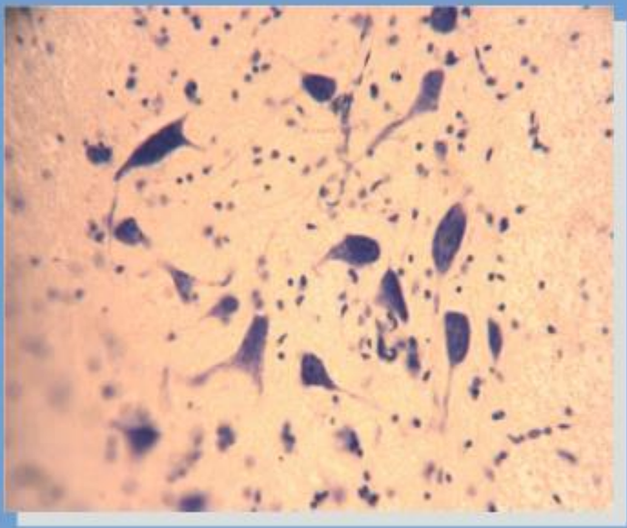
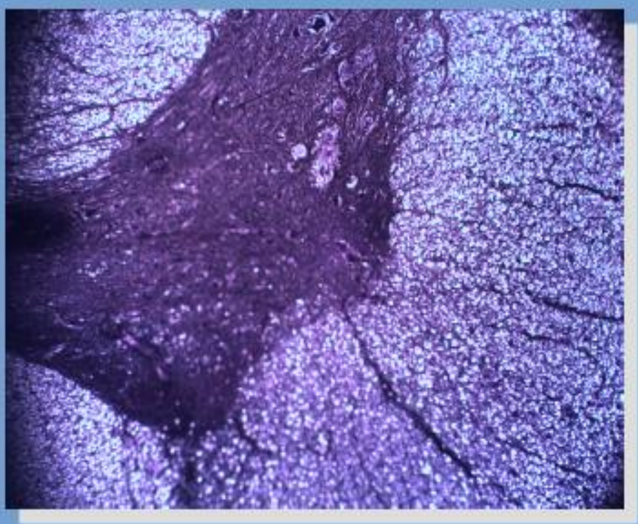


Nervous Tissue



Nervous System

Sensory System

Study guide

Edited by L. I. Kiptenko

Ministry of Education and Science of Ukraine
Ministry of Health of Ukraine
Sumy State University

Nervous Tissue. Nervous System. Sensory System

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Recommended by the Academic Council of Sumy State University

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This manual is intended for the students of medical higher educational institutions of IV accreditation level, who study Histology, Cytology and Emryology in English language.

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Contents

Topic: Nervous Tissue

The Nervous tissue refers to the specialized tissues.

Functions of the nervous tissue:

1) the ability to perceive irritation;
2) transformation of irritation into nervous impulse;
3) nervous impulse transmission;
4) storage of information;
5) synthesis of biologically active substances.

The nervous tissue provides the connection between the organism and the environment. It regulates and interconnects cells, tissues, organs and systems of organs.

Structure

The nervous tissue includes neurons, which perform the principal function and neuroglia, which form environment for neurons. Neuroglia is divided into two genetically different types:

1) macroglia, which performs supporting, trophic and secretory functions;
2) microglia, which performs defensive function.

The nervous tissue

neurons neuroglia

macroglia microglia

Neurons

Neurons are morphological and functional units of the nervous tissue. They are composed of the body and processes. The life span of neurons is the same as the life span of the human organism.

In the central part of the cell body (perikaryon) there is one round light nucleus with small amount of heterochromatin. One or few nucleoli are located in the nucleus. The cytoplasm of neurons (neuroplasm) contains three types of structures:

- organelles of general importance;
- inclusions: carbohydrates (glycogen), pigment (melanin) and various secrets (in neurosecretory cells);
- special organelles: chromatophilic substance and neurofibrils.

Chromatophilic substance or basophilic substance (Nissl's substance) appears as the aggregation cisterns of granular endoplasmic reticulum. When stained by special dyes, they appear as basophilic granules. Basophilic substance is present only in perikaryon and dendrites of the neuron. A great number of *chromatophilic substance* indicates to high level of synthetic processes.

Neurofibrils consist of neurofilaments and neurotubules, which form a reticulum in the perikaryon and parallel bundles in neuronal processes. Neurofibrils compose the supporting and drain systems.

Processes represent diverticulum and branching of the cytoplasm of different length. They are covered with the cell membrane (plasmalemma) and terminate by specialized nerve endings.

According to functions, the neuronal processes are divided into *neurites (or axons)* and *dendrites.* As for neurites, the impulse is transmitted from perikaryon to the ending along them. Dendrites conduct the nervous impulse to the neuron body.

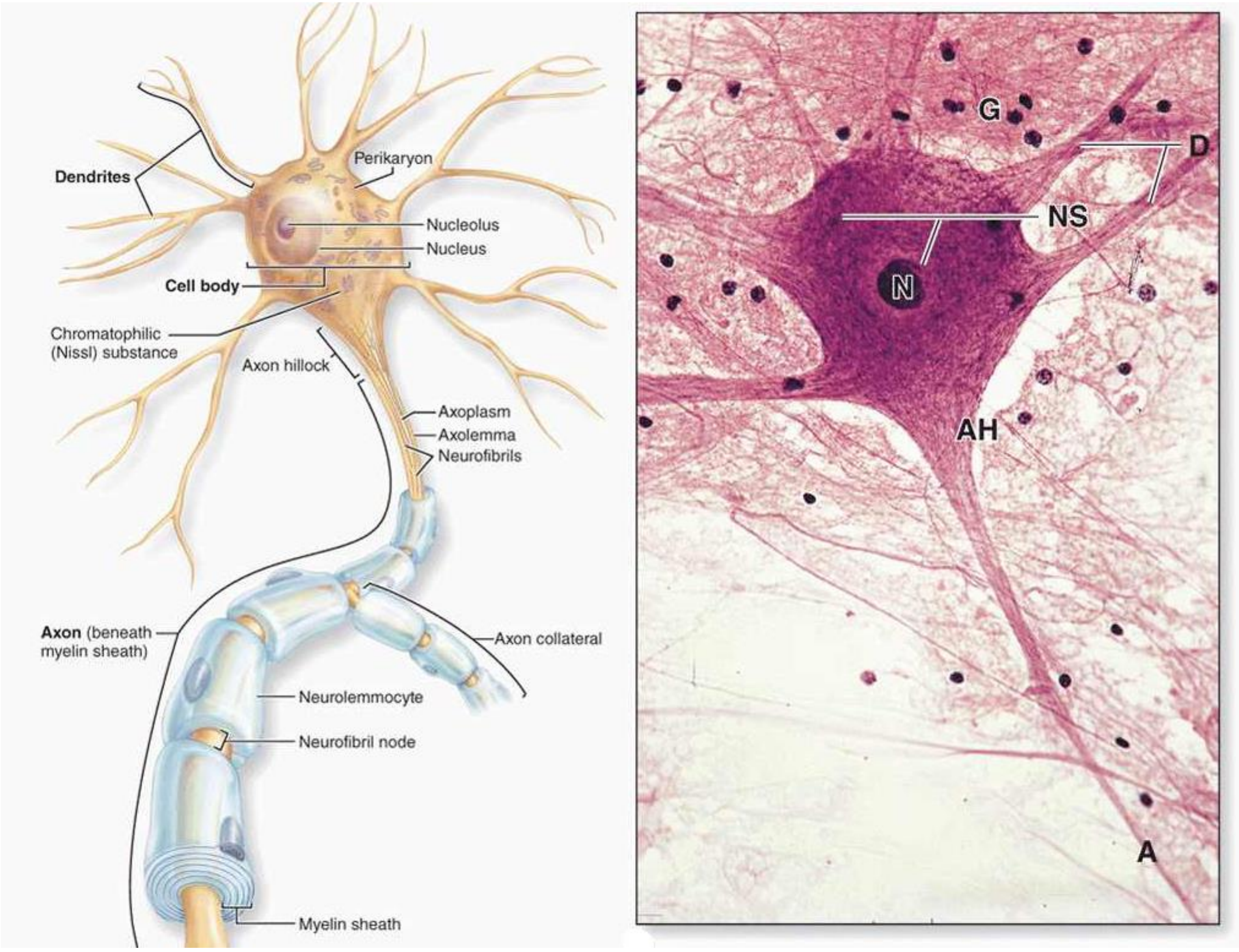


Figure 1 – Neuron. Hematoxylin & eosin (H&E) staining:
A — axon;, AH — axon hillock; D — dendrites; G — glial cells; N — nucleus;
NS — Nissl substance

Neurofibrils form the complex of microtubules in the processes along, which substances move from the nerve endings to the perikaryon *(retrograde transport in the dendrites)* and from the perikaryon to the nerve ending *(axonal transport)*. The nerve cell can contain different number of dendrites and only one axon.

Morphological classification of neurons is based on the number of processes:

1) *unipolar*, they have only one process. These are neuroblast cells: they are present in embryo.

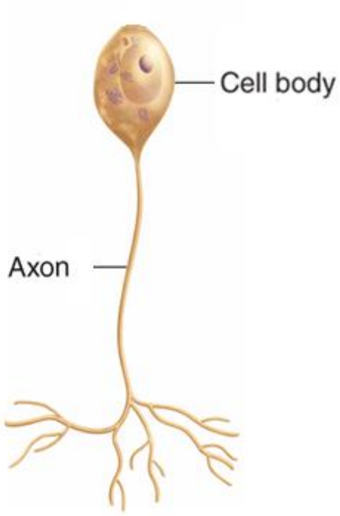


Figure 2 – Neuron. Unipolar type

2) *bipolar* neurons have two processes — axon and dendrite. They are present in the eye's retina.

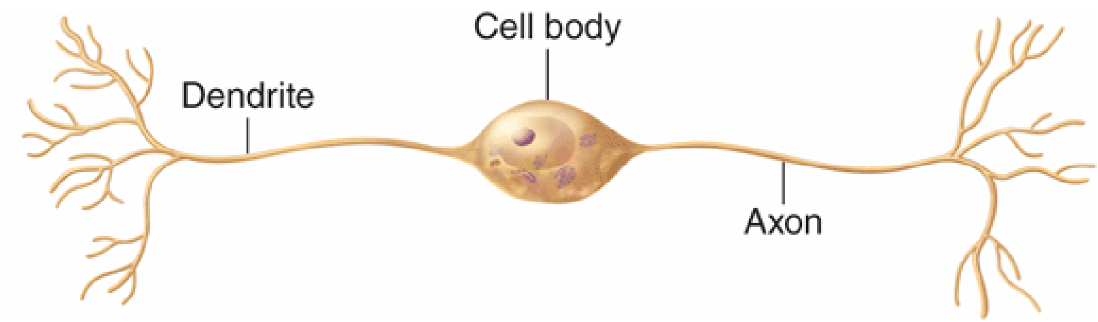


Figure 3 – Neuron. Bipolar type

3) *pseudounipolar* neurons have one process which is divided into the axon and dendrite at the distance from nerve cell body. They are found in the spinal ganglia.

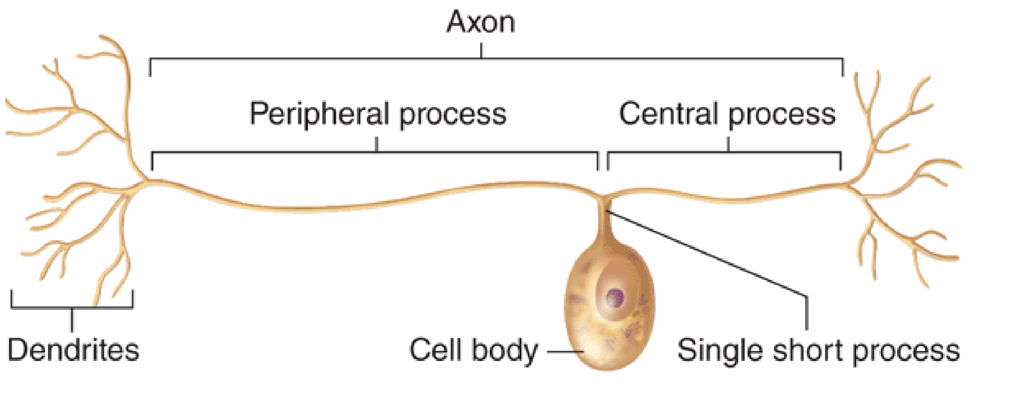


Figure 4 – Neuron. Pseudounipolar type

3) *multipolar* neurons have many processes, one of which is an axon, and all the rest are dendrites. This is the most numerous group of neurons.

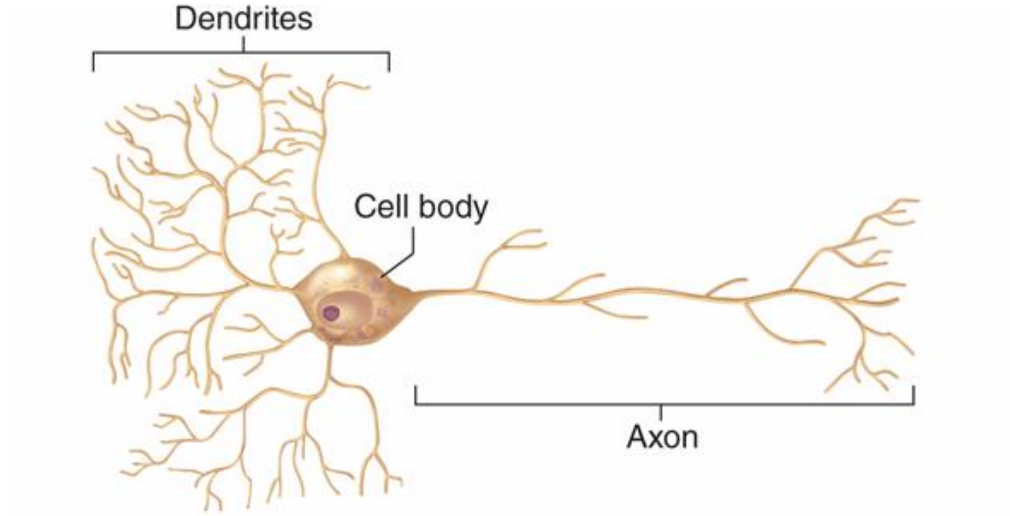


Figure 5 – Neuron. Multipolar type

The *functional classification of neurons* is based on the function of the nerve cell along with the reflex arc:

1) afferent (sensory) neurons receive the impulse;

2) associative (intercalatine) neurons transmit the impulse from the sensory neurons to the motor ones;

3) efferent (motor, locomotive) neurons transmit the impulses to the working organs.

Reflex arc - a chain of nerve cells, which transmit a nerve impulse from sensory nerve ending (receptor) to the locomotive nerve ending (effector). The latter is situated in the working organ. Simple reflex arcs are composed of two neurons: afferent and efferent. Complex reflex arcs have associative nerve cells between the afferent and efferent neurons. The nerve impulse travels along the reflex arc only in one direction.

1. Receptors.
2. Dendrite of the afferent (sensory) neuron.
3. Perikaryon of the afferent (sensory) neuron.
4. Craniospinal ganglion.
5. Axon of the afferent (sensory) neuron.
6. Associative neuron (interneuron).
7. Locomotive (efferent or motor neuron).
8. Axon of the efferent neuron.
9. The anterior root of the spinal cord.
10. The posterior root of the spinal cord.
11. The spinal nerve.
12. Muscle.
13. The white substance of the spinal cord.
14. The grey substance of the spinal cord.

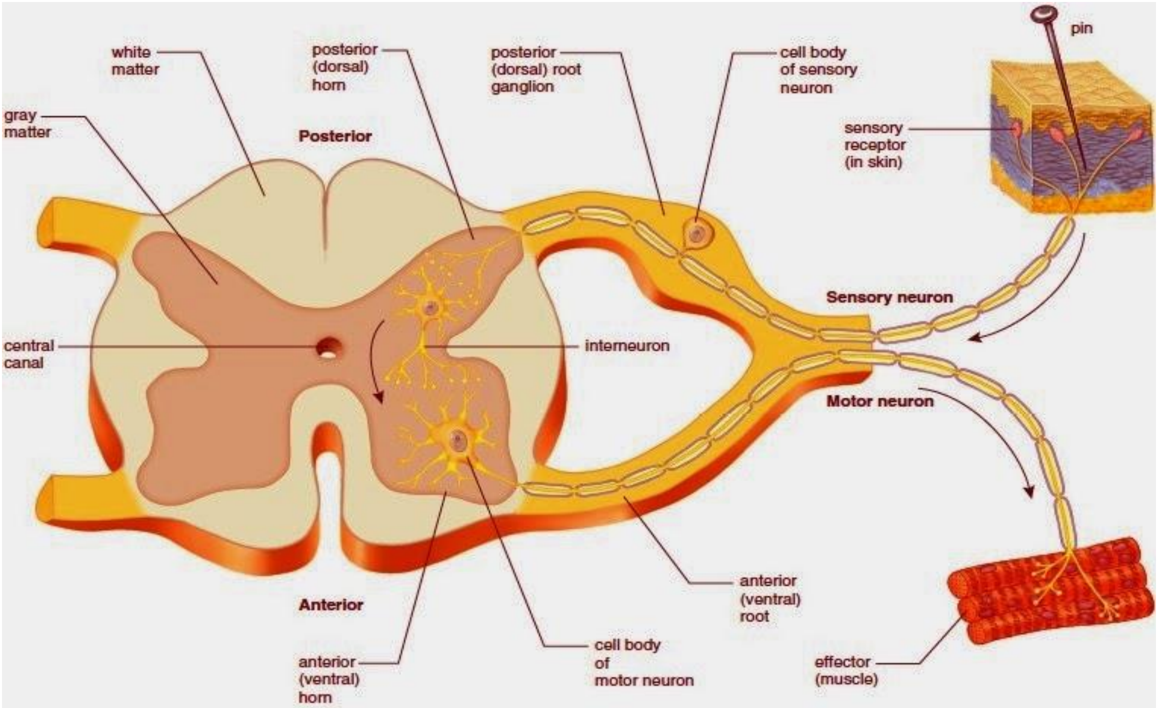


Figure 6 – Reflex arc.

The receptors receive the stimulus, transform it into the nervous impulse and transmit it to the spinal ganglia along the dendrite of the afferent neuron. The bodies of the sensory neurons are present here. The nervous impulses along the axons of these cells enter the grey substance of the spinal cord or the brain on the associative neurons. These cells transmit the impulse to the bodies of efferent neurons. The axons of these cells pass to the working organs.

Nerve Fibers

Nerve fibers are the processes of the neurons covered with glial sheaths. Depending on the sheath structure they are divided into two groups: *myelinated* and *unmyelinated* ones. They are composed of the process of the nerve cell, which is in the center of the fiber and called *axis cylinder*. It is surrounded by the glial sheath which is formed by glial cells. These are oligodendrocytes in central nervous system and Schwann cells (neurilemma cells, lemmocytes) in peripheral nervous system.

When unmyelinated fibers are forming, an axon plunged into neurilemma cell, the plasmalemma of which caved in and enveloped the axis cylinder tightly in the muff shape, and the margins of plasmalemma are closed above it. A double fold of the plasmalemma of the neurilemma cell – *mesaxon* - is formed. The neighboring lemmocytes, entering the composition of the entire glial band opposed to each other closely.

Myelinated nerve fibers are much thicker than unmyelinated ones. They are composed of the axis cylinder, myeline sheath, plasmalemma of Schwann cell and the basal membrane. Schwann cell membrane surrounds the axon, forming mesaxon. During further development, Schwann cell is wrapping around the axis cylinder and forming concentric layers of mesaxon around the axis cylinder. The cytoplasm of the lemmocyte and its nucleus stay peripherally and form neurolemma. The inner layer consisting of mesaxon spires is called *myelin* or *myelin sheath*.

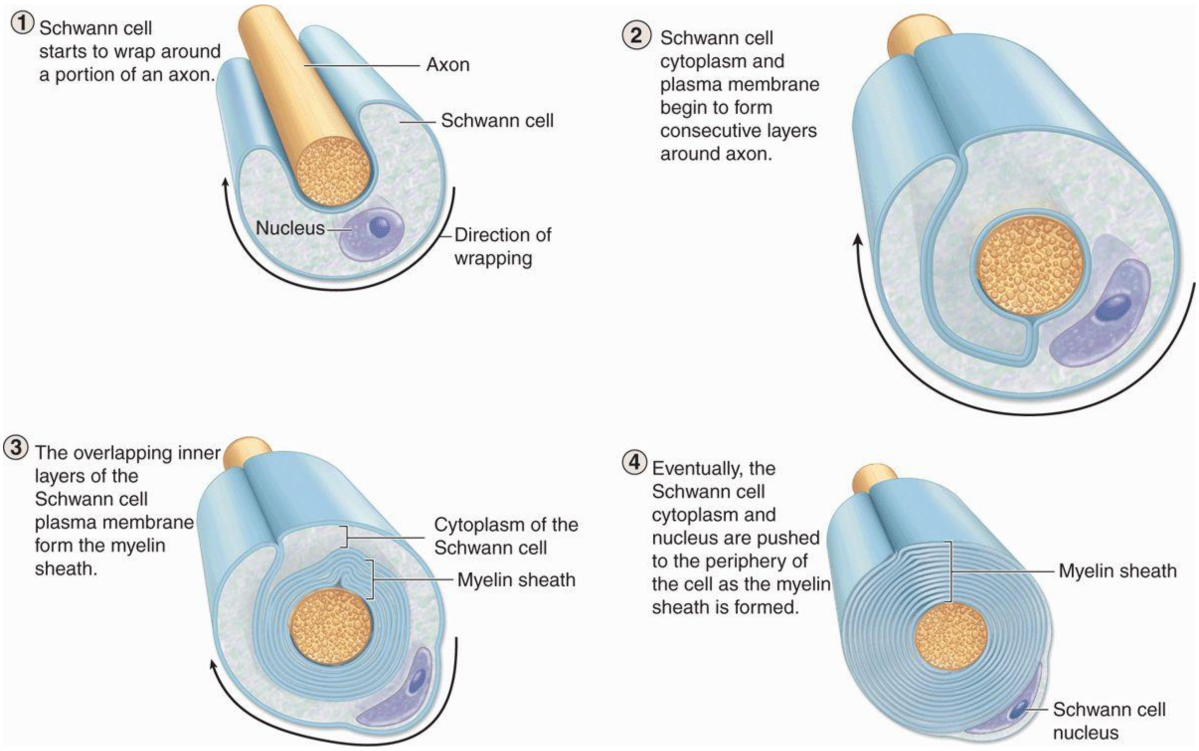


Figure 7 – Formation of the myelinated fibers

Each mesaxon spire corresponds to the lipid layers of two plasmalemma leaflets of the Schwann cells. Thin sheaths of Schwann cell cytoplasm are present between each turn of the mesaxon. They are called *myelin clefts*.

The sheath of one nerve fiber is formed by numerous lemmocytes. The sites of their contacts are called *myelin-sheath gaps* or *nodes of Ranvier*. Myelin is absent in these sites. The portion of a nerve fiber between two nodes of Ranvier is called an *internodal segment*. One internodal segment corresponds to a Schwann cell. The plasma membrane of an axon is called *axolemma*. It provides the transmission of the nerve impulse.

In unmyelinated nerve fibers the impulse passes continuously along the entire axolemma. In myelinated nerve fibers the impulse arises only in the node of Ranvier. So, the impulse passes not continuously as in unmyelinated nerve fibers, but saltatory. This provides high transmission speed of a nerve impulse 5-120 m/sec.

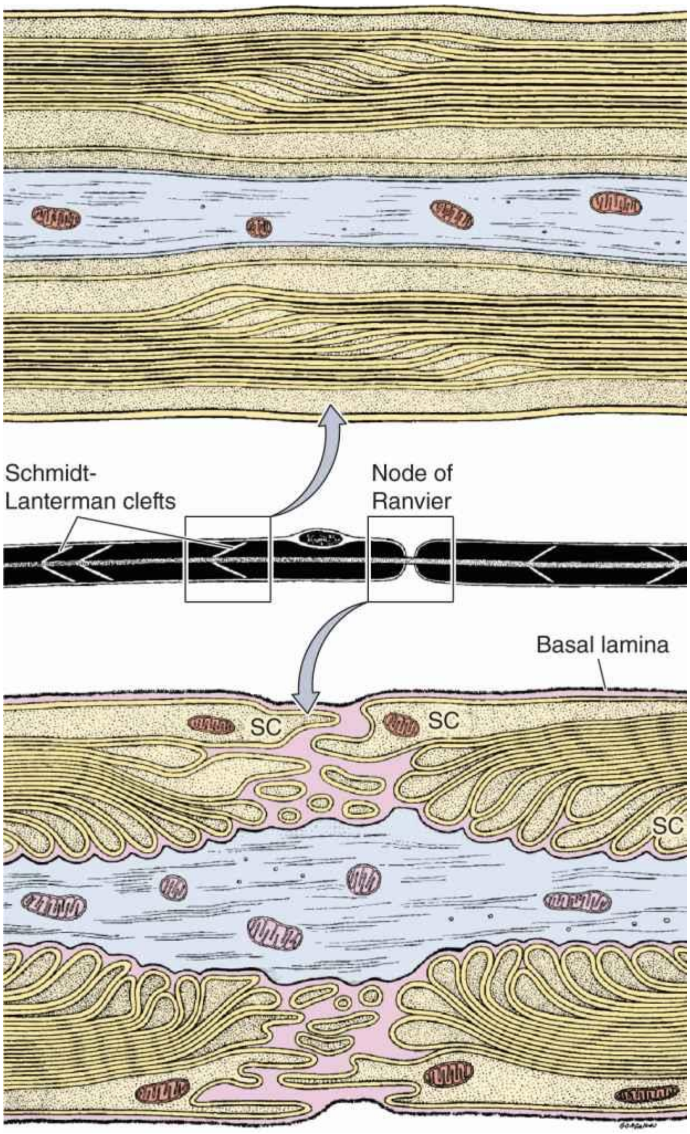


Figure 8 – Myelin maintenance and nodes of Ranvier. SC – Schwann cells

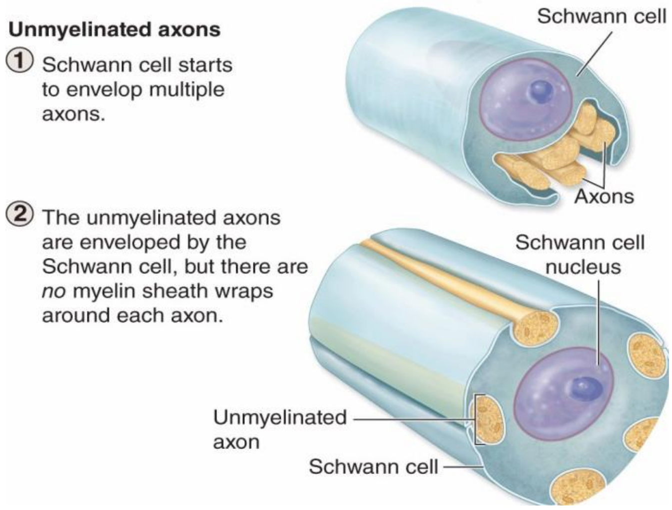


Figure 9 – Formation of the unmyelinated fibers

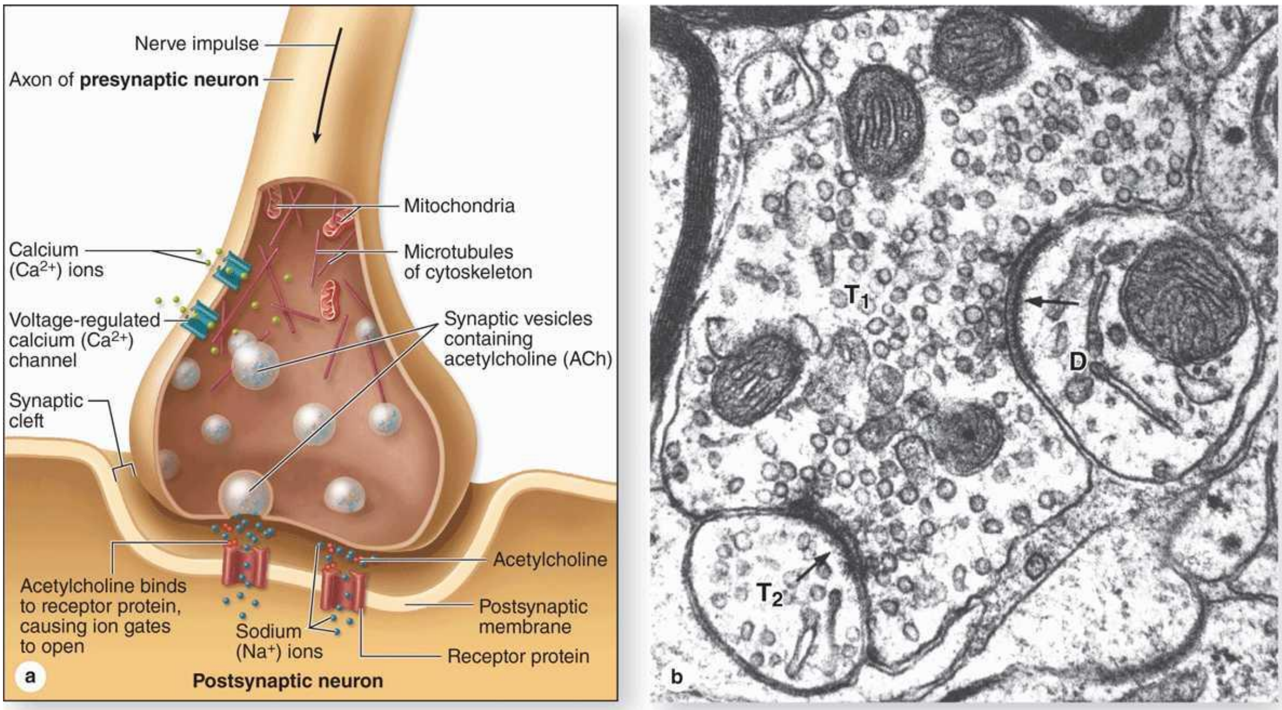


Figure 10 – Synapse: D – dendrite; T_1, T_2 - presynaptic terminals; arrows - synaptic clefts.

Synapses

They consist of two parts:

- a *presynaptic* part formed by the axon ending expansion of the transmitting cell;
- a *postsynaptic* part. This is the cytolemma site of the receiving cell.

Between these two parts there is microscopic space called a *synaptic cleft*. The axolemma part, which lies adjacent the synaptic cleft is called a *synaptic membrane*. The cytolemma site of the receiving cell, which is restricts the synaptic cleft, is called *postsynaptic membrane*.

The receptors are built-in postsynaptic membrane. In synaptic axon expansion of the transmitting cell neurofibriles, mitochondria and secretory vesicles are present. The vesicles contain neurotransmitters (mediators). Neurotransmitter is a substance-mediator in the transmission of stimulation.

Neurotransmitters may be:

- excitatory (acetylcholine, adrenalin);
- inhibitory (glycine, dophamin).

When a nerve impulse arrives, the permeability of the synaptic membrane increases. The neurotransmitter is released from the synaptic vesicles into the synaptic cleft. The neurotransmitter fuses with the receptors of the postsynaptic membrane and the nerve impulse arise on it. The neurotransmitter acts on the postsynaptic membrane for a very short period of time. Depending on the localization of the postsynaptic membrane, different synapses are distinguished: axosomatic, axoaxonic, axovasal, axomuscular and dendro-dendritic.

Neuroglia

Glia (neuroglia) is a type of cells in nerve tissue, which perform the auxiliary function in relation to neurons. Glia cells are special environment for neurons. Neuroglia performs supporting, trophic, secretory, and defensive functions.

All cells of neuroglia are divided into two genetic types:

- gliocytes (macroglia).
- glial macrophages (microglia).

Gliocytes are divided:

oligodendrocytes ← → astrocytes → ependymocytes

Macroglia arises from neural tube, microglia – from blood monocytes.

Oligodendrocytes surround the nerve cell. Oligodendrocytes are small cells of spherical shape, with very short processes. They surround the neuron bodies and participate in the formation of the nerve fiber sheaths. Oligodendrocytes perform a trophic function in relation to neurons.

Astrocytes. There are two types of astrocytes: plasmatic and fibrous ones. They provide the transport of substances from capillary walls to cytolemma of neurons. Fibrous astrocytes lie between the neuron body and the capillary, and plasmatic ones lie between nerve fibers. The presence of dense bundle of microtubules in the cytoplasm, help the astrocytes to serve supporting function.

Ependymocytes line the brain ventricles and the central canal of the spinal cord. They serve supporting function. On the surface of cells facing the cavity one can see cilia. They drive circulation of the cerebrospinal fluid (CSF). The processes branched from the opposite surface of cell formed the supporting apparatus of the brain. Some ependymocytes perform a secretory function. They participate in the formation and regulation of the cerebrospinal fluid composition.

Microglia represent a population of small cells with processes, that are located in the grey and white matter of the brain and are capable to phagocytosis.

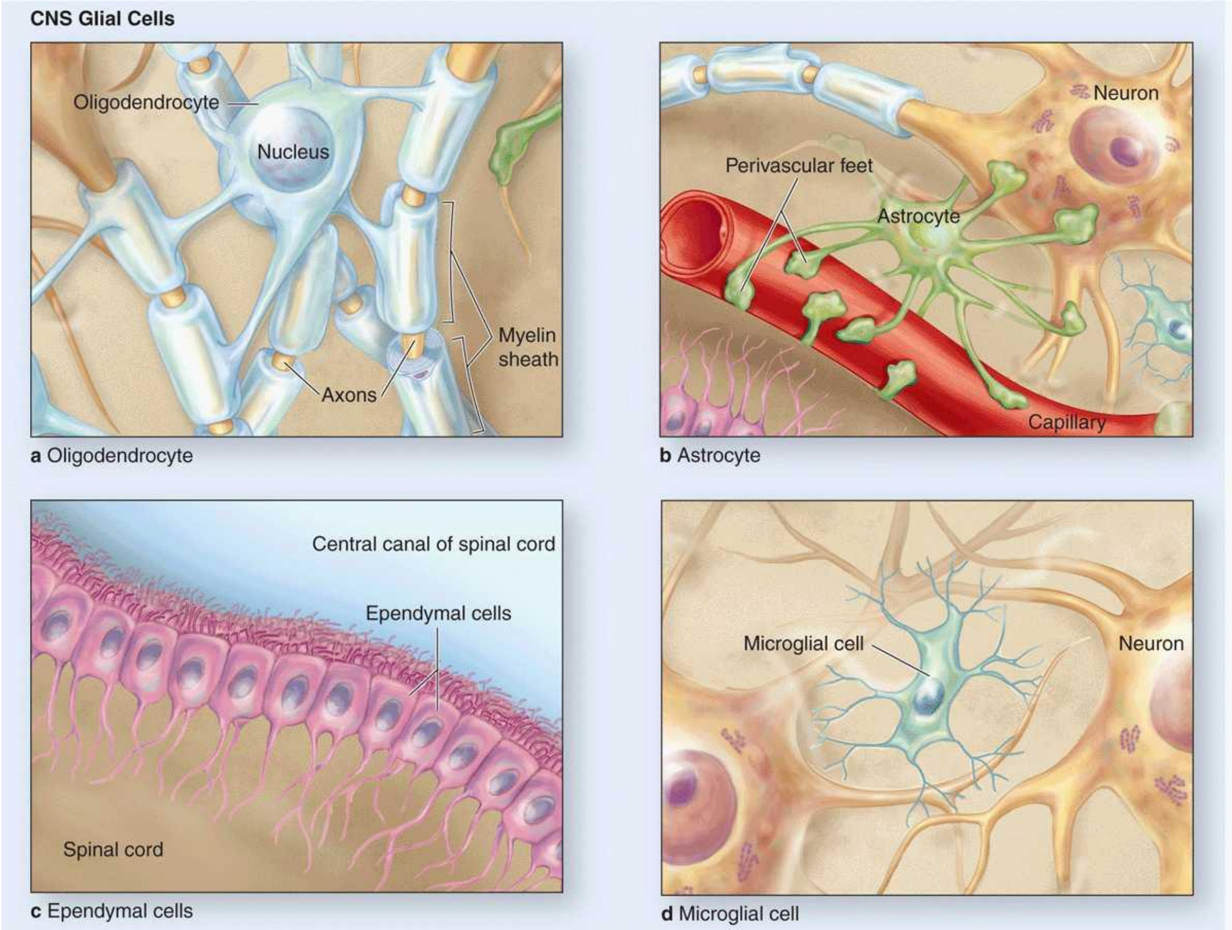


Figure 11 – Neuroglial cells

Receptors are sensory dendrites endings of nerve cells. They adopt to receive the stimulation and transform it into nerve impulse.

There are:

- *exteroreceptors*, receive external stimulation;
- *interoreceptors*, receive the stimulation from own tissues of the organism.

Proprioreceptors is a type of interoreceptors, which are present in muscles and tendons.

Depending on the type of the stimulation one can distinguish:

- *thermoreceptors*, receive the temperature change;
- *chemoreceptors*, receive the action of chemical substances;
- *mechanoreceptors*, receive the action of mechanical stimulations.

There are *free nerve endings* and *non-free endings* depending on structure. *Free nerve endings* are composed only of terminal branches of nerve process. For example, the receptors of the epiderma, which receive pain and temperature stimulations.

Non-free nerve endings contain branching of dendrites and neuroglia cells. Such endings are often covered by the connective tissue capsule. Therefore, they are called *encapsulated nerve endings*. If they have no capsules, they are called *non-encapsulated nerve endings*.

Let us consider the structure of encapsulated receptor ending. Take the onion-shaped body as an example (Vater-Pachini corpuscle). The nerve ending is located in the center. It has no myelin sheath. There is aggregation of modified neurolemmocytes around the nerve ending. These cells form *internal capsule*.

Around the internal capsule the collagen fibers are arranged in concentric layers and form the lamina. Fibroblasts lie between these laminas. The lamina and fibroblasts form *external capsule*. It constitutes the basic mass of the Pacinian corpuscle.

The Vater-Pachini corpuscles are numerous in the connective tissue, in the internal organs. They perceive pressure.

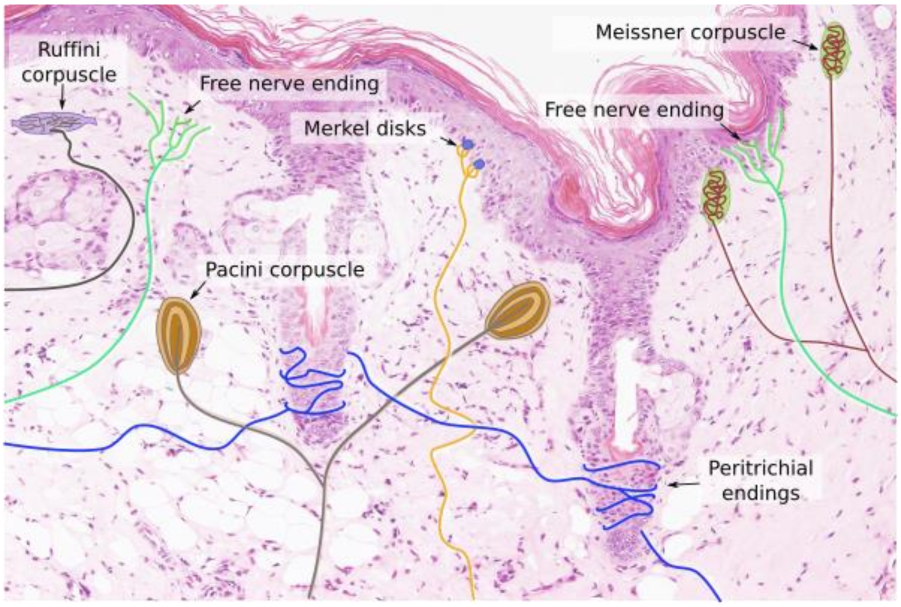


Figure 12 – Nerve endings of skin

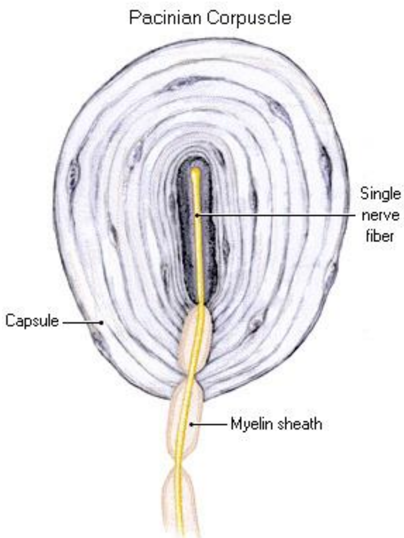
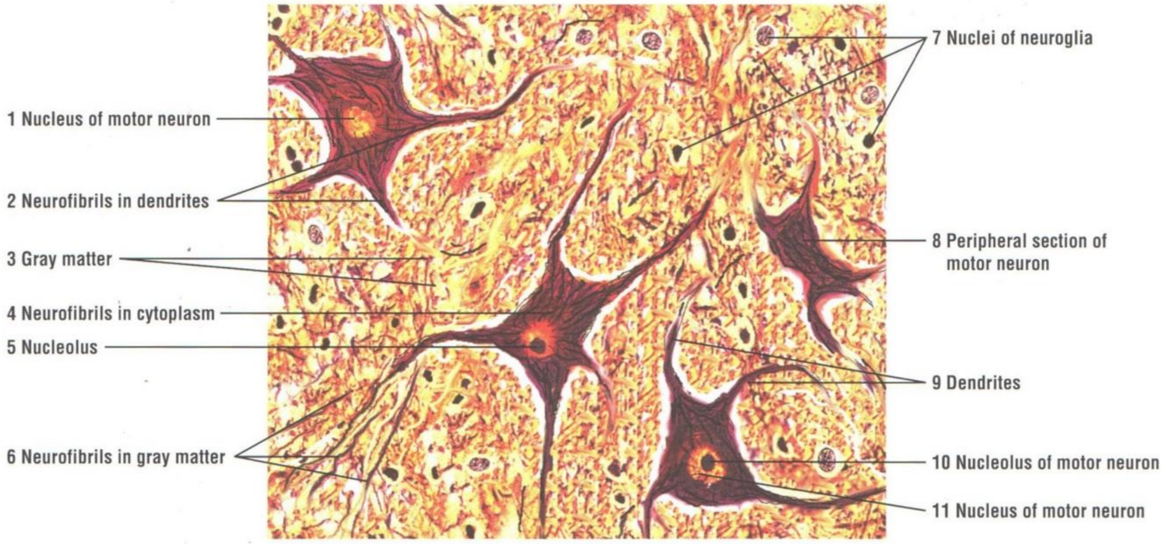
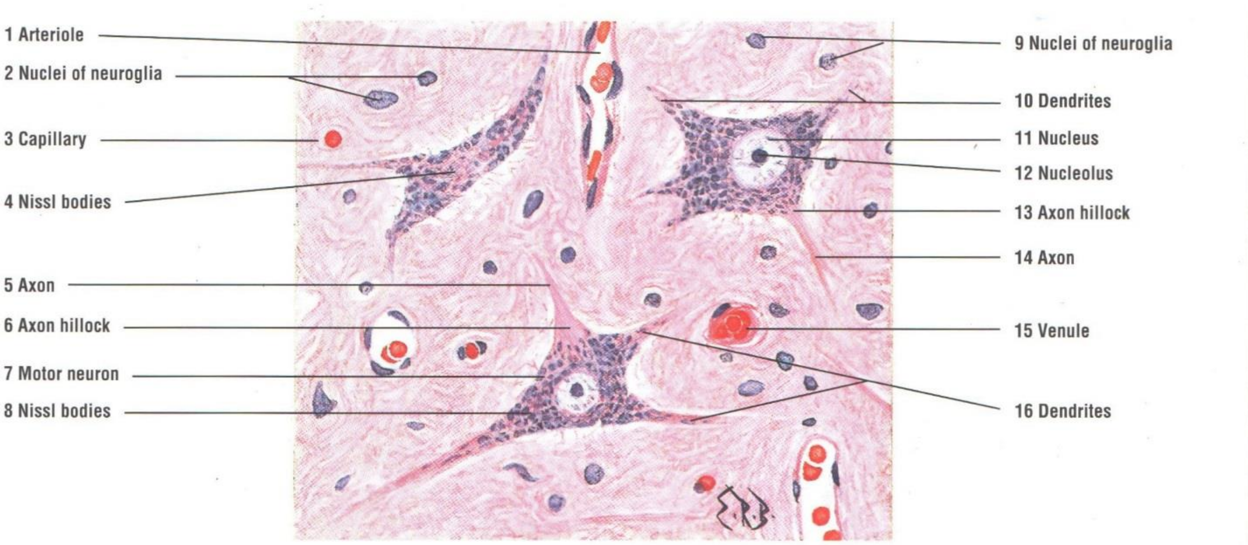


Figure 13 – Structure of the Pachinian corpuscle

Practical Part I



Slide 1. Neurofibrils and motor neurons.
Staining: silver impregnation.



Slide 2. Tigroid (Nissl bodies) in motor neurons.
Staining: hematoxylin and eosin.

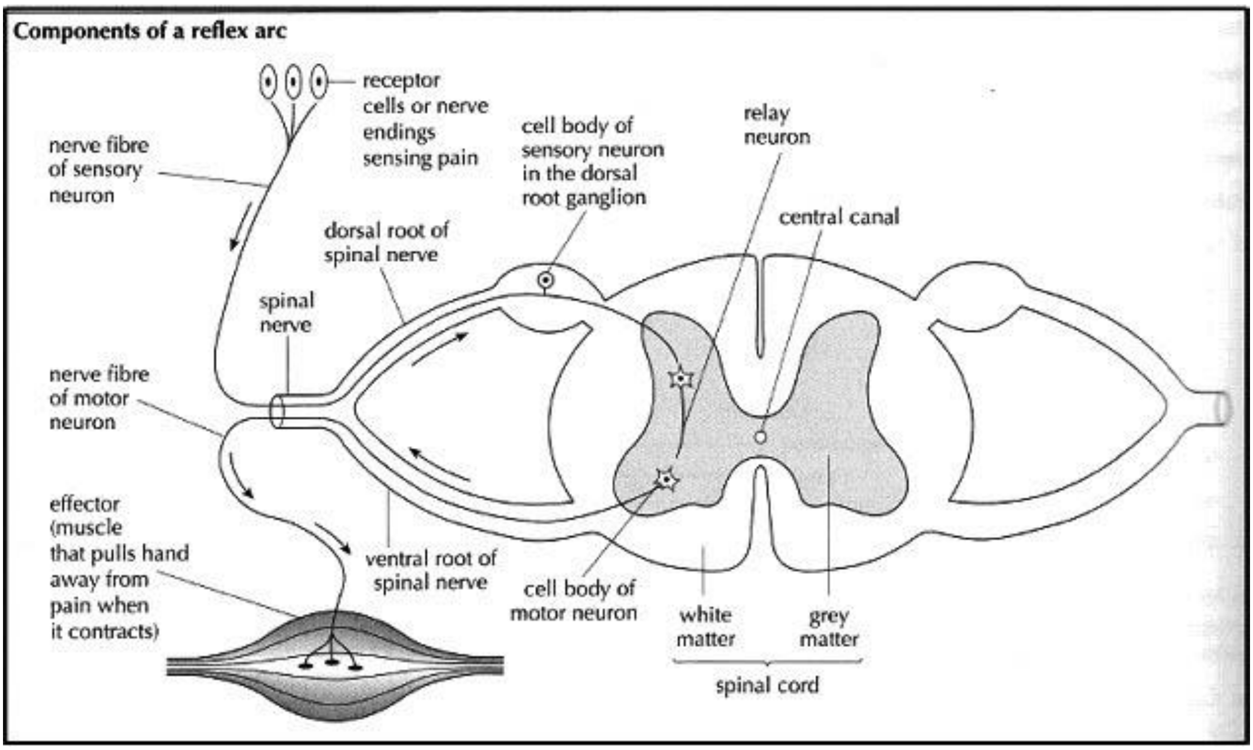


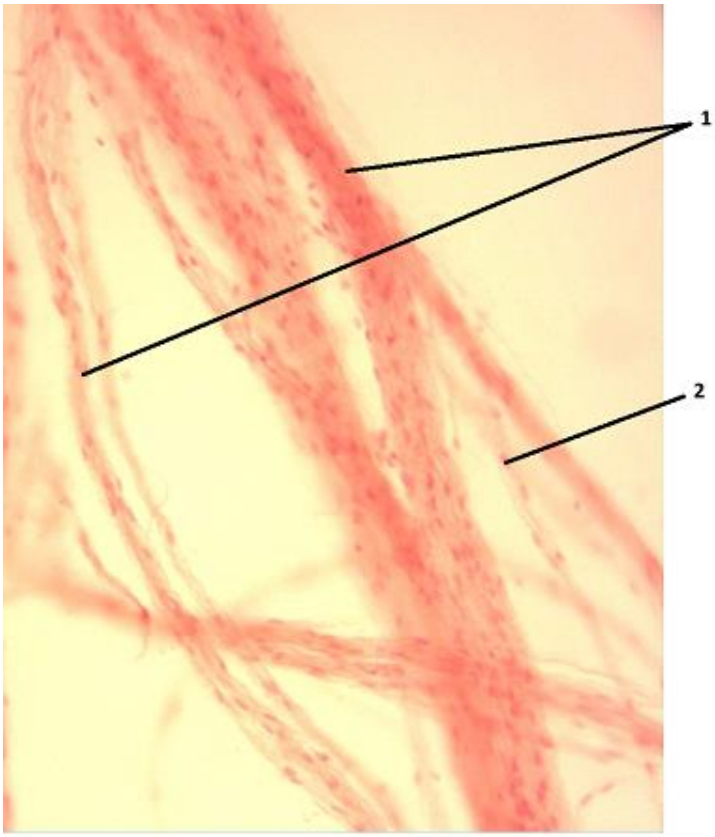
Diagram 1: Simple reflex arc.

Practical part II

Slide 1: Myelinated nerve fibers

Staining: osmic acid

1- myelin sheath.
2- axon.
3- neurofibrillar nodes (of Ranvier).



Slide 2: Unmyelinated nerve fibers

Staining: hematoxylin and eosin.

1- Shwann cell cytoplasm.
2- Shwann cell nucleus.

Ultrastructure 1: Myelinated nerve fiber

1 – axon (neuron process):
a) axolemma.

2 – myelin sheath.

3 – Schwann cell cytoplasm.

4 – Schwann cell nucleus.

5 – neurolemma.

6 – basement membrane.

Questions for self-control.

1. **What are the supporting cells in the central nervous system called?**
a. Schwann cells
b. Basket cells
c. Ganglion
d. Neuroglia
e. Satellite cells

2. **Which of the following is an element of the peripheral nervous system?**
a. Receptors
b. Brachial plexus
c. Ganglia
d. Sciatic nerve
e. All of the above

3. **What are most neurons in the body?**
a. Unipolar
b. Pseudounipolar
c. Bipolar
d. Multipolar
e. Both a and b

4. **What is the cell body of a neuron called?**
a. Ganglion
b. Perikaryon
c. Astrocyte
d. Nissl
e. Terminal bouton

5. **Which cell is a macrophage found in the central nervous system?**
a. Kupffer cells
b. Histiocyte
c. Dust cell
d. Langerhans cell
e. Microglia

6. **Which type of neuron is multipolar?**
a. Motor neurons
b. Interneurons
c. Sensory neurons
d. Both a and b
e. All of the above

7. **What provides tensile strength to a neuron?**
a. Meninges
b. Myelinated nerve fibers
c. Cell bodies
d. Nodes of Ranvier
e. Neurofilaments

8. **What is the primary component of myelin?**
a. Amino acids
b. Protein
c. Carbohydrate
d. Lipid
e. Both b and c

9. **Which of the following lines the ventricles?**
a. Astrocytes
b. Ependymal cells
c. Oligodendrocytes
d. Microglia
e. Schwann cells

10. **Which of the following is involved in the blood brain barrier?**
a. Astrocytes
b. Ependymal cells
c. Oligodendrocytes
d. Microglia
e. Schwann cells

Answers:

1. Answer: d
Schwann cells are responsible for the myelination of neurons in the peripheral nervous system. Basket cells are a type of neuron seen in the cerebellum. A ganglion is a collection of nerve cell bodies outside of the CNS. Neuroglia are the supporting cells in the central nervous system Sometimes, neuroglia called glial cells or glia. Satellite cells are found in the ganglia of the peripheral nervous system.

2. Answer: e
The central nervous system consists of the brain and spinal cord. All other nervous system elements are considered to be in the peripheral nervous system. Thus, the peripheral nervous system includes receptors, the brachial plexus, the sciatic nerve, and ganglia.

3. Answer: d
Most neurons in the body (over 99%) are multipolar.
Neurons can be classified based on the number of axons and dendrites stemming off from the cell body. A unipolar neuron has one process which branches off from it. This process then immediately divides into two. Thus, a unipolar neuron is sometimes also called a pseudounipolar neuron. Sensory neurons are unipolar.
A bipolar neuron has two processes that branch from it: an axon and a dendrite. Bipolar neurons are not very common and are found in some of the organs for special senses. Bipolar neurons are found in the retina, inner ear, and the region of the nose involved with smell.
Multipolar neurons have one axon and many (at least two) dendrites that branch off from it. Most neurons are multipolar. Motor neurons and interneurons are multipolar.

4. Answer: b
A ganglion is a collection of neuron cell bodies outside of the central nervous system. The cell body of a neuron is called a perikaryon or soma. An astrocyte is a supporting cell seen in the central nervous system. The basophilic clusters of ribosomes and rough endoplasmic seen in neuron cell bodies is called Nissl, Nissl bodies or Nissl substance. The terminal bouton is the end portion of an axon. It is also called an axon terminal or end bulb. The terminal bouton will be associated with another neuron in a synapse.

5. Answer: e
Macrophages are mononuclear phagocytes. Many tissues have resident (fixed) macrophages. Fixed macrophages are given a unique name, depending on the tissue that they are located in. Kupffer cells are the hepatic macrophages. Histiocytes are macrophages seen in connective tissue. Dust cells are alveolar macrophage found in the respiratory tract. Langerhans cells are macrophages seen in the skin. Microglia are the central nervous system macrophages.

6. Answer: d
Both motor neurons and interneurons are multipolar.

7. Answer: e
The meninges are composed of the three connective tissue covers which surround the brain and spinal cord. White matter is myelinated nerve fibers. Grey matter is essentially neuron cell bodies and associated dendrites or unmyelinated axons. Nodes of Ranvier are the gaps that occur in the myelin sheath. Neurofilaments are a type of intermediate filaments seen in neurons which provide rigidity and tensile strength.

8. Answer: d
The primary component of myelin is lipid. It is formed by the cell wrapping itself around the axon. Thus, it is primarily the plasma membrane of either the Schwann cells or the oligodendrocytes.

9. Answer: b (see an explanation in answer 10)

10. Answer: a
Neuroglia are the supporting cells of the central nervous system. Sometimes, neuroglia called glial cells or glia. Astrocytes, ependymal cells, oligodendrocytes, and microglia are all neuroglia.
Of the neuroglia cells, astrocytes are the most abundant and the largest. These are star shaped cells involved in the blood brain barrier.
Ependymal cells line the ventricles and spinal canal.
Oligodendrocytes form myelin in the central nervous system.
Microglia are the central nervous system macrophages.
Schwann cells are seen in the peripheral nervous system and are not considered neuroglia. Schwann cells are responsible for the myelination of neurons in the peripheral nervous system.

Topic: Nervous System

Embryogenesis of the nervous system:

The dorsal ectoderm originates the Nervous tissue. On day 18 the neural plate is formed in the human embryo. From the neural plate the neural tube arises. Some of the cells of the neural plate does not participate in the neural tube composition. Neural crest cells arise from these cells. Neural crest cells give rise to cells of:

1. Spinal ganglia.
2. Autonomous nervous system ganglia.
3. Adrenal medulla.

The cranial end of the neural tube forms the brain and cerebellum and the caudal end develops to form the spinal cord.

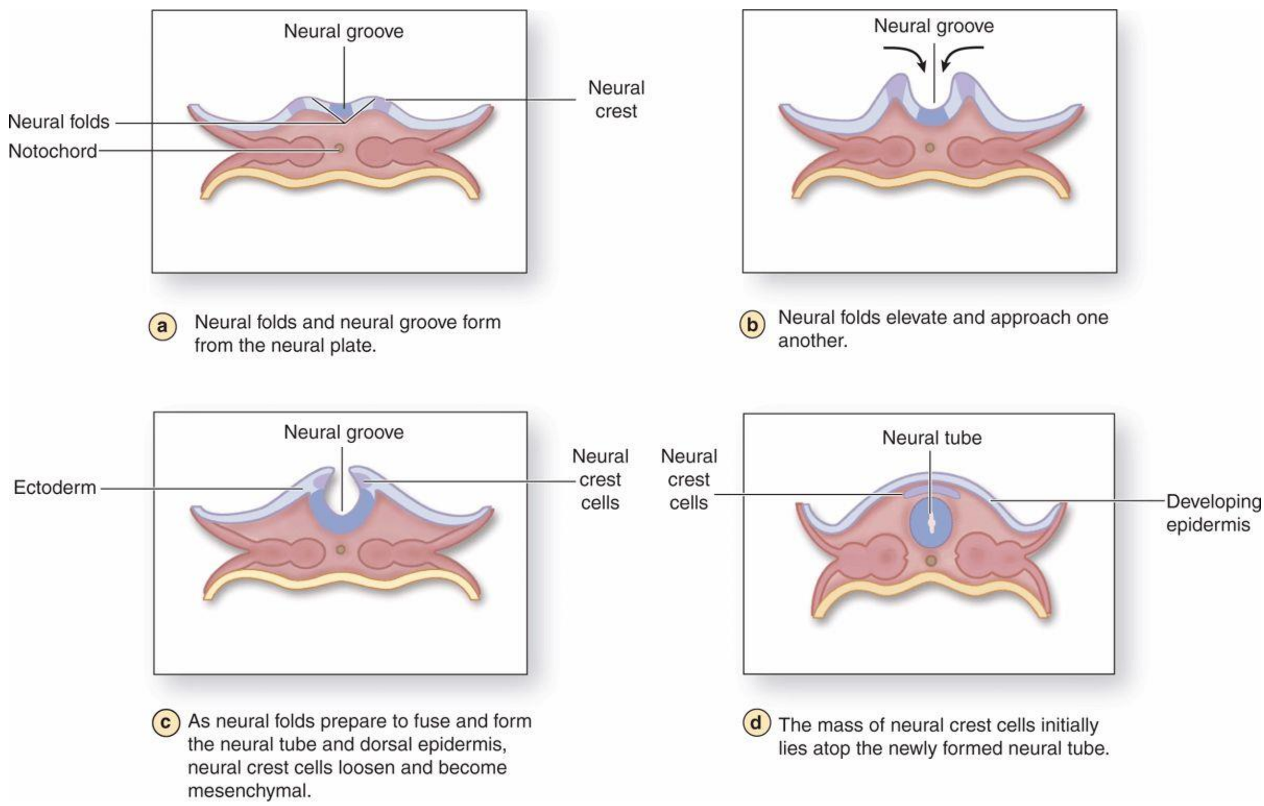


Figure 14 – Development of the nervous system.

Functions of the nervous system:

Firstly, the nervous system connects parts of the bode into a single whole.

Secondly, it coordinates the functions of various organs and tissues.

Thirdly, it provides the interaction of the body with the external environment.

The nervous system receives information from internal organs and external environment, analyses and integrates it to produce appropriate coordinated responses.

Anatomically, the nervous system is divided into:

↙ ↘

CNS (central nervous system) - brain and spinal cord

PNS (peripheral nervous system) - ganglia, nerves and nerve endings

Physiologically, the nervous system is divided into:

↙ ↘

Somatic - innervates body (besides organs innervated by autonomous n.s.)

Autonomous (Vegetative) - innervates the internal organs, vessels, glands.

Brain

The brain comprises the grey matter and the white matter. The most part of the grey matter lies on the surface of the cerebrum and in the cerebellum and forms the cerebral cortex. The small part of the grey matter forms the nuclei of the brainstem.

The nuclei of the brainstem are divided into:

1. Sensitive.
2. Motor.
3. Associative.

The white matter of the brainstem consists of nerve fibers, which form ascending and descending tracts. They connect different parts of CNS.

The brain consists of the forebrain (prosencephalon), midbrain (mesencephalon) and hindbrain (rhombencephalon). Forebrain contains telencephalon (cerebral hemispheres, covered with cerebral cortex), and diencephalon, or interbrain, in the deep (consist of thalamus, hypothalamus, epithalamus, and subthalamus). Hindbrain contains brainstem, which contains medulla oblongata and pons.

Cerebral Cortex

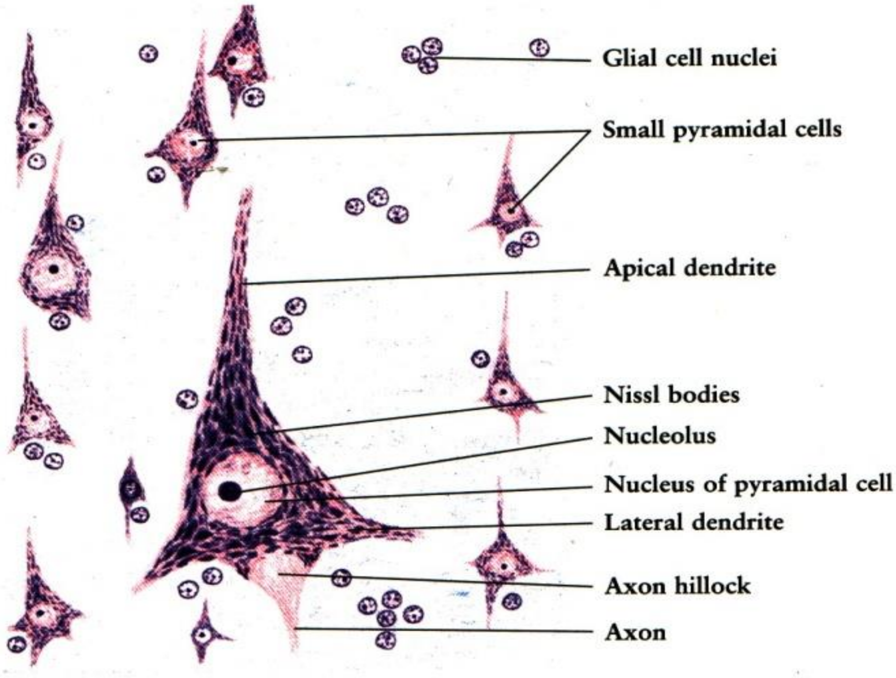
The cerebral cortex ensures the regulation of body functions and complex forms of behavior. Each of two cerebral hemispheres has the cerebral cortex – an outer layer of grey matter layer with a thickness of 3-5 millimeters. The grey matter contains 10 - 15 billion of nerve cells and over 100 billion nerve fibers and neuroglia cells.

The cortex neurons are multipolar of various sizes and shapes. There are more than sixty types of cortex neurons among which we distinguish two main ones - pyramidal and nonpyramidal.

Pyramidal cells constitute 50 – 90% of all cortex neurocytes. The apical dendrite extends from the apical pole of the cell body and enter the molecular layer of the cortex, where it is branched. 5 – 16 lateral dendrites extend from the basal and lateral parts of the cell body. They are branched within that layer, where there is the cell body. From the middle of the basal surface of the body a long axon arises, which extends to the white matter. The sizes of pyramidal neurons may vary from 10 - 140 μm. Giant, large, medium and small pyramidal cells are distinguished.

Non-pyramidal cells lie in all cortex layers, receive afferent impulses and their axons transmit impulses to the pyramidal neurons.

Cerebral Cortex: Pyramidal Cell
Human • Nissl stain • High magnification



Cerebral Cortex: Pyramidal Cell
Human • Golgi stain • High magnification

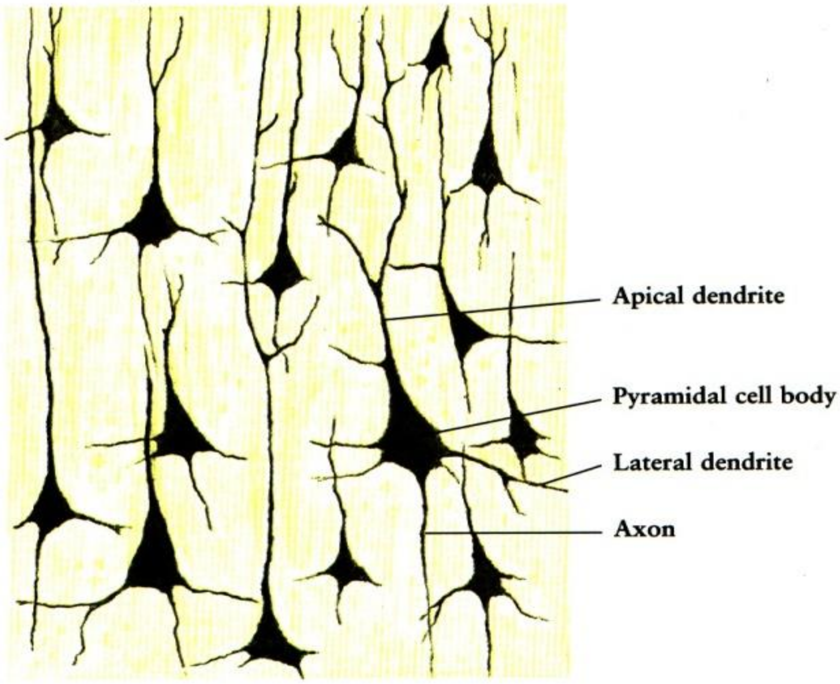


Figure 15 – Pyramidal cells in cerebral cortex.

Cytoarchitectonics in Cerebral Cortex in a layer arrangement

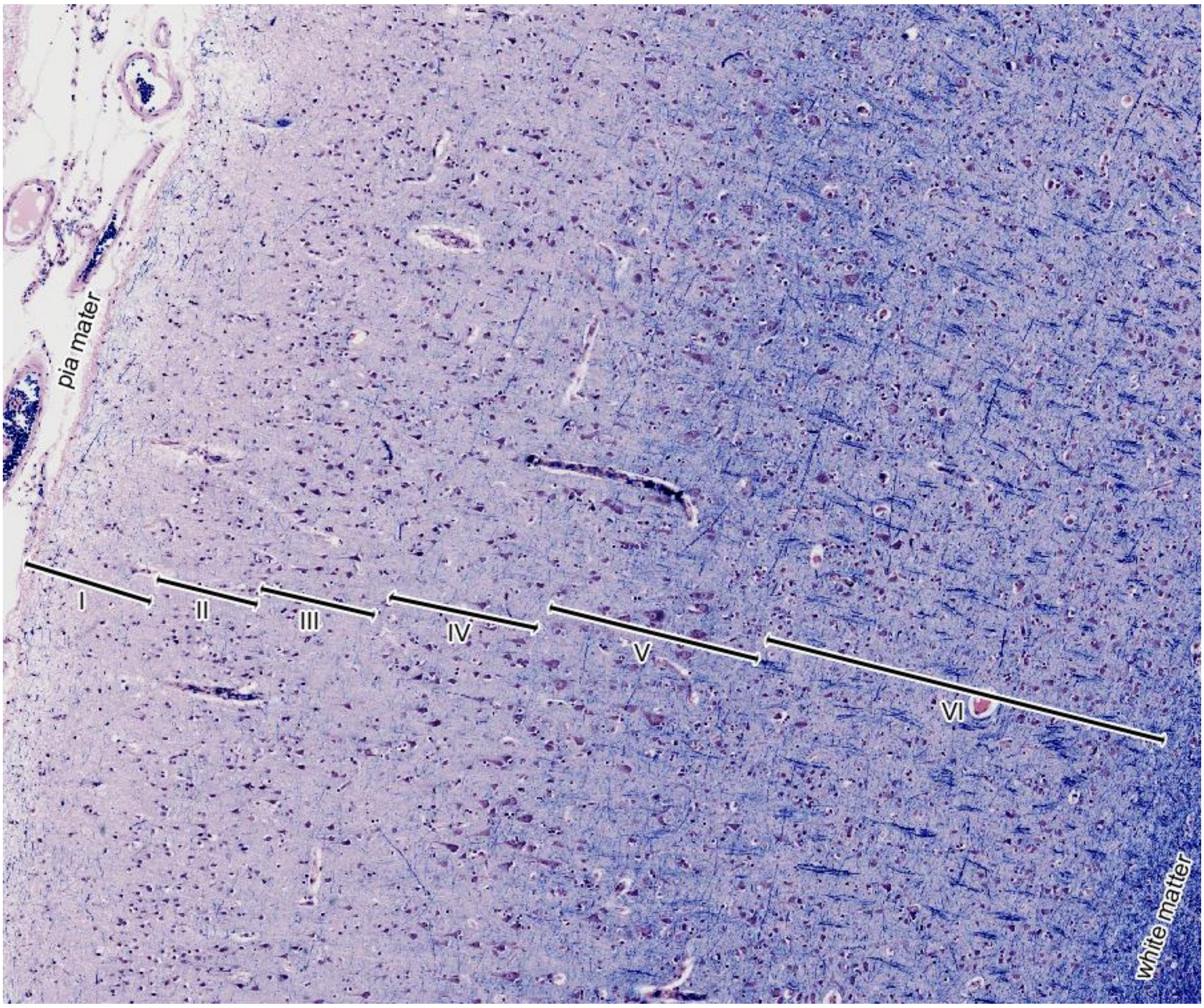


Figure 16 – Cytoarchitectonics in cerebral cortex. Luxol fast blue staining

The cerebral cortex consists of six layers:

I. *Molecular layer* lies beneath pia matter encephalic. It is composed of a few small neurons — horizontal cells with long dendrites which extends from a spindle shaped body. Their axons take part in forming the fibre plexus of this layer.

II. *External granular layer* is a relatively thin layer composed of numerous small pyramidal and satellite cells, dendrites and axons, ascending towards the molecular layer.

III. *Pyramidal layer* is composed of small-, medium- and large-sized pyramidal cells. The apical dendrites pass into the molecular layer, and the lateral ones forms synapses with the cells of their own layer. Axons terminate the grey matter or pass to the white matter. Non-pyramidal cells are also present in this layer. These cells interconnect with cells of their own hemisphere or with cells of the opposite hemisphere.

IV. *Internal granular layer* is wide in visual and acoustic regions of the cortex and is almost absent in the sensomotor region. This layer is arranged by pyramidal and satellite cells.

V. *Internal pyramidal* (*Ganglionic) layer* is arranged by large pyramidal cells, but in the region of motor cortex — by the giant pyramidal cells (Betz cells). The apical dendrite extends to the first layer, and the lateral dendrites are within their own layer. The axon extends to the motor nuclei of the brain and spinal cord as parts of the pyramidal tracts.

VI. *Multiform layer* is formed by cells of various shapes. The axons of these cells in the composition of efferent tracts pass into the white matter, but the dendrites extend to the molecular layer.

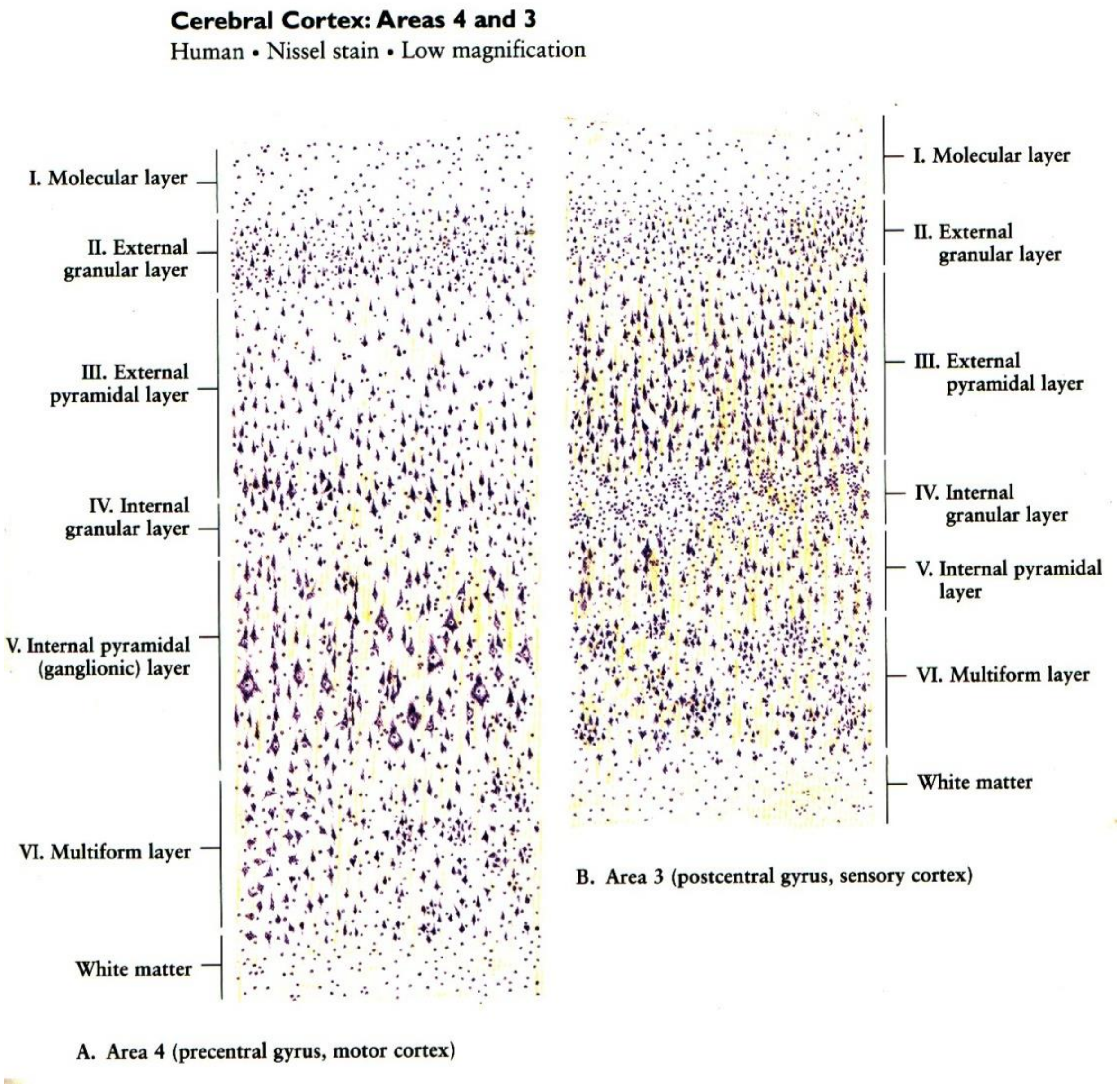


Figure 17 – Cytoarchitectonics in various zones of cerebral cortex.

Types of cortex structure.

The cerebral cortex shows two types, depending on performing various functions. There are agranular and granular types of cortex.

Agranular type of the cortex is characteristic for motor centres. The III, V, VI layers of the cortex being developed the most.

Granular type of the cortex is characteristic for the regions, where sensory cortical centres are situated, the granular layers being developed the most. There are few pyramidal cells here.

Cortex myeloarchitectonic of the brain hemisphere.

The nerve fibers of brain hemisphere can be divided into three groups:

1. *Afferent* - the most part of them terminates on the level of the fourth layer.

2. *Associative* and *commissural* are intracortical fibers, connecting different cortical regions of same or another hemisphere.

3. *Efferent* fibers connect the cortex with the subcortical nuclei.

Cerebellum

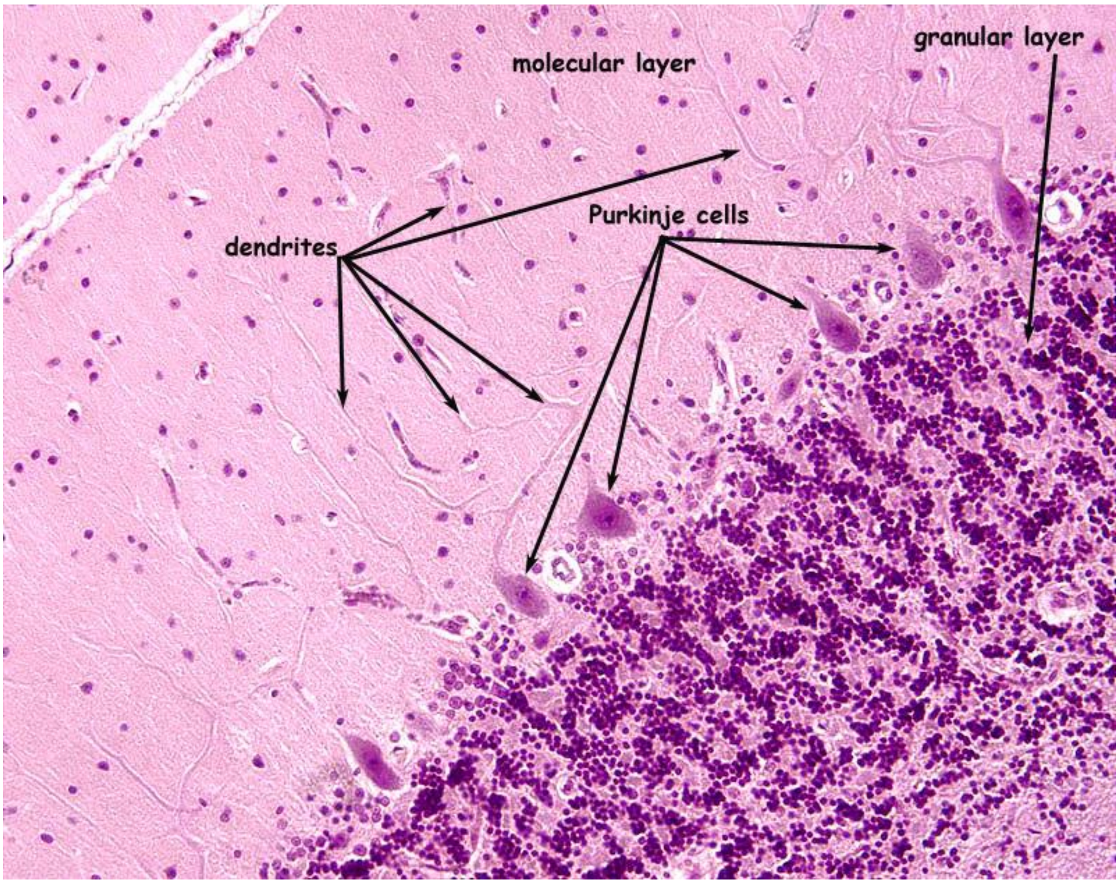


Figure 18 – Layers of cerebellar grey matter.

The cerebellum is the equilibrium and coordination center of body movements, concerns with the maintenance of muscular tension and consists of two hemispheres.

The grey matter constitutes the cerebellum cortex and nuclei, which are in the thickness of the white matter.

The cerebellar cortex is organized in three layers: molecular, ganglionary and granular layers.

I. *The molecular layer* is formed by the bodies of basket and stellate cells. The basket cells lie in the inner part of the molecular layer. Their short dendrites are connected with fibers of the molecular layer, and long axon transverses the convolution and send collaterals to the Purkinje cell bodies, surround perikaryons like baskets and form the inhibitory axosomatic synapses. There are small and large stellate cells. Dendrites and axons of small stellate cells form synapses with dendrites of Purkinje cells. Large stellate cells form synapses with dendrites and bodies of the flask-shaped cells. Basket and stellate neurons of the molecular layer are inserted neurons, which transmit inhibitory nervous impulses to the dendrites and bodies of Purkinje cells.

II. *Purkinje cell layer (or ganglionic layer)* is formed by a single row of flask-shaped Purkinje cells. From a large body of Purkinje cell two-three dendrites reach up into molecular layer. At the body base the axon arise, which terminate on the cells of cerebellar subcortical nuclei.

III. *The granular layer* contains some types of cells:

1) Numerous and tiny *granule cells*. From the neuron bodies three to four dendrites extend, and branch in this layer like a bird paw. They form synapses with *mossy fibers* and form so-called glomeruli of the cerebellum. Axons of the granule cells enter the molecular layer and there they are divided into two branches in the shape of the letter T. These branches run parallel to the surface of the cerebellar folium and form numerous synapses with the dendrites of the Purkinje, basket and stellate cells. Thus, the excitatory impulses are transmitted along the axons of the granule cells from the mossy fibers to numerous Purkinje cells.

2) large *Golgi cells*. They have two varieties:

a) – Golgi cell type I (with long axons) which dendrites ramify in the granular layer and which axons enter the white matter. These cells interconnect different regions of the cerebellar cortex.

b) - Golgi cell type II (with short axons). Their dendrites form synapses with the axons of the granule cells in the molecular layer. In the granular layer the axons form synapses with dendrites of the granule cells in the zone of the cerebellar glomeruli. These cells inhibit the impulses transmitting along mossy fibers to the granule cells.

The excitatory afferent impulses to the cerebellum cortex are transmitted by *mossy* and *climbing* fibers.

The *mossy fibers* terminate in the glomeruli of the cerebellar granular layer, where the synapses with the granule cells dendrites arise. The granule cells axons transmit the impulse to the dendrites of the flask-shaped (Purkinje), basket, stellate neurons and Golgi cells of the granular layer.

The climbing fibers. A direct contact between climbing fibers and the bodies and dendrites of Purkinje cells results in synapses.

Thus, the excitatory impulses to the cerebellar cortex enter and reach flask-shaped (Purkinje) neurons directly through the climbing fibers or mossy fibers via granule cells. Inhibitory signals are those, which the stellate and basket neurons of the molecular layer and Golgi cells of the granular layer convey. Efferent inhibitory impulses are transmitted to the cerebellar nuclei through the axons of the Purkinje cells.

Nerve center is the aggregation of nerve cells in CNS and PNS, between which synaptic transmission occurs.

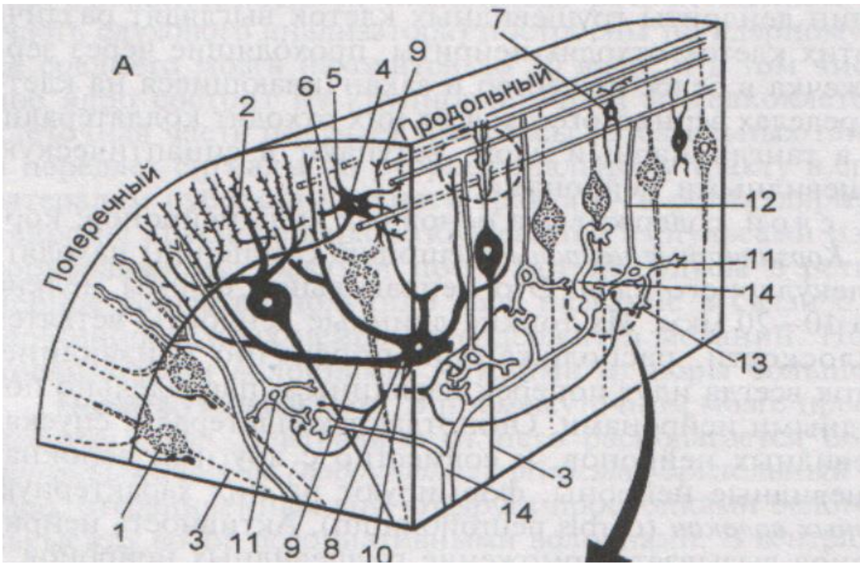


Figure 19 – Structure of cerebellar grey matter.

1. Body of flask-shaped Purkinje cell.
2. Dendrites of flask-shaped Purkinje cell.
3. Axon of flask-shaped Purkinje cell.
4. Basket cell.
5. Dendrites of basket cell.
6. Axon of basket cell.
7. Stellate cells.
8. Body of Golgi cell type II (with short axons).
9. Dendrites Golgi cell type II (with short axons).
10. Axon of Golgi cell type II (with short axons).
11. Body of the granule cell.
12. Axon of the granule cell.
13. Dendrites of the granule cell.
14. Mossy fibers.
15. Climbing fibers.

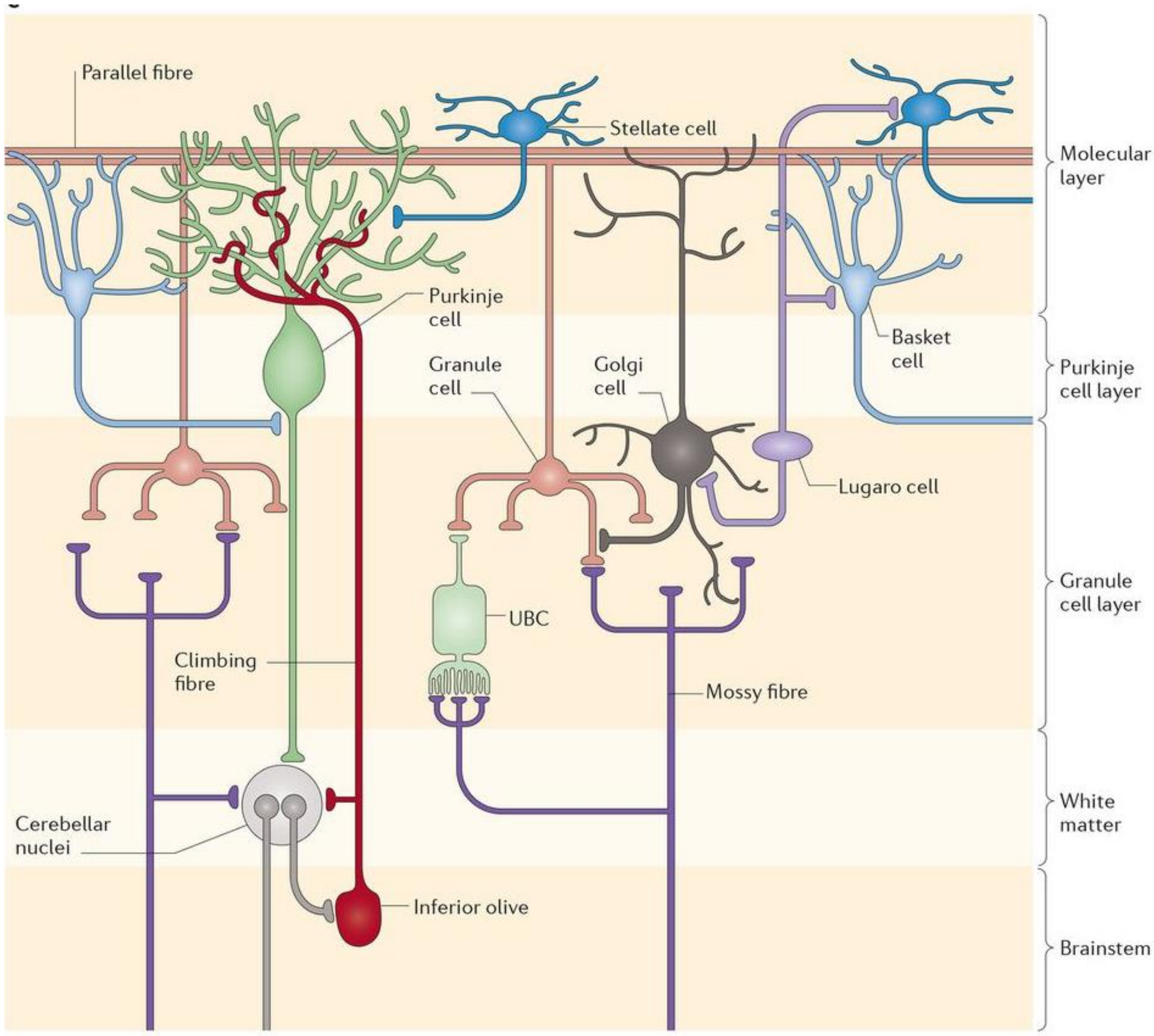


Figure 20 – Interneuronal connections in cerebellum.

Spinal cord

In adult, the spinal cord begins under the great foramen of the skull and ends between the first and second lumbar vertebrae. It is composed of grey and white matter. The grey matter is constituted by the neuronal cell bodies.

Topography of Neurocytes in the Grey Matter

In the grey matter, the neurocyte bodies are grouped and are called nuclei. The cells of the same morphology and function form these groups. These groups are *nervous centers*. There are five nucleus groups in the anterior horns, which are composed of the motor neurons. These groups refer to the *first nucleus type*. They are classified into:

- the medial group of nuclei, which innervate muscles of the trunk;
- the lateral group of nuclei innervating limb muscles.

The axons of these cells enter the composition of the anterior roots of the spinal cord.

The *second nucleus type* is in the posterior horns

- proper nucleus of the posterior horns; - thoracic nucleus	These nuclei are composed by multi-polar associative neurons

The axons of these cells enter the white matter and form the conduction tracts.

In the C_{VIII} - L_{II} segments of the spinal cords there are lateral horns where the intermediolateral nucleus lies. It is formed by the vegetative nervous system. Their axons leave the spinal cord in the composition of the anterior roots, forming preganglionary fibers, which extend to the sympathetic and parasympathetic ganglia.

The white matter

It is divided into the anterior, lateral and posterior funicles, which are composed of myelin nervous fibers and form descending and ascending tracts.

Cerebrospinal ganglion

It is located in the posterior roots of spinal cord. The cerebrospinal ganglion is surrounded by connective tissue, from which the layers of connective tissue pass into parenchyma of ganglion and form the ganglion base. The cerebrospinal neurons of ganglion lie peripherally in the organ in groups, the processes of these cells being in the center. The dendrites in the composition of the cerebrospinal nerves extend to the periphery and terminate with receptors. The axons form posterior roots and conduct nervous impulses into the grey matter of the spinal cord or medulla oblongata.

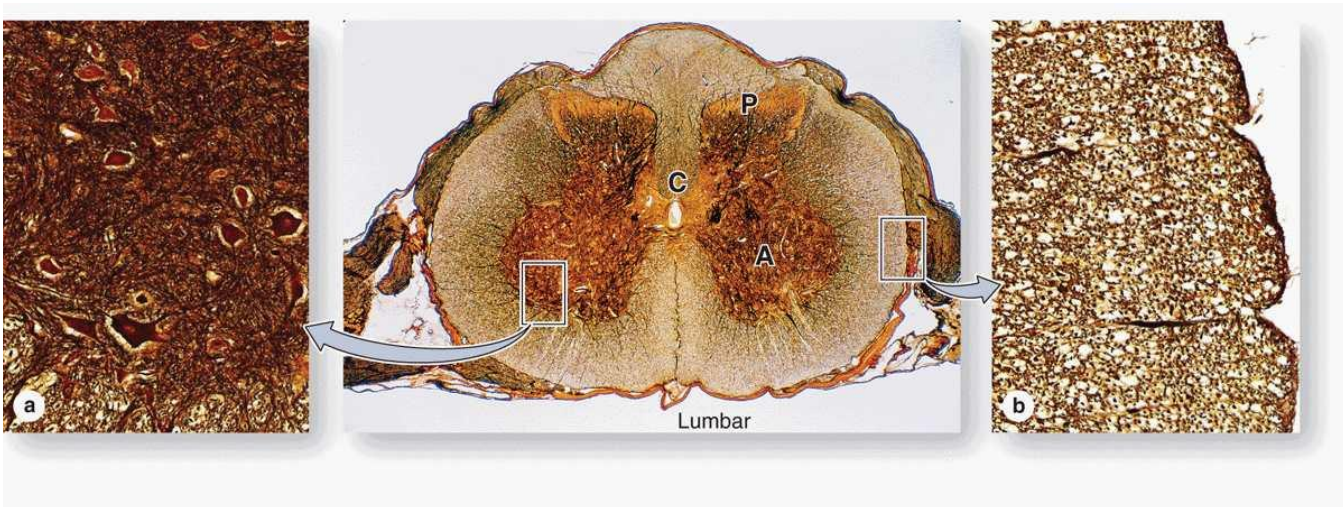


Figure 21 – Spinal cord. Silver stained.

A - anterior horn, P - posterior horn, C - central canal

a - neurons of grey matter, b - white matter.

There are pseudounipolar sensory neurons in the spinal ganglia. These neurons are I (the first) cells of the reflex arc. Perikaryons of the pseudounipolar neurocytes are enveloped by two membranes:

-internal (mantle gliocytes)

-external (connective tissue membrane)

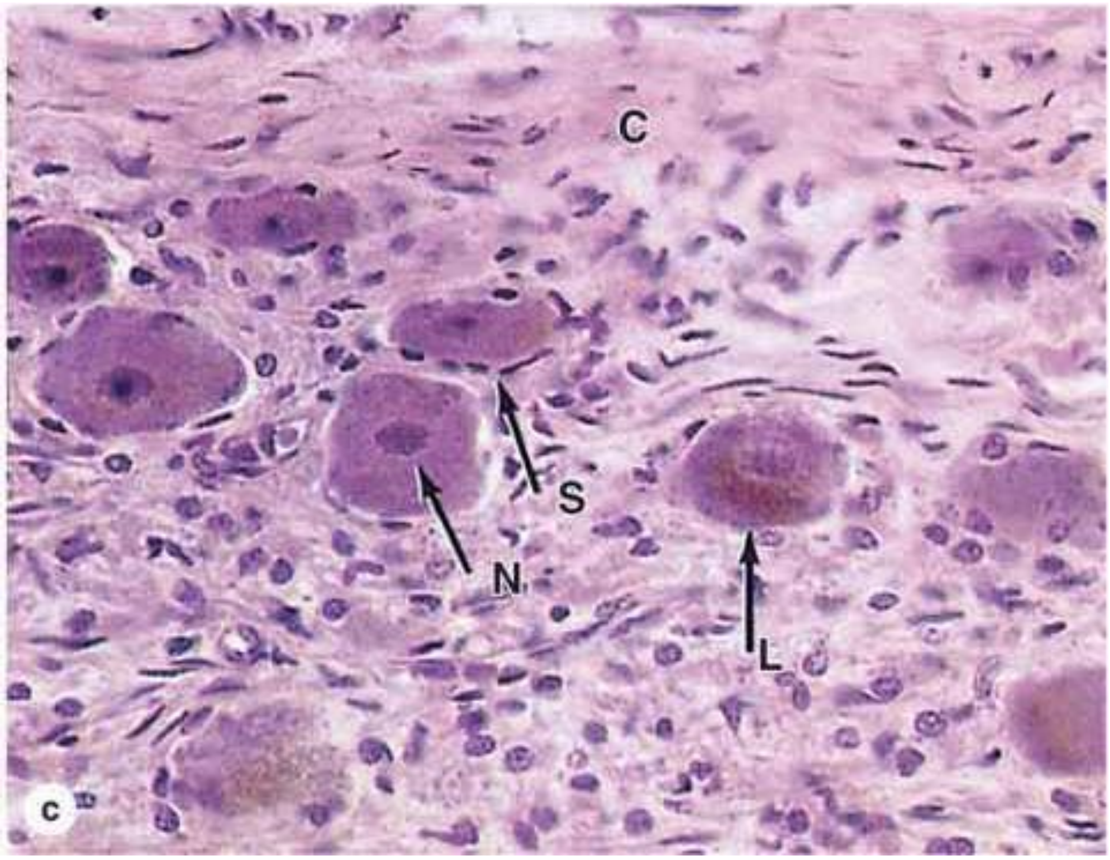


Figure 22 – Sensory ganglion. H&E staining.

C - connective tissue capsule,

N - neuronal cell bodies,

L - neurons, which contains lipofuscin,

S - sheets from satellite cells (gliocytes)

Practical Part I

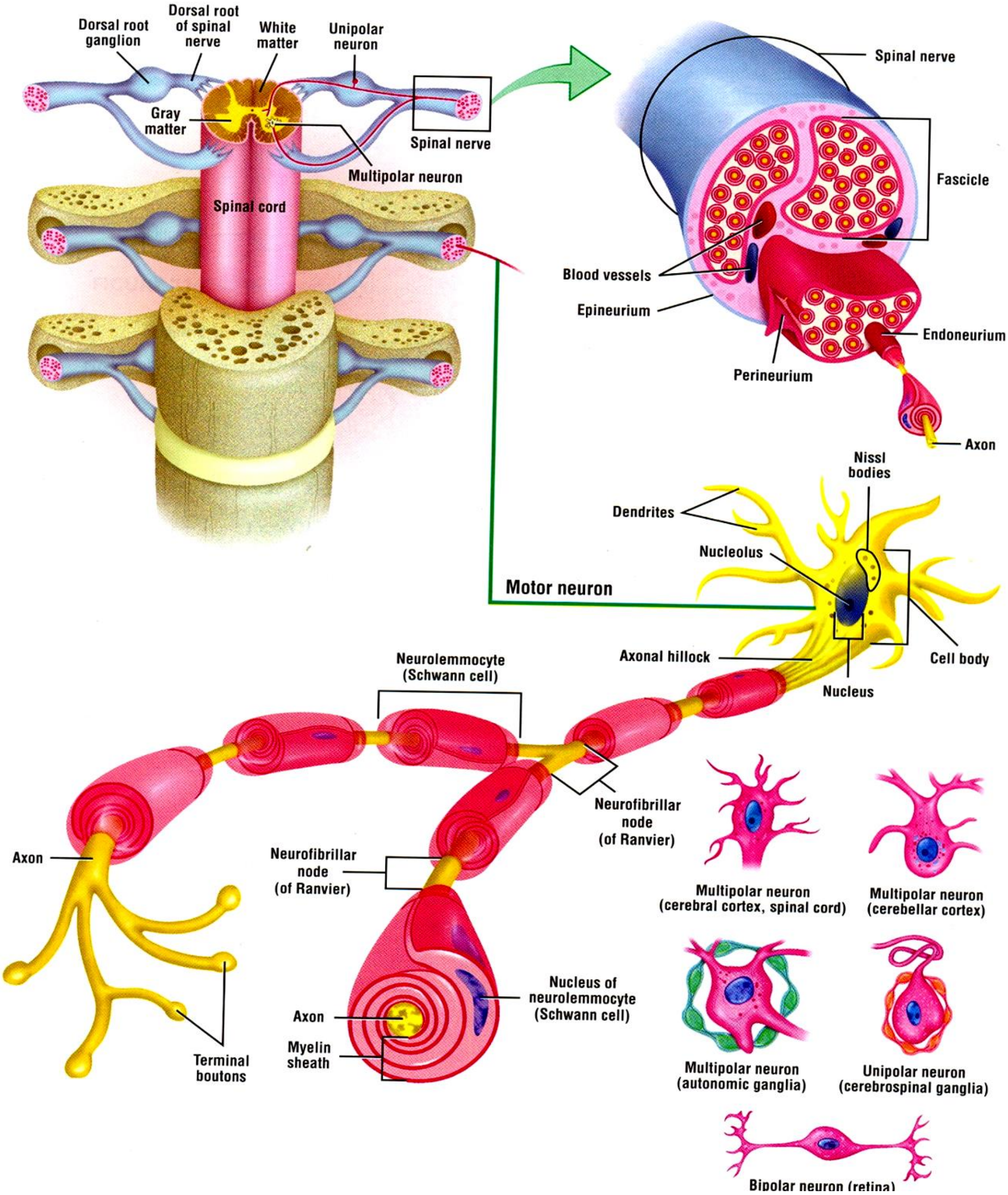
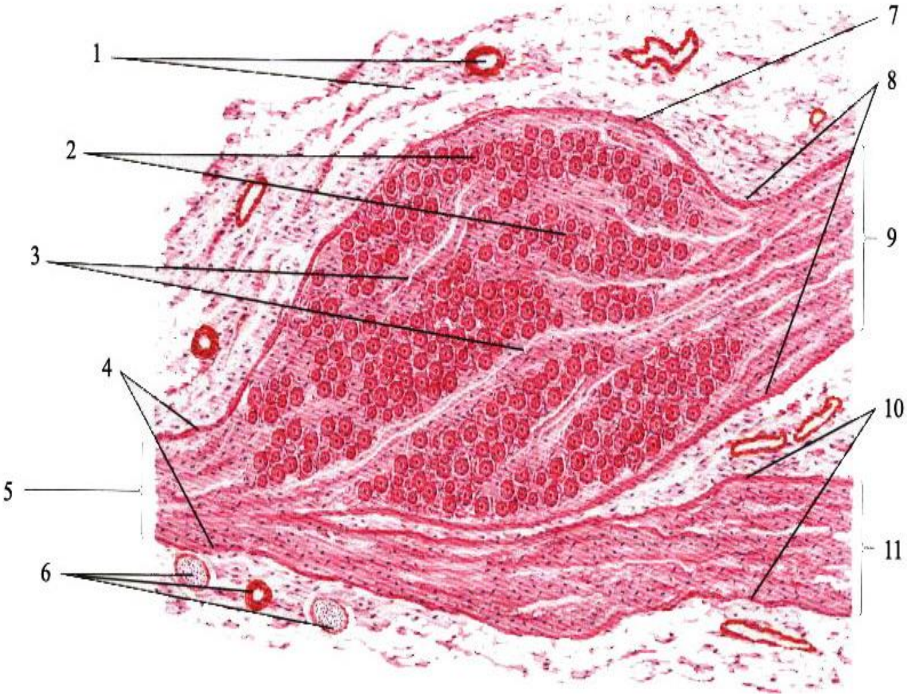
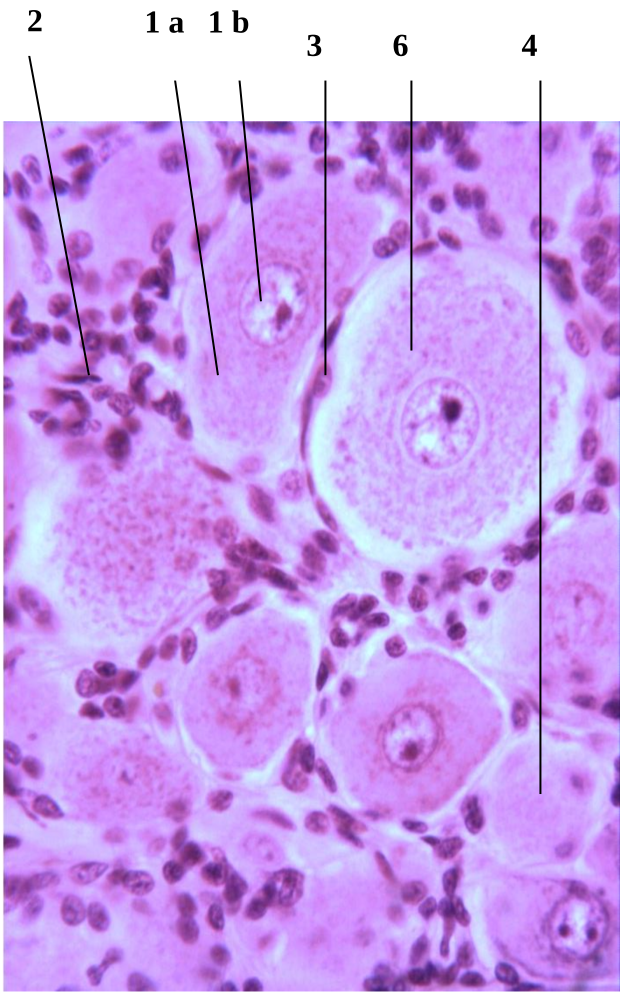


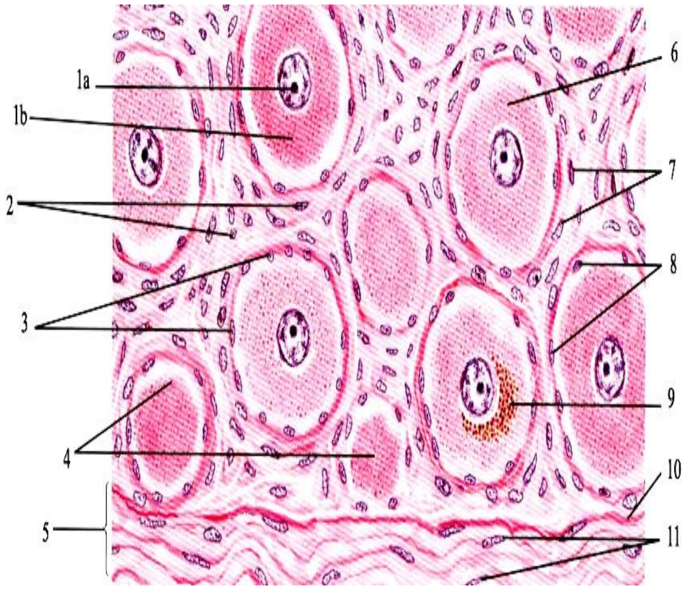
Diagram 1: Peripheral nervous system



Slide 1: Spinal ganglion (longitudinal section)
Staining: hematoxylin and eosin
Low magnification

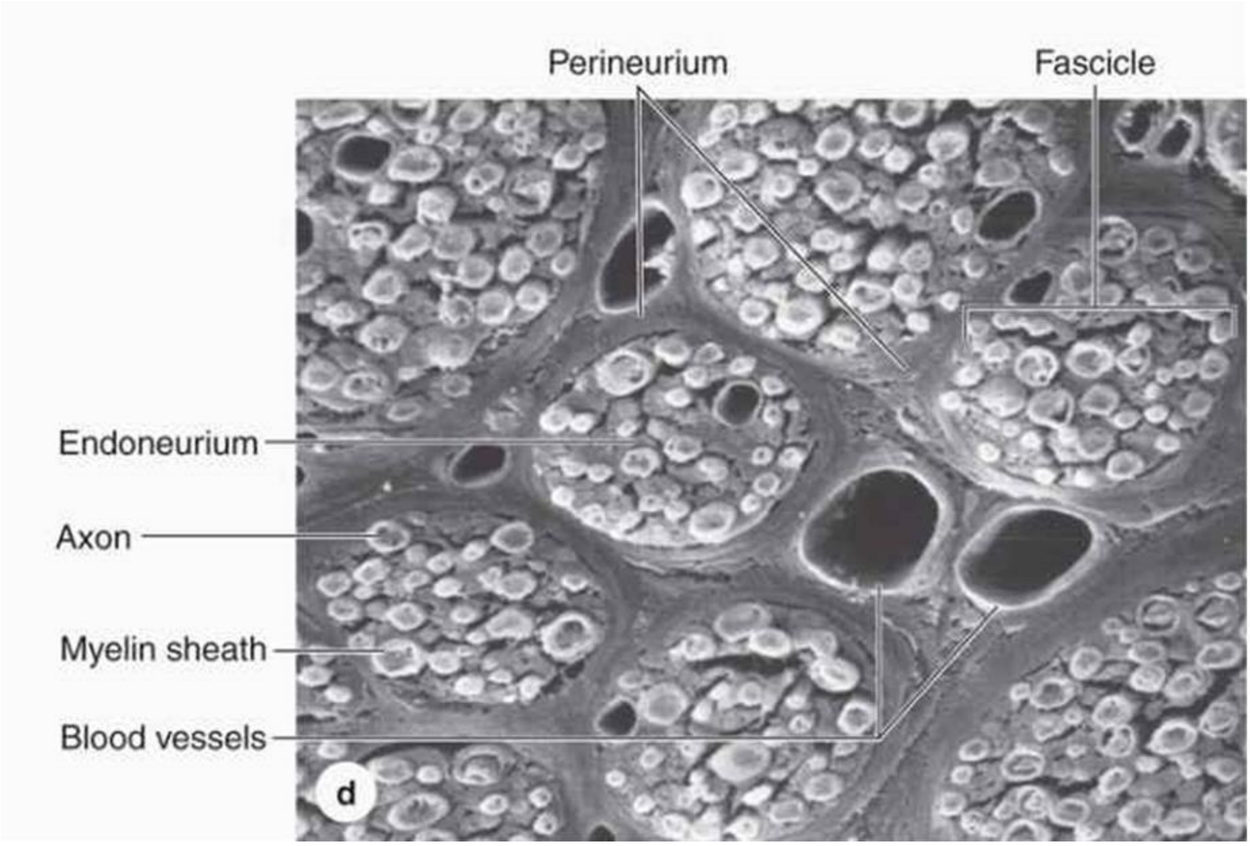
1 - connective tissue layer with blood vessels;
2 - unipolar neurons of dorsal root ganglion;
3 - nerve fascicles;
4 - epineurium of spinal nerve;
5 - spinal nerve;
6 - nerves and blood vessel in the connective tissue layer;
7 - dorsal root ganglion;
8 - arachnoid sheath of dorsal root;
9 - dorsal nerve root;
10 - arachnoid sheath of ventral root;
11 - ventral nerve root





Slide 2: Spinal ganglion
Staining: hematoxylin – eosin
High magnification

1 - pseudounipolar neuron:
   1a nucleus and nucleolus;
   1b cytoplasm;
2 - fibrocytes;
3 - satellite cells;
4 - cytoplasm of neurons;
5 - myelinated axons;
6 - pseudounipolar neuron;
7 - capsule cells;
8 - satellite cells;
9 - lipofuscin pigment;
10 - myelinated axon;
11 - neurolemmocytes (Schwann cells).



Ultrastructure 1: Nerve trunk.

Practical Part II

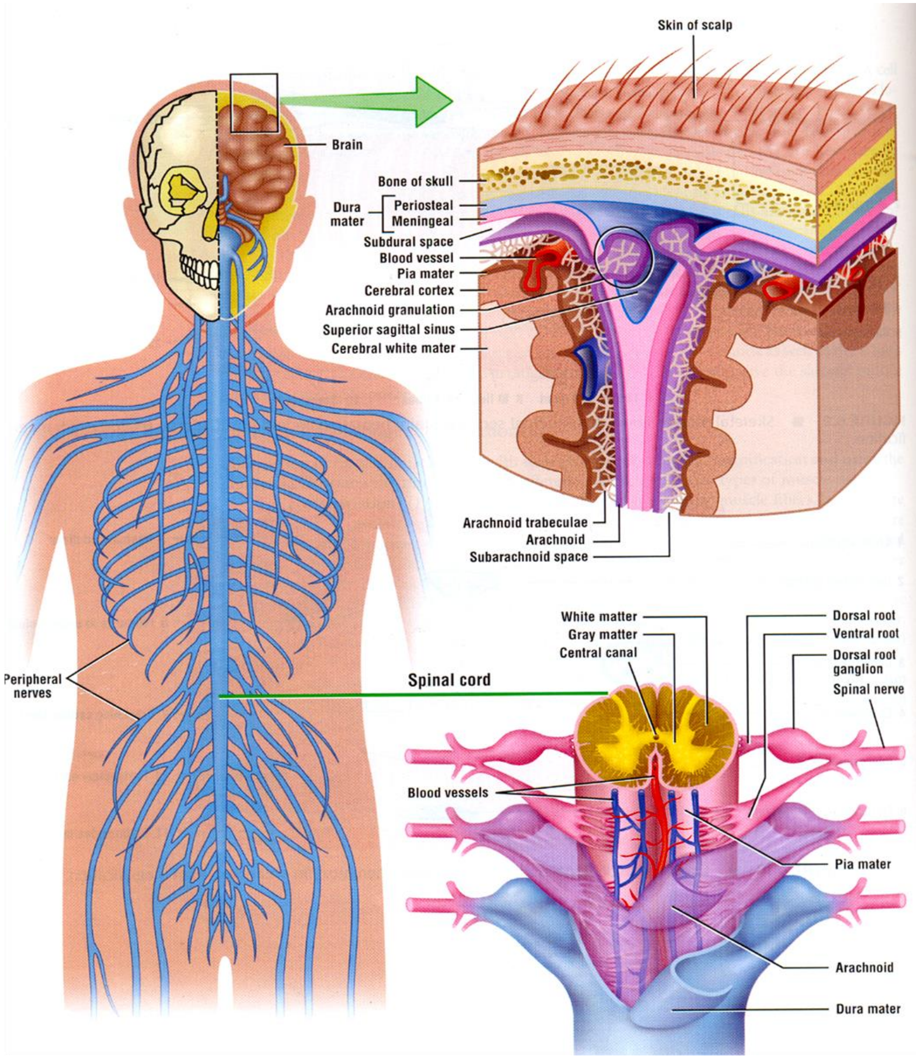
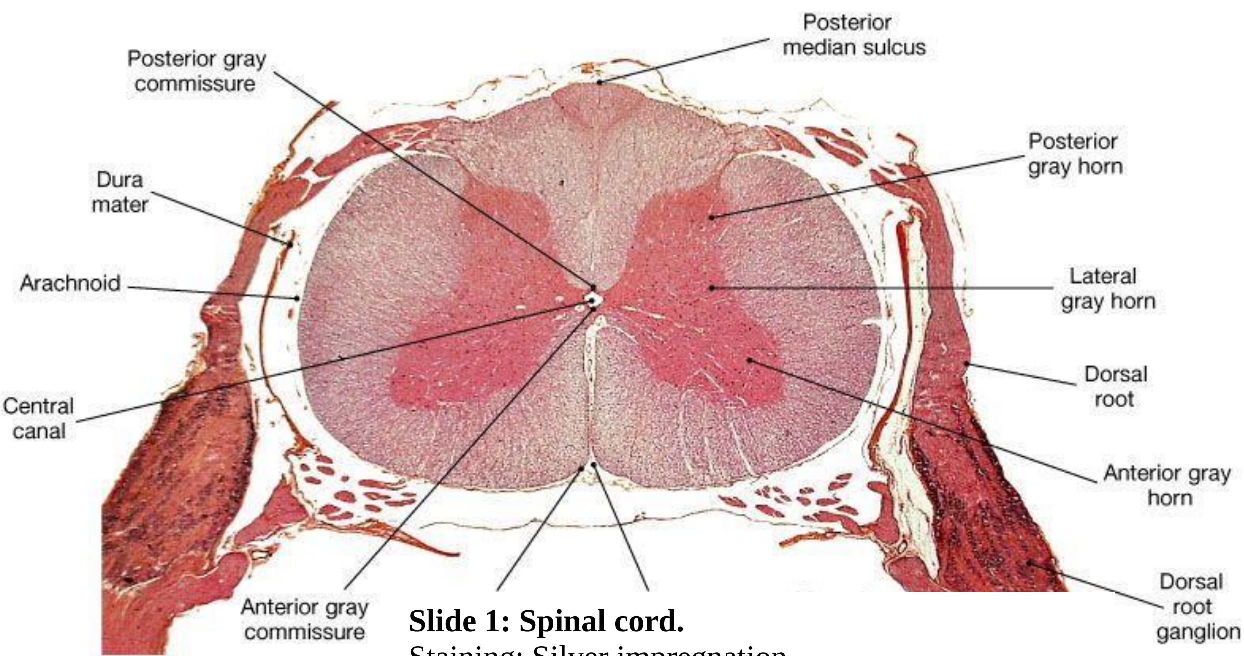
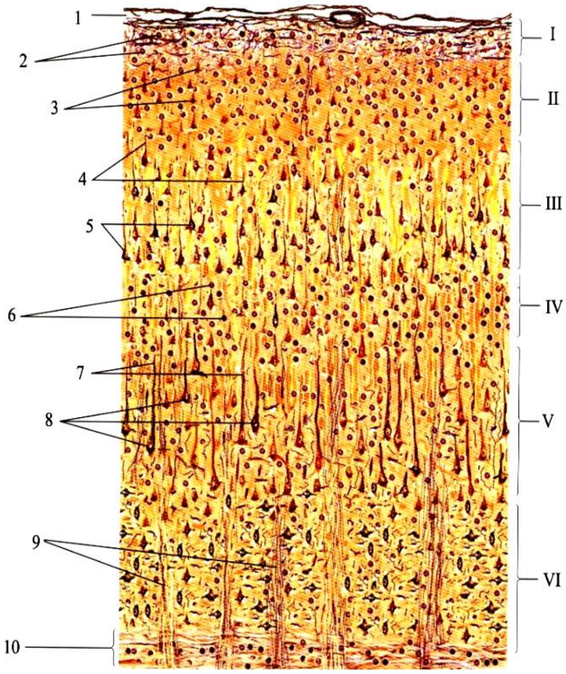
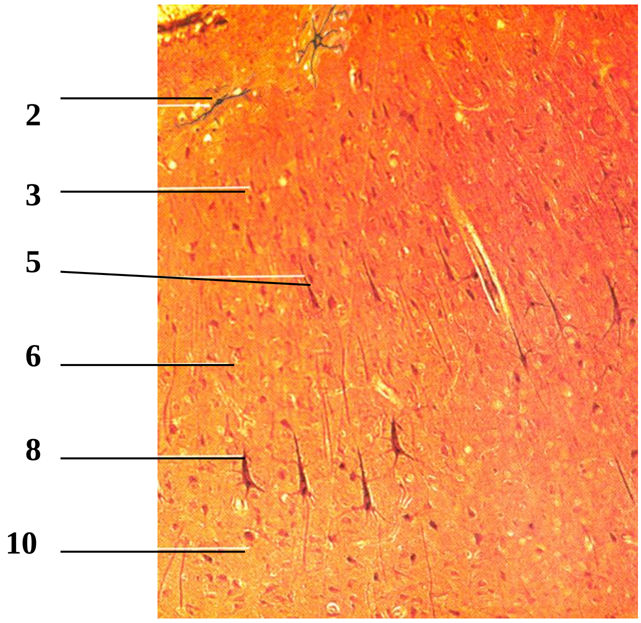


Diagram 2: Central nervous system



Slide 1: Spinal cord.
Staining: Silver impregnation



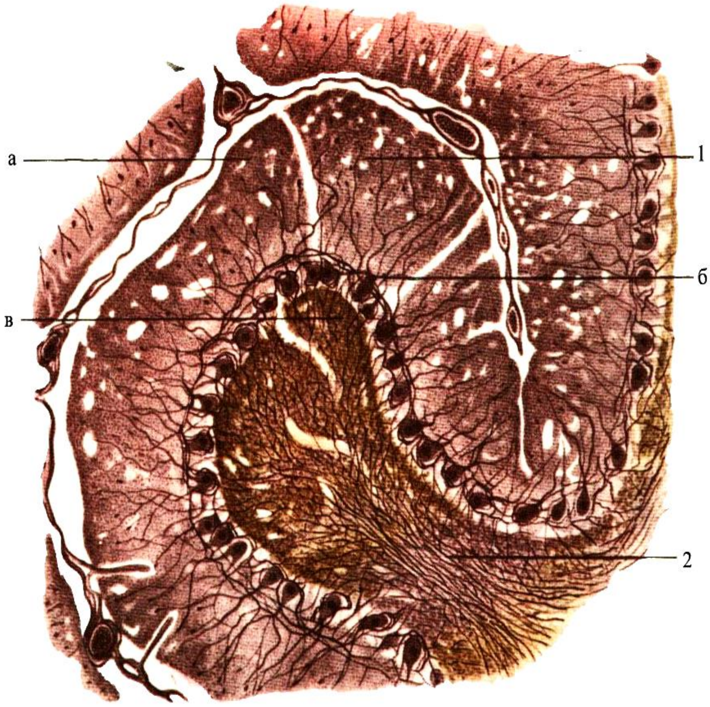


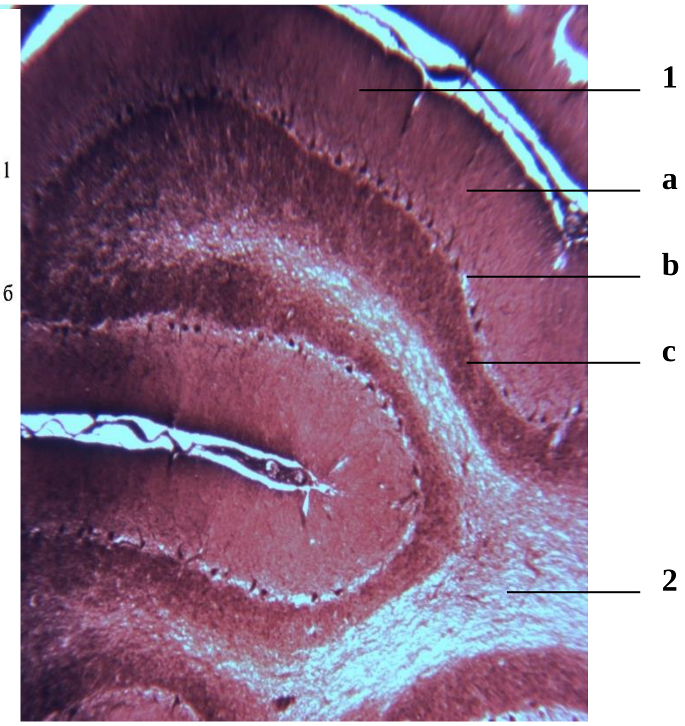
Slide 2: Cerebral cortex: grey matter
Staining: silver impregnation

1 - pia matter with blood vessels;
2 - neuroglial cells;
3 - small pyramidal cells;
4 - dendrite of pyramidal cells;
5 - medium-sized pyramidal cells;
6 - granule cells;
7 - dendrites of pyramidal cells;
8 - large pyramidal cells;
9 - bundles of axons;
10 - white matter

I. Molecular layer;
II. External granular layer;
III. External pyramidal layer;
IV. Internal granular layer;
V. Internal pyramidal layer;
VI. Multiform layer.

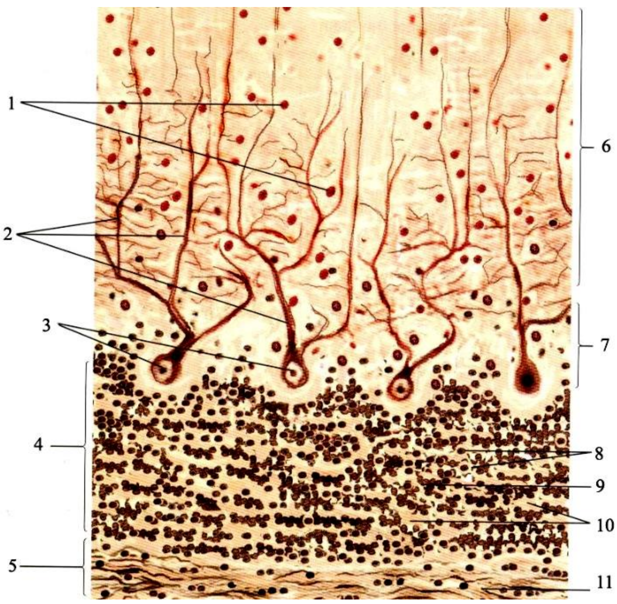
Practical Part III

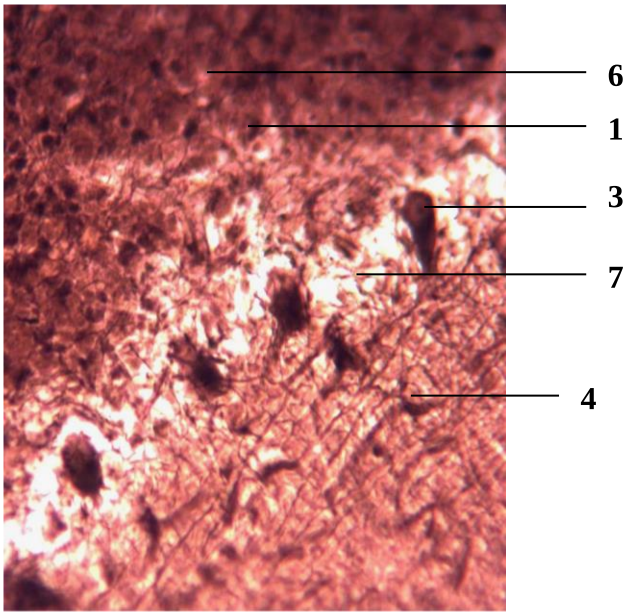




Slide 3 Cerebellum (transverse section)
Staining: silver impregnation

Low magnification
1 - cerebellar cortex;
a - molecular layer; b - ganglionic layer; c - granular cell layer;
2 - white matter.





Slide 4: Cerebellar cortex.
Staining: silver impregnation
High magnification

1 - basket cells;
2 - dendrites of Purkinje cells;
3 - purkinje cells with nucleus and nucleolus;
4 - granular cell layer;
5 - white matter;
6 - molecular cell layer;
7 - Purkinje cell layer;
8 - Golgi cells with short axons;
9 - granule cells;
10 - glomeruli;
11 - axons.

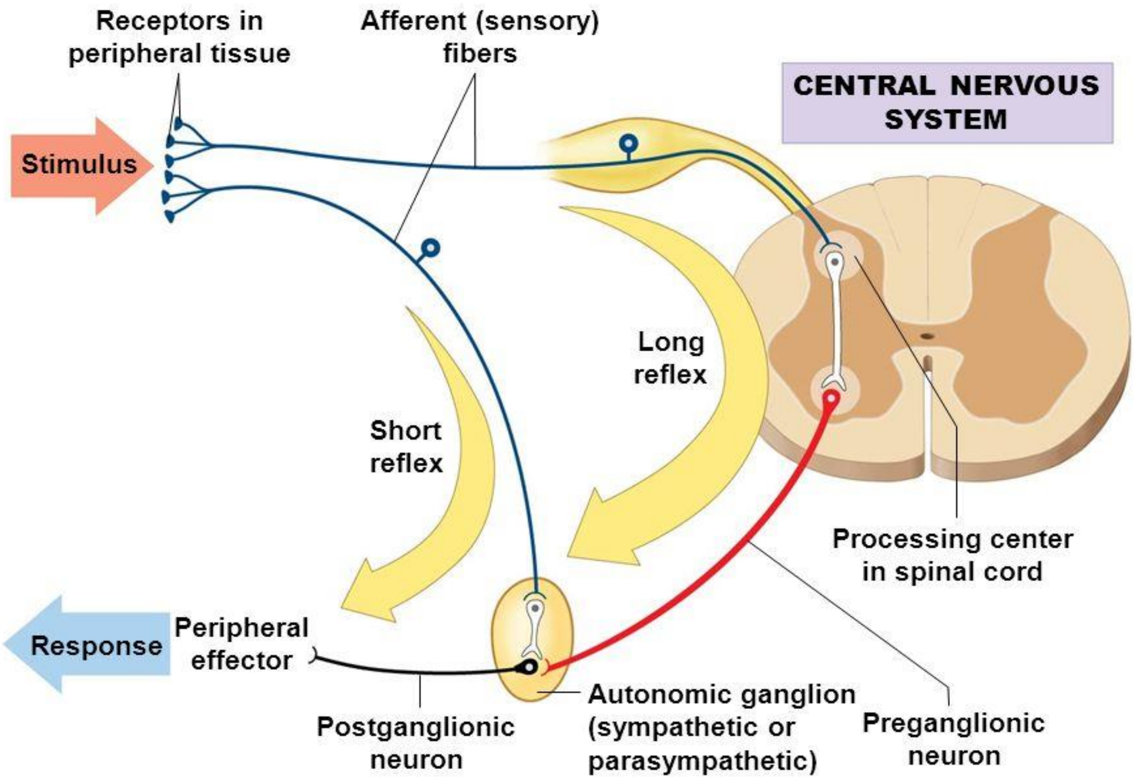


Diagram 1: Autonomic reflex arc.

Questions for self-control:

1. What is related to the nervous system:
a. motor and sensory innervation of viscera is done by somatic nervous system
b. specific effectors of internal organs (smooth muscles, cardiac conducting cells, glandular epithelium) are affected by autonomic nervous system
c. autonomic nervus system controls under conscious voluntary work
d. somatic nervous system is divided into sympathetic and parasympathetic
e. none of the above

2. Peripheral nervous system consist of all the following except:
a. nerve endings
b. ganglia
c. motor nerves
d. sensory nerves
e. nuclei

3. What is related to the cerebral cortex? Which is false?
a. composed of grey matter and white matter
b. mainly it composed of cell bodies with pyramidal shape
c. coordinates muscular activity of body
d. responsible for integration of sensory information
e. composed of three layers (molecular, Purkinje and granule)

4. What is related to the cerebellum? Which is false?
a. it composed of grey matter and white matter
b. grey matter composed of three layers
c. Purkinje cells are present in the cerebellum
d. none of the above

5. The blood-brain barrier? Which is false?
a. have fenestrated capillaries
b. perivascular feet rest on capillary from neuroglia
c. occluding junctions between endothelial cells
d. none of the above

6. What is related to ganglia?
a. spinal ganglia’s cells are multipolar
b. autonomic ganglia’s cells are pseudounipolar
c. spinal ganglia have discontinuous satellite cells and connective tissue capsule
d. eccentric nucleus present in spinal ganglia but not in the autonomic ganglia

Answers:
1. What is related to the nervous system:
Answer: b.

2. Peripheral nervous system composed of all the following except:
Answer: e.

3. What is related to cerebral cortex? Which is false?
Answer: e.

4. What is related to the cerebellum? Which is false?
Answer: d.

5. The blood-brain barrier? Which is false?
Answer: a.

6. What is related to ganglia?
Answer: c

Topic: "Sensory system"

Common characteristic

Sense organs are peripheral parts of analyzers. Analyzers are complex systems, which perform the connection of the central nervous system with external and internal medium.

There are three parts in an analyzer:

- peripheral, in which the perception of irritation takes place;
- intermediate part is the conduction tracts, along which impulses are transmitted;
- central - this is cerebral cortex, where the analysis and synthesis of perceptive sensation take place.

Sense organs are specialized organs perceive the stimulations transduce them into nervous impulse and transmit the information, coded in the number of nervous impulses via the intermediate parts of analyzers into the central parts. The perception of the sensations occurs with the help of receptors.

Classification of sense organs.

There are three main types of sense organs:

1. Neurosensory or primarily sensitivity.

Visual organ and organ of smell refer to this type. These organs have nerve cells, which perceive sensory signals by their peripheral processes (dendrites), transduce them into nervous impulses and transmit into the cerebral cortex along the central processes (axons). During embriogenesis these organs are developing from the neural plate.

2. Sensory - epithelial or secondary sensitive.

Organ of taste, equilibrium and organ of hearing are of this type. These organs have specialized epithelial cells, which perceive sensory signals. The stimulation from these cells is transmitted on nerve endings of the neurons, constituting the intermediate part of analyzers. During embriogenesis they are developing from the thickening of the ectoderm placode.

3. Mixed.

A group of receptors encapsulated, and non-encapsulated nerve endings refers to the third type. They give the possibility to perceive the pressure, temperature and taction.

Visual organ

Visual organ perceives and analyses beams. Peripheral part of the visual analyzer is visual organ or an eye. An eye consists of:

1. An eyeball, containing photoreceptive cells. It is connected through the optic nerve with the brain.
2. Auxiliary apparatus, which consists of eyelids, lacrimal apparatus and oculomotor muscles.

An eyeball wall is composed of three tunics:

1. External - fibrous (consists of the sclera and cornea).
2. Middle - vascular (contains the vascular lay proper, ciliary body and iris of the eye).
3. Internal – reticular (retina).

There is a lens in the eyeball too. It is attacked to the ciliary body by the fibers of the ciliary zonula. The anterior chamber of the eye is located between the cornea, the iris and the lens. The posterior - between the iris, the processes of the ciliary body, ciliary zonule and the lens. Both chambers are filled with watery humor, which is produced by the ciliary body and is absorbed in the venous sinus of sclera. The space surrounded by the retina and filled with the vitreous body, which is located behind the lens and the ciliary zonula.

Functional apparatus of the Eye

1. Photorefracting (the cornea, watery humor, the lens, the vitreous body) - ensures the refraction of beams and projects the observed subjects on the retina.
2. Accomodative (the iris, the ciliary body together with ciliary zonula) focuses an image on the retina by changing the form of the lens and regulates the intensity of retina illumination (by changing the diameter of the pupil).
3. Receptor (retina) ensures the perception and primary processing of the light signal.

Structure of the Eyeball

Fibrous tunic. This tunic forms the external part of the eye and is composed of the sclera, covering the most eye surface, and changing into the cornea in its anterior part.

Sclera is formed by dense fibrous connective tissue, consisting of laminas. The laminae is constituted by collagen fibers, between them fibroblasts and separate elastic fibers are present. Sclera performs the defensive and supporting functions. Tendons of the eye muscles are attached to its external surface. Sclera changes into the cornea in the region of limbus. On system of canals, leading to the venous sinus of sclera is located. This is the way of outflow of watery humor from the anterior chamber of the eye. If the disorder of outflow takes place, the intraocular pressure increases and results in glaucoma.

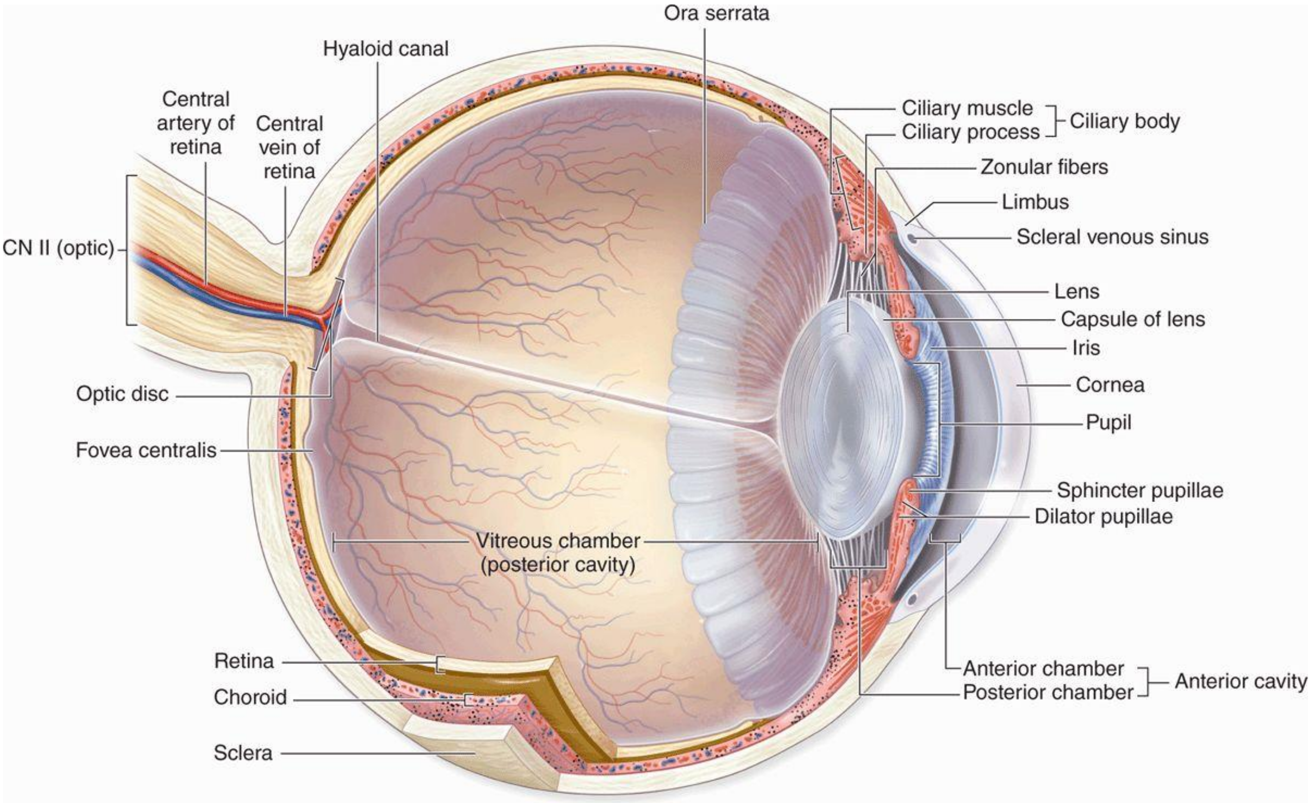


Figure 23 – Structure of eyeball.

Cornea - is the anterior transparent part of the fibrous tunic, which is composed of five layers:

1. The anterior epithelium. This is a multi-layers flat non-keratinized layer, which contains nerve endings, ensuring high sensitivity. The anterior epithelium is constantly moistened by the secretion of lacrimal glands. The epithelium has high capability to regeneration, renewing every seven days. It changes into the epithelium of the conjunctiva in the region of limbus.

2. The anterior boundary membrane is located under the basal membrane of the anterior epithelium. It consists of collagenic fibrils.

3. The proper substance constitutes 90% of the cornea thickness. It is composed of laminal collagenic fibers and fibroblasts, lying between them. The laminal are plunged into the amorphous substance, which is rich in glycosaminoglycans. They ensure the transparency of the substance proper of the cornea. The blood and lymphatic vessels are absent.

4. The posterior boundary lamina is composed of collagenic fibrils.

5. The posterior epithelium is monolayer flat or cubic epithelium. It faintly regenerates. The nutrition of the cornea is carried out by watery humor.

The vascular tunic contains the choroid, the ciliary body and the iris.

The *choroid* ensures the nutrition of the retina. There are four layers in its composition:

1. Supravascular layer is the external, lies on the boundary with the sclera. It is composed of loose connective tissue with a great number of elastic fibers and pigment cells.

2. Vascular layer is composed of arteries and veins, among which the loose connective tissue is located.

3. Vascular - capillary layer is composed of network of capillaries.

4. The basal complex. There is a layer of elastic fibers, a layer of collagenic fibers and basal membrane in the basal complex.

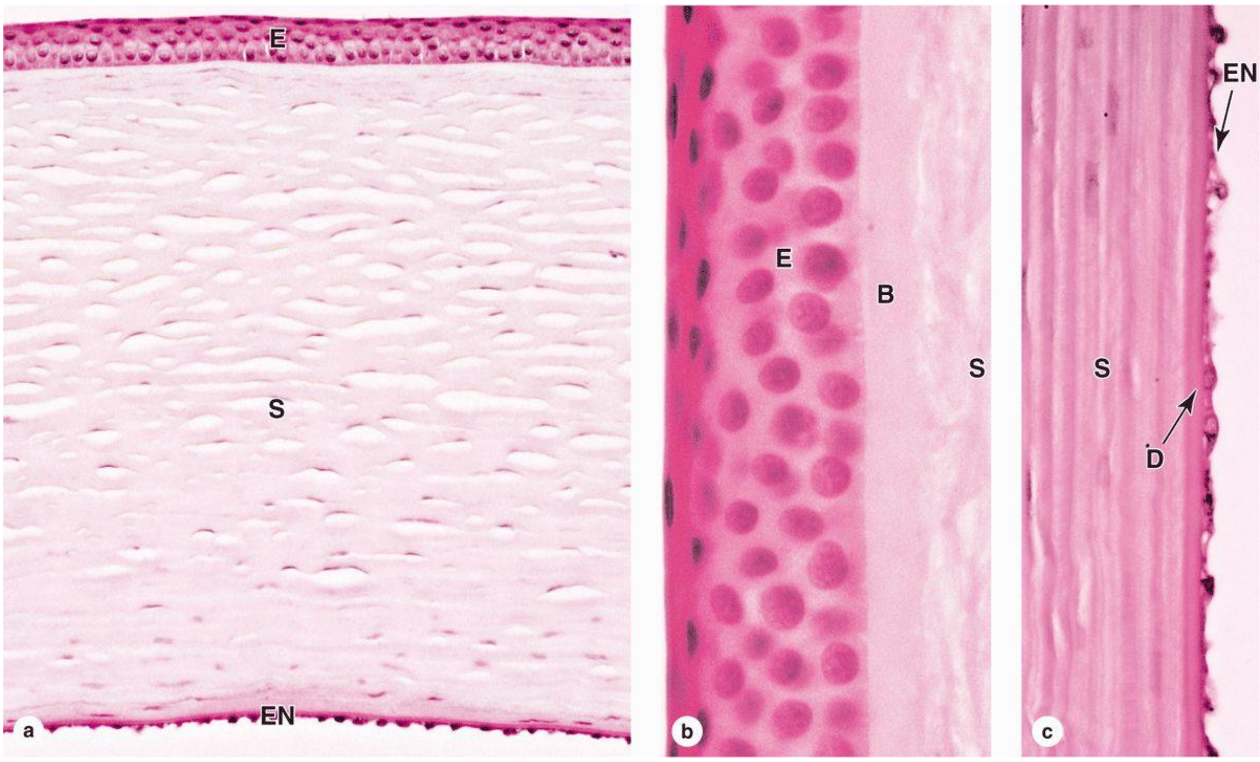


Figure 24 – Cornea. H&E staining.

E - stratified squamous non-keratinized epithelium.
B - Bowman`s membrane.
S - stroma.
D - Descemet`s membrane.
EN - endothelium.

The *ciliary body* is the anterior site of the anterior site of the vascular tunic. It has the form of muscular-fibrous ring, located between the denticulated line and the iris radix. The ciliary body participates in the eye accommodation (changes the lens curvature) and in producing of watery humor. The bases of the ciliary body composed ciliary muscle, ciliary processes diverge from the ciliary body and it is covered with the ciliary epithelium.

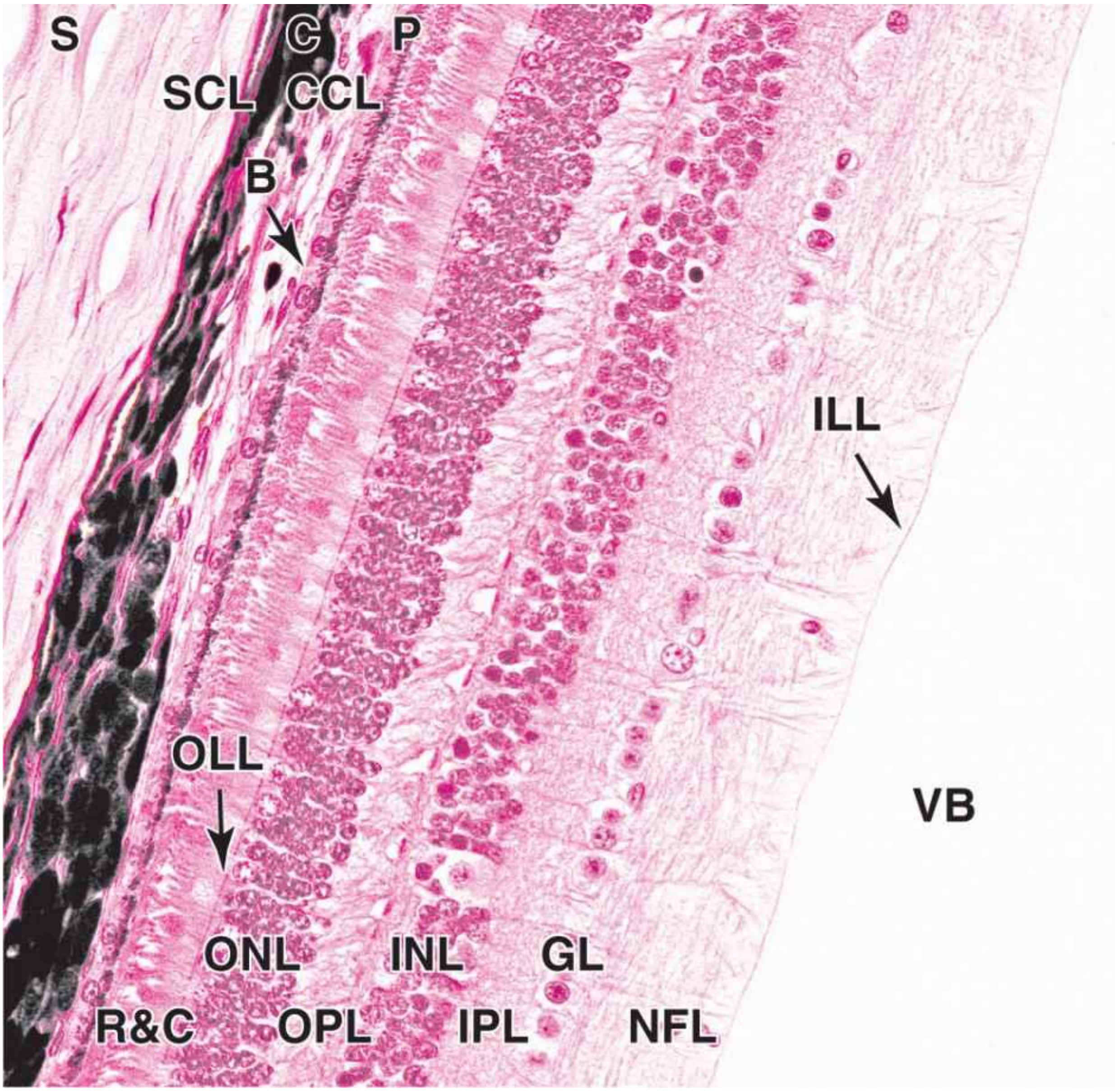


Figure 25 – Sclera, choroid and retina. H&E staining.

S - connective tissue of sclera.

C - connective tissue of choroid.

SCL - suprachoroidal lamina.

CCL - choroidocapillary lamina.

B - Bruch`s layer.

P - pigmented layer of cuboidal epithelium containing melanin.

R&C - rods and cones (dendrites of rods and cones)

OLL - outer limiting layer.

ONL - outer nuclear layer (cell bodies of R&C, first neurons).

OPL - outer plexiform layer (axons of R&C).

INL - inner nuclear layer (second neurons).

IPL - inner plexiform layer (axons of second neurons).

GL - ganglionic layer (third neurons).

NFL - nerve fiber layer (axons of third neurons).

ILL - inner limiting layer.

VB - vitreous body.

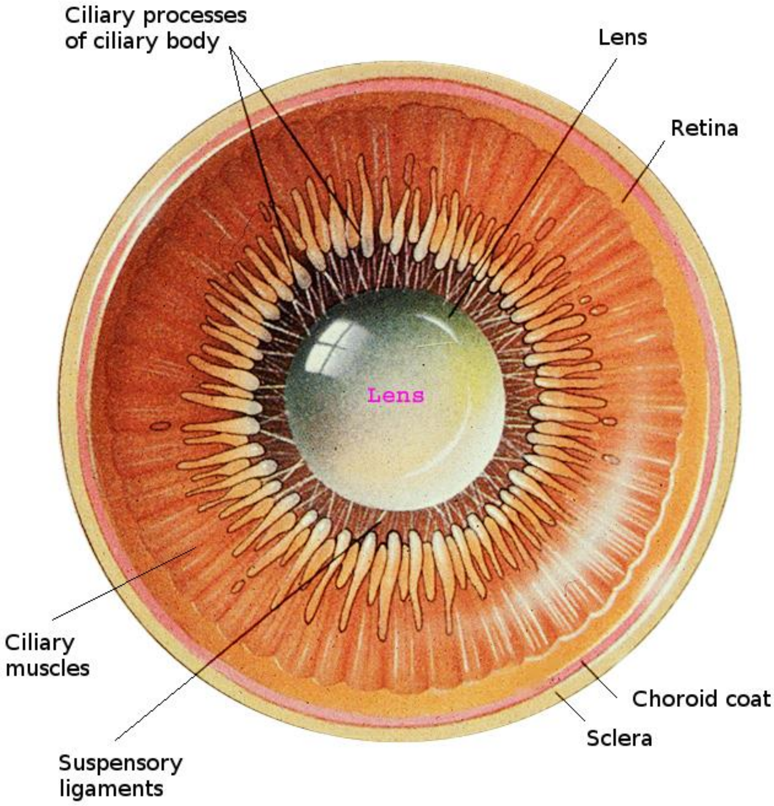


Figure 26 – Ciliary muscles, ciliary processes & lens.

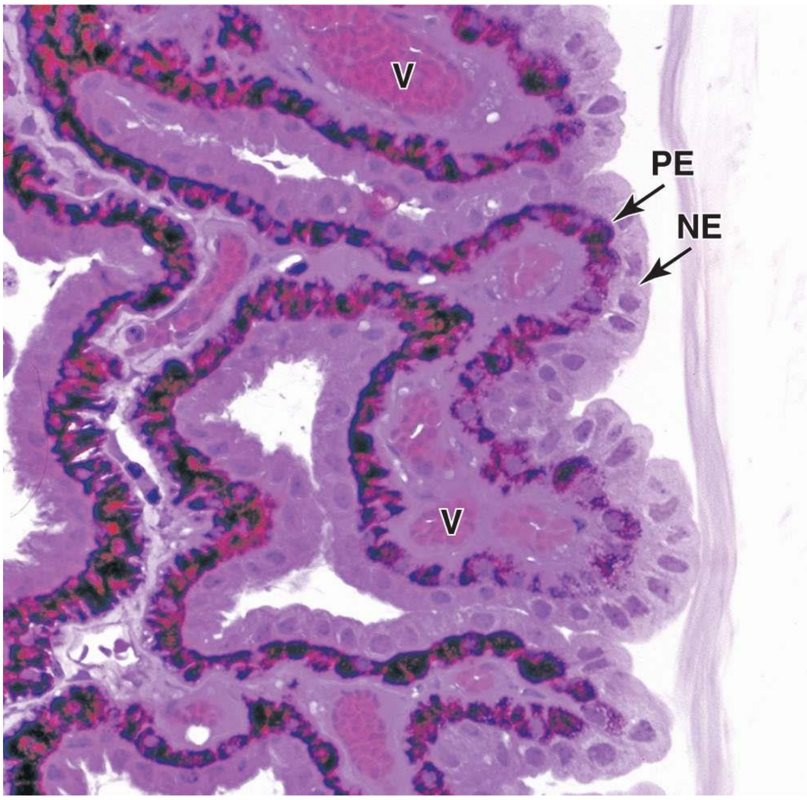


Figure 27 – Epithelium of ciliary processes.

NE - non-pigmented epithelium (low columnar or cuboidal).

PE - pigmented epithelium. V - blood vessels.

The *ciliary muscle* is composed of the bundles of smooth muscle cells, which lies in three directions: meridional, radial and circular. When contracted, it loosens the tension of fibers of ciliary belt, increases the lens curvature and focuses the eye on the close objects.

The *ciliary processes* are the folds of the ciliary body. They are composed of the connective tissue with a great number of elastic fibers and pigment cells and capillaries, covered with the ciliary epithelium. One end of them is attached to the ciliary belt fibers, the opposite end is attached to the lens capsule.

The *ciliary epithelium,* covering the processes is two-layers and cubic. It is composed of inner unpigmented and external pigmented cells. It produces aqueous humor and is involved in forming the barrier between the blood and humor.

The *iris* is the anterior part of the vascular tunic. It divides the anterior and posterior chambers of the eye. It is the annular-shaped lamina with the hole in the center. It is the pupil. The basis of the iris is the loose connective tissue with a great number of vessels and pigment cells, which determine the color of eyes.

The iris consists of five layers:

1. The anterior epithelium is a monolayer flat epithelium. It is the prolongation of the posterior epithelium of the cornea.
2. The external boundary layer contains much pigment cells and fibroblasts.
3. The vascular layer contains numerous vessels.
4. The internal boundary layer.
5. The posterior pigment epithelium is the prolongation of the two-layer epithelium of the retina, covering the ciliary body and the processes.

The iris performs the function of the eye diaphragm with the help of two muscles: sphincter (musculus sphincter pupillae) and dilatation (musculus dilatator pupillae) of the pupil. These muscles are constituted by smooth muscle cells. They change the diameter of the pupil and regulate the quantity of light, falling on the retina.

The lens.

The lens is a transparent convexo-convex body, which is retained by the fibers of ciliary belt. It changes its curvature depending on tension of the fibers and provides the ability to focus the objects on the retina, which are situated at different distance from the eye.

The lens is covered with the transparent capsule, to which the fibers of ciliary belt are attached. The anterior wall of the lens adjoining the capsule consists of the flat epithelium.

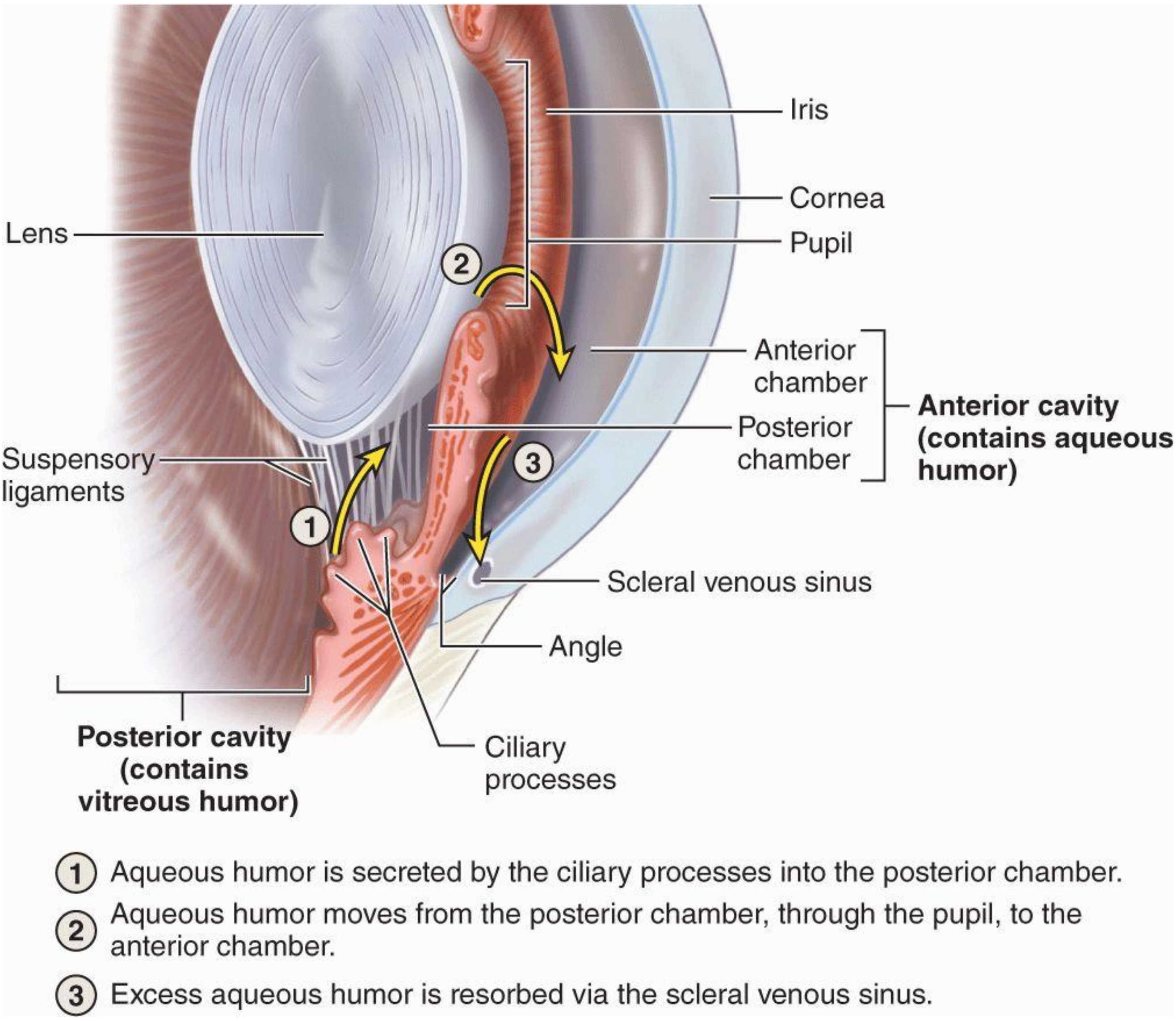


Figure 28 – Production and removal of aqueous humor.

To the direction of the equator, the epitheliocytes become higher and form the growth zone of the lens. This zone produces new cells. These new epitheliocytes are transformed into lens fibers. There is a transparent protein - *crystallin* in the cytoplasm of the lens fibers. The fibers located in the center lose their nuclei, shorten and putting on each other, forming the *lens nucleus.*

The vitreous body.

This is transparent mass of jelly form substance. It fills the cavity between the lens and the retina. The vitreous body contains the protein *vitrein* and the *hyaluronic acid*. It provides passing of the light rays, preserving the lens position.

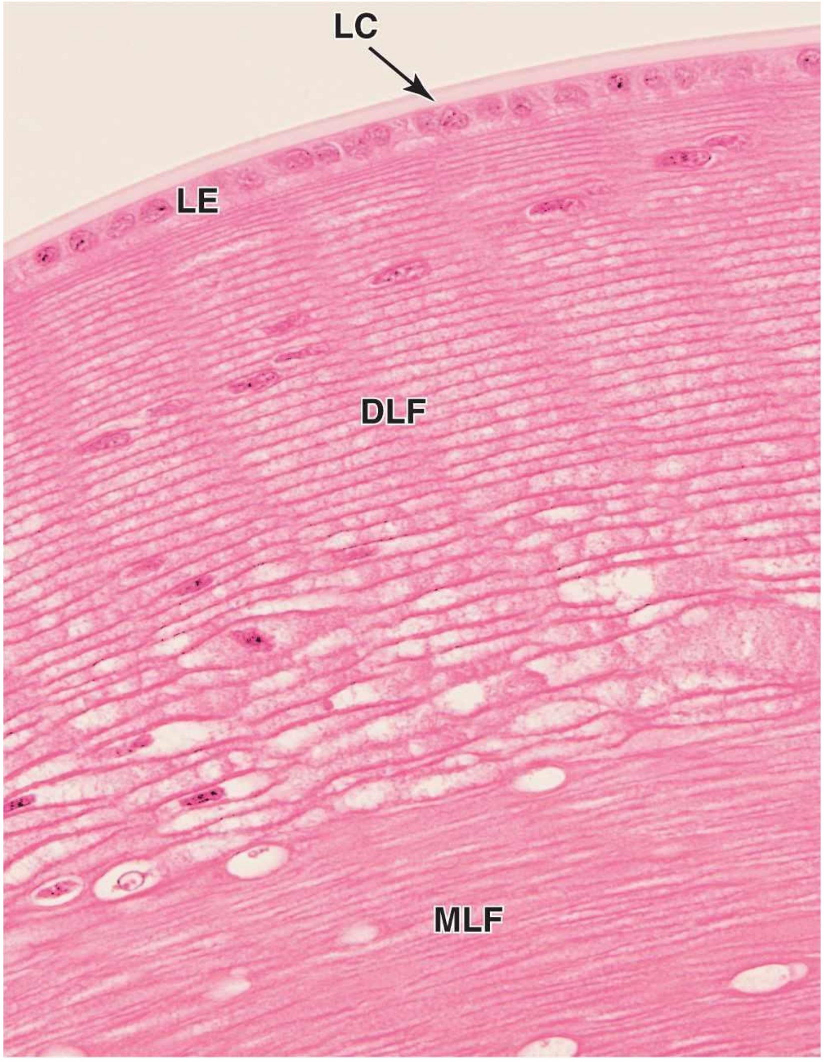


Figure 29 – Lens. H&E staining.

LC - lens capsule.
LE - simple columnar lens epithelium.
DLF - differentiating lens fibers with cristallins.
MLF - mature lens fibers.

Reticular tunic.

This is internal photosensitive tunic of the eye. It is divided into optic *(visual) part as far* as *blind* part, covering the ciliary body and the posterior surface of the iris. There is a *blind spot* on the posterior wall of the retina. The blind spot is the site, which doesn't contain photoreceptory cells and it is the place optic nerve outlet.

The *yellow spot* is the site with the greatest concentration of photoreceptory cells, it is the place of the best vision.

The retina consists of three neuron types:

- external - photoreceptory,
- middle - associative,
- internal – ganglionic.

There are two more types of neurons, located on the level of the contract of the first and second neurons. These are *horisontal neurons.* The *amacrinal neurons* are located on the level of junction of the second and third neurons.

Photoreceptory or neurosecretory bipolar neurons have modified dendrites, called rods (one cell type) and cones another cell type. The light rays are perceived by the rods and cones of the neurosensory cells.

The rods and cones consist of external and internal segments, connected by the cilia. The external segment of the rod is a cylinder - shaped and is composed of a great number of flat membraneous closed discs. There is an optic pigment - rhodopsin in the membraneous discs. The external segment of the cones is conic-shaped, it is wider and shorter than that of rods. It is composed of semidiscs, arised as a result of invagination of plasmolemma. The semidiscs contain the optic pigment – iodopsin.

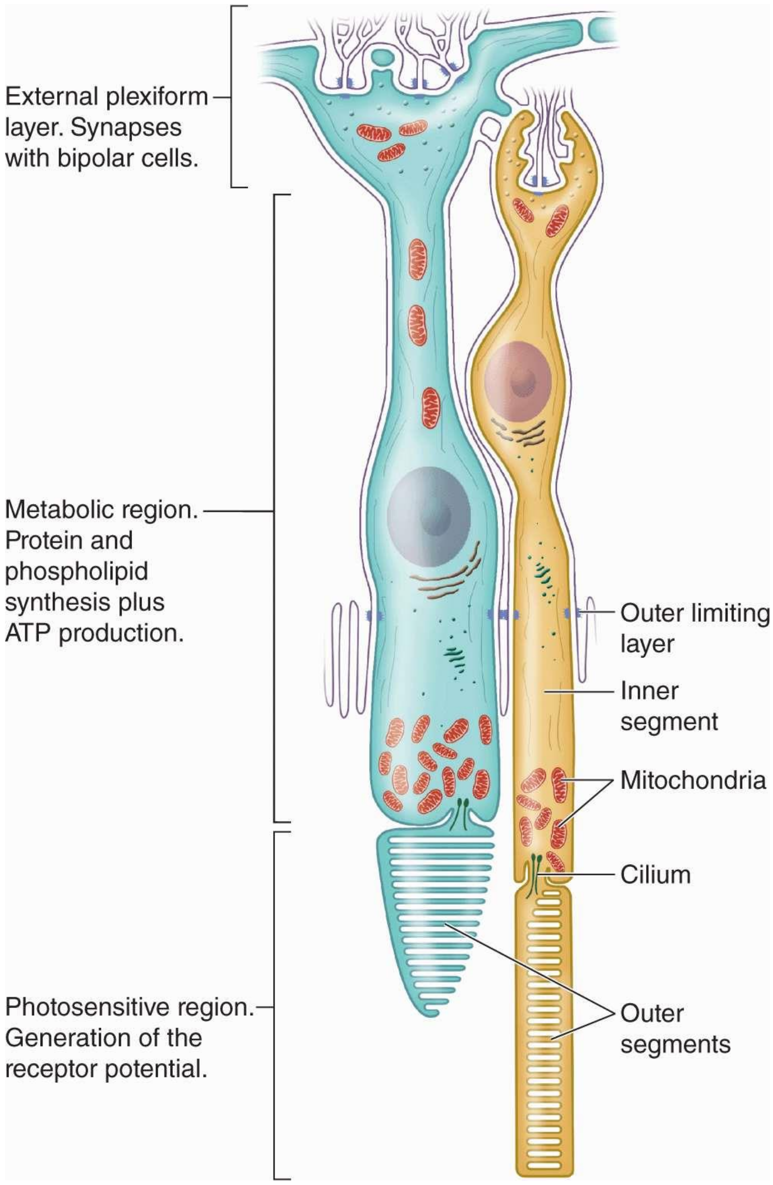


Figure 30 – Rods (right) and cones (left)

The internal segments of the rods and cones contain organelles, the internal segments of conuses containing a large lipid drop.

The quantity of rod cells numbers 130 ml and conus cells – 6-7 ml. The rods are the receptors of twilight vision, that is black white vision, and the cones are the receptors of daylight vision, that is color vision.

The bodies of neurosensory cells with nuclei are located behind the internal segment of rods and cones. The axons run from the bodies. They form synapses with the dendrites of bipolar associative neurons. The axons of bipolar cells transmit the impulses on the dendrites of ganglionar (multipolar) cells.

The axons of the horizontal nerve cells contract with the axons of rods and cones. At the same time the blocade in the transmission of impulses from photoreceptors to the bipolar neurons occurs. This leads to contrast increasing of observed objects.

Amacrine cells play the role similar to that of horizontal cells only on the level of connection bipolar and multipolar - ganglionar nerve cells.

In total the cells and their processes form *ten layers of the retina.*

I. The pigment layer is composed of poligonal cells, lying on the basal membrane, which borders on the vascular tunic. The processes runs from the pigment cells. They envelope the external segments of the photoreceptory cells. There are melanosomas, phagosomes and organelles of common meaning in the processes. Phagosomes phagocytize the worked out disks of the external segments of the rods and cones, which have stopped functioning.

II. Photoreceptory layer is the dendrites of photoreceptory cells – rods and cones.

III. The outer limiting layer - is composed by the processes of the cells of the neuroglia of the retina.

IV. The outer nuclear layer - contains the nuclei of the photosensory cells.

V. The outer plexiform layer. This is the region of synapses between the axons of photoreceptory cells and the dendrites of the bipolar and horizontal cells.

VI. The inner nuclear layer - is formed by the nuclei of bipolar, amacrine, horizontal cells and the nuclei of the cells of neuroglia.

VII. The inner plexiform layer. This is the region of synapses between the axons of bipolar cells and the dendrites of ganglionic and amacrine cells.

VIII. The ganglionic layer is composed of the bodies of the ganglionic cells.

IX. The layer of the nerve fibers consists of the axons of the ganglionic cells, which form the optic nerve.

X. The inner limiting layer is composed of the processes of the cells of the neuroglia of the retina. This layer separates the retina from the vitreous body.

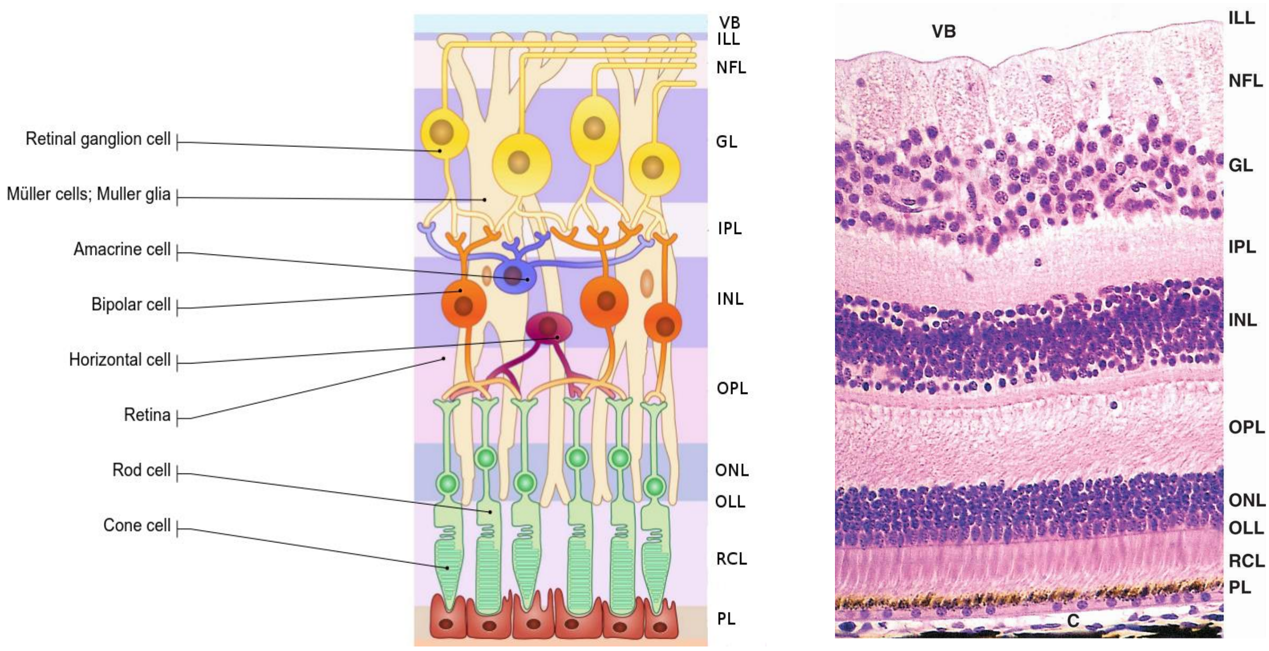


Figure 31 – Retina

C - choroid.
PL - pigmented layer of cuboidal epithelium containing melanin.
RCL - rods and cones layer.
OLL - outer limiting layer.
ONL - outer nuclear layer (cell bodies of R&C, first neurons).
OPL - outer plexiform layer (axons of R&C).
INL - inner nuclear layer (second neurons).
IPL - inner plexiform layer (axons of second neurons).
GL - ganglionic layer (third neurons).
NFL - nerve fiber layer (axons of third neurons).
ILL - inner limiting layer.
VB - vitreous body.

The auxiliary apparatus of the eye

This department provides the defense and movements of eyes. It consists of eyelids, eye muscles and lacrimal apparatus.

1. Eyelids.

One can distinguish the anterior skin surface and the posterior – conjunctiva, which is continued into the eye conjunctiva. Inside the eyelids there is a lamina, consisting of dense fibrous connective tissue. In the thickness of the eyelid the circular muscle lies. The layer of loose connective tissue is between the bindles of muscles. I this layer there are tendons of muscle, elevating the upper eyelid (musculus levator palbebrae superioris).

Along the eyelid margin the eyelashes are located which are organized into two-three rows. The excretory ducts of the sebaceous glands and the ducts of the ciliary glands are opened into the funnel of eyelash radix. The ducts of the cilia glands sure modified sudoriferous glands.

2. Eye muscles.

These are cross-striated muscles, which are attached to the sclera by their tendons and provide the eyeball movements.

3. The lacrimal apparatus of eye.

This consists of the lacrimal glands, lacrimal sac and nasolacrimal duct. The lacrimal glands are constituted by some groups of complex alveolar-tubular glands with the serous secret. The secret moistens the surface of cornea and conjunctiva goes into the lacrimal canaliculi. They are connected with the lacrimal sac. The lacrimal sac continues into the nasolacrimal canal.

Embryogenesis of the visual organ

The retina and optic nerve of the eye formed from the neural tube, the epithelium of the cornea and the lens are developing from the ectoderm, the cornea proper substance, sclera, vascular tunic and vitreous body are developing from the mesenchyme.

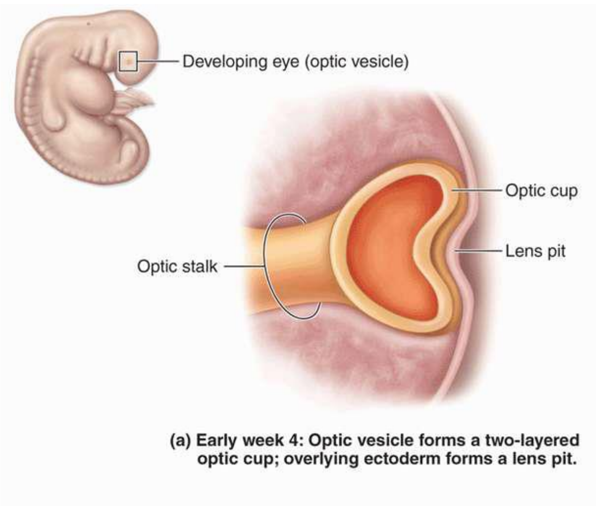


Figure 32-1: Development of the visual organ. 1 of 4

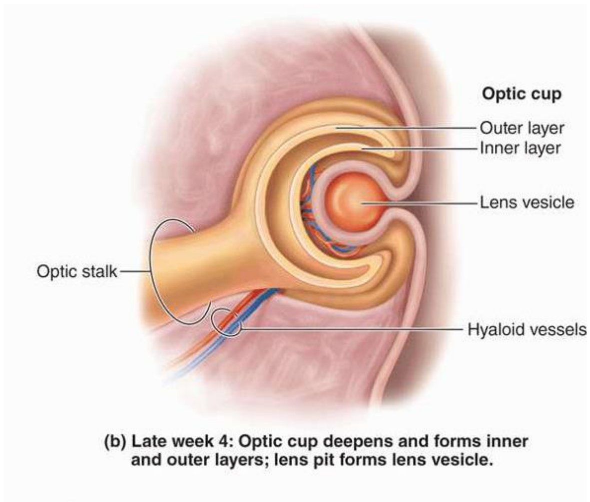


Figure 32-2: Development of the visual organ. 2 of 4

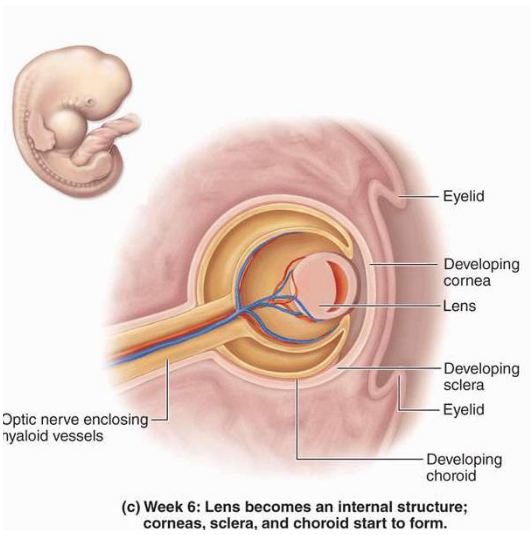


Figure 32-3: Development of the visual organ. 3 of 4

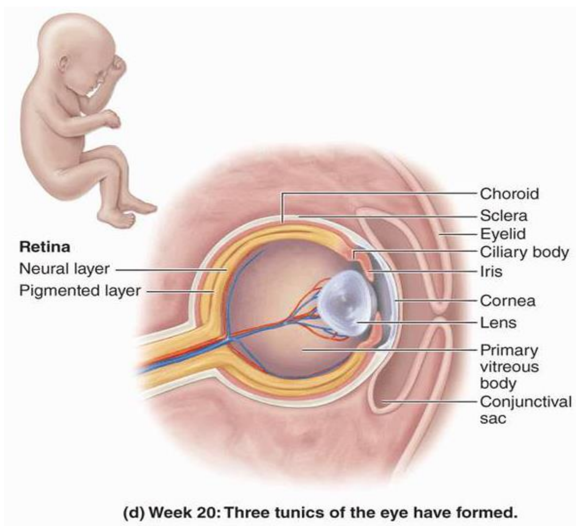


Figure 32-4: Development of the visual organ. 4 of 4

Olfactory organ

The olfactory organ is located in the nasal cavity, in the superior one third of the nasal septum and in the superior nasal concha. It is lined with the mucous membrane, which is composed of the epithelium and the lamina proper.

The olfactory epithelium contains the cells of three types:

1. Olfactory epithelium cells. These are modified bipolar neurons. Their axons form the olfactory nerve. The dendrites at the end contain the olfactory, from which the long immobile olfactory cilia runs from. The receptors of odorous substances are located in the cilia membrane. The receptors cells are renewed every thirty days.

2. *Supporting cells* have the shape of high prisms. In cytoplasm there is a nucleus, organelles and pigment granules, which give the olfactory region its yellow color. The function of these cells is supporting.

3. *Basal cells.* These are small faint-differentiated cells. They are capable to give rise to receptory and supporting cells.

The lamina proper is formed by the connective tissue and contains the terminal regions of the olfactory glands, secreting to the surface of the olfactory epithelium. The secret washes the olfactory cilia and dissolves the odorous substances.

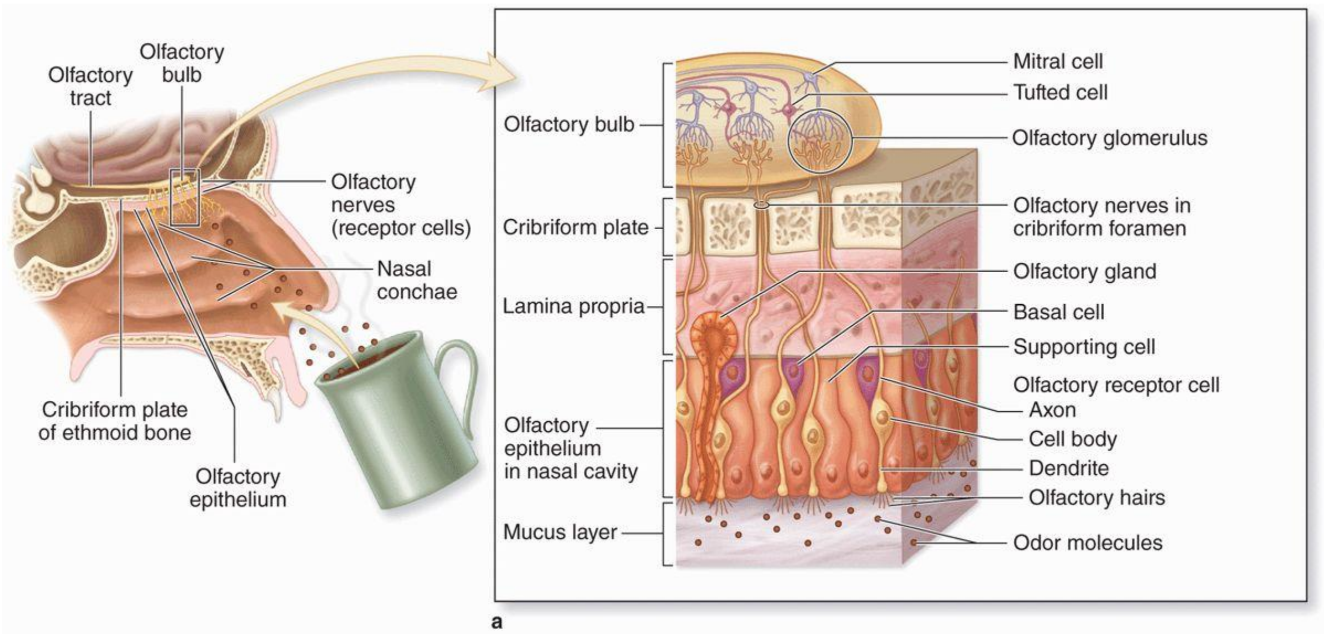


Figure 33 – Olfactory organ

Ear

Each ear consists of three major parts:

- The external ear, which receives sound waves;
- The middle ear, in which sound waves are transmitted from air to fluids of the internal ear via a set of small bones;
- The internal ear, in which these fluid movements are transduced to nerve impulses that pass via the acoustic nerve to the CNS. In addition to the auditory organ, or cochlea, the internal ear also contains the vestibular organ that allows the body to maintain equilibrium.

Most structures of the middle and internal ear develop in the embryo and are enclosed within the temporal bone as it forms from head mesenchyme.

External Ear

The auricle, or **pinna** (Latin for "wing") is an irregular, funnel-shaped plate of elastic cartilage, covered by tightly adherent skin, which directs sound waves into the ear.

Sound waves enter the **external acoustic meatus** (Latin for "passage"), a canal lined with stratified squamous epithelium that extends from the auricle to the middle ear.

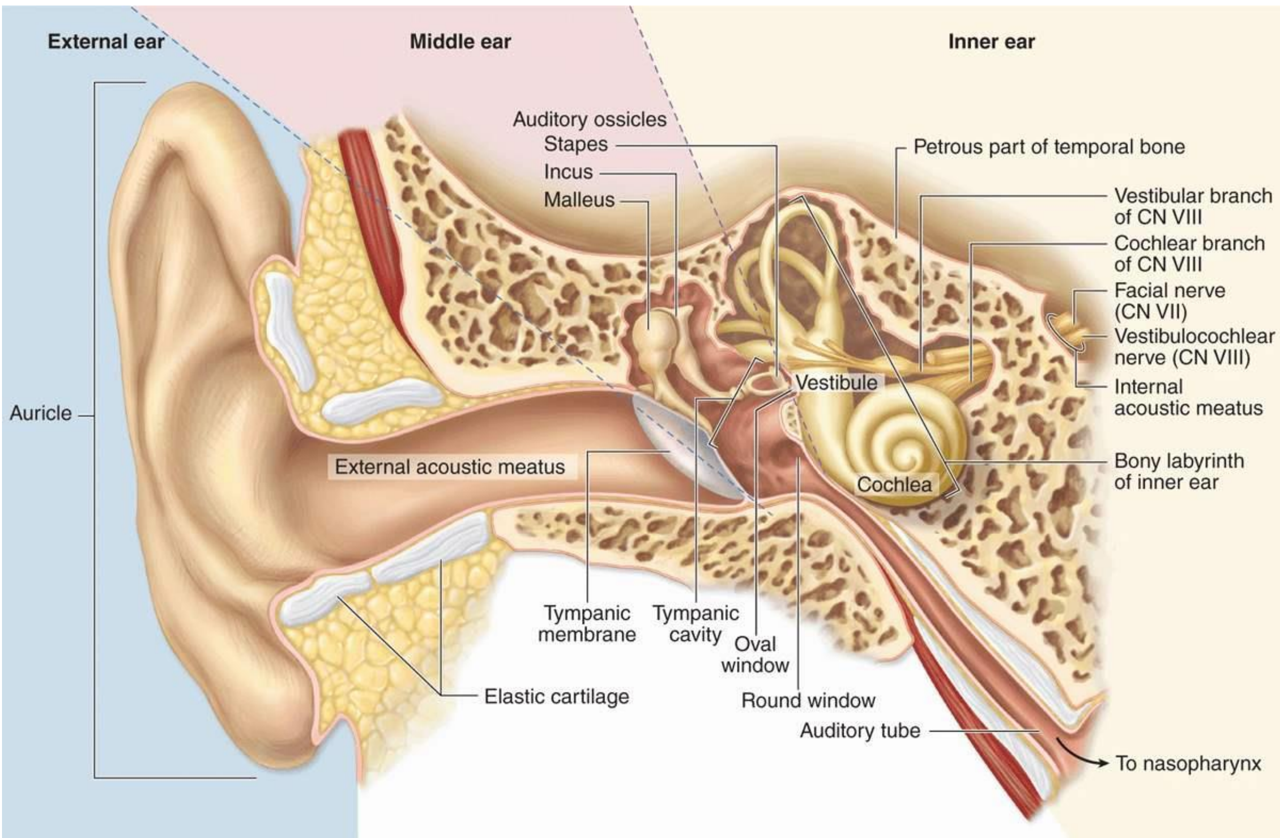


Figure 34 – Auditory organ

Near its opening hair follicles, sebaceous glands, and modified apocrine sweat glands called ceruminous glands are found in the submucosa. Cerumen, the waxy material formed from secretions of the sebaceous and ceruminous glands, contains various proteins, saturated fatty acids, and sloughed keratinocytes and has protective, antimicrobial properties. The wall of the external auditory meatus is supported by elastic cartilage in its outer third, while the temporal bone encloses the inner part.

Across the deep end of the external acoustic meatus lies a thin, somewhat transparent sheet called the **tympanic membrane** or **eardrum**. This membrane consists of fibroelastic connective tissue covered externally with epidermis and internally by the simple cuboidal epithelium of the mucosa that lines the middle ear cavity. Sound waves cause vibrations of the tympanic membrane, which transmit energy to the middle ear.

Middle Ear

The middle ear contains the air-filled tympanic cavity, an irregular space that lies within the temporal bone between the tympanic membrane and the bony surface of the internal ear. Anteriorly, this cavity communicates with the pharynx via the **auditory tube** (also called the eustachian or pharyngotympanic tube) and posteriorly with the smaller, air-filled mastoid cavities of the temporal bone. The simple cuboidal epithelium lining the cavity rests on a thin lamina propria continuous with periosteum. Entering the auditory tube, this simple epithelium is gradually replaced by the ciliated pseudostratified columnar epithelium that lines the tube. Below the temporal bone this tube is usually collapsed; swallowing opens it briefly, which serves to balance the air pressure in the middle ear with atmospheric pressure. In the medial bony wall of the middle ear are two small, membrane-covered regions devoid of bone: the **oval** and **round** windows with the internal ear behind them.

The tympanic membrane is connected to the oval window by a series of three small bones, the auditory ossicles, which transmit the mechanical vibrations of the tympanic membrane to the internal ear. The three ossicles are named for their shapes the **malleus**, **incus**, and **stapes**, the Latin words for “hammer,” “anvil,” and “stirrup,” respectively. The malleus is attached to the tympanic membrane and the stapes to the membrane across the oval window. The ossicles articulate at synovial joints, which along with periosteum are completely covered with simple squamous epithelium. Two small skeletal muscles, the tensor tympani and stapedius, insert into the malleus and stapes, respectively, restricting ossicle movements and protecting the oval window and inner ear from potential damage caused by extremely loud sound.

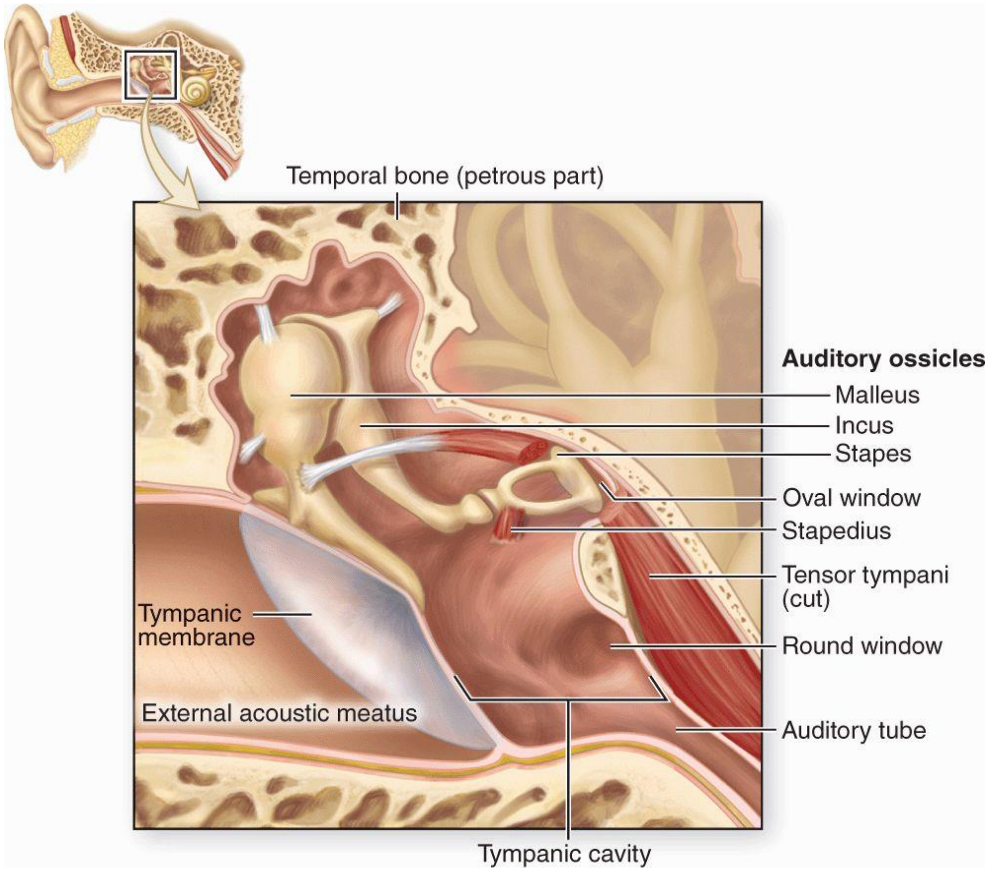


Figure 37 – Middle ear

Internal Ear

The internal ear is located completely within the temporal bone, where an intricate set of interconnected spaces, the **bony labyrinth**, houses the smaller **membranous labyrinth**, a set of continuous fluid-filled, epithelium-lined tubes and chambers. The membranous labyrinth is derived from an ectodermal vesicle, the otic vesicle, which invaginates into subjacent mesenchyme during the fourth week of embryonic development, loses contact with the surface ectoderm, and becomes embedded in rudiments of the developing temporal bone.

The embryonic otic vesicle, or otocyst, forms the membranous labyrinth with its major divisions:

- Two connected sacs called the **utricle** and the **saccule**,
- Three **semicircular ducts** continuous with the utricle,
- The **cochlear duct**, which provides for hearing and is continuous with the saccule.

Mediating the functions of the inner ear, each of these structures contains in its epithelial lining large areas with columnar mechanoreceptor cells, called hair cells, in specialized sensory regions:

- Two **maculae** of the utricle and saccule,
- Three **cristae ampullares** in the enlarged ampullary regions of each semicircular duct,
- The long spiral **organ of Corti** in the cochlear duct.

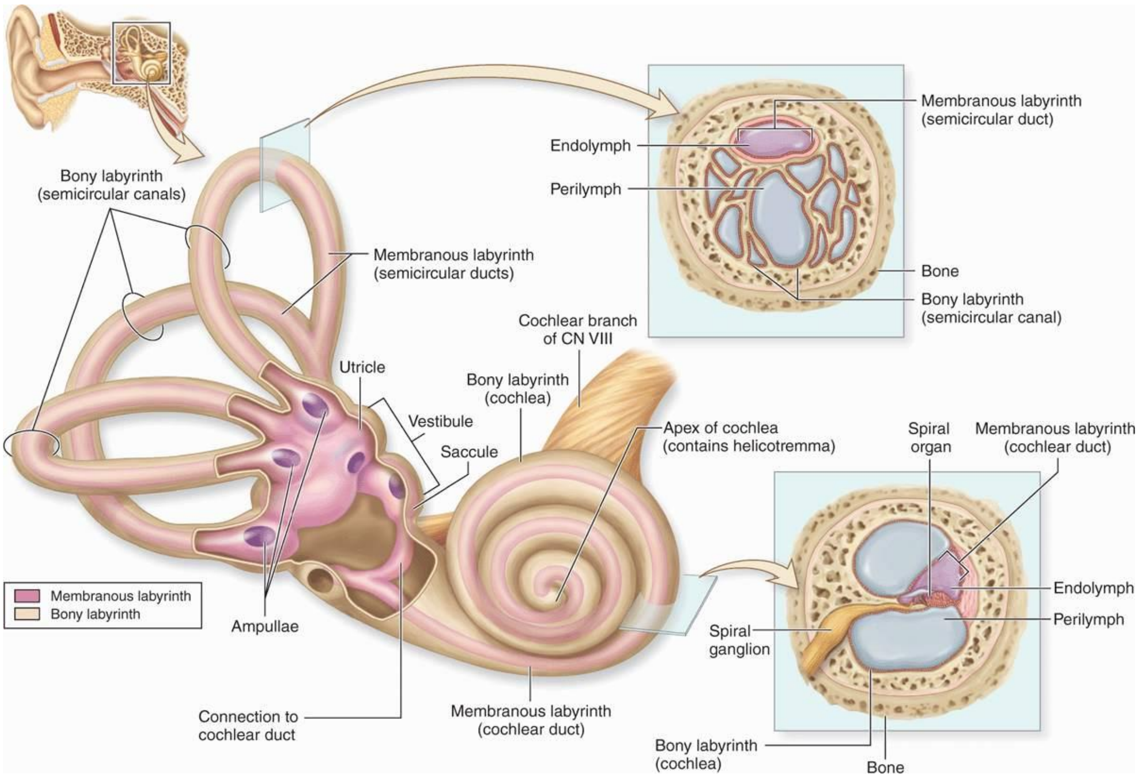


Figure 36 – Internal ear

The entire membranous labyrinth is within the bony labyrinth, which includes the following regions:

- An irregular central cavity, the **vestibule** (L. vestibulum, area for entering) houses the saccule and the utricle.

- Behind this, three **osseous semicircular canals** enclose the semicircular ducts.

- On the other side of the vestibule, the **cochlea** (L. snail, screw) contains the cochlear duct. The cochlea is about 35 mm long and makes 2¾ turns around a bony core called the **modiolus** (L. hub of wheel). The modiolus contains blood vessels and surrounds the cell bodies and processes of the acoustic branch of the eighth cranial nerve in the large spiral or cochlear ganglion. The bony and membranous labyrinths contain two different fluids. The separation and ionic differences between these fluids are important for inner ear function.

Perilymph fills all regions of the bony labyrinth and has an ionic composition similar to that of cerebrospinal fluid and the extracellular fluid of other tissues, but it contains little protein. Perilymph emerges from the microvasculature of the periosteum and drains via a perilymphatic duct into the adjoining subarachnoid space. Perilymph suspends and supports the closed membranous labyrinth, protecting it from the hard wall of the bony labyrinth.

Endolymph fills the membranous labyrinth and is characterized by a high-K^+ (150 mM) and low-Na^+ (16 mM) content, similar to that of intracellular fluid. Endolymph is produced in a specialized area in the wall of the cochlear duct (described below) and drains via a small endolymphatic duct into venous sinuses of the dura mater.

Vestibule. Utricle and Saccule.

The interconnected, membranous **utricle** and the **saccule** are composed of a very thin connective tissue sheath lined with simple squamous epithelium and are bound to the periosteum of the bony labyrinth by strands of connective tissue containing microvasculature. The maculae in the walls of the utricle and saccule are small areas of columnar neuroepithelial cells innervated by branches of the vestibular nerve. The macula of the saccule lies in a plane perpendicular to that of the utricle, but both are similar histologically. Each consists of a thickening of the wall containing several thousand columnar hair cells, each with surrounding supporting cells and synaptic connections to nerve endings.

Hair cells act as mechanoelectrical transducers, converting mechanical energy into the electrical energy of nerve action potentials. Each has an apical hair bundle consisting of one rigid cilium, the kinocilium, up to 40 μm long, and a bundle of 30-50 rigid, unbranched stereocilia. The base of each stereocilium is tapered and connected to an actin-rich region of apical cytoplasm, the cuticular plate, which returns these rigid projecting structures to a normal upright position after bending. They are arranged in rows of decreasing length, with the longest adjacent to the kinocilium. The tips of the stereocilia and kinocilium are embedded in a thick, gelatinous layer of proteoglycans called the otolithic membrane. The outer region of this layer contains barrel-shaped crystals of $CaCO_3$ and protein called otoliths (or otoconia) typically 5-10 μm in diameter.

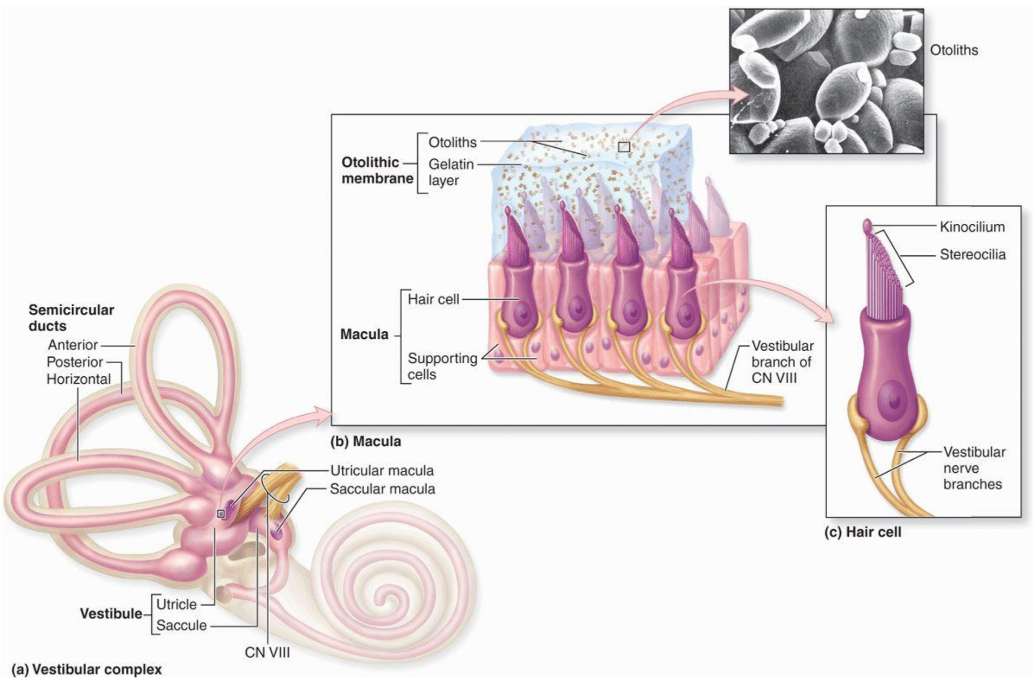


Figure 37 – Vestibular maculae

All hair cells have basal synapses with afferent (to the brain) nerve endings but are of two types:

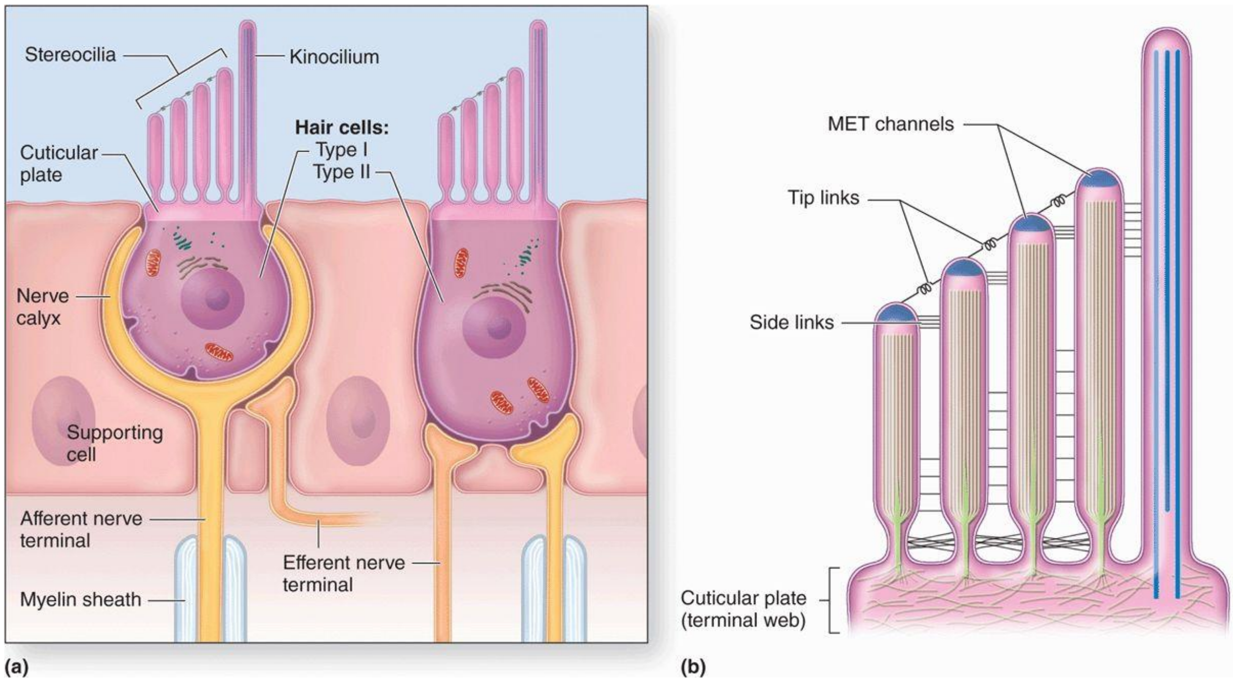


Figure 38 – Hair cells and hair bundles

1) **Type I hair cells** have rounded basal ends completely surrounded by an afferent terminal calyx (Latin for "cup").

2) The more numerous **type II hair cells** are cylindrical, with bouton endings from afferent nerves.

Synaptic connections with efferent (from the brain) fibers are also present on hair cells of both types, or on their afferents, to modulate the sensitivity of these mechanoreceptors. The supporting cells provide metabolic and physical support for the mechanoreceptors.

Sensory information from the utricle and saccule allows the brain to monitor the **static position** and **linear acceleration** of the head. This information, along with that provided visually and by musculoskeletal proprioceptors, is important for maintaining equilibrium and allowing the eyes to remain fixed on the same point while moving the head. The head's position determines the position of the otolithic membrane in contact with hair cells of the two maculae. Because the otoliths are heavier than endolymph, the hair bundles are deflected by gravity when the head is not moving, when the head is tilted, and when the individual is moving in a straight line and inertia causes drag on the otolithic membrane.

Deflection or bending of the stereocilia changes the hair cells' resting potential and their rate of neurotransmitter release to the afferent nerves, which is the basis for mechanoelectrical transduction. When the hair bundle is deflected toward the kinocilium, protein fibrils called **tip links** connecting the stereocilia are pulled and mechanically gated channels open to allow an influx of K+ ions (the major cation in endolymph). The resulting depolarization of the hair cell opens voltage-gated

Ca2+ channels in the basolateral membrane, and Ca2+ entry stimulates release of neurotransmitter and generates an impulse in the afferent nerve.

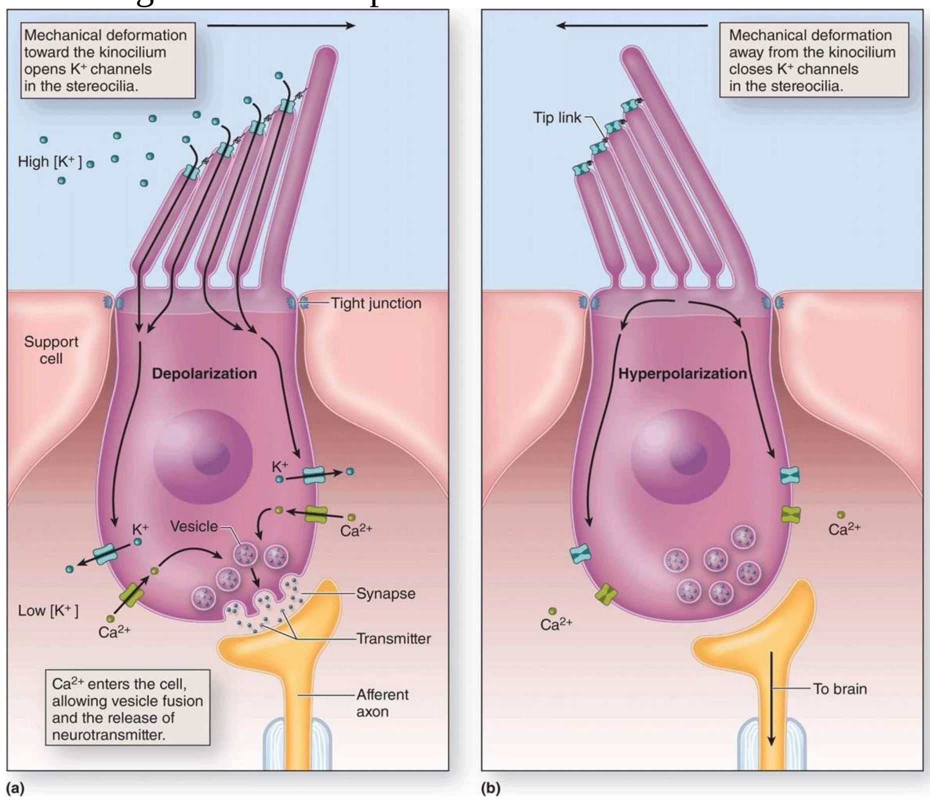


Figure 39 – Mechanotransduction in hair cells

Hair cells and supporting cells are part of an epithelium with tight junctions. The apical ends of the cells are exposed to endolymph with a high concentration of K+, and perilymph with a much lower K+ concentration bathes their basolateral surface. At rest, hair cells are polarized with a small amount of K+ entry and a low level of neurotransmitter release to afferent nerve fibers at the basal ends of the cells.

As shown on Figure 39, head movements that cause the stereocilia bundle to be deflected toward the kinocilium produce tension in the tip links, which is transduced to electrical activity by opening of adjacent cation channels. Entry of K+ depolarizes the cell, opening voltage-gated basolateral Ca2+ channels, which stimulates release of neurotransmitter. When this movement stops, the cells quickly repolarize.

Movements in the opposite direction, away from the kinocilium, produce slackness on the tip links, allowing the mechanically gated apical K+ channels to close completely, producing hyperpolarization, and inhibiting transmitter release. With different numbers of afferent and efferent fibers on the hair cells and with various hair cells responding differently to endolymph movements due to their positions within the maculae and cristae ampullares, the sensory information produced collectively by these cells can be processed by the vestibular regions of the brain and used to help maintain equilibrium.

When the head stops moving, the stereocilia straighten and hair cells quickly repolarize and reestablish the resting potential. Head movements that bend the stereocilia away from the kinocilium cause the tip links to be slack, allowing closure of the apical cation channels and hyperpolarization of the cell. This in turn closes Ca2+ channels and reduces neurotransmitter release.

Semicircular Ducts

The three semicircular ducts extend from and return to the wall of the utricle. They lie in three different spatial planes, at approximately right angles to one another.

Each semicircular duct has one enlarged ampulla end containing hair cells and supporting cells on a crest of the wall called the **crista ampullaris**. Each crista ampullaris is perpendicular to the long axis of the duct. Cristae are histologically similar to maculae, but the proteoglycan layer called the **cupula** attached to the hair cells apically lacks otoliths and is thicker. The cupula extends completely across the ampulla, contacting the opposite nonsensory wall.

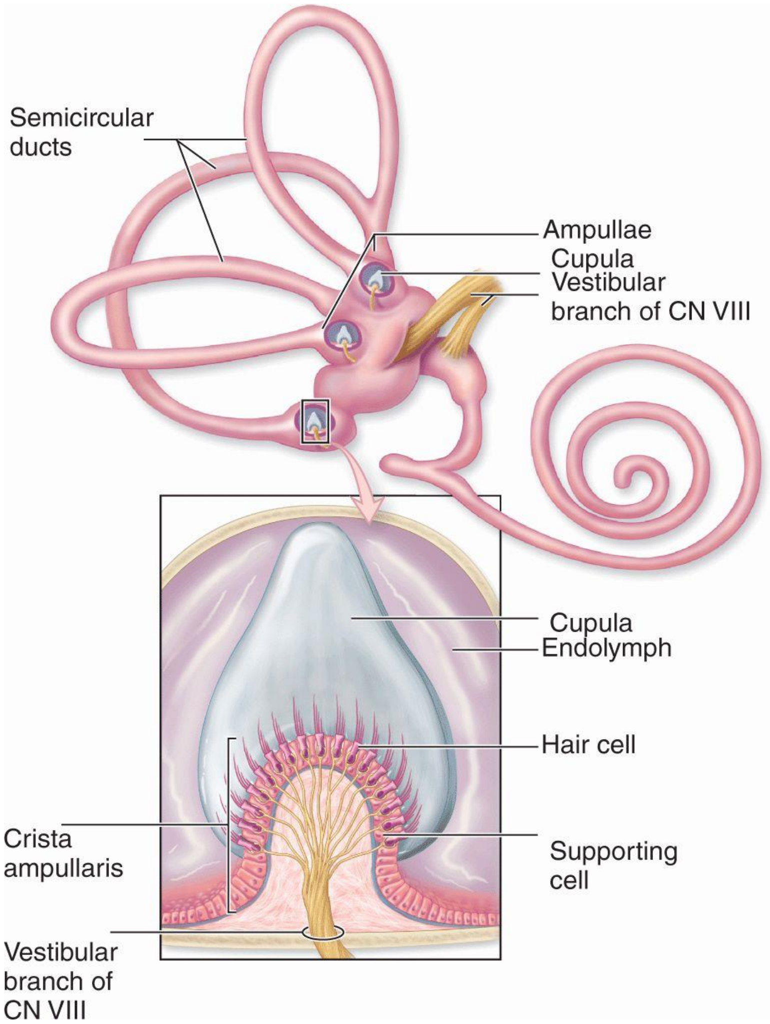


Figure 40 – Ampullae and cristae of the semicircular ducts

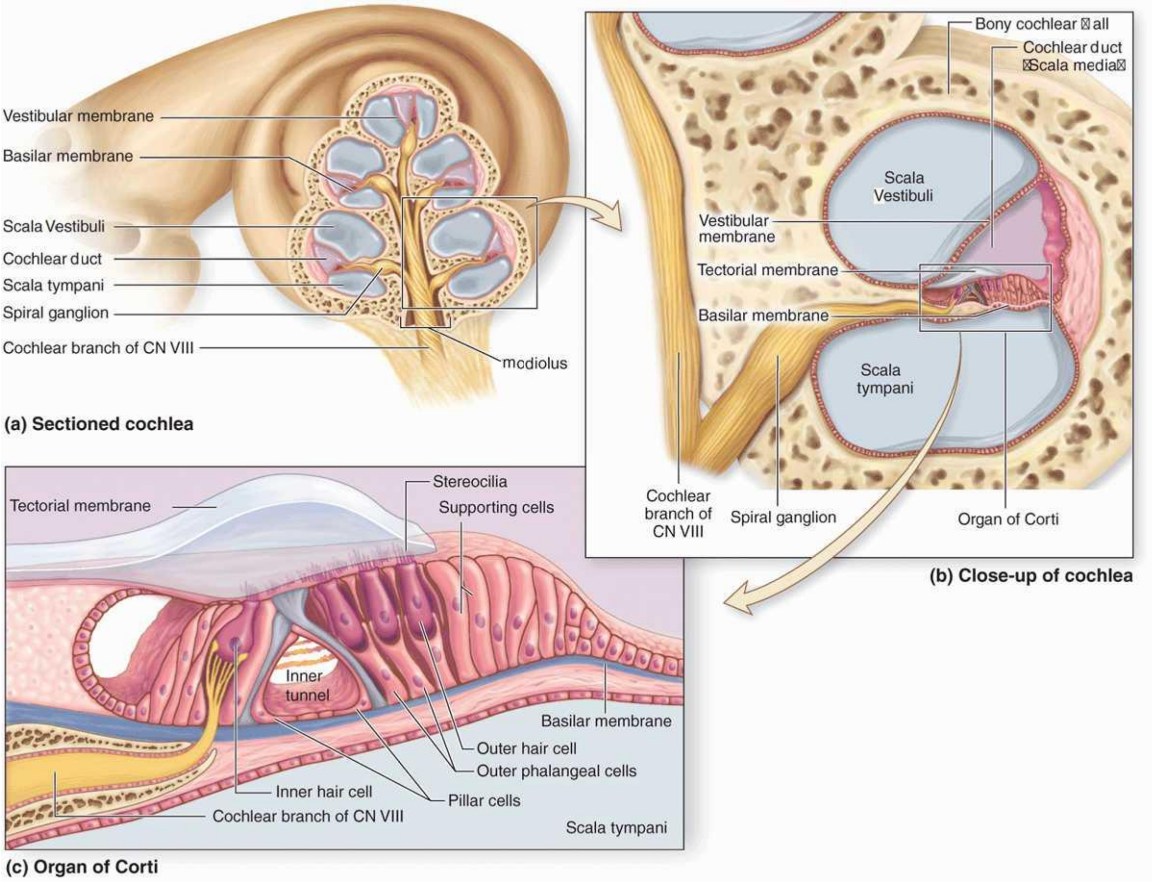
The hair cells of the cristae ampullares act as mechanoelectrical transducers like those of the maculae in the utricle and saccule, signaling afferent axons by pulsed transmitter release determined by depolarization and hyperpolarization states. Here the mechanoreceptors detect rotational movements of the head as they are deflected by endolymph movement in the semicircular ducts. The cells are oriented with opposite polarity on each side of the side, so that turning the head causes hair cell depolarization on one side and hyperpolarization on the other. Neurons of the vestibular nuclei in the CNS receive input from the sets of semicircular ducts on each side simultaneously and interpret head rotation on the basis of the relative transmitter discharge rates of the two sides.

Inputs from the semicircular ducts travel together with those from the utricle and saccule along the eighth cranial nerve to vestibular nuclei in the CNS. There they are interpreted together with inputs from mechanoreceptors of the musculoskeletal system to provide the basis for perceiving movement and orientation in space and for maintaining equilibrium or balance.

Cochlear Duct

The **cochlear duct**, a part of the membranous labyrinth shaped as a spiral tube, contains the hair cells and other structures that allow auditory function. Held in place within the bony cochlea, this duct is one of three parallel compartments, or scalae (Latin for “ramps” or “ladders”) which coil 2¾ turns within the cochlea:

- The cochlear duct itself forms the middle compartment, or **scala media**, filled with endolymph. It is continuous with the saccule and ends at the apex of the cochlea.
- The larger **scala vestibuli** contains perilymph and is separated from the scala media by the very thin **vestibular membrane** (Reissner’s membrane) lined on each side by simple squamous epithelium. Extensive tight junctions between cells of this membrane block ion diffusion between perilymph and endolymph.
- The **scala tympani** also contains perilymph and is separated from the scala media by the fibroelastic basilar membrane.



(a) Sectioned cochlea
(b) Close-up of cochlea
(c) Organ of Corti

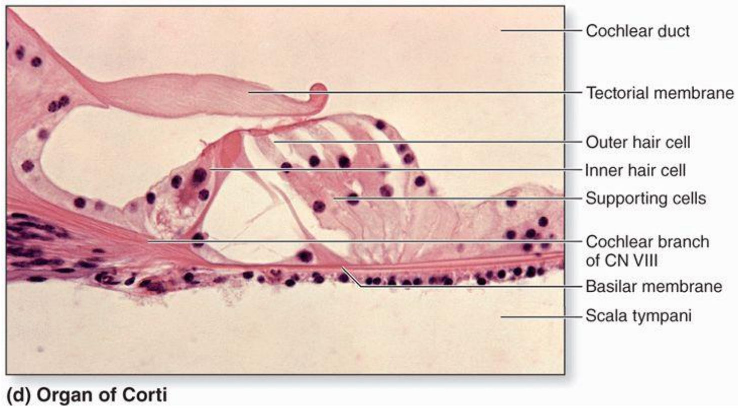


Figure 41 – Cochlea and spiral organ (of Corti)

(a) The auditory portion of the inner ear, the cochlea, has a snail-like spiral shape in both its bony and membranous labyrinths. A section of the whole cochlea shows its three parallel compartments cut in several places.

(b) This diagram shows a more detailed view of one such turn of the cochlear duct (scala media), the organ of Corti on the basilar membrane, and the adjacent perilymph-filled spaces, the scala vestibuli and scala tympani. Endolymph in the cochlear duct is produced by the stria vascularis (not shown), a capillary-rich area in the lateral wall.

(c) This diagram shows the organ of Corti in more detail, including the **tectorial membrane**, the general locations and shape of the **inner and outer hair cells**, their supporting **phalangeal cells**, and the **pillar cells** making the inner tunnel.

(d) The micrograph shows major features of the organ of Corti histologically. X75. H&E.

The scalae tympani and vestibuli communicate with each other at the apex of the cochlea via a small opening called the **helicotrema (Breschet hiatus)**. Thus, these two spaces with perilymph are actually one long tube; the scala vestibuli begins near the vestibular oval window and the scala tympani ends at the round window.

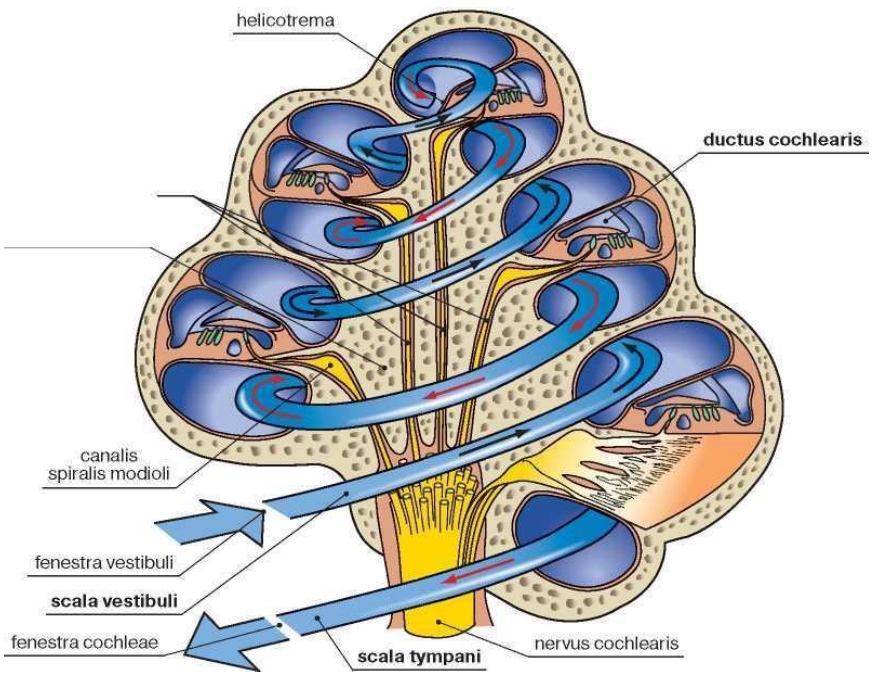


Figure 42 – Flow of the perilymph

The **stria vascularis**, located in the lateral wall of the cochlear duct (scala media), produces the endolymph with high levels of K+ that fills the entire membranous labyrinth. Stratified epithelial cells of the stria vascularis extend cytoplasmic processes and folds around the capillaries of an unusual intraepithelial plexus. K+ released from the capillaries is transported across tightly joined cells at the strial surface into the endolymph, which bathes the stereocilia of hair cells and produces conditions optimal for depolarization of these cells.

The **organ of Corti**, or **spiral organ**, where sound vibrations of different frequencies are detected, consists of hair cells and other epithelial structures supported by the basilar membrane. Here the sensory hair cells have precisely arranged V-shaped bundles of rigid stereocilia; each loses its single larger kinocilium during development. Two major types of hair cells are present:

- **Outer hair cells**, about 12,000 in total, occur in three rows near the saccule, increasing to five rows near the apex of the cochlea. Each columnar outer hair cell bears a V-shaped bundle of stereocilia.
- **Inner hair cells** are shorter and form a single row of about 3500 cells, each with a single more linear array of shorter stereocilia.

Both outer and inner hair cells have synaptic connections with afferent and efferent nerve endings, with the inner row of cells more heavily innervated. The cell bodies of the afferent bipolar neurons constitute the spiral ganglion located in the bony core of the modiolus.

Two major types of columnar supporting cells are attached to the basilar membrane in the organ of Corti:

- **Inner and outer phalangeal cells** extend apical processes that intimately surround and support the basolateral parts of both inner and outer hair cells and the synaptic nerve endings. The apical ends of phalangeal cells are joined to those of the hair cells by tight zonulae occludens, forming an apical plate across the spiral organ through which the stereocilia bundles project into endolymph.
- **Pillar cells** are stiffened by heavy bundles of keratin and outline a triangular space, the inner tunnel, between the outer and inner complexes of hair cells and phalangeal cells. The stiff inner tunnel also plays a role in sound transmission.

On the outer hair cells the tips of the tallest stereocilia are embedded in the gel-like tectorial membrane, an acellular layer that extends over the organ of Corti from the connective tissue around the modiolus. The tectorial membrane consists of fine bundles of collagen (types II, V, IX, and XI) associated with proteoglycans and forms during the embryonic period from secretions of cells lining this region.

By detecting minute movements of the stereocilia, hair cells in the spiral organ of Corti act as mechanoelectrical transducers very much like those of the vestibular maculae described previously and mediate the sense of hearing. Sound waves collected by the external ear cause the tympanic membrane to vibrate, which moves the chain of middle ear ossicles and the oval window. The large size of the tympanic membrane compared to the oval window and the mechanical properties of the ossicle chain amplify the movements and allow optimal transfer of energy between air and perilymph, from sound waves to vibrations of the tissues and fluid-filled chambers.

Pressure waves within the perilymph begin at the oval window and move along the scala vestibuli. Each pressure wave causes momentary displacement of the vestibular and/or basilar membranes and the endolymph surrounding the organ of Corti.

The width, rigidity, thickness, and other physical properties of the basilar membrane and its organ of Corti all vary in precise gradients along its length. This allows the region of maximal displacement to vary with the sound waves' frequency, that is, the number of waves moving past a point per unit of time (measured in hertz). High-frequency sounds displace the basilar membrane maximally near the oval window. Sounds of progressively lower frequency produce pressure waves that move farther along the scala vestibuli and displace the spiral organ at points farther from the oval window. The sounds of the lowest frequency that can be detected produce movement of the basilar membrane at the apex or helicotrema of the cochlea. After crossing the cochlear duct (scala media) and organ of Corti, pressure waves are transferred to the scala tympani and exit the inner ear at the round window.

The main mechanoreceptors for the sense of hearing are the more heavily innervated inner hair cells in the organ of Corti. The outer hair cells, with their stereocilia tips embedded in the tectorial membrane, are depolarized when stereocilia are deformed, as described previously, for vestibular hair cells. In the organ of Corti, however, hair cell activities are more complex, allowing greater control on sensory reception.

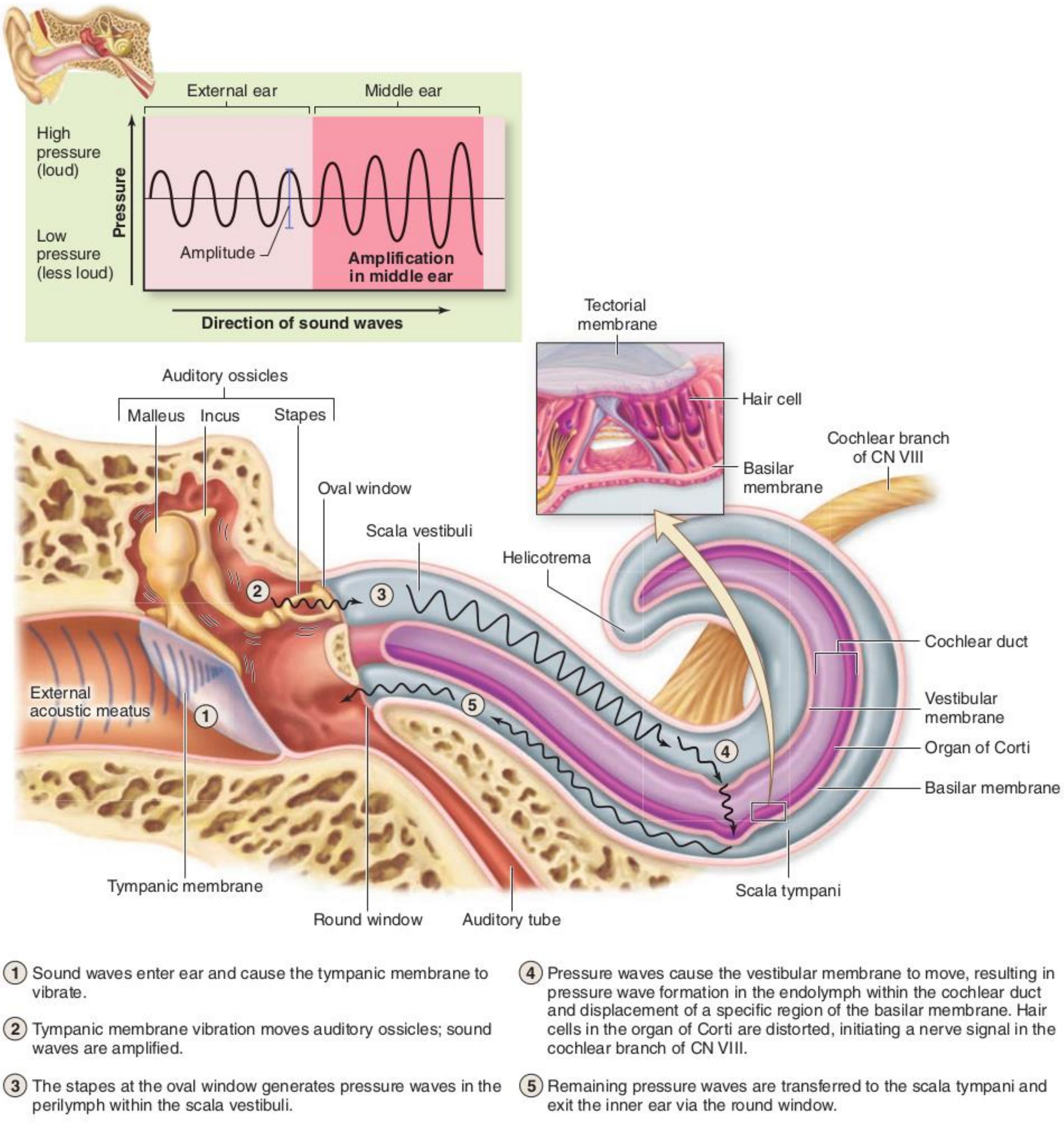


Figure 43 – Path of sound waves through the ear

Depolarization of the outer hair cells causes these columnar cells to shorten very rapidly, an effect mediated by an unusual 80-kD transmembrane protein called prestin (It. presto, very fast) abundant in the lateral cell membranes. Prestin undergoes a voltage-dependent conformational change that affects the cytoskeleton, rapidly shortening the cells when the membrane is depolarized and elongating them again with membrane hyperpolarization.

Piston-like movements of the outer hair cells pull down the tectorial membrane against the stereocilia of the inner hair cells, causing depolarization of these cells which then send the signals to the brain for processing as sounds. This sequential role for outer and inner hair cells produces further cochlear amplification of the sound waves.

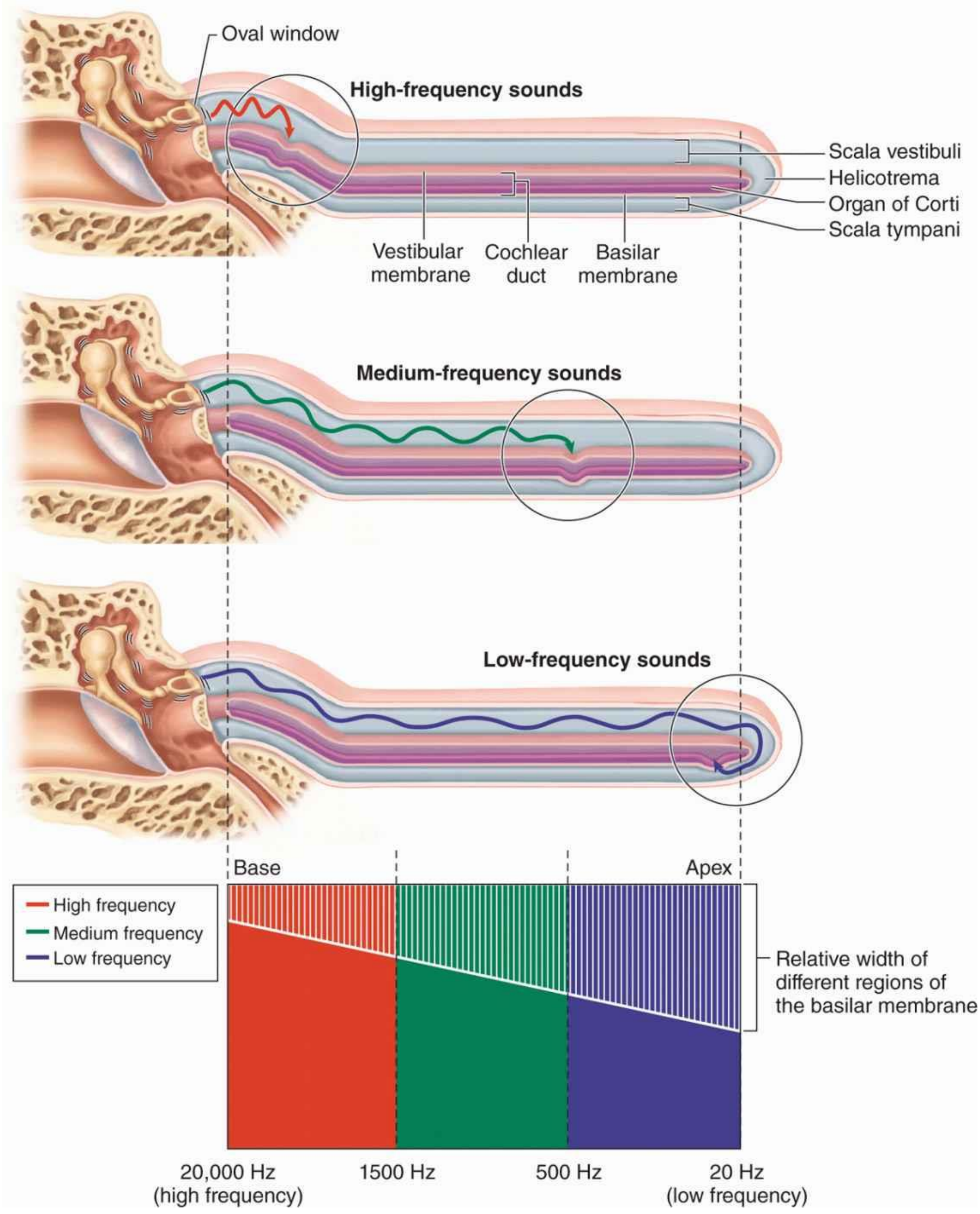
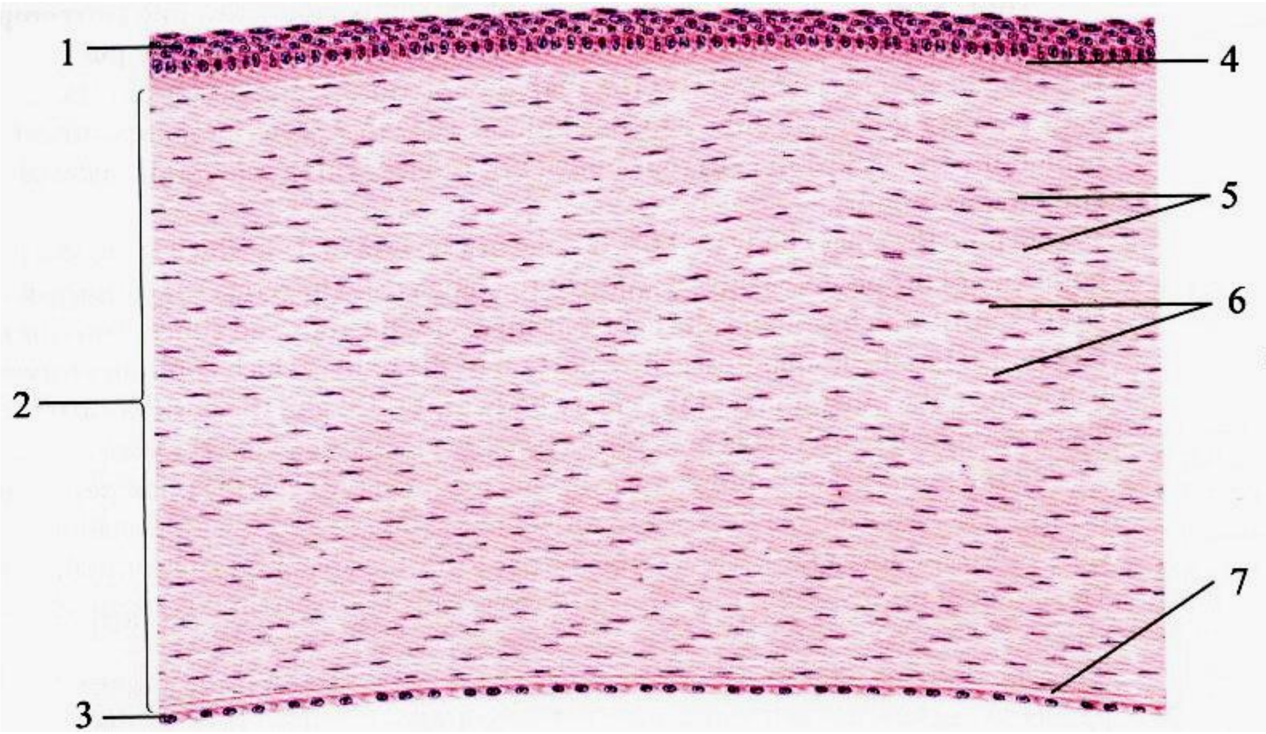


Figure 44 – Interpretation of sound waves in the cochlea

Practical Part I



Slide 1 - Cornea
Staining: hematoxylin and eosin
1- stratified squamous corneal epithelium;
2- cornea stroma (substantia propria);
3- posterior epithelium;
4- anterior limiting (Bowman's) membrane;
5- collagen fibers;
6- fibroblast;
7- posterior limiting (Descemet's) membrane.

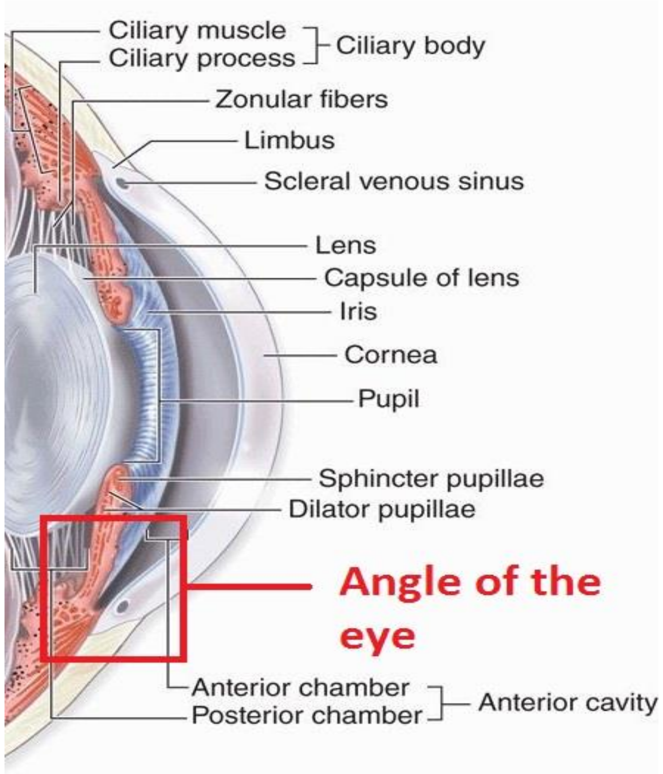


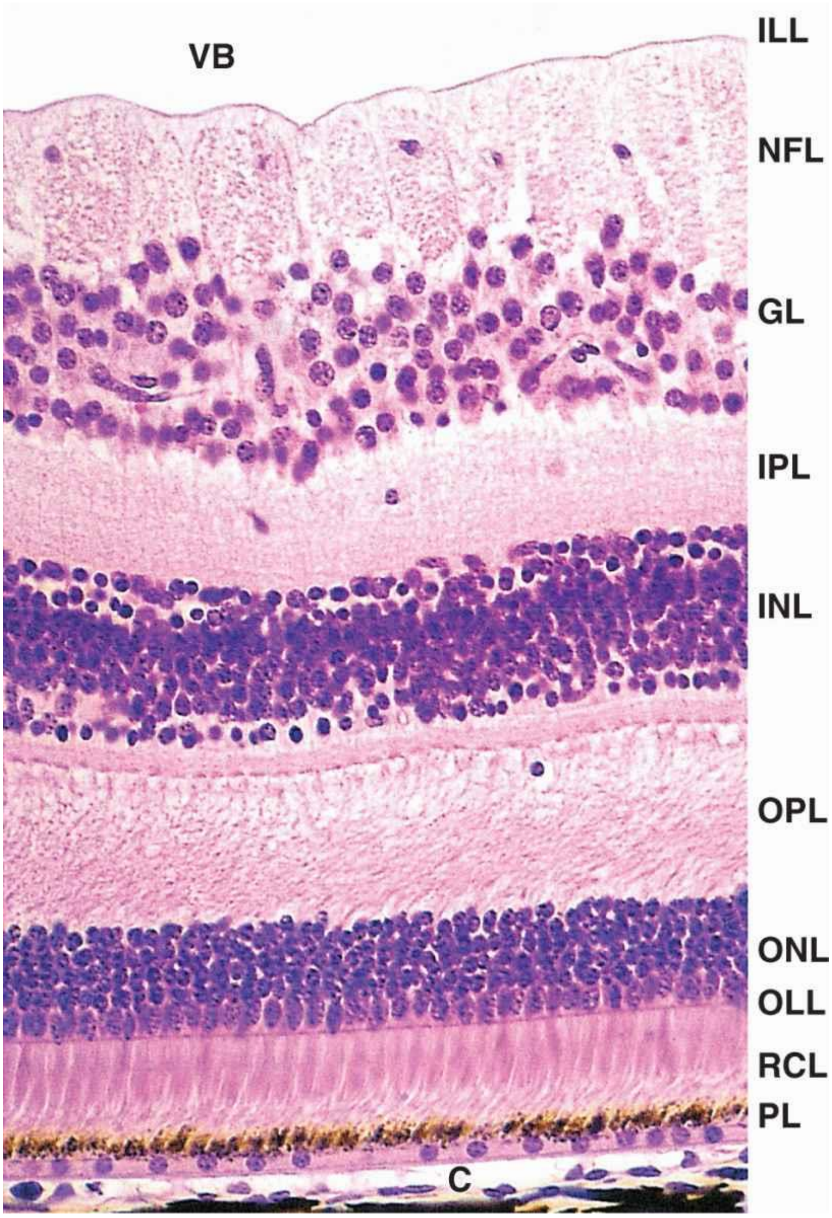
Diagram 1: Angle of the eye.

Slide 2: Angle of the eye.

Staining: hematoxylin and eosin.

1 - anterior chamber;
2 – iris;
3 – cornea;
4 – sclera;
5 - posterior chamber;
6 – retina;
7 – lens;
8 - ciliary body

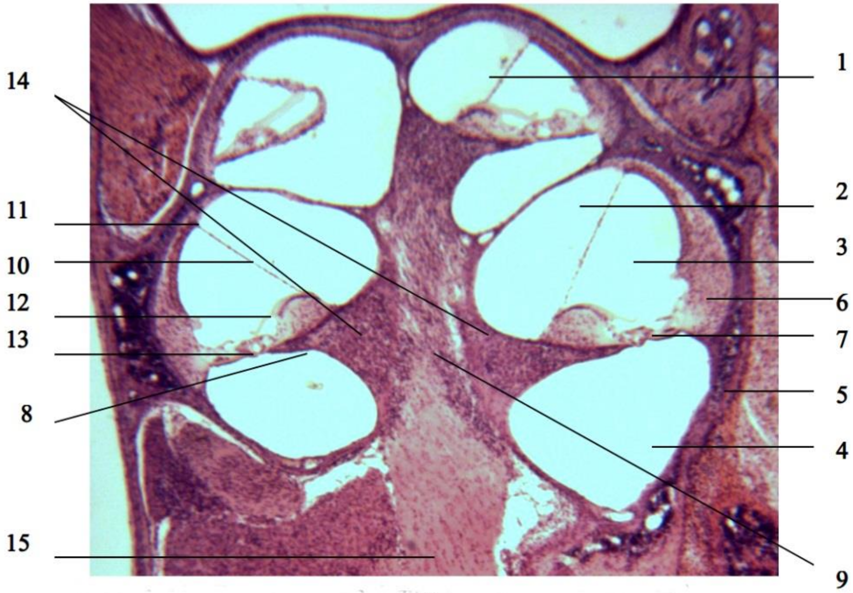
Practical Part II



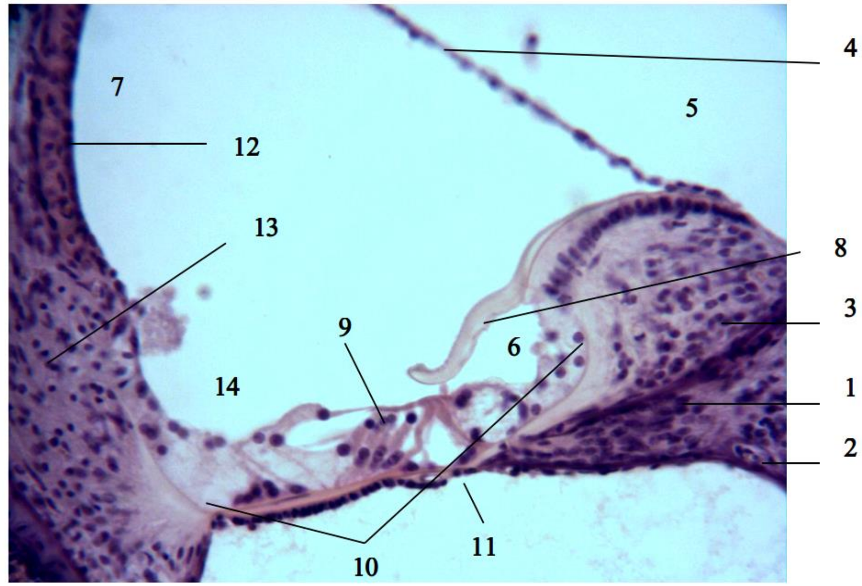
Slide 1: Retina
Staining: hematoxylin and eosin.

C - choroid.
PL - pigmented layer of cuboidal epithelium containing melanin.
RCL - rods and cones layer.
OLL - outer limiting layer.
ONL - outer nuclear layer (cell bodies of R&C, first neurons).
OPL - outer plexiform layer (axons of R&C).
INL - inner nuclear layer (second neurons).
IPL - inner plexiform layer (axons of second neurons).
GL - ganglionic layer (third neurons).
NFL - nerve fiber layer (axons of third neurons).
ILL - inner limiting layer.
VB - vitreous body.

Practical Part III



Slide 1. Inner ear: cochlear (vertical section)
Staining: hematoxylin and eosin.
Low magnification.
1 - helicotrema;
2 - scala vestibuli (vestibular dust);
3 - cochlear duct (scala media);
4 - scala tympani (tympanic duct);
5 - outer bony wall of cochlea;
6 - spinal ligament;
7 - basilar membrane;
8 - osseous spiral lamina;
9 - cochlear nerve;
10 - vestibular membrane;
11 - attachment of vestibular membrane to spiral ligament;
12 - tectorial membrane;
13 - organ of Corti;
14 - spinal ganglion;
15 - modiolus



Slide 2. Inner ear: cochlear duct.
Staining: hematoxylin and eosin.
Medium magnification.
1 - peripheral processes of ganglion cells;
2 - spiral ganglion cells;
3 - spiral limbus;
4 - vestibular membrane;
5 - scala vestibul;
6 - internal spiral sulcus;
7 - cochlear duct;
8 - tectorial membrane;
9 - hair cells;
10 - organ of Corti;
11 - basilar membrane;
12 - stria vascularis;
13 - spiral ligament;
14 - outer spiral sulcus.

Questions for Self-Control:

1. What are the receptors for vision?

a. Rods
b. Cones
c. Bipolar cells
d. Ganglion cells
e. Both a and b

2. Where is the ciliary muscle located?

a. Ciliary body
b. Optic disc
c. Fovea centralis
d. Lamina vitrea
e. Lamina cribrosa

3. What are the openings within the sclera which allow nerve fibers to exit?

a. Os
b. Optic chiasm
c. Lamina cribrosa
d. Optic disc
e. Ora serrata

4. Which of the following is NOT part of the retina?

a. Receptor cells
b. Neurons
c. Pigmented epithelium
d. Ciliary body
e. Supporting cells

5. What structure adjusts the shape of the lens?

a. Internal oblique muscle
b. Orbicularis oculi
c. Tarsus
d. Ciliary muscle
e. Levator muscle

6. What is the inner layer of the choroid?

a. Ciliary body
b. Optic disc
c. Fovea centralis
d. Lamina vitrea
e. Lamina cribrosa

7. Where does aqueous humor from anterior chamber collect into?

a. Canaliculi
b. Canal of Hering
c. Canal of Muller
d. Canal of Descemet
e. Canal of Schlemm

8. Which layer of the cornea is acellular?

a. Epithelium
b. Endothelium
c. Descemet's membrane
d. Substantia propria
e. None of the above

9. Which structure is avascular?

a. Retina
b. Cornea
c. Choroid
d. Sclera
e. Uvea

10. What is within the membranous labyrinth?

a. Lymph
b. Blood
c. Endolymph
d. Perilymph
e. Air

11. What is within the bony labyrinth?

a. Lymph
b. Blood
c. Endolymph
d. Perilymph
e. Air

12. Which contains endolymph?

a. Scala vestibuli
b. Scala tympani
c. Cochlear duct

d. Both a and b
e. All a, b, and c

13. Which contains perilymph?
a. Scala vestibuli
b. Scala tympani
c. Cochlear duct
d. Both a and b
e. All a, b, and c

14. Where are the sensory receptors for hearing?
a. Saccule
b. Utricle
c. Organ of Corti
d. Semicircular canals
e. Both a and b

15. Where are the sensory receptors for movement?
a. Saccule
b. Utricle
c. Organ of Corti
d. Semicircular canals
e. Both a and b

16. Where are the sensory receptors for position?
a. Saccule
b. Utricle
c. Organ of Corti
d. Semicircular canals
e. Both a and b

17. What structure is shaped like a snail shell?
a. Saccule
b. Utricle
c. Organ of Corti
d. Semicircular canals
e. Cochlea
Answer: e

18. Where is the organ of Corti?
a. Saccule
b. Utricle

c. Crista ampullaris
d. Semicircular canals
e. Cochlea

19. What sensation does the crista ampullaris recognize?
a. Sound
b. Position
c. Movement
d. Vibration
e. All of the above

20. Which cell type is the receptor cell within the organ of Corti?
a. Cells of Hensen
b. Hair cells
c. Inner border cells
d. Outer phalangeal cells
e. Inner pillar cells

Answers

1. What are the receptors for vision?
Answer: e

The retina consists of the rods, cones, bipolar cells, ganglion cells, horizontal cells, and amacrine cells. The receptors for vision are the rods and cones. The rods are located on the periphery, and are not color sensitive. The cones are the receptors for color.

2. Where is the ciliary muscle located?
Answer: a

The ciliary body is a thickening in the uvea. It contains the ciliary muscle.

The site where the optic nerve leaves the eyeball is the optic disc. This region is also called the anatomical blind spot. Since there are no photoreceptors at this spot, it causes a blind spot in the visual field.

The fovea centralis is part of the retina. There are only cone cells in the fovea centralis. It is the site for maximal visual acuity.

The inner layer of the choroid is the lamina vitrea. The lamina vitrea is also referred to as Bruch's membrane.

The lamina cribrosa are small openings within the sclera where the fibers forming the optic nerve travel through.

3. What are the openings within the sclera which allow nerve fibers to exit?
Answer: c

An os is an opening or mouth. The optic chiasm is the anatomical region shaped like an "X" where the two optic nerves join. The region where the optic nerve exits the eye is the optic disc. The openings within the sclera which allow nerve fibers to exit is the lamina cribrosa. The anterior pigmented portion of the retina is called the ora serrata.

4. Which of the following is NOT part of the retina?
Answer: d

The retina contains receptor cells, neurons, pigmented epithelium and supporting cells. The nervous element in the retina consists of bipolar cells and ganglion cells. Ciliary body is not part of the retina.

5. What structure adjusts the shape of the lens?
Answer: d

The ciliary muscle is within the ciliary body. The ciliary muscle adjusts the shape of the lens.

6. What is the inner layer of the choroid?

Answer: d

The ciliary body is a thickening in the uvea. It contains the ciliary muscle.

The site where the optic nerve leaves the eyeball is the optic disc. This region is also called the anatomical blind spot. Since there are no photoreceptors at this spot, it causes a blind spot in the visual field.

The fovea centralis is part of the retina. There are only cone cells in the fovea centralis. It is the site for maximal visual acuity.

The inner layer of the choroid is the lamina vitrea. The lamina vitrea is also referred to as Bruch's membrane.

The lamina cribrosa are small openings within the sclera where the fibers forming the optic nerve travel through.

7. Where does aqueous humor from anterior chamber collect into?

Answer: e

Aqueous humor collected from the anterior chamber via the canal of Schlemm.

8. Which layer of the cornea is acellular?

Answer: c

There are five layers to the cornea: epithelium, Bowman's membrane, substantia propria, Descemet's membrane, and endothelium.

The surface of the cornea is covered by a non-keratinized stratified squamous epithelium. Bowman's membrane and Descemet's membrane are acellular. The majority of the cornea is from the substantia propria. The endothelium is a simple epithelium.

9. Which structure is avascular?

Answer: b

The cornea is avascular.

10. What is within the membranous labyrinth?

Answer: c

11. What is within the bony labyrinth?

Answer: d

The membranous labyrinth contains endolymph. The bony labyrinth contains perilymph.

12. Which contains endolymph?

Answer: c

13. Which contains perilymph?

Answer: d

The scala vestibuli and scala tympani contain perilymph. The cochlear duct contains endolymph.

14. Where are the sensory receptors for hearing?
Answer: c

15. Where are the sensory receptors for movement?
Answer: d

16. Where are the sensory receptors for position?
Answer: e

The receptors for hearing are located within the organ of Corti. The receptors for movement are located within the semicircular canals. The receptors for position are located within the utricle and saccule.

17. What structure is shaped like a snail shell?
Answer: e

18. Where is the organ of Corti?
Answer: e

The cochlea is a spiral shaped structure. Within the cochlea is the organ of Corti.

19. What sensation does the crista ampullaris recognize?
Answer: c

The crista ampullaris is the receptor for movement.

20. Which cell type is the receptor cell within the organ of Corti?
Answer: b

The hair cells are the receptor cells. The other cells are supporting cells.

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