Structure and Physiology of Eye and Ear

Content Outline

Introduction

Human body possesses different sense organs for example, skin, eye, ear, nose and tongue. These sense organs receive stimuli from the external environment and help to maintain equilibrium and balance between external environment and body.

It is generally said that the human body possesses five senses like touch, smell, taste, vision and hearing (and equilibrium). Out of all these, the touch is regarded as general sense whereas rest are called special **senses**. Receptors responsible for receiving general senses are located throughout the body are usually modified nerve endings. Special sense receptors are specially located in the head regions. These receptors are special receptors either enclosed within special sense organs or in the form of distinct epithelial structures (taste buds are modified epithelial structures).

Eye: The Organ of Vision

Vision is one of the most dominant senses in the body. About 70% of the sensory receptors are located in the eyes. About half of the cerebral cortex is involved in the processing of visual information. The eyes are responsible for detection of visual light which ranges from 400-700 nm. Visible light spectrum is a part of the electromagnetic spectrum radiated in the

form of electromagnetic radiation, the energy emitted by the Sun. The wavelength of visible light determines colors. An object looking red reflects red wavelength and absorbs the rest of the wavelength. An object appearing black in color absorbs all wavelengths and reflects none.

- **Structure of Eye**

Eye consists of the most important functioning part called the eyeball, positioned inside a bony, hollow socket. It is associated with other accessory parts like eyebrows, eyelids, eyelashes etc.

- **Accessory Structure of Eye**

  The accessory structures of the eyes include eyebrows, eyelids, eyelashes, lacrimal apparatus and extrinsic eye muscles etc.

  ***Eyebrows*:** These are generally coarse hairs arranged in arc shape. They overhang eyes and protect eyes from intense sunlight, trickling down sweat from forehead etc.

  Eyelids: The upper and lower eyelids protect the eyes from dust, intense light, heat and other foreign objects and during sleep. They secrete lubricating fluid and protect the eyes from drying up.

Sometimes we feel a twitch in the eyelid which lasts for few seconds. This is normally harmless and arises due to fatigue and stress.

Eyelids are thin, skin covered parts which are supported internally by connective tissue. From the border of each eyelid arise eyelashes. Follicles of eyelashes are richly innervated so anything as light as feather if touches eyelashes causes blinking of eyes.

Located at the upper, inner corner of the upper eyelid is present **Meibomian glands**. The ducts of these glands open at the edge of the eyelid just posterior to the eyelashes. These glands produce an oily secretion which prevents the eyelids from sticking together.

Conjunctiva: It lines the eyelids and folds back over the anterior surface of the eyeball (ocular conjunctiva). The latter is very thin and transparent; blood vessels

beneath this layer can be observed clearly. The main function of conjunctiva is to produce a lubricating mucus which protects the eyes from drying out.

Inflammation of conjunctiva is called *conjunctivitis*. Symptoms of conjunctivitis are reddening, inflammation and watering of eyes. *Pinkeye* a conjunctivitis infection due to bacteria or virus is highly contagious.

Lacrimal Apparatus: It consists of lacrimal glands and lacrimal ducts. Lacrimal glands are almond shaped, exocrine glands situated just below the upper eyelid. It secretes the aqueous part of tears. Lacrimal fluid secreted by lacrimal gland contains water, mucus, antibodies and lysozyme. The latter is an enzyme which kills bacteria.

Nasal cavity mucus is continuous with lacrimal duct system. During cold or inflammation, the mucus membrane swells and constricts lacrimal ducts. This results in blockage in flushing out of tears through nasal cavity. It causes in watering of eyes when one catches cold.

The extrinsic muscles enable eyeballs to rotate in different directions.

- **Structure of Eyeball***:* The eyeball itself is called an eye. It is located inside a bony socket called **orbit**. Eyeball is slightly oval and hollow. Structurally it has two poles. The most anterior and most posterior parts are called anterior and posterior poles respectively. Eyeball measures about 2.54 cm. in diameter. Out of the total surface area only one sixth is exposed at the front side; the rest of the eyeball remains hidden inside the orbit. Eyeball is basically composed of walls (tunics), internal chambers, fluids and some other associated parts.

***Walls or tunics of eyeball*:** Eyeball is surrounded by three significantly different walls. From outer to inner these tunics are fibrous, vascular and sensory in basic composition.

(i) ***Fibrous tunic:*** This layer consists of dense connective tissues. This coating is without supply of any vascular. It possesses two distinct regions**- Cornea** and **Sclera**.

Cornea is a transparent layer which covers the iris. Cornea is curved and it helps to focus light rays on the retina. Cornea itself consists of three layers - (a) outer surface is made up of non-keratinised stratified squamous epithelium. (b) Middle region consisting of collagen fibres and fibroblasts. (c) Inner region is made up of simple squamous epithelium.

Sclera the white part of the eye consists of dense connective tissue. Sclera covers the eyeball entirely except the cornea. It protects and provides shapes to the eyeball. It is also the site of attachment for some eye muscles.

(ii) ***Vascular tunic-*** This covering is also called as uvea forms the middle layer of the wall of the eyeball. It consists of three parts: choroid, ciliary body and iris. Choroid is the posterior part of uvea and it covers most of uvea. Choroid is highly vascularised and it provides nourishment to the retina. Choroid also possesses melanocytes which produce melanin. The latter absorbs stray light and helps to focus the light rays entering through cornea and lens, thus producing a sharp image.

At the interior part of the eyeball the choroid becomes a ciliary body. Ciliary body looks dark brown in colour due to the presence of melanin. Ciliary body extends from the internal jagged anterior margin of the retina and lies just posterior to the junction of sclera and cornea. Ciliary body possesses ciliary processes and ciliary muscles.

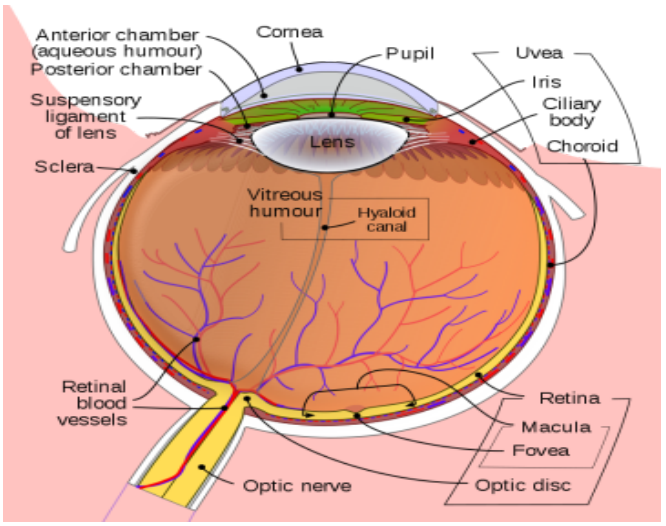


Fig 1. Structure of Eye

Albino people lack melanin even in their choroid. Quite often they have to use sunglasses even at indoors as even low intensity of light getting scattered through choroid gives a confused vision.

Ciliary processes contain blood capillaries which secrete aqueous humor. Ciliary muscles, suspensory ligaments and zonular fibres that attach with the lens extend from ciliary processes. Ciliary muscles are bands of smooth muscles which remain attached with suspensory ligaments. By contraction and relaxation of ciliary muscles suspensory ligaments

are adjusted. This in turn alters the shape of the lens to adjust to the light for near and far vision.

Iris, the third part of the vascular tunic is coloured, flattened doughnut shaped structure positioned between cornea and lens. It remains attached with the inner margin of the ciliary process and consists of circular and radial muscles. Its round, central opening called **pupil** allows light to enter the eye. The diameter of the pupil is adjusted depending on the intensity of light. In close vision and bright light, the circular muscles contract resulting in constriction of pupils. In distant vision and dim light, the radial muscles contract and the pupil dilates allowing more light to enter the eyes. Pupillary adjustments are reflex actions and its constrictions and dilations are controlled by parasympathetic and sympathetic nerve fibres respectively.

The iris literally meaning rainbow is the colourful part of the eye. It contains melanocytes which produce melanin. The amount of melanin present in the iris determines the colour of eye. It is brown or black if melanin concentration is very high, green if melanin is moderate and blue if melanin is low.

In general, eyes look black because when we look into the eyes through a lens we see reflection of heavily pigmented inside and backside of eyes. When directly light falls on the eyes it looks red as vasculature of eye is viewed.

The main function of the pupil is to regulate the amount of light which enters into the eyes.

(iii) Sensory Tunic (Retina) – The third or innermost layer of the eyeball is the retina. It is a delicate and double layered structure. The outer pigmented layer which is single celled thick and lies closely adhered to the choroid and extends anteriorly to cover the ciliary body and the posterior part of the iris. The pigmented epithelial cells of this layer absorb light and prevent it from scattering. This layer stores vit.A for proper functioning of photoreceptors cells and also acts as phagocytes. The transparent inner neural layer extends anteriorly up to the posterior end of the ciliary body. Retina consists of millions of photoreceptor cells that convert light energy to accessible energy to neurons. The pigmented layer and neural layer are very close to each other but they are not fused with each other.

Neural layer consists of three layers. From posterior to anterior these layers are **photoreceptors, bipolar cells** and **ganglion cells**. These layers are separated by two zones: the outer synaptic region and inner synaptic region.

Photoreceptors are of two different types- rods and cones. Each retina possesses about 6 million cones and 120 million rods. Rods help to see in dim light but cannot distinguish between colours. Cones help to see in bright light and allow us to see colours. Three types of cones help us to see three basic colours. Different colours can be seen when different combinations of these three basic colours are seen together.

Detachment of retina may occur due to sudden blow to head, different eye disorders or aging process. Detachment occurs between pigmented layer and neural layer. Fluid accumulates in this gap. Detachment of retina causes distorted vision and partial blindness. Reattachment of retina can be done by laser and cryosurgery.

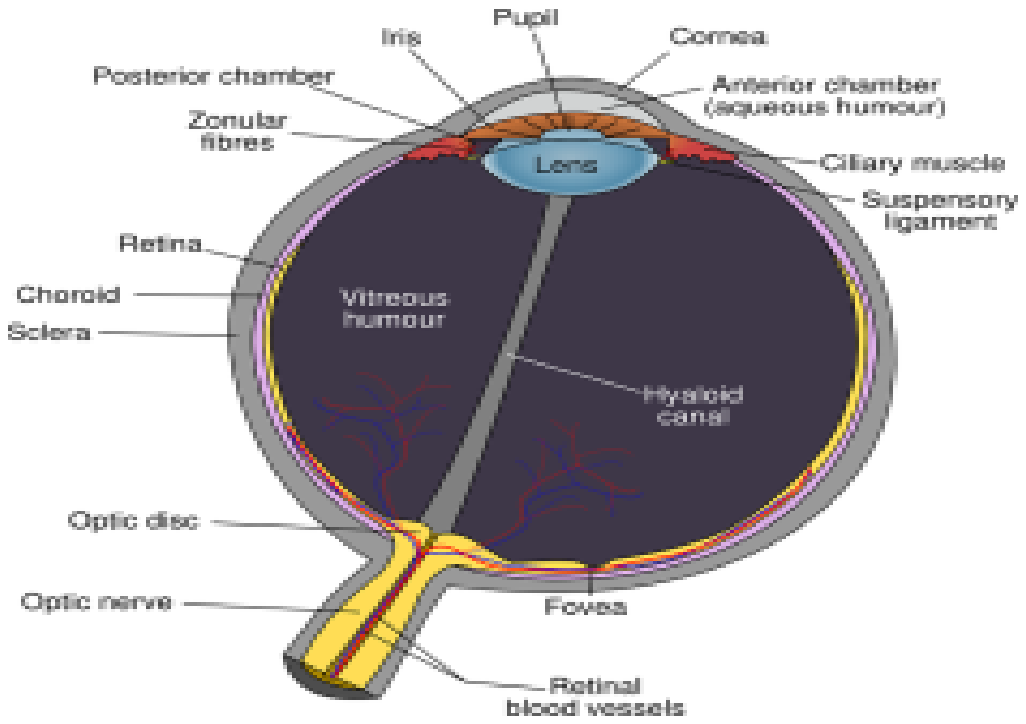


Fig 2. Anatomy of Eye

When light falls on a pigmented layer local current develops. This current generates impulses which flow through the outer synaptic zone to bipolar cells and then through the inner synaptic zone to the ganglionic layer. The axons of ganglion cells extend posteriorly. They bundle up and exit as optic nerves. The region from where the optic nerve emerges is called the optic disc. This is also called as **blind spot** because this region does not possess any

pigmented cells. So when light falls on it, no image is formed. Lateral to the blind spot and exactly at the centre of the posterior pole of retina is present **macula lutea**. There is a small depression on **macula lutea,** called **fovea centralis.** It consists of only cones and bipolar neurons and ganglion cells do not cover cones here. As a result when light falls on this region the sharpest image is formed.

Lens: Behind the pupil and iris, within the cavity of the eyeball lies the lens.it is biconvex, transparent, flexible structure. It is held in place by suspensory ligaments. Lens is made up of lens epithelium cells.

Lens epithelial cells constantly gets differentiated into lens fibres. Which form concentric layers like onion. The fibres are made up of protein crystallin. Along with age, crystalline proteins clump together and decreases transparency of the lenses. Such pathological condition is called as "cataract". It may occur due to aging, heavy smoking, diabetes or malnutrition.

- **Eye: The Organ of Vision**
  - Structure and Anatomy of Eye

Interior of the Eyeball: The lens divides the interior of the eye into two cavities

(a) **Anterior Cavity**: the space anterior to the lens consists of two chambers- anterior chamber and posterior chamber. Anterior chamber is the space between the cornea and iris. The posterior chamber is the space between iris and zonular fibres. Both the chambers are filled with a transparent fluid called **aqueous humor**. The latter is filtered out from the blood capillaries of the ciliary body and it nourishes the lens and cornea. Fresh stock of aqueous humor is normally secreted after every 90 minutes.

The hollow of the eyeball is called vitreous chamber and it is filled with **vitreous body** or vitreous humor. The latter is transparent, jelly-like fluid. It basically consists of water, collagen fibres and hyaluronic acid. Vitreous body is formed only once in lifetime. It pushes the retina stretched towards sclera and keeps it stretched so that it gets maximum light.

Intra ocular pressure (the pressure within eye) is maintained by aqueous humor and to some extent by vitreous body. This maintains the shape of eyeball and keeps retina stretched and attached with sclera. Puncture in the eye causes draining out of aqueous humor. This may lead to blindness.

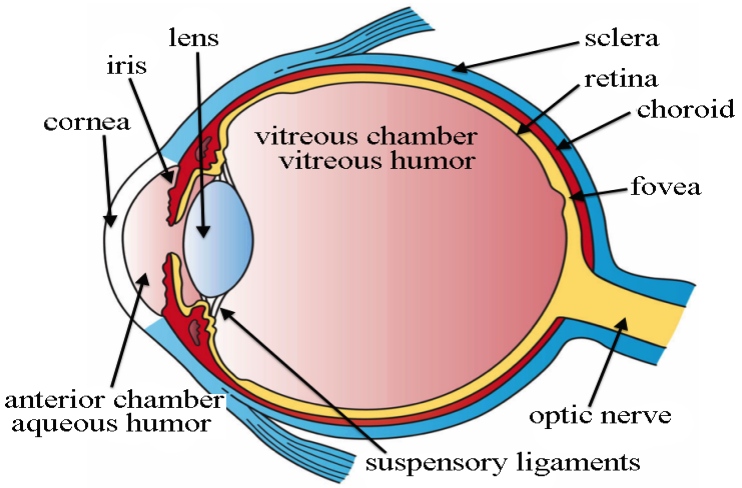
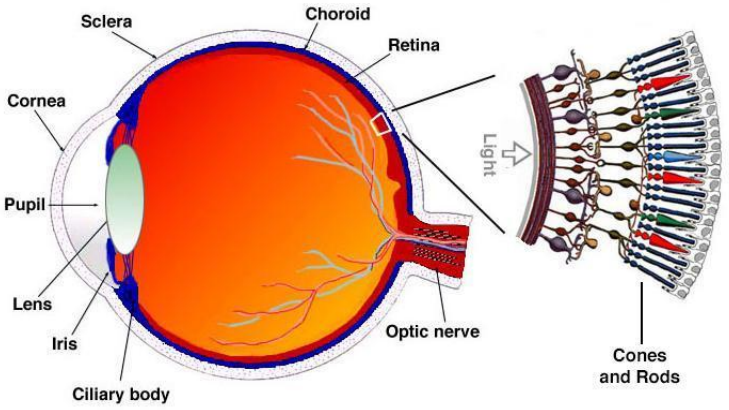


Fig 3. Chambers of Eye

- **Physiology of Vision**

  Electromagnetic radiation coming from the Sun includes all energy waves, i.e., starting from long radio waves to very short gamma waves. The range of electromagnetic radiation is called the electromagnetic spectrum. The eyes can detect spectrum ranging from 400-700 nm. This spectrum is called the visible **light spectrum.**

  Photoreceptors and Photopigments **:** Photoreception is the process by which photoreceptor cells detect and receive light energy. Photoreceptor cells are responsible for initiating the process by which light energy gets converted to a form of energy which is able to generate nerve impulse. Photoreceptors are modified neurons. There are two types of photoreceptors- **rods** and **cones**. They are named such because of their structural resemblances with rods and cones. Each rod or cone cell possesses a cell body and cell extension. The extension remains embedded in the pigmented region. The extended region possesses visual pigments arranged in stacks or discs in the plasma membrane. Absorption of light brings about configurational change in visual pigments. This generates stimulus in ganglionic cells and information is sent to the brain. Brain decodes and enables us to understand the nature of the image.



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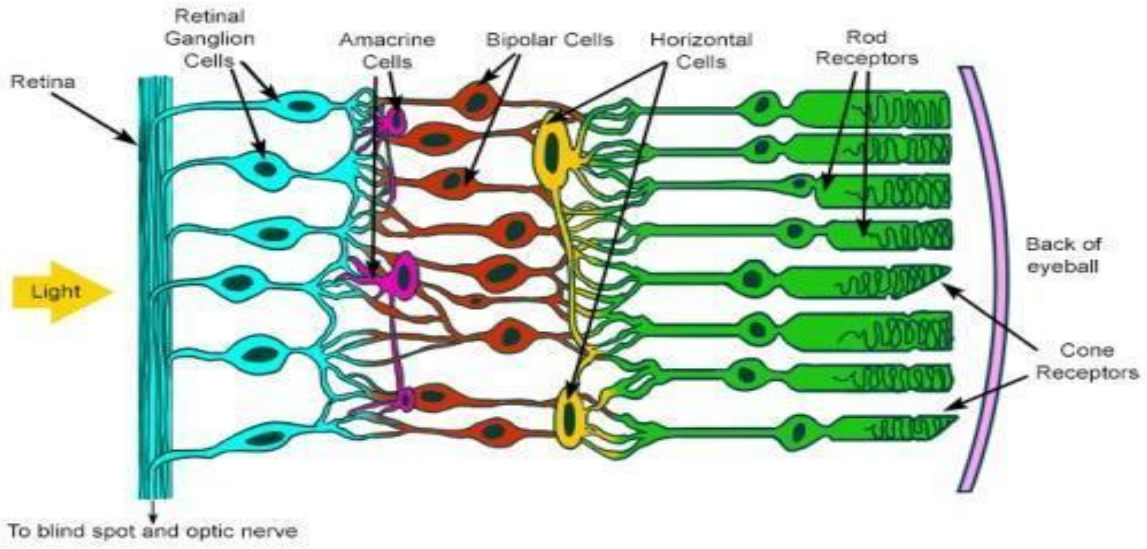

Fig 4. Eye with magnified pigmented layer

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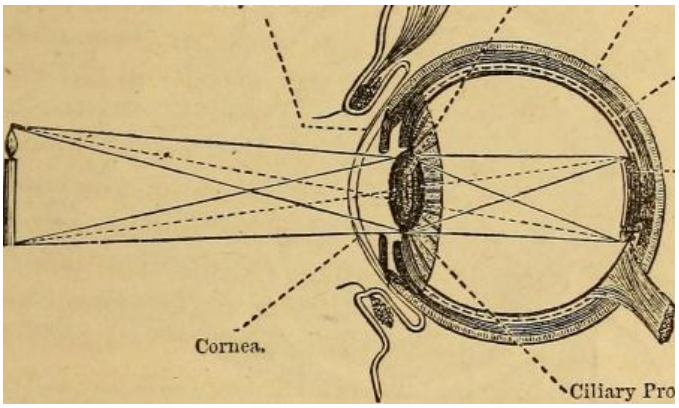
- **Formation of Image in the Eye**

  The image formation in the eye is exactly like the working of a camera. The image formed on the retina is inverted. The image formed also shows lateral inversion. Formation of image after seeing an object and visualisation of the image takes place in two steps. The image is formed on the retina and its interpretation takes place in the cerebral cortex of the brain.



About 75% of the total light falling on the eye is refracted and only 25% is focussed by the lens. Light from objects less than 6 metres away diverge as it approaches the eyes, so to receive this light there are some adjustments done in the eye. These adjustments take place through the following three ways:-

- ***Accommodation of the lenses:*** Ciliary muscles contract and release tension on suspensory ligaments. As the elastic lens is without tension it recoils and bulges out. It allows a shorter focal length to focus the image on the retina.
- ***Constriction of the pupil:*** The circular muscles of the iris relax and decrease the size of pupil. This allows the light from a nearby object to fall on the lens.
- ***Convergence of the eyeball:*** Our eyeballs converge when we look at close objects and allow the light to fall on the retinal fovea.

Accommodation of eye to distant vision **:**

Our eyes are best adapted to distant vision. For seeing distant objects only eyeballs are to be adjusted so that light from that object falls on the lens.

- **Defects of Vision**

  Some persons suffer from defective vision which are of the following three types.

  - ***Myopia:*** Also called nearsightedness. Such defect occurs either due to elongation of the eyeball or excessive curvature of the lens. The affected person can not see far away objects as the image is formed inner to the retina. The defect can be corrected by using a concave lens.

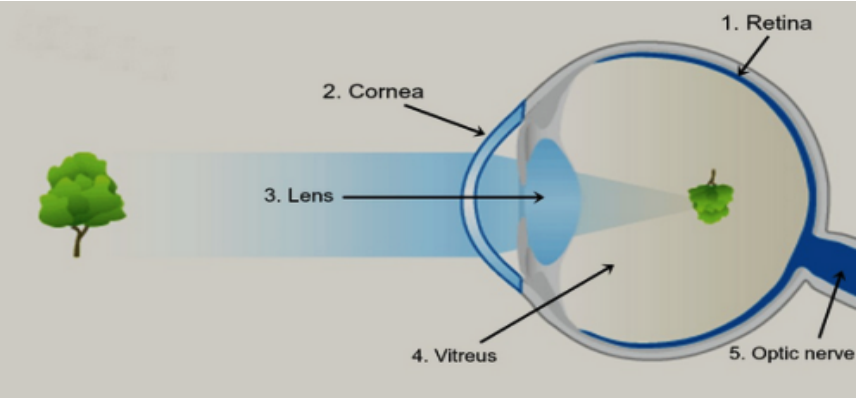


Fig 5. Myopic condition

- ***Hypermetropia:*** This defect is also called farsightedness as nearby objects can not be seen clearly. This problem usually occurs in later stages of life as weakening of ciliary muscles and reduced flexibility of eye lens result in formation of image behind the retina. This defect can be corrected by using convex lenses.

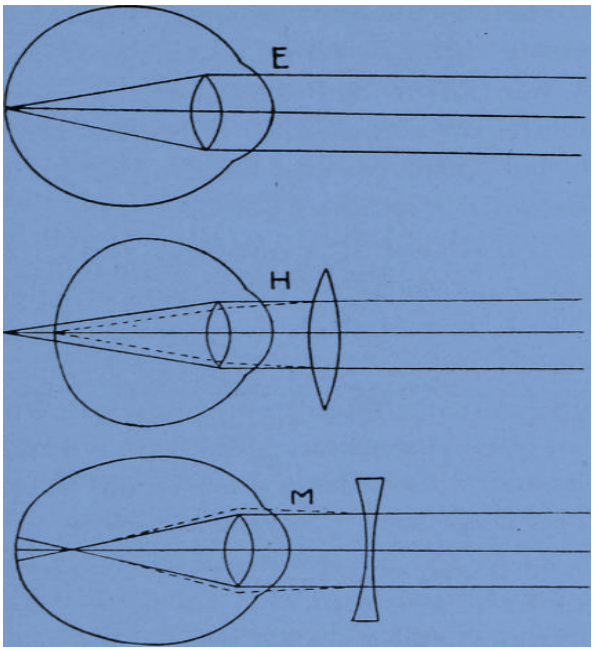


Fig 6. Normal, myopic and hypermetropic vision

- ***Presbyopia:*** It usually occurs in aged persons. It is a refractive error caused due to hardening of the lens. It may occur along with nearsightedness, farsightedness and astigmatism (defective curvature of eye or lens).

Ear: The Organ of Hearing and Equilibrium

The ear is a wonderful device which can transduce sound with extremely small amplitudes into electrical signals, which is 1000 times faster than the photoreceptors responding to light.

Besides receiving sound waves, the internal ear also helps to maintain equilibrium of the body.

Ear serves dual purposes of hearing and maintenance of equilibrium. Although these two functions seem diverse, the organs for these functions are interconnected anatomically.

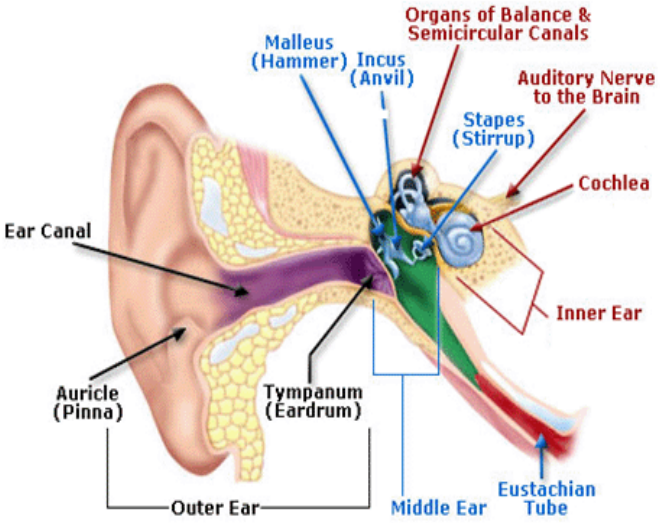
- **Structure of Ear**

  The ear is divided into three main regions:- (i) External ear (ii) Middle ear and (iii) Internal ear.

  (i) ***External ear:*** It consists of **pinna**, **external auditory canal** and **ear drum.** Pinna is a shell shaped cartilaginous flap surrounding the external opening of the external auditory canal. Pinna is made up of an elastic cartilage covered by skin. Function of pinna is to collect sound waves and direct it towards the external auditory canal.

Fig 7. Pinna (External ear)

External auditory canal is a short curved tube of 2.5 cm. long that extends from the pinna. It ends in an ear drum which is also called a tympanic membrane or tympanum. External auditory canal bears certain hairs and modified sweat glands called **ceruminous glands** towards the external opening. Ceruminous glands secrete cerumen or ear wax. A combination of hair and ear wax prevents dust and foreign objects from entering the inside ear.



Tympanic membrane is a thin, semi transparent partition present between external auditory canal and middle ear.

(ii) ***Middle ear:*** The external ear leads into a small, air filled cavity called middle ear. Middle ear cavity is lined by epithelium. Middle ear is separated from the external ear by a tympanic membrane and from the internal ear by a very small bony partition possessing two small membrane covered structures called a round **window** and **oval window**. Three small bones called auditory **ossicles** remain attached with ligaments and extend through the middle ear cavity. These bones are the smallest bones of the body. From the tympanum side these bones are malleus(hammer), incus(anvil) and stapes (stirrup). A part of malleus is attached to the tympanum. The head of malleus is articulated with the body of incus. Incus articulates with the body of stapes. The base of the stapes articulates with the oval window. Just below the oval window is a round window. The anterior of the middle ear contains an opening which directly leads into the auditory tube called the **Eustachian tube**.

Eustachian tube normally remains closed at its pharyngeal end. During yawning and swallowing it opens. The opening of Eustachian tube allows entry or exit of air out of the middle ear until the pressure of middle ear is equal to the atmospheric pressure.

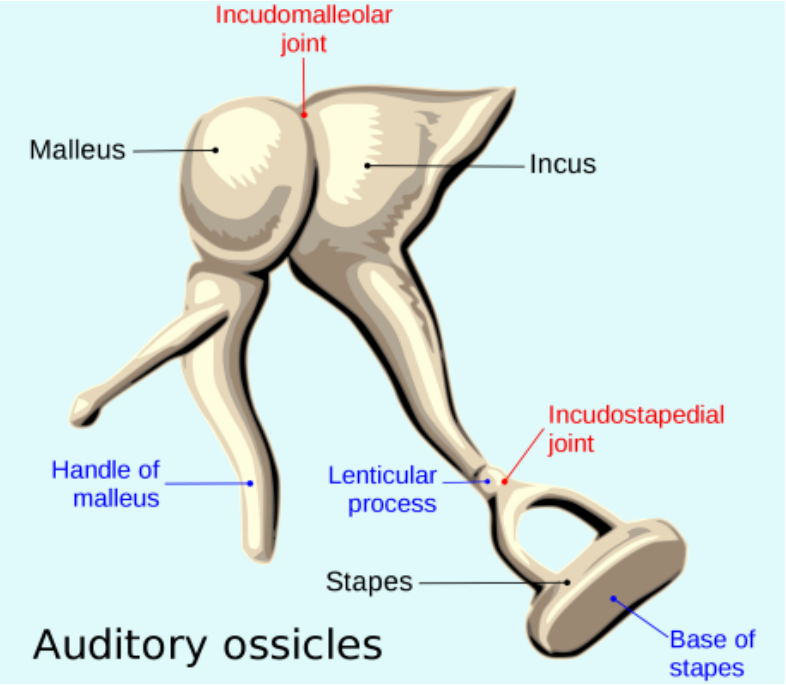


Fig 8. Auditory Ossicles

(iii) ***Internal ear:*** Internal or inner ear is also called a labyrinth as it consists of a series of coiled tubes. Labyrinth consists of two sets of coiled tubes: bony labyrinth and membranous labyrinth.

Bony labyrinth is the outer wall of the inner ear which is rigid and bony. It is located inside the hollow of the temporal bone of the skull. Bony labyrinth consists of three parts; *vestibule, semicircular canal* and *cochlea.* These are hollow cavities. Vestibule and semicircular canals possess receptors for equilibrium. Cochlea is responsible for hearing. Bony labyrinth consists of perilymph. The latter is chemically similar to cerebrospinal fluid. It surrounds a membranous labyrinth.

Membranous labyrinth: It is the inner set of the internal ear enclosed by bony labyrinth and perilymph. It consists of a series of epithelial sacs and tubes. It has the general structure of a bony labyrinth. The epithelial membranous labyrinth contains endolymph. Endolymph contains a high concentration of K^+ in comparison to extracellular fluid.

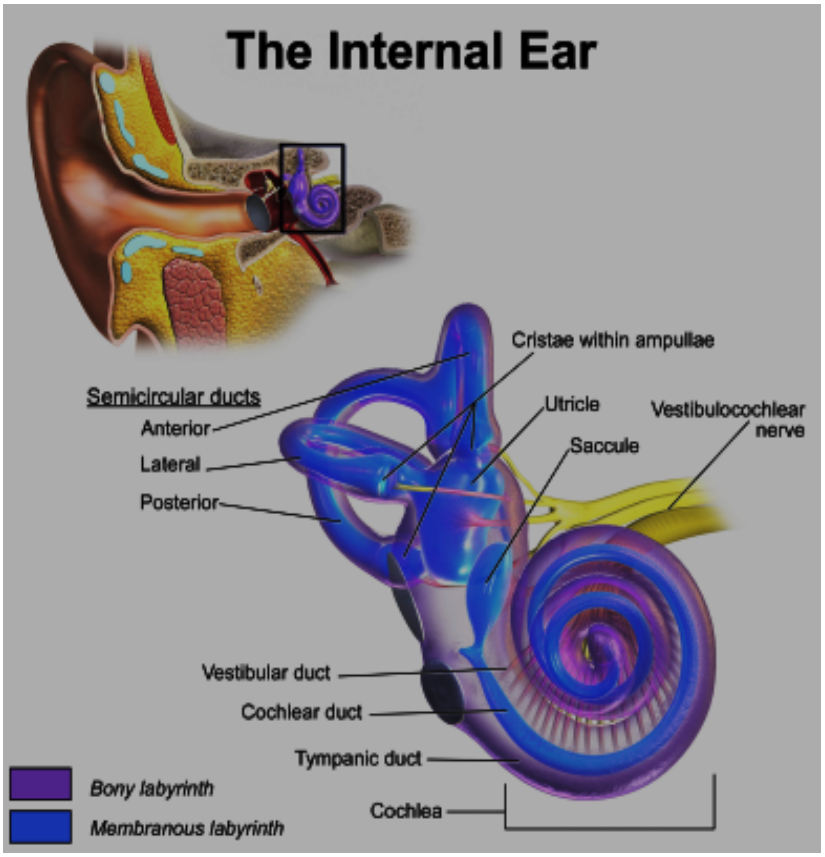


Fig 9. Internal Ear

Bony labyrinth possesses an oval, central, swollen part called vestibule. Inside the vestibule the membranous labyrinth possesses two sacs and they are called as utricle and saccule. The walls of both the utricle and saccule contain small, thickened regions called **macula.** Macula helps to maintain equilibrium. Posterior and superior to the vestibule are projected three semicircular canals. Each of the canals is perpendicular to the other two. At one end of each canal is a swollen part called an ampulla. Another prominent part of the internal ear is the cochlea. Cochlea is anterior to the vestibule and it is a bony, spiral canal.

The vestibular membrane separates the cochlear duct from scala vestibule and the basillar membrane separates the cochlear duct from scala tympani. Resting on the basilar membrane is present **organ of corti** . the latter consists of thousands of hair cells. Tectorial membrane, which is a flexible, gelatinous membrane overhanging and covering the hair cells of organ of corti. In fact, the tips of the hair cells of organ of Corti lie in the tectorial membrane and bodies of hair cells lie on the basilar cells.

Internal view of cochlea reveals that it consists of three chambers; **scala vestibuli, scala media** or cochlear duct and **scala tympani**. Scala tympani and scala vestibuli are parts of

bony labyrinth and are filled with perilymph. Scala vestibuli and scala tympani respectively open into an oval window and round window.

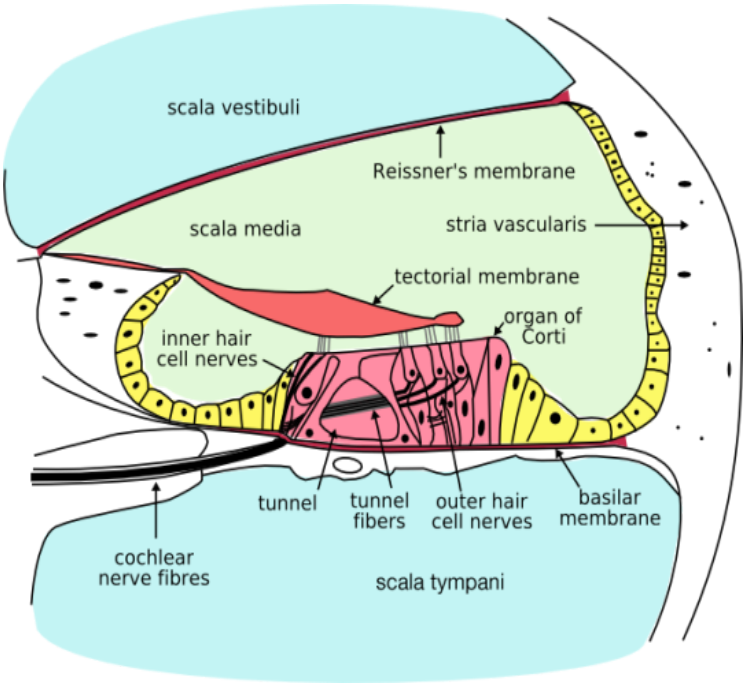


Fig 10. Organ of Corti

- **Physiology of Hearing**

  Physiology of hearing involves the following steps

  - The pinna directs the sound waves to external auditory meatus and the waves reach to the tympanic membrane.
  - Tympanic membrane starts vibrating forth and back . How much the membrane moves depends on the intensity and frequency of the sound waves.
  - The centre of tympanum is attached with the part of malleus. The vibration of malleus causes vibration of malleus, then incus and ultimately stapes.
  - As the stapes move back and forth, it pushes the membrane of the oval window back and forth generating pressure in perilymph of scala vestibuli. The latter is in continuation of perilymph of scala tympani.
  - Generation of pressure in scala tympani causes vibration in the round window membrane.
  - Movement of perilymph also causes vibration in the vestibular membrane and endolymph. The latter results in vibration of basilar membrane and bending of tips of hair cells against tectorial membrane. This generates nerve impulse.

- Auditory nerve transmits this impulse to the brain and the latter decodes it.

The decoding of received soundwaves depends to a great extent on the previous experience and memory.

Summary

- Specialised sense organs are located on the head region.
- Eyeballs are covered by three walls or tunics and they contain fluids and other associated parts.
- Blind spot is the part on the retina on which when light falls no image is formed.
- Iris is the only coloured part of the eye.
- Image formed on the eye is inverted and is decoded by the brain.
- Ear is the organ of hearing and maintenance of equilibrium.
- Ear consists of three parts; external, middle and internal ear.
- Internal ear possesses vestibule, semicircular canal and cochlea.