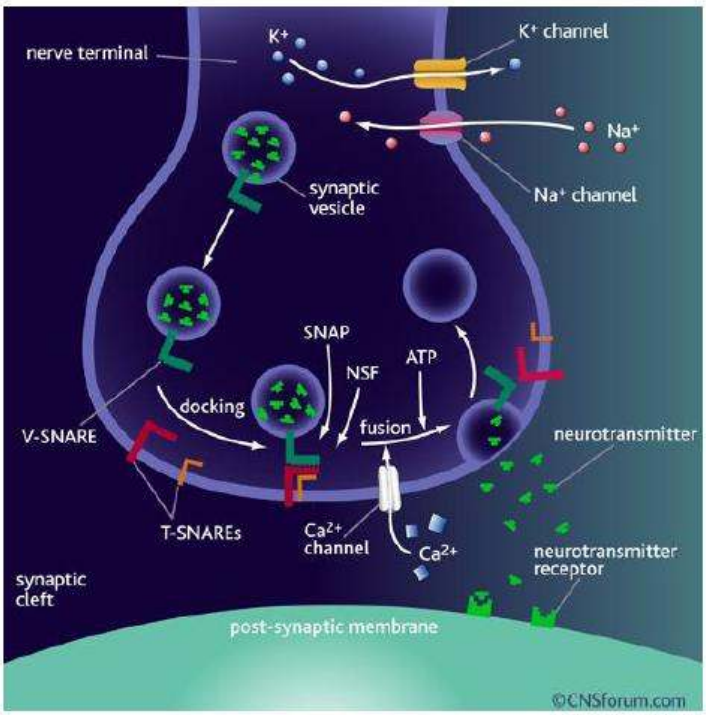
Docking

The process of insertion of synaptic vesicles into the presynaptic grid and establishing contact with the presynaptic membrane.

Excitation of secretory vesicles

1. Action potentials open voltage gated calcium channels in the terminals that allow the influx of calcium. The calcium channels are situated in the membrane facing the active zone of the synapse where the docked and primed vesicles are waiting for release. The elevation of the intracellular calcium concentration evokes transmitter release even under blocked sodium action potential and potassium channels: it liberates the synaptic vesicles from actin filaments of the cytoskeleton. Divalent cations that block calcium channels arrest the vesicular release of transmitters.
2. Membrane fusion: the ***snare*** protein superfamily is composed of dozens of peptides. A key role of snare proteins is to assist the docking, fusing and emptying of synaptic vesicles. In addition to the synaptic membrane protein synaptobrevin, proteins syntaxin and snap 25 contribute to the formation of the snare or pore complex. Syntaxin and snap-25 are primarily associated with the cell membrane. The vesicular components of the complex are referred to as ***V-snare***, while the membrane-associated unit is called ***T-snare***. The tight snare complex brings together the two membranes. The calcium influx triggers the formation of an initial membrane pore similar to a gap junction that gradually enlarges and leads to the collapse of the exocytotic vesicle. Synaptotagmin serves as calcium sensor in the process.
3. Recycling of synaptic vesicles: during transmitter release, the synaptic vesicles fuse with the plasma membrane and empty their content into the synaptic cleft. The synaptic membrane is retrieved by endocytosis. The clathrin-coated recovered membrane appears in endosomes that are used for the production of new vesicles. The presynaptic membrane of the axon terminal contains transmitter transporters (for choline, dopamine, noradrenaline, GABA, glutamate, serotonin) that allow the uptake of the transmitter or its breakdown product from the synaptic cleft for recycling. Drugs acting on membrane transporters are powerful modulators of synaptic functions and performance of neuronal networks.

SCHEMATIC ILLUSTRATION OF DOCKING AND FUSION OF SYNAPTIC VESICLES



COURTESY OF LUNDBECK INSTITUTE, DENMARK

NOTE THE INTERACTION OF VESICULAR AND TARGET MEMBRANE-ASSOCIATED PROTEINS (V-SNARE AND T-SNARE). THE PROTEIN COMPLEX ATTACHES THE VESICLE TO THE MEMBRANE. NSF AND SNAP PROTEINS ALSO CONTRIBUTE TO THE FORMATION OF THE FUSION COMPLEX. THE FUSION AND FISSION OF THE VESICLE IS TRIGGERED BY CALCIUM AND THE DISASSEMBLY OF THE FUSION COMPLEX BY ATP HYDROLYSIS (NSF). THE TRANSMITTER GETS RELEASED AND THE VESICULAR MEMBRANE RECYCLED. BOTULINUM AND TETANUS TOXINS CLEAVE THE SNARE PROTEINS AND PREVENT THE RELEASE OF THE TRANSMITTERS. BOTH INFECTIONS MAY BE LETHAL

Neuropeptides

Biologically active substances used as signal molecules in interneuronal communication. These peptidergic neurons contain mRNAs in their cytoplasm that encode the neuropeptides precursor proteins. Their ***synthesis*** takes place in RER than the newly synthesized peptide is directed to the Golgi complex where its modification occurs. The maturing proteins are packed into secretory

vesicles (80-200 nm) that are released from the trans-Golgi face. The constitutive transport directs the vesicles to the axon terminals utilizing anterograde transport mechanisms. In peptidergic synapses recycling of neuropeptides doesn't occur – they rather diffuse and get cleaved by endopeptidases. The activity of endopeptidases can locally regulate the peptide concentration and consequently the activation of the G-protein coupled receptors.
In the CNS their number exceeds 100. ***Location***: in axon terminals. The hypothalamus (that regulates the endocrine system) is especially rich in neuropeptides.
Examples: insulin, gastrin, secretin, oxytocin, enkephalin.

Neurotransmitters Endogenous substances that act as chemical messengers by transmitting signals from a neuron to a target cell across a synapse. 2 types: excitatory NTs (glutamate, epinephrine and norepinephrine) and inhibitory NTs (GABA, glycine, and serotonin).

NT transporters Membrane transport proteins with 12 membrane spanning domains. Their primary function is to carry neurotransmitters across these membranes and to direct their further transport to specific intracellular locations.

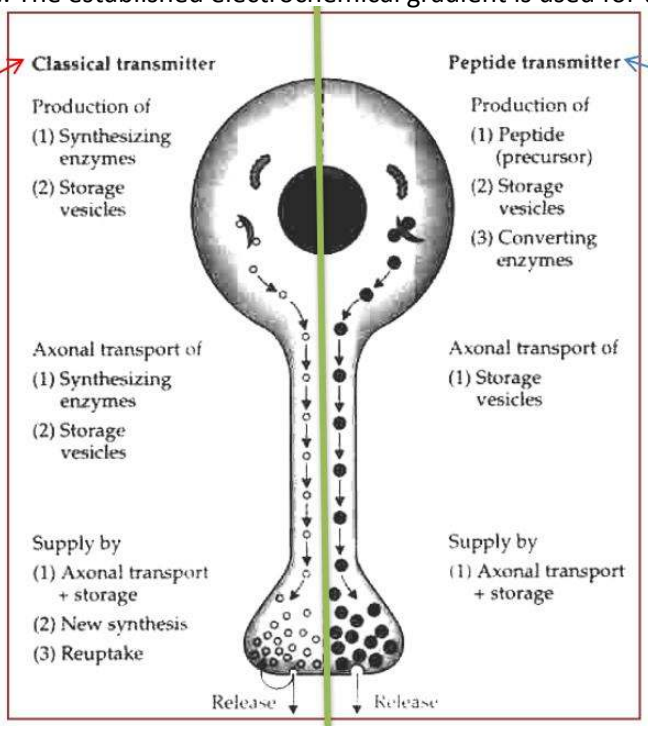
Presynaptic grid Hexagonal array of electron dense particles attached to the cytoplasmic face of the presynaptic membrane. It consists of 50 nm pyramid-shaped particles being interconnected by 100 nm spaced fibrils. It can be revealed by staining with ethanolic phosphotungstic acid.

Protein structures built in the synaptic membrane

1. Vesicular transmitter transporters: uptake and accumulation of transmitters
2. Proton pump: generation of electrochemical gradient
3. Synaptobrevin: vesicular fusion
4. Synaptotagmin: binding of calcium ions
5. Synapsin: binding to actin
6. RAB3: regulation of vesicle targeting
7. Cysteine string protein: regulation of Ca channels

Synaptic vesicles Small, 40-50nm electron lucent round or flattened vesicles, which carry classic (amine) NTs. They contain proton pump, which catalyses the translocation of protons from cytoplasm to the organelle. The established electrochemical gradient is used for the uptake of NTs into the vesicles.

ADRENALINE



OXYTOCIN

Table of Common Neurotransmitters

Transmitter Molecule	Transmitter Class	Derived from	Receptors / Activities / Comments
Acetylcholine		Choline	functions in both the CNS and the PNS; receptors are cholinergic; 2 receptor classes: muscarinic (metabotropic) and nicotinic (ionotropic); within the periphery ACh is the major transmitter of the autonomic nervous system where it activates muscles; within the brain its major effects are inhibitory or anti-excitatory; its actions in cardiac tissue are also inhibitory
GABA	amino acid	Glutamate	major inhibitory neurotransmitter in the CNS; also exerts effects in the periphery; binds to two classes of receptor termed $GABA_A$ (ionotropic) and $GABA_B$(metabotropic)
Glutamate	amino acid		most abundant excitatory neurotransmitter in the CNS; glutamate binds to the metabotropic glutamate receptors (mGluRs) of which there are eight ($mGluR_1$–$mGluR_8$) divided into three families; glutamate also binds to several ionotropic receptors including the *N*-methyl-D-aspartate (NMDA) receptor (NMDAR), the kainate receptors (KAR), and the α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor (AMPAR)
Aspartate	amino acid		stimulates the NMDA receptor but not as strongly as glutamate
Glycine	amino acid		inhibitory neurotransmitter in the CNS primarily within the brainstem, spinal cord, and retina; binds to glycine receptors (GlyR) which are ionotropic; there are two separate subunit proteins of each GlyR (α and β) that combine in various ways to generate a pentameric structure; there are four α-subunit genes ($\alpha_{1–4}$) and one β-subunit gene; the primary adult form of GlyR is composed of three α_1 subunits and two β subunits; is also a required co-agonist with glutamate on NMDA receptors and in this capacity exerts an excitatory effect
Histamine	diamine	histidine	produced by mast cells, basophils, enterochromaffin-like cells (ECL) of the stomach, and hypothalamus; within the gut histamine stimulates gastric parietal cells to secrete acid; released from mast cells when allergens bind to IgE-antibody complexes; there are four histamine receptors (H1–H4) all of which are GPCRs
Serotonin 5-hydroxytryptamine (5-HT)	monoamine	tryptophan	most abundantly expressed in enterochromaffin cells of the gut where it regulates motility, also found in the CNS and platelets; released from activated platelets where it stimulates further activation propagating role of platelet aggregation in coagulation; in the CNS 5-HT regulates mood, appetite, sleep, memory and learning; selective serotonin re-uptake inhibitors (SSRIs) used in the treatment of depression

Epinephrine synthesis pathway	monoamine	tyrosine	catecholamine neurotransmitter and hormone; binds to both α- and β-adrenergic receptors (GPCRs); produced in the adrenal medulla and some CNS cells; primary hormone of the fight-or-flight response of the sympathetic nervous system; is a major regulator of metabolic processes in numerous tissues; regulates heart rate, induces vasoconstriction and bronchodilation
Norepinephrine synthesis pathway	monoamine	tyrosine	catecholamine neurotransmitter and hormone; binds to both α- and β-adrenergic receptors (GPCRs); produced in CNS by sympathetic nerves; major neurotransmitter function is in regulation of cardiac chronotropic (rate) function; functions along with epinephrine in the fight-or-flight response; involved in adaptive thermogenesis in brown adipose tissue (BAT)
Dopamine synthesis pathway	monoamine	tyrosine	within the CNS dopamine plays a major role in reward-motivated behavior such as feeding and drug-seeking behaviors; also involved in motor control; in the periphery dopamine regulates the release of several hormones such as insulin from the pancreas and norepinephrine from blood vessels; functions by binding to a family of dopaminergic receptors (GPCRs)
Anandamide	other	phospholipids via at least 2 pathways	an endocannabinoid, binds to the cannabinoid receptors (CB_1 and CB_2) with highest affinity for CB_1; CB_1 is most abundant receptor in the CNS; classic response to CB_1 activation is stimulation of food intake; exerts peripheral effects on overall energy homeostasis
Adenosine	other	ATP	is an inhibitory neurotransmitter within the CNS, suppresses arousal thus promoting sleep; within the periphery adenosine exerts anti-inflammatory actions, induces bronchospasm in the lungs, and within the heart where it affects the cardiac conduction system; adenosine binds to a family of adenosine receptors (GPCRs) identified as A_1, A_{2A}, A_{2B}, and A_3
ATP	other		as a neurotransmitter ATP is released from sympathetic, sensory and enteric nerves; binds to $P2Y_{12}$ which is a member of the purinergic family of GPCRs (metabotropic receptors of which there are 12 genes in humans: $P2Y_{1, 2, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14}$; $P2Y_{12}$ is primarily expressed on the surface of platelets; also binds to the ionotropic family of purinergic receptors (P2X) which consists of seven members ($P2X_{1–7}$); these receptors modulate synaptic transmission throughout the CNS, PNS, and autonomic nervous system; in the periphery the P2X receptors activate contractile activity of various muscle types
Nitric oxide, NO	gas	arginine	endothelial cells, phagocytic cells, CNS, gastrointestinal tract; binds to and activates soluble guanylate cyclase, oxidizes iron-containing proteins, nitrosylates protein sulfhydryl groups

Receptors

Apoptosis Steps: breakdown of the cytoskeleton by caspases → chromatin undergoes condensation into compact patches against the nuclear envelope → the nuclear envelope becomes discontinuous and the DNA becomes fragmented → the cell membrane shows blebs (=irregular buds) → the cell breaks apart into several vesicles, called apoptotic bodies which will be phagocytosed.

EPSP Excitatory Postsynaptic potential. A gerjesztő NT-ek hatására a Na^+ csatornák megnyílnak → Na^+ ionok áramlanak a posztszinaptikus neuronba → a nyugalmi potenciálhoz képest emelkedik a membránpotenciál → nagyobb valséggel keletkezik akciós potenciál

Ionotropic receptors Transmitter receptors that form pores, specific ion channels in the membrane that allow the passage of ions upon activation. They perform as ligand-gated ion channels.

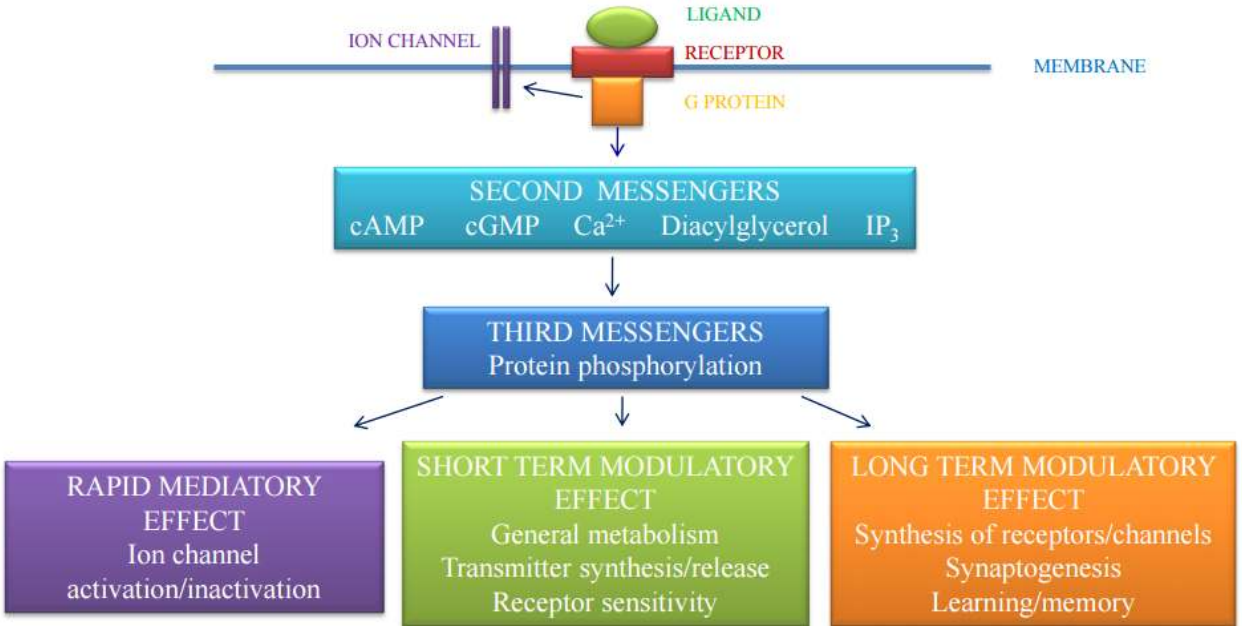
- ***fast*** postsynaptic responses:
- ligand binds → channel opens → ions flow in along the gradient
- excitatory: nicotinic acetylcholine receptor (nAChR), glutamate receptors (NMDA, AMPA and Kainate type), serotonin receptor
- inhibitory: $GABA_A$ receptor, glycine receptor

nAChR Functional roles: execution of movement and autonomic functions, modulation of CNS networks via pre- and postsynaptic regulation

IPSP Inhibitory Postsynaptic potential. A gátló transzmitterek hatására a Cl^- és K^+ csatornák megnyílnak → Cl^- ionok áramlanak a posztszinaptikus neuronba és K^+ ionok áramlanak a szinaptikus résbe → a nyugalmi potenciálhoz képest csökken a membránpotenciál → kisebb valséggel keletkezik akciós potenciál

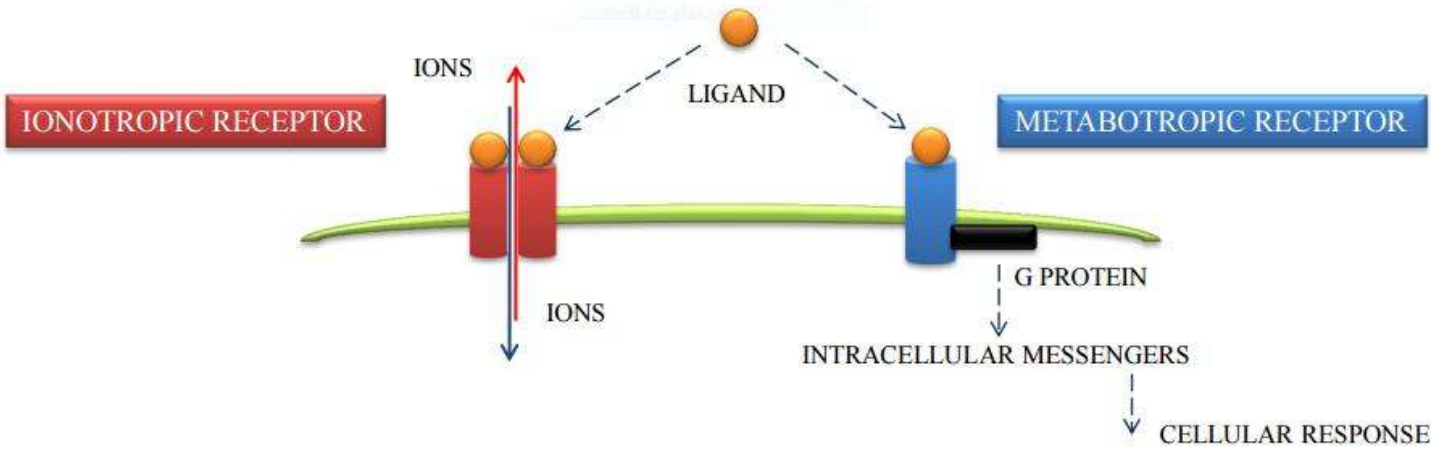
Metabotropic receptors Transmitter receptors that are coupled to GTP-binding proteins (G proteins) via their intracellular domains. G protein activation evokes secondary responses in the cell that alter its metabolism.

- slower onset, but longer duration
- peptides use only these receptors (!)
- the activated GPCR can turn on an associated G protein by exchanging its bounded GDP to a GTP
- the G protein has α,β and γ subunits → the α subunit with the bounded GTP dissociates and affects second messengers
- e.g.: muscarinic acetylcholine receptor (mACh), metabotropic glutamate, dopamine

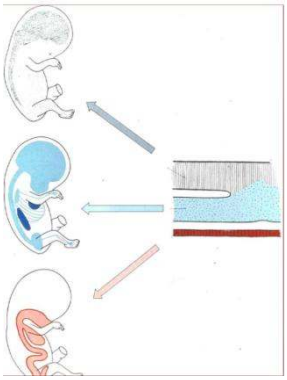


Necrosis Steps: plasma membrane and the nuclear membrane becomes irregular → small blebs form → the blebs fuse and become larger → the cell membrane ruptures and releases the cell's content.

Receptors Complex proteins that show high affinity binding for transmitter ligands. Ligand binding alters the conformation of the receptor that evokes postsynaptic responses. The response depends on the amount of the transmitters, the number and state of the receptor. As well as being present on the surfaces of postsynaptic neurons, neurotransmitter receptors are found on presynaptic neurons. In general, presynaptic neuron receptors act to inhibit further release of neurotransmitter Transmitter receptors belong to 2 categories: the receptors that are of the GPCR family are referred to as *metabotropic* receptors, whereas, the ligand-gated ion channel receptors are referred to as *ionotropic* receptors.



Development of the nervous system



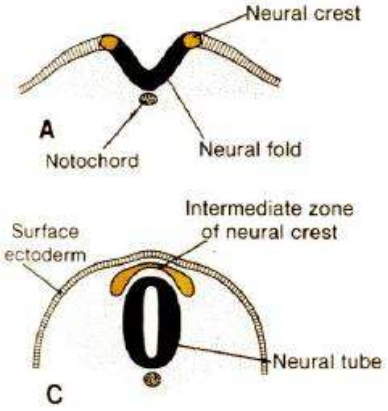
Neural plate

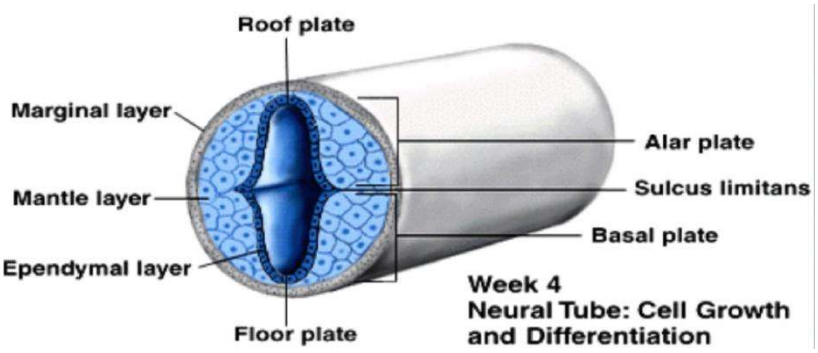
During the stage of neural plate formation the embryo consists of three cell layers: the ***ectoderm*** that eventually forms the skin and neural tissues, the ***mesoderm*** that forms muscle and bone, and the ***endoderm*** that will form the cells lining the digestive and respiratory tracts. The progenitor cells that make up the precursors to neural tissues in the neural plate are called ***neuroepithelial cells***. The formation of the neural plate starts when dorsal mesoderm signals ectodermal cells above it to lengthen into columnar neural plate cells.

Neural tube

The embryo's precursor to the CNS. The center of the tube is the neural canal.

<u>*Derives from*</u>: The neural groove gradually deepens as the neural folds become elevated (emelkedett), and ultimately the folds meet and merge in the middle line and convert the groove into the closed neural tube. The other cells that were part of the neural plate migrate away from the tube as neural crest cells.





<u>*Develops into*</u>: 4 regions of the CNS: prosencephalon, mesencephalon, rhombencephalon and spinal cord. The epithelial cells lining the neural tube divide heavily and give rise to the cellular constituents of the brain and spinal cord. At first glioblast and neuroblast cells develop: glioblasts differentiate into glial cells, neuroblasts into neurons.

Layers growing around the neural canal

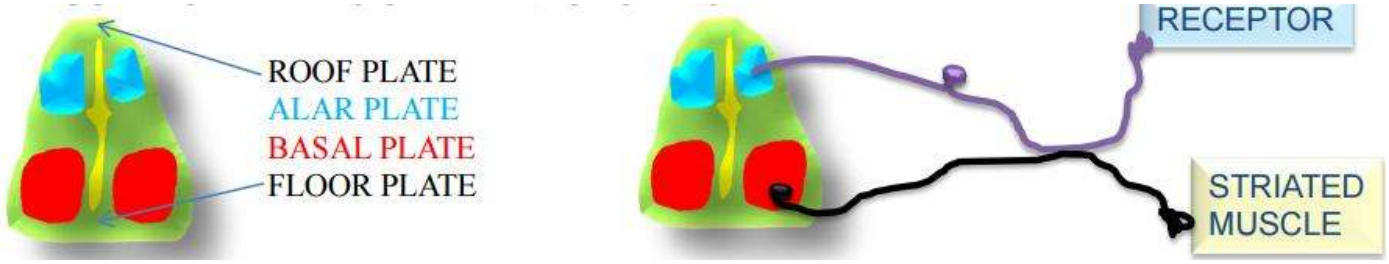
1. Ependymal layer: undifferentiated, proliferating cells
2. Mantle layer: forms the grey matter
3. Marginal layer: forms the white matter

Migrating neurons

Postmitotic cells incapable of dividing. The migratory process is called **radial migration**.

Development of the spinal cord

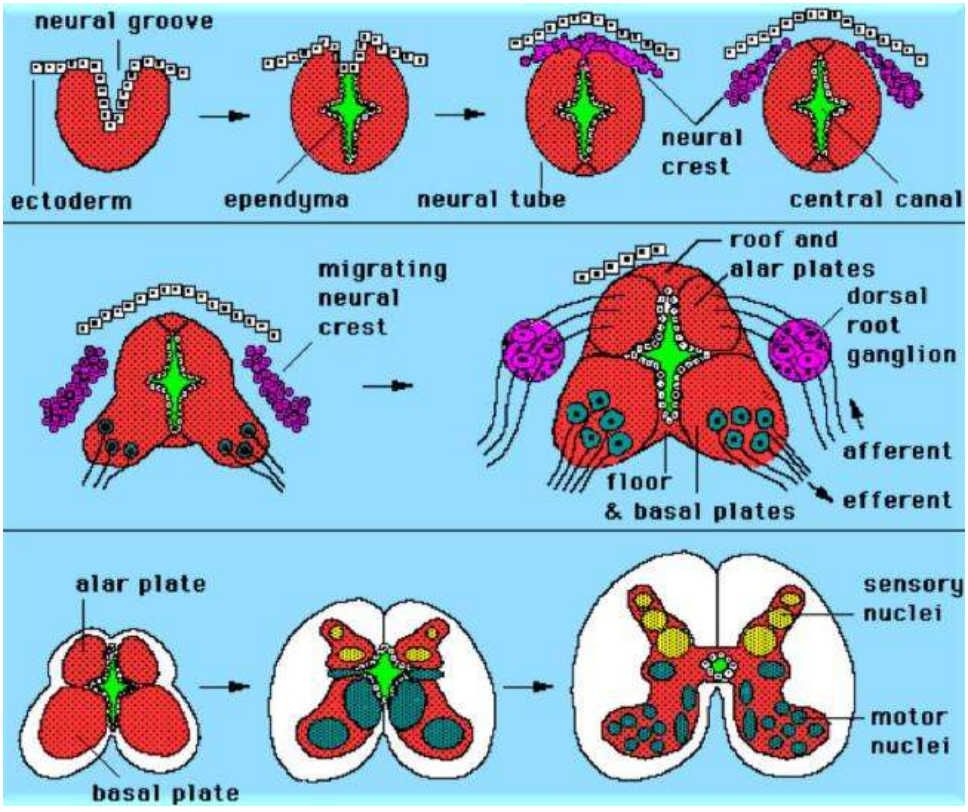
Within the 4th embryonic week, the mantle layer differentiates into ventrally located ***basal*** and dorsally positioned ***alar plates*** on both sides. In the median sagittal plane, the mantle layer remains thin forming the floor plate ventrally and the roof plate dorsally. From the basal plate the ventral horn of spinal cord develops. The dorsal, *sensory* horn derives *from* the *alar* plate.



Somato-motor neurons developing in the basal plate grow axons that leave the spinal primordium and establish connections with striated muscles developing in the same segment. This is the early formation of the neuromuscular junctions.

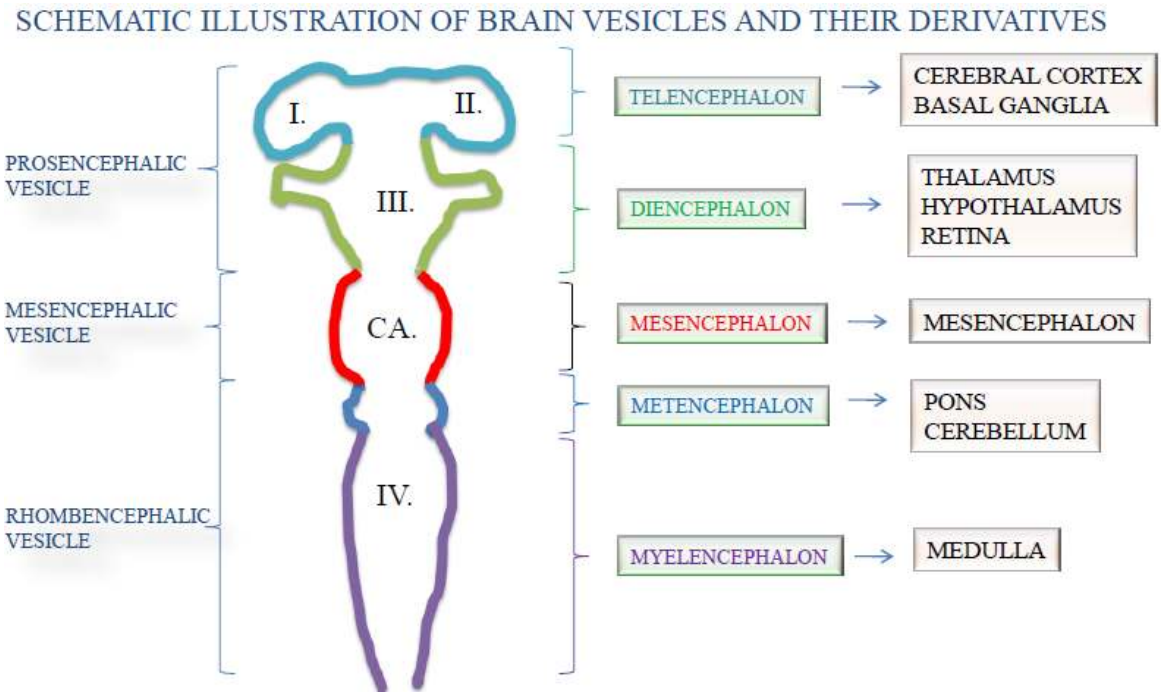
Neurons of the alar plate differentiate further and establish complex nuclei that are functionally coupled to the processing of sensory information. The sensory stimuli are carried to the alar plate by the central processes of external pseudo-unipolar neurons. These cells differentiate from the neural crest and establish the sensory dorsal root ganglia in the segments of the body. The peripheral processes of these sensory neurons are linked with receptors.

In the marginal layer, axon bundles can be found. They either belong to short intersegmental connections or to major ascending and descending fiber tracts interconnecting the spinal segments with other regulatory parts of the neuroaxis.



Development of the brain

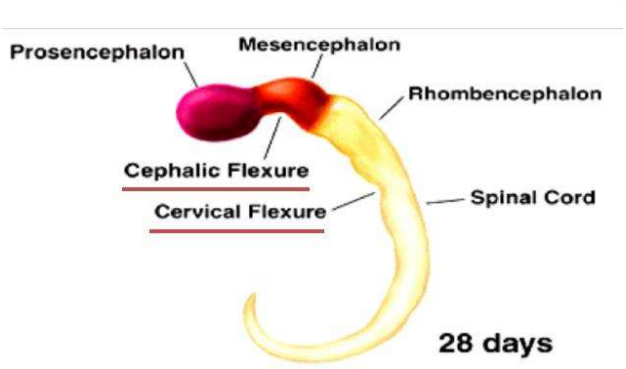
From the rostral (feji) part of the neural tube ***3 brain vesicles*** derive: the *prosencephalic*, the *mesencephalic* and the *rhombencephalic* vesicles. Further differentiation divides the prosencephalon in two secondary brain vesicles: the telencephalic and the diencephalic ones. The mesencephalic vesicle maintains its original integrity without splitting into parts. The development of the rhombencephalic vesicle results in the formation of the secondary metencephalic and myelencephalic vesicles.
From the original cavity of the prosencephalon the lateral and third ventricles, from the cavity of the mesencephalon the cerebral aqueduct and from that of the rhombencephalon the fourth cerebral ventricle develop.

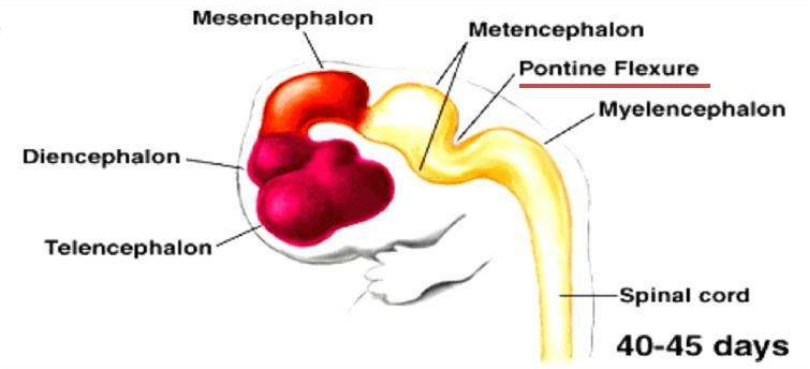


Folding of the brain, compartmentalization of the brain stem

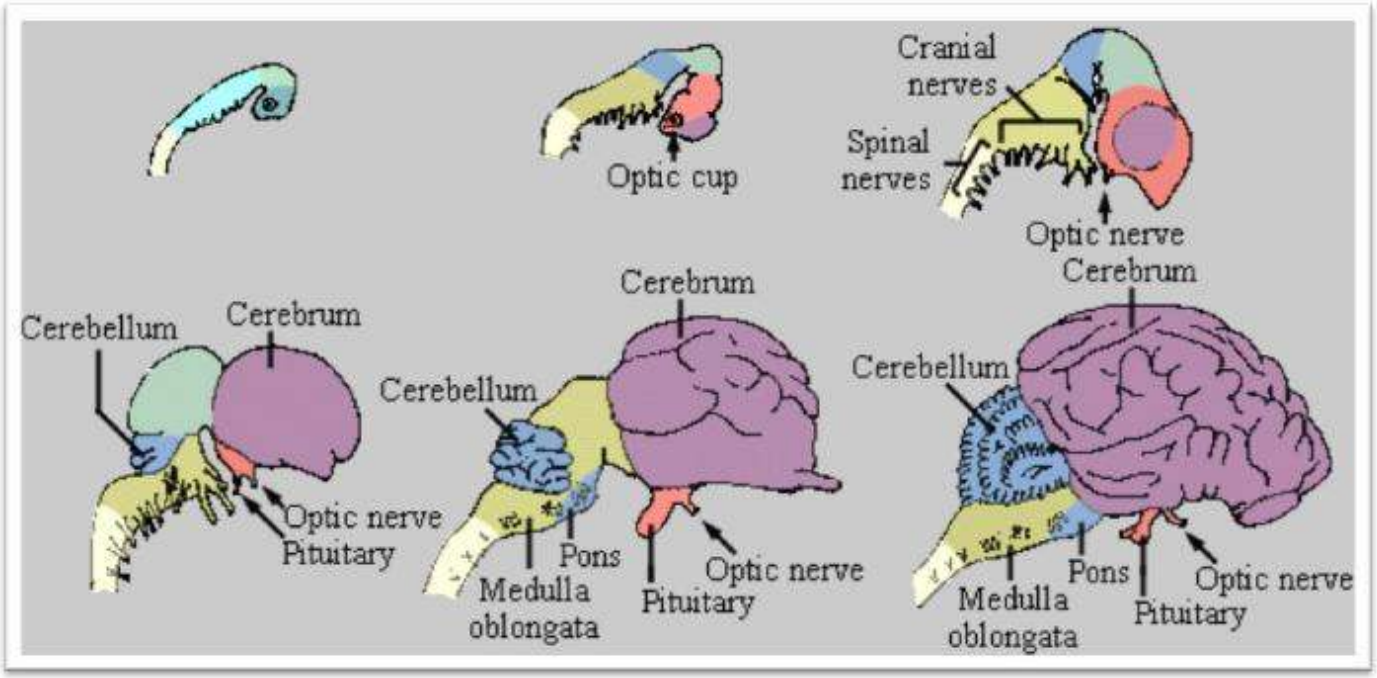
At the end of the first month, two flexures (=curves) of the brain are obvious. The cervical flexure occurs between the spinal cord and the medulla, the mesencephalic flexure develops at the level of the midbrain. The concavity of both flexures points toward the ventral part of the body.

Later, a third flexure develops at the level of the rhombencephalon, called the pontine flexure. It folds the metencephalon back to the myelencephalon.





The lateral out-pocketings of the telencephalic vesicles are also characteristic features, together with the development of the optic cup which provides the primordium of the retina. The brain stem shows an organization resembling the pattern of the spinal cord. From the basal and alar plates centers of certain cranial nerves develop.



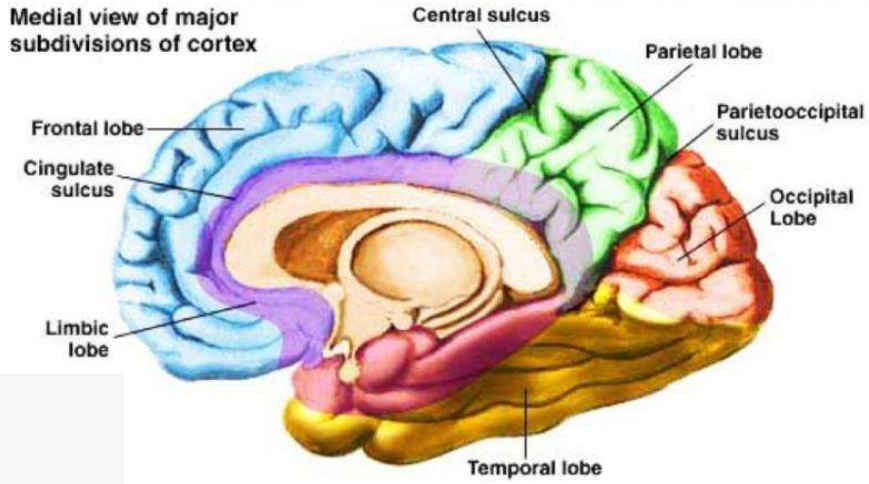
Development of the telencephalon

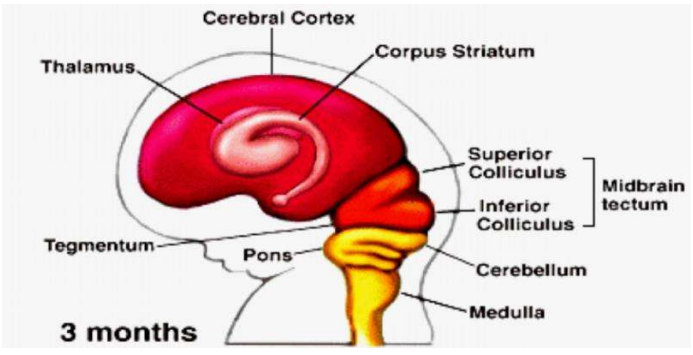
The telencephalic vesicles grow laterally as bubbles on both sides. The developing vesicle provides the frontal (homlok-), parietal (fali -), temporal (halántéki -) and occipital (nyakszirti lebeny) lobes, as well as, the insula. These parts gradually cover and hide the diencephalon.

The cavity of the telencephalic vesicle is the lateral ventricle (oldalsó kamra).
From the dorsal part of the wall of the growing telencephalic vesicle the cerebral cortex develops.
From the thicker, ventral part of the vesicle the corpus striatum develops.

The ventral surface of the telencephalic vesicle gets juxtaposed to the diencephalic structure, the thalamus. This border zone is crossed by an extremely massive and functionally crucial fiber bundle system, the internal capsule. It contains fibers establishing communication between the thalamus and the cerebral cortex, and also multiple connections among the cortex, the brain stem and the spinal cord. Both ascending and descending fiber tracts are represented in it.

Derivatives of prosecephalon →





← Development of telencephalon

Spinal cord

Spinal cord

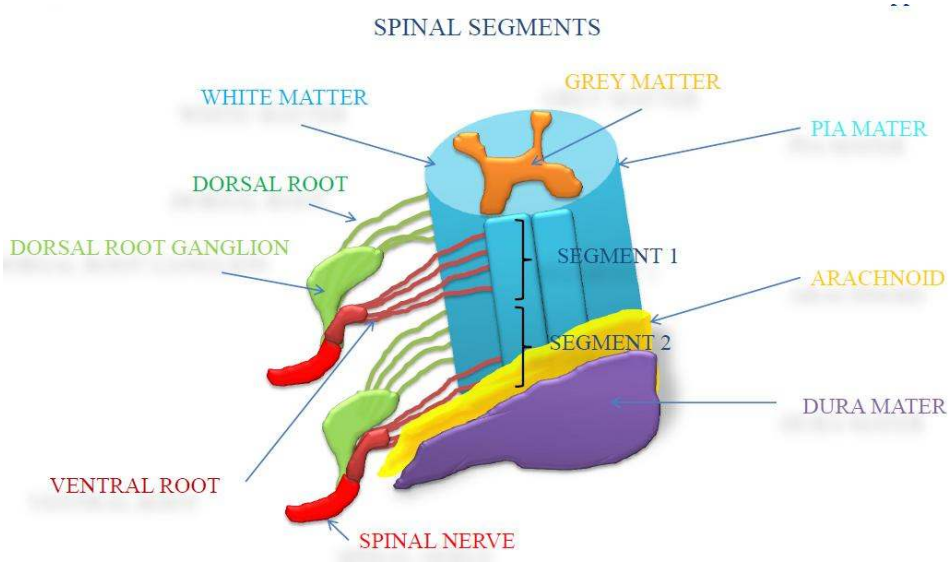
Cylindrical structure, slightly flattened dorsoventrally that IS enclosed by the meninges (agyhártyák). ***Location***: in the vertebral canal, it is surrounded by vertebrae (vertebral columns + + intervertebral discs). The ratio of white/grey matter volume changes: the cervical segments are larger with much more white matter in them in comparison with caudal, sacral segments.

Spinal meninges

2 types: pachimeninx and leptomeminx. The pachimeninx is formed by the dura mater (kemény agyhártya). The arachnoid and the pia mater form the inner envelopes. They establish the liquor-filled subarachnoid space. The innermost pia mater smoothly and tightly covers the entire surface of the spinal cord. Arising from this membrane serrated ligaments can be found on both sides of the spinal cord that attach the cord to the dura mater. Actually, the spinal cord is suspended (felfüggesztett) and floats in the CSF. Caudal to termination of the spinal cord, the meninges (hártyák) surround the bundles of the dorsal and ventral roots (cauda equina) of lumbosacral segments. This is the preferred locus of lumbar puncture (lumbálás).

Units of spinal cord

1. Grey Matter: – located centrally within the spinal cord; butterfly-shaped
   – composed of neurons and glial cells
2. White Matter: • peripheral location, surrounding the grey matter
   • consists of fiber bundles, so-called tracts and glial cells
3. Spinal Segments: the incoming sensory fibers (dorsal root) and the outgoing motor axons (ventral root) – 1-3 cm high divisions of the cord. The 2 roots join and form the spinal nerve that after a short journey splits into dorsal and ventral rami (ágak). There are 31 segments: 8 cervical (nyaki), 12 thoracic (háti), 5 lumbar (ágyéki), 5 sacral (keresztcsonti) and 1 coccygeal (farokcsigolya)



Dermatomes

Well-defined and shaped segmented regions of the skin which are innervated by the sensory components of a given pair of spinal nerves.

Muscle innervation

Skeletal muscles of the body develop predominantly from *myotomes* that are derivatives of the mesoderm layer. Myotomes provide myogenic cells that generate the muscles. They are segmented structures. Accordingly, muscles developing from given segments are innervated by somatic motoneurons developing in the ventral horn of the spinal cord of the same segments. These neuromuscular connections are established early. As muscles migrate to their final destination they pull the motoneuron axons with themselves. The function of the muscles and their innervating nerves can be examined by electromyography (EMG).

Grey matter

Made up of nerve cell bodies. Organized into 3 horns: dorsal, lateral and ventral horns. In the center of grey matter the original cavity of the neural tube, the canalis centralis is located. Cranially it is continuous with the 4th cerebral ventricle.

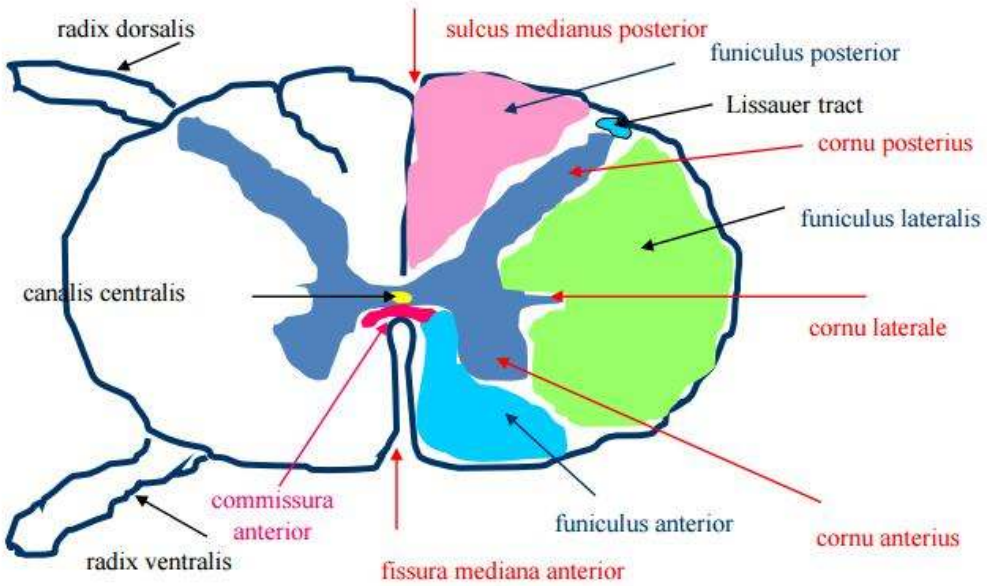
The *posterior horn* is associated with sensory information processing → this is where the pain nerve cells are located. The sensory messages are conveyed via the dorsal root to the posterior horn.
The *lateral horn* is explicit at certain thoraco-lumbar (T1-L3) and sacral (S2-S4) segments from where the sympathetic and parasympathetic outflows occur. Accordingly, the lateral horn is packed by autonomic, preganglionic cells. Their axons leave the spinal cord and enter the ventral root.
The *anterior horn* consists of large, somatic motoneurons and interneurons. The axonal projection of motoneurons uses the ventral root and the spinal nerve for exiting.

Dorsal root fibers

They belong to 2 categories:

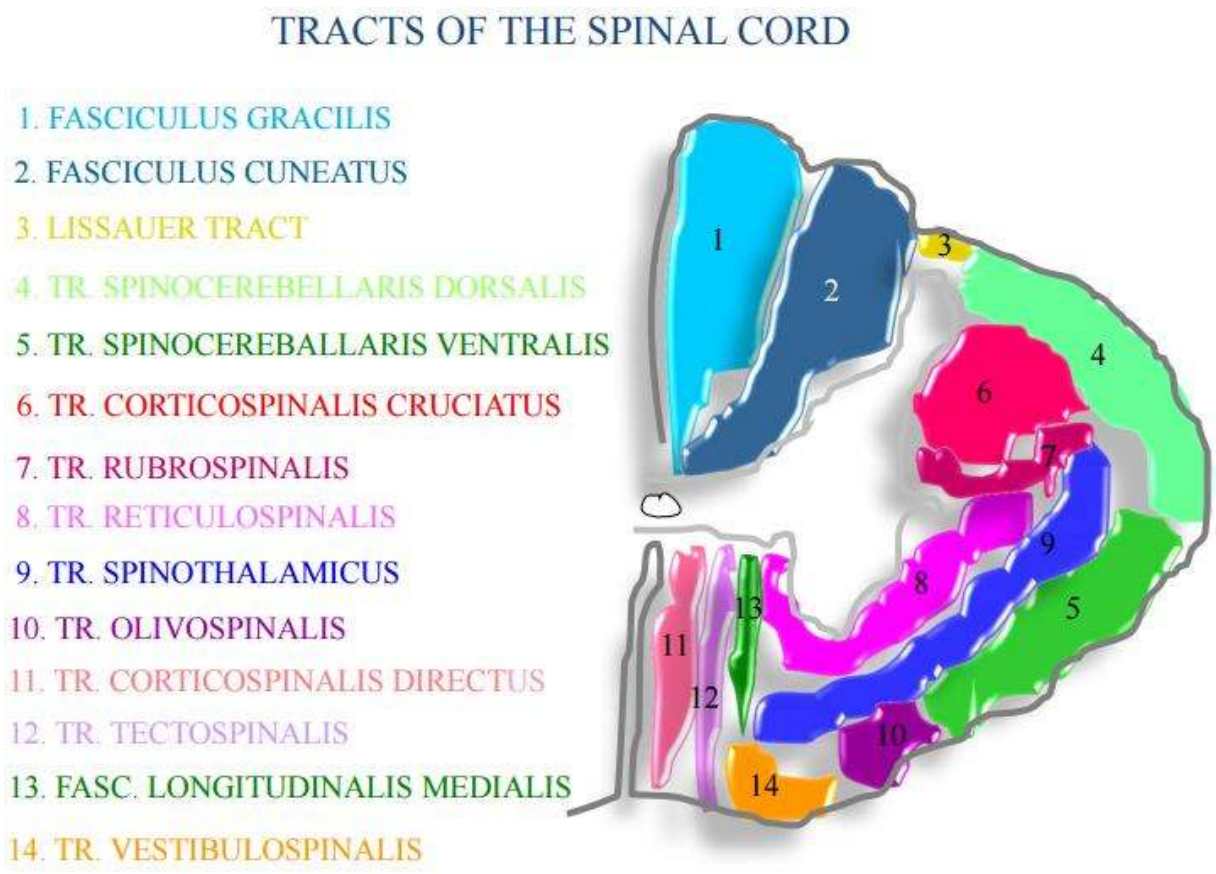
1. *Thick, myelinated axon group*: entering the spinal cord divide into ascending and descending branches that further give rise to collateral branches. The ascending branches enter the dorsal funiculus and project to the medulla. Another termination site for myelinated ipsilater dorsal root fibers is the Clarke nucleus. The thick myelinated fibers carry information from encapsulated receptors (muscle spindle, Golgi tendon organ)
2. *Thin, myelinated or non-myelinated axon group*: carry information associated with light touch, pain and thermal stimuli. They enter a thin fiber compartment, called the Lissauer zone, that covers the surface of the posterior horn. Fibers entering the grey matter most frequently terminate in layers I and II. This kind of sensory information is relayed further to the thalamus via the crossed spinothalamic tract.

SCHEMATIC ILLUSTRATION OF THE CROSS-SECTIONED SPINAL CORD



THE GRAY MATTER IS ORGANIZED INTO DORSAL, LATERAL AND VENTRAL HORNS. THE FIBER TRACTS OF THE WHITE MATTER RUN IN THE POSTERIOR, LATERAL AND ANTERIOR FUNICULI

Tracts of the spinal cord



Ascending (felszálló) tracts:

- 1. Fasciculus Gracilis: sensory → light touch, vibration, 2-point discrimination, position sense
- 2. Fasciculus Cuneatus: sensory → light touch, vibration, 2-point discrimination, position sense
- 4. Dorsal Spinocerebellar Tract: coordination of movements and posture
- 5. Ventral Spinocerebellar Tract: coordination of movements
- 9. Spinothalamic Tract: sensory → noxious pain and thermal stimuli, crude (nyers) touch

Descending (leszálló) tracts:

- 6. Tractus Corticospinalis Cruciatus: the main regulatory tract of motorneurons
- 7. Tractus Rubrospinalis: conveys information from the cortex and cerebellum mainly to motor neurons innervating flexor and extensor muscles
- 8. Tractus Reticulospinalis: controls voluntary movements, muscle tone, central sensory transmission, regulates respiratory and circulatory activities
- 10. Tractus Olivospinalis: innervates cervical segments
- 11. Tractus Corticospinalis Directus: carries motor commands to neurons
- 12. Tractus Trectospinalis: controls the movements of the head
- 13. Fasciculus Longitudinalis Medialis: carries information from secondary vestibular neurons to cervical segments; controls the movements of the head
- 14. Tractus Vestibulospinalis: mediates cerebellar and vestibular information toward the spinal cord; exerts facilitatory influence on spinal reflexes and controls muscle tone

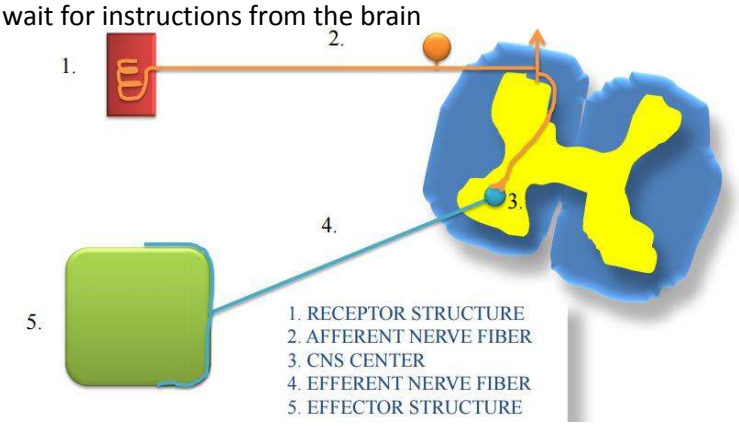
Stretch reflex

Reflex Rapid, involuntary neuronal regulatory action executed in response to sensory stimuli. It ensures the adaptation of the body to external and internal environments and the continuously changing challenges. Some reflexes are innate, others are learnt ones. The reflex mechanism structurally is organized in the reflex arc.

Reflex arc Reflexes are executed via reflex arcs. Each has 5 main structural constituents:

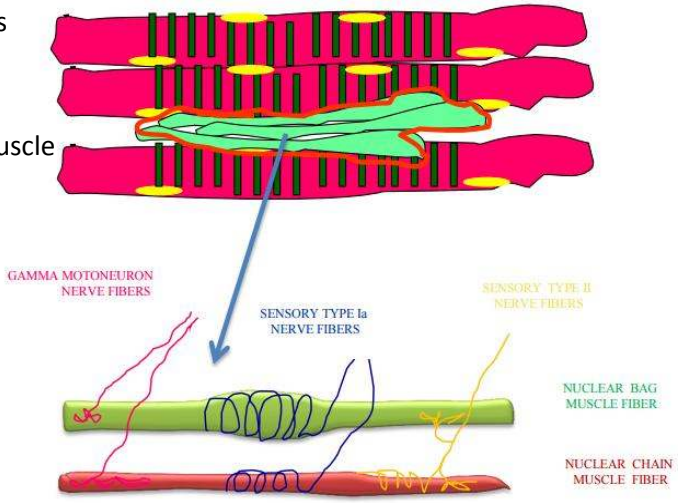
1. *receptor*: picks up the information from the internal and external environments in forms of physical and chemical stimuli
2. *afferents*: sensory nerves that are linked to the receptors and carry the stimulus-evoked information to the processing center. In case of spinal reflexes, neurons of the dorsal root ganglia serve the role of afferents by their processes interconnecting the receptors with the grey matter of the spinal cord
3. *center*: part of the spinal cord or brainstem that handles, processes the incoming sensory information
4. *efferents*: somatomotor or visceromotor nerves that convey the generated adaptive response to the site of the compensatory action
5. *effector*: these units execute the regulatory commands

While all sensory information does eventually get sent to the brain for analysis, the advantage of the reflex arc is that it can process the rapid, protective response directly in the spinal cord, without the need to wait for instructions from the brain



Stretch reflex A monosynaptic, postural reflex that among others works against the gravity force. It controls muscle length and muscle tone. Characteristics of the reflex:

1. *stimulus*: stretching of the muscle
2. *receptor*: muscle spindle (izomorsó), intrafusal muscle fibers, nuclear bag and nuclear chain receptors
3. *afferent path*: Ia and II type nerve fibers of sensory ganglion cells
4. *center*: spinal cord, ventral horn, somatomotor neurons (alpha type)
5. *efferent path*: axons of alpha motoneurons
6. *effector structure*: extrafusal muscle fibers of the muscle
7. *compensatory action*: shortening of the muscle



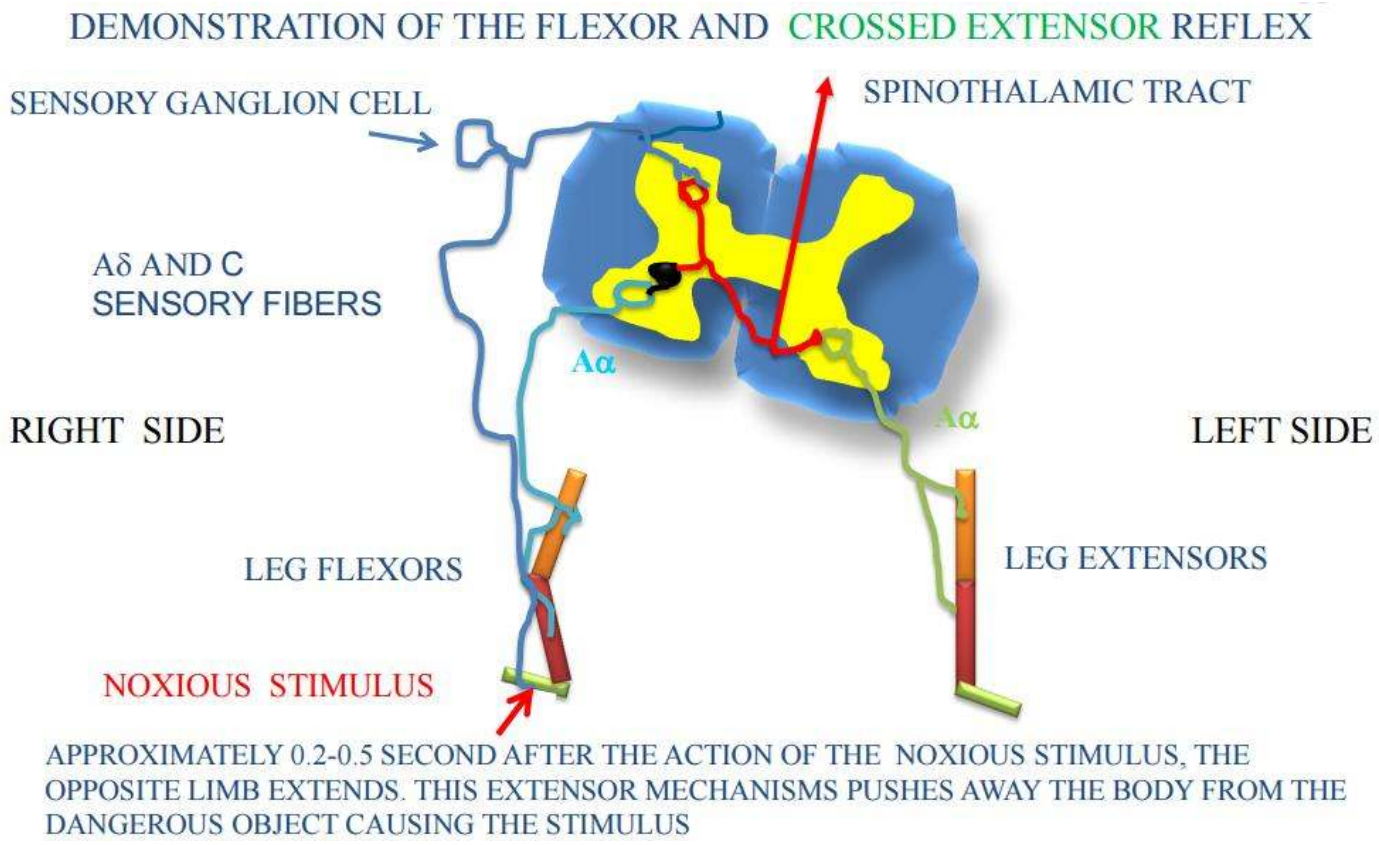
Flexor reflex

Flexor reflex

Fájdalom érzékelése esetén a végtagot rövidítő reflex. The shortening of the limb on 1 side generally evokes a compensatory mechanism that extends the limb on the other side; therefore, the reflex is also referred to as flexor-crossed extensor reflex. Other synonym is nociceptive reflex which refers to the noxious nature of the stimulus.

Features of flexor

stimulus: crude and dangerous stimuli that can destroy the integrity of the affected tissues of the limb. Noxious pain and thermal stimuli are the triggers.
receptor: heat and pain receptors in the skin
afferent path: thin, myelinated and unmyeleinated axons of pseudounipolar cells of spinal ganglia
center: spinal cord, dorsal and ventral horns, involvement of interneurons
efferent path: axons of alpha motorneurons innervating flexor muscles of the limb ipsilaterally and axon projections from contralaterally located motorneurons innervating extensors of the limb on the opposite side to the stimulus
effector structure: extrafusal muscle fibers of the involved muscles
actions: ipsilateral flexion and contralateral extension (azonos oldali hajlítás és ellentétes oldali feszítés)



Autonomic reflex Modulates the operations of the visceral organs. The organs receive a dual visceromotor innervations by getting supply from both sympathetic and parasympathetic sources. The CNS utilizes it for executing modulatory actions in response to incoming visceral stimuli (pain, heat, pressure).

Features of autonomic reflex

stimulus: change in pressure, alteration of chemical milieu, inflammation related pain and heat, distension of luminal viscera

receptor: baroreceptor, chemoreceptor, mechanoreceptor, heat receptor

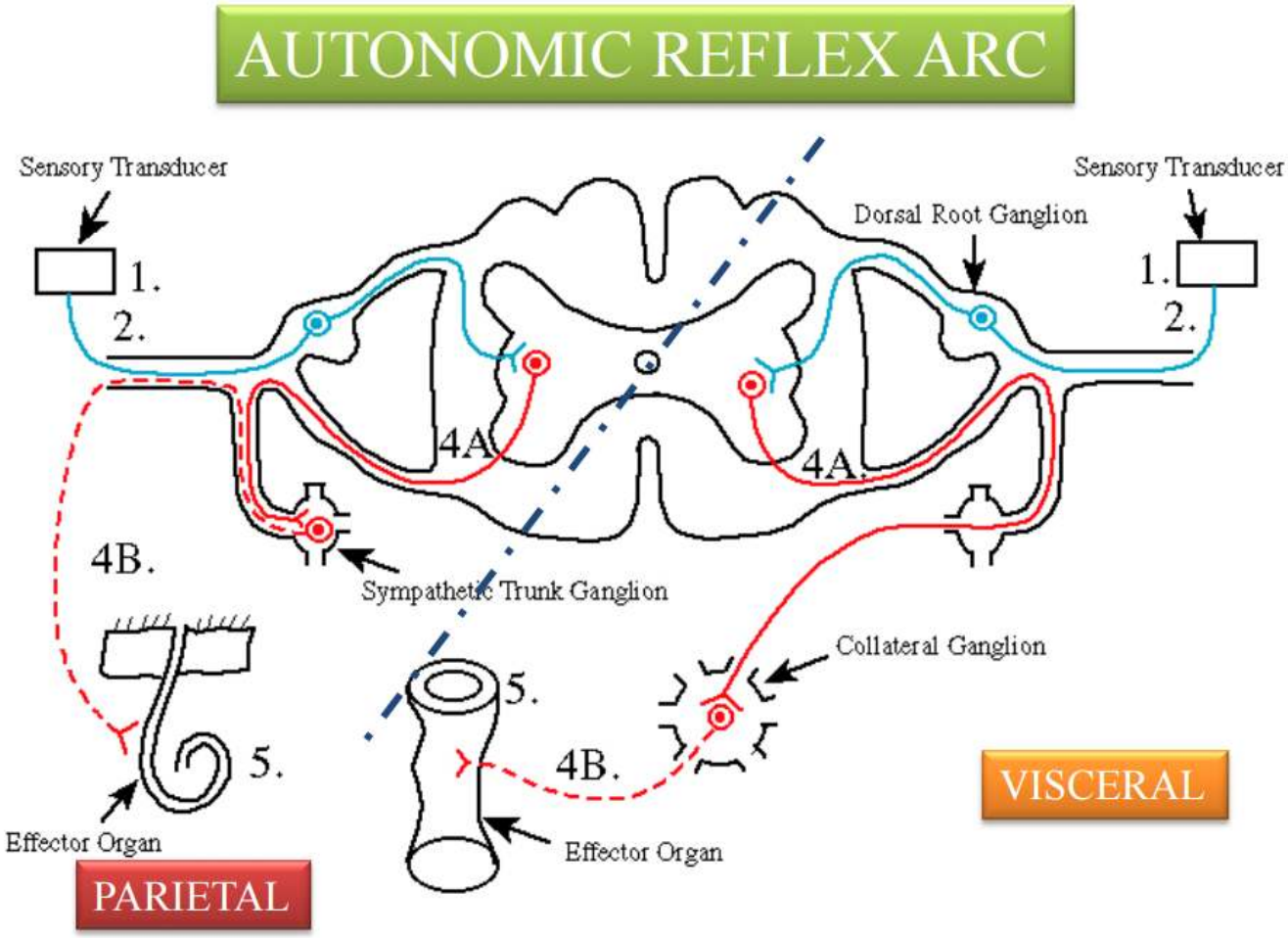
afferent path: processes of pseudo-unipolar cells of spinal ganglia

center: spinal cord and brain stem

efferent path: 1. preganglionic neurons projecting from the intermediolateral nucleus to the peripheral autonomic ganglia. 2. processes of visceral ganglion cells projecting to the organs

effector structure: cardiac muscle (for heart) and smooth muscle (for other organs)

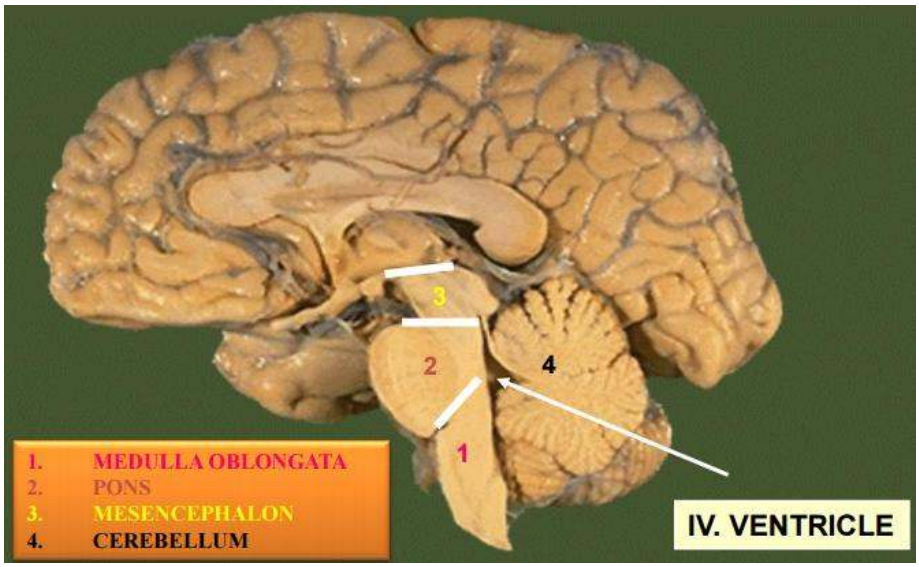
actions: modulation of visceral functions (pacemaker activity in heart, lumen of blood vessels, smooth muscles of bronchi, the secretion of glands, peristaltic movement of the Gi tract)



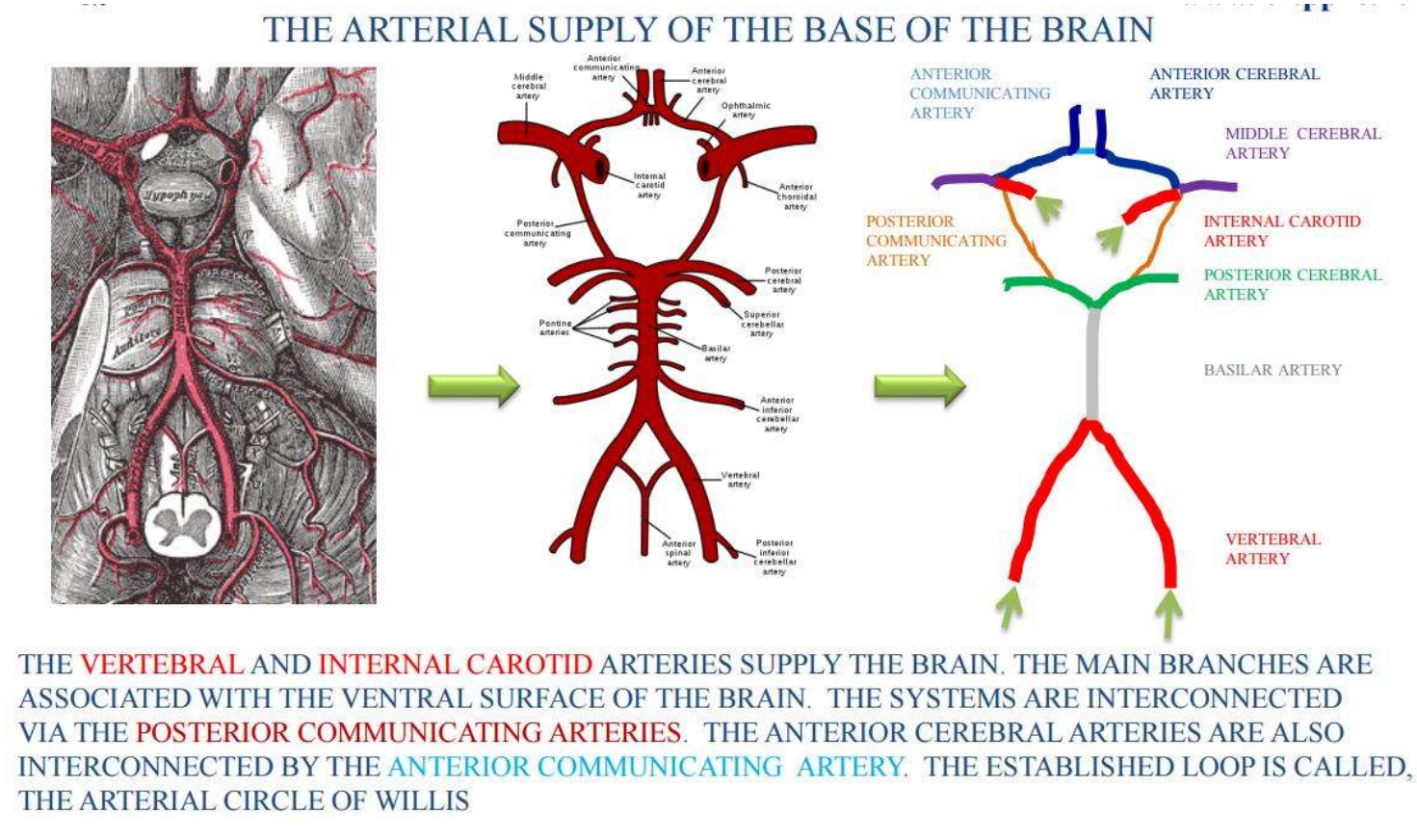
*Szimpatikus idegrendszer: Hatására a szívritmus fokozódik, a bőr és a belek arteriolái összehúzódnak, a vázizmoké kitágulnak, és a vérnyomás emelkedik. A vér eloszlása megváltozik úgy, hogy csökken a bőr és a gyomor-bél rendszer (gastrointestinalis tractus) vérellátása, több vér kerül az agyba, a szívbe és a vázizmokba. Ehhez társul még, hogy a szimpatikus idegek a pupillákat kitágítják; gátolják a hörgők, a belek és a hólyag falának simaizomzatát; zárják a záróizmokat (sphinctereket). A szőrszálak fölmerednek és verejtékezés indul meg.

*Paraszimpatikus idegrendszer (ha nincs para): Működése az energia megőrzésére és újratermelésére irányul. A szívritmus csökken, a pupillák összeszűkülnek, a perisztaltika és a mirigyek kiválasztó működése fokozódik, a záróizmok megnyílnak, és a hólyag simaizomzata összehúzódik.

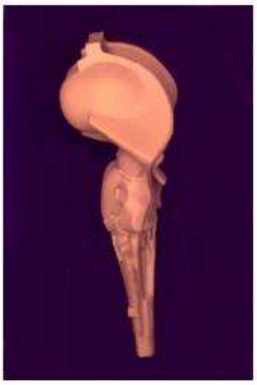
Brainstem

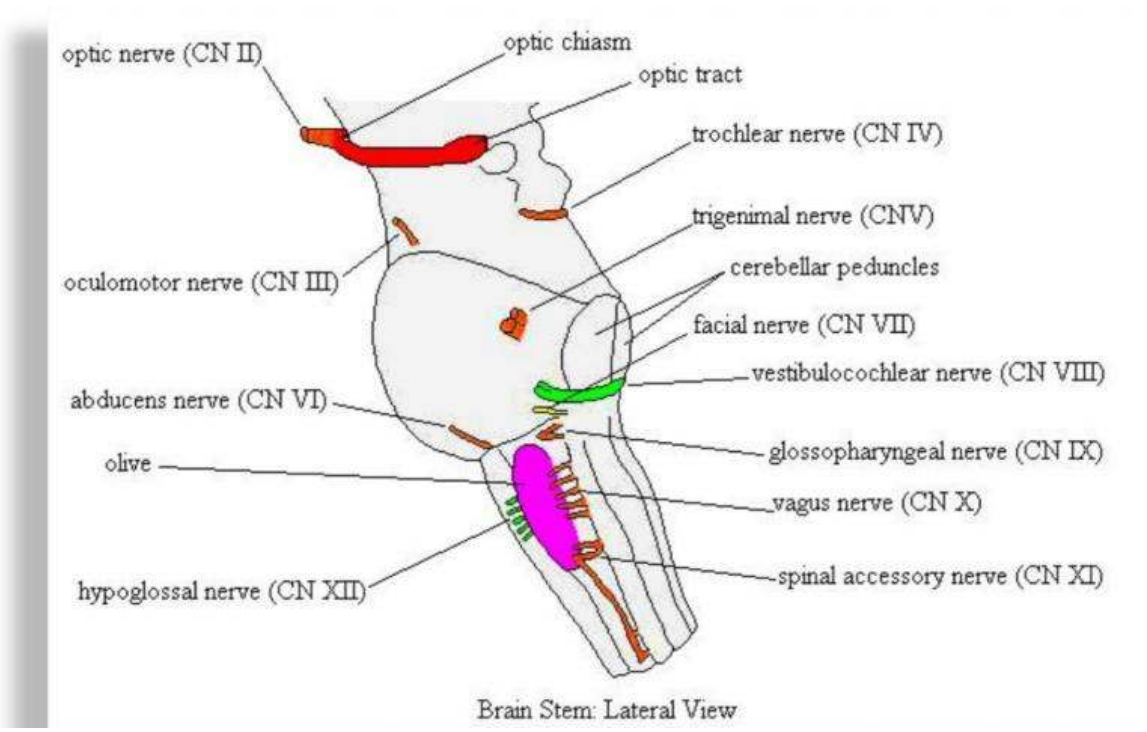


Characteristics Its constituents derive from the rhombencephalon. Important somatic and autonomic centers are located here. The processing centers of most cranial nerves are within the brainstem.



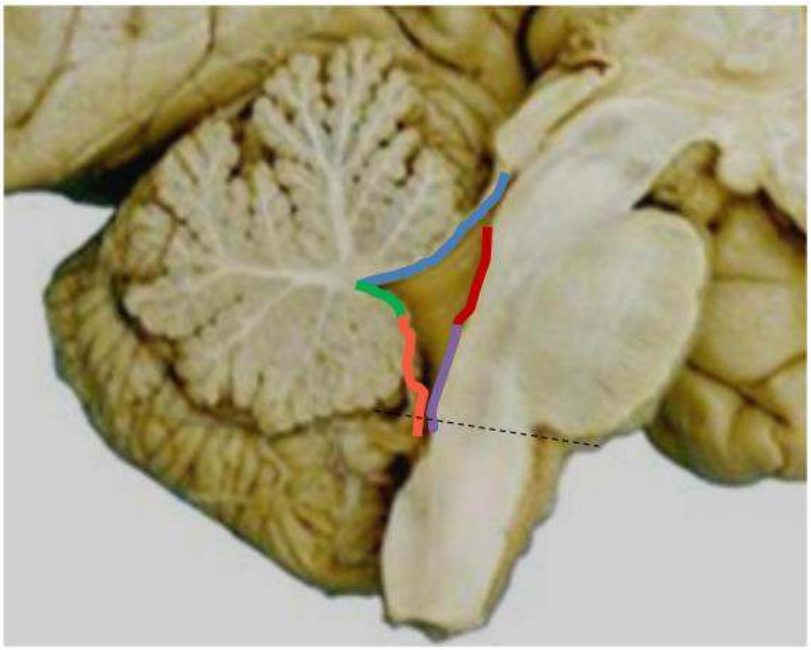
Cranial nerves exiting the brainstem:



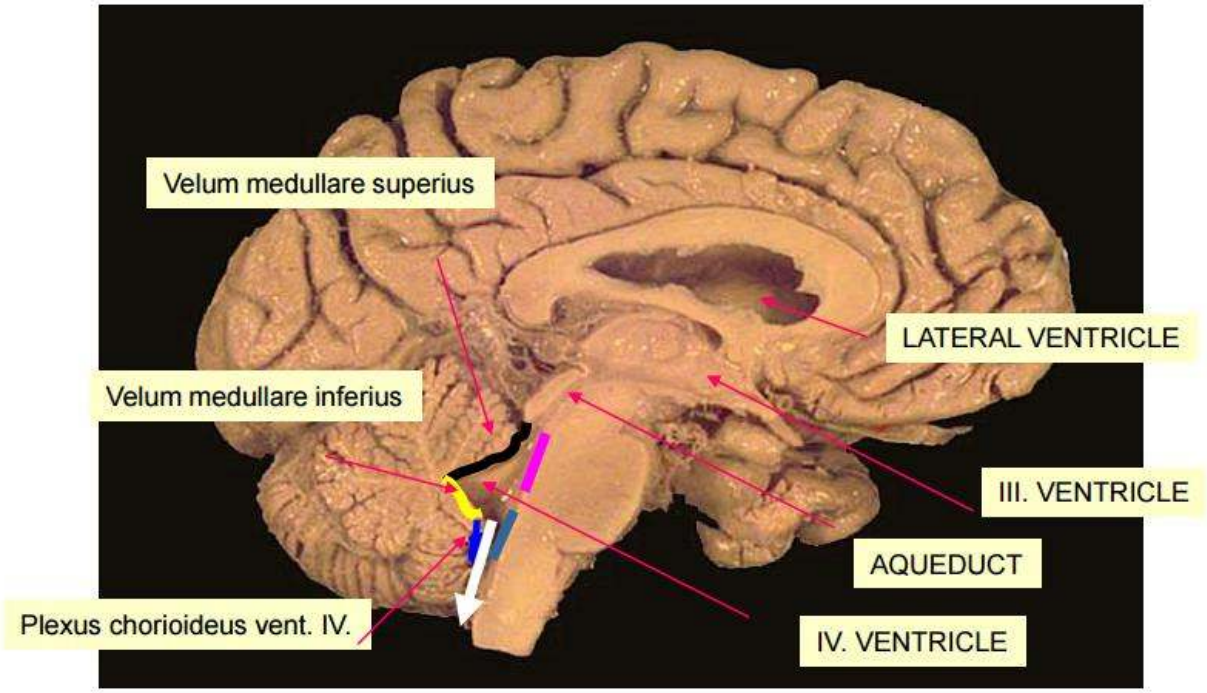


The 4th ventricle

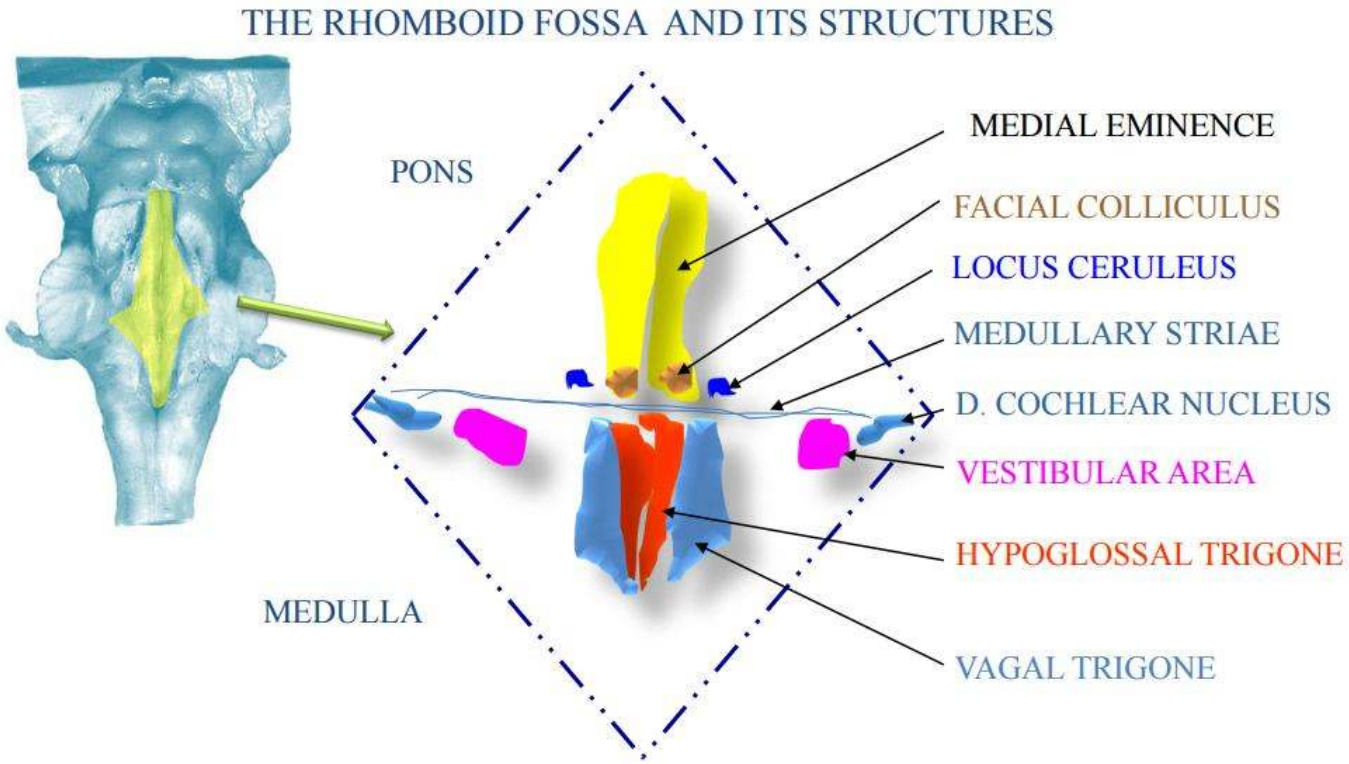
THE BOUNDARIES OF THE IV TH VENTRICLE



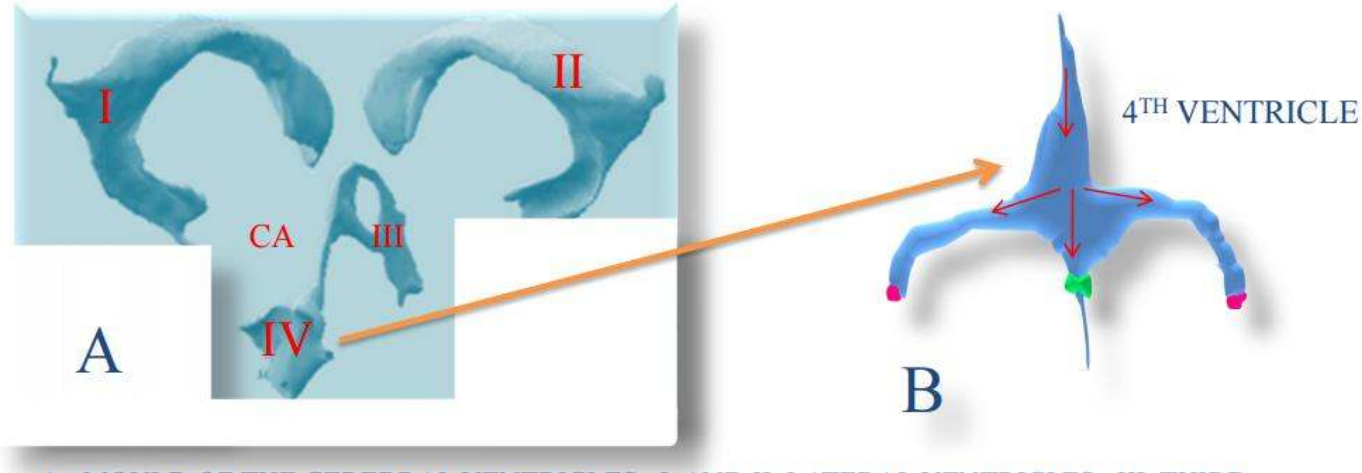
THE ROOF THE 4TH VENTRICLE IS COMPOSED OF THE SUPERIOR MEDULLARY VELUM, THE INFERIOR MEDULLARY VELUM AND THE CHOROID PLEXUS OF THE VENTRICLE. THE FLOOR HAS A RHOMBOID SHAPE. ITS UPPER PART IS FORMED BY THE PONS, THE LOWER HALF IS MADE BY THE OPEN PART OF THE MEDULLA. THE DASHED LINE DEMARCATES THE CLOSED AND OPEN SEGMENTS OF THE MEDULLA OBLONGATA.
THE CEREBROSPINAL FLUID LEAVES THE VENTRICULAR SYSTEM THROUGH OPENINGS OF THE 4TH VENTRICLE



Rhomboid fossa A rhombus-shaped depression (bemélyedés) that is the anterior part of the 4th ventricle. Its anterior wall, formed by the back of the pons and the medulla oblongata, constitutes the floor of the 4th ventricle.



COMMUNICATION BETWEEN THE INTRA- AND EXTRACEREBRAL LIQUOR COMPARTMENTS



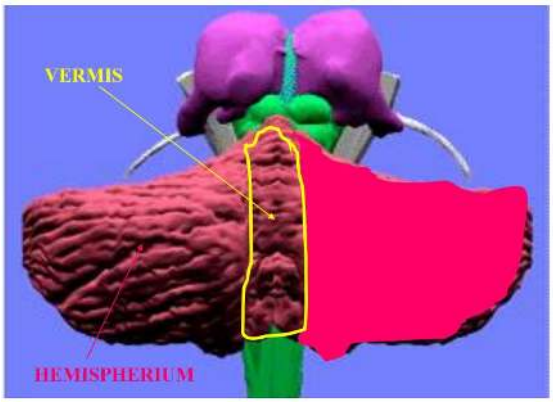
A. MOULD OF THE CEREBRAL VENTRICLES. I. AND II. LATERAL VENTRICLES. III. THIRD VENTRICLE. CA. CEREBRAL AQUEDUCT. IV. FOURTH VENTRICLE.

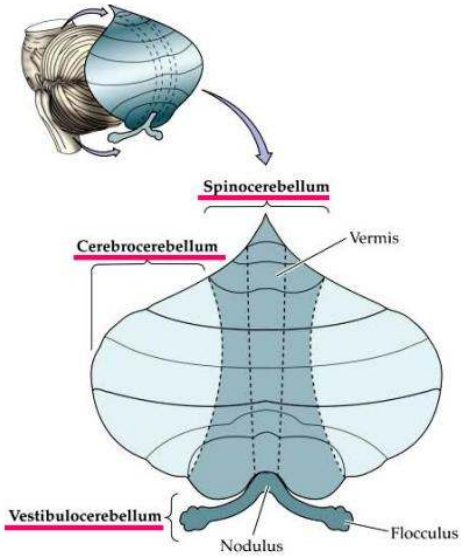
B. LIQUOR PRODUCED BY THE CHOROID PLEXUS IN THE LATERAL, THIRD AND FOURTH CEREBRAL VENTRICLES GETS OUT OF THE INTRACEREBRAL COMPARTMENT TO THE EXTERNAL, SUBARACHNOID SPACE VIA THE MAGENDIE AND LUSCHKA FORAMINA DEPICTED IN FIGURE B

Formatio reticularis = agytörzsi hálózatos állomány: nem különül el a fehér- és szürkeállomány. Ez a képlet felel az ébrenlét, az izomtónus kialakításáért

Cerebellum

Consists of 3 basic constituents: **cerebellar cortex**, the **medullary substance** and the **deep, intrinsic nuclei**. These components build up the **2** symmetrical **hemispheres** and the **vermis** (kisagyféreg) wedged between them.





Cerebellar fissures divide the cerebellum into lobes (anterior, posterior and flocculo-nodular) that contain further subunits (lobules I-X). The division pertains to both the hemispheres and the vermis.

Phylogenetically it has 3 parts:

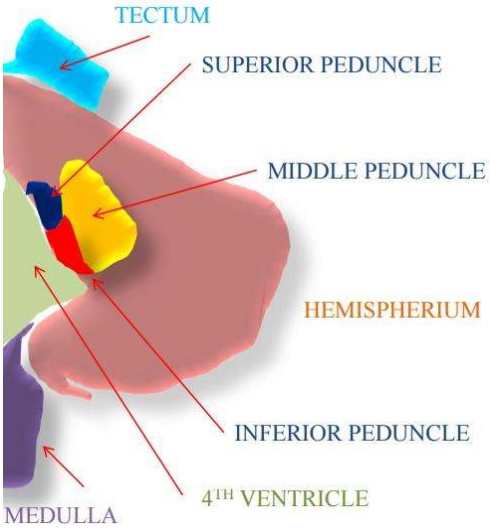
1. *archicerebellum*: this ancient part contains the flocculo-nodular system. It is related to the vestibular system and concerned with equilibrium. Functionally, it is the *vestibulo-cerebellum*.
2. *paleocerebellum*: it consists of the anterior portions of the hemispheres and most of the vermis. It is linked to spinal cord, also called as *spinocerebellum*
3. *neocerebellum*: the remainder of the cerebellum linked to the cerebral cortex. Its synonym is *cerebro-cerebellum*

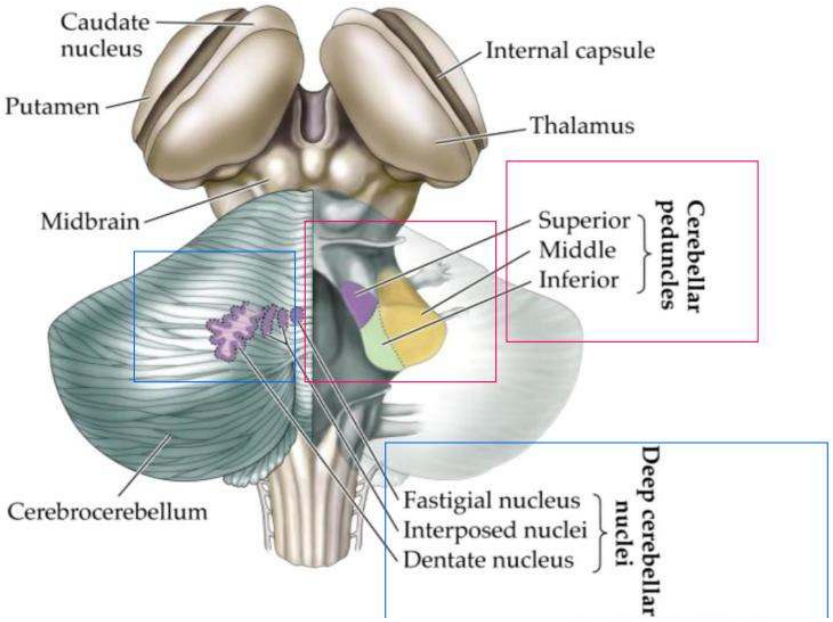
Although the cerebellum receives a large quantity of sensory information, it is **not concerned with conscious perception**. The stimuli from the receptors are important regulators of cerebellar mechanisms controlling the automatic coordination of somatic movement, muscle tone and maintenance of equilibrium. The processed information from the cerebellar cortex is transmitted to the deep cerebellar nuclei the main relay structures that project to distinct brains stem and diencephalic nuclei.

Main ***functions*** of the cerebellum include the coordination of skilled voluntary movements, the regulation of the muscle tone and the control of equilibrium

Deep nuclei: the incoming afferent axons give excitatory collaterals to the deep nuclei. They receive the heaviest innervation from the Purkinje cells. The cortical input to the deep nuclei is inhibitory, utilizing GABA for neurotransmission.

The cerebellum is tightly bound to the brainstem via the ***cerebellar peduncles***. There are 3 pairs of them. The *superior peduncle* is mainly composed of efferent fibers projecting to the thalamus and the red nucleus of the midbrain. The *middle peduncle* is the thickest. It connects the cerebellum to the pons. It carries axons from the contralateral pontine nuclei that mainly receive cerebral cortical afferents. The *inferior peduncle* establishes communication with the spinal cord and structures located in the caudal part of the brainstem.



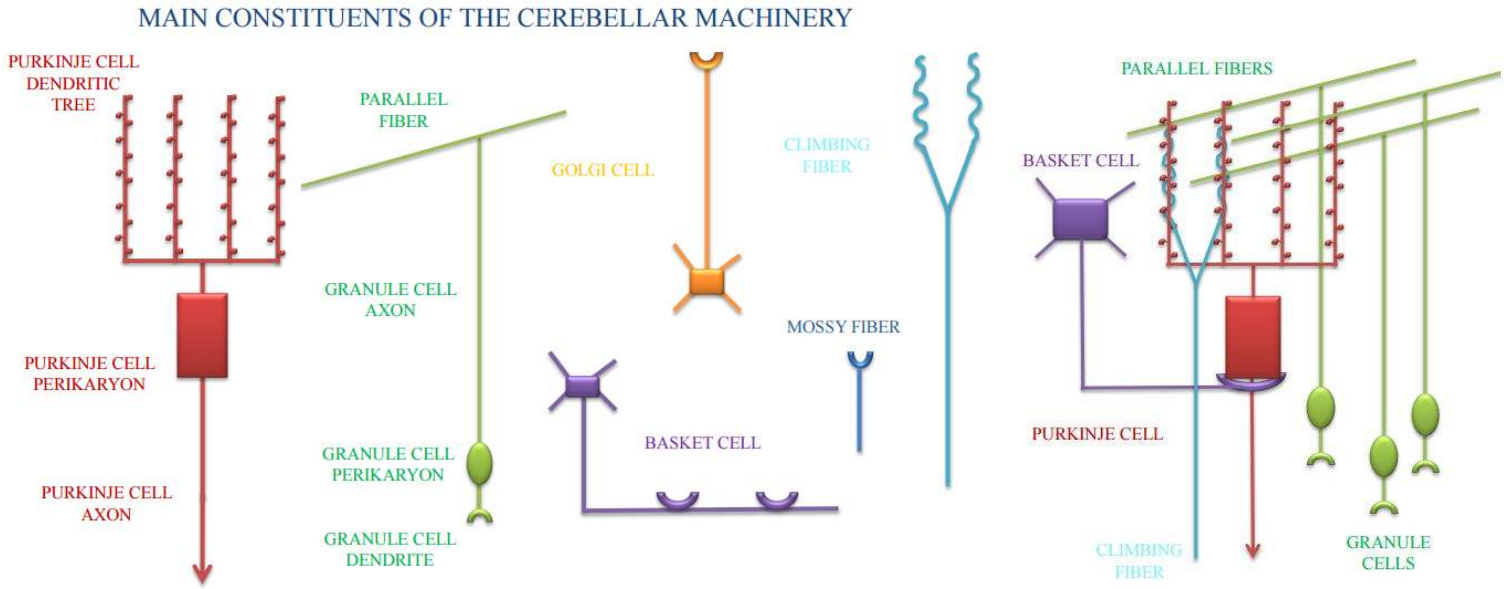


3 layers:

- molecular layer: poor in cells, but densely innervated by axon bundles
- Purkinje cell layer: contains the cell bodies of Purkinje cells
- granule cell layer: packed by small sized neurons

The cerebellar cortex converts the excitatory information into inhibitory signals transmitted by the axons of Purkinje cells mainly to deep cerebellar nuclei.

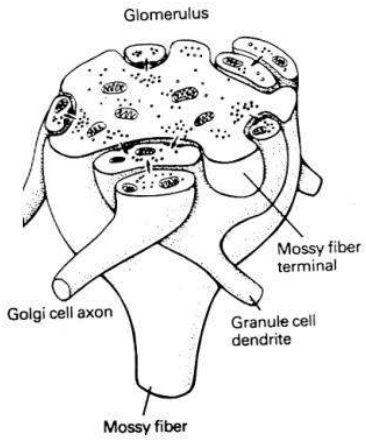
Fibers:

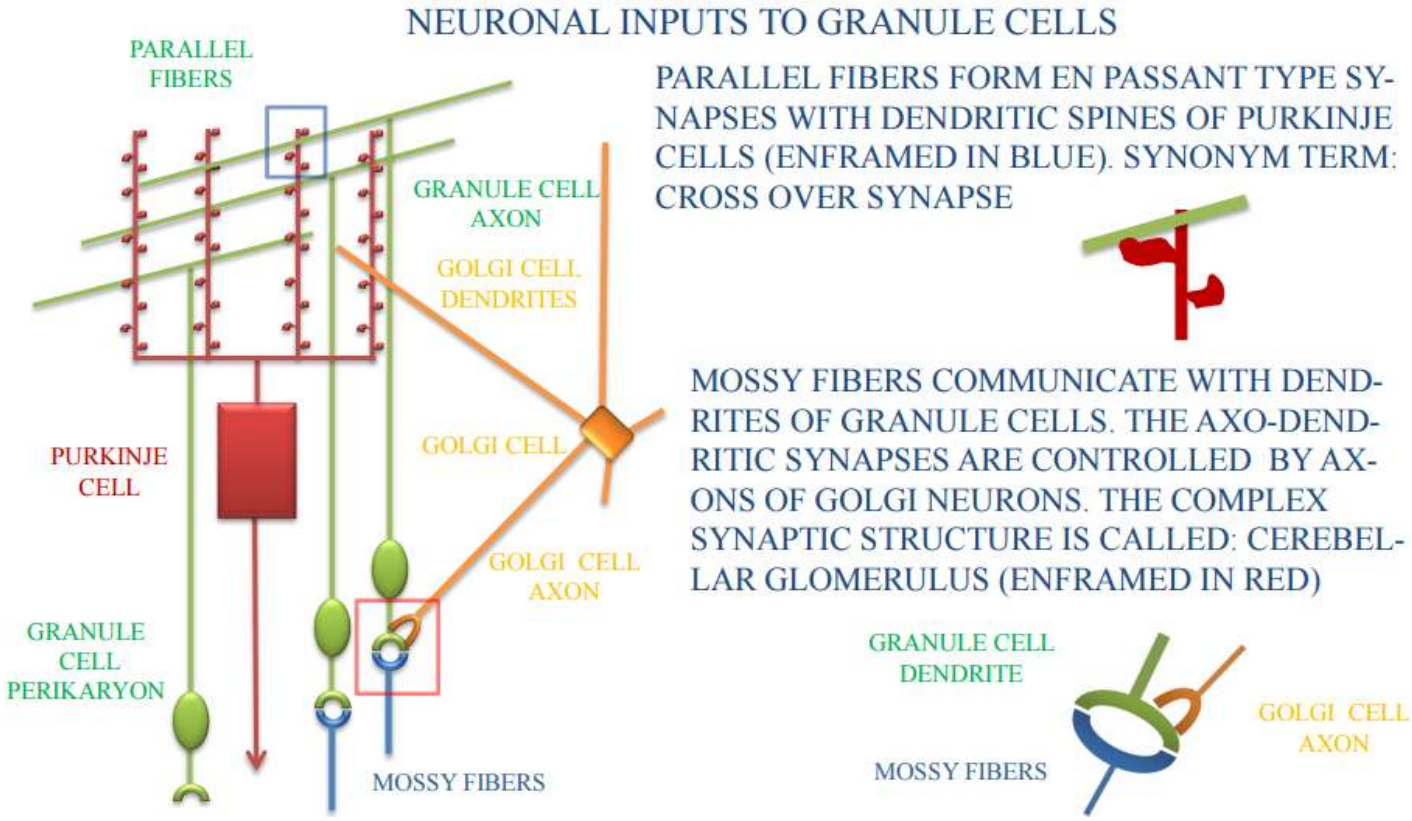


Climbing fibers arising from the inferior olive of the medulla wrap around the dendrites of the Purkinje cell establishing multiple synaptic contacts.

Parallel fibers are axons of granule cells that synapse with the spine of Purkinje cell dendrites. A single Purkinje neuron communicates with ~70.000 parallel fibers.

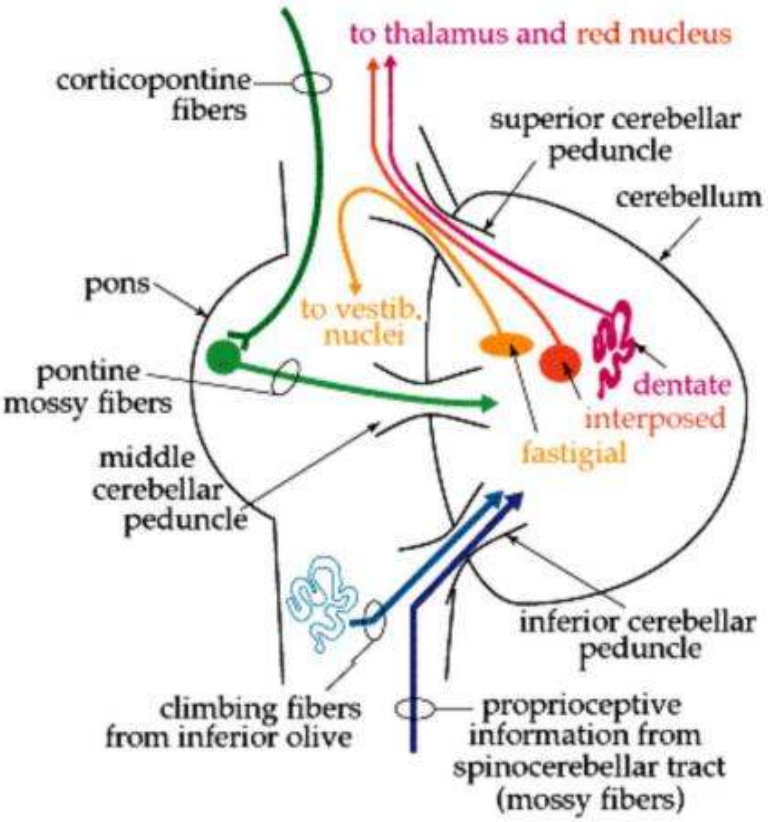
Basket cells – located in the molecular layer – innervate Purkinje cells by forming a dense terminal field at the axon hillock. They generate the collateral inhibition.





The *input* comes from the climbing and the mossy fibers; the output goes to the deep cerebellar nuclei through the Purkinje cell axon.

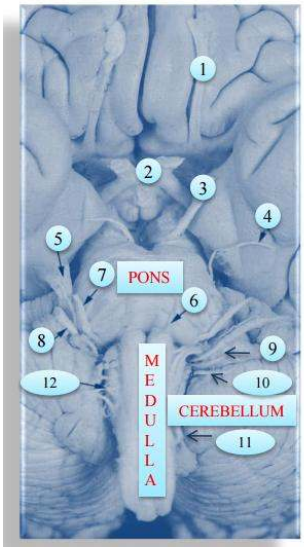
Jelentőség:



EFFERENTS

Cranial nerves

12 pairs with sensory, motor and autonomic functions. The olfactory (I) and optic (II) nerves are associated with prosencephalic derivatives, the rest belongs to the brainstem.



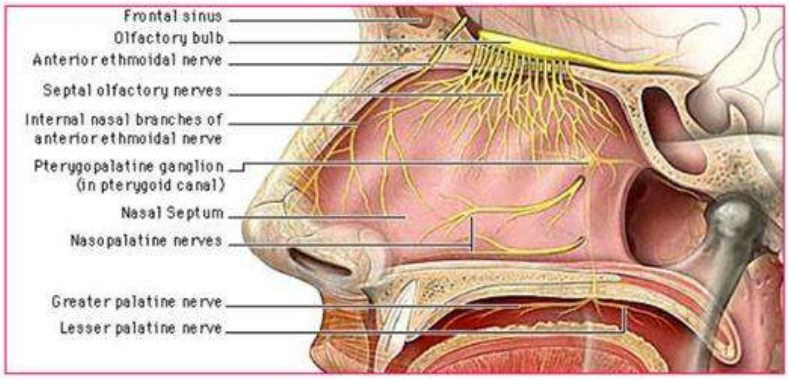
1. OLFACTORY NERVE
2. OPTIC NERVE
3. OCULOMOTOR NERVE
4. TROCHLEAR NERVE
5. TRIGEMINAL NERVE
6. ABDUCENT NERVE
7. FACIAL NERVE
8. VESTIBULOCOCHLEAR NERVE
9. GLOSSOPHARYNGEAL NERVE
10. VAGUS NERVE
11. ACCESSORY NERVE
12. HYPOGLOSSAL NERVE

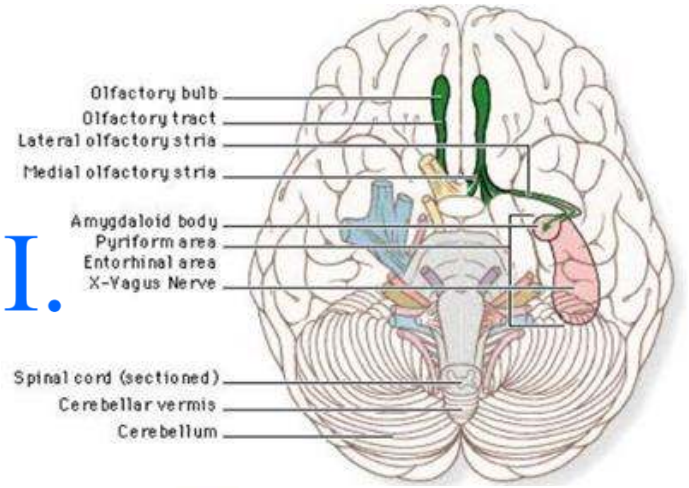
Sensory function: I, II, VIII – they modulate smell, vision, balance and hearing.

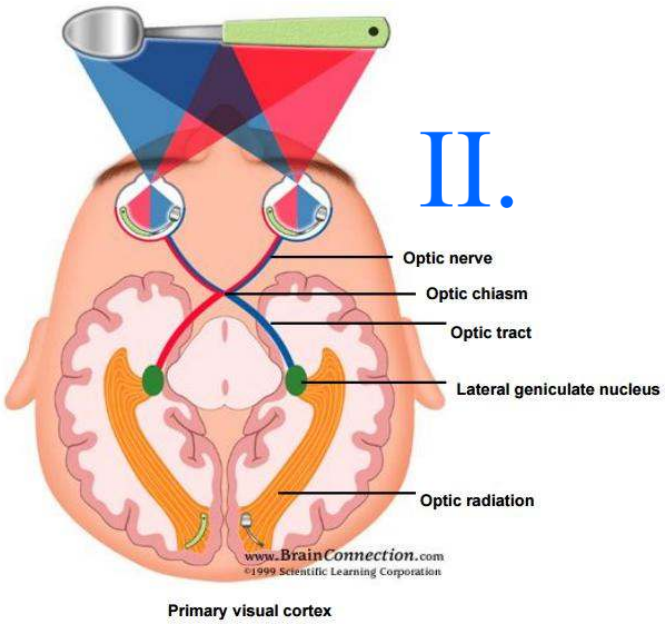
Motor function: III, IV, VI, XI, XII – they enable eye movements, movement of the shoulder girdle (vállöv), swallowing and speech.

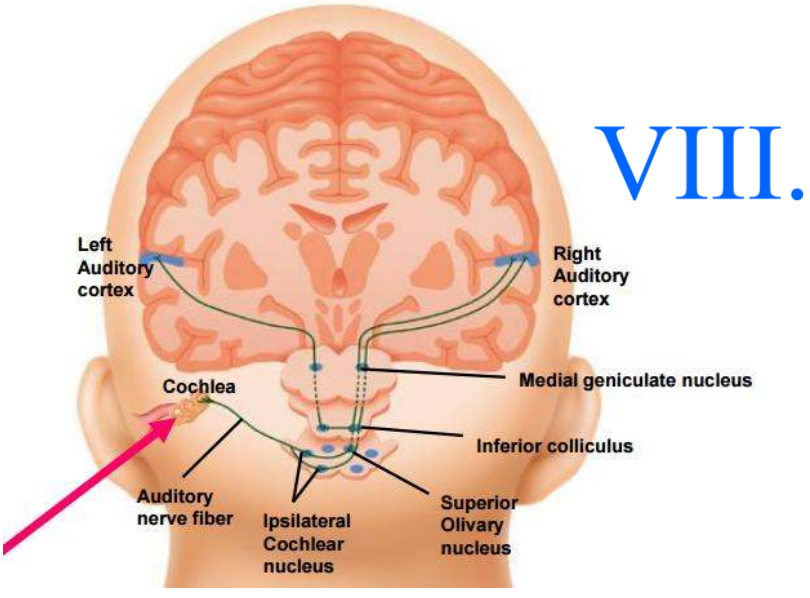
Mixed functions: V, VII, IX, X. Trigeminal (V) controls many sensory processes from the head region and regulates the muscles of mastication.

Dominant parasympathetic components: III, VII, IX, X. The vagus nerve (X) provides parasympathetic control of the body including the regulation of the lungs and the heart.



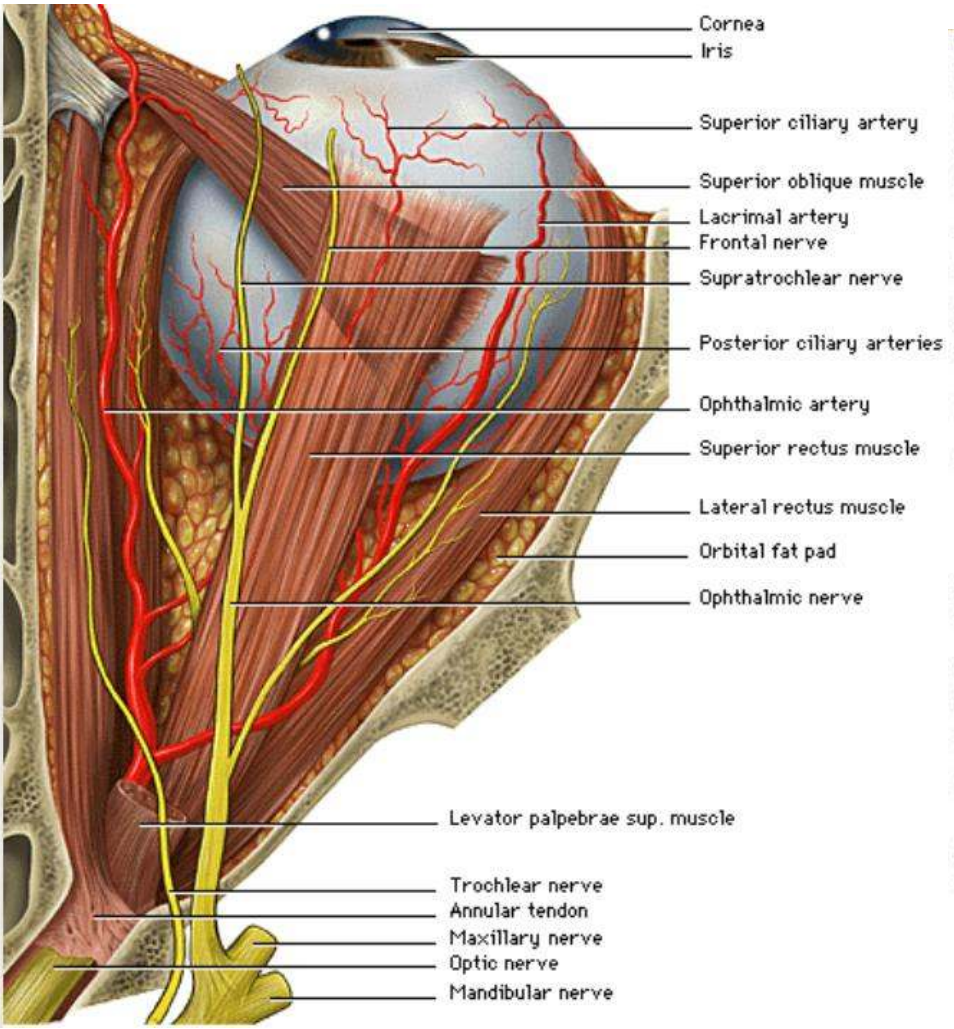


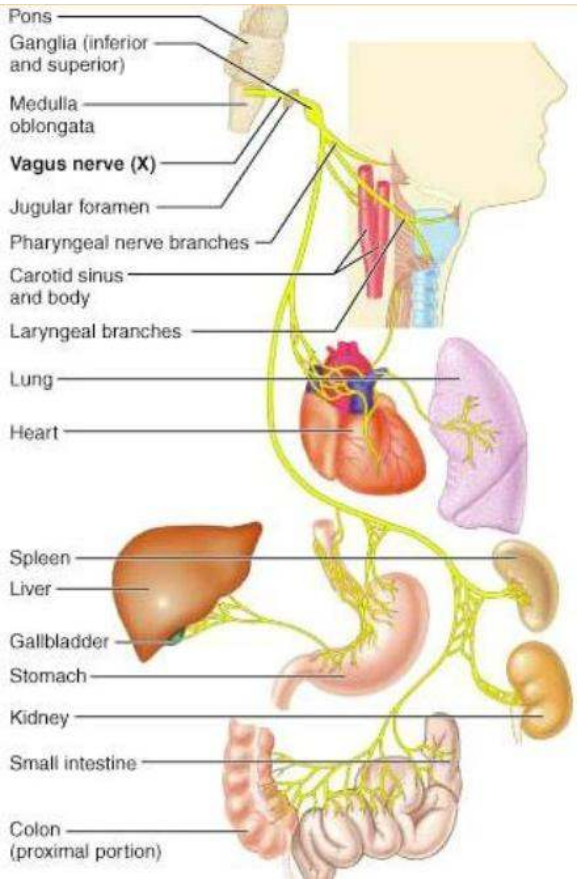




Functions of parasympathetic cranial nerves

- III. oculomotor: constricts pupil, lens accommodation (pupillaszűkítés, lencse alkalmazkodás)
- VII. facial: lacrimation (könnyezés), nasal gland secretion, salivation (nyálképzés)
- IX. glossopharyngeal: salivation
- X. vagus: gland secretion, peristalsis



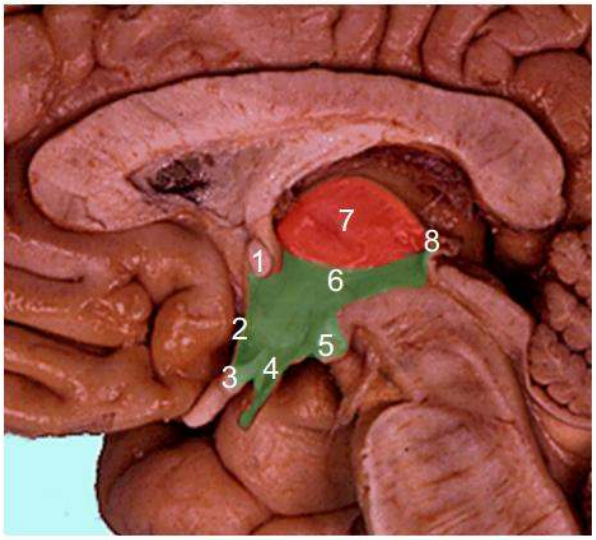


Diencephalon

Develops from the prosencephalic vesicle, its cavity is the 3rd cerebral ventricle. With the exception of its ventral (hasi) part, it is covered by telencephalic structures.
Major constituents: thalamus, hypothalamus, metathalamus, epithalamus, subthalamus and the 3rd ventricle.

Thalamic structures are in reciprocal connection with the cerebral cortex, communicate with major motor and sensory systems and they are linked to the limbic system. The Hypothalamus controls autonomic centers and via the pituitary it orchestrates the performance of the endocrine system. It secretes a wide scale of hormones into the systemic and portal circulation.

Parcellation:



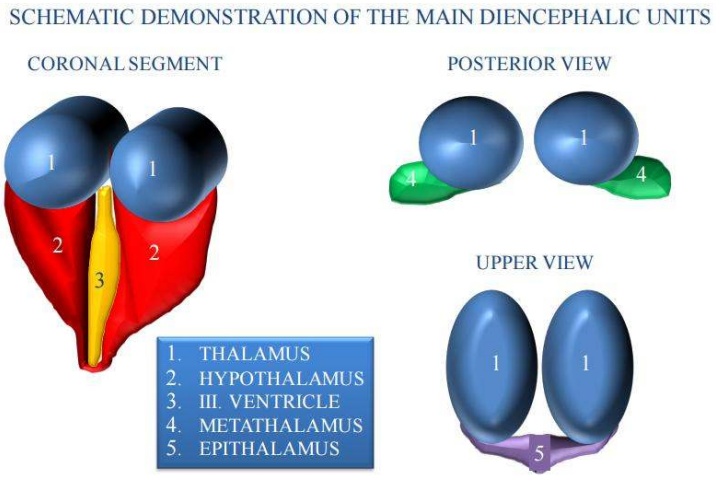
1. COMMISSURA ANTERIOR
2. LAMINA TERMINALIS
3. CHIASMA OPTICUM
4. INFUNDIBULUM
5. CORPUS MAMILLARE
6. SULCUS HYPOTHALAMICUS
7. THALAMUS
8. EPITHALAMUS

1. elülső lemez
2. a 3. agykamra elülső fala
3. látóideg-kereszteződés
4. a 3. agykamra fenekének lefelé boltosulása
5. emlőtest
6. hipotalamusz-barázda
7. thalamus
8. epithalamus

THE PICTURE DEPICTS THE DIENCEPHALON IN THE MID-SAGITTAL PLANE. THE THALAMUS IS HIGHLIGHTED IN RED, THE HYPOTHALAMUS IN GREEN COLOR

Harmadik agykamra: rés a kétoldali talamusz között. Elől a páros oldalkamrákkal áll összeköttetésben a Monro-féle nyílások közvetítésével, hátul az (aqueductus cerebri) a negyedik agykamrával köti össze. Üregét ependyma béleli. Az elülső falát egy vékony szürkeállomány réteg, a határlemez (lamina terminalis) alkotja. A hátsó fal a Sylvius-féle csatorna (aqueductus cerebri) benyílása. Az oldalsó falát felül a talamusz, alul a hipothalamusz medialis felszíne képezi, Ezt a két részt egy barázda (sulcus hypothalmicus) választja el egymástól. A kamra felső falát egy ependyma réteg alkotja, amely fölött a pia mater kétrétegű lemeze található. Az utóbbiban futó artériák a középsík mindkét oldalán egy-egy sagittalis csíkban betüremítik az ependymalis réteget, és kialakítják a harmadik agykamra érfonatát plexus choroideus ventriculi tertii, amely agy-gerincvelői folyadékot (liquor cerebrospinalis) termel. A felső falban futnak a belső agyi vénák. Az agykamra felső fala felülről a boltozattal (fornix) és a kérges testtel (corpus callosum) érintkezik. Az alsó falat (aljzatot) a látóidegkereszteződés (chiasma opticum), a tölcsér (infundibulum), és az emlőtestek (corpus mammillare) alkotják. Az agyalapi mirigy (hypophysis cerebri) a tölcsér alsó végéhez kapcsolódik

Talamusz: A harmadik agykamra 2 oldalán elhelyezkedő ovoid szürkeállomány-tömeg. Fogadja a fő érzőpályákat (a szaglópálya kivételével), és átkapcsolja őket az agykéreg megfelelő központjai felé. Szürke állományát egy fehérállományból álló Y alakú függőleges lemez három fő részre osztja. A lemezt olyan idegrostok kötegei alkotják, amelyek talamusz magvakat kötnek össze. A talamusz mind a három része talamusz magokat: idegsejt-csoportokat tartalmaz. Ezek neuronjain történik meg a pályák átkapcsolódása.

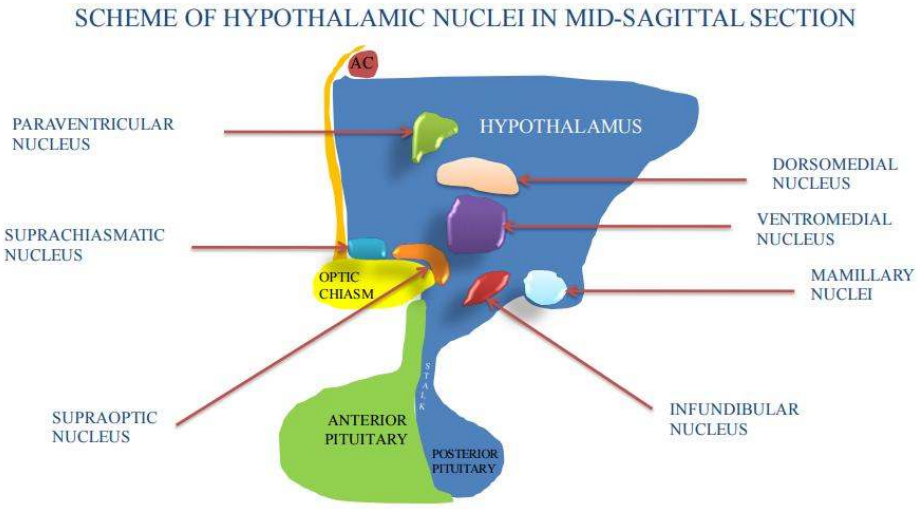


Hipotalamusz: kontrollálja az autonóm és az endokrin rendszer működését, alapvető szerepe van a homeosztázis fenntartásában. Közreműködik a testhőmérséklet szabályozásában, a testfolyadék ok viszonylagosan állandó összetételének biztosításában, a táplálék- és vízfelvétel elősegítésében, a szexuális viselkedés és az érzelmi élet alakításában.

Szubtalamusz: szerep az izomaktivitás kontrolljában

Epitalamusz: a tobozmirigy szárában található mag.

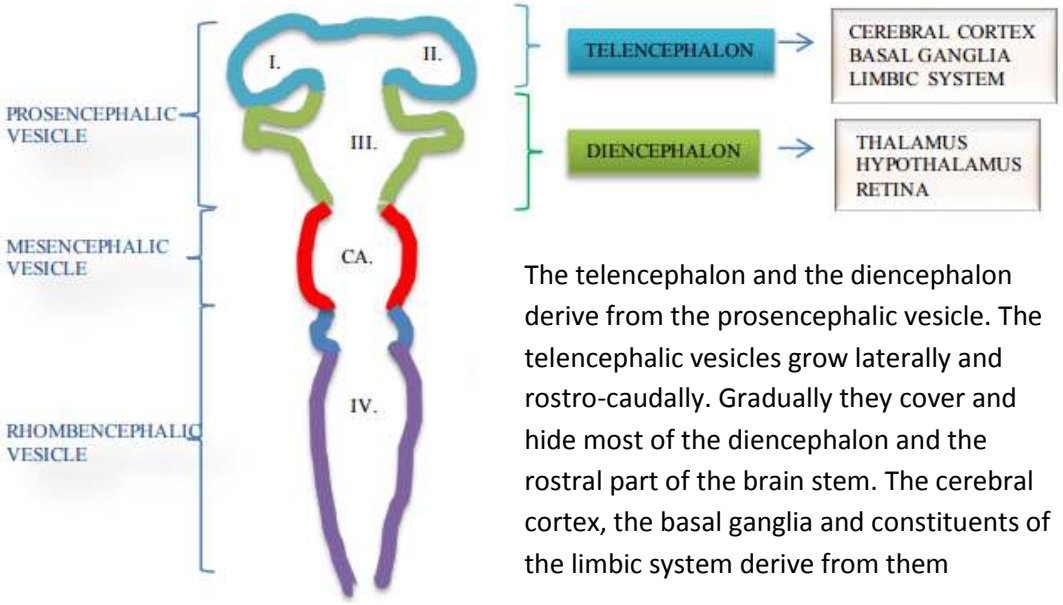
Hypothamaic nuclei:



Parvicellular neurosecretory system: parvicelluar neurons secret releasing (LHRH, CRH, TRH, GHRH) and release-inhibiting (SRIF) hormones into the portal circulation. The hormones control the troph hormone output of different anterior pituitary gland cells. The system regulates reproduction, stress, adaptation, body growth and metabolism.

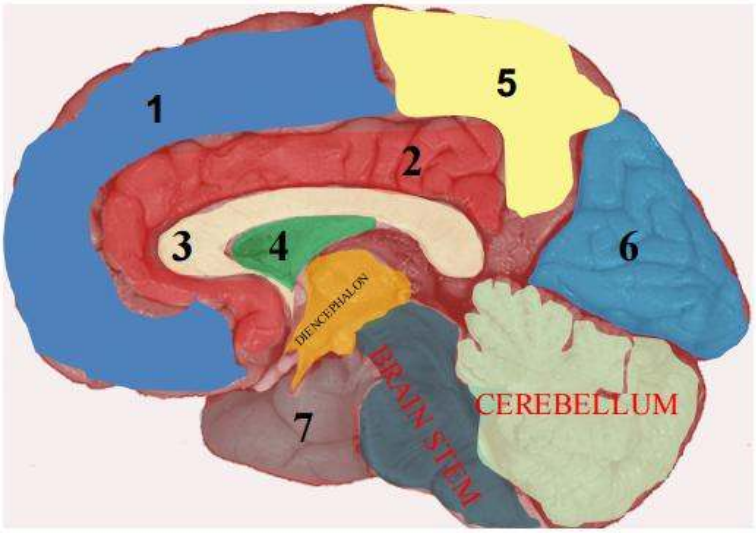
Sajátos funkciója a **neuroszekréció**: az egyik nagy sejtes magja (paraventricular nucleus) az antidiuretikus hormont (ADH) termeli, míg a másik (supraoptic nucleus) az oxitocint. Előbbi anyag a vesékben a víz visszaszívódását fokozza (és vérnyomásemelő hatása is van), az utóbbi a méhizomzat összehúzódását és a tejelő emlő tejkiürítését segíti elő.

Telencephalon



The telencephalon and the diencephalon derive from the prosencephalic vesicle. The telencephalic vesicles grow laterally and rostro-caudally. Gradually they cover and hide most of the diencephalon and the rostral part of the brain stem. The cerebral cortex, the basal ganglia and constituents of the limbic system derive from them

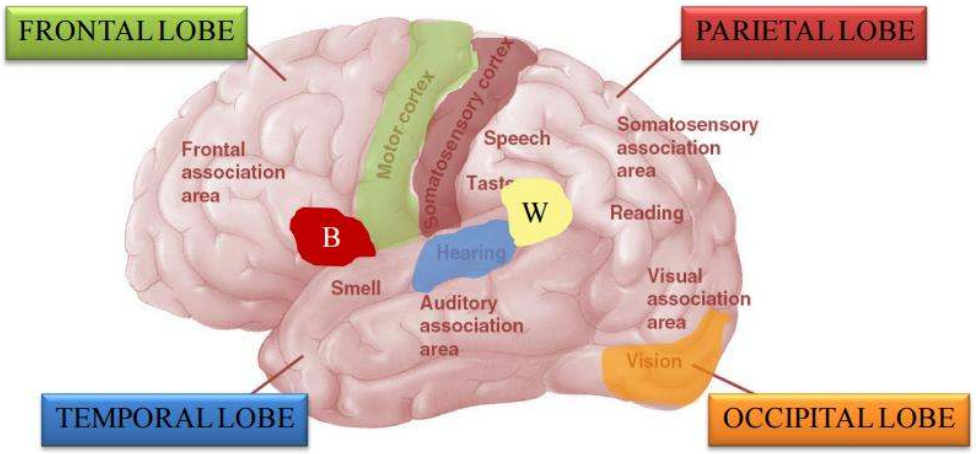
SCHEME OF THE MEDIAN SAGITTAL BRAIN SURFACE



1. FRONTAL LOBE
2. GYRUS CINGULI
3. CORPUS CALLOSUM
4. SEPTUM PELLUCIDUM
5. PARIETAL LOBE
6. OCCIPITAL LOBE
7. TEMPORAL LOBE

Functions of the frontal cortex: attention, behavior, problem solving, emotion, intellect, judgment; coordinated movements, generalized mass movements, muscle movements, skilled movements, sense of smell, physical reaction, sexual urges

ASSOCIATION OF SPECIFIC FUNCTIONS WITH CORTICAL AREAS



MOST NEURONAL FUNCTIONS OF THE BODY ARE REPRESENTED IN THE CEREBRAL CORTEX. COLOR CODED ARE THE PRIMARY MOTOR CENTRE IN THE FRONTAL, THE PRIMARY SOMATOSENSORY CENTER IN THE PARIETAL, THE VISUAL CENTER IN THE OCCIPITAL AND THE HEARING CENTER IN THE TEMPORAL LOBE. THE SENSORY, WERNICKE (W) AND THE MOTOR, BROCA (B) SPEECH FIELDS ARE ALSO INDICATED

Broca's aphasia Broca beszédzavar: a sérült megérti a nyelvet, de ő maga nem tud helyesen szavakat formálni: beszéde lassú és egybefolyó.

Wernicke's aphasia Wernicke beszédzavar: a sérült nem érti a beszédet; tisztán, kivehetően képes beszélni, azonban a szavak egymásutánja értelmetlen (szó-saláta).

Basal ganglia Törzsdúcok. Mindkét oldali agyféltekében megtalálható, szürkeállományból álló tömörülések. Az agykéreg befolyásolásán keresztül kontrollálják az izmok mozgását.
Ezek: corpus striatum (csíkolt test), corpus amygdaloideum (mandulamag).

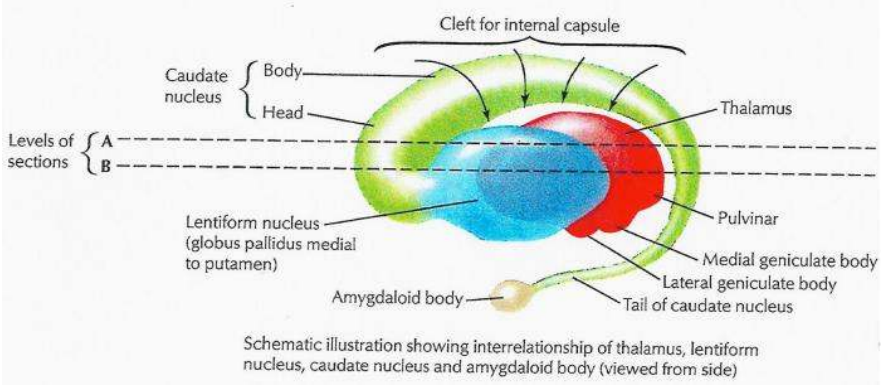
Corpus striatum A talamusztól laterálisan elhelyezkedő törzsdúc, melyet a capsula interna (fontos pályákat tartalmazó fehérállomány-lemez) oszt két részre: a nucleus caudatusra (farkas mag) és a nucleus lentiformisra (lencsemag)

Nucleus caudatus Nagy, C-alakú szürkeállomány-tömörülés, mely a talamusztól oldalra helyezkedik el, az oldalsó agykamra határolásában vesz részt, annak görbületét követi. Feji, testi és farki része van. A farokrész elöl, a mandulamagban végződik.

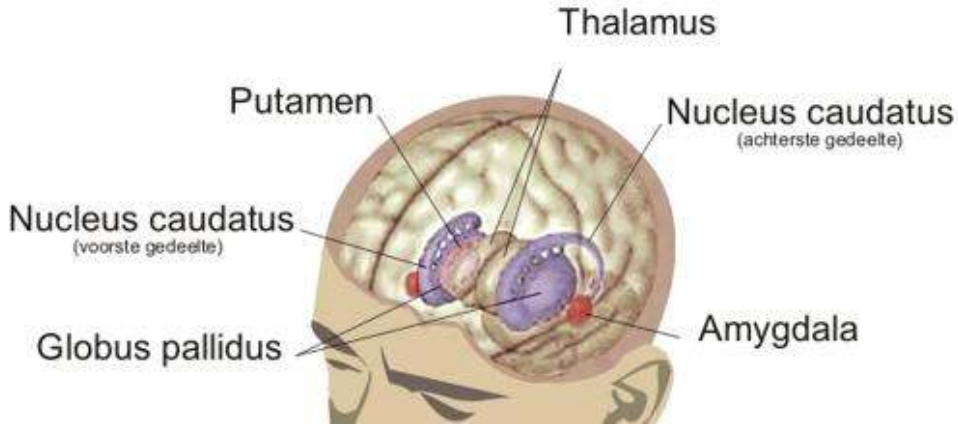
Nucleus lentiformis Az agyfélteke fehérállományába mélyen beágyazott, szürkeállományból álló képlet.

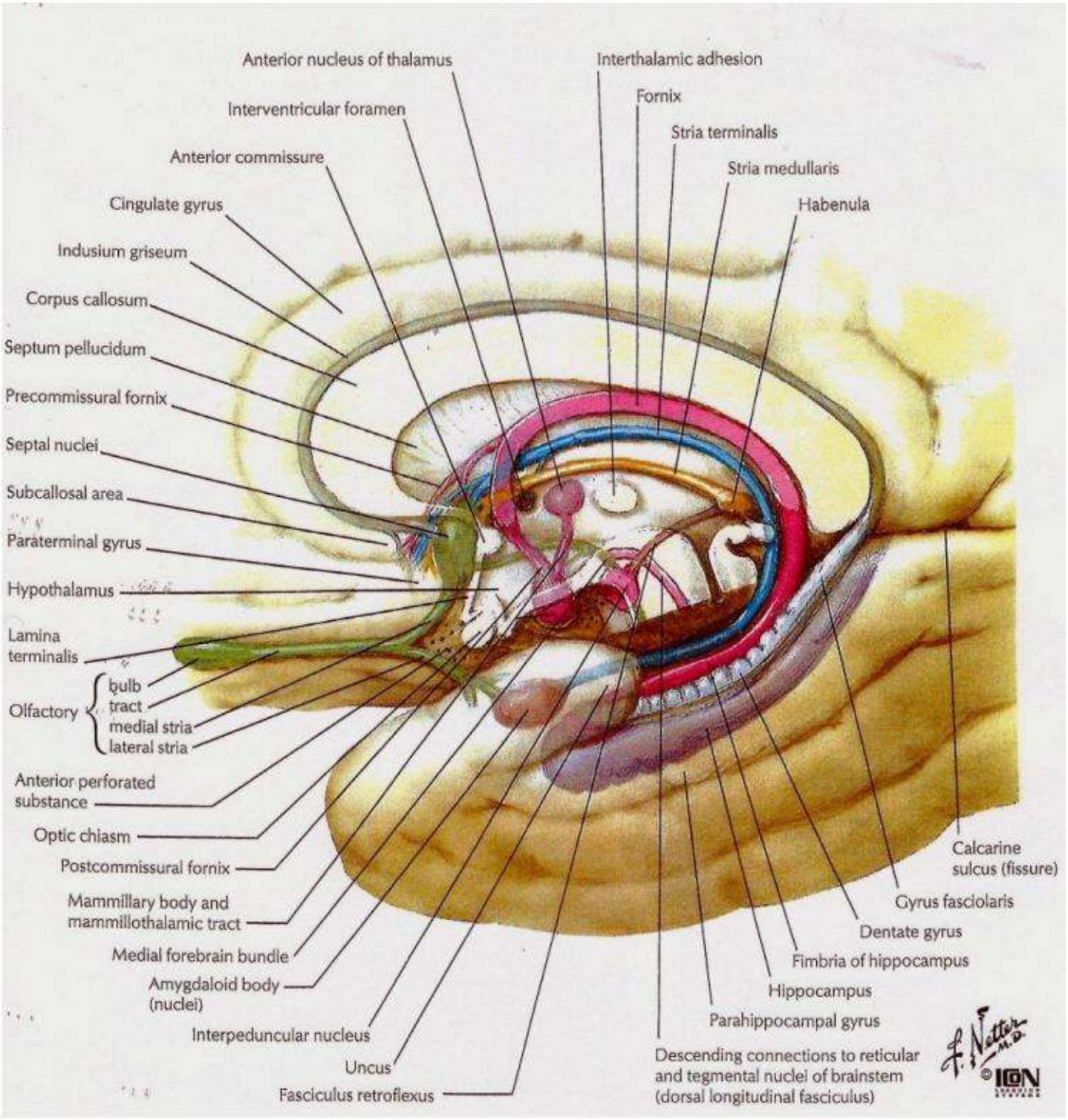
Corpus amygdaloideum A limbikus rendszer része, a halántéklebenyben elhelyezkedő törzsdúc. Befolyásolni tudja a szervezetnek a környezeti változásokra bekövetkező válaszreakcióit. Félelem hatására pl. meg tudja változtatni a szívritmust, a vérnyomást, a bőrszínt és a légzésszámot.

Internal capsule:

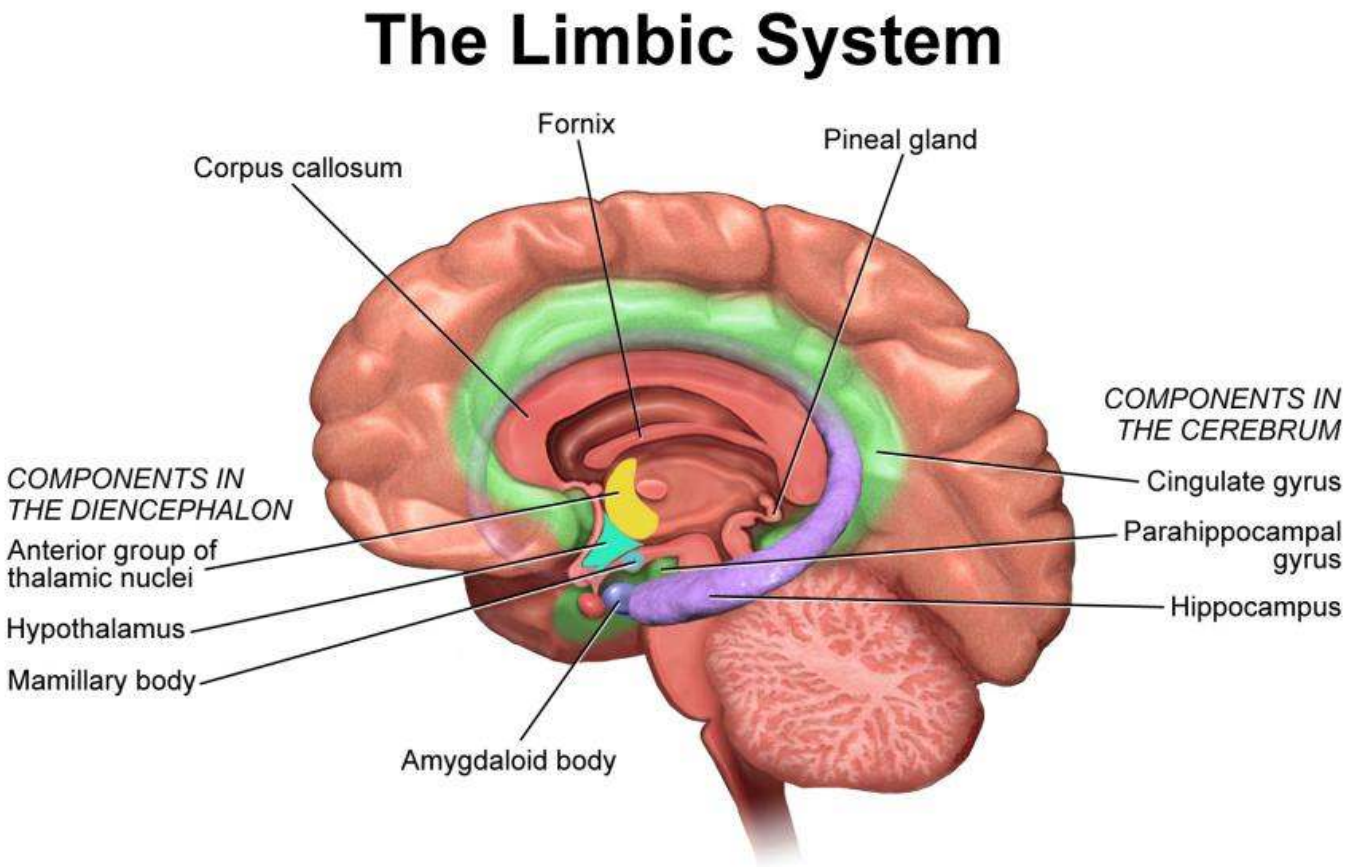


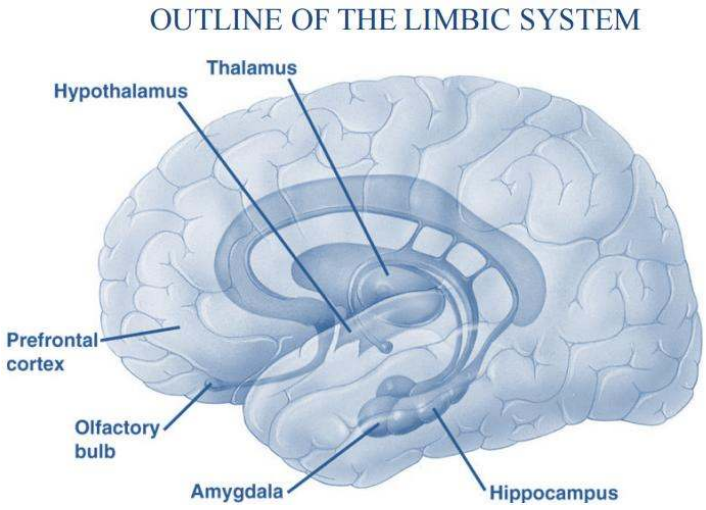
Schematic illustration showing interrelationship of thalamus, lentiform nucleus, caudate nucleus and amygdaloid body (viewed from side)


Thalamus
Putamen
Nucleus caudatus
(achterste gedeelte)
Nucleus caudatus
(voorste gedeelte)
Amygdala
Globus pallidus


Anterior nucleus of thalamus
Interventricular foramen
Anterior commissure
Cingulate gyrus
Indusium griseum
Corpus callosum
Septum pellucidum
Precommissural fornix
Septal nuclei
Subcallosal area
Paraterminal gyrus
Hypothalamus
Lamina terminalis
Olfactory
bulb
tract
medial stria
lateral stria
Anterior perforated substance
Optic chiasm
Postcommissural fornix
Mammillary body and mammillothalamic tract
Medial forebrain bundle
Amygdaloid body (nuclei)
Interpeduncular nucleus
Uncus
Fasciculus retroflexus
Interthalamic adhesion
Fornix
Stria terminalis
Stria medullaris
Habenula
Calcarine sulcus (fissure)
Gyrus fasciolaris
Dentate gyrus
Fimbria of hippocampus
Hippocampus
Parahippocampal gyrus
Descending connections to reticular and tegmental nuclei of brainstem (dorsal longitudinal fasciculus)
F. Netter M.D.
©

Limbic system Consists of the limbic lobe, hippocampal formation, amygdaloid body and their widespread connections. It arises from the transition zone between the diencephalic and telencephalic vesicle. It is associated with learning, memory, emotions and regulation of homeostasis.

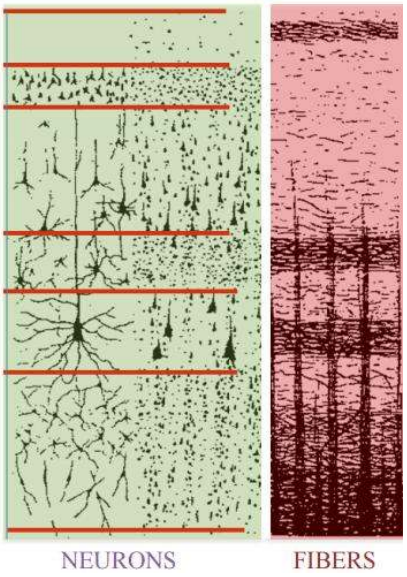




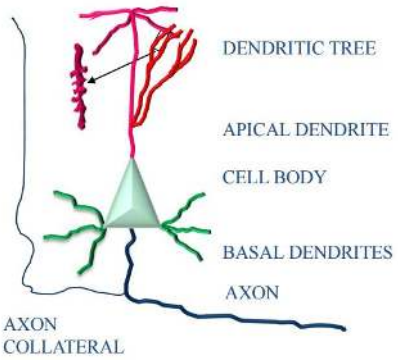
Cerebral cortex Consists of the hippocampal formation (archicortex), olfactory areas (paleocortex) and neocortex. It is built up by principal and pyramidal neurons, inhibitory interneurons and glial cells. The incoming subcortical and cortical afferents transfer the information to interneurons that relay it further to principal cells.

Neocortex Comprised of 6 superimposed layers:

1. MOLECULAR LAYER
2. EXTERNAL GRANULAR LAYER
3. EXTERNAL PYRAMIDAL LAYER
4. INTERNAL GRANULE LAYER
5. INTERNAL PYRAMIDAL LAYER
6. MULTIFORM LAYER



Pyramid neuron:



Cortical column A neokortex egysége. ~300µm wide and has the height of the cortex (2.5-3 mm). Each hosts about 5000 neurons. The outflow from the column is executed by axons of pyramid cells. Layer III cells project to cortical regions as associative and commissural fibers, while the large betz pyramidal neurons of layer V establish the descending connections.

DIFFERENT FUNCTIONAL OUTPUTS OF CORTICAL MODULES OF DIFFERENT BRAIN REGIONS

CORTICAL AREA	FUNCTION
PREFRONTAL CORTEX	PROBLEM SOLVING, EMOTION, COMPLEX THOUGHT
MOTOR ASSOCIATION CORTEX	COORDINATION OF COMPLEX MOVEMENT
PRIMARY MOTOR CORTEX	INITIATION OF VOLUNTARY MOVEMENT
PRIMARY SOMATOSENSORY CORTEX	RECEIVES TACTILE INFORMATION FROM THE BODY
SENSORY ASSOCIATION AREA	PROCESSING OF MULTISENSORY INFORMATION
VISUAL ASSOCIATION AREA	COMPLEX PROCESSING OF VISUAL INFORMATION
VISUAL CORTEX	DETECTION OF SIMPLE VISUAL STIMULI
WERNICKE'S AREA	LANGUAGE COMPREHENSION
AUDITORY ASSOCIATION AREA	COMPLEX PROCESSING OF AUDITORY INFORMATION
AUDITORY CORTEX	DETECTION OF SOUND QUALITY (LOUDNESS, TONE)
MOTOR SPEECH CENTER (BROCA'S AREA)	SPEECH PRODUCTION AND ARTICULATION

Sensory systems

From most parts of the body, two general sensory systems carry the information from receptors to higher processing centers, the ***spinothalamic system*** and the ***medial lemniscus system***. From the head region, the trigeminal and dorsal trigeminal tracts forward the sensory information to the thalamus. The systems are crossed and multisynaptic in nature. They are linked to the sensory nuclei of the thalamus, especially the ventral postero-medial and ventral postero-lateral nuclei. The major processing site of general sensory information is in the primary somatosensory cortex located in the postcentral gyrus of the parietal lobe (Brodmann areas 3, 2, 1).

1. The medial lemniscus system

a) Origin - first order neurons

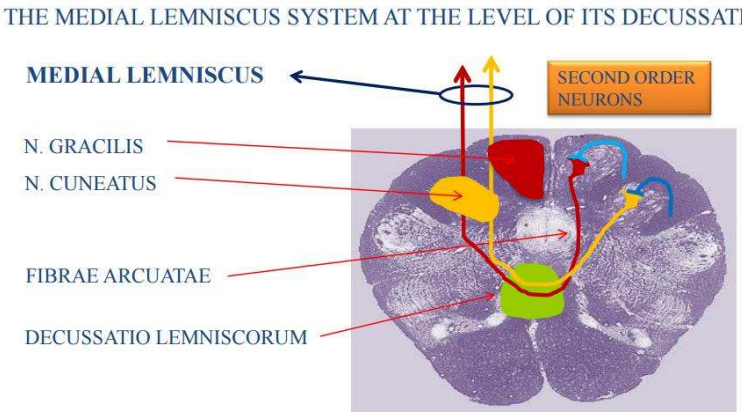
Fasciculus gracilis Thick myelinated fibers from S, L, T6-12 segments.
origin: spinal ganglia
termination: nucleus gracilis in medulla
function: sensory: light touch, vibration, 2-point discrimination, position sense

Fasciculus cuneatus Thick myelinated fibers from T1-6 and all C segments.
origin: spinal ganglia
termination: nucleus cuneatus in medulla
function: sensory: light touch, vibration, 2-point discrimination, position sense

} ***origin*** of the medial lemniscus system

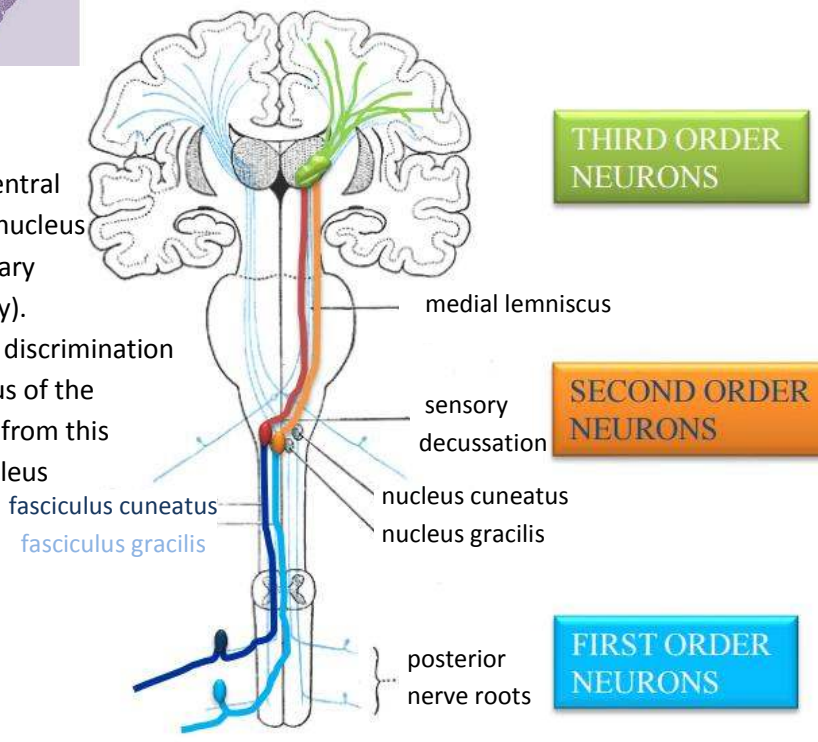
b) Decussation – second order neurons

The axons of the first order neurons terminate on second order neurons residing in nucleus gracilis and nucleus cuneatus. The ascending, crossed tract originating from them is the medial lemniscus, projecting to the thalamus.



c) Termination – third order neurons

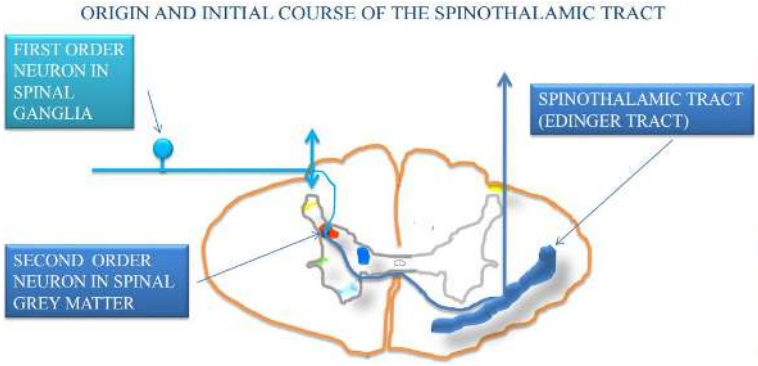
The ascending medial lemniscus terminates in the ventral posterolateral nucleus of the thalamus. Cells of this nucleus serve as third order neurons and project to the primary somatosensory cortex in the parietal lobe (fali lebeny).
From the head region, light touch, vibration, 2-point discrimination senses are processed by the principle sensory nucleus of the trigeminal nerve located in the pons. The projection from this nucleus terminates in the ventral posteromedial nucleus of the thalamus.

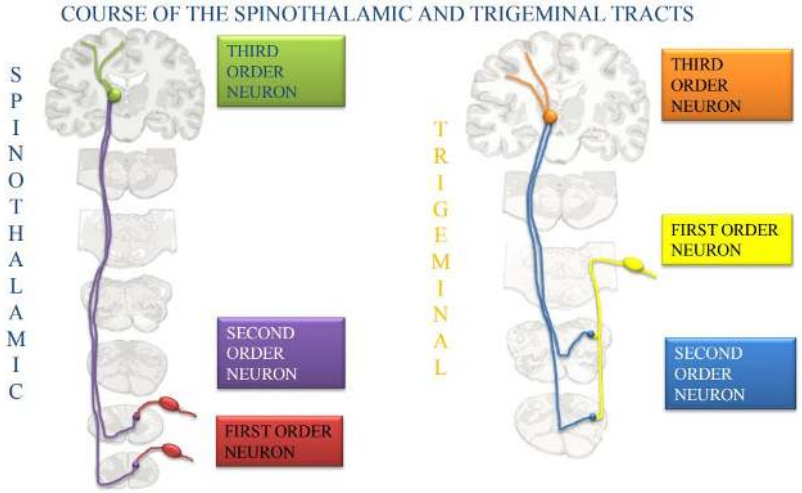


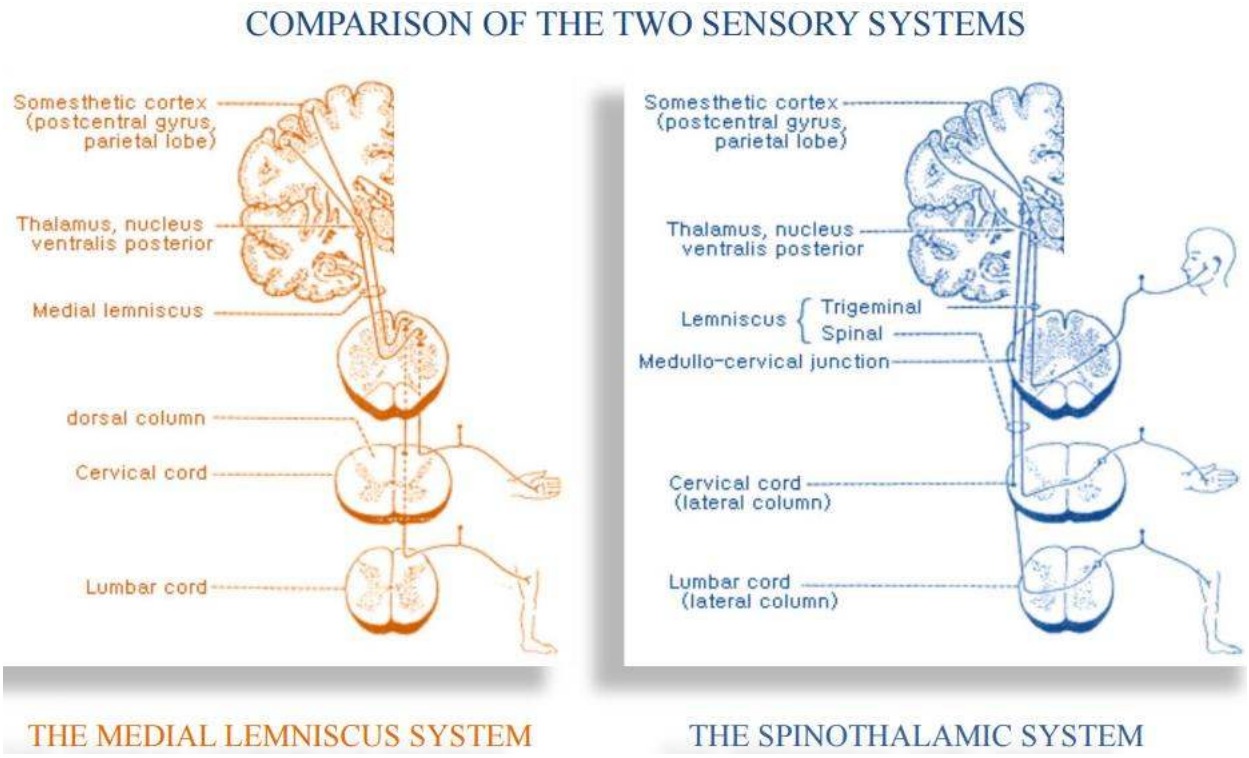
2. The spinothalamic tract

a) Origin

Spinothalamic tract *origin*: contralateral grey matter, laminae I, IV and V
termination: thalamus
function: sensory – noxious pain and thermal stimuli, crude touch





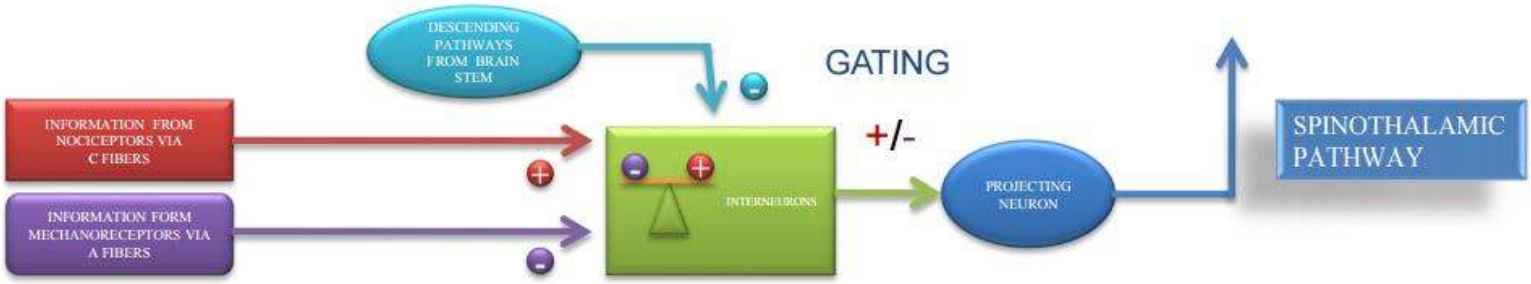


SOMATIC SENSATIONS TRANSMITTED BY THE TWO SENSORY SYSTEMS

MEDIAL LEMNISCUS	SPINOTHALAMIC
TOUCH SENSATIONS WITH HIGH DEGREE OF LOCALIZATION OF THE STIMULUS	PAIN
TOUCH SENSATIONS REQUIRING TRANSMISSION OF FINE GRADIENTS OF INTENSITY	CRUDE TOUCH AND PRESSURE SENSATIONS
SENSATIONS THAT SIGNAL MOVEMENT OCCURES AGAINST THE SKIN	THERMAL SENSATIONS (COLD, WARM)
PHASIC SENSATION (VIBRATION)	SEXUAL SENSATIONS
POSITION SENSATIONS	TICKLE SENSATION
PRESSURE SENSATIONS, FINE DEGREES OF JUDGMENT OF PRESSURE INTENSITY	ITCH SENSATION

Pain gate theory

The projecting neurons carrying tissue damage/pain-related information to higher processing sensory centers are controlled locally in the grey matter. By incoming information of non-noxious stimuli, these arrive from the segmental level via thick, myelinated fibers of mechanoreceptors and also tracts descending from the brain stem. Opening of the pain gate and pain threshold level seem to depend on the actual balance of information supplied by these, multiple systems.



Motor systems

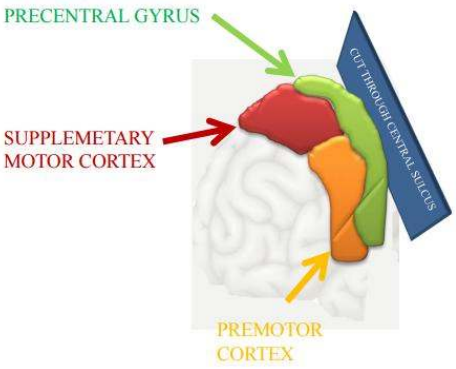
Extrafusal striated muscle fibers and alpha motoneurons that innervate them form the *motor unit*. The somato-motoneurons are distributed in the brain stem and the spinal cord. Collectively, they are called as **lower motoneurons**.

Lower motoneurons are controlled by **upper motoneurons**. The term refers to descending pathways (corticospinal, rubrospinal, tectospinal, vestibulospinal, reticulospinal tracts) that regulate the lower motoneurons either by a direct or an interneuron-mediated manner.

The main motor systems include the motor cortex, the cerebellar machinery and the basal ganglia. The latter two systems are channeled to the frontal motor cortex via the ventral lateral nucleus of the thalamus.

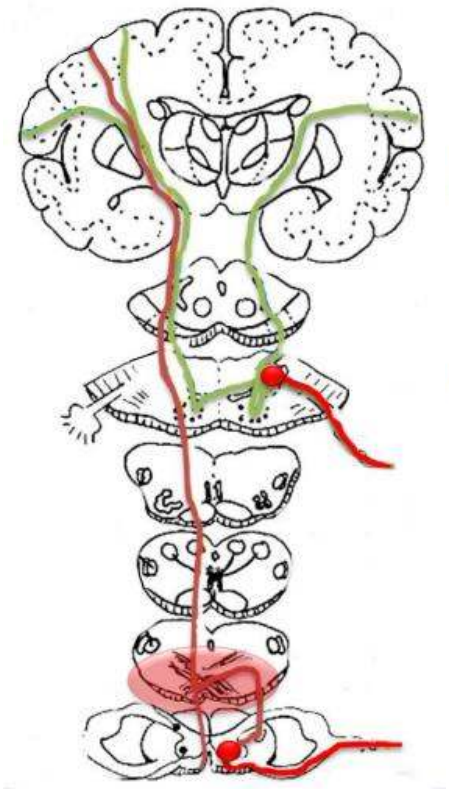
The main cortical motor system uses the ***corticobulbar*** and ***corticospinal tracts*** for execution of voluntary movements. Lesion (károsodás) of the upper motor neuron pathways results in spastic paralysis (görcsös bénulás), exaggerated (túlzott) stretch reflex and some abnormal reflexes. Cerebellar disorders change the rate, direction, range and force of movements. Lesions of the basal ganglia are manifested in dyskinesia. (A törzsdúcok károsodása mozgási zavarban mutatkozik meg.)

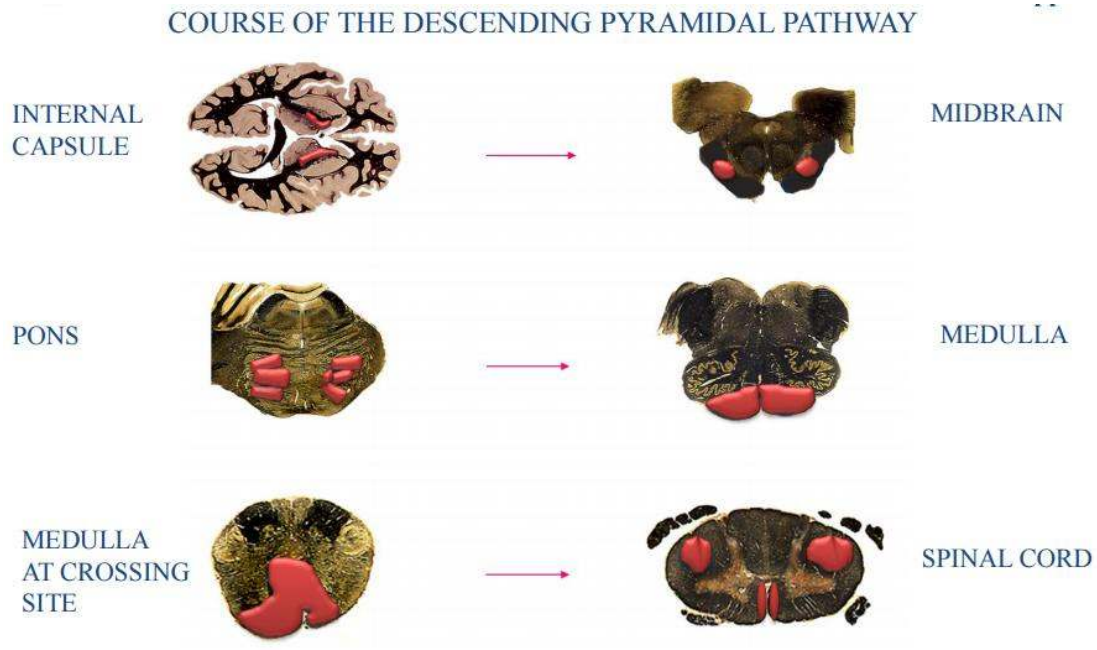
Motor cortex The precentral gyrus contains it. It contains the primary motor center, the supplementary motor cortex, the prefrontal motor cortex and certain parietal lobe regions.



Corticobulbar tract The descending corticobulbar motor fibers supply motoneurons of the brainstem.

Corticospinal tract The corticospinal projection that splits at the level of the medulla feeds the lower motoneurons of the spinal cord via the lateral and anterior corticospinal tracts. Note the bilateral innervation of the trigeminal motor nucleus in the pons. The crossing of the majority of corticospinal axons in the medulla is highlighted by pink shadow.





CORTICOSPINAL PROJECTION WITHIN THE INTERNAL CAPSULE

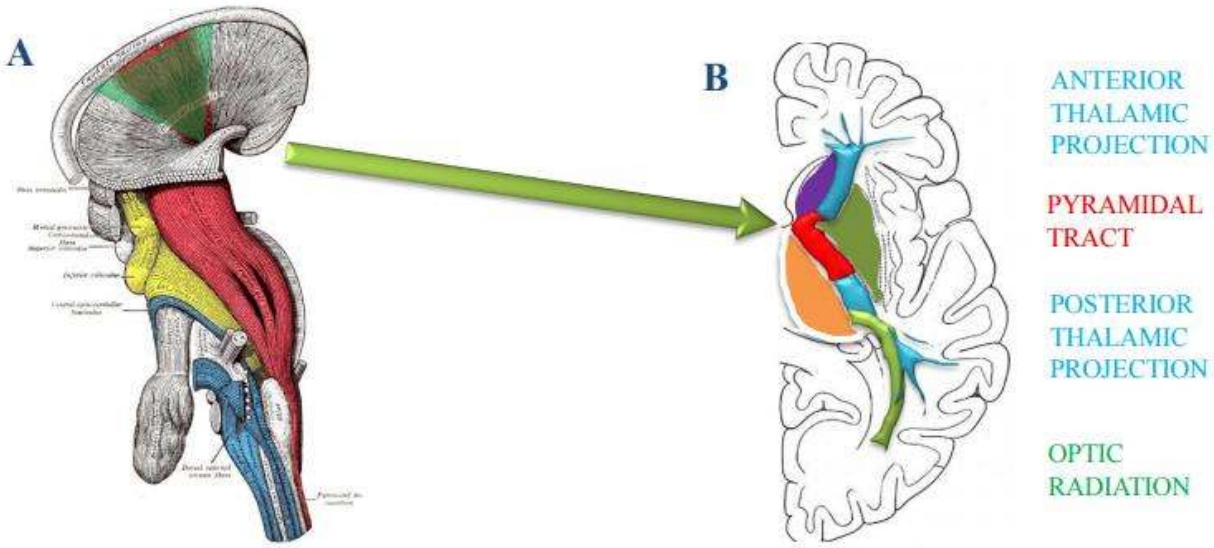
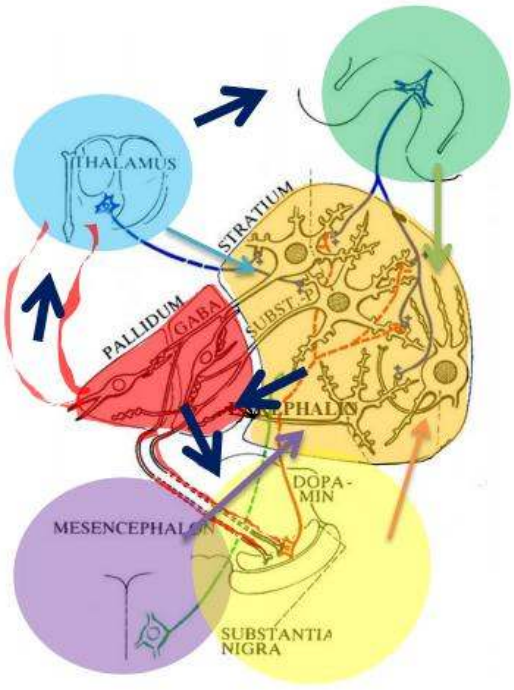


FIGURE **A** DEPICTS THE DOWNSTREAM COURSE OF CORTICOSPINAL FIBERS. NOTE THE CONVERGENCE (HIGHLIGHTED IN GREEN) TOWARD THE INTERNAL CAPSULE. FIGURE **B** ILLUSTRATES THE PYRAMIDAL TRACT IN THE GENU OF THE CAPSULE WEDGED BETWEEN THE ANTERIOR AND POSTERIOR THALAMIC PROJECTIONS. THE OPTIC RADIATION IS SHOWN IN GREEN

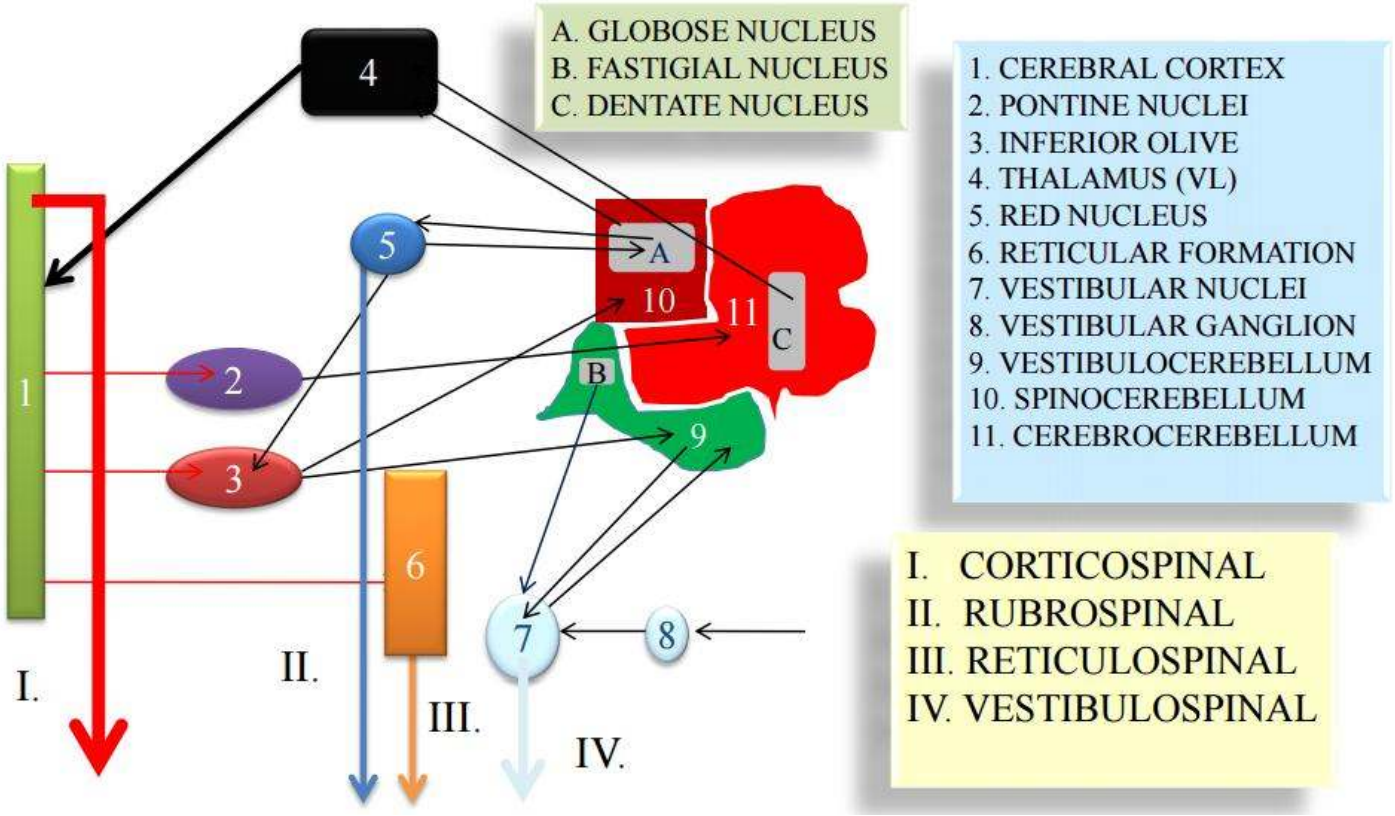
NEURONAL LINKS AND LOCAL CIRCUITS OF THE STRIATUM



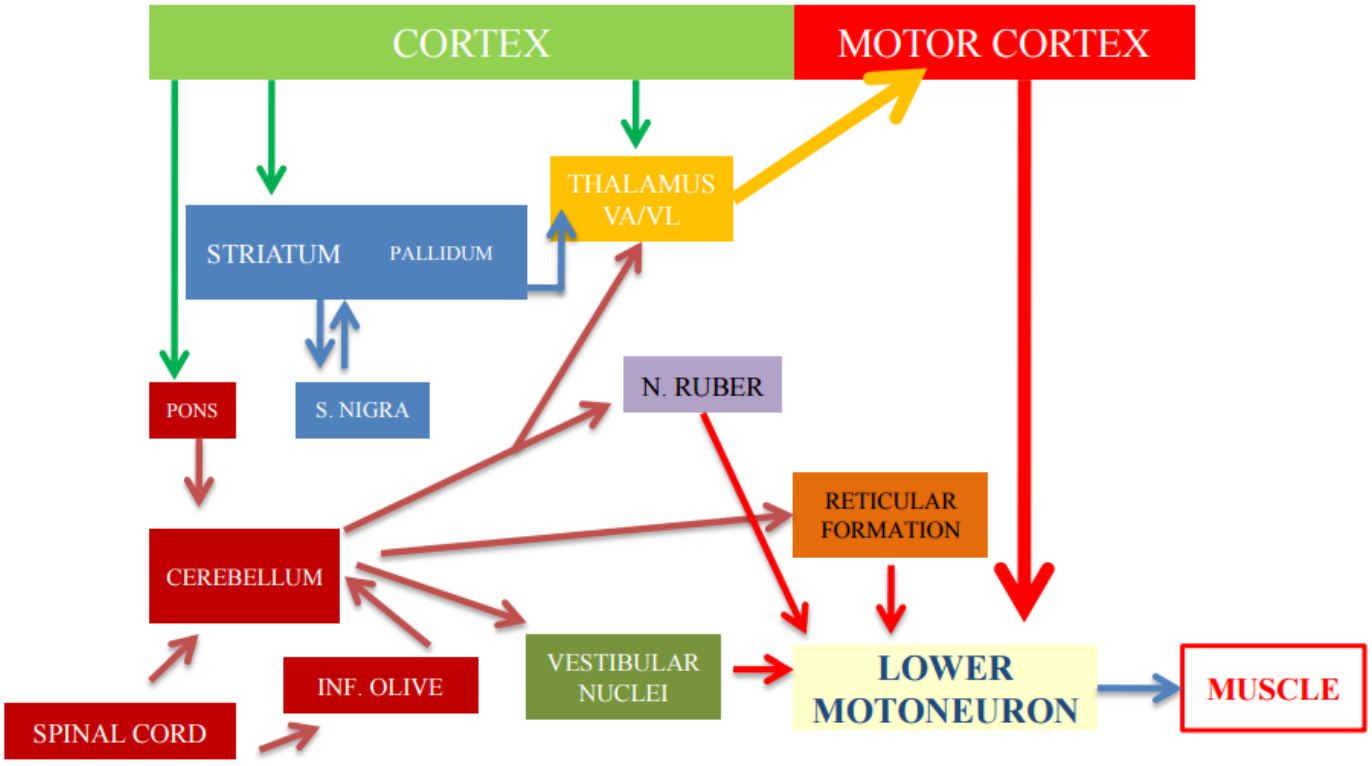
THE PUTAMEN PART OF THE CAUDATE NUCLEUS RECEIVES INFORMATION FROM THE THALAMUS, CEREBRAL CORTEX, MESENCEPHALON AND SUBSTANTIA NIGRA. GLUTAMATE INPUTS FROM THE THALAMUS AND CORTEX ARE EXCITATORY, THE DOPAMINE INNERVATION FROM THE SUBS-TANTIA NIGRA IS SUPPOSED TO BE INHIBITORY. THE INPUTS ARE RECEIVED BY SPINY ENKE-PHALIN- AND SUBSTANCE P-ERGIC NEURONS. THEY TRANSMIT THE PROCESSED INFORMATION TO THE GLOBUS PALLIDUS (PALLIDUM) THAT IS THE MAIN EFFERENT STRUCTURE OF THE SYSTEM. IT SENDS PROJECTIONS TO THE SUBSTANTIA NIGRA AND DIFFERENT NUCLEI OF THE THALAMUS. THE THALAMUS FEEDS THE INFORMATION BACK TO THE CORTEX

The information processed in the striatum is transmitted to the cerebral cortex. The cortex incorporates (egyesíti) the striatal message and conveys (átad) the outgoing motor information via the corticospinal tract.

ROLE OF CEREBELLUM IN CONTROL OF MOVEMENT



INTEGRATION OF THE DIFFERENT MOTOR SYSTEMS



Hippocampal formation

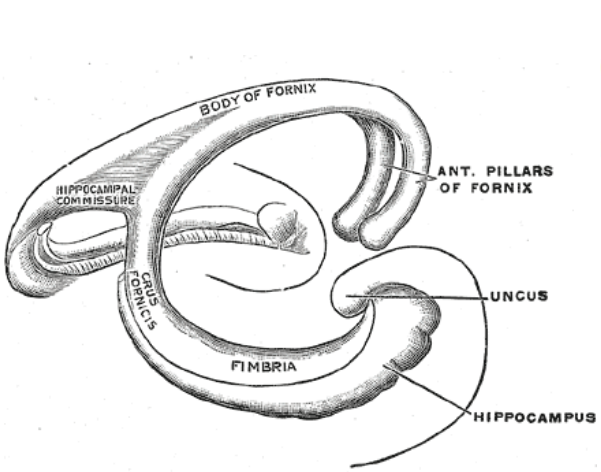
(Hippokampális rendszer)

Hippocampal formation

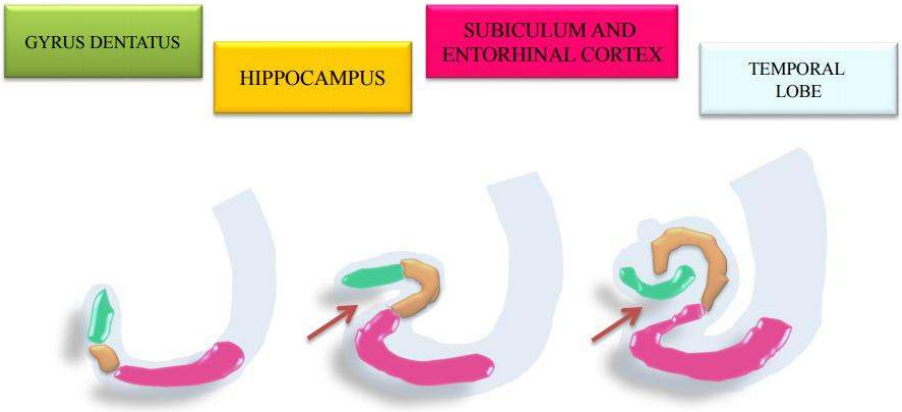
Part of the limbic system. It is composed of the *dentate gyrus* (fogazott tekervény) and the *hippocampus* (cornu ammonis). The complex structure belongs to the allocortex.
Afferents arrive via the *perforant and alvear paths*, ***efferent*** fiber projections leave the temporal lobe via the *fornix system*. It gives rise to both associative and commissural efferents. The hippocampus via the limbic connections is linked with multiple brain networks.
Information conveyed by the perforant path is processed in a trisynaptic intrinsic (belső) circuit within the hippocampal formation.

Fornix

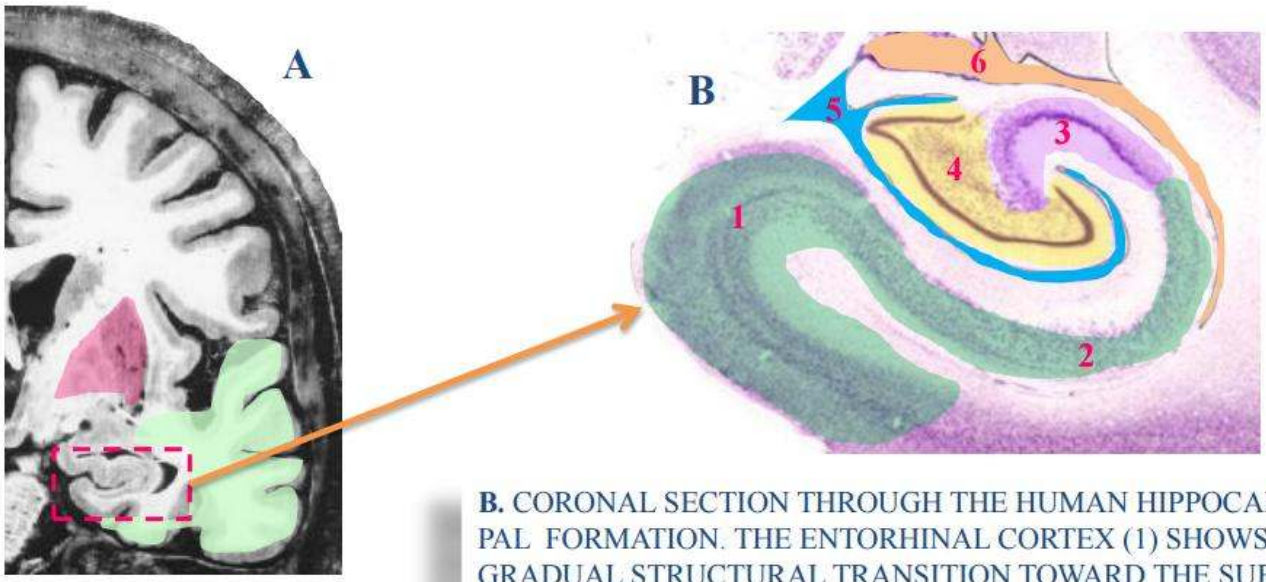
A C-shaped bundle of nerve fibers in the brain that carries signals from the hippocampus to the mammillary bodies and then to the anterior nuclei of thalamus. It is part of the limbic system.



DEVELOPMENT OF THE HIPPOCAMPAL FORMATION



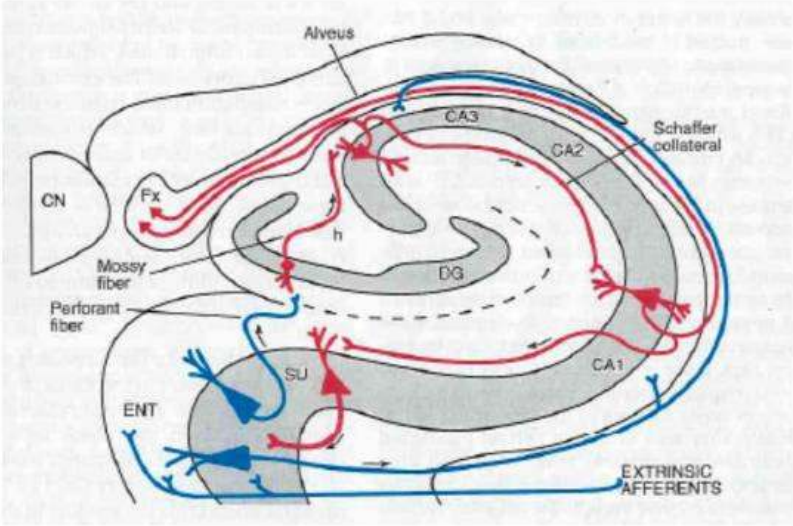
ORGANIZATION OF THE HIPPOCAMPAL FORMATION *IN SITU*



A. CORONAL RADIOLOGICAL PICTURE DEPICTS THE BRAIN *IN SITU*. IN THE TEMPORAL LOBE (GREEN HIGHLIGHT), THE HIPPOCAMPAL FORMATION APPEARS (ENFRAMED). LENTIFORM NUCLEUS IS IN PINK HIGHLIGHT

B. CORONAL SECTION THROUGH THE HUMAN HIPPOCAMPAL FORMATION. THE ENTORHINAL CORTEX (1) SHOWS A GRADUAL STRUCTURAL TRANSITION TOWARD THE SUBICULUM (2). THE HIPPOCAMPUS (3) WITH ITS 3 LAYERS IS APPARENT. NOTE AS THE HIPPOCAMPUS INVADES THE DENTATE GYRUS (4) THROUGH ITS HILUS. THE IMPORTANT HIPPOCAMPAL FISSURE (5) IS HIGHLIGHTED IN BLUE. A NEIGHBORING LANDMARK IS THE CHOROID FISSURE (6)

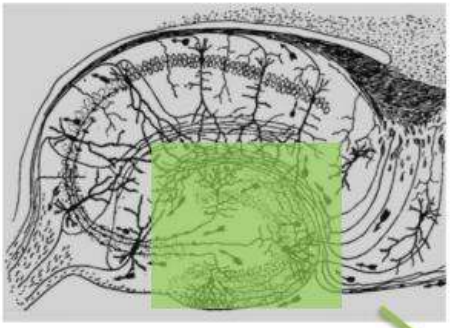
AFFERENT AND EFFERENT CONNECTIONS OF THE HIPPOCAMPUS

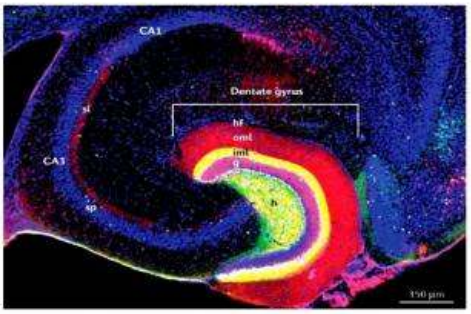


MAIN AFFERENT INPUTS ARRIVE FROM ENTORHINAL CORTEX VIA THE PERFORANT AND ALVEAR PATHS. EFFERENTS ARE SENT TO THE SOURCES OF AFFERENT INPUTS. THE FORNIX IS THE MAIN PROJECTING EFFERENT SYSTEM TO THE SEPTUM, SUBSTANTIA INNOMINATA, ANTERIOR HYPOTHALAMUS AND THE MAMMILLARY BODY

Dentate gyrus It involves the *molecular layer*, the *granule cell layer* and the *hilus* (bemélyedés, nyílás). In its subgranular zone adult neurogenesis occurs.

HISTOLOGICAL AND CHEMICAL DISSECTION OF THE DENTATE GYRUS

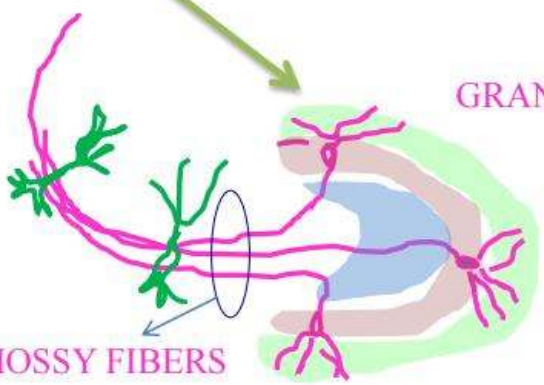




Nature Reviews Neuroscience 7, 259-268, 2006

CA3 PYRAMIDAL CELLS

GRANULE CELLS

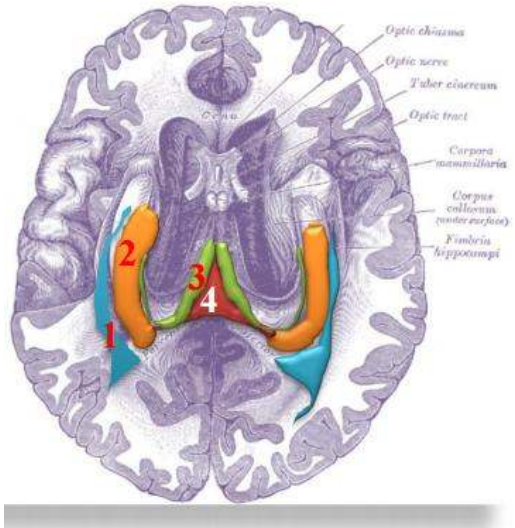


MOSSY FIBERS

MOLECULAR LAYER
GRANULE CELL LAYER
HILUS

Hippocampus Divided into 3 sectors: CA1 (Sommer's sector), CA2 and CA3. There are 3 architectural layers in the hippocampus: the *molecular*, the *pyramidal* and the *polymorphic* (oriens) *layers*. It has a pivotal role in long term memory and spatial navigation. It is vulnerable to hypoxia, excitotoxins and amyloid.

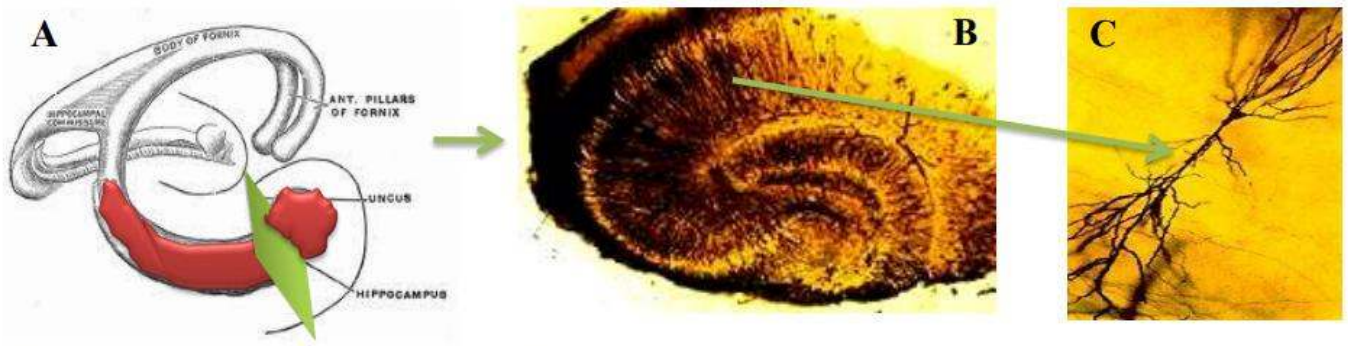
MACROSCOPIC PROPERTIES OF THE HIPPOCAMPUS

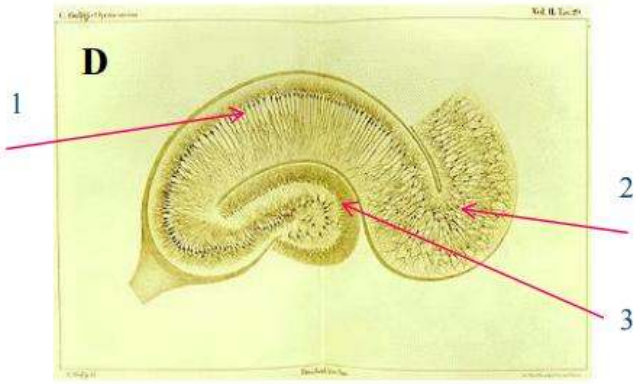


1. LATERAL VENTRICLE
2. HIPPOCAMPUS
3. FORNIX
4. COMMISSURA FORNICIS

FOR A FIRST IMPRESSION, THE SUPERIOR VIEW OF A HORIZONTALLY SLICED BRAIN IS USEFUL. THE HIPPOCAMPUS IS A C-SHAPED, PAIRED STRUCTURE LOCATED IN THE TEMPORAL LOBE. ANTERIOR TO IT IS THE AMYGDALA, IN DORSAL DIRECTION THE LENTIFORM NUCLEUS IS A CLOSE NEIGHBOR. THE STRUCTURE PROTRUDES INTO THE INFERIOR HORN OF THE LATERAL VENTRICLE. ITS EFFERENT AND AFFERENT PATHS FORM THE FORNIX. IT BEGINS AS A THIN CRUS, CONTINUES AS CORPUS AND TERMINATES AS COLUMN SPLITTING INTO PRE- AND POST-COMMIS-SURAL COMPONENTS THAT TERMINATE IN THE SEPTUM AND HYPOTHALAMUS. FIBERS INTERCONNECTING THE TWO HIPPOCAM-PAL STRUCTURES FORM DAVE'S LYRE

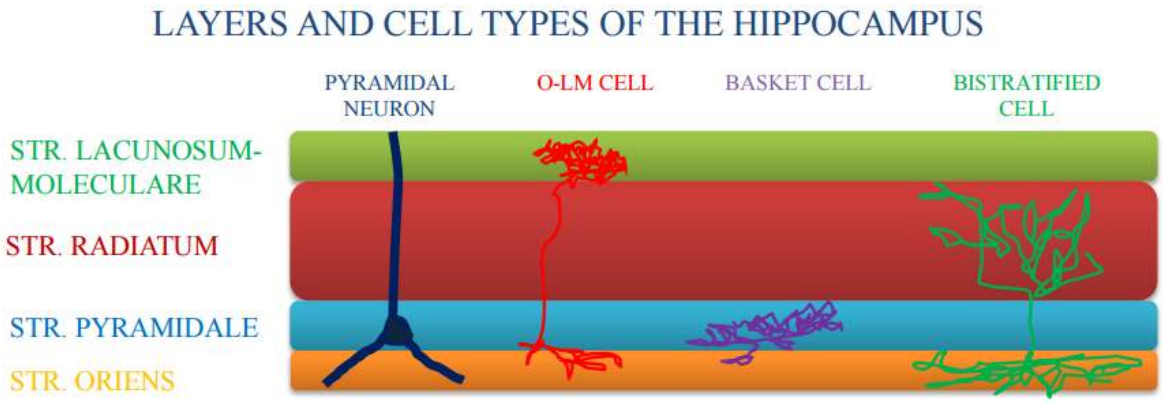
HIPPOCAMPUS REVEALED BY GOLGI IMPREGNATION





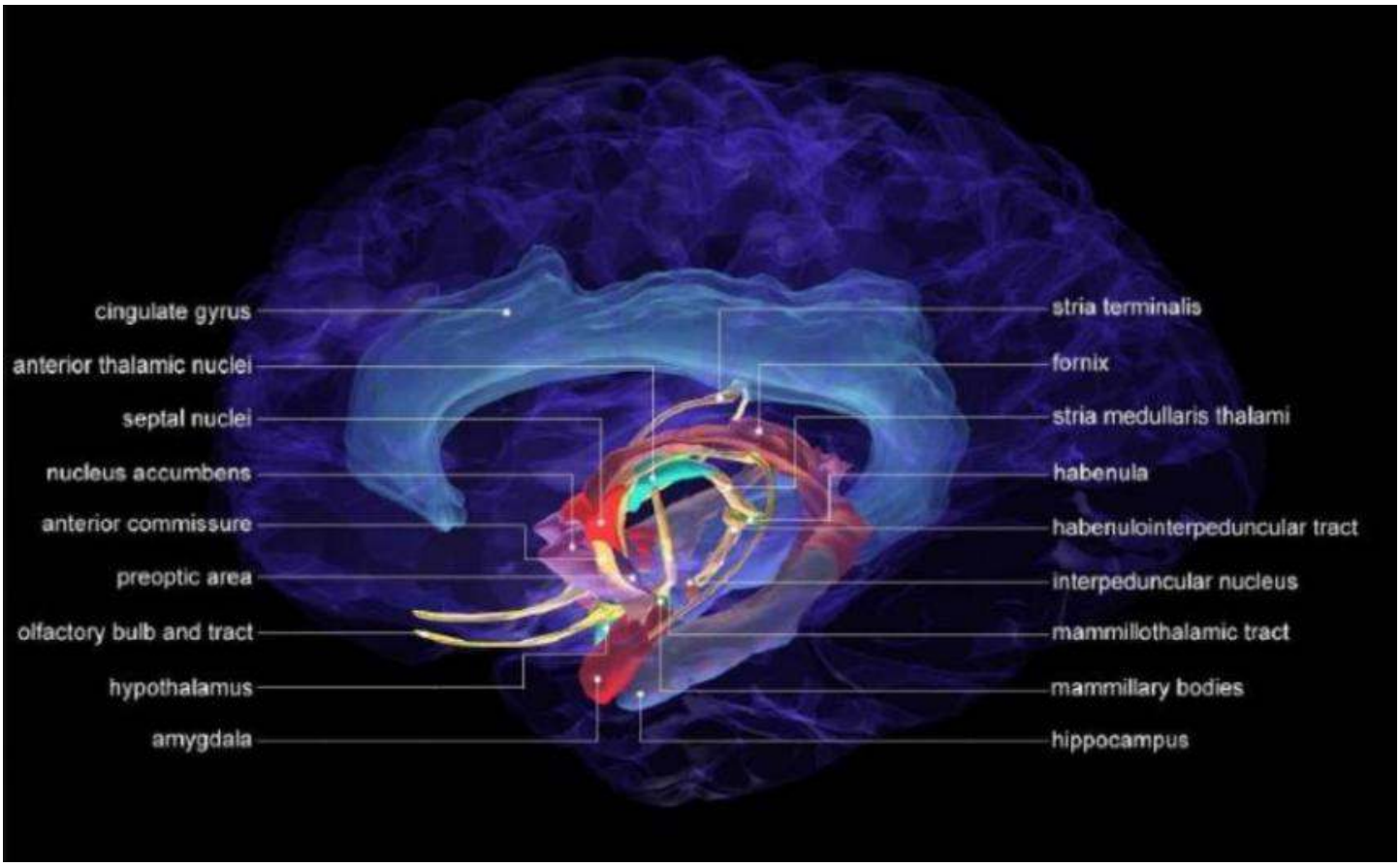
A CORONAL SLICE (**B**) CUT FROM THE HIPPO-CAMPUS (**A**) WAS IMPREGNATED BY THE GOLGI TECHNIQUE. IT VISUALIZES THE CELLULAR CONSTITUENTS INCLUDING THE PYRAMIDAL NEURONS (**C**). THE DRAWING (**D**) OF C. GOLGI MADE ABOUT HIS PREPARATION REVEALS THE PYRAMIDAL LAYER OF THE HIPPOCAMPUS (1), THE ENTORHINAL CORTEX (2) AND THE DENTATE GYRUS (3)

Principal, pyramidal neurons and inhibitory interneurons, such as O-LM cells, basket cells and bistratified cells occupy the main layers of the hippocampus.



Connection between the hippocampus and the limbic system

The main limbic structures are highly integrated with each other. A prominent formation is the circuit (ring) of ***papez***. It involves the connections and projections of the hippocampal formation with emphasis on the link with the mammillary body. This nucleus projects via the thalamus to the cingulate cortex that is known to feed back to entorhinal cortex. A descending unit is called the mamillotegmental fasciculus oriented mainly to the raphe nuclei and the reticular formation.

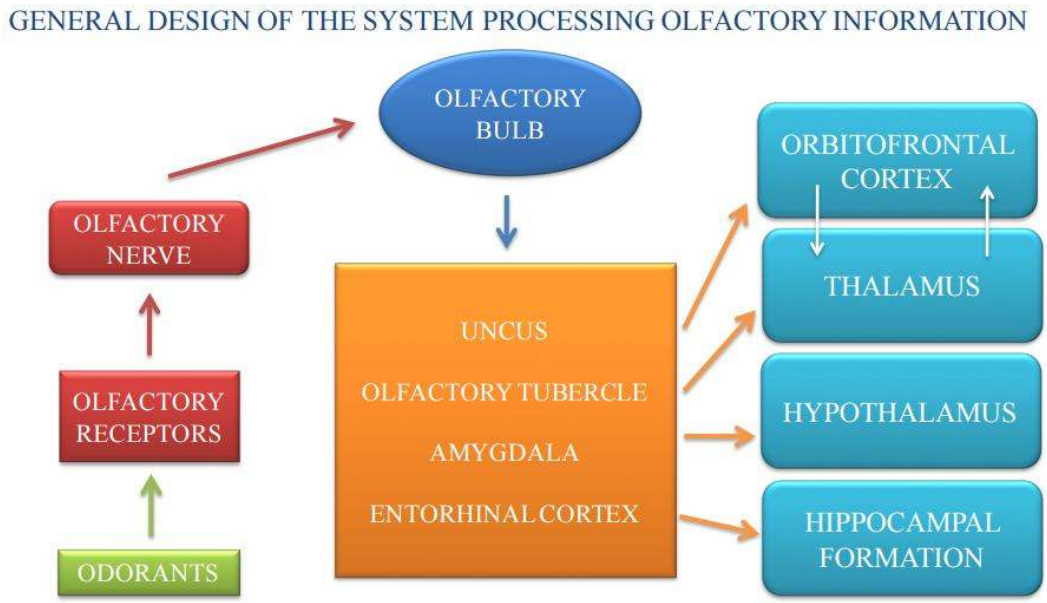


Spatial memory, learning, emotions, behavior; depression, epilepsy, schizophrenia, amnesia, Alzheimer disease, etc.

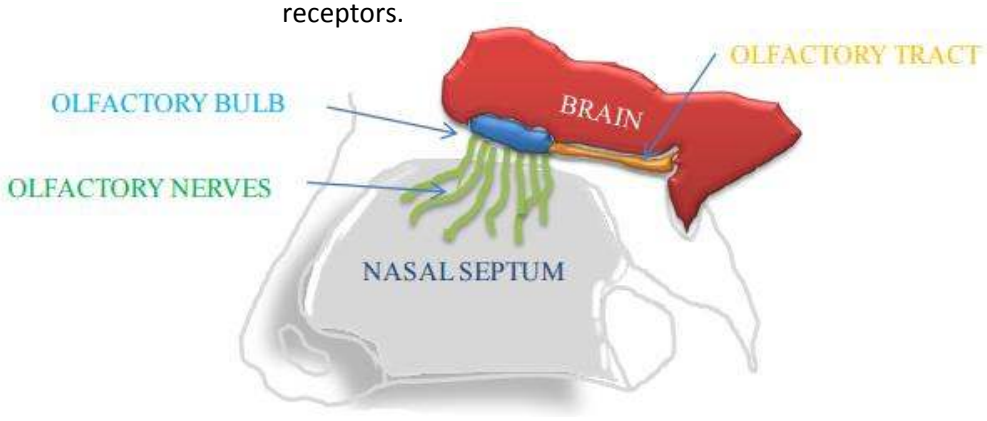
Olfactory system

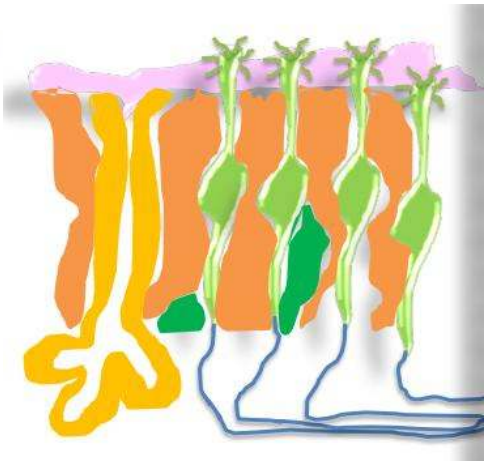
Odorants Chemical substances of the environment that are sensed by the olfactory system. They provide information about members of the biological community and potential hazards threatening the individuals. Species specific odorants, called **pheromones**, are linked with reproduction.

Olfactory system Odorants triggers specific *G-protein* coupled receptors in the olfactory epithelium cells. The information of cells is conveyed by the *olfactory nerve* (I.) to the *olfactory bulb* for initial processing. The olfactory bulb projects via the *olfactory tract* to higher processing centers like the *pyriform cortex* and the *amygdala*. These areas relay the information further to the *orbitofrontal cortex, hypothalamus and the hippocampus*. These connections allow the conscious perception of smell and processing its emotion, motivation and memory-related components.



Olfactory mucosa Primary sensory epithel cells are embedded in the olfactory mucosa situated at the top of the nasal cavity. The cells possess cilia that contain odorant receptors. Water soluble odorant substances are taken through the nasal cavity during a sniff or breathing where they bind to their receptors.

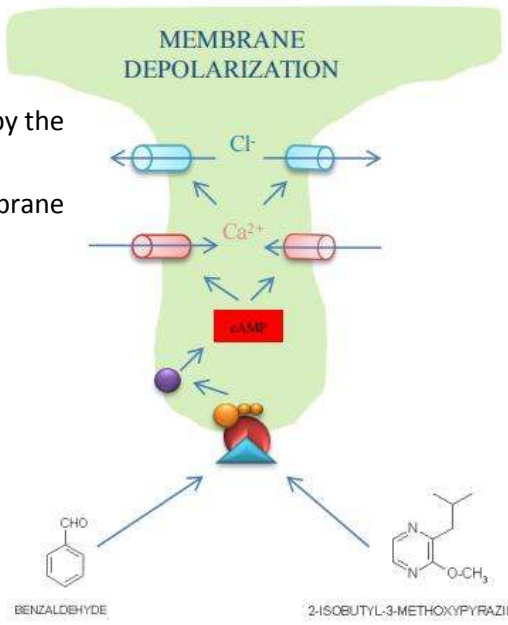


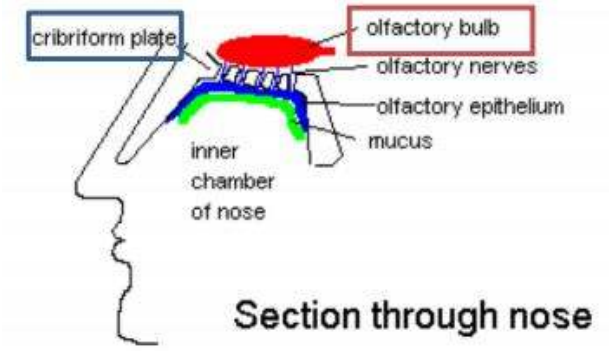


Olfactory epithelium The **sensory epithel cells** are bipolar. Their peripheral poles form olfactory vesicles that are decorated with cilia. The vesicles with the cilia are embedded in a **mucous fluid** produced by special **glands**. The sensory cells are surrounded by **supporting epithel cells**. The olfactory epithelium has a remarkable regenerative capacity. The renewal originates from the **basal cells** that show high mitotic activity. The **axon processes** of the bipolar cells gather into 20 bundles on each side and enter the anterior cerebral fossa of the skull through the cribriform plate. They terminate in the olfactory bulb.

Olfactory receptor

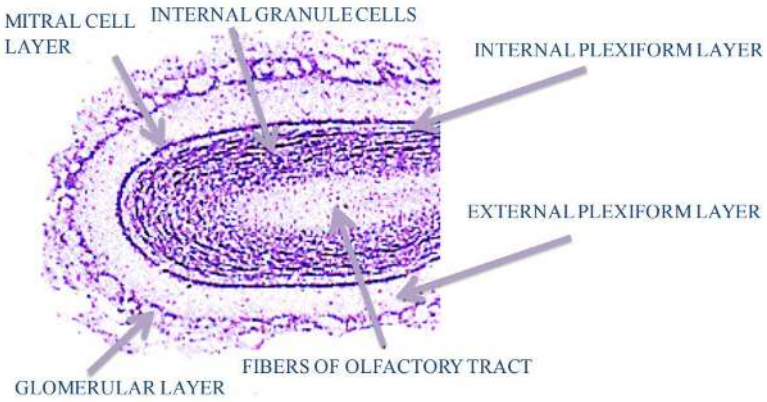
Binding of the **ligand** activates **G-proteins** that in turn activate **adenyl cyclase III** generating **cAMP**. It is followed by the opening of Na/Ca channels. The inflow of calcium opens Ca-gated Cl-channels leading to depolarization of the membrane of cilia.

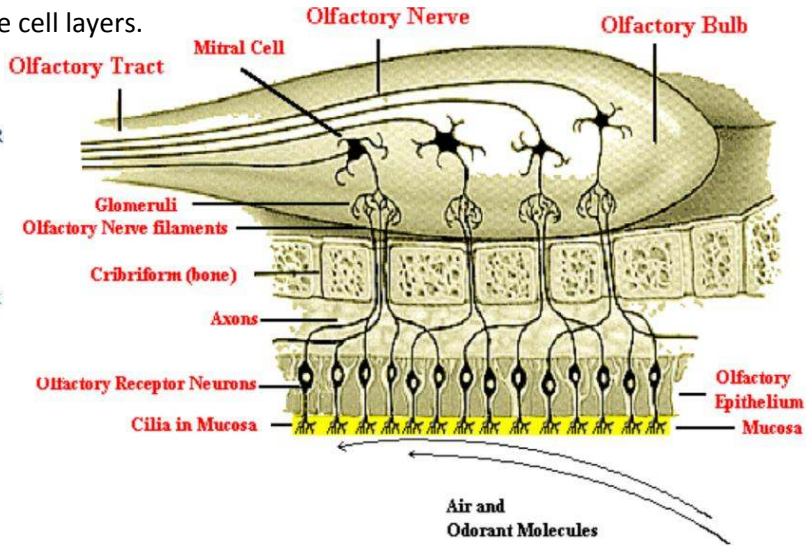




Olfactory bulb

It has 3 main layers (from outside to inside): glomerular layer; external plexiform and mirtal cell layers; internal plexiform and granule cell layers.



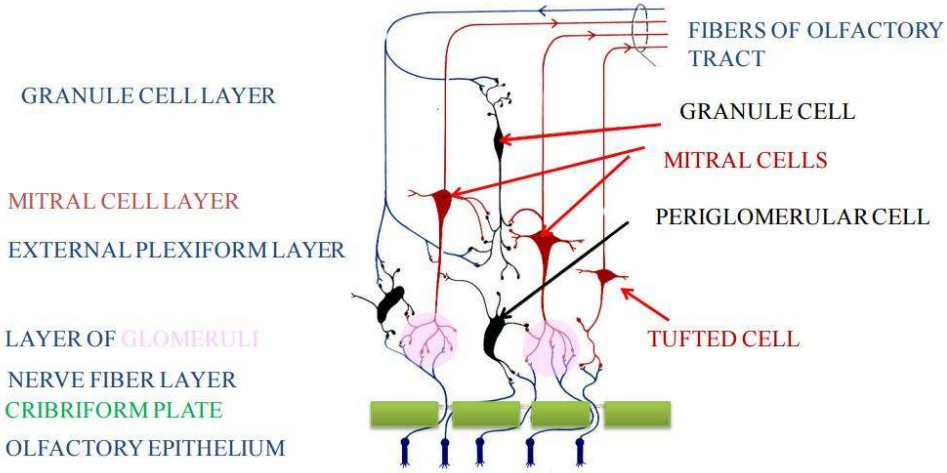


Networking:

It receives 2 kinds of AFFERENT inputs (they are both excitatory): the *olfactory fibers* from olfactory epithelium and *centrifugal fibers* from the olfactory tubercle (multiszenzoros központ). Within the bulb, ***olfactory fibers*** establish connections with dendrites of *mitral, tufted and periglomerular cells*. These structures together form the characteristic compositions of the olfactory bulb, the **glomeruli**.

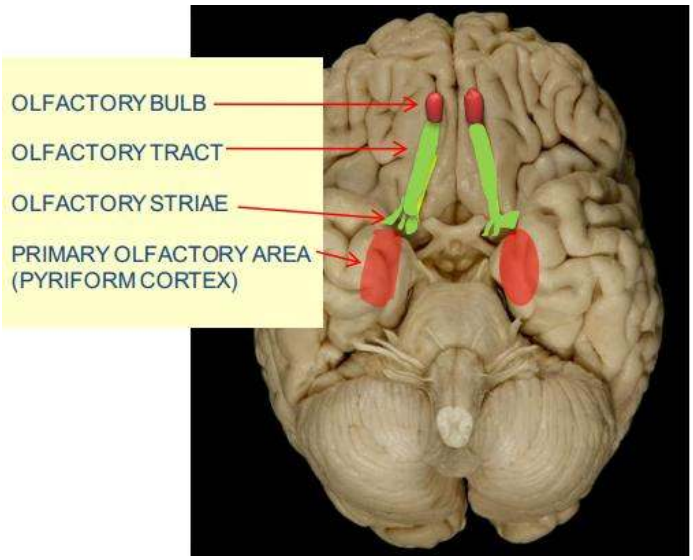
The ***centrifugal fibers*** communicate mainly with the inhibitory *periglomerular and the granule cells*. Granule cells have no definitive axons. Their dendrites pick up the information from the centrifugal fibers and establish connections with mitral cell dendrites. They contribute to lateral inhibition. The inhibitory cells are replaced throughout life.

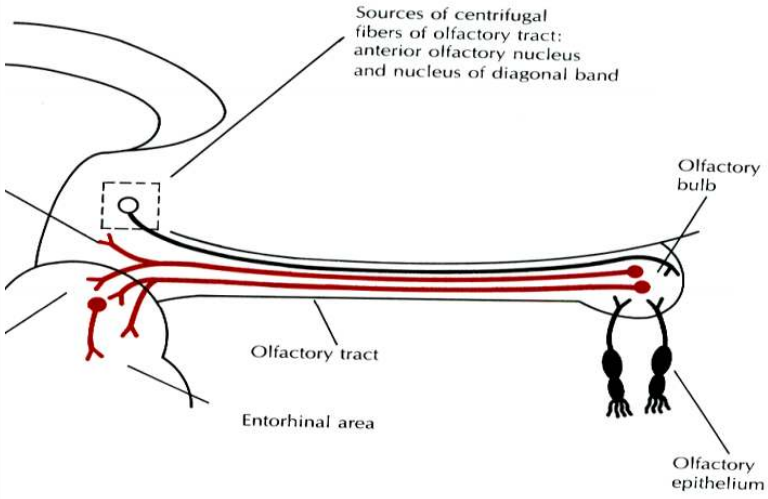
The EFFERENT projections are sent by axons of mitral and tufted cells via the olfactory tract.



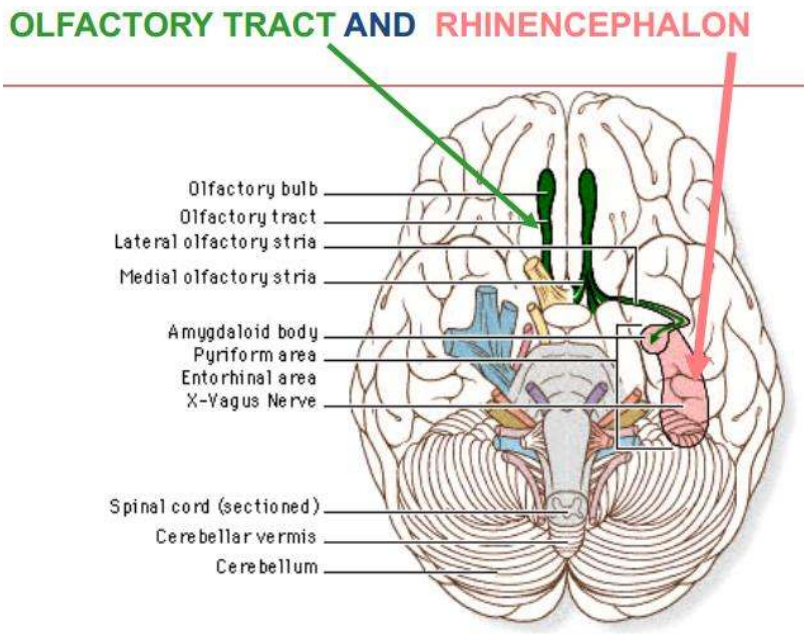
Glomerulus A spherical structure located in the olfactory bulb of the brain where synapses form between the terminals of the olfactory nerve and the dendrites of mitral, periglomerular and tufted cells. All glomeruli are located near the surface of the olfactory bulb. The number of glomeruli in humans decreases with age. The glomerulus is the basic unit in the odor map of the olfactory bulb, because each odor activates a different pattern of glomeruli.

Primary olfactory area From the olfactory bulb the information is taken via the olfactory tract and olfactory striae to higher level processing centers. The lateral stria is interconnected with the ***uncus***, the ***entorhinal cortex*** and the ***limen insulae***. These structures form the primary olfactory area which is pear shaped in rodents (pyriform cortex). The system is linked to the amygdala as well. The conscious perception of odor takes place in the orbitofrontal and cingulate cortex.



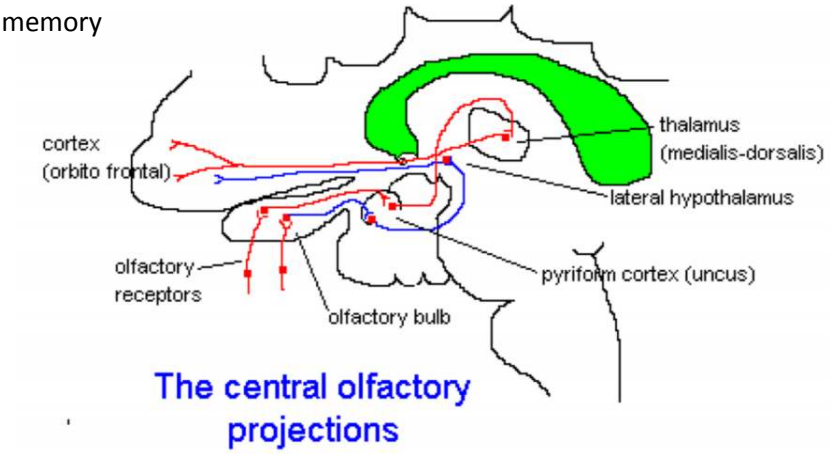


Rhiencephalon A composite substructure of the endbrain that includes the olfactory bulb, the olfactory tract, the olfactory trigone, the medial olfactory stria, the lateral olfactory stria, the olfactory tubercle, the medial olfactory gyrus, the pyriform area, the diagonal band, the subcallosal area and the paraterminal gyrus.



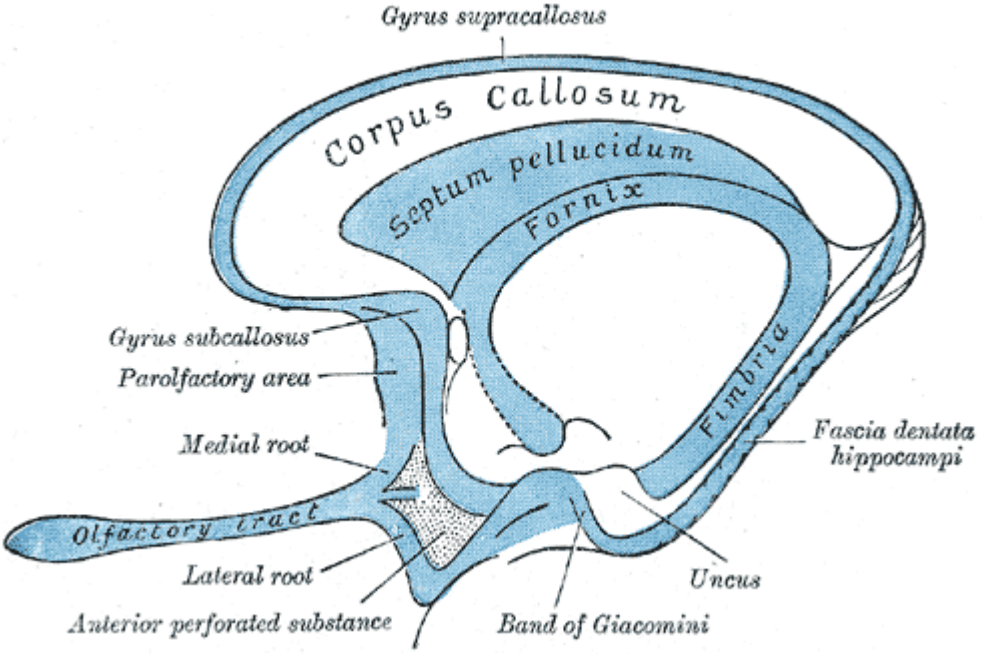
Processing of olfactory information:

- frontal cortex: conscious perception of smell (a szagok tudatos érzékelése)
- hypothalamus, amygdala: motivational and emotional aspects of smell
- hyppocampus: odor memory



Olfactory tract [wiki]

Bundle of axons connecting the mitral and tufted cells of the olfactory bulb to several target regions in the brain, including pyriform cortex, amygdala, and entorhinal cortex. It lies in the olfactory sulcus on the inferior surface of the frontal lobe, and divides posteriorly into two striae, a medial olfactory stria and a lateral olfactory stria. Fibers of the olfactory tract appear to end in the antero-lateral part of the olfactory tubercle, the dorsal and external parts of the anterior olfactory nucleus, the frontal and temporal parts of the prepyriform area, the cortico-medial group of amygdaloid nuclei and the nucleus of the stria terminalis.



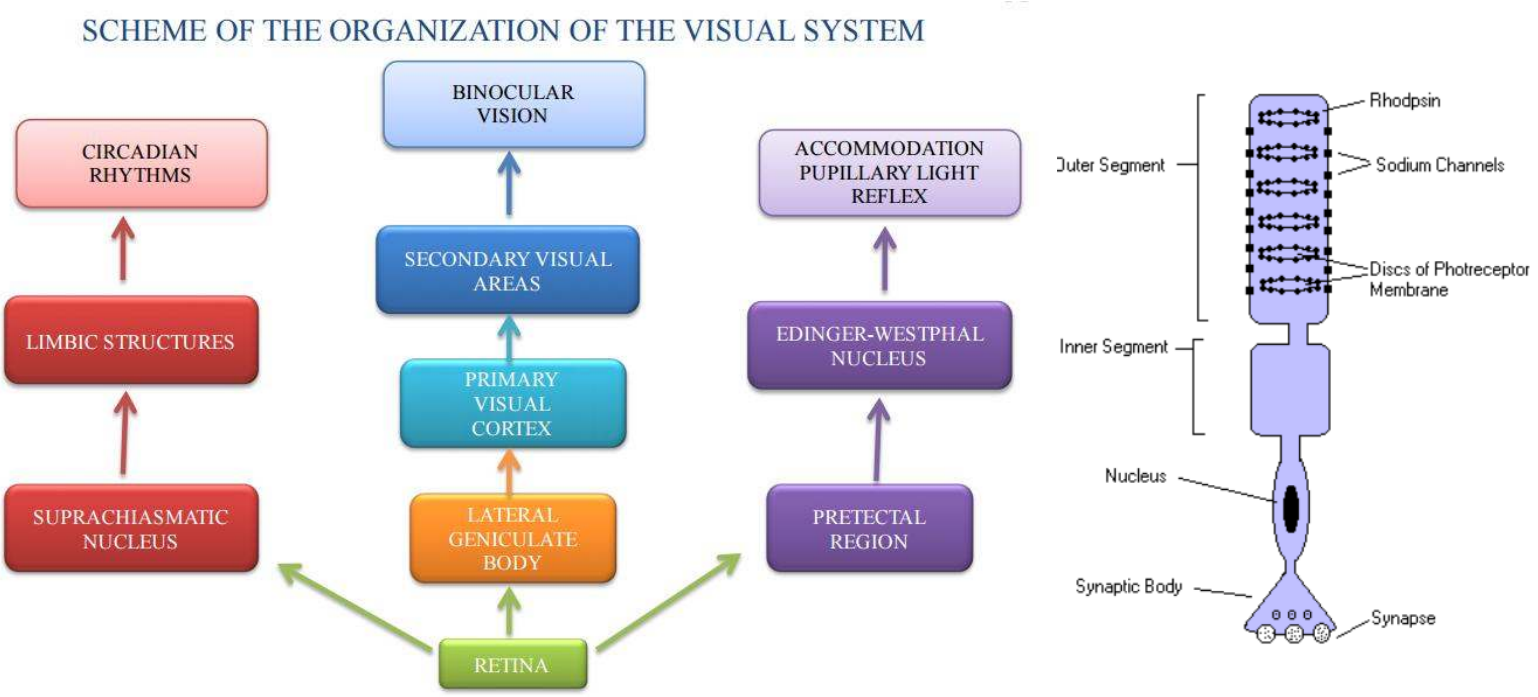
Magyarul a szaglásról:

A szaglás receptorai a felső orrjárat szagló nyálkahártyájában (regio olfactoria) vannak. A szagló nyálkahártyát többrétegű szaglóhám fedi, amely basalis sejtekből, magas, sárgásbarna pigmentet tartalmazó, henger alakú támasztósejtekből és az általuk övezett szagló hámsejtekből áll. A szagló hámsejtek primer érzékhámsejtek „kihelyezett", módosult bipoláris idegsejtek. Egy vastag, szőr alakú, dendritikus nyúlványuk van, amely a támasztósejtek között a felületre tör, és ott kis gömböcskékben, szaglóbunkókban végződik. A gömböcskéből 20-25 db szaglószőr ered, amely a hámot borító rétegbe van ágyazva. A szaglósejtek centrális irányú neuritjai szaglórostokká egyesülnek, amelyek a rostacsont lyukain át a koponyaüregbe, a szaglóhagymába térnek. A szagingert olyan illó anyagok molekulái keltik, amelyek oldódnak a hámot borító, lipoidokban gazdag szerózus nyálkarétegben. A szájüregbe került anyagok (pl. feromonok) szagának érzékelésére alkalmas a Jacobson-féle szerv. Falát vakon végződő, cső alakú nyálkahártya béleli, amely az orr- és a szájüreggel is közlekedik.
Az ingerületi állapotba jutó szaglósejtek akciós potenciáljai a sejtek axonjaiban - amelyek a rostacsont lyukain haladnak át - a szaglóhagymába (bulbus olfactorius) jutnak. Ezek alkotják az I. agyidegpárt (nervus olfactorius). Itt szinaptikus kapcsolat alakul ki a köztes átcsatoló sejtekkel és a koponyaalapi terület ősi szaglómezőjébe, valamint a limbikus rendszerbe sugárzó idegekkel.

Visual system

Visual system

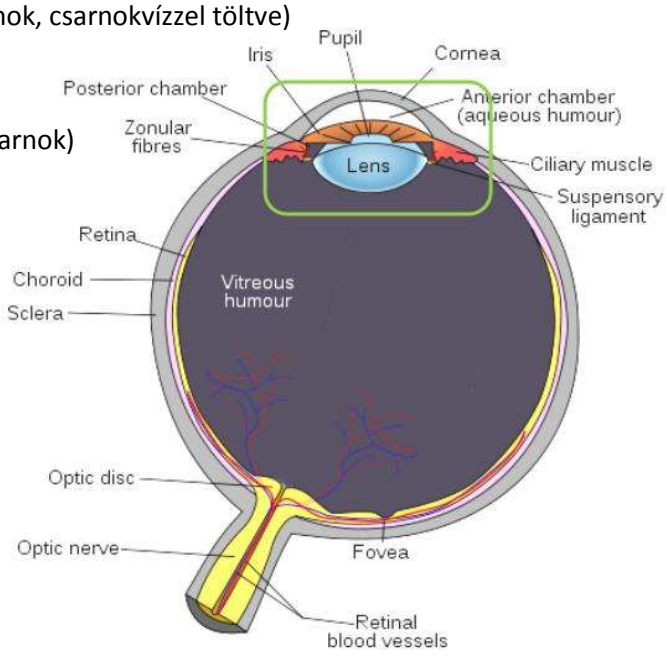
Part of the CNS. It consists of the retina and its projections, the lateral geniculate body, the optic radiation, the primary and secondary cortical processing centers. In association with the system, the oculomotor reflex and accommodation are functionally important mechanisms.
The **main task** of the visual system is the conscious perception of the visual scene. The information about the light/dark periods of the day is directed to the suprachiasmatic nucleus of the hypothalamus that orchestrates the diurnal (circadian) rhythm of several neuronal, endocrine and metabolic functions.
Although the visual field is represented in all key units of the visual system from the retina to the cortical visual areas, the proper binocular vision (shape, size, sharpness, depth, color of objects) requires a delicate cooperation of processing structures performing at different levels in the hierarchy of the neuronal organization. The image and special attributes of the objects seen in the binocular visual field are gradually built up from simplex (retina) to complex (visual cortex) processing levels.



Eyeball

The light ray traverses through the following structures en route to the photoreceptors:

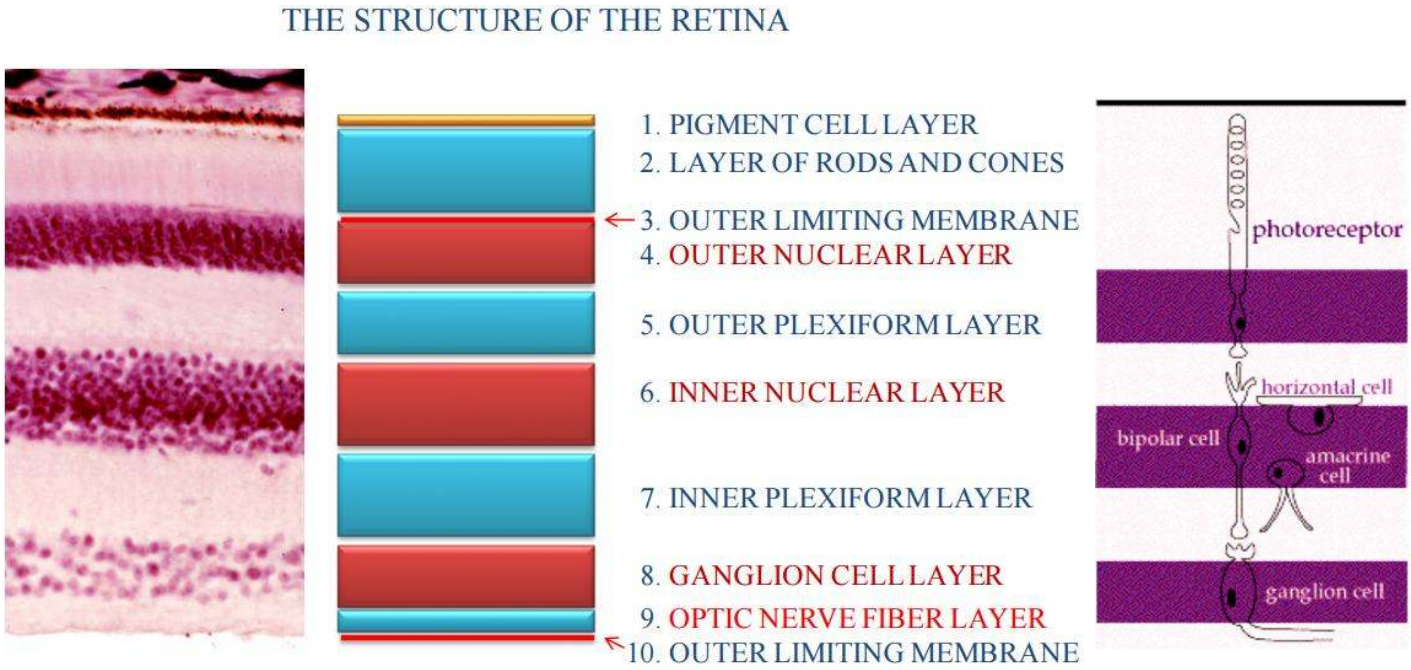
– cornea (szaruhártya)
– anterior chamber (elülső szemcsarnok, csarnokvízzel töltve)
– pupil
– lens (szemlencse)
– posterior chamber (hátulsó szemcsarnok)
– vitreous body (üvegtest)
– retina (ideghártya)



Fovea centralis

Látógödör: a retina bemélyedése a sárgafolt (macula lutea) közepén.

Retina



Photoreceptors

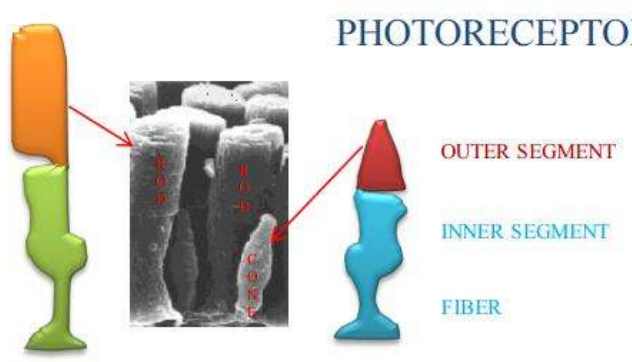
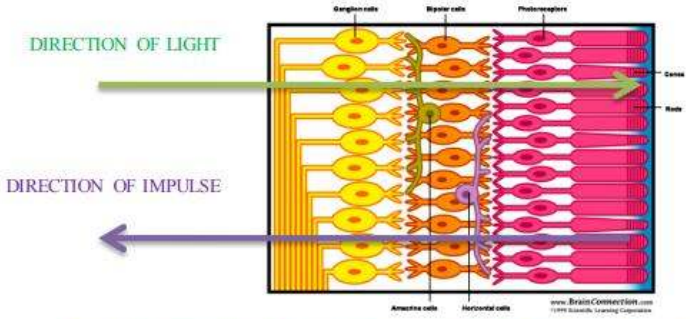
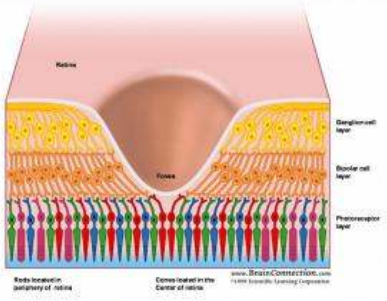


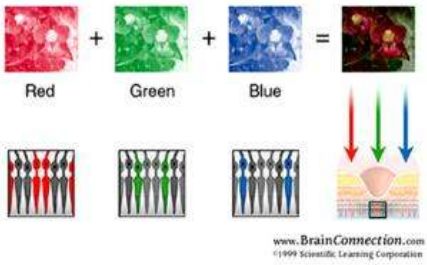
ILLUSTRATION OF RODS AND CONES, THE PHOTORECEPTORS OF THE RETINA



NETWORKING OF PHOTORECEPTOR, BIPOLAR, HORIZONTAL, GANGLION AND AMACRINE CELLS IN THE RETINA. NOTE THE CONVERGENCE



DEPICTION OF THE FOVEA CENTRALIS. NOTE THE EXCLUSIVE PRESENCE OF CONES

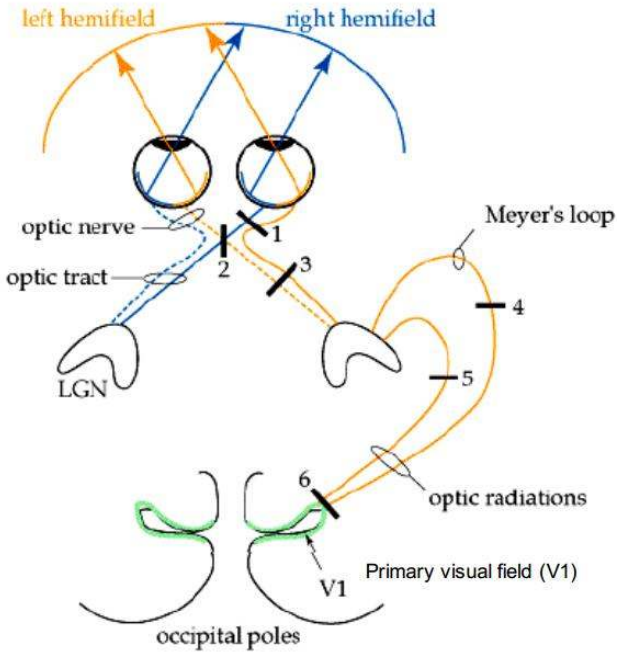


THE TRICOLOR MECHANISM OF COLOR DETECTION. SPECTRUM SENSITIVE CONES

Signal transduction The light ray passes through the inner layers of the retina and reaches the outer segments of photoreceptor cells, the rods and cones. Shining light on photoreceptors leads to hyperpolarization of the receptor cells. In dark, the receptor cells are depolarized resulting in sodium and calcium influx through cyclic guanosine monophosphate (cGMP)-gated channels. This inward current at the outer segment is opposed by an outward current of potassium. The net balance of cations results in a membrane potential of -40 mV.

The absorption of light reduces the cGMP content in the photoreceptor leading to the closure of outer segment cation channels. Accordingly, the efflux of potassium ions becomes dominant, the positive charge decreases and hyperpolarization develops.

After the retina



1. optic nerve
2. optic chiasm
3. optic tract
4. Lateral Geniculate Nucleus
5. optic radiation
6. primary visual cortex in the occipital lobe

Magyarul a szemről:
Két részből álló gyűjtőlencse típusú objektívvel rendelkezik. A külső a szaruhártya, a belső a szemlencse. A szivárványhártya (iris), amely a szem színét is meghatározza, a szembe lépő fény mennyiségét csökkenti. A szivárványhártya nyílása a pupilla, melynek átmérője a fényerősségtől függően változik, a fényrekesz szerepét tölti be. A belépő fénysugarak áthaladnak az üvegtesten (corpus vitreum) és a recehártyára (retina) fókuszálódnak. Ezután a központi idegrendszer közreműködésével alakul ki a kép.
Az **ínhártya (sclera)** a szemgolyó rostos burkának hátsó négyötödét teszi ki. Rajta tapadnak a szemizmok és átfúrja a szemideg. A felszínnel párhuzamosan rendeződött kollagén rostok hálózatából áll, ebből adódik fehér színe (a kötőhártyán át látható része a szemfehérje).
A **szaruhártya (cornea)** a rostos burok elülső, megkülönböztetett része. Mivel teljesen átlátszó, és mögötte optikai közegek (csarnokvíz, mögötte az üvegtest) vannak, maga is – törőközegként – lencsehatással bír.

Az **érhártya** három fő részből áll: a tulajdonképpeni érhártyából (choroidea) és annak elülső származékaiból, a szivárványhártyából (iris) és a sugártestből (corpus ciliare).
A **choroidae** funkcionálisan két fontos rétege van: a külső, prekapilláris arteriolákat és postkapilláris vénákat tartalmazó réteg (lamina vasculosa) és a belső, az emberi szervezet legsűrűbb hajszálérhálózatát alkotó réteg (lamina choriocapillaris). Ez utóbbit az ideghártyától csak egy alaphártya választja el, így ezen keresztül nagyon fontos szerepet játszik a retina tápanyagellátásában és gázcseréjében.
A szivárványhártya (**írisz**) alapját egy finom kötőszövetes állomány képezi, amelyben két ellentétes hatású simaizom, a pupillaszűkítő izom (musculus sphincter iridis (pupillae)) és a pupillatágító izom (musculus dilatator pupillae) található. Ezek hajtják végre a pupilla fényre alkalmazkodásának, illetve egyéb reflexeiből (akkomodációs reflex) következő szűkítő és tágító reakcióit. Kettős (szimpatikus és paraszimpatikus) beidegzését az autonóm idegrendszerből kapja. Szimpatikus túlsúlyra a pupilla kitágul, míg paraszimpatikus túlsúlyra beszűkül.
A sugártest (**corpus ciliare**) a szivárványhártya mögött elhelyezkedő, alapjában simaizomból álló képződmény. Erre van felfüggesztve finom rostokkal a szemlencse. Széli nyúlványai (processus ciliares) érben gazdagok, és folyadékot, a csarnokvizet termelik. A sugártest izmai a szaruhártya–ínhártya határán erednek (természetesen a körkörös rostok kivételével). Abból következően, hogy erre van felfüggesztve a szemlencse, alapvető szerepe van az akkomodációban (a szem optikájának távolsághoz való alkalmazkodásában). Nyugalmi helyzetben (nagy távolságra alkalmazkodás), helyzete lényegében passzív, azaz elernyedt állapotban van, így a szemlencse a szem belső nyomása következtében kifeszül (törőereje csökken). Közelre nézéskor a sugártest izmainak megfeszülése csökkenti a szemlencsére ható feszítő hatást, ami rugalmasságánál fogva összehúzódva domborúbb lesz, törőereje nő, így a látott képet a retinára fókuszálja. Beidegzését szintén az autonóm idegrendszerből kapja.

A szem legbelső burka az ideghártya (**retina**). A retina fényérzékeny receptorokat tartalmazó része a szemgolyó hátsó kétharmadában van meg, ez előtt egy hullámos vonal (ora serrata) mentén fényérzékeny receptorait és rétegezettségét elveszti, és pigmenthám réteggé alakul. Többek között a pigmenthám rétegek teszik a szemet fényképezőgéphez hasonlítható sötétkamra (camera obscura) jellegűvé. Három egymás után kapcsolt neuron láncolatai alkotják. Az első (legkülső) a csap- és pálcikasejtek neuronja, amelyeknek részei a fényérzékelő receptorok. Ezek ingerülete egy bipoláris köztes neuronra tevődik át, amely a jeleket a harmadik neuronra, a nagy idegsejtekre továbbítják. Ez utóbbiak összeszedődő, centrális nyúlványai alkotják a látóideget, melynek rostjai a látóidegkereszteződésen keresztül, majd a látókötegbe folytatódva az oldalsó térdes test neuronjaira kapcsolódik át. A köztes neuronok másként viselkednek a csap- és pálcikasejtek esetében. Előbbieknél az ingerületáttevődés egy-egy arányú (lineáris kapcsolat), míg az utóbbiaknál egy köztes neuron több pálcikasejt ingerületét is összegyűjti (konvergáló kapcsolat). Ez is a magyarázata annak, hogy a csapok az éles látásban, míg a pálcikák a kis fényerőnél történő látásban játszanak meghatározó szerepet. A retinában oldalirányú (asszociációs) kapcsolatokat biztosító és szabályozó működéseket ellátó neuronok, valamint támasztó sejtek is vannak.
A retinában a fény érzékelésére szolgáló speciális **fotoreceptorok**, pálcikák és csapok találhatók. A **pálcikák** az alacsonyabb intenzitású fényre is érzékenyek, az erősebb fényingert igénylő **csapok** a színlátást és az éles látást szolgálják. Az úgynevezett sárgafoltban (macula lutea) levő látógödörben (fovea centralis) csak tömötten egymás mellé rendeződött csapok vannak, ez az éles látás helye. A csap- és pálcikasejtek kültagjaiban ismétlődő sejtmembránkorongok találhatók, amelyek membránjaiban fényérzékeny festékanyagok (rodopszinok) vannak. Amikor a megfelelő hullámhosszú fény éri ezeket a festékanyagokat, molekuláik megváltoznak, és ingerületbe hozzák az adott receptorok egész membránrendszerét.
A **sárgafolt** (**macula lutea**) a színlátás helye a retinán. A látóidegfőtől (vakfolt) oldalra található. Benne helyezkedik el a látógödörnek (fovea centralis) nevezett bemélyedés, amely az éleslátásért felelős.

A **szemlencse** állományában kocsonyásabb kéregállomány (cortex lentis) és tömöttebb mag (nucleus lentis) különböztethető meg. A lencse rugalmas képződmény, amely ellazult állapotban összeugrik, azaz domborúsága növekszik. A lencsemag az életkorral növekszik, ettől rugalmassága csökken, ezzel laposabb állapotban rögzül, törőereje kisebb lesz. A lencse szélén körkörösen elöl és hátul finom függesztő rostok tapadnak, amelyek egymással kereszteződve a sugártest nyúlványai között ellentétes oldalon (azaz hátul és elöl) rögzülnek. Amikor a sugártest izomzata elernyedt állapotban van, a lencsefüggesztő rostokon keresztül a szem belső nyomása a lencsét megfeszíti és laposabbá teszi, így törőereje csökken, azaz távollátásra van beállítódva. A körben elhelyezkedő lencsefüggesztő rostok (zonula ciliaris) között közlekedik egymással az elülső és hátsó szemcsarnok tere.
Alkalmazkodás: a szem nyugalmi állapotban távolra nézésre beállítódott állapotban van. Közelre nézéshez a szemlencse törőerejének fokozására van szükség. Ezt a szem azzal éri el, hogy a sugártest izomzata összehúzódik, ezzel jobban kiemelkedik, és a lencsefüggesztő rostok ellazulnak. A szemlencse természetes rugalmasságánál fogva domborúbbá válik, törőereje fokozódik. Az alkalmazkodás (accomodatio) tehát a sugárizom (musculus ciliaris) aktív működésén és a szemlencse rugalmasságán alapul. Az életkorral az utóbbi csökken, emiatt alakul ki az időskori távollátás (presbiopia).

Az **üvegtest** (**corpus vitreum**) optikailag teljesen átlátszó, sejtes szerkezetet nem mutató kocsonyás anyag. Nagy része víz (90%), amelyben néhány speciális fehérje mellett hialuronsav található. Elöl a hátsó szemcsarnoktól egy határhártya választja el. A retina felé határhártyája nincs. A szem belső nyomásának közvetítésével szerepet játszik a szemgolyó alakjának fenntartásában. A szem sérülése során esetleg elvesztett üvegtestállomány nem pótlódik.

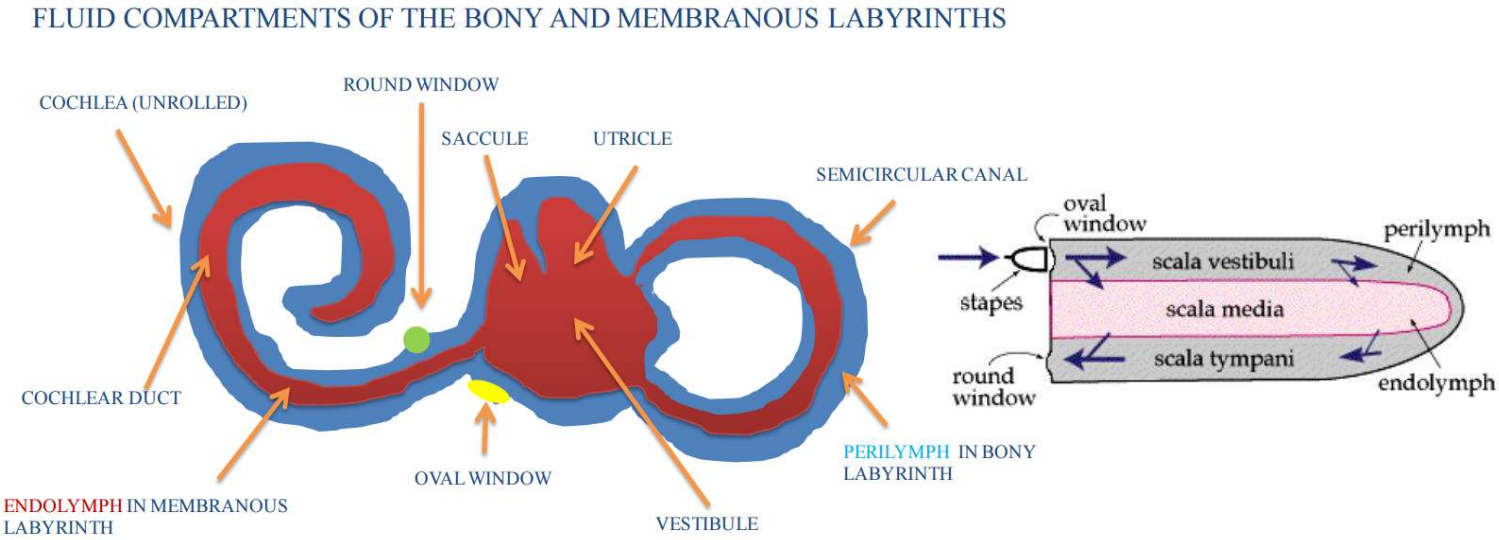
A **szemcsarnokok** (camerae bulbi) a szaruhártya mögött az üvegtest elülső határhártyájáig terjedő, víztiszta, átlátszó folyadékkal, csarnokvízzel (humor aquosus) kitöltött terek. A tereket a szivárványhártya osztja elülső és hátsó szemcsarnokokra. A két rész közötti összeköttetés a pupillán keresztül valósul meg, bár ennek előtte a csarnokvíznek át kell haladnia a szivárványhártya hátsó felszíne és a lencse közötti kapilláris résen. A csarnokvíz a hátsó szemcsarnokban a sugártest nyúlványainak ereiből szűrődik ki, majd a pupillán keresztül a szaruhártya és a szivárványhártya közötti elülső szemcsarnokba jut, ahol a szivárványhártya rögzülésénél, a szaruhártya és ínhártya találkozásánál (corneoscleralis határ) lévő sajátos képződményen keresztül felszívódva visszakerül a vénás vérbe. A csarnokvíz termelődésének és visszaszívódásának dinamikus egyensúlya tartja fenn a szem belső nyomását, amely megközelítőleg 20 mmHg.

Cochlear and vestibular systems

(Halló és egyensúlyozó rendszer)

Fluids in the inner ear

The cochlear canals contain two types of fluid: perilymph and endolymph. **Perilymph** has a similar ionic composition as extracellular fluid found elsewhere in the body and fills the scalae tympani and vestibuli. **Endolymph**, found inside the cochlear duct (scala media), has a unique composition not found elsewhere in the body.



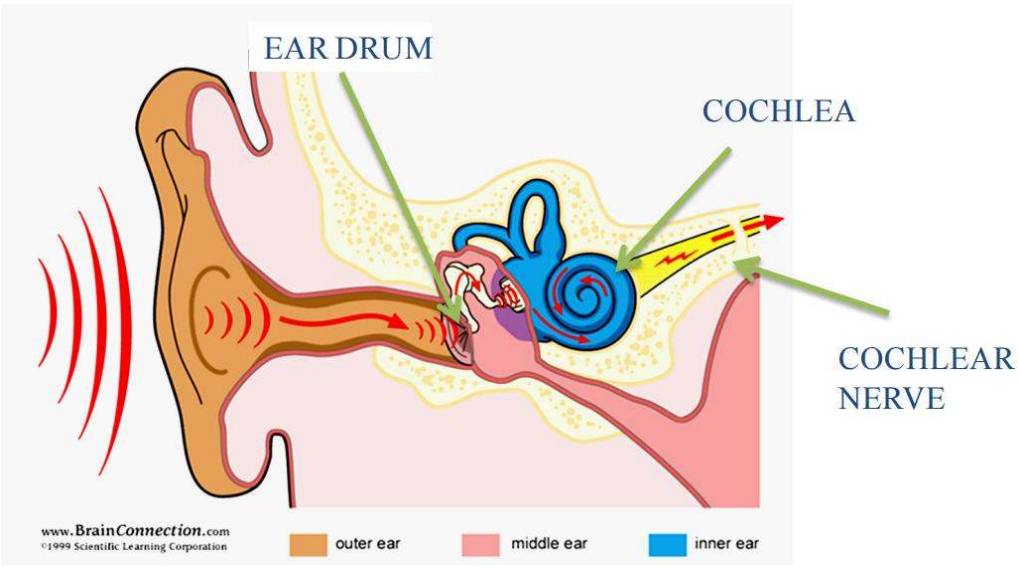
Auditory system

Sound causes vibration of the tympanic membrane (dobhártya) that is transmitted via the otic ossicles (hallócsontocskák) to the perilymphatic fluid. It generates a spreading wave in the cochlear duct (hallójárat) filled with endolymph. As a result, the hair cells in the organ of Corti become activated. This signal is transmitted by the cochlear nerve to cochlear nuclei of the brainstem. The cochlear nuclei project upstream and send the information via brain stem and metathalamic structures to the primary auditory cortex located in the superior temporal gyrus.

Vestibular system

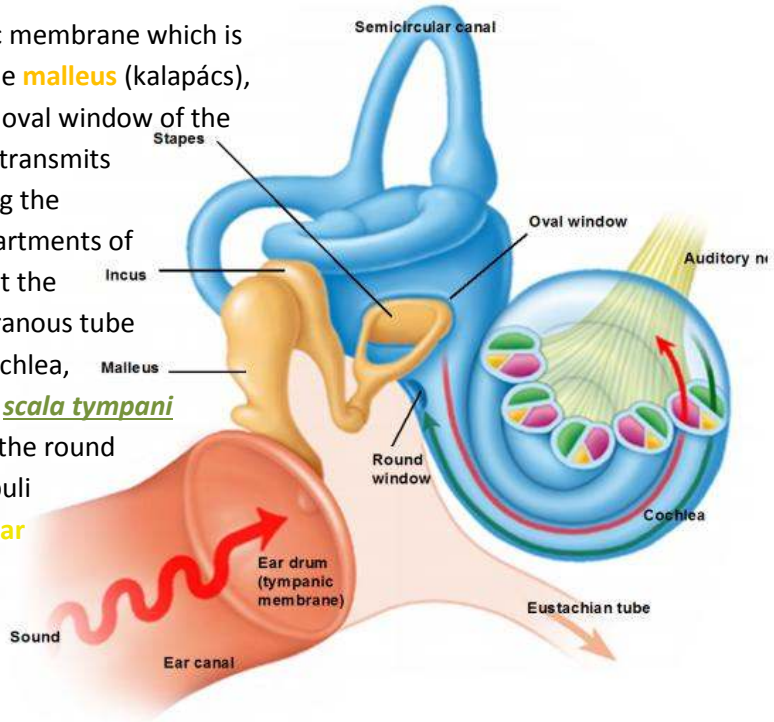
It senses linear acceleration, deceleration and angular rotation of the head. There are receptors in the utricle (tömlőcske), saccule (zsákocska) and the semicircular canals (félkörös ívjáratok, 3). The generated signals are carried by the vestibular nerve to its nuclei for processing. The system is interconnected with motor nuclei of muscles regulating the movements of eye.

Organization of the ear



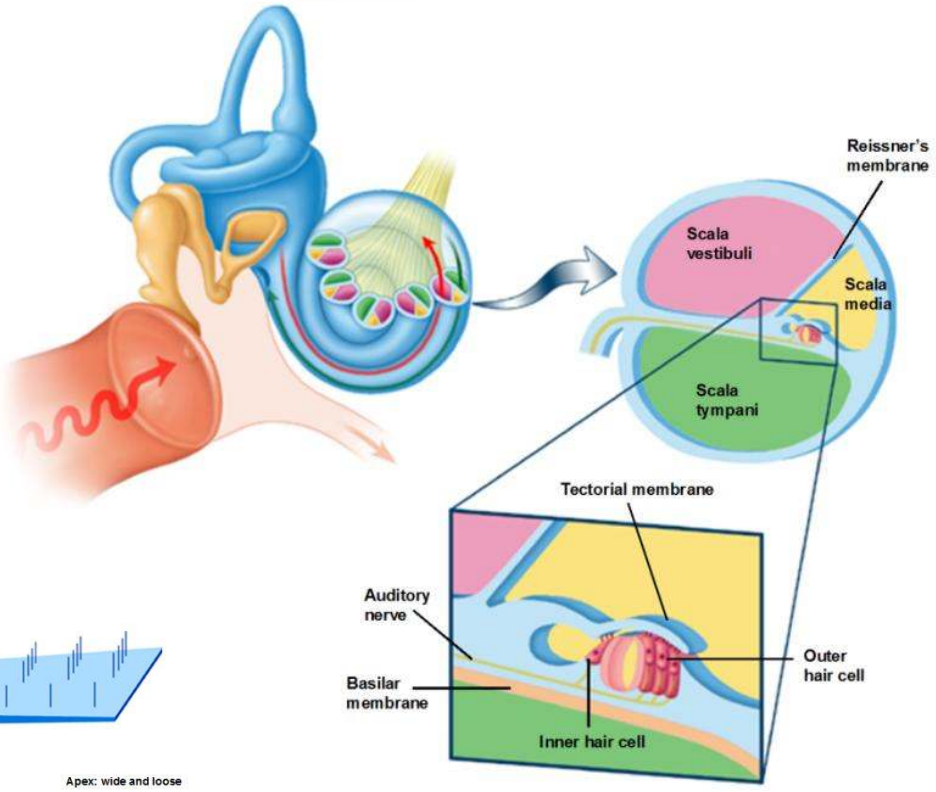
Signal propagation

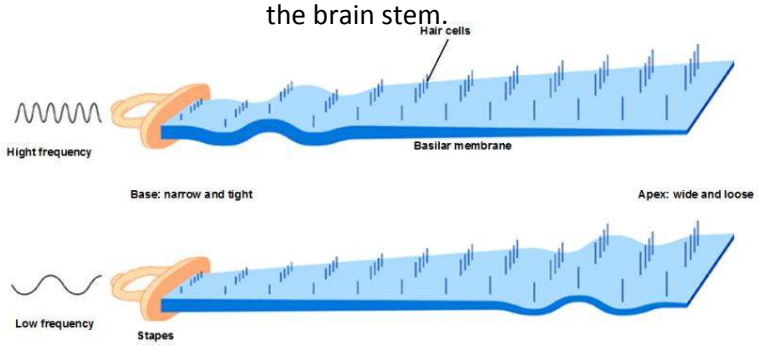
Sound causes vibration of the tympanic membrane which is transmitted by a chain of tiny bones, the **malleus** (kalapács), **incus** (üllő) and **stapes** (kengyel) to the oval window of the cochlea (csiga). The basis of the stapes transmits the signal to the perilymph, a fluid filling the scala vestibuli and scala tympani compartments of the cochlea. The ***scala vestibuli*** starts at the oval window and the fluid filled membranous tube winds around the vertical axis of the cochlea, then it turns downhill and continues as ***scala tympani*** which ends at the membrane covering the round window. Scala tympani and scala vestibuli surround the membranous tube **cochlear duct** which is filled with endolymph.



Corti organ

Situated within the cochlear duct. It is built by sensory epithel hair cells and supportive epithel cells. The sensory cells pick up the signal of the spreading endolymphatic fluid wave. Neurons of the cochlear ganglion convey the information to auditory centers of the brain stem.



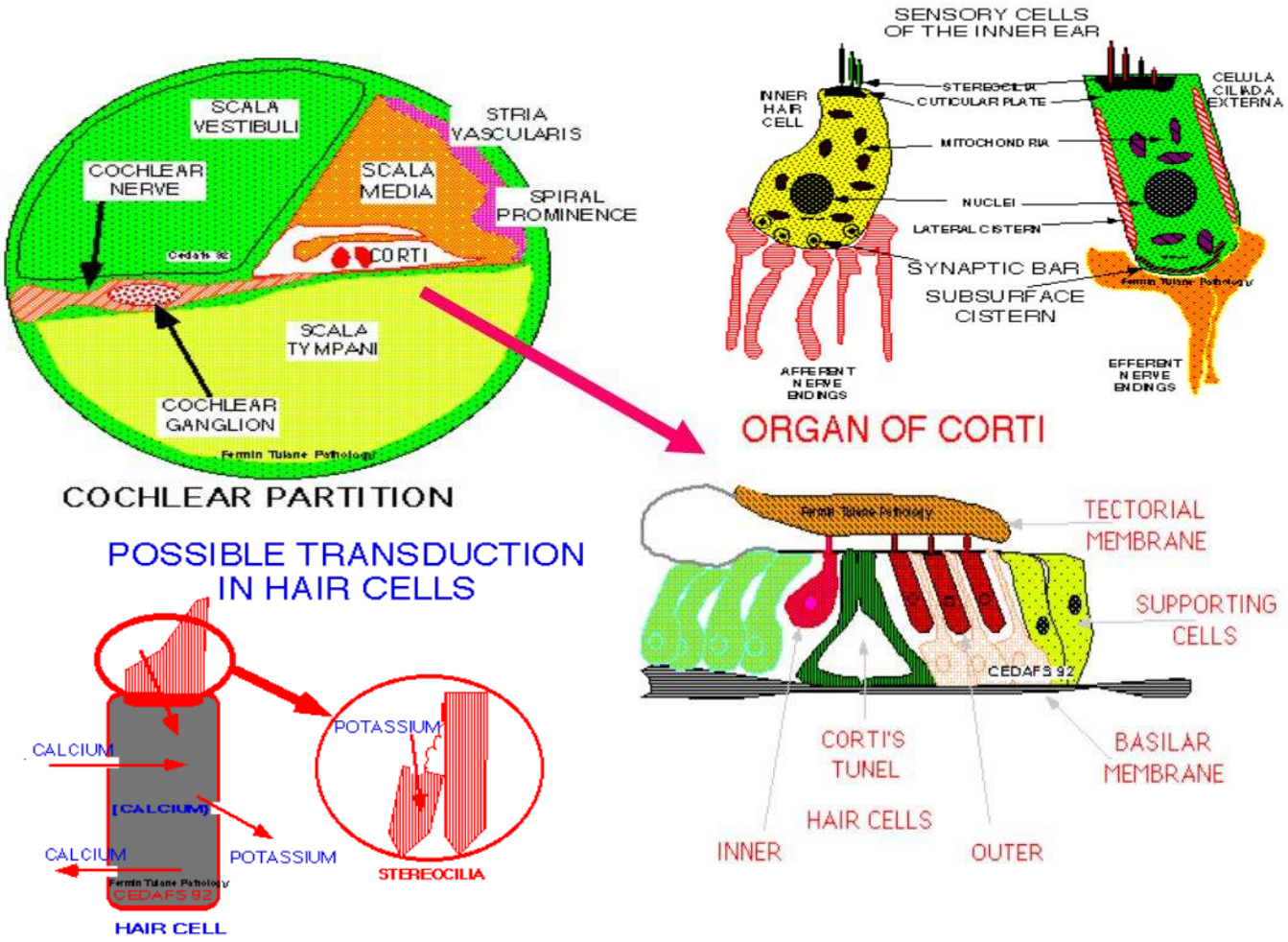


Hair cell activation

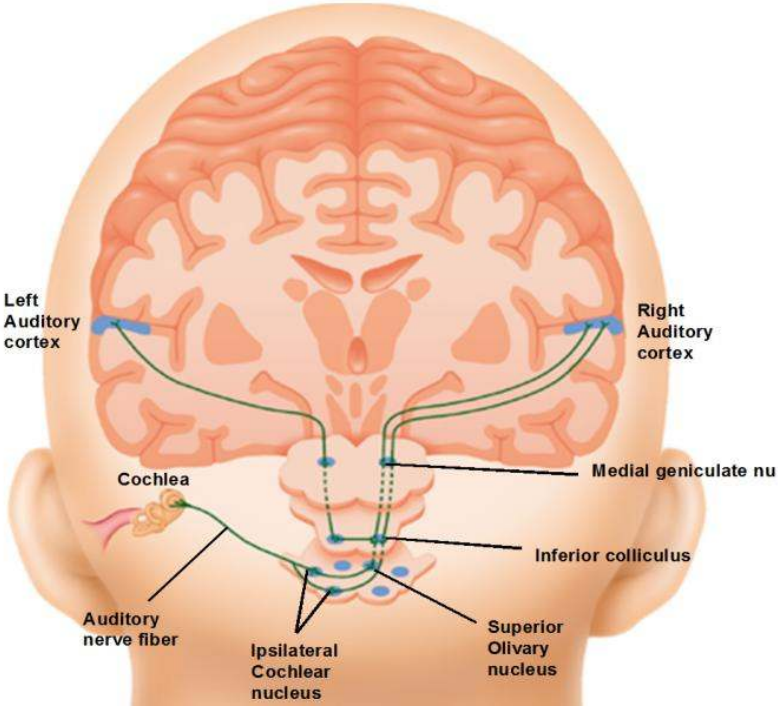
Depending on the pitch (hangmagasság) of the sound, a particular region of the basilar membrane vibrates with a maximal intensity. Signals at high frequency generate vibrations at the base of the membrane, while sounds at low frequency initiate movement at the wider and looser apical part of the basilar membrane. The evoked movement results in bending (görbülés) of the hairs of sensory epithel cells toward the stereocilium which, in turn, causes depolarization and increases the release of transmitters from hair cells. This event activates the peripheral processes of cochlear ganglion neurons.

magas freki → basilar eleje, ahol a kengyel van

alacsony freki → a basilar szélesebb, lazább messzi része remeg be



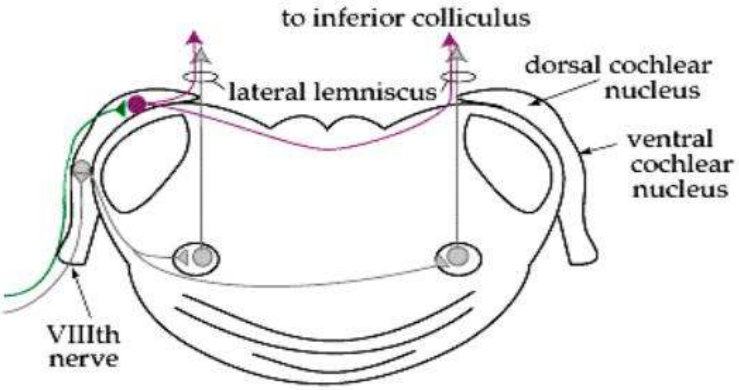
Auditory pathway The central processes of cochlear ganglion cells terminate in the dorsal and ventral *cochlear nuclei* of the brain stem. The cochlear nuclei communicate with the *superior olive* from where the auditory fibers ascend to the *inferior colliculus* forming the **lateral lemniscus**. This nucleus relays the information to the *medial geniculate body* of the *thalamus*. The final acoustic radiation reaches the *primary auditory field* (A1) of the *superior temporal gyrus*. The auditory center has a tonotopic* organization, the apex of the cochlea projects to the anterior part of the field, high frequency sounds are represented at the posterior pole. Behind this region is the sensory speech area of Wernicke.

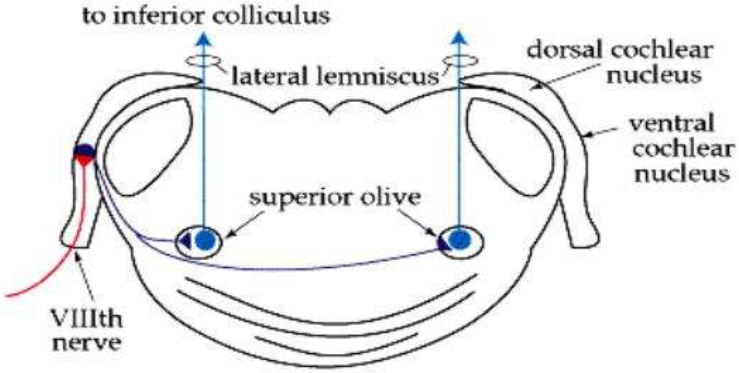


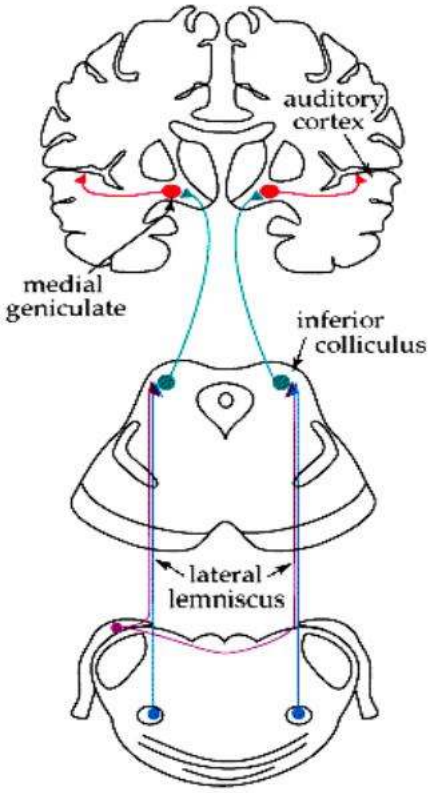
magas freki → a center hátsó részén
alacsony freki → a központ elülső részében

Tonotopy The spatial arrangement of where sounds of different frequency are processed in the brain (from Greek tono=frequency and topos = place). Tones close to each other in terms of frequency are represented in topologically neighboring regions in the brain.

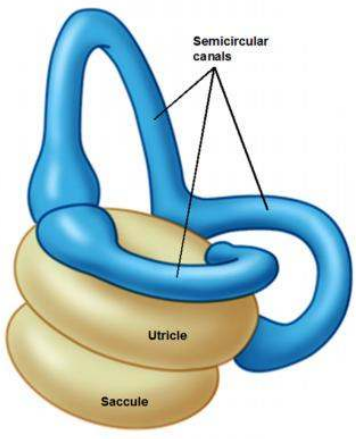
Wernicke speech area One of the two parts of the cerebral cortex linked to speech; the other is Broca's area. It is involved in the production of written and spoken language.







Vestibular system The receptor structures of the vestibular system are located in the bony vestibule (dobüreg) and semicircular canals of the inner ear. The **linear acceleration and deceleration** are sensed by receptors built into the endolymph-filled *utricle* (tömlőcske) *and saccule* (zsákocska). The **angular rotation** is monitored by hair cells of the crista ampullaris (a hártyás ívjáratok kiemelkedése), a receptor structure present in each of the *membranous semicircular canals*. The spatial arrangement of the semicircular canals enables the detection of angular rotation of the head in all directions.



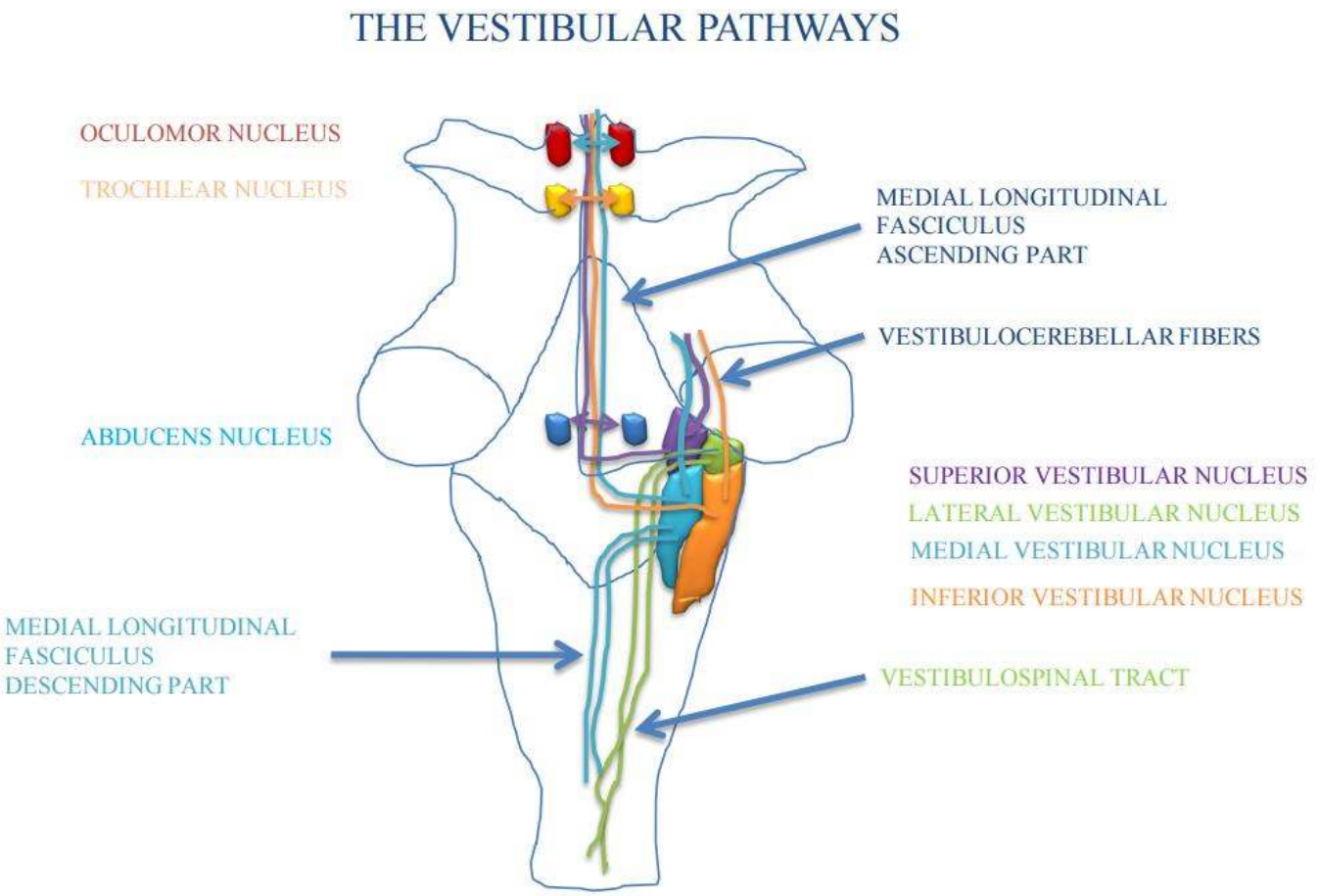
The hair cells of the utricle and saccule possess hairs embedded in the otolith membrane. (A tömlőcskében és a zsákocskában lévő szőrsejtek szőröket bocsátanak ki, amelyek másik oldal be van ágyazva a hallókő membránjába)The calcium concretions (kőképződések) give the otolith membrane a higher specific gravity than the endolymph, and by bending the hairs (a szőröket hajlítva) it can stimulate the hair cells. Because of their orientation in the head, the utricle is sensitive to a change in horizontal movement, and the saccule gives information about vertical acceleration.

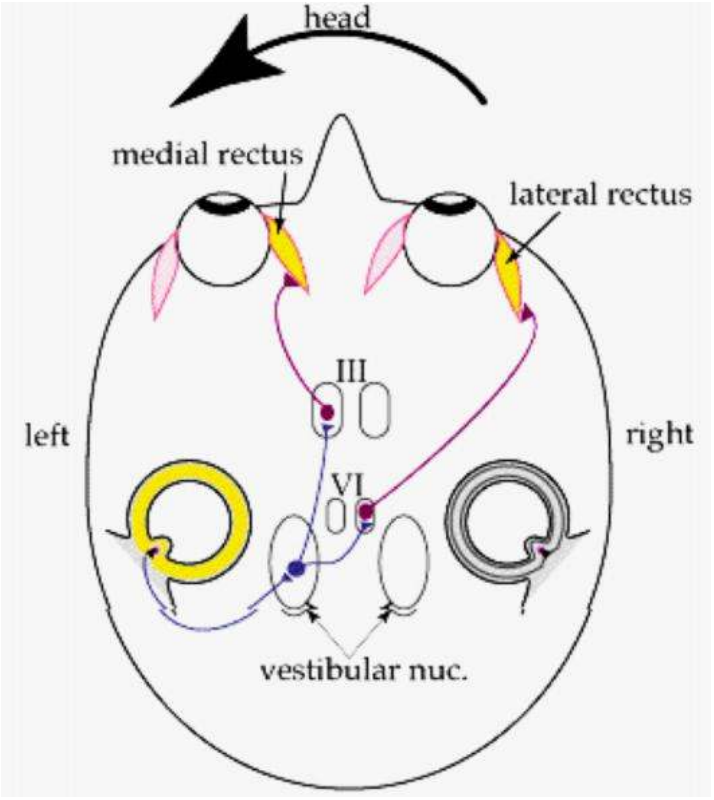
In the semicircular canals, the movement of endolymph triggers the hair cells and changes their activity depending on the direction of the flow. The altered receptor status is reported by the vestibular nerve.

Otolith (hallókő) Small particles, composed of a combination of a gelatinous matrix and calcium carbonate in the viscous fluid of the saccule and utricle. The inertia (tehetetlenség) of these small particles causes them to stimulate hair cells when the head moves.

Otolithic membrane It is part of the otolith organs in the vestibular system. The otolith organs include the utricle and the saccule. The otolith organs are beds of sensory cells in the inner ear, specifically small patches of hair cells. Overlying the hair cells and their hair bundles is a gelatinous layer and above that layer is the otolithic membrane. The utricle serves to measure horizontal accelerations and the saccule responds to vertical accelerations. The reason for this difference is the orientation of the macula in the two organs.

Basilar membrane It is located in the cochlea of the inner ear. A stiff structural element that separates two liquid filled tubes that run along the coil of the cochlea, the scala media and the scala tympani

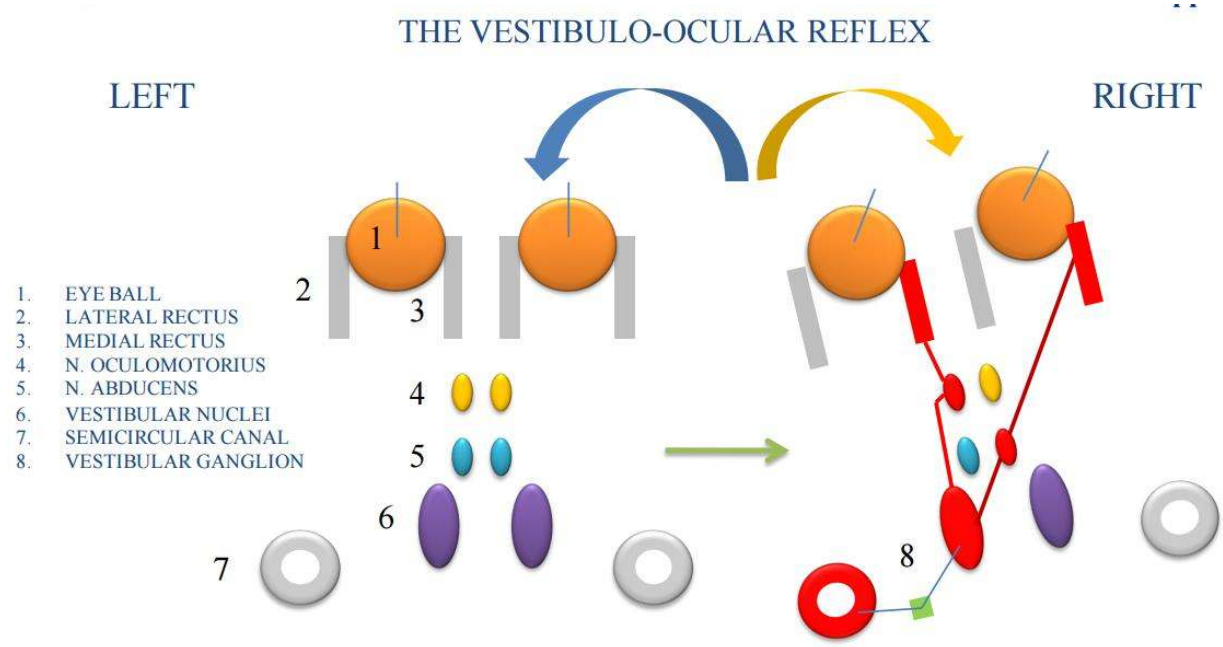




Magyarul az egyensúlyozásról:
A hártyás fallal határolt, folyadékkal telt labirintusszerv egyik része, a **tömlőcske** és a **zsákocska** *fejünk térbeli helyzetéről* szolgáltat információt. Érzékszőrökkel rendelkező receptorsejtjei fölött kocsonyás rétegbe ágyazódva apró mészszemcsék helyezkednek el. Ezek a kristályok súlyuknál fogva nyomják az alattuk levő érzékszőröket. Ha a fej térbeli helyzete megváltozik, a szemcsék más irányban, más sejteket ingerelnek.

Fejünk elfordulását, forgó mozgását a **három félkörös ívjárat** segítségével érzékeljük. A félkörös ívjáratok egymásra merőlegesen, a tér három síkjában, félkör alakban görbülő csövek, belsejüket folyadék tölti ki. Ha a fej elmozdul, az elfordulás síkjába eső ívjáratban a folyadék, tehetetlensége miatt ellenkező irányban áramlik. Az áramló folyadék sodrása meggörbíti az ívjárat végénél levő receptorsejtek érzékszőreit. Ez kelti az ingerületet.

A labirintusszerv receptoraiból az ingerület az agyideg rostjain halad a *talamusz* felé, ahonnan átkapcsolás után a *fali lebeny*ben található érzőmezőbe és a mozgásszabályozás központjaiba jut. Így izmaink működtetésével azonnal válaszolhatunk az ingerre.



A hallás és egyensúlyozás szerve (organum vestibulocochleare) összetett, kettős érzékszerv, egyfelől a hallás, másfelől az egyensúlyozás szolgálatában áll. A halántékcsont külső felületén és a sziklacsontban helyezkedik el.
A hallás szerve három részből áll: külső-, közép- és belső fülből. Az egyensúlyozás szerve a belső fülben található.

A külső fül fülkagyló + külső hallójárat a dobhártyáig

A középfül

A halántékcsont dobűri részében helyeződő, nyálkahártyával bélelt, levegővel telt üregből: a külső és a belső fül közötti ***dobüreg***ből, valamint a dobhártyát a belső füllel összekötő hallási csontocskákból áll. A hallási csontocskák: a ***kalapács***, az ***üllő*** és a ***kengyel***, a dobhártyától az ***ovális ablak***ig terjedő csontláncolat, amelyben a csontokat két ízület és szalagok kapcsolják egymáshoz. A dobhártya rezgéseit közvetítik az ovális ablakon át a belső fülbe.
A ***fülkürt*** (tuba auditiva Eustachii) a dobüreget a garatüreggel összeköti, ezáltal a dobüreg a külvilággal közlekedik, s a légnyomást a dobhártya mindkét oldalán kiegyenlíti.

A belső fül

A *sziklacsont*ban elhelyezkedő, egymással közlekedő, csontos falú, csonthártyával bélelt üregekben és járatokban, a ***csontos labirintus***ban foglal helyet. Ezen belül található a hártyás falú szerv, amit ***hártyás labirintus***nak neveznek. A hártyás labirintus folyadékban, ***perilimfá***ban, úszik. A hártyás labirintust folyadék, ***endolimfa***, tölti ki; falában a hallás és egyensúlyozás végkészülékei, receptorszervei foglalnak helyet.

A csontos labirintus három részből áll: a tornác, a félkörös ívjáratok, a csiga.
A ***tornác*** (vestibulum) gömb alakú üreg, melynek medialis falán beemelkedő alacsony léc csiga felőli öblöt (sacculi), és egy ívjáratok felé eső öblöt (utriculi) különít el egymástól.
A ***félkörös ívjáratok***, amelyek közelében levő átlyuggatott területen a hártyás labirintusból eredő idegek lépnek ki, a tornácba nyílnak. Résein át a perilimfa a szubarachnoideális folyadékkal közlekedik. A medialis falán levő kerek lyukhoz a kengyel talpa illeszkedik. A csontos ívjáratok félkör alakú, szűk csatornák, a tornác caudodorsalis felületén tágulattal nyílnak.
A ***csiga*** (cochlea) az éticsiga házához hasonló; tengelye körül spirálisan csavarodó, a vége felé elvékonyodó cső. A csiga üregének spirális, lemez alatti rekesze a dobűri lépcső, afölötti része pedig a tornáclépcső.

A **hártyás labirintus** vékony, kötőszövetes falú, üreges szerv. Fala vékony, érdús, lemezekbe rendeződött kötőszövetből (basalis membrán) és egyrétegű hámból áll. A hám helyenként specifikusan differenciált érzéki hám, a hallás és egyensúlyozás végkészüléke.
Részei: a tömlőcske, a zsákocska, a hártyás ívjáratok, a csigajárat.
A ***tömlőcske*** (utriculus), a zsákocskánál (sacculus) nagyobb, tojásdad alakú. A ***zsákocska*** kicsi és kerek; a kettőt egymással szűk járat köti össze. Mindkettő a tornácban helyezkedik el.
A ***három hártyás ívjárat*** a csontos ívjárat domború felületéhez simul, a járatok ampullaszerű tágulattal a tömlőcskébe szájadzanak.

A **Corti-féle szerv** (organum spirale) a hallás tulajdonképpeni receptor szerve. Spirális szalag alakú; hámja pillér- és támasztósejtekből (érzéki hámsejtek vagy szőrsejtek) áll, amelyek az alapmembránon (membrana basilaris) ülnek. A belső pillérsejteket egy, a külsőket 3-5 sor érzéki hámsejt határolja, amelyeket kívülről támasztósejtek öveznek.
Az érzéki hámsejtek fölé az ún. Corti-féle hártya, membrana tectoria, nyúlik be. A hártya a labium vestibularéról ered, és a szőrsejtek külső sora fölött szabad szélben végződik; nedvdús, kocsonyaszerű, hámsejtkutikulából származik, vázát vékony fibrillumok hálózata adja.

A hang érzékelése

A hallás folyamatának adekvát ingere a hang. A külső hallójáratban vezetett hanghullámok frekvenciájuknak megfelelő rezgést keltenek a dobhártyán. Ennek elmozdulásai kitérítik a hallási csontocskákat, majd a hanghullámok a kengyel talpának rezgései révén átterjednek a perilimfára. A perilimfa folyadékrezgései a dobűri lépcső csúcsáig terjedő, az artériás pulzushoz hasonló hullámokat keltenek. E hullámok a tornáclépcsőben folytatódnak, majd a csiga csúcsáról átterjed az endolimfát tartalmazó csigajáratra is. A hangrezgés hatására a két merev lemez, az alaphártya (membrana basilaris) és a tetőlemez (membrana tectoria) között eltolódás keletkezik, ami a hallószőröket elhajlítja. A szőrsejtekben ezáltal keletkezett ingerületet a bipoláris idegsejtek periferikus szakasza veszi át, és centrális velőhüvelyes nyúlványaihoz továbbítja. A centripetális rostok (felvéve a vestibularis készülékből származókat is) nervus vestibulochlearis-sá (VIII. agyideg) egyesülnek, és a nyúltvelőbe jutnak. Ott részben kereszteződnek, majd a talamuszon át az agykéreg halántéklebenyi területére futnak.

Az egyensúlyozás készüléke és működése

A belső fülben lévő tornácból csontos járatok indulnak ki, a tömlőcske, a zsákocska és a 3 félkörös ívjárat – mindháromba idegek lépnek be. Az idegek a két előbbi macula statica-nak, ill. az ampullákban a lécnek (crista) nevezett receptor területen végződnek. A macula támaszósejtjei között érzékhámsejtek ülnek. Ezek nyúlványai az egészet borító kocsonyás rétegbe nyúlnak. A réteget mészkristályok (statolith) vékony rétege fedi. Az ampullában egy ugyancsak kocsonyás anyagból álló cupula az, amelybe az érző szőrök benyúlnak.
A fej vagy a test mozgása miatt, az endolimfa tehetetlensége folytán különböző mértékben elhajlítja az ampullákban lévő cupulákat. Ez a szőrsejtekben ingerületi állapotot kelt a maculákban a le, fel, ill. az előre, hátra irányú mozgások révén változik a statolith réteg által okozott terhelés, ami ingerületet vált ki a kocsonyás rétegbe ágyazott szőrsejtekben.

Az érzéksejtek ingerületét a bipoláris ganglionsejtek veszik fel és n.vestibulocochlearis (VIII) részeként előbb a nyúltvelőbe térnek. Innen a kötegek (tractus) többfelé vezetnek, így a kisagyvelő lebenyébe, a szemmozgatató idegek ducaihoz, a gerincvelői mozgatóidegek magjaihoz és az agykéreghez fut be a test egyensúlyi helyzetéről impulzus. Mindez együtt az állás- és mozgás koordinációhoz, valamint a szemmozgások beállításához is ad információt.