Subject I SENSORY ORGANS.

Program of lecture

- **Conception about analizators.**
- **Main analizators.**
- **Olfactory organ and olfactory analizator.**
- **Vision organ and analizator.**
- **Histophysiology of retina.**
- **Reception of vision.**
- **Taste organ and analizator.**
- **Histophysiology of tactile sense.**
- **Renewal and repair features of receptor cells. Age changes.**
- **Sensoepithelial sensory organs: organs of hearing and equilibrium.**

The central nervous system receives some information from outside and the inner organs of the organism with the aid of sensory system. The sensations resulted from this information reflect something existing regardless of our consciousness - the objective reality of everything around us. Needless to say, without our sense ograns we would be completely helpless and unable to survive.

A vital function of the nervous system is the gathering of sensory information, which is derived from variety of specialized sensory nerve endings.

These include:

-sensory endings in the skin to detect touch (fine touch, pressure) pain and temperature;

-tendon organs and muscle spindles to detect movement and position of the limbs;

-chemoreceptive organs such as carotid body.

In addition, information is obtained by the specialized sensory organs, the eye and the ear; the ear and the vestibular system detect sound, acceleration and position, and the eye perceives light.

The term sensory organ means special organ, which can recognize some exact irritation from outside. Due to the origin and structure sense organs (or sensory structures) are classified in the next way:

1. Primary sensory (neurosensory) organs

    a) smell organ;

    b) visual organ

2. Secondary sensory (sensoepithelial) organs

    a) taste buds;

b) audiovestibular organ

3. Sensory endings or sensory peripheral nerve terminals.

Analizator is common term, which means the neurophysiologic system, which consists of three components: sensory, connective and central. The first portion is present by sensory organ or ending, the last one ï brain cortex of granular (sensory) type. They are connected by nerves, which resemble the intermediate part of analizator. Due to the type of sensation there such principal analizators in human body: visual, audiovestibular, smell, taste, touch, pressure, pain and so on.

Sensory nerve endings or **receptors** perceive various stimuli and transmit this sensory input to the CNS. These sensory receptors are classified into three types, depending on the source of the stimulus, and are components of the general or special somatic and visceral afferent pathways:

- Exteroceptors
- Proprioceptors
- Interoceptors

Exteroceptors, located near the body surface, are specialized to perceive stimuli from the external environment. **Proprioceptors** are specialized receptors located in joint capsules, tendons, and intrafusal fibers within muscles. **Interoceptors** are specialized receptors that perceive sensory information from within organs of the body; therefore, the modality serving this function is the **general visceral afferent** modality.

The dendritic endings of certain sensory receptors, located in various regions of the body, including muscles, tendons, skin, fascia, and joint capsules, are specialized to receive particular stimuli. These adaptations help the dendrite respond to a particular stimulus. Thus, these receptors are classified into three types:

- **Mechanoreceptors,** which respond to touch
- **Thermoreceptors,** which respond to cold and warmth
- **Nociceptors,** which respond to pain due to mechanical stress, extremes of temperature differences, and chemical substances

ORGAN OF VISION

The eyes (orbs), approximately 24 mm in diameter, are located within the hollow bony orbits of the skull. They are the **photosensory organs** of the body. Light passes through the cornea, lens, and several refractory structures of the orb; light is then focused by the lens on the light-sensitive portion of the neural tunic of the eye, the **retina,** which contains the photosensitive **rods and cones (Fig. 1).** Through a series of several layers of nerve cells and supporting cells, the visual information is transmitted by the optic nerve to the brain for processing.

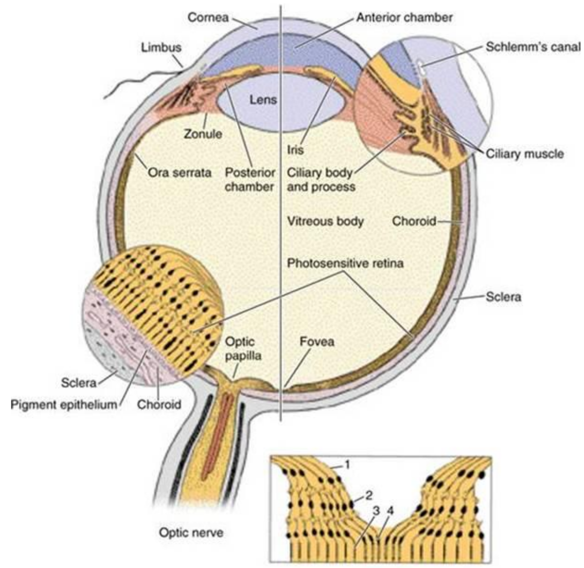

Fig. 1.

The eyes begin to develop from three different sources at about the 4th week of embryonic development. Outgrowths of the forebrain, the future retina and optic nerve, are the first to be observed. As a result of continued growth of this structure, the surface ectoderm is induced to develop into the lens and some of the accessory structures of the anterior portion of the eye. Later in development, adjacent mesenchyme condenses to form the tunics and associated structures of the orb.

The bulb of the eye is composed of three tunics, or coats.

- A **fibrous tunic,** forming the tough outer coat of the eye
- A **vascular tunic,** the pigmented and vascular middle coat
- A **neural tunic,** the retina, composing the innermost coat

The fibrous tunic of the eye also receives insertions of the **extrinsic muscles** of the eye, which are responsible for coordinated movements of the eyes to gain access to various visual fields. Smooth muscles located within the orb accommodate focusing of the lens and control the aperture of the pupil. Located outside the orb, but still within the orbit, is the **lacrimal gland** (tear gland), which secretes **lacrimal fluid** (tears) that moistens the anterior surface of the eye. The lacrimal fluid moistens the eye and the inner surface of the eyelids by passing through the **conjunctiva,** a transparent membrane that covers and protects the anterior surface of the eye (Fig.2).

The photosensitive retina proper communicates with the cerebrum through the optic nerve and extends forward to the ora serrata.

All structures of the eye may be organized in three systems or apparatuses due to their functions:

1. Dioptric (cornea, lens, vitreous body).

2. Visual (retina)

3. Accommodative (ciliary body)

TUNICA FIBROSA

The eyeôs outermost tunic has two main components. The anterior surface forms the transparent cornea; the posterior ï opaque (white) sclera. The junction between the cornea and sclera is the limbus. This tunic proves tough, fibroelastic support for the eye.

Cornea is transparent clear avascular disk bulging from the front of the eye, which has a smooth not uniformly curved surface**.** It belongs to the dioptric media of an eye. It is slightly thicker than the sclera and is composed of five histologically distinct layers (Fig. 3):

- Corneal epithelium
- Bowman's membrane
- Stroma
- Descemet's membrane
- Corneal endothelium

Anterior epithelium is stratified squamous nonkeratinized epithelium 50 mm thick, with five or six layers of cells. The epithelium is highly sensitive, with numerous free nerve endings and excellent regenerative properties.

Bowmanôs membrane is cell-free 8 mm thick basement membrane composed of ground substance and a flatwork of fine collagen type I fibers.

The transparent **stroma** is the thickest layer of the cornea, constituting about 90% of its thickness. It is composed of collagenous connective tissue, consisting mostly of type I collagen fibers that are arranged in 200 to 250 lamellae, each about 2 εm in thickness. The collagen fibers within each lamella are arranged parallel to one another, but fiber orientation shifts in adjacent lamellae. The collagen fibers are interspersed with thin elastic fibers, embedded in ground substance containing mostly chondroitin sulfate and keratan sulfate. Long, slender fibroblasts are also present among the collagen fiber bundles. During inflammation, lymphocytes and neutrophils are also present in the stroma. At the **limbus** (sclerocorneal junction) is a scleral sulcus whose inner aspect at the stroma is depressed and houses endothelium-lined spaces, known as the **trabecular meshwork,** that lead to the canal of Schlemm. The **canal of Schlemm** is the site of outflow of the aqueous humor from the anterior chamber of the eye into the venous system.

Posterior limiting membrane (Descemetôs) is 5 to 7 mm thick centrally but thicker at the periphery. It is a thick basement membrane, which differs from Bowmanôs in position and composition. It has elastin, but no elastic fibers. Its network of atypical collagen fibers is decorated with granules.

The corneal endothelium (posterior epithelium) is a simple cuboidal epithelium lining the internal surface of cornea. It is responsible for synthesis of proteins that are necessary for secreting and maintaining Descemetôs membrane. Excess fluid within the stroma is resorbed by this epithelium.

The cornea is avascular and its nutrition (and hydration) depends on diffusion from blood vessels in the limbus and from aqueous humor, through the endothelium.

Sclera is opaque white connective tissue, which covers the eyeœ posterior five sixths. This is dense fibrous tissue, about 1mm thick. It is composed of flat bundles of collagen fibers, which lie mainly parallel to the surface.

The sclera consists of dense fibro-elastic connective tissue, the fibres of which are arranged in bundles parallel to the surface. This layer contains little ground substance and few fibroblasts. The sclera varies in thickness, being thickest posteriorly and thinnest at the coronal equator of the globe (Fig.2).

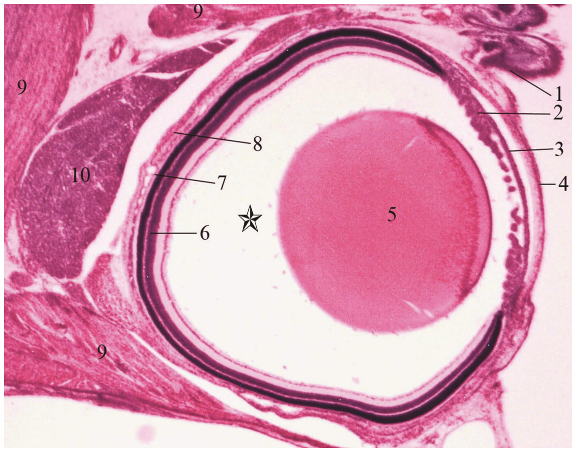

Fig. 2

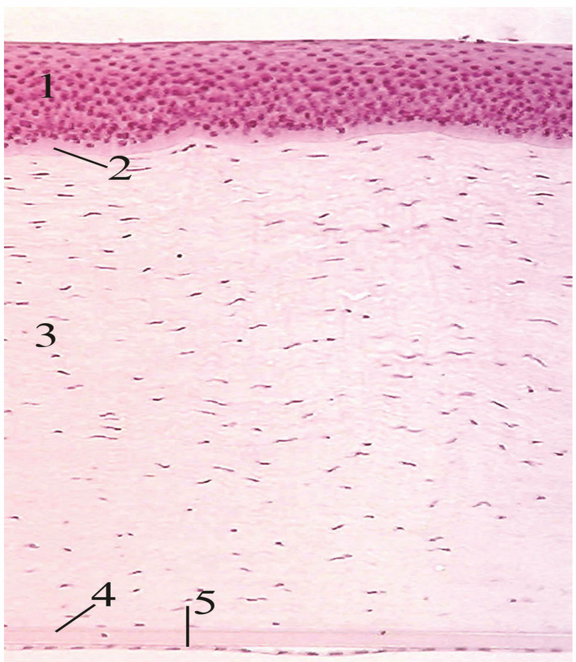

Fig.3

TUNICA VASCULOSA (UVEA)

The middle tunic of the eye has three components: the choroids (posterior part), ciliary body (middle) and iris (anterior).

The **choroid** is a layer of loose, highly vascular connective tissue lying between the sclera externally and the retina internally. The choroid and retina are separated by a thin membrane known as Bruch's membrane which probably represents the basement membrane of the pigmented epithelium. The choroid contains numerous large, heavily pigmented melanocytes which confer the dense pigmentation characteristic of the choroid. The pigment absorbs light rays passing through the retina and prevents interference due to light reflection.

The coroid consists of loose connective tissue, which houses a dense network of blood vessels. Connective tissue cells and melanocytes are numerous. The latter give the choroid its dark colour. Small blood vessels are especially frequent in the innermost part of the choroid, which is called the choriocapillary layer. This layer supplies the retina with nutrients. Bruch's membrane is located between the choroid and the retina. It consists of two layers of collagen fibres and a network of elastic fibres between them.

IRIS

This structure controls the amount of light that reaches the retina and gives the eye its color. In front the lens, it projects as a flat ring from the ciliary body, leaving a circular opening ï the pupil- at its center. The iris includes the most anterior extensions of the tunica vasculosa and tunica interna, forming the border between the anterior and posterior chambers. The anterior chamber lies between the cornea and iris; the posterior chamber is located between the iris and the lens-zonule complex (Fig. 4).

The posterior surface of the iris is covered by the retina. The inner layer of the retina, i.e. the layer facing the posterior chamber, is called the posterior epithelium of the iris. Both layers of the retina are pigmented, but pigmentation is heavier in the inner layer. In the region of the central opening of the iris, the pupil, the retina extends for a very short distance onto the anterior surface of the iris. The iridial stroma consists of a vascularized loose connective tissue rich in melanocytes in addition to macrophages and fibrocytes, which are all surrounded by a loose meshwork of fine collagen fibers. The anterior surface of the iris is not covered by an epithelium - instead of we find a condensation of fibrocytes and melanocytes, the anterior border layer of the iris.

The iris forms the aperture of the eye. Myoepithelial cells in the outer (or anterior) layer of the retina, i.e. the layer adjacent to the stroma of the iris, have radially oriented muscular extensions. These extensions form a flat sheet immediately beneath the anterior layer of the retina, the dilator pupillae muscle. Embedded in the central portion of the iridial stroma are smooth muscle cells which form the annular sphincter pupillae muscle. In humans, this muscle surrounds the pupil as a less than 1 mm wide and only 0.2 mmthick band. The two muscles regulate the size of the pupil. Pupillary constriction, which is mediated by the sphincter pupillae muscle, is clinically refered to as miosis - dilation, mediated by the dilator pupillae muscle, as mydriasis (Fig. 4).

The pigmentation of cells in the stroma and anterior border layer of the iris determines to color of the eyes. If cells are heavily pigmented the eyes appear brown. If pigmentation is low the eyes appear blue. Intermediate levels create shades of green and grey.

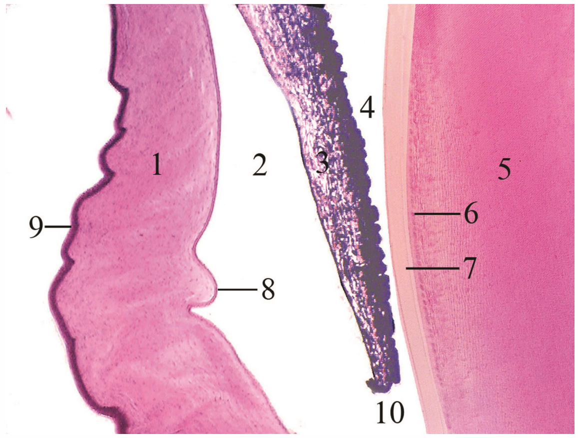

Fig. 4

CILIARY BODY

The ciliary body, the wedge-shaped extension of the choroid that rings the inner wall of the eye at the level of the lens, occupies the space between the ora serrata of the retina (the junction between and anterior and posterior portions of the retina) and the iris. One surface of the ciliary body abuts the sclera at the sclerocorneal junction, another surface abuts the vitreous body, whereas the medial surface projects toward the lens, forming short, finger-like projections known as **ciliary processes.**

The ciliary body is composed of loose connective tissue containing numerous elastic fibers, blood vessels, and melanocytes. Its inner surface is lined by the **pars ciliaris of the retina,** a pigmented layer of the retina that is composed of two cell layers. The outer cell layer, which faces the lumen of the orb, is a nonpigmented columnar epithelium **(nonpigmented ciliary epithelium),** whereas the inner cell layer is composed of a pigmented simple columnar epithelium **(pigmented ciliary epithelium),** which is rich in melanin.

The anterior one third of the ciliary body has about 70 **ciliary processes,** which radiate out from a central core of connective tissue containing abundant fenestrated capillaries. Fibers, composed of fibrillin **(zonule fibers),** radiate from the ciliary processes to insert into the lens capsule, forming the **suspensory ligaments of the lens,** which anchor the lens in place.

The ciliary processes are covered by the same two layers of epithelium that cover the ciliary body. The inner nonpigmented layer has many interdigitations and infoldings; its cells transport a protein-poor plasma filtrate, the **aqueous humor,** into the posterior chamber of the eye. The aqueous humor flows from the posterior chamber into the anterior chamber by passing through the **pupillary aperture** between the iris and the lens. The aqueous humor exits the anterior chamber by passing into the trabecular meshwork near the limbus and, finally, as stated previously, into the canal of Schlemm, which leads directly into the venous system. Aqueous humor provides nutrients and oxygen for the lens and the cornea.

The bulk of the ciliary body is composed of three bundles of smooth muscle cells called the **ciliary muscle.** One bundle, because of its orientation, stretches the choroid, thus altering the opening of the canal of Schlemm for drainage of the aqueous humor.

IRIS

The iris, the anteriormost extension of the choroid, lies between the posterior and anterior chambers of the eye, completely covering the lens except at the **pupillary aperture (pupil).** The iris is thickest in the middle, thinning toward its junction with the ciliary body and at the rim of the pupil. The anterior surface consists of two concentric rings: the **pupillary zone,** lying nearest the pupil, and the wider **ciliary zone.** The anterior surface of the iris is irregular, with trenches extending into it; it also contains contraction furrows, which are easily distinguished when the pupil is dilated. An incomplete layer of pigmented cells and fibroblasts covers the anterior surface of the iris. Deep to this layer is a stroma of poorly vascularized connective tissue containing numerous fibroblasts and melanocytes, which gives way to a well-vascularized, loose connective tissue zone.

The posterior surface of the iris is smooth and is covered by the continuation of the two layers of retinal epithelium that cover the ciliary body. The surface facing the lens is composed of heavily pigmented cells, which block the light from passing through the iris except at the pupil. The epithelial cells facing the stroma of the iris have extensions that form the **dilator pupillae muscle.** Hence, this muscle is myoepithelial in nature. Another muscle, the **sphincter pupillae muscle,** is located in a concentric ring around the pupil. Contractions of these smooth muscles alter the diameter of the pupil. The diameter of the pupil changes inversely to the amount of light entering it. Thus, bright light causes constriction of pupillary diameter, whereas dim light dilates it. Pupil diameter is the result of the the functions of the two intrinsic muscles contained within the iris. The dilator pupillae muscle, innervated by the sympathetic nervous system, dilates the pupil; the sphincter pupillae muscle, innervated by parasympathetic fibers of the oculomotor nerve (CN III), constricts the pupil.

VITREOUS BODY

This transparent, gel-like body (mostly water and hyaluronan) fills the large vitreous space between the lens and the retina. Some peripheral fibris form its capsule. It contains a few macrophages and hyalocytes ï stellate cells with oval nuclei that produce the fibrils and hyaluronan. During development, the central aretery extends from optic disk through the vitreous to the lens as hyaloid artery. It subsequently degenerates, leaving the narrow hyaloid canal.

LENS

The lens of the eye is a flexible, biconvex, transparent disk composed of epithelial cells and their secretory products. The lens consists of three parts: lens capsule, subcapsular epithelium, and lens fibers. It is suspended by the zonule of the ciliary body behind the pupil. Ciliary muscle contraction changes the curvature of the lens to enable focus on objects near or far, a process called accommodation. The lens has three main components.

The lens capsule is generated by the cells of the subcapsular epithelium and corresponds to a thick, elastic basal lamina. The zonule fibres insert into the lens capsule.

Cells of the subcapsular epithelium (or anterior lens cells) are mitotically active. In adult individuals they only cover the anterior "hemisphere" of the lens. As they divide, cells gradually move towards the equator of the lens where they tranform into lens fibres. The apical part of the gradually elongating cell extends between the subcapsular epithelium and adjacent lens fibres towards the anterior pole of the lens. The basal part extends towards the posterior pole. The nucleus remains close to the equatorial plane of the lens.

The mature lens fibres, i.e. very long (up to 12 mm), hexagonal cells, form the body of the lens. They are located immediately deep to the cells of the subcapsular epithelium. Lens fibres are nucleated in the soft, outer cortex of the lens. As new lens fibres are added to the periphery of the cortex, lens fibres located deeper in the cortex loose their nuclei and become part of the somewhat harder nucleus of the lens. In the intact lens, lens fibres are tightly connected to each other. Few organelles are scattered in a cytoplasm filled with cystallin proteins. These proteins are responsible for the transparency and refractive properties of the lens and account for up to 60% of the mass of lens fibres (Fig.5).

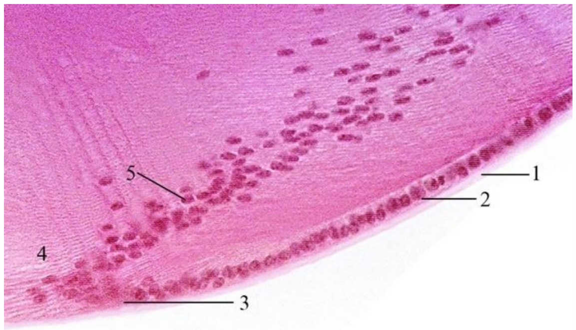

Fig.5

The optical properties of the lens change from periphery to central parts, because of differences in the amounts of crystallins contained in lens fibres. These difference correct for distortions of colours and shapes (called spherical and chromatic aberrations) which commonly occur at the margins of glass lenses. These aberrations are easy to observe when you look through a loupe - or even in not-so-good microscopes at the margins of the field of view, where they are easy to detect when to slide is moved.

VITREOUS BODY

The vitreous body is a transparent, refractile gel that fills the cavity of the eye **(vitreous cavity)** behind the lens. It is composed mostly (99%) of water containing a minute amount of electrolytes, collagen fibers, and hyaluronic acid. It adheres to the retina over its entire surface, especially at the ora serrata. Occasional macrophages and small cells called **hyalocytes** are observed at the periphery of the vitreous body; these are believed to synthesize collagen and hyaluronic acid. The fluid-filled **hyaloid canal,** a narrow channel that was occupied by the hyaloid artery in the fetus, extends through the entire vitreous body from the posterior aspect of the lens to the optic disk.

RETINA

Tunica interna (retina) is the innermost layer of eyeball. It comprises an anterior, nonsensitive portion, which lies over the ciliary body, and a posterior functional, or optical, portion, the photoreceptor organ (Fig. 6).

The retina is formed of an outer **pigmented layer** that develops from the outer wall of the optic cup. The neural portion of the retina develops from the inner layer of the optic cup and is called the **retina proper.** The pigmented layer of the retina covers the entire internal surface of the orb, reflecting over the ciliary body and the posterior wall of the iris, whereas the retina proper stops at the ora serrata. The cells composing the retina proper constitute a highly differentiated extension of the brain.

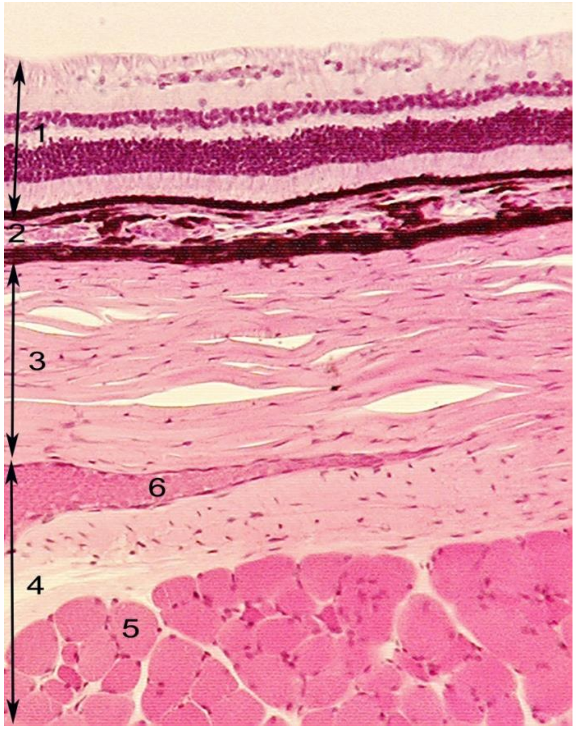

Fig.6

The **optic disk,** located on the posterior wall of the orb, is the exit site of the optic nerve. Because it contains no photoreceptor cells, it is insensitive to light and is therefore called the **"blind spot"** of the retina. Approximately 2.5 mm lateral to the **optic disk** is a yellow-pigmented zone in the retinal wall called the **macula lutea** (yellow spot). Located in the center of this spot is an oval depression, the **fovea centralis,** where visual acuity is greatest. The fovea is a specialized area of the retina containing only cones, which are packed tightly as the other layers of the retina are pushed aside. As distance from the fovea increases, the number of cones decreases and the number of rods increases

The Neural Tunic: Retina

Retina has 10 layers.

1. **Pigment cell layer**
2. **Layer of rods and cones**
3. **External limiting membrane**
4. **External nuclear layer**
5. **External plexiform layer**
6. **Inner nuclear layer**
7. **Inner plexiform layer**
8. **Ganglionic layer**
9. **Layer of optic nerve fibers**
10. **Internal limiting membrane**

Similar to the retinal lining of the iris and ciliary body, the outer layer of the light sensitive retina forms a single layer of cuboidal cells - the pigment epithelium. The inner layer of the retina contains the photoreceptors, the first neurones which process the sensory information, and the neurones which convey the pre-processed sensory information to the central nervous system (Fig. 7).

The pigment epithelium, derived from the outer layer of the optic cup, is composed of cuboidal to columnar cells (14 εm wide and 10 to 14 εm tall) whose nuclei are located basally. The cells are attached to Bruch's membrane, which is located between the choroid and the pigment cells. Mitochondria are especially abundant in the cytoplasm near the numerous cell invaginations with Bruch's membrane, suggesting transport in this region. Desmosomes, zonulae occludentes, and zonulae adherentes are present on the lateral cell membranes, forming the blood-retina barrier. Moreover, gap junctions on the lateral cell membranes permit intercellular communication. The cell apices exhibit microvilli and sleeve-like structures that surround and isolate the tips of the individual photoreceptor cells.

The pigmented epithelium has several functions. Pigmented epithelial cells absorb light after it has passed through and stimulated the photoreceptors, thus preventing reflections from the tunics, which would impair focus. These pigmented cells continually phagocytose spent membranous disks from the tips of the photoreceptor rods. Pigment epithelial cells also play an active role in vision by esterifying vitamin A derivatives in their SER.

Receptors, neurones, supporting cells and their processes are segregated into nine layers:

1. The layer of rods and cones contains the outer, rod- or cone-shaped light sensitive segements of the photoreceptive cells. The lights sensitive part and the perikayon of the rods and cones are connected by a narrowed bridge of cytoplasm. At the level of this connection the rods and cones are surrounded by the processes of a specialised type of glial cells, Müller cells, which form the

2. outer limiting membrane.

3. The outer nuclear layer contains the nuclei and perikarya of the rods and cones. Their processes form part of the

4. outer plexiform layer, where they form synapses with the processes of neurones whose cell bodies are located in the

5. inner nuclear layer. The cells of the inner nuclear layer are concerned with the initial processing of the sensory input. The three major neurone types are horizontal, bipolar and amacrine cells. The inner nuclear layer also houses the perikarya of the Müller cells.

6. The inner plexiform layer contains the processes of the inner nuclear layer neurones which convey the sensory input to the

7. ganglion cell layer. Ganglion cells are not evenly distributed. There are few of them towards the periphery of the retina. Close to the fovea, ganglion cells form a densely packed layer. Both ganglion cells and the cell bodies located in the inner nuclear layer which contact the rods and cones of the fovea are displaced towards the margins of the fovea.

8. Layer of optic nerve fibres. The axons of the ganglion cells travel in this layer towards the optic disc. Towards the optic disc, the thickness of this layer increases as more and more axons are added to it.

The inner limiting membrane corresponds to a basal lamina formed by the Müller cells.

Müller cells (dark fibrous cells) appear to be structurally and functionally equivalent to the astrocytes of the central nervous system, in that they envelop and support the neurons and nerve processes of the retina (Fig.8).

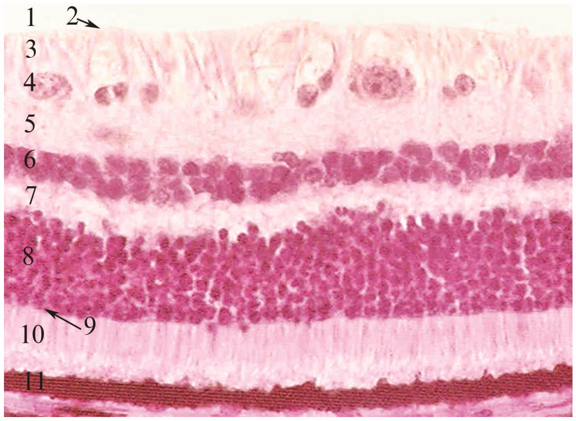

Fig.7

The optical portion of the retina houses two distinct types of photoreceptor cells called rods and cones. Both rods and cells are polaarized cells whose apical portions, known as the **outer segments,** are specialized dendrites. The outer segments of the rods and cones are surrounded by pigmented epithelial cells (Fig. 8). The bases of the rod and cone cells form synapses with the underlying cells of the bipolar layer. There are approximately 100 to 120 million rods and 6 million cones. Rods are specialized receptors for perceiving objects in dim light, whereas cones are specialized receptors for perceiving objects in bright light reception. Cones are further adapted for color vision, whereas rods perceive only light. Rods and cones are unevenly distributed in the retina, in that cones are highly concentrated in the fovea; thus, this is the area of the retina where high-acuity vision occurs.

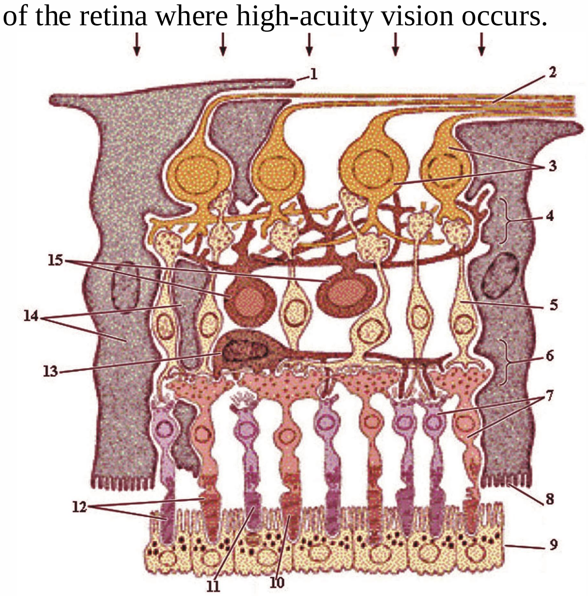

Fig.8

Rods, which are activated in dim light only, are so sensitive that they can produce a signal from a single photon of light. However, they cannot mediate signals in bright light, and they cannot sense color. Rods are elongated cells (50 εm long by 3 εm in diameter) oriented parallel to one another but perpendicular to the retina. These are composed of an outer segment, an inner segment, a nuclear region, and a synaptic region.

The **outer segment of the rod,** its dendritic end, presents several hundred flattened membranous lamellae oriented perpendicular to its long axis. Each lamella represents an invagination of the plasmalemma, which is detached from the cell surface, thus forming a disk. Each disk is composed of two membranes separated from each other by an 8-nm space. The membranes contain **rhodopsin (visual purple),** a light-sensitive pigment. Because the outer segment is longer in rods than in cones, rods contain more rhodopsin, respond more slowly than cones, and have the capacity to collectively summate the reception.

The **inner segment of the rod** is separated from the outer segment by a constriction called the **connecting stalk.** Passing through the connecting stalk and into the outer segment of the rod is a modified cilium (lacking the central singlet microtubules) that arises from a basal body located at the apical end of the inner segment.

The process of photoreception is as follows:

- **1** Photoreception by rods begins with absorption of light by the light-sensitive photopigment **rhodopsin,** composed of the transmembrane protein **opsin** bound to ***cis* retinal,** the aldehyde form of vitamin A .
- **2** Absorption of light causes isomerization of the retinal moiety into **all-*trans* retinal,** which then dissociates from opsin.
- **3** This **bleaching** yields activated opsin, which facilitates binding of guanosine triphosphate (GTP) to the Ŭ-subunit of **transducin,** a trimeric G protein.
- **4** The resulting **GTP-G**$_{Ŭ}$ activates cyclic guanosine monophosphate (cGMP) phosphodiesterase, an enzyme that catalyzes the breakdown of 3',5'-cGMP.
- **5** The decreasing cytosolic cGMP concentration results in closure of Na^+ channels in the plasma membrane of the rod so that Na^+ cannot leave the cell, and the **rod becomes hyperpolarized.**
- **6** Hyperpolarization of the rod results in the **inhibition of neurotransmitter release** into the synapse with the bipolar cells.
- **7** During the next dark phase, the level of cGMP is regenerated, the Na^+ channels are reopened, and the **Na^+ flow** resumes as before.
- **8** The **all-*trans* retinal** remaining from the breakdown **diffuses** and is carried to the retinal pigment epithelium via retinal binding proteins.
- **9** The **all-*trans* retinal is recycled** to its 11-*cis* retinal form.
- **10** Finally, *cis* retinal is returned to the rod, where it is once again bound to opsin to form **rhodopsin**

When the rod is not activated by light, cGMP maintains open Na^+ channels in the plasmalemmae of rod cells. During the dark phase, sodium ions are pumped out of the inner segment and enter the outer segment of the rods through sodium-gated ion channels. The presence of sodium ions in the outer segment results in the release of neurotransmitter substance into the synapse with the bipolar cells.

The signal is not induced by depolarization, as it is in most cells; rather, light-induced hyperpolarization causes the signal to be transmitted through the various cell layers to the ganglion cells, where the signal generates an action potential along the axons to the brain (Fig. 9).

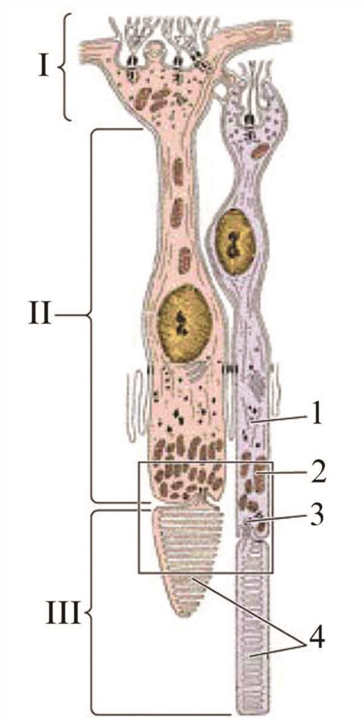

Fig.9

Although the mode of function of the cones is similar to that of rods, cones are activated in bright light and produce greater visual acuity compared with rods. There are three types of cones, each containing a different variety of the photopigment **iodopsin.** Each variety of iodopsin has a maximum sensitivity to one of three colors of the spectrum-red, green, and blue-and the difference resides in the opsins rather than in the 11-*cis* retinal.

Their structure is similar to that of rods with the following few exceptions:

- Their apical terminal (outer segment) is shaped more like a cone than a rod.
- The disks of cones, although composed of lamellae of the plasmalemma, are attached to the plasma membrane, unlike the lamellae of the rods, which are separated from the plasma membrane.
- Protein produced in the inner segment of cones is inserted into the disks throughout the entire outer segment; in the rods, it is concentrated in the most distal region of the outer segment.
- Unlike rods, cones are sensitive to color and provide greater visual acuity.
- Recycling of the cone photopigment does not require the retina pigment cells for the processing.

ACCESSORY STRUCTURES OF THE EYE

A transparent mucous membrane, known as the **conjunctiva**, lines the inner surface of the eyelids **(palpebral conjunctiva)** and covers the sclera of the anterior portion of the eye **(bulbar conjunctiva).** The conjunctiva is composed of a stratified columnar epithelium that contains goblet cells overlying a basal lamina and a lamina propria composed of loose connective tissue. Secretions of the goblet cells become a part of the **tear film,** which aids in lubricating and protecting the epithelium of the anterior aspect of the eye. At the corneoscleral junction, where the cornea begins, the conjunctiva continues as the stratified squamous **corneal epithelium** and is devoid of goblet cells (Fig.10).

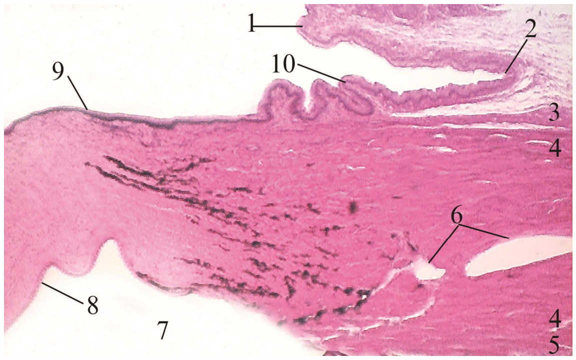

Fig.10

The **eyelids** are formed as folds of skin that cover the anterior surface of the developing eye. Accordingly, stratified squamous epithelium of skin covers their external surface; at the **palpebral fissure,** palpebral conjunctiva covers their inner surface. The eyelids are supported by a framework of **tarsal plates.** Sweat glands are located in the skin of the eyelids, as are fine hairs and sebaceous glands. The dermis of the eyelids is generally thinner than in most skin, contains numerous elastic fibers, and is without fat. The margins of the eyelids contain **eyelashes** arranged in rows of three or four, but they are without arrector pili muscles (Fig.11).

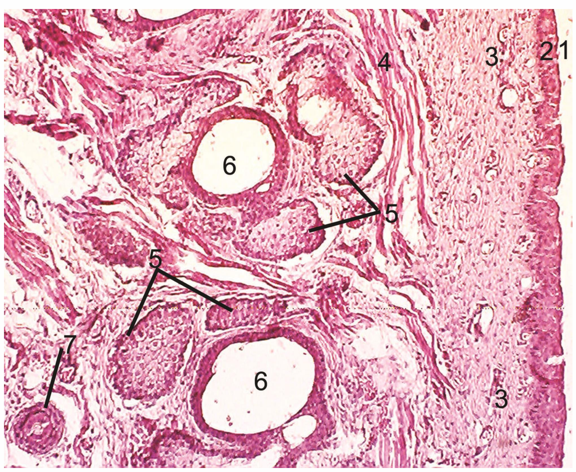

Fig.11

Modified sweat glands, called **glands of Moll,** form a simple spiral before opening into the eyelash follicles. **Meibomian glands,** modified sebaceous glands located in the tarsus of each lid, open on the free edge of the lids. The oily substance secreted by these glands becomes incorporated into the tear film and impedes evaporation of the tears. Other smaller, modified sebaceous glands, the **glands of Zeis,** are associated with the eyelashes and secrete their product into the eyelash follicles.

The lacrimal apparatus consists of:

- The lacrimal gland, which secretes the lacrimal fluid (tears)
- The lacrimal canaliculi, which carry the lacrimal fluid away from the surface of the eye
- The lacrimal sac, a dilated portion of the duct system

- The nasolacrimal duct, which delivers the lacrimal fluid to the nasal cavity

The **lacrimal gland** lies in the lacrimal fossa located in the superolateral aspect of the orbit. It lies outside the conjunctival sac, although it communicates with the sac via 6 to 12 secretory ducts, which open into the sac at the lateral portion of the superior conjunctival fornix. The gland is a serous, compound tubuloalveolar gland that resembles the parotid gland. Myoepithelial cells completely surround its secretory acini

OLFACTORY (SMELL) ORGAN

Analizator of smell includes olfactory mucosa, olfactory nerve and field of cortex near hippocamp on the inner surface of cerebral hemispheres. Olfactory mucosa lies in the roof of nasal cavity (superior concha and adjacent part of septum) and has yellowish brown color in contrast with pink color of the respiratory mucosa.

The olfactory epithelium is tall, pseudostratified columnar epithelium about 60 mm in height lacking goblet cells and with no distinct basal lamina. It contains three types of cells: sustanticular or supporting, basal and olfactory.

Sustentacular cells are most numerous, 50- to 60 mm-tall columnar cells whose apical aspects have a striated border composed of microvilli. Their oval nuclei lie in the apical part of the cell. There are secretory granules here housing a yellow pigment chatacteristic of the color of mucosa. Electron micrographs of sustentacular cells demonstrate their junctional complexes with the olfactory vesicle region of sensory cells as well as with contiguous sustentacular cells. These cells are believed to provide the physical support, nourishment and electrical insulation for the olfactory cells (Fig. 12).

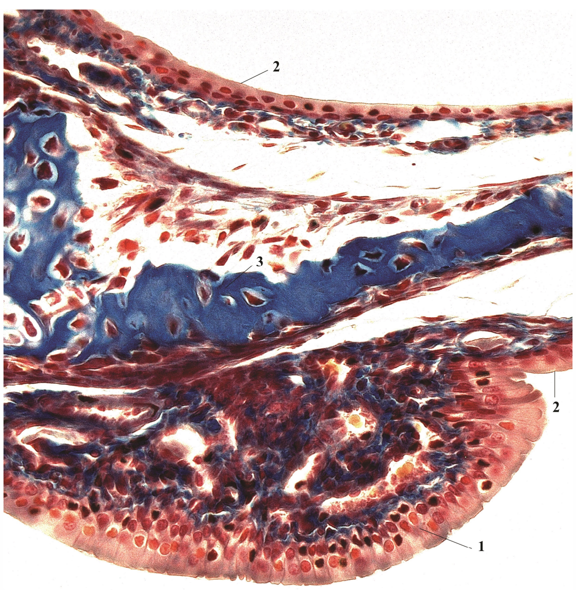

Fig.12

Olfactory cells are bipolar neurons whose apical aspect, the distal terminus of its slender dendrite, is modified to form bulb, the olfactory vesicle, which projects above the surface of the sustentacular cells. Their nuclei are spherical and lie basally. Six to eight long nonmotile olfactory cilia extend from the olfactory vesicle on the free surface of the epithelium. Axon arises from the basal part of olfactory cell, penetrates the basal lamina and joins similar axons to form bundles of nerve fibers. Each axon, although unmyelinated, has a sheath of Schwann cells. The nerve fibers pass through the cribrifirm plate in the roof of nasal cavity to synapse with secondary neurons in the olfactory bulb.

Basal cells are short, basophilic, pyramid-shaped cells, which lie near the basement membrane. Their nuclei are centrally located. These cells have considerable proliferative capacity and can replace sustentacular cells. Life span of last ones is less then a year in healthy person.

Few brush cells may be found in the olfactory mucosa with thick short microvilli and apparently contacting nerve fibers originating in the trigeminal nerve (Fig.13).

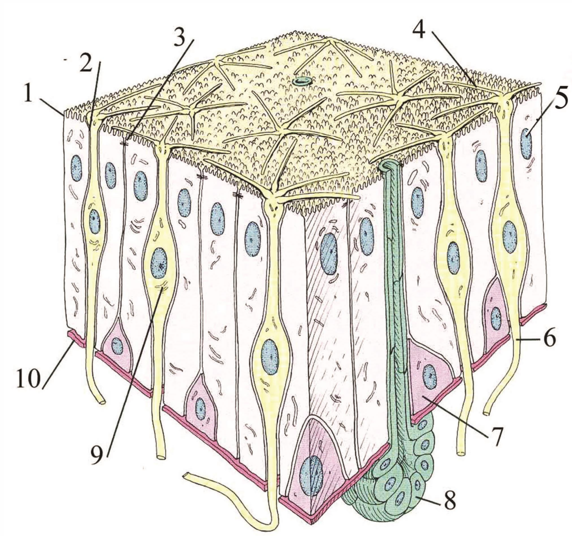

Fig. 13

The lamina propria of the olfactory epithelium contains lymph and venous plexuses, the former communicating with the suprachoroid space via capillaries running with the fila olfactoria. Branched tubuloalveolar serous glands (the glands of Bowman) lie in the lamina. They secrete a watery fluid, carried to the surface by slender ducts. This fluid acts as a solvent for odoriferous substances. Olfactory cells are frequently damaged owing to repeated exposure to infection and other trauma, and some cells may be loosed (Fig.14).

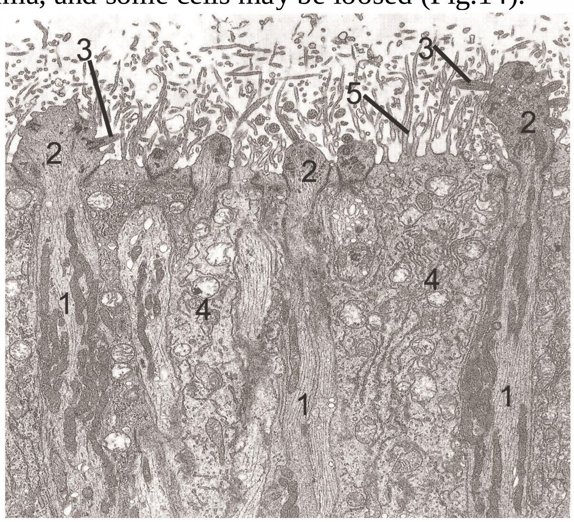

Fig.14

TASTE ORGAN

On the basis of their structure and function, the lingual papillae are of four types: filiform, fungiform, foliate, and circumvallate. They are all located anterior to the sulcus terminalis on the dorsal or lateral aspect of the tongue. Most of them contain taste buds. Taste is a sensation perceived by taste buds, receptors located principallyon the tongue (there are about 10.000 taste buds on the human tongue) and in smaller numbers on the soft palate and laryngeal surface of the epiglottis. Lingual taste buds are embedded within the stratified epithelium of the circumvallate, foliate, and fungiform papillae. Chemicals enter the taste pore, a small aperture providing access to receptor cell (Fig.15, 16, 17).

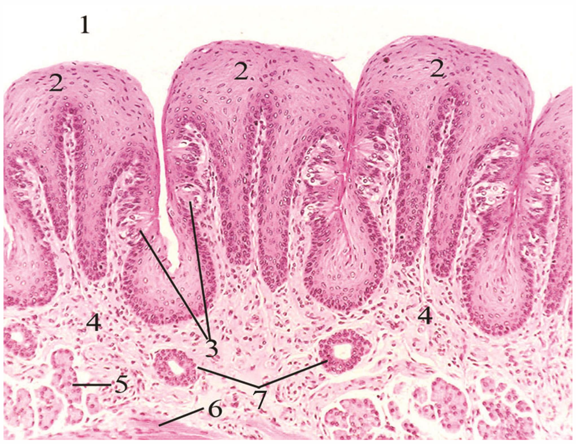

Fig.15

The narrow end of the taste bud, located at the free surface of the epithelium, projects into an opening, the **taste pore,** formed by the squamous epithelial cells that overlie the taste bud (Fig. 16, 19).

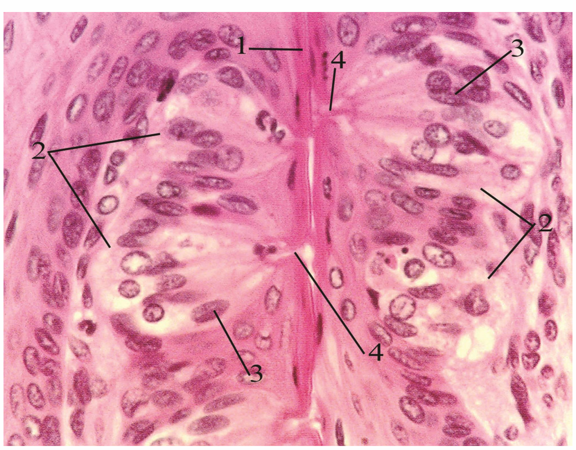

Fig.16

Four types of cells constitute the taste bud:

- Basal cells (type IV cells)
- Dark cells (type I cells)
- Light cells (type II cells)
- Intermediate cells (type III cells)

The relationship among the various cell types is not clear, although researchers agree that basal cells function as reserve cells and regenerate the cells of the taste buds, which have an average life span of 10 days. Most investigators believe in the following progression: Basal cells give rise to dark cells, which mature into light cells, which become intermediate cells and die (Fig. 17, 18).

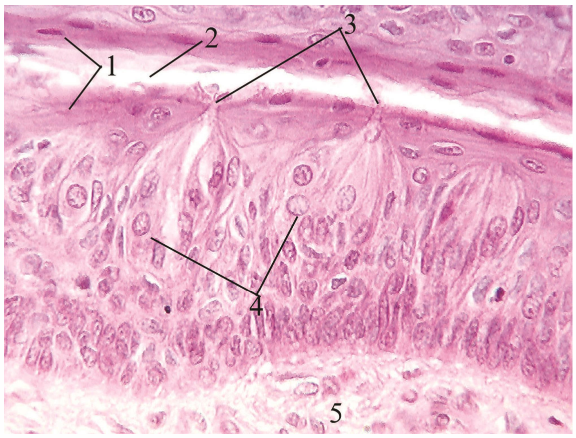

Fig.17

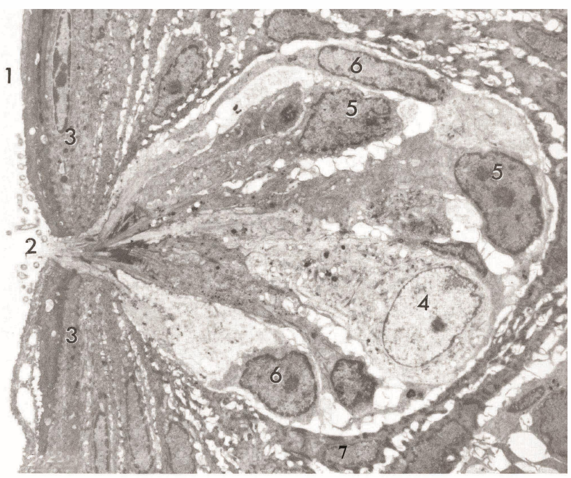

Fig.18

Nerve fibers enter the taste bud and form synaptic junctions with type I, type II, and type III cells, indicating that all three cell types probably function in the discernment of taste. Each of these cell types has long, slender microvilli that protrude from the taste pore. In the past, these microvilli were noted with the light microscope and were called **taste hairs (Fig. 19).**

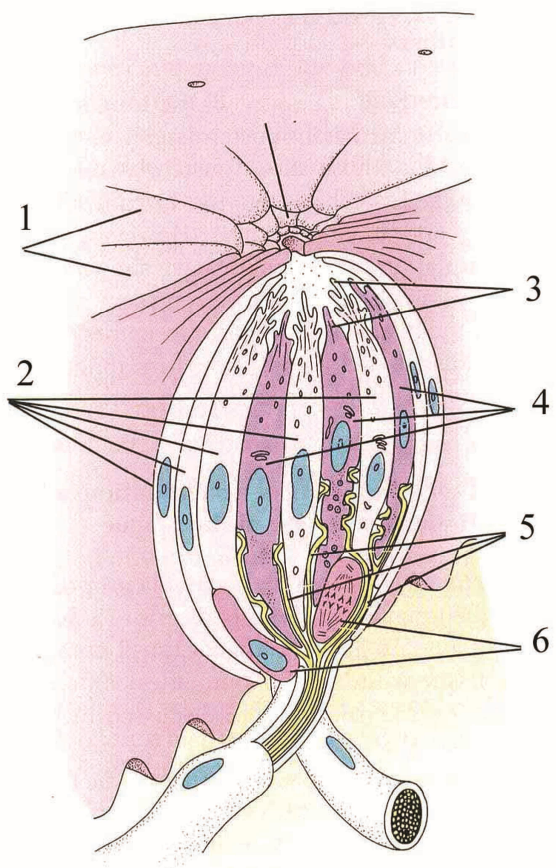

Fig. 19.

Tastants, chemicals from food dissolved in saliva, interact either with ion channels or with receptors located on the microvilli of the taste cells, effecting electrical alterations in the resting potentials of these cells resulting in depolarization of the cell and initiating an action potential that is transmitted to the brain where the signals are interpreted as specific taste sensations. There are five primary taste sensations: salty, sweet, sour, bitter, and umami (a savory taste sensed via glutamate receptors).

Audiovestibular organ

This organ includes the external, middle and internal ear.

The external ear consists of auricle, external auditory meatus and tympanic membrane.

The **auricle** (pinna) is funnel-like plate of elastic cartilage covered with skin, which collects and focuses sound waves toward the meatus. Auricle has typical shape due to a plate of elastic cartilage, 0,5 to 1mm thick, covered by e perichondrium with high content of elastic fibers. The surface of auricle is covered by the skin with poorly developed hairs and sweat glands. Modified apocrine sweat glands (ceruminous glands) secrete a waxy cerumen. Sounds gathered by the auricle are carried inward by the meatus to vibrate the **tympanic membrane** (eardum) covering its internal orifice. This membrane has three layers: the outer epithelium (thin skin), middle dense connective tissue (external radial and internal circular fibers), and inner cuboidal epithelium of the mucosa. Malleus is attached to the center of the internal surface of membrane.

The middle ear, or **tympanic cavity,** is an air-filled space located in the petrous portion of the temporal bone. This space communicates posteriorly with the mastoid air cells and anteriorly, via the **auditory tube (eustachian tube),** with the pharynx. The three bony ossicles are housed in this space, spanning the distance between the tympanic membrane and the membrane at the oval window.

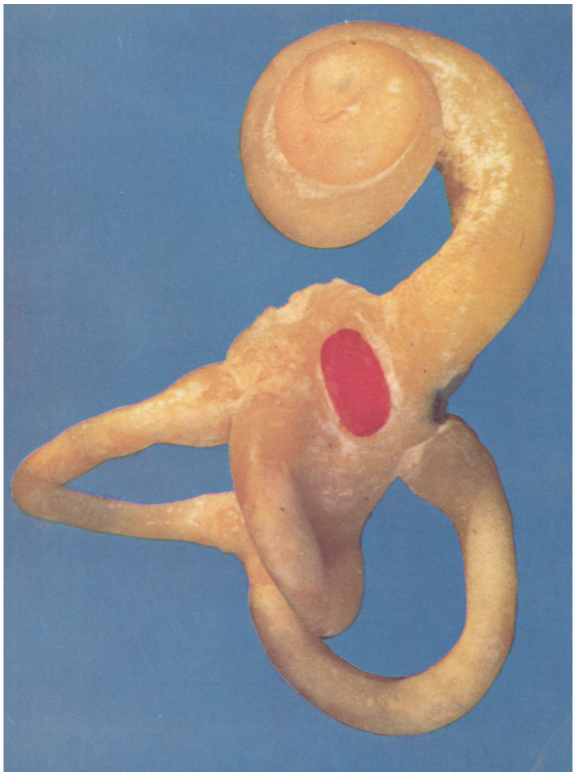

Fig.20

The tympanic cavity is lined by simple squamous epithelium, which is continuous with the internal lining of the tympanic membrane. In its deepest two thirds, however, the bone of the tympanic cavity gives way to cartilage as it approaches the auditory tube. Similarly, its epithelial covering becomes a pseudostratified ciliated columnar epithelium as it approaches the auditory tube. The lamina propria over the bony wall adheres to it tightly and does not contain glands, but the lamina propria overlying the cartilaginous portion contains many mucous glands whose ducts open into the lumen of the tympanic cavity. Additionally, goblet cells and lymphoid tissue are found in the vicinity of the pharyngeal opening (Fig. 21).

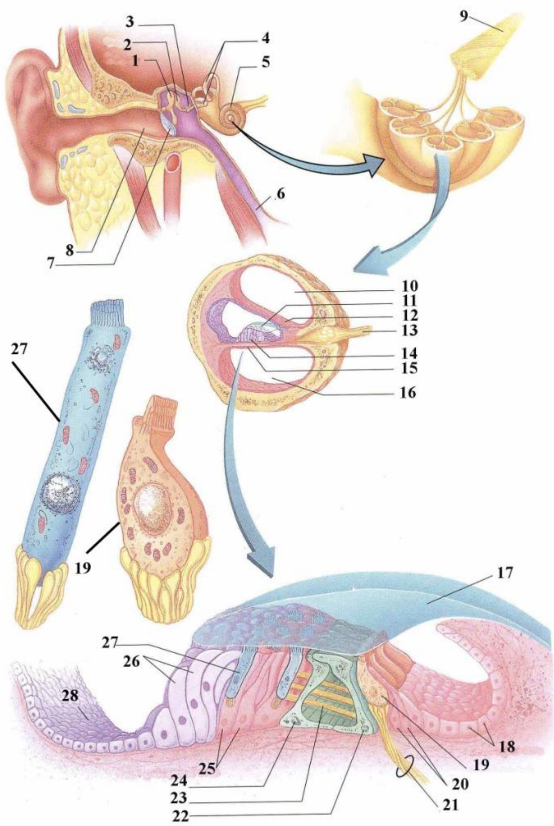

Fig.21

The inner ear is composed of the **bony labyrinth,** an irregular, hollowed-out cavity located within the petrous portion of the temporal bone, and the **membranous labyrinth,** which is suspended within the bony labyrinth (Fig.22).

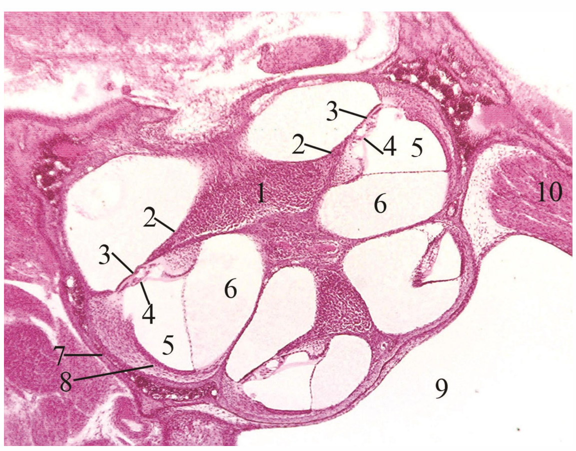

Fig.22

The bony labyrinth is lined with endosteum and is separated from the membranous labyrinth by the **perilymphatic space.** This space is filled with a clear fluid called the **perilymph,** within which the membranous labyrinth is suspended. The central region of the bony labyrinth is known as the **vestibule.**

The three **semicircular canals (superior**, **posterior**, and **lateral)** are oriented at 90 degrees to one another. One end of each canal is enlarged; this expanded region is called the **ampulla.** All three semicircular canals arise and return to the vestibule, but one end of each of two of the canals shares an opening to the vestibule; consequently, there are only five orifices to the vestibule. Suspended within the canals are the **semicircular ducts,** which are regionally named continuations of the membranous labyrinth.

The **vestibule** is the central portion of the bony labyrinth located between the anteriorly placed cochlea and the posteriorly placed semicircular canals. Its lateral wall contains the **oval window (fenestra vestibuli),** covered by a membrane to which the footplate of the stapes is attached, and the **round window (fenestra cochleae),** covered only by a membrane. The vestibule also houses specialized regions of the membranous labyrinth (the **utricle** and the **saccule**).

The **cochlea** arises as a hollow bony spiral that turns upon itself, like a snail shell, two and one-half times around a central bony column, the **modiolus.** The modiolus projects into the spiraled cochlea with a shelf of bone called the **osseous spiral lamina,** through which traverse blood vessels and the **spiral ganglion,** the cochlear division of the vestibulocochlear nerve (Fig. 23).

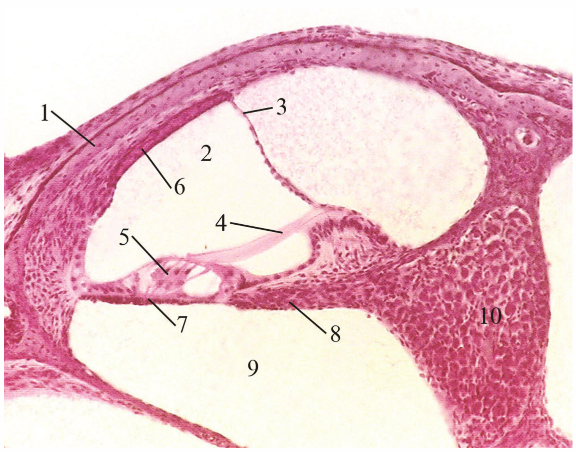

Fig.23

The membranous labyrinth is filled with endolymph and possesses the following specialized areas: the saccule and utricle, the semicircular ducts, and the cochlear duct.

The membranous labyrinth is composed of an epithelium derived from the embryonic ectoderm, which invades the developing temporal bone and gives rise to two small sacs, the **saccule** and **utricle,** as well as to the **semicircular ducts** and the **cochlear duct**. Circulating through the entire membranous labyrinth is **endolymph,** a viscous fluid that resembles extracellular fluid in its ionic composition (i.e., it is sodium-poor but potassium-rich). (Fig.24, 25).

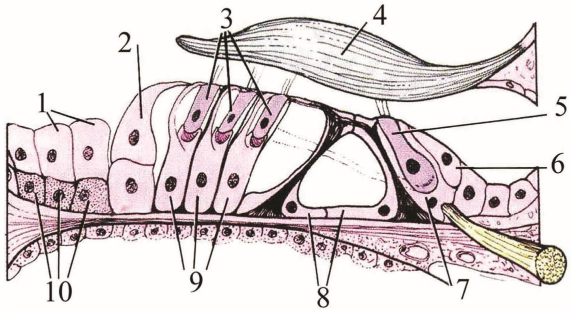

Fig.24

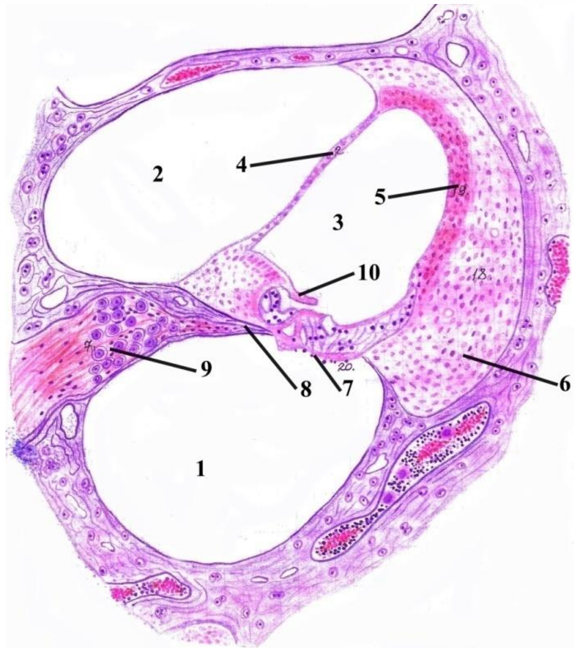

Fig. 25

The saccule and utricle are connected to each other by a small duct, the **ductus utriculosaccularis.** Additionally, small ducts from each join to form the **endolymphatic duct,** whose dilated blind end is known as the **endolymphatic sac.** Another small duct, the **ductus reuniens,** joins the saccule with the duct of the cochlea.

The walls of the saccule and utricle are composed of a thin outer vascular layer of connective tissue and an inner layer of simple squamous to low cuboidal epithelium. Specialized regions of the saccule and utricle act as receptors for sensing orientation of the head relative to gravity and acceleration, respectively. These receptors are called the **macula of the saccule** and the **macula of the utricle.**

The cochlear duct and its organ of Corti are responsible for the mechanism of hearing.

The cochlear duct, a diverticulum of the saccule, is another regionally named portion of the membranous labyrinth. The cochlear duct is a wedge-shaped receptor organ housed in the bony cochlea and surrounded on two sides by perilymph but separated from it by two membranes. The roof of the **scala media (cochlear duct)** is the **vestibular (Reissner's) membrane,** whereas the floor of the scala media is the **basilar membrane.** The perilymph-filled compartment lying above the vestibular membrane is called the **scala vestibuli,** whereas the perilymph-filled compartment lying below the basilar membrane is the **scala tympani.** These two compartments communicate at the **helicotrema,** near the apex of the cochlea (Fig. 26).

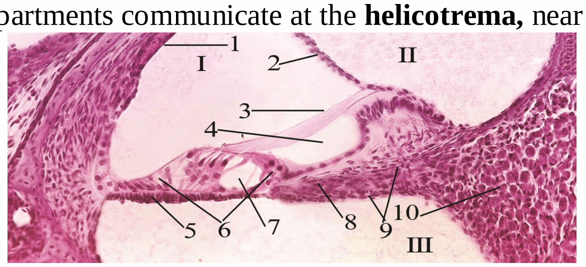

Fig.26

The **vestibular membrane** is composed of two layers of squamous epithelia separated from each other by a basal lamina. The inner layer is the lining cells of the scala media, and the outer layer is the lining cells of the scala vestibuli. Numerous tight junctions seal both layers of cells, thus ensuring a high ionic gradient across the membrane. The **basilar membrane,** extending from the spiral lamina at the modiolus to the lateral wall, supports the organ of Corti and is composed of two zones: the zona arcuata and the zona pectinata. The **zona arcuata** is thinner, lies more medial, and supports the organ of Corti. The **zona pectinata** is similar to a fibrous meshwork containing a few fibroblasts **(Fig. 25, 26).**

Dark-staining **marginal cells** have abundant microvilli on their free surfaces. Their dense cytoplasm contains numerous mitochondria and small vesicles. Labyrinthine, narrow cell processes containing elongated mitochondria are abundant on the basilar portion of the cells.

Light-staining **basal cells** and **intermediate cells** have less dense cytoplasm containing only a few mitochondria. Both have cytoplasmic processes that radiate out from the cell surfaces to interdigitate with the cell processes of the marginal cells and with other intermediate cells. Basal cells also have cellular processes that ascend around the bases of the marginal cells, forming cup-like structures that isolate and support the marginal cells. **Intraepithelial capillaries** are positioned in such a fashion that they are surrounded by the basal processes of the marginal cells and the ascending processes of the basal and intermediate cells.

At the narrowest portion of the cochlear duct, where the vestibular and basilar membranes meet, periosteum covering the spiral lamina bulges out into the scala media, forming the **limbus of the spiral lamina.** Part of the limbus projects over the **internal spiral sulcus (tunnel).** The upper portion of the limbus is the **vestibular lip,** and the lower portion is called the **tympanic lip** of the limbus, a continuation of the basilar membrane. Numerous perforations in the tympanic lip accommodate branches of the cochlear division of the vestibulocochlear nerve (acoustic nerve). **Interdental cells** located within the body of the spiral limbus secrete the **tectorial membrane,** a proteoglycan-rich gelatinous mass containing numerous fine keratin-like filaments, that overlies the organ of Corti. Stereocilia of specialized receptor hair cells of the organ of Corti are embedded in the tectorial membrane (Fig.25).

The **organ of Corti,** the specialized receptor organ for hearing, lies on the basilar membrane and is composed of neuroepithelial hair cells and several types of supporting cells. Although the supporting cells of the organ of Corti have different characteristics, they all originate on the basilar membrane and contain bundles of microtubules and microfilaments, and their apical surfaces are all interconnected at the free surface of the organ of Corti. Supporting cells include **pillar cells, phalangeal cells**, **border cells,** and **cells of Hensen (Fig. 25).**

Neuroepithelial hair cells are specialized for transducing impulses for the organ of hearing. Depending on their locations, these cells are called inner hair cells and outer hair cells.

Inner hair cells, a single row of cells supported by inner phalangeal cells, extend the inner limit of the entire length of the organ of Corti. Inner hair cells are short and exhibit a centrally located nucleus, numerous mitochondria (especially beneath the terminal web), RER and SER, and small vesicles. The basal aspect of these cells also contains microtubules. Their apical surface contains 50 to 60 stereocilia arranged in a "V" shape. The core of the stereocilia contains microfilaments, cross-linked with fimbrin, as in the type I hair cells of the vestibular labyrinth. The microfilaments of the stereocilia merge with those of the terminal web. Although a kinocilium is not present in inner hair cells, a basal body and centriole are both evident in the apical region of these cells. The basal aspects of these cells synapse with afferent fibers of the cochlear division of the vestibulocochlear nerve.

Outer hair cells, supported by outer phalangeal cells, are located near the outer limit of the organ of Corti and are arranged in rows of three (or four) along the entire length of this organ. The outer hair cells are elongated cylindrical cells whose nuclei are located near their bases. Their cytoplasm contains abundant RER, and their mitochondria are located basally. The cytoplasm of those cells just beneath the lateral walls contains a **cortical lattice,** composed of 5- to 7-nm filaments cross-linked by thinner filaments, that appears to support the cell and resist deformation. Afferent and efferent fibers synapse on the basilar portion of the hair cells. Extending from the apical surface of the outer hair cells are as many as 100 stereocilia organized in the shape of the letter "W." These stereocilia vary in length and are arranged in ordered gradation. Like inner hair cells, outer hair cells do not have a kinocilium but do have a basal body.

The maculae of the saccule and utricle are located so that they are perpendicular to each other (i.e., the macula of the saccule is located predominantly in the wall, thus detecting linear vertical acceleration, whereas the macula of the utricle is located mostly in the floor, thus detecting linear horizontal acceleration). The epithelium of the nonreceptor regions of the saccule and utricle is composed of light and dark cells. **Light cells** have a few microvilli, and their cytoplasm contains a few pinocytotic vesicles, ribosomes, and only a small number of mitochondria. The cytoplasm of the **dark cells,** however, contains an abundance of coated vesicles, smooth vesicles, and lipid droplets as well as numerous elongated mitochondria located in compartments formed by infoldings of the basal plasma membrane. Nuclei of the dark cells are irregular in shape and are often located apically. Although the function of these two cell types is not known, it is thought that light cells play a role in absorption and that dark cells control endolymph composition (Fig. 27).

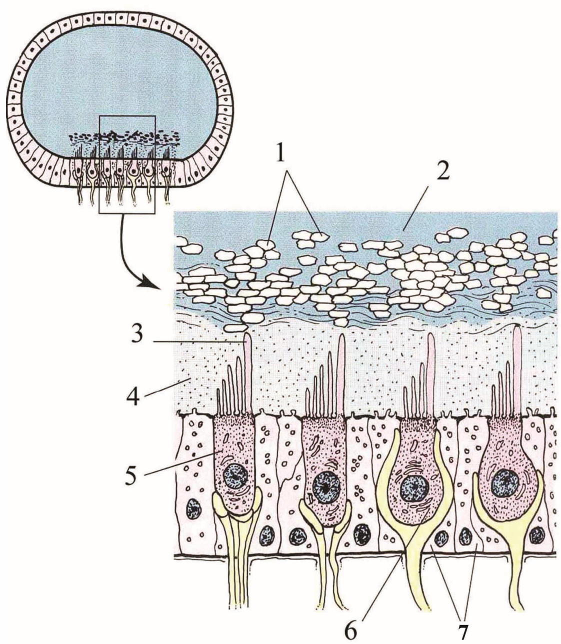

Fig.27

The maculae are thickened areas of the epithelium, 2 to 3 mm in diameter. They are composed of two types of **neuroepithelial cells** called **type I and type II hair cells,** as well as of supporting cells that sit on a basal lamina. Nerve fibers from the vestibular division of the vestibulocochlear nerve supply the neuroepithelial cells (Fig.28).

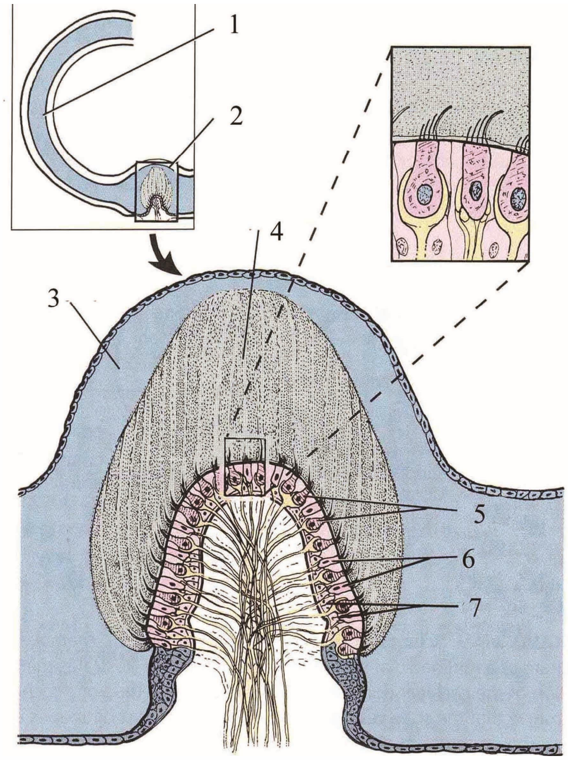

Fig.28

Supporting cells of the maculae, which are interposed between both types of hair cells, have a few microvilli. Thick junctional complexes bind these cells to each other and to the hair cells. They exhibit a well-developed Golgi complex and secretory granules, suggesting that they may help maintain the hair cells or may contribute to the production of endolymph.

Each semicircular duct, a continuation of the membranous labyrinth arising from the utricle, is housed within its semicircular canal and thus conforms to its shape. Each of the three ducts is dilated at its lateral end (near the utricle). These expanded regions, called the **ampullae,** contain the **cristae ampullares,** which are specialized receptor areas (Fig.28). Each crista ampullaris is composed of a ridge whose free surface is covered by sensory epithelium consisting of **neuroepithelial hair cells** and **supporting cells**. The supporting cells sit on the basal lamina, whereas the hair cells do not; rather, the hair cells are cradled between the supporting cells. The neuroepithelial cells, also known as **type I** and **type II hair cells,** exhibit the same morphology as the hair cells of the maculae (discussed earlier). The **cupula,** a gelatinous glycoprotein mass overlying the cristae ampulares, is similar to the otolithic membrane in structure and function, but it is cone-shaped and does not contain otoliths.

The sense of position in space and during movement is essential to activate and deactivate certain muscles that function in accommodating the body for balance. The sensory mechanism for this function is the **vestibular apparatus,** which is located in the inner ear. This apparatus comprises the utricle, saccule, and semicircular ducts.

Stereocilia of neuroepithelial hair cells located in the ampullae of the utricle and saccule are embedded in the otolithic membrane. **Linear movements** of the head cause displacement of the endolymph, which disturbs the positioning of the otoliths within the otolithic membrane and, consequently, the membrane itself, thereby bending the stereocilia of the hair cells. Movements of the stereocilia are transduced into action potentials, which are conducted by synapses to the vestibular division of the vestibulocochlear nerve for transmittal to the brain.

Circular movements of the head are sensed by receptor sites in the semicircular ducts housed within the semicircular canals. Stereocilia of the neuroepithelial hair cells of the cristae ampullares are embedded in the cupula. Movements of the endolymph within the semicircular ducts disturb the orientation of the cupula, which subsequently distorts the stereocilia of the hair cells. This mechanical stimulus is transduced to an electrical impulse, which is trans-ferred by synapse to branches of the vestibular division of the vestibulocochlear nerve for transmission to the brain.

Cochlear Functions

Sound waves collected by the external ear pass into the external auditory meatus and are received by the tympanic membrane, which is set into motion. The tympanic membrane converts sound waves into mechanical energy. Vibrations of the tympanic membrane set the malleus, and consequently the remaining two ossicles, into motion.

Because of a mechanical advantage rendered by the articulations of the three bony ossicles, the mechanical energy is amplified about 20 times when it reaches the footplate of the stapes, where it impinges on the membrane of the fenestra vestibuli (oval window). Movements of the oval window membrane initiate pressure waves in the perilymph within the scala vestibuli. Because fluid (in this instance, perilymph) is incompressible, the wave is passed through the scala vestibuli, through the helicotrema, and into the scala tympani. The pressure wave in the perilymph of the scala tympani causes the basilar membrane to vibrate.

Because the organ of Corti is firmly attached to the basilar membrane, a rocking motion within the basilar membrane is translated into a shearing motion on the stereocilia of the hair cells that are embedded in the overlying rigid tectorial membrane. When the shearing force produces a deflection of the stereocilia toward the taller stereocilia, the cell becomes depolarized, thus generating an impulse that is transmitted via the afferent nerve fibers of the cochear division of the vestibulocochear nerve.

How differences in sound frequency or pitch are distinguished is not understood. It has long been thought that the basilar membrane, which becomes longer with each turn of the cochlea, vibrates at different frequencies relative to its width. Therefore, low-frequency sounds would be detected near the apex of the cochlea, whereas high-frequency sounds would be detected near the base of the cochlea. Evidence suggests that outer hair cells contain the necessary machinery to react rapidly to efferent input, causing them to vary the length of their stereocilia and consequently altering the shear force between the tectorial membrane and the basilar membrane, thus "tuning" the basilar membrane. This action then alters the response of the sound-detecting inner hair cells, affecting their reaction to different frequencies.