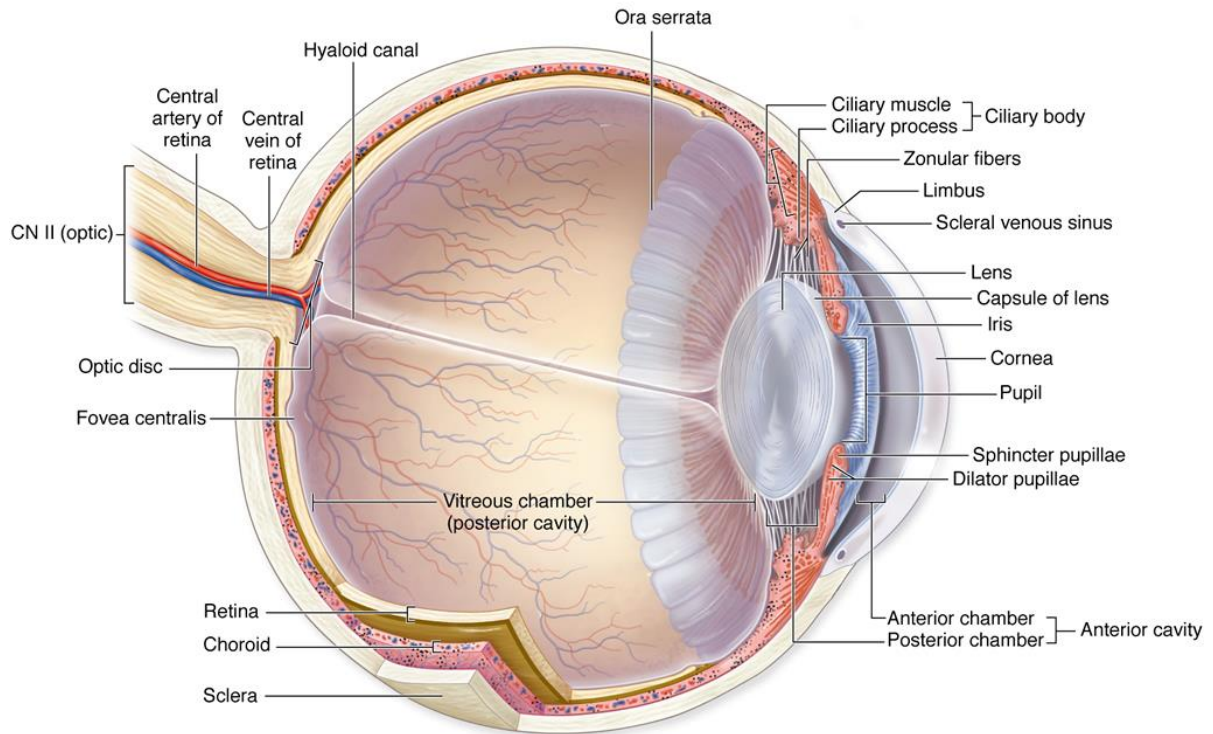


Special Senses – The Eye

The eye is a complex highly developed photosensitive organ responsible for light reception.

Each eye is located in a protective bony chamber in the skull,

the **orbit**, that gives origin to the extraocular muscles. Behind the eyeball, the orbit is filled with retrobulbar fat. The **optic nerve** is attached to the eyeball just medial to the posterior pole of it. The eyeball is slightly flattened anteroposteriorly (i.e: it's A-P diameter is smaller than the vertical), with the anterior 1/6th of the sphere (the cornea) being more convex.



Histologically, the eye consists of 3 concentric layers:

- **External (fibrous) layer:** cornea (ant. 1/6th) & sclera (post. 5/6th)
- **Middle (vascular) layer:** choroid (post.), ciliary body & iris (ant.)
- **Internal (nervous) layer:** retina.

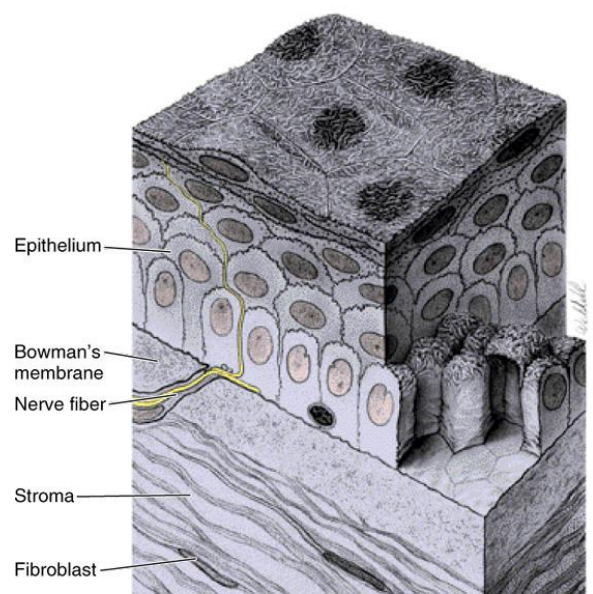
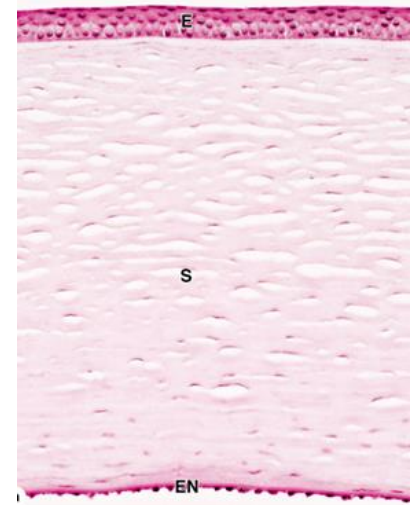
The lens & its suspensory ligament (zonule) divide the eyeball into 2 compartments, the posterior one (**vitreous space**) is filled with a gelatinous transparent structure (the **vitreous body**). The anterior one is filled with a fluid (the **aqueous humor**) & is subdivided by the iris into the **anterior chamber** (between the cornea & the iris) & the **posterior chamber** (between the iris & the lens with its ligament). The 2 chambers communicate through the central opening of the iris (the **pupil**).

External (Fibrous) Layer:

The Sclera: It is the white part of the eye, an opaque layer of dense connective tissue that protects delicate internal structures & gives the eye its shape. It is relatively avascular, consisting of: flattened bundles of type I collagen fibers running in different directions parallel to the eyeball surface, moderate amount of ground substance, & few fibroblasts. The innermost layer of sclera (adjacent to the choroid) is less dense, with thinner collagen fibers, more fibroblasts, melanocytes, & elastic fibers. The sclera thickens posteriorly, reaching 1 mm at the optic nerve attachment, where it becomes continuous with the epineurium of the nerve.

The Cornea: the most anterior part of the eye, a highly transparent convex structure made of 5 layers (anteroposteriorly):

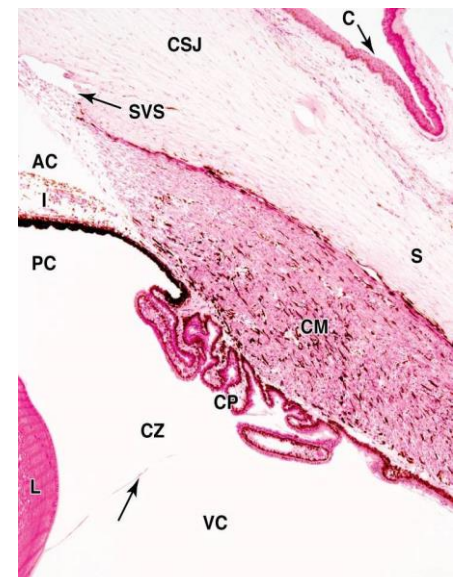
1. **The epithelium:** stratified squamous epithelium (non-keratinized) consisting of 5-6 cell layers. The basal layer regenerates other cells (corneal epithelial turnover occurs each 7 days) & mitotic figures are seen especially at the periphery. The surface cells have microvilli protruding into the tearfilm. The epithelium has a very rich sensory nerve supply.
2. **Anterior limiting (Bowmann's) membrane:** the very thick (8-12 μm) basement membrane of the epithelium, consisting of randomly running collagen fibers, it is responsible for corneal strength.
3. **The stroma:** about 60 layers of parallel highly organized collagen bundles crossing at right angles to each other. The uniform orthogonal array of these collagen fibrils contributes to the corneal transparency. Fibroblast-like cells (keratocytes) have flattened cytoplasmic extensions (like butterfly wings) between collagen fibrills, with proteoglycan-rich extracellular substance. Lymphoid cells are seen in the stroma.



- The **corneoscleral junction (the limbus)** is the highly vascularized transitional zone between the cornea & sclera. In the stromal layer of the limbus, there is the **scleral venous sinus** or **Schlemm's canal**, an irregular endothelium-lined space that communicate with the anterior chamber of the eye via many tiny openings at the **iridocorneal angle**. Schlemm's canal is connected to the venous system & act to drain the aqueous humor to it. The cornea is avascular, it is nourished by diffusion from:
- 1.vessels in the limbus
 - 2.the aqueous humor.

This consists of 3 parts:

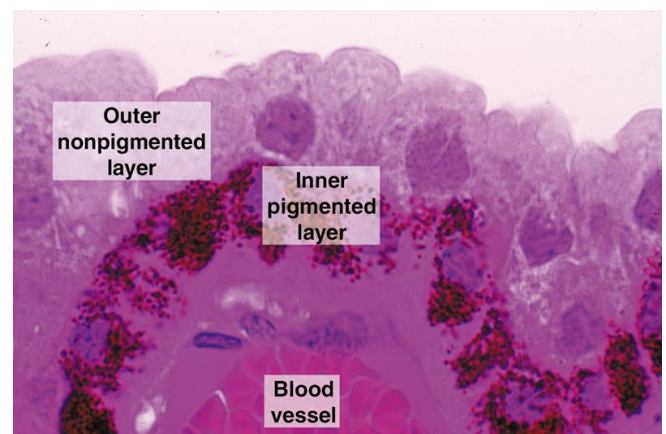
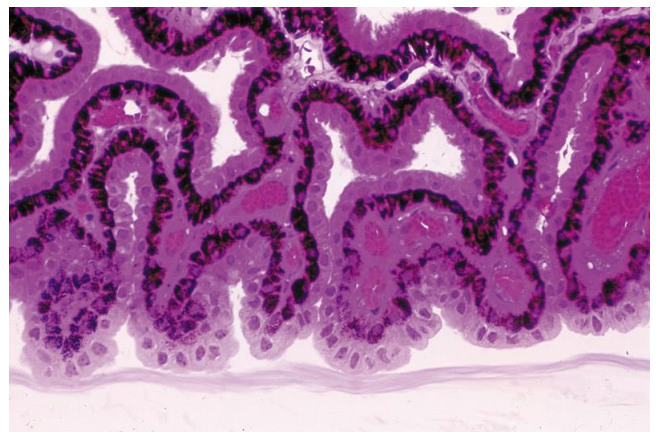
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- A histological section of the choroid stained with hematoxylin and eosin (H&E). The image shows the choroid, a layer of vascular tissue in the eye. Several white arrowheads point to dark, pigmented cells, which are labeled as melanocytes. The surrounding tissue is labeled as Sclera and Choroid.



cross section, having one surface in contact with the sclera, one with the vitreous body & the 3rd irregular surface facing the posterior chamber of the eye. Histologically, ciliary body consists of loose connective tissue rich in blood vessels, elastic fibers & melanocytes. Apart from the surface adjacent to the sclera, the ciliary body is covered by 2 layers of simple columnar epithelium, both are derived from the retina. The first (inner) layer (directly adjacent to ciliary stroma) consists of melanin-rich (**pigmented**) cells & represents the anterior continuation of the pigment epithelium of the retina. The second layer covers the first & consists of **non-pigmented** cells that represent the anterior continuation of the sensory layer of the retina. The 2 layers lie head-to-head.

The ciliary body is divided into:

- **Ciliary muscles:** 2 bundles of smooth muscle fibers divided into thick inner circular & thin outer longitudinal layers, they are important in visual accommodation.
- **Ciliary processes:** about 75 ridge-like or finger-like projections from the ciliary body, each consists of a loose connective tissue core rich in fenestrated capillaries & covered by 2 layers of epithelium (mentioned above). Ciliary processes serve 2 functions:
 - a- Give attachment to the fibers of suspensory ligament of the lens (that extend from the basement membrane of the pigmented epithelium to the capsule of the lens).
 - b- Secrete the aqueous humor (by the non-pigmented epithelium) into the posterior chamber of the eye.



Aqueous humor secretion & circulation: Non-pigmented cells have tight junctions & extensive basal & Na⁺/K⁺-ATPase in their lateral membrane, they filterate blood in the ciliary process vessels secreting aqueous humor (1). Aqueous humor is similar to plasma but with a minimal amount of proteins. It is secreted into the posterior chamber & flows via the pupil (2) to the anterior chamber to supply the cornea by nutrients & then enters

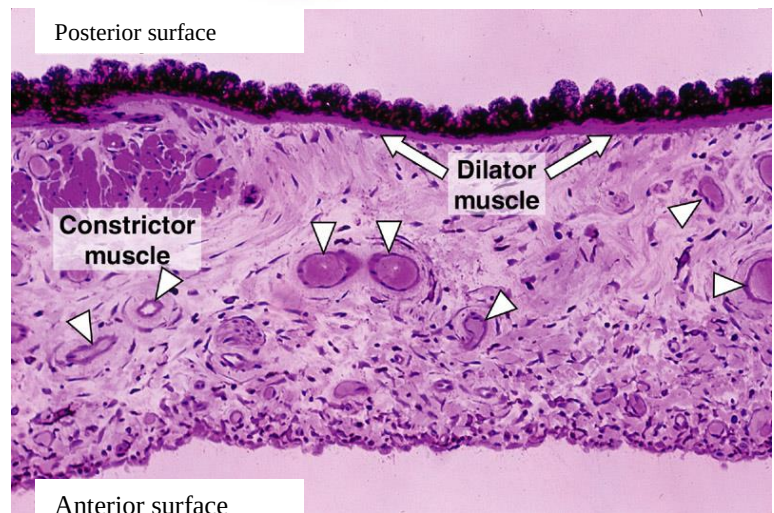
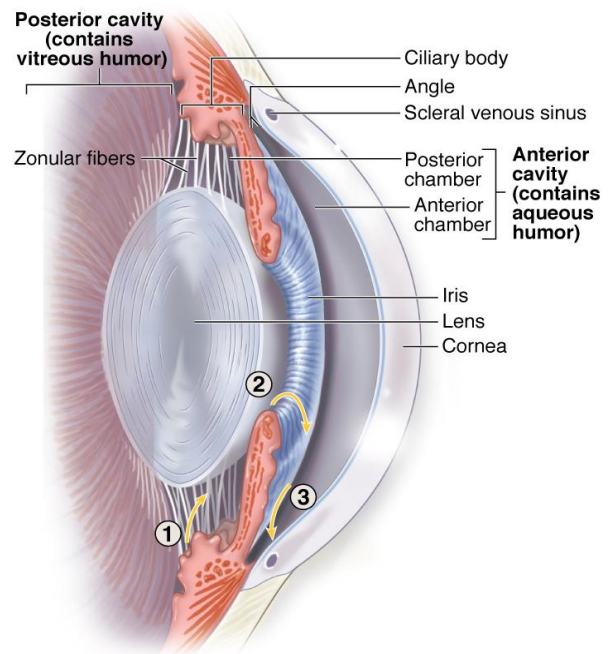
the canal of Schlemm (through the trabecular meshwork in the iridocorneal angle) (3), then drained to the veins in the limbus.

3. **The Iris:** It is the anterior part of the uveal tract (the coloured part of the eye), a disc-like structure attached to the ciliary body peripherally & having a rounded aperture (the pupil) centrally. It has the following layers:

- a- **Anterior surface:** this is not covered by epithelium, but formed by a discontinuous layer of fibroblasts & melanocytes, with interdigitating processes giving an irregular, rough grooved appearance.
- b- **Stroma:** a loose connective tissue with an anterior zone poorly vascularized & rich in fibroblasts & melanocytes, & a highly vascularized posterior zone.

Around the pupil, the stroma contains circularly-arranged smooth muscle fibers innervated parasympathetically, the **sphincter pupillae muscle**.

- **Posterior surface:** a smooth surface covered by the same 2 epithelial layers covering the ciliary body. The posterior layer (facing the posterior chamber) cells are heavily pigmented, preventing light from entering the eye except via the pupil. The anterior layer (adjacent to the stroma) consists of less pigmented myoepithelial cells that have radially arranged processes forming the **dilator pupillae muscle** (innervated sympathetically).
- Posterior pigmented epithelium & melanocytes in the stroma of the iris are responsible for the eye colour. People with few melanocytes have blue eyes, people with more melanocytes & collagen in the iris stroma have darker eyes. People with albinism lack pigment in their cells, they have pink eyes from the visible blood vessels of the iris.



The Lens:

It is a biconvex transparent structure with great elasticity (that decreases with age). The lens has 3 components:

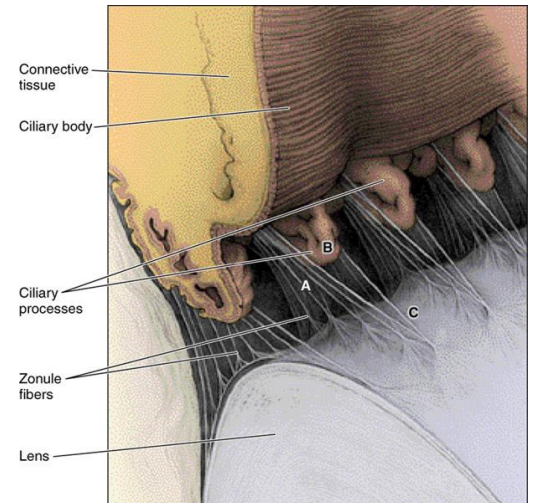
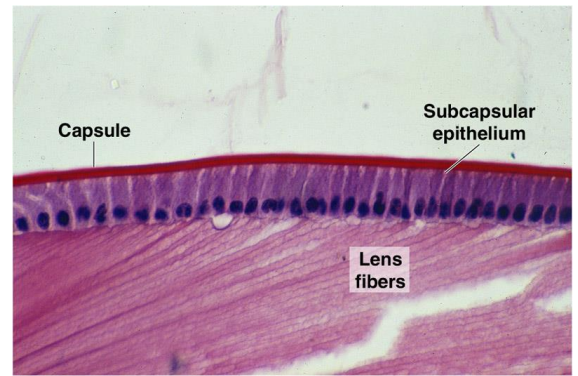
1. **Lens capsule:** a thick (10-20 μm) homogenous refractile external layer that represents the basement membrane of the lens epithelium. It consists of type IV collagen & glycoprotein.
2. **Subcapsular epithelium:** simple cuboidal or columnar cells lining the ant. half of lens capsule. They show interdigitation with the lens fibers. Cells at the lens periphery divide to give new lens fibers.
3. **Lens fibers:** extremely elongated highly differentiated epithelial cells that fill the lens.

They originate from the subcapsular epithelium & lose their nuclei & organelles to become very long, thin, flattened structures filled with proteins (**crystallins**).

The suspensory ligament of the lens (Zonule): a group of radially oriented fibers extending from the ciliary processes to the lens capsule. Zonular fibers are similar to the microfibrils of elastic fibers.

Accommodation: A process that helps us to concentrate on near objects. When the eye is resting or looking at a far object, the ciliary muscles are relaxed, zonular fibers are tense, & the lens is more flattened. When we look at a near object, both ciliary muscles contract, pulling the ciliary body forwards & reducing its diameter, causing the zonule (attached to the ciliary processes) to relax, & the elastic lens becomes more spherical (increasing its refractive power) so the image of the near object falls on the retina.

Vitreous Body: a transparent gelatinous medium filling the vitreous space between the lens & retina. It consists of water (99%) with hyaluronate & small amounts of collagen. Vitreous body is surrounded by the vitreous membrane, made by type IV collagen. The only cells in the vitreous body are few macrophages & a small number of hyaluronate-producing cells (**hyalocytes**) near the membrane.

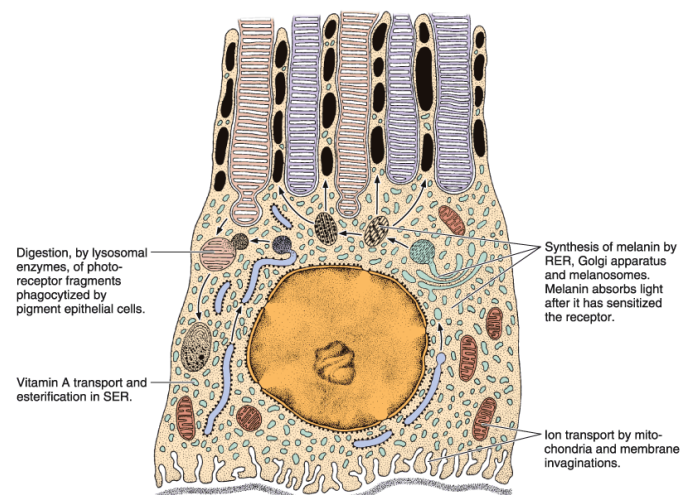
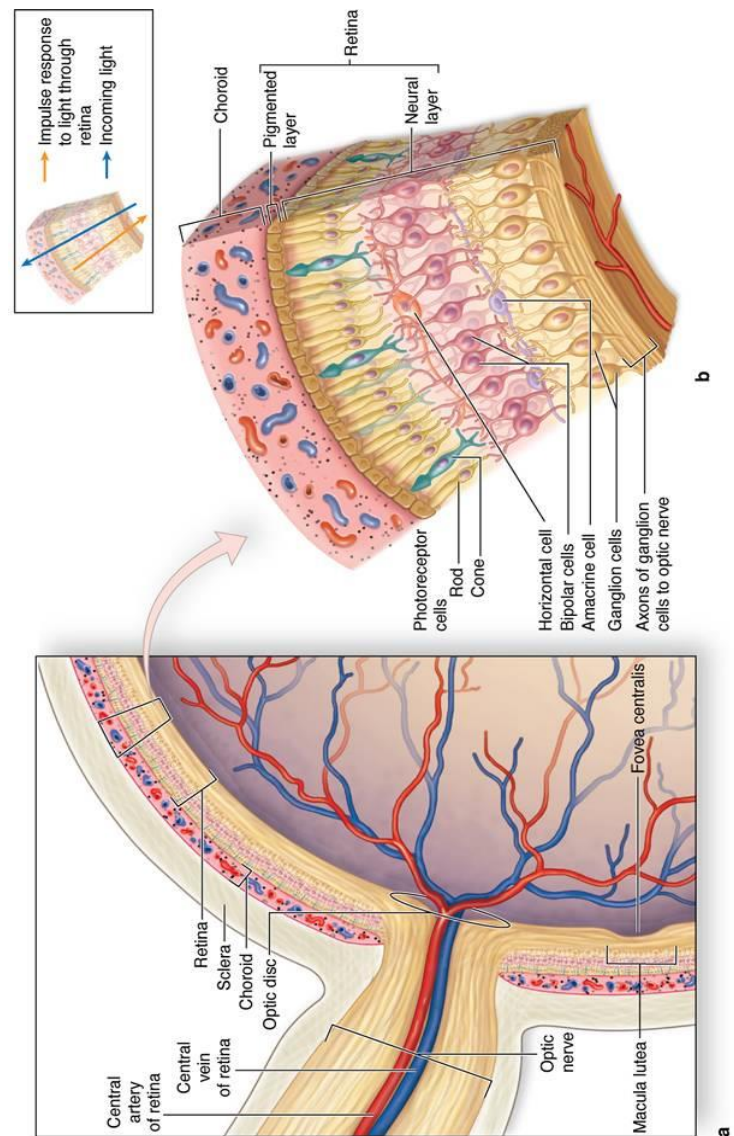


The Retina (Nervous Layer)

The retina is the innermost layer of the eyeball. It consists of 2 parts: the posterior part is photosensitive, extending from the optic disc to a dentate line called the **ora serrata** (along the junction between the choroid & ciliary body). The anterior part (not photosensitive) is a double layer of epithelial cells that covers the ciliary body & back of iris.

The photosensitive retina consists of 4 cellular layers arranged in a complex way so that they show 10 distinctive layers in histological sections. From external layer inward, these are:

I- Pigment epithelium: simple cuboidal or low columnar cells with a basal nucleus. The basal lamina of those pigment cells adhere firmly to Bruch's membrane. The basal part of the cells has many intercellular tight & gap junctions (as part of blood-retina barrier), basal enfoldings & mitochondria (indicating ion transporting activity). The apical part has cytoplasmic processes & cylindrical invaginations that envelop the photoreceptors, melanin granules (to absorb the light & prevent its reflection), phagocytic vesicles & lysosomes (to phagocytose & digest the tips of photoreceptors). The cytoplasm is filled with large amount of sER (for vit.A metabolism, from which *all-trans-retinal* is derived). This layer extends in the anterior part of the retina as the pigmented epithelium.



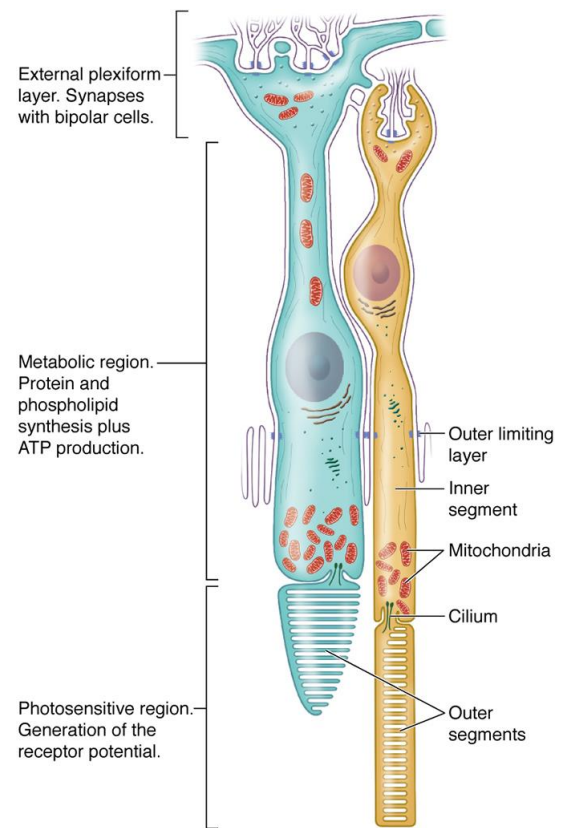
II- Photoreceptor cells:

These are thin elongated polarized neurons that lie parallel to each other extending from the pigment epithelium to the bipolar cells. Photoreceptor cells are either rod cells or thicker cone cells. A photoreceptor cell is divided into 4 regions:

- **Outer segment (the photoreceptor):** a single modified photosensitive structure connected to the rest of the cell by a restriction (the connecting stalk), which is a modified cilium arising from a basal body. The outer segment is "rod" in rod cells & "cone" in cone cells.
- **Inner segment:** from the outer segment to the nucleus, containing large number of mitochondria & polyribosomes (that synthesize proteins necessary for vision, like visual pigments).
- **Nuclear region:** the zone containing the nucleus. Cone cells nuclei are slightly closer to the pigment epithelium than rod cells nuclei.
- **Synaptic region:** above the nucleus, a dilated region where photoreceptor cells synaps with bipolar & horizontal cells.

Photoreceptors: as mentioned above, these are the outer parts of photoreceptor cells. They include:

- **The rods:** rod-like structures (120 million in each retina) containing numerous flattened membranous discs stacked up like coins. These discs are isolated from the cell membrane, they contain the rodopsin pigment which is bleached by light initiating the visual stimulus. Rods are extremely sensitive to light (even a single photon can stimulate them) enabling us from seeing at night, they percept light as low resolution grey scale images. New membranous discs are continuously formed from the cell membrane near the connecting stalk, separate & move to the tip of rod, until the tip detaches from the rod & phagocytosed by the pigment epithelial cells.
- **The cones:** much smaller cone-like structures (6-7 million in each retina) containing numerous flattened stacked membranous discs. These discs are continuous with the

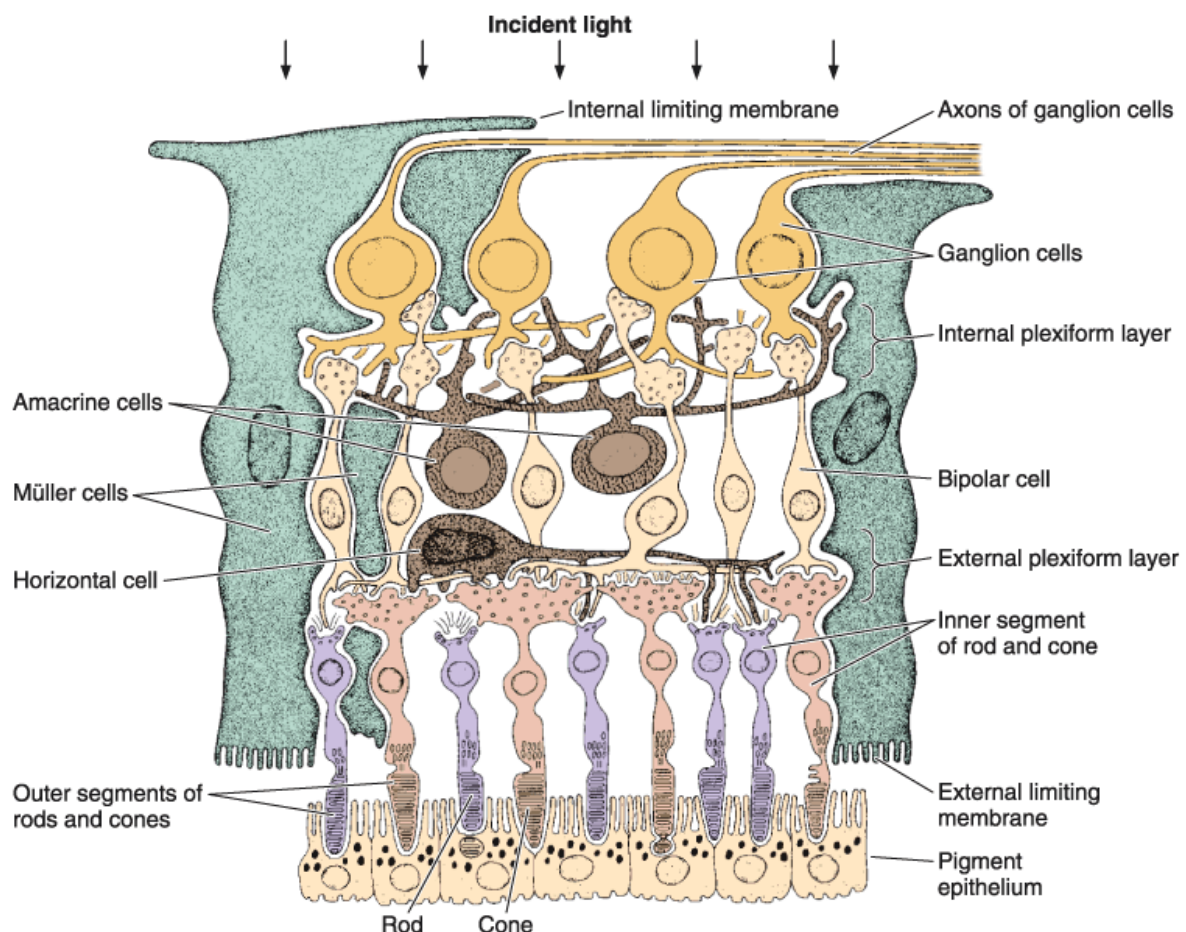


cell membrane from one side (as membrane invaginations), they contain the iodopsin pigment. There are at least 3 types of cones, each one is maximally sensitive to either red, blue or green light. Cones need higher light intensity (like daylight) to be sensitized than rods, they percept light as high resolution coloured images. Discs are shed much less frequently than in rods.

III- Bipolar (& other) cells:

Bipolar neurons synapse with the photoreceptor cells externally & the ganglionic cells internally, transmitting the signals to them. Other cells are present in the same level of bipolar cells, including:

- **Horizontal cells:** neurons that establish contact between different photoreceptor cells. They may act to integrate stimuli.
- **Amacrine cells:** neurons that establish contact with many ganglion cells. Their function is obscure.
- **Supporting (Müller) cells:** These are the neuroglia of the retina. They are large, extensively branched cells that extend from the external to the internal limiting membrane, filling the spaces between all other cells in the retina.
- **Microglial cells:** scattered throughout the retina.

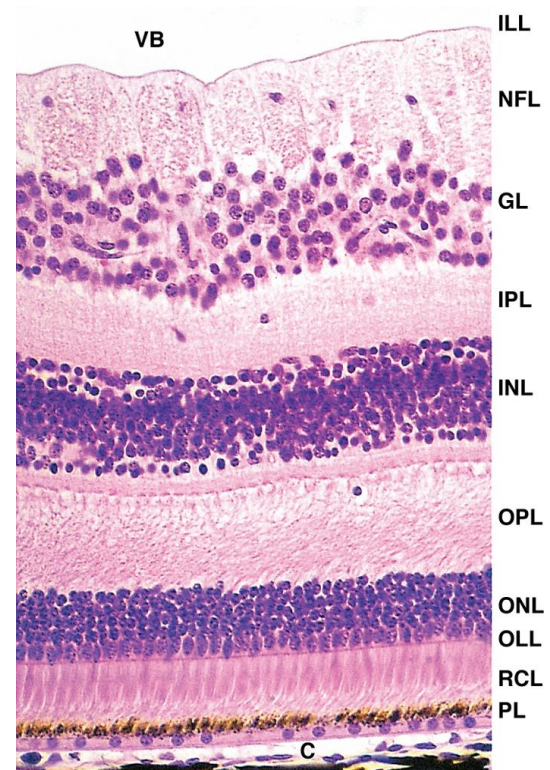


IV- Ganglion cells:

Giant typical neurons that have euchromatic nuclei & basophilic Nissle bodies. They synapse with bipolar & amacrine cells & send their axons to the optic disc where they form the optic nerve responsible for transmitting visual sensation to the brain.

The 10 layers of retina: From the choroid inward, histological sections of the retina show the following layers:

1. *Pigmented epithelium*,
2. *Photoreceptor layer* (rods & cones),
3. *External limiting membrane*: At the level of inner segments of photoreceptor cells, there are tight junctions connecting these cells to Müller cells, forming this membrane.
4. *External nuclear layer*: the nuclei of photoreceptor cells.
5. *External plexiform layer*: the region of synapses between photoreceptor cells & bipolar (& horizontal) cells.
6. *Internal nuclear layer*: the nuclei of bipolar, horizontal, amacrine, & Müller cells.
7. *Internal plexiform layer*: the region of synapses of bipolar (& amacrine) cells with the ganglion cells.
8. *Ganglion cell layer*:
9. *Nerve fiber layer*: the axons of ganglion cells.
10. *Internal limiting membrane*: a thin layer formed by flattened processes of Müller cells that separate nerve fiber layer from the vitreous body.



Specialized Areas of the Retina:

The visual part of the retina is behind the ora serrata. At the optic disc (the exit of the optic nerve, slightly medial to the posterior pole of the eyeball), there are no photoreceptors, hence, no vision occurs here & it is called the **blind spot** of the retina.

At the posterior pole of the optical axis, there is a shallow depression called the "**fovea centralis**" where the retina becomes very thin because bipolar & ganglion cells

accumulate at the periphery of the fovea. Its center consists only of cone cells with long thin highly packed cones & no rods, in addition, blood vessels do not cross over the photoreceptor cells here. These factors make the fovea the region of the maximal visual acuity & colour perception. Around the fovea centralis is the **macula lutea** (5.5 mm diam.), here all the layers of the retina are present, & the two plexiform layers are rich in **carotenoids** (which give a yellowish colour) that protect the fovea from dangerous short wavelength light by their antioxidant properties. When we move towards the periphery of the retina, the number of rods increases & cones decrease.

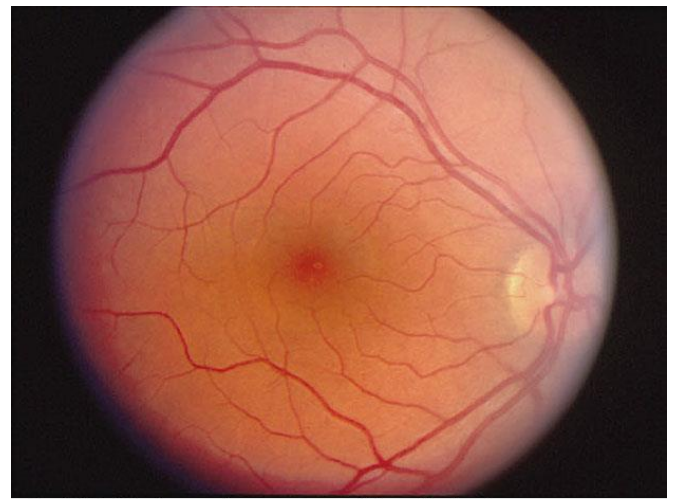
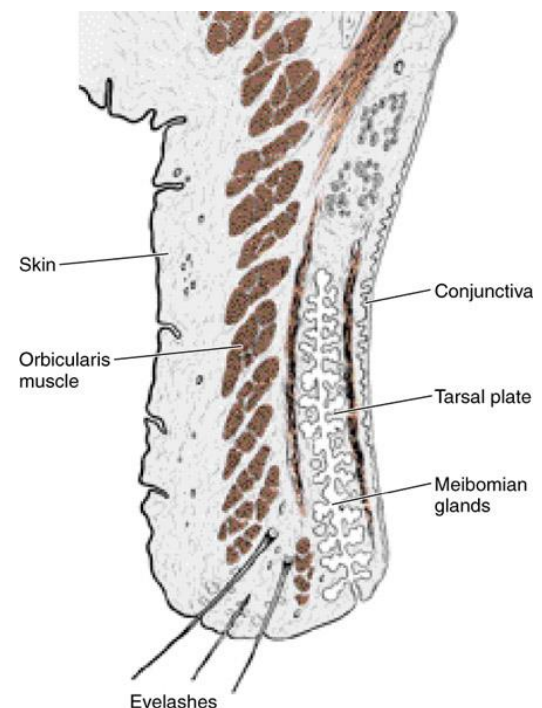


Fig. 14. Ophthalmoscopic appearance of the retina to show the macula lutea (yellow around fovea).

The Conjunctiva: Thin transparent mucous membrane that covers the front of the eye (except the cornea) & lines the eyelids. The upper & lower limits of the conjunctiva are the superior & inferior **fornices**. It consists of loose connective tissue lamina propria lined with stratified columnar epithelium rich in goblet cells.

The Eyelids: Mobile folds of tissue that protect the eye. Each eyelid consists of the following layers:

- Skin: thin, elastic skin with eyelashes at its free margin.
- Loose connective tissue containing 2 muscles: orbicularis oculi & levator palpebri superioris.
- Tarsal plate: tough plate of dense connective tissue that contains the meibomian glands.
- Conjunctiva.

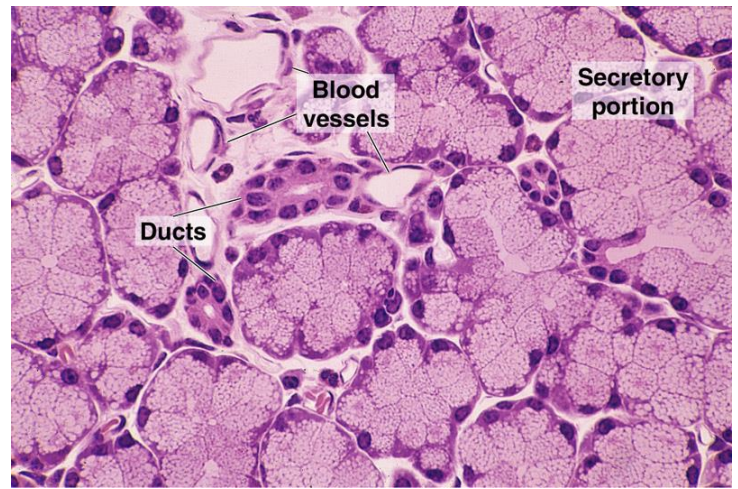


The eyelid contain 3 types of glands:

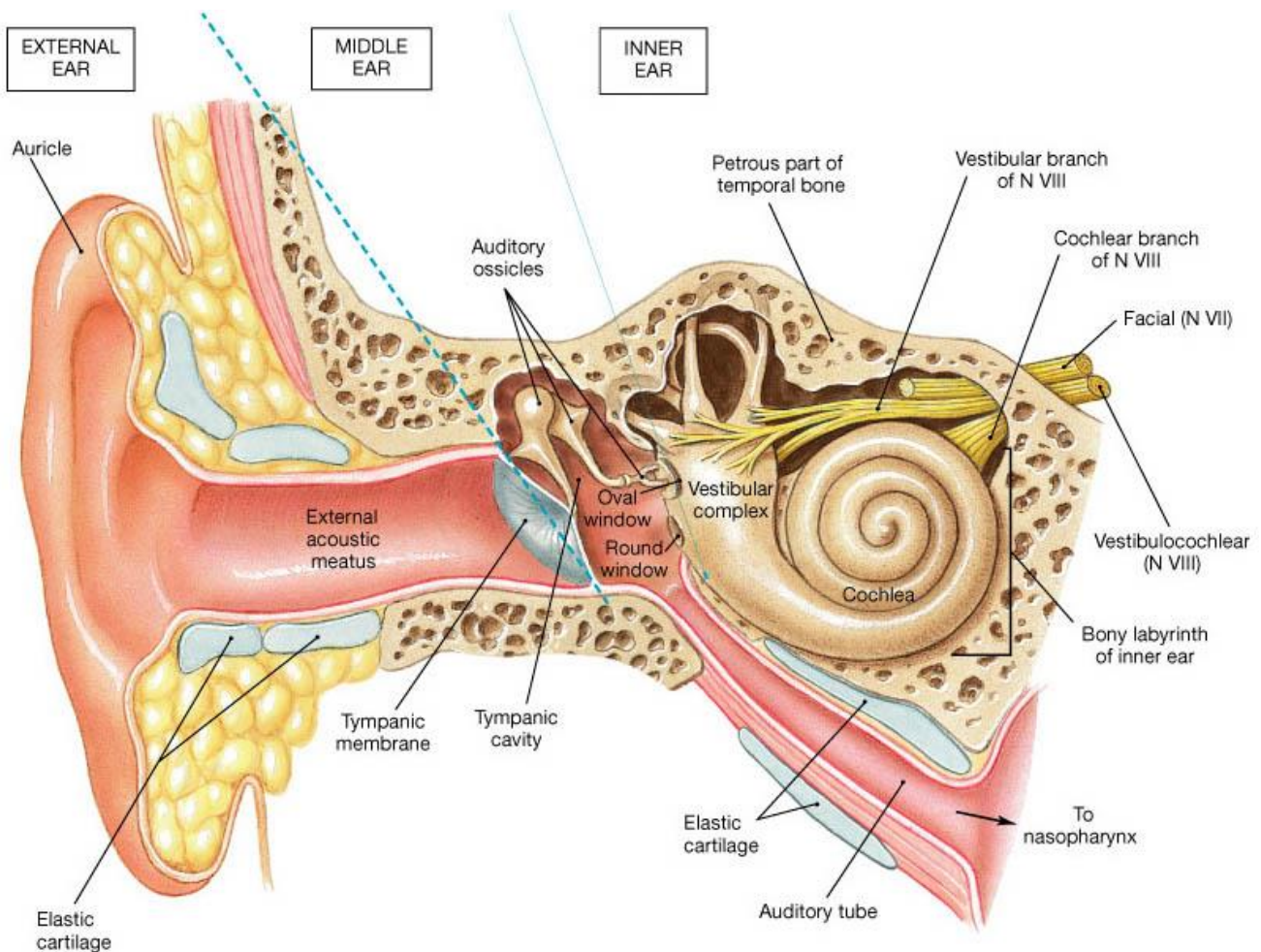
- Meibomian glands:** long sebaceous glands in the tarsal plate. They don't communicate with the hair follicles of eyelashes & produce an oily layer on the surface of the tearfilm preventing its rapid evaporation.
- Zeis glands:** smaller modified sebaceous glands connected to the hair follicles.
- Moll glands:** spiral sweat glands that open in the hair follicles of the eyelashes.

The Lacrimal Apparatus

- **Lacrimal gland:** It is the tear secreting gland, located in the antero-supero-lateral part of the orbit. It consists of several lobes with several ducts that open in the superior conjunctival fornix. The lacrimal gland is tubuloalviolar gland composed of serous columnar cells rich in secretory granules. The secretory portion is surrounded by myoepithelial cells. Tearfilm moisturizes the front of the eye & is drained by:
 - **Lacrimal canaliculi**, that begin at two lacrimal puncta (tiny openings at the medial end of the free margin of each eyelid), run medially about 8mm then unite forming one canaliculus (all lined with stratified squamous epithelium) before opening into:
 - **Lacrimal sac**, which passes tears to the nasal cavity via the nasolacrimal duct.



Special Senses - The Ear



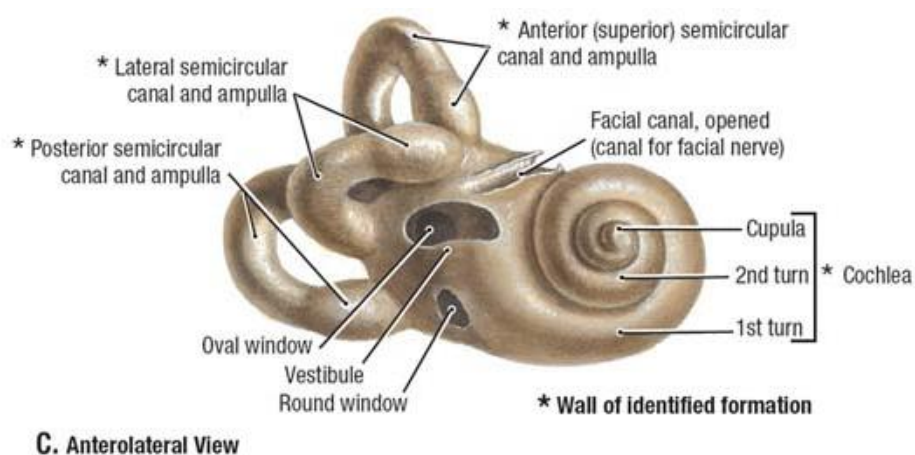
I- **The External Ear:** it consists of:

- **The Auricle:** an irregular plate of elastic cartilage covered by tightly adherent skin.
- **The External Auditory Meatus:** a flattened canal extending from the auricle to the **tympanic membrane**. It is lined with hairy thin skin, beneath which sebaceous glands & ceruminous glands (modified sweat glands secreting cerumin or ear wax) are found. The wall of meatus is formed by elastic cartilage (outer 1/3rd) & temporal bone (inner 2/3rd). The external side of tympanic membrane is covered by thin epidermis resting on a dense connective tissue layer.

II- **The Middle Ear:** a slit-like irregular cavity extending from the tympanic membrane to the internal ear. It communicates anteriorly with the nasopharynx via the auditory tube & posteriorly with the mastoid air cells. The middle ear is lined by simple squamous epithelium (that becomes cuboidal on the tympanic membrane) resting on a thin lamina propria adherent to the periosteum. In the bony medial wall of middle ear, there are 2 membrane-closed openings: **oval & round windows**. The tympanic membrane is connected to the oval window by 3 small **auditory ossicles**: the malleus, incus & stapes. These bones are covered by simple squamous cells & articulated by synovial joints. 2 muscles are connected to the ossicles to regulate sound conduction.

III- **The Internal Ear:** situated inside the petrous part of temporal bone, the internal ear consists of 2 labyrinths:

- **Bony labyrinth:** a series of spaces within the bone: the irregular central cavity is the **vestibule**, from its posterior side, three **semicircular canals** arise (each one is perpendicular to the other



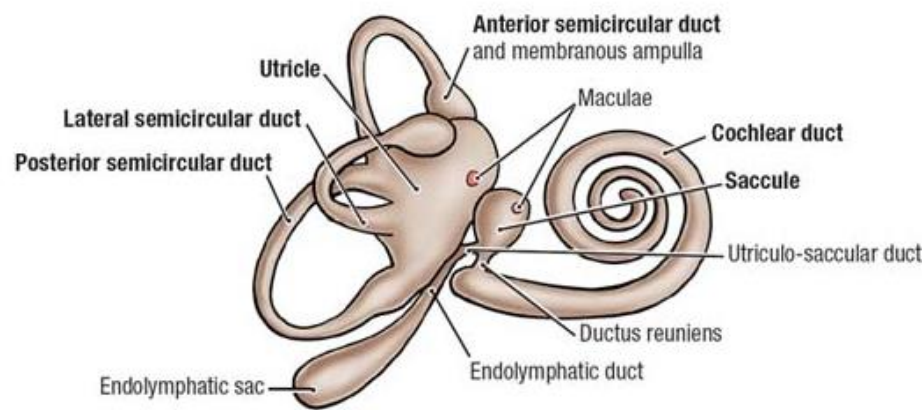
two). From the anterolateral side of the vestibule, a spiral canal arise (the **cochlea**), making 2.5 turns around a bony core (the **modiolus**). The modiolus has a thin spiral ridge (the **osseous spiral lamina**) projecting into the cochlea along its length. Deep to the attachment of this lamina, the modiolus contains the **spiral ganglion** (the sensory

ganglion of the cochlear part of the cranial nerve VIII) from which nerve fibers aggregate at the base of modiolus forming the **cochlear nerve**, which enters the cranial cavity (with the vestibular nerve) through the **internal auditory meatus**.

The bony labyrinth contains the membranous labyrinth, with the space between them filled with a fluid called the "**perilymph**" that communicates with the CSF via the **perilymphatic duct**.

- **Membranous labyrinth:** a series of interconnected membranous cavities lined with simple squamous epithelium & filled with fluid (the **endolymph**).

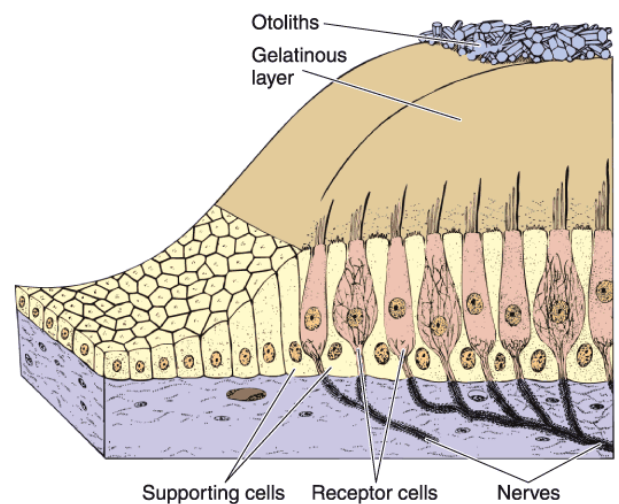
Those cavities roughly resemble the bony labyrinth containing them. They include the **utricle** & **sacculle** (in the vestibule), the utricle is connected to 3 **semicircular ducts** (in the semicircular canals) & the sacculle is connected to the **cochlear duct** (in the cochlea). From the junction of the utricle & sacculle, the slender **endolymphatic duct** arise & run inside the bone to end as the dilated **endolymphatic sac** beneath the dura mater.



E. Anterolateral View

Sacculle & Utricle: These are epithelium-lined connective tissue sheaths that contain regions of spacialized epithelium called the "**maculae**" (the macula of sacculle lie in its floor & that of utricle in its lateral wall). The macula consists of high epithelial cells covered by a thick gelatinous glycoprotein layer, at the top of it are many **otoliths** (calcium salts crystals). The epithelial cells include:

- Receptor cells: long spindle-shaped cells having sensory nerve endings at their base. The apical surface of each cell contain a row of steriocilia (highly specialized microvilli) & a single cilium. Receptor cells are either type I (with a large single nerve ending surrounding the cell base) or type II (with many nerve endings).

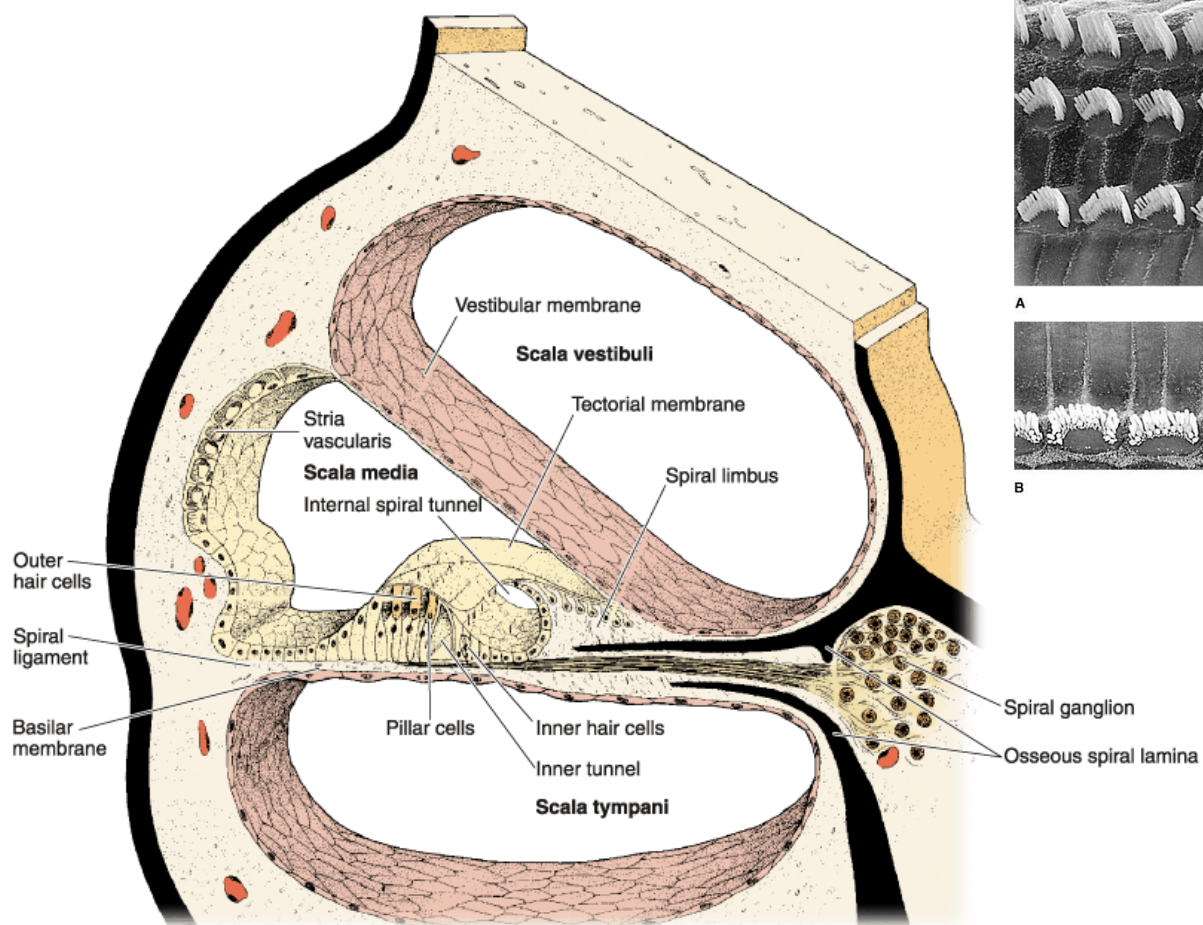
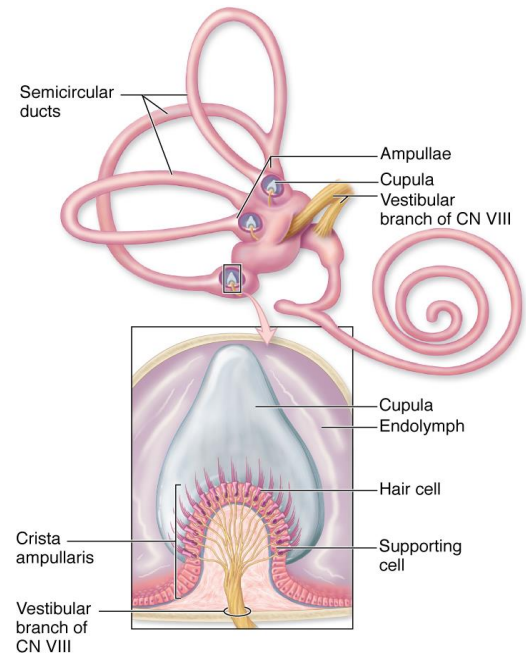


- Supportive cells: columnar cells with short microvilli. They may have a role in the secretion of the gelatinous layer.

Semicircular ducts: Each one of these 3 ducts has a dilated **ampulla** at one end, that contain the receptor area (the **crista ampullaris**). Crista ampullaris has the same structure of the macula, but the gelatinous layer is conical in shape (called the **cupula**) & has no otoliths. The cupula is so high that it touches the opposite wall of the ampulla.

Note: Afferent nerve fibers from the maculae & cristae ampullares converge forming the vestibular part of cranial nerve VIII.

Endolymphatic duct: Extending from the vestibule to the subdural space, this duct is lined with simple squamous epithelium that gradually changes into simple columnar near the endolymphatic sac.

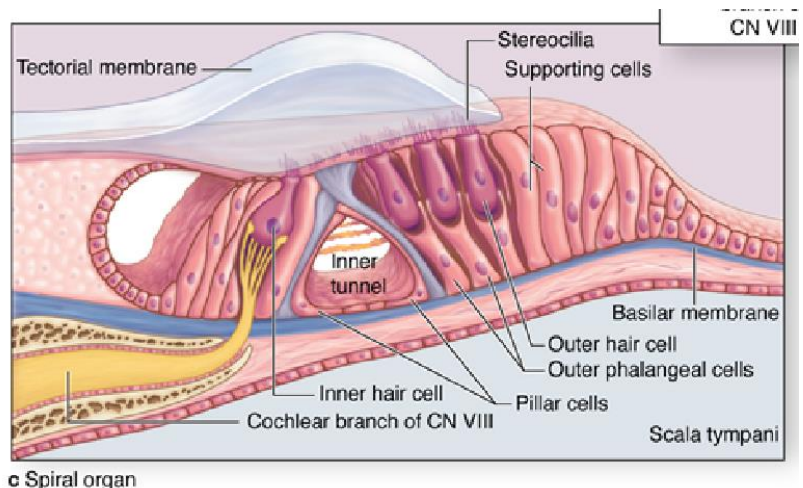


Cochlear duct: This blindly ended tube is the part concerned with sound reception. The duct extends from the base of bony cochlea to the tip, hanging between the spiral lamina & the peripheral wall of the cochlea. Thus, it divides the cochlea into 3 compartments:

scala vestibuli (above it), **scala tympani** (below it) & **scala media** which is the cochlear duct itself. Scala vestibuli is connected to the oval window, & scala tympani to the round window, they communicate at the tip of cochlea via the helicotrema.

The upper wall of cochlear duct is the thin **vestibular membrane** (a double layer of simple squamous epithelium). The lateral wall is thickened as the **stria vascularis**, while the lower wall is the thick **basilar membrane** extending from the osseous spiral lamina to the spiral ligament, carrying the specialized hearing area: the **organ of Corti**.

Organ of Corti: a complex structure resting on the basilar membrane. It consists of 2 masses: the **spiral limbus** (on the osseous spiral lamina) & the sensory epithelium laterally, separated by the **internal spiral tunnel**. The sensory epithelium includes:



1. **Hair cells:** these are the receptor cells connected at their base to nerve terminals of the sensory neurons in the spiral ganglion, & have apical **stereocilia**. Hair calls lie in 2 groups:

a- **Outer hair cells:** 3-5 rows of high cells with a W-shape arrangement of stereocilia.

The tips of the tallest stereocilia are embeded in the tectorial membrane (a gelatinous glycoprotein structure secreted by -& attached to-the cells of the spiral limbus).

b- **Inner hair cells:** a single row of shorter sensory cells with free stereocilia arranged as a line. These cells are separated from the outer cells by a triangular space (the **inner tunnel**) & have a greater afferent innervation than them.

2. **Supporting cells:** simple columnar cells that support hair cells. The pillar cells are supportive cells that limit the inner tunnel.

