Sense Organs

Chapter 16

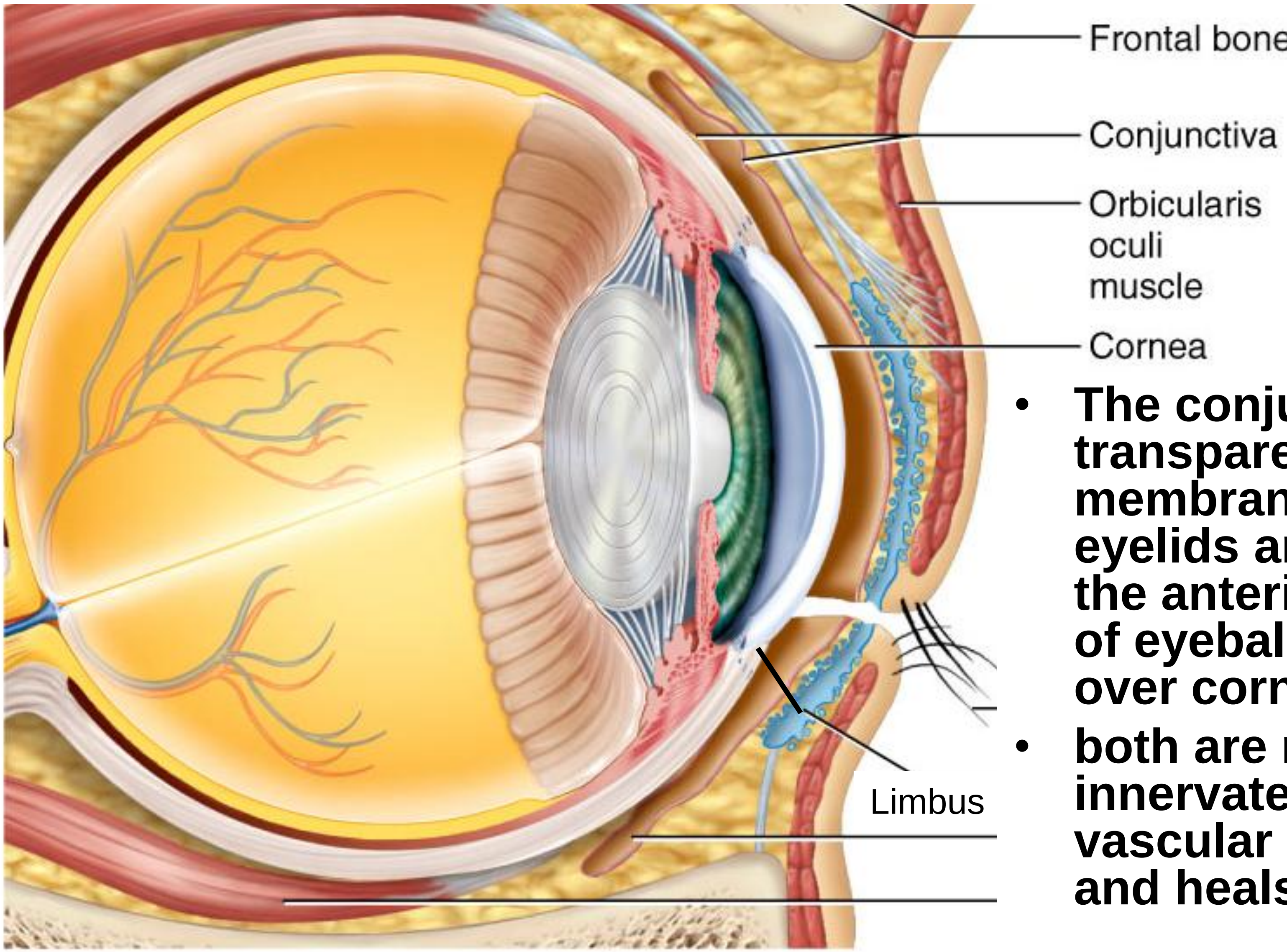
Eye

and

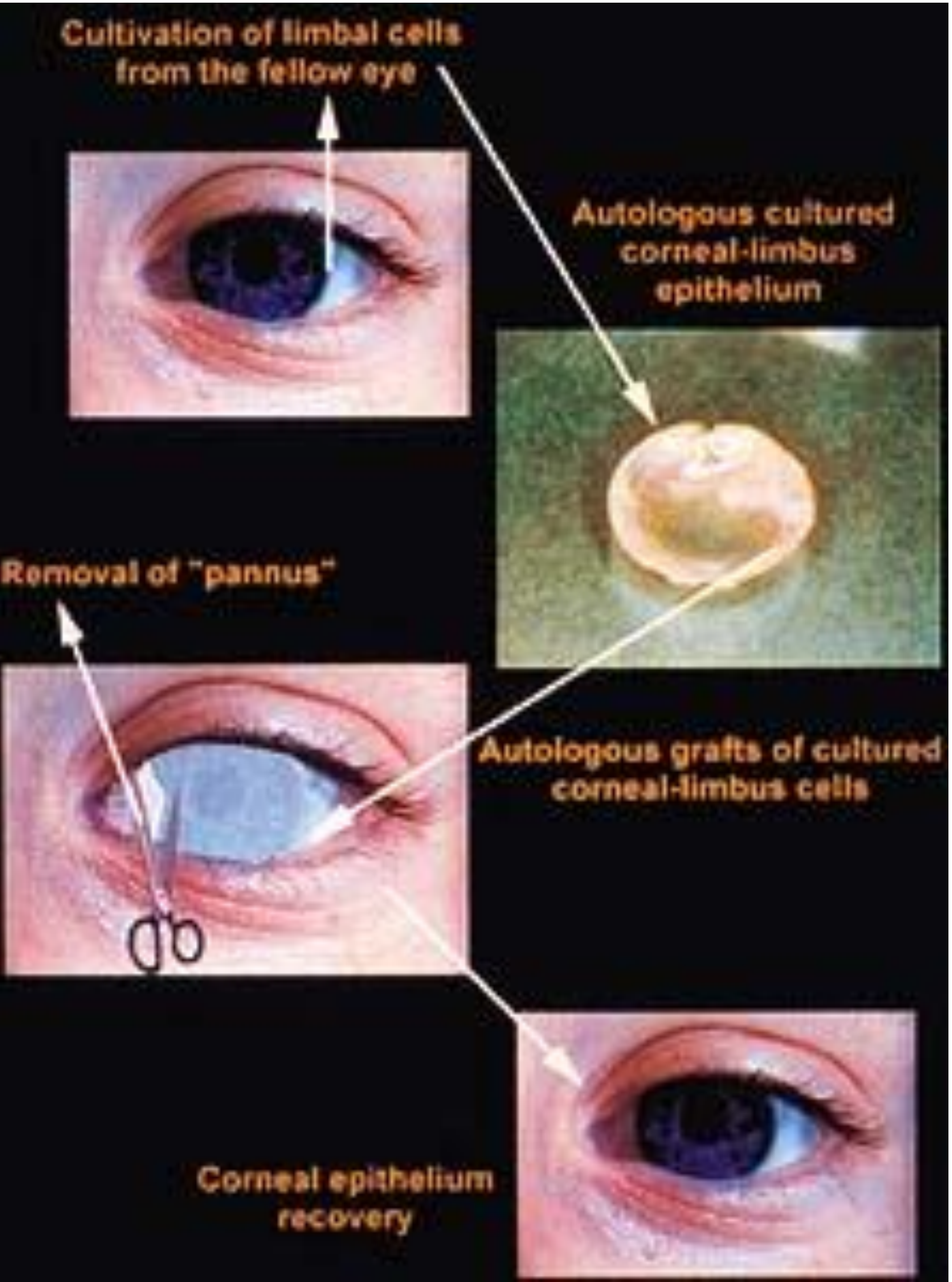
Ear

Cornea and Conjunctiva

Cornea is a strong, clear tissue continuous with the sclera that provides initial focus of light entering the eye.



- **The conjunctiva is a transparent mucous membrane that lines eyelids and covers the anterior surface of eyeball except over cornea.**
- **both are richly innervated and vascular (sensitive and heals quickly).**



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Limbal Stem-Cell Therapy and Long-Term Corneal Regeneration

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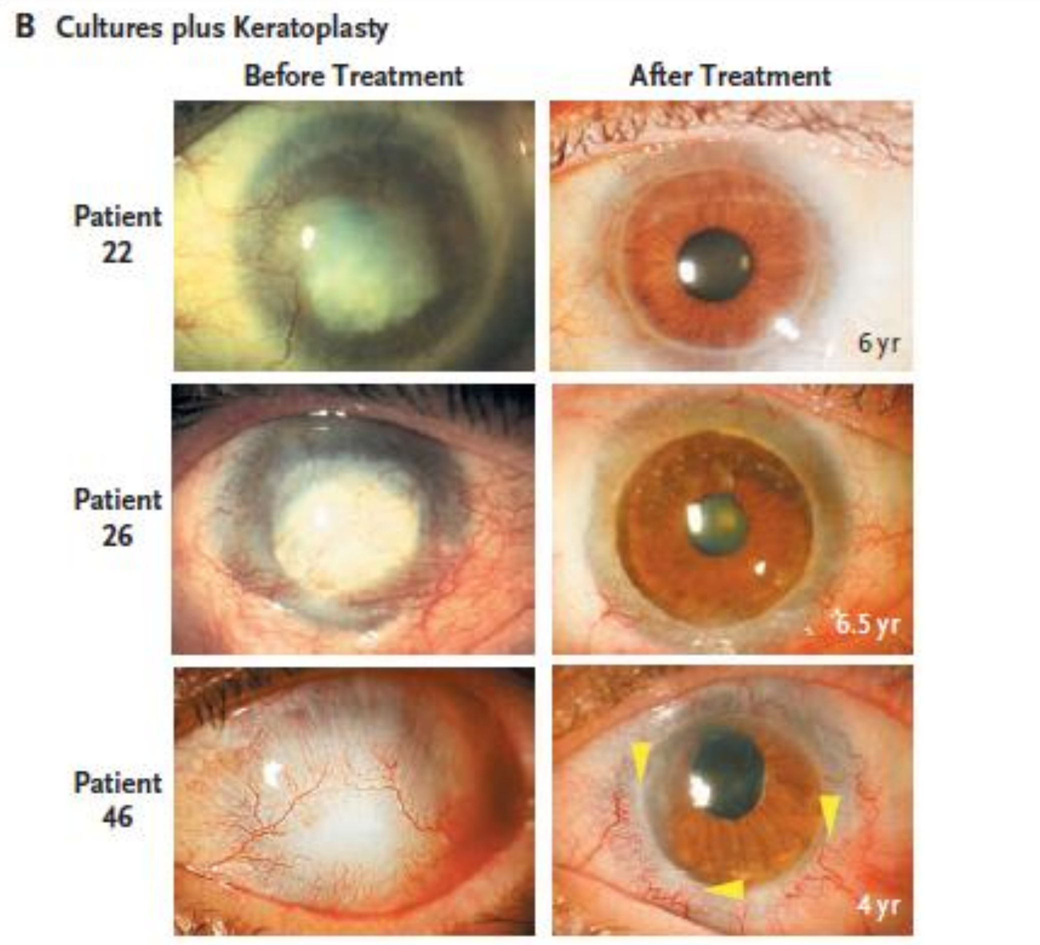


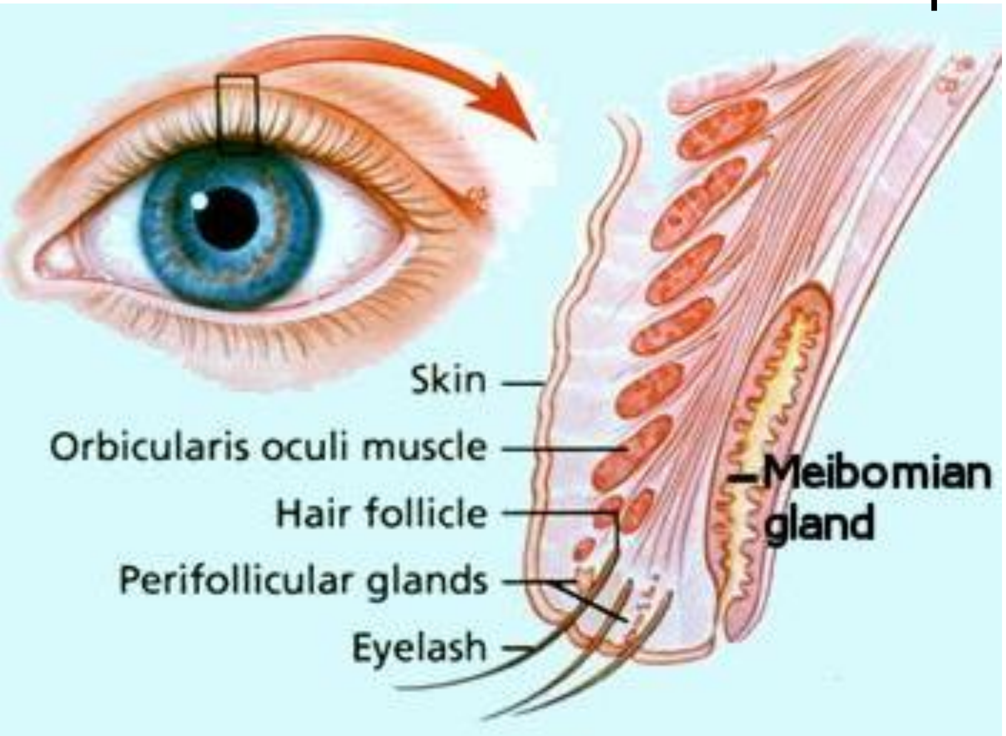
Figure 3. Regeneration of a Functional Corneal Epithelium and Restoration of Visual Acuity.

Figure 3. Regeneration of a Functional Corneal Epithelium and Restoration of Visual Acuity.

Panel A shows the left eye of Patient 93 (see Table 1 in the Supplementary Appendix, available with the full text of this article at NEJM.org), who had total limbal stem-cell deficiency due to an acid burn (image at left). His visual acuity was reduced to counting fingers. A graft of autologous limbal cultures was sufficient to regenerate functional corneal epithelium (image at right) and to restore normal vision (visual acuity, 0.7), since the eye had no stromal scarring. Panel B shows the eyes of Patients 22, 26, and 46 (see Table 1 in the Supplementary Appendix), which were damaged by alkali burns and were treated with unsuccessful surgery 13, 30, and 3 years before admission, respectively. All three eyes had total limbal stem-cell deficiency, complete corneal opacification, and stromal scarring (images at left). Vision was reduced to counting fingers (in Patient 22) or perceiving hand movements (in Patients 26 and 46). In all three patients, autologous limbal stem-cell cultures successfully regenerated functional corneal epithelium. To improve their visual acuity after grafting, the patients underwent penetrating keratoplasty. In all three eyes, the engrafted limbal stem cells resurfaced the donor stroma. At the last follow-up visits (at 6, 6.5, and 4 years, respectively), all eyes were covered by stable corneal epithelium (images at right). The keratoplasty resulted in complete restoration of visual acuity in Patients 22 and 46 (0.9 and 0.8, respectively). The visual acuity of Patient 26 increased to only 0.3 because of a concomitant amblyopia (the alkali burn had occurred 30 years before admission). In Patient 46, the follow-up image shows that the conjunctival vessels stop at the conjunctival–corneal boundary (arrowheads); they do not invade the restored corneal surface.

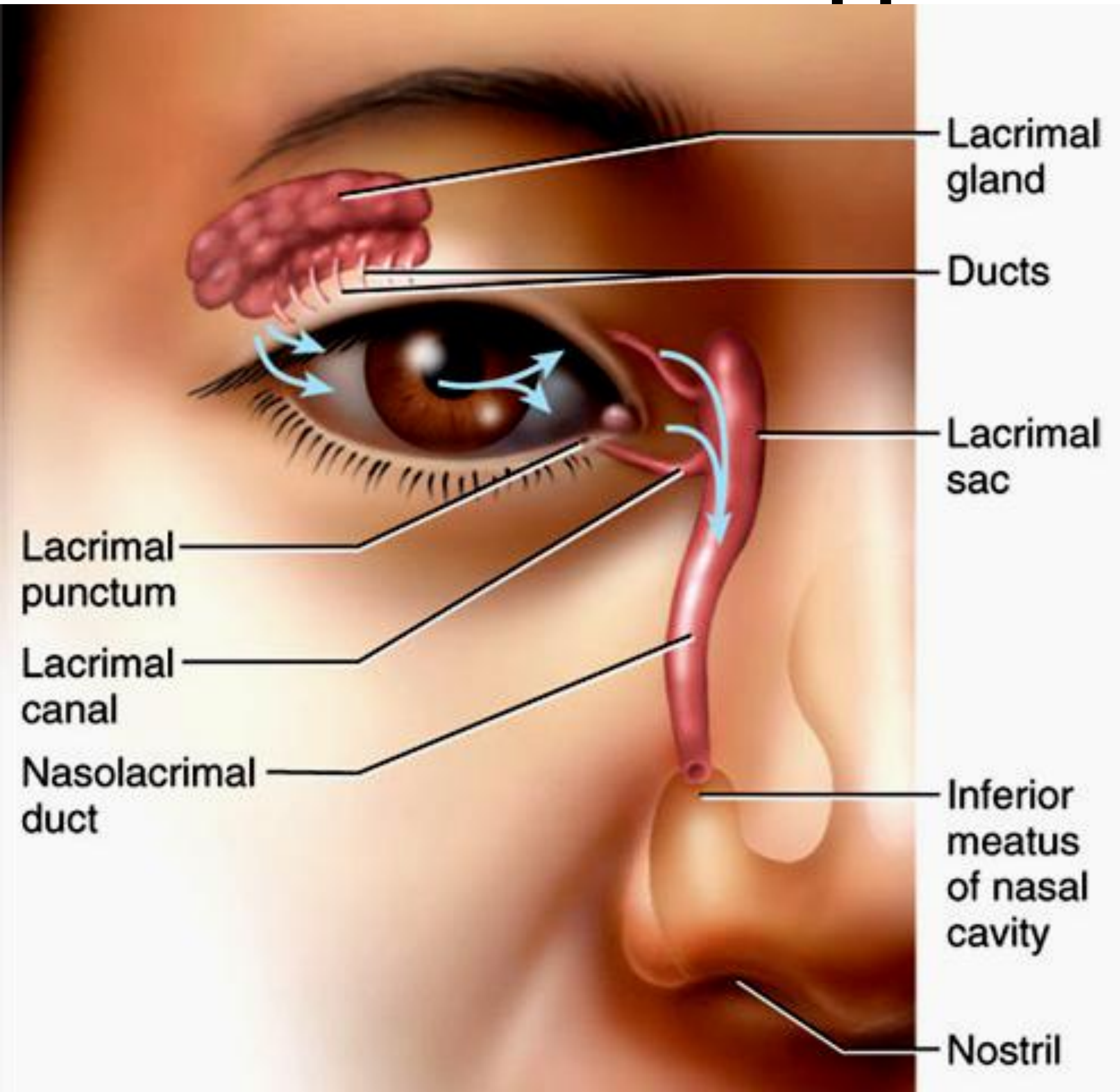
Meibomian Glands

The 25-30 tiny Meibomian glands are located between eye lashes and release oil that reduces evaporation of tears.



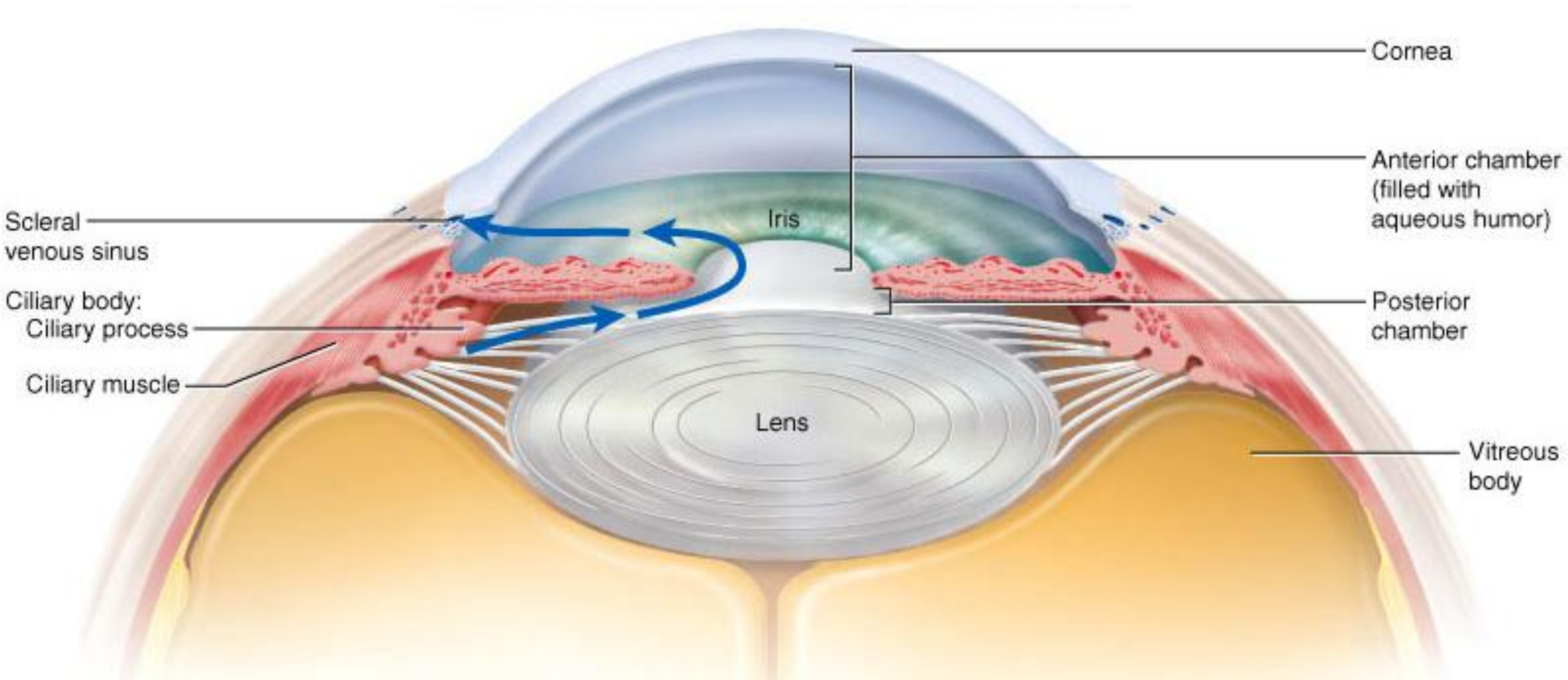
A sty (sometimes spelled stye) is a tender, painful red bump located at the base of an eyelash or on, inside, or under the eyelid. A sty results from an acute infection of Meibomian glands that can occur if these glands have become clogged. A sty also may arise from an infected hair follicle at the base of an eyelash. The bacterium *Staphylococcus aureus* is responsible for 90-95% of cases of styes.

Lacrimal Apparatus



Tears flow across eyeball to wash away foreign particles, help with diffusion of O_2 and CO_2, and to inhibit bacteria with enzymes.

Eye Chambers and the Aqueous Humor

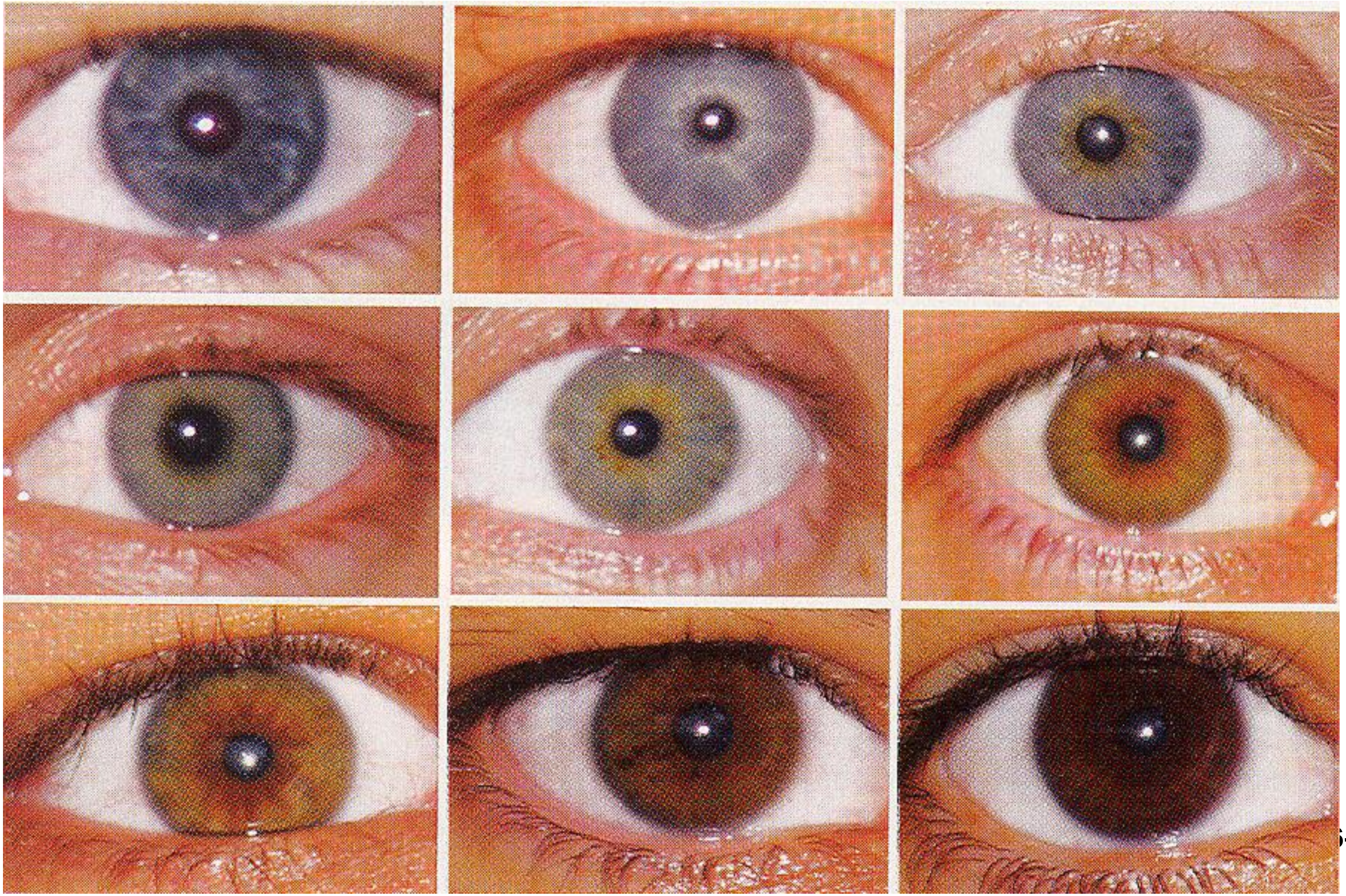


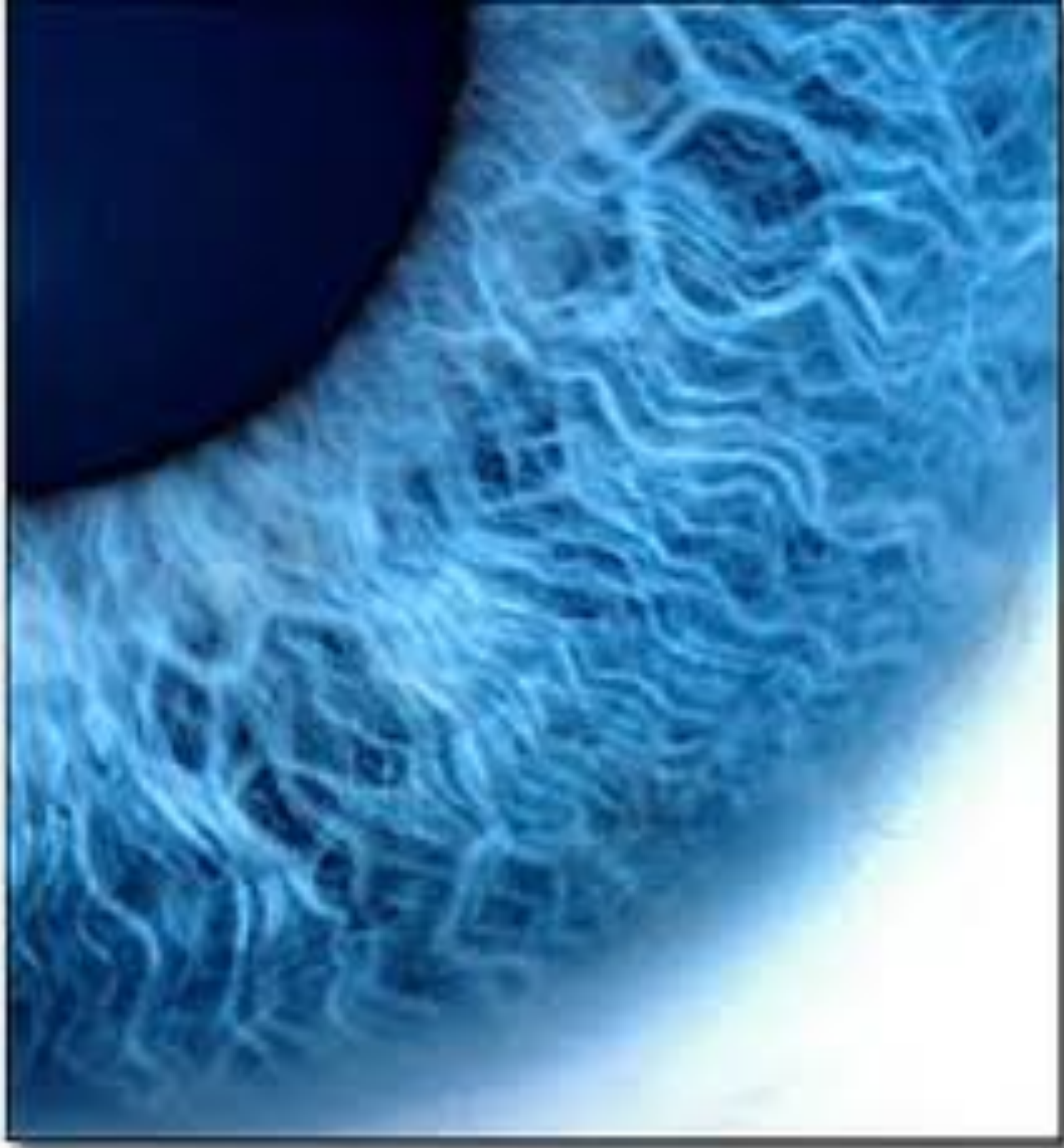
- **Aqueous Humor is produced by the ciliary body in the posterior chamber and flows from posterior chamber through pupil into the anterior chamber where it is reabsorbed through the canal of Schlemm (scleral venous sinus) and then back into the venous circulation.**

Glaucoma

- Glaucoma is a painless condition of elevated pressure within the eye.
- It may be caused by an obstruction of the canal of Schlemm (scleral venous sinus) or an overproduction of aqueous humor.
- Glaucoma may result in death of retinal cells due to elevated pressure on delicate retinal capillaries.
- Symptoms may include loss of peripheral vision, colored halos and dimness of vision.

Iris color results from the amount of melanin covering the ordered collagen fibers of the iris. Collagen fibers not covered with melanin reflect blue light.





16-12

Pupillary Responses

- Iris regulates the amount of light that passes through the pupil by dilating or constricting.
- Pupillary Constrictor - smooth muscle encircling the pupil reduces the size of the pupil in response to:
  - increase light intensity
  - parasympathetic stimulation
- Pupillary Dilator - spokelike myoepithelial cells widen the pupil in response to:
  - decreased light
  - sympathetic stimulation
- Photopupillary reflex: both pupils should constrict even if only one eye is illuminated.

Optical Components of the Eye

Structures that help focus light on the retina:

- **Cornea provides initial focusing of light rays**
- **Lens Accommodation = changes in lens shape to help focus light**
    - **Near Vision: When the ciliary muscle contracts, it pulls in on the sclera and reduces the diameter of the muscular ring around the lens. The suspensory ligaments do not put tension on the lens, and the lens takes a rounded, convex shape.**
    - **Far Vision: When the ciliary muscle relaxes, the elasticity of the sclera pulls on the ciliary body, increasing the diameter of the muscular ring around the lens. The lens flattens due to the pull of the suspensory ligaments.**
    - **Ageing of the lens reduces its elasticity and ability to take the rounded shape needed for near vision.**
    - **Cataract - clouding of lens and be caused by aging, diabetes, smoking, UV light**

Accommodation of Lens

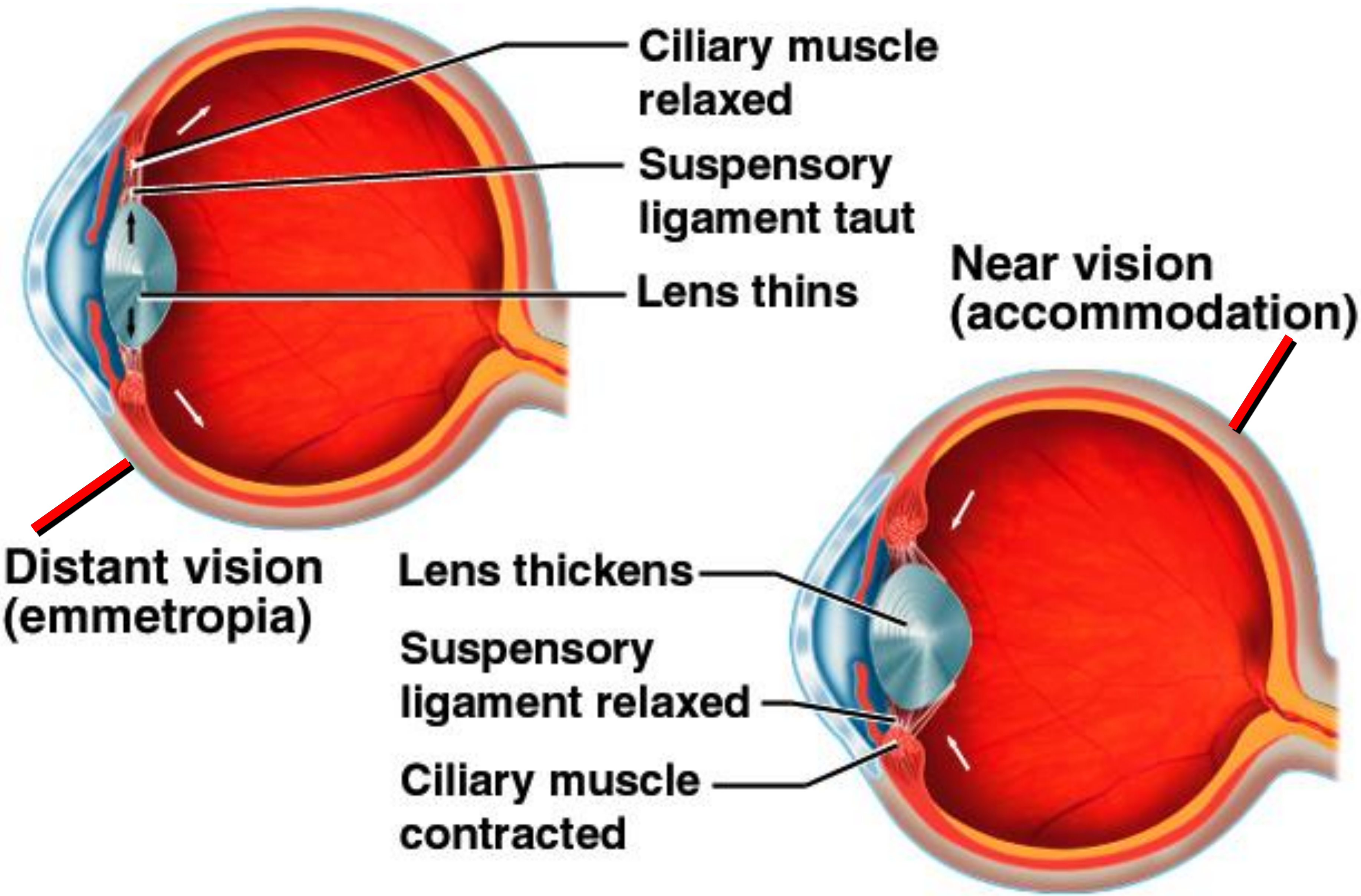
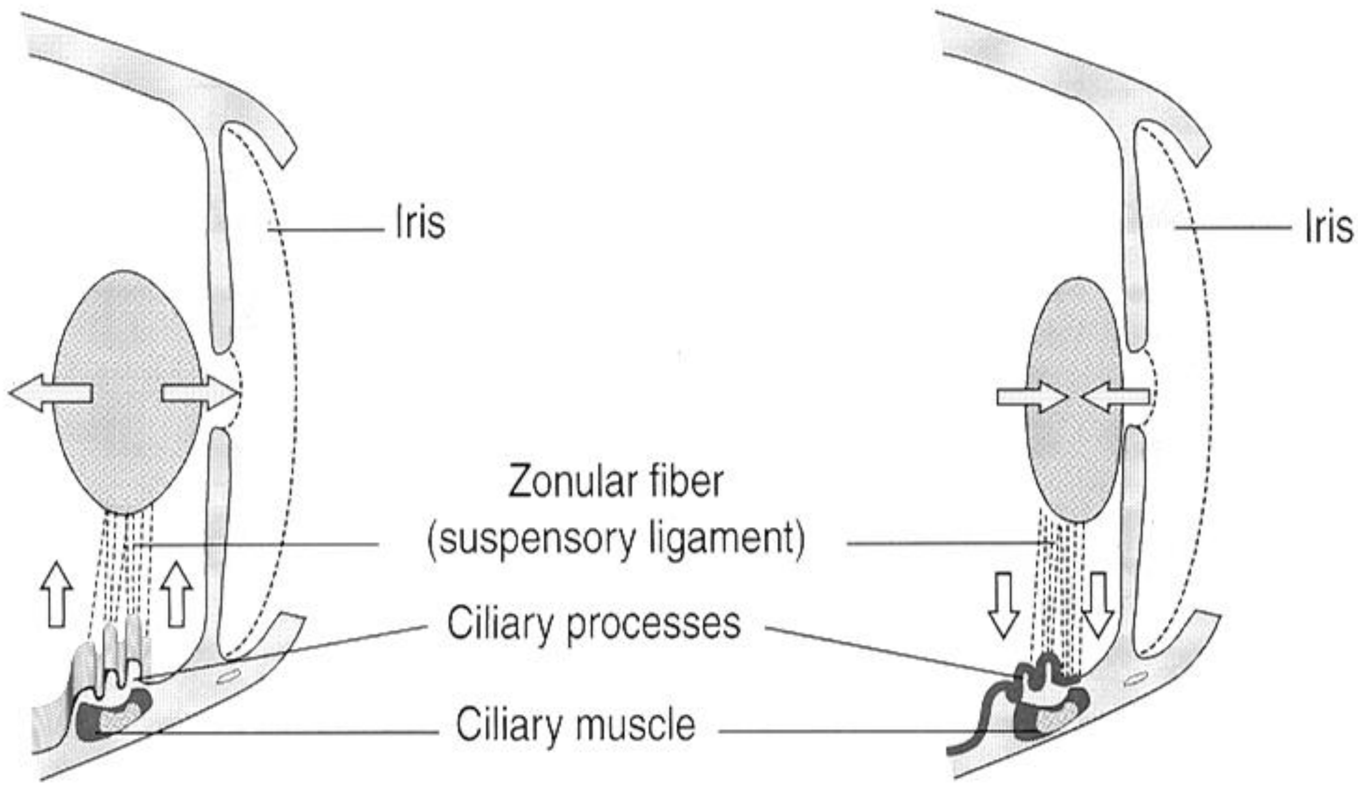


Figure 9-12. **Accommodation**



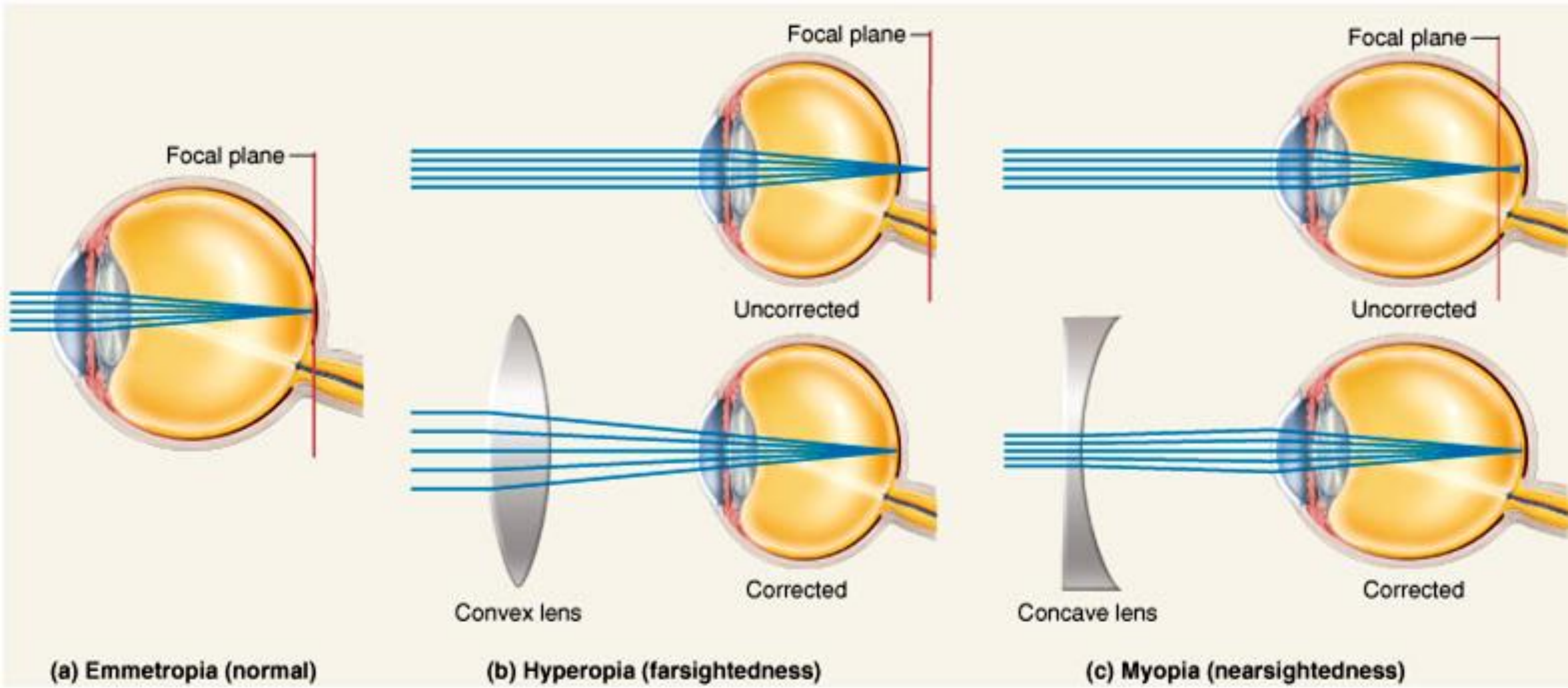
For close vision

1. The ciliary muscle contracts.
2. The ciliary body with inserted zonula fibers moves closer to the lens.
3. The tension is reduced and the lens rounds up.

For distant vision

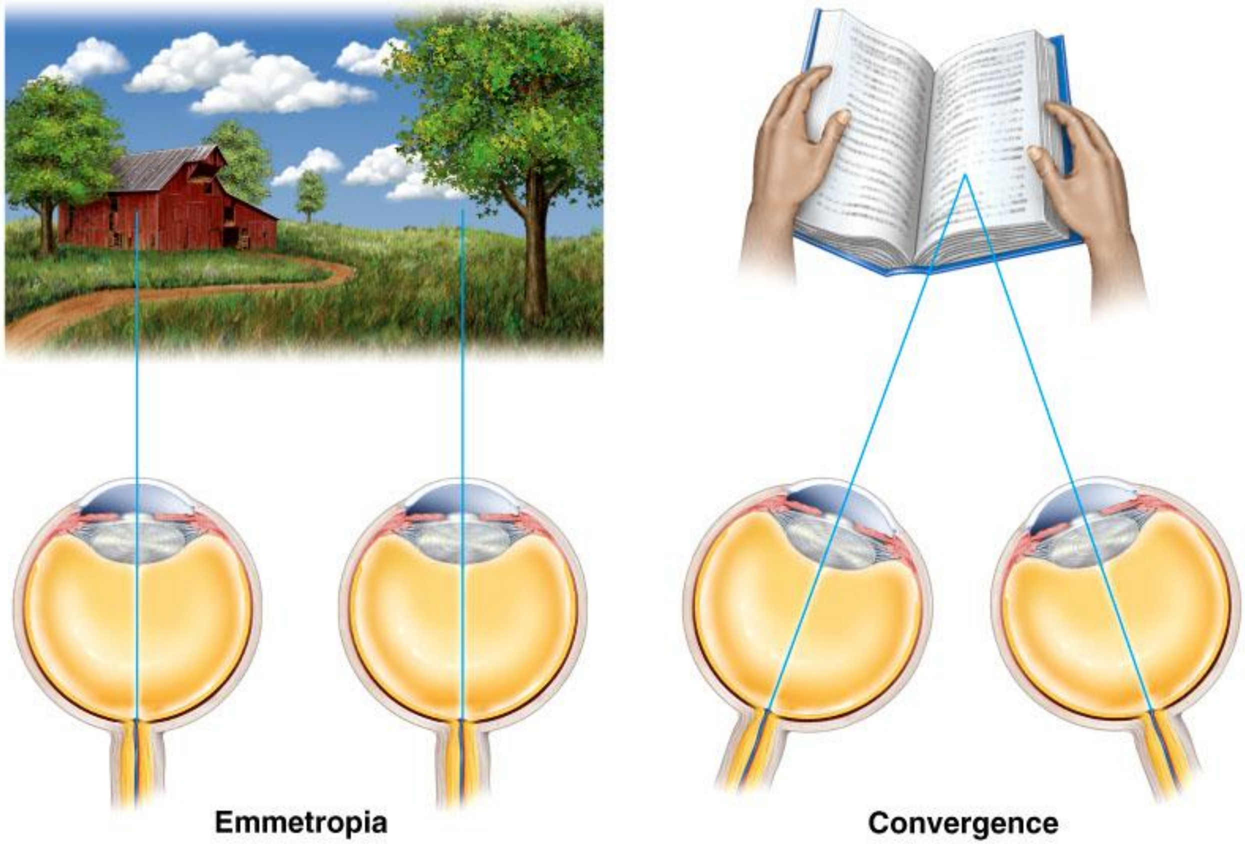
1. The ciliary muscle is relaxed.
2. The ciliary body with inserted zonula fibers moves away from the lens.
3. The tension of the zonula fibers increases and the lens flattens.

Effects of Corrected Lenses



- **Hyperopia - farsighted (eyeball too short)**
  - **correct with convex lenses**
- **Myopia - nearsighted (eyeball too long)**
  - **correct with concave lenses**

Emmetropia and Near Response



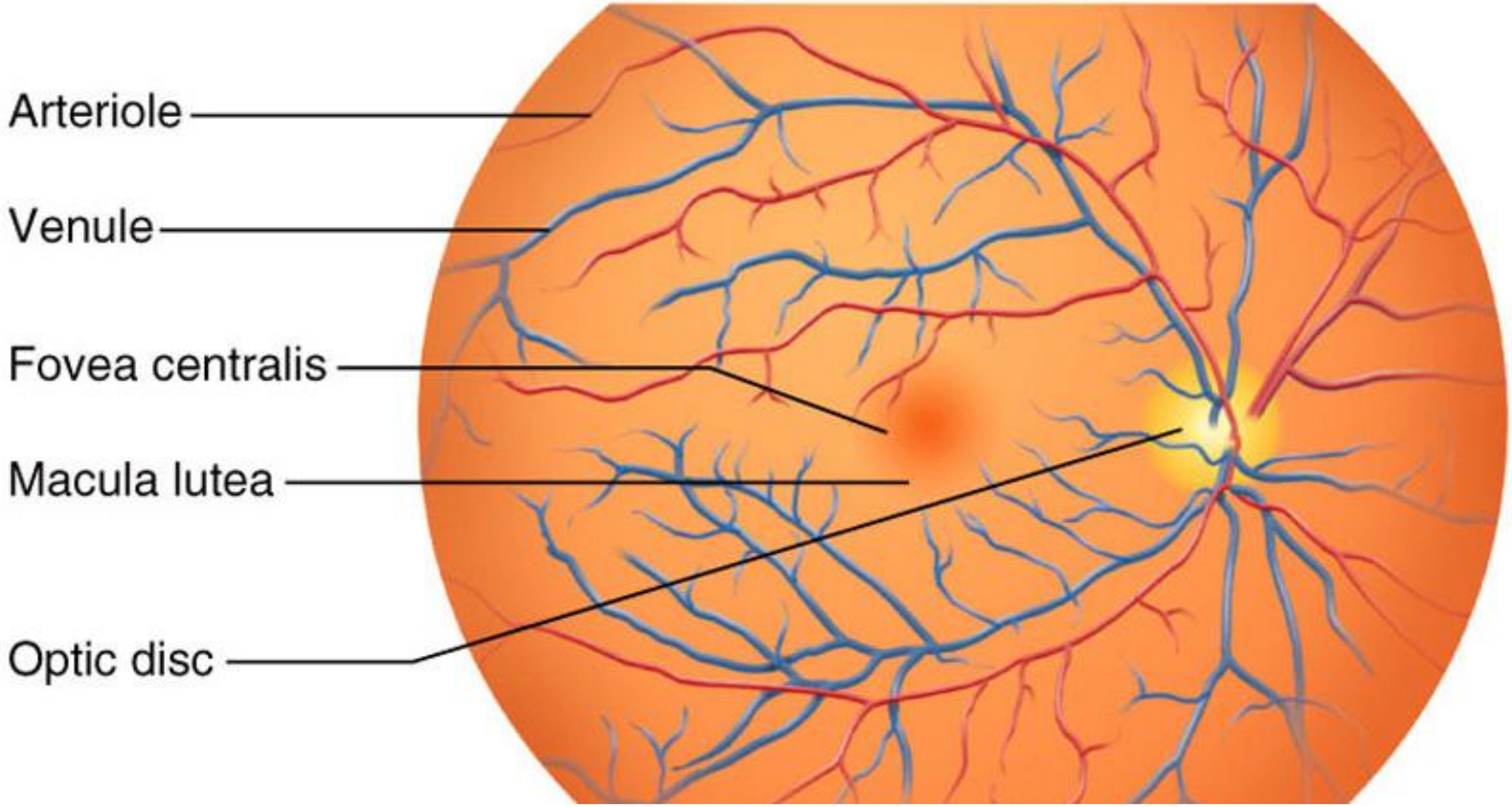
(a)

Distant object **Close object**

Retina and Optic Nerve

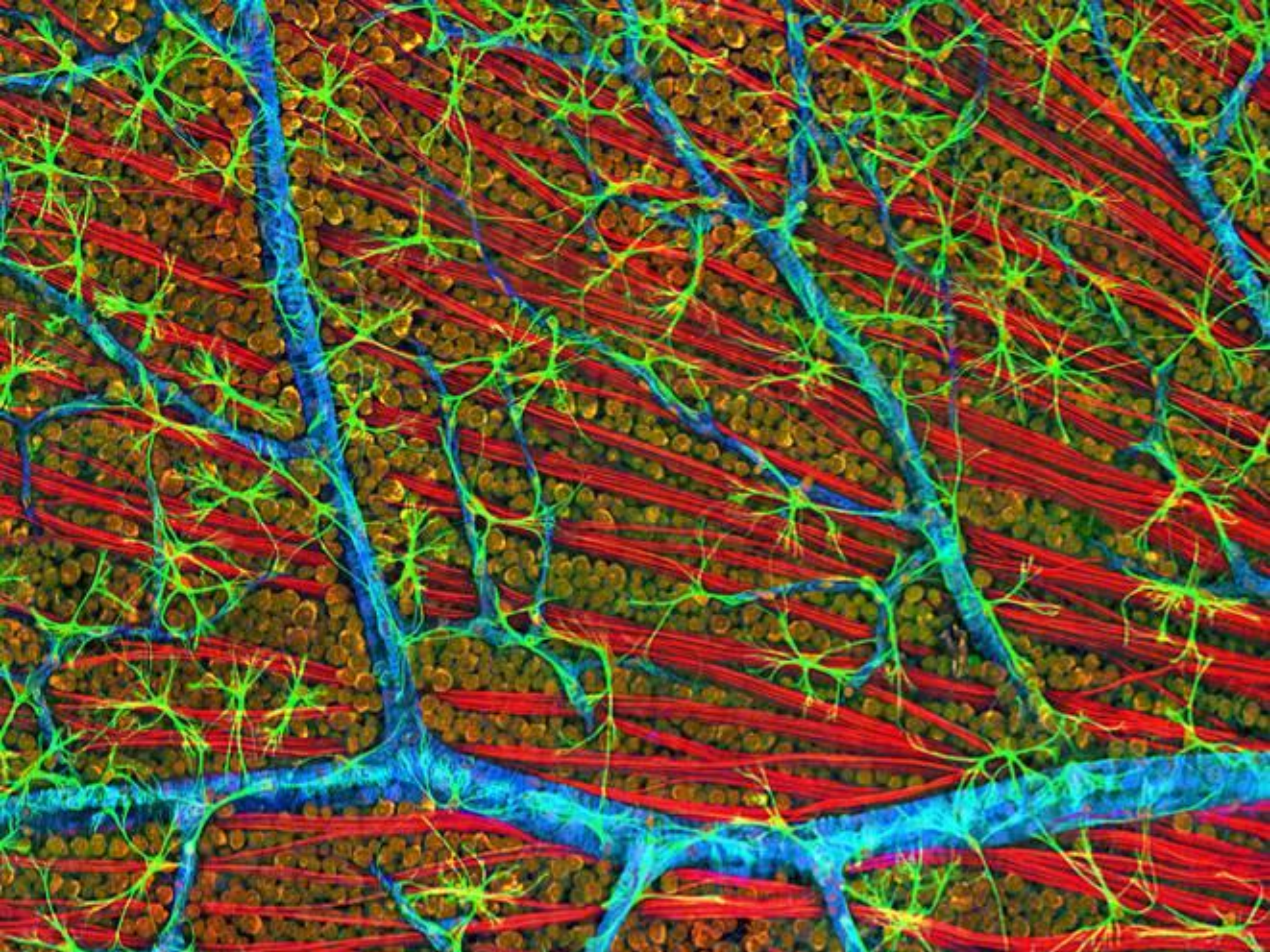
- **Retina**
  - forms as an outgrowth of the brain and is composed of photoreceptors (rods and cones) and other interneurons
  - attached at optic disc and at ora serrata
  - pressed against choroid by the vitreous body
- **Detached Retina**
  - can be caused by a blow to head or a lack of vitreous humor
  - symptoms include blurry areas in field of vision
  - disruption of blood supply leads to blindness
- **Optic Nerve and Optic Disk**
  - Optic disk is formed by the meeting of all of the axons of retinal cells that are leaving the eye and forming the optic nerve to the brain. Because the optic disk has no photoreceptor cells, it forms a blind spot in the visual field.

Drawing of an Ophthalmoscopic View of the Retina

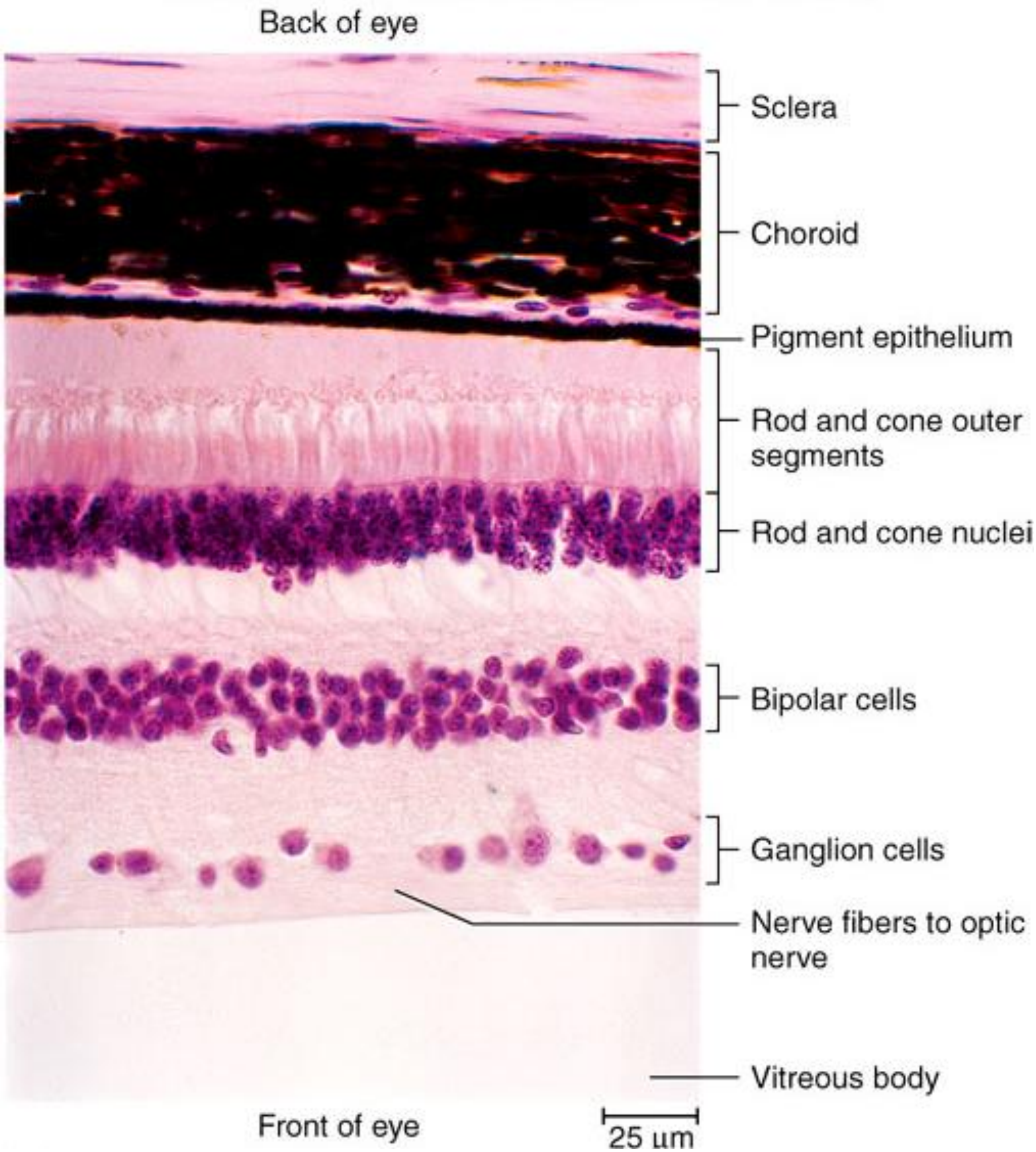


- **Macula Lutea is a 3mm diameter cluster of cells at the focal point of the lens**
- **Fovea Centralis is the center of macula and has the highest density of photoreceptor cells (all cones) in the retina which give finely detailed color images**

Ophthalmoscopic View of the Retina



Histology of the Sclera, Choroid and Retina



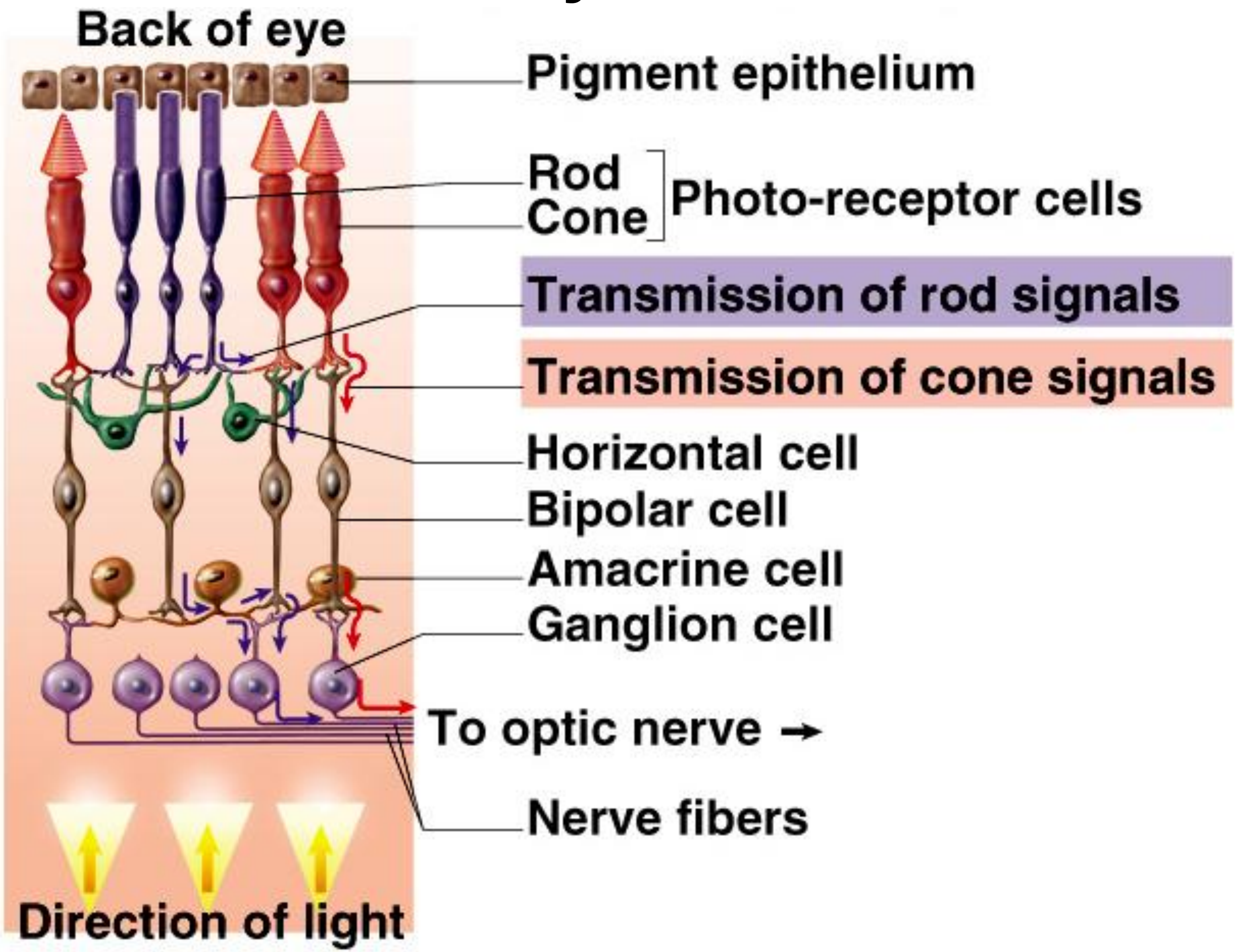
Sclera is composed of densely woven collagen fibers.

Choroid and Pigment Epithelium contain melanin that absorbs the light not used by the retina.

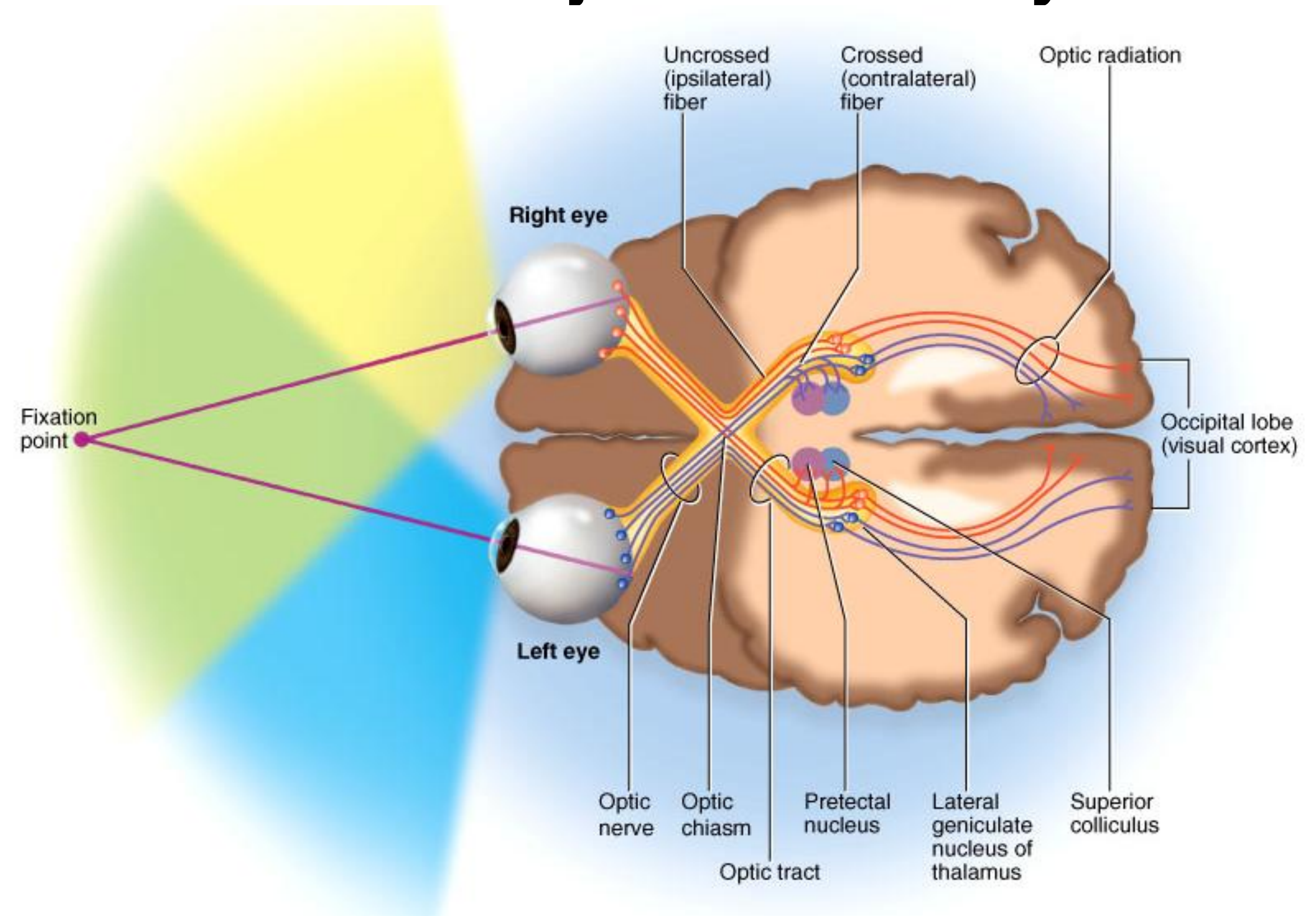
Retina is composed of photoreceptor cells (rods and cones) and other neurons.

Note direction of light penetration.

Schematic Layers of the Retina



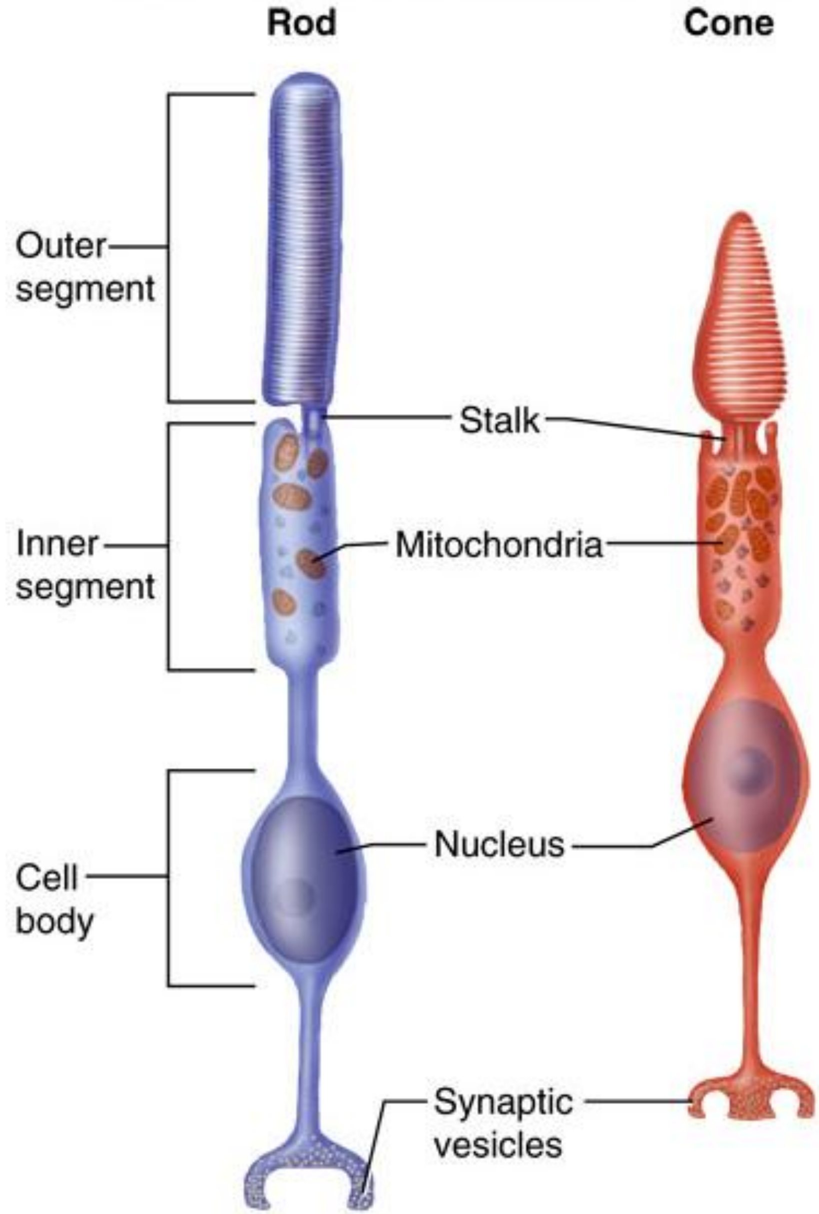
Visual Projection Pathway



Photoreceptor Cells of the Retina

Photoreceptors

- Rod Cells are effective in low light and peripheral vision.
- Cone Cells are sensitive to either red, blue or green wavelengths and are most effective in bright light.
- Outer Segments have coin-like stacks of membranous discs that contain the visual pigments.

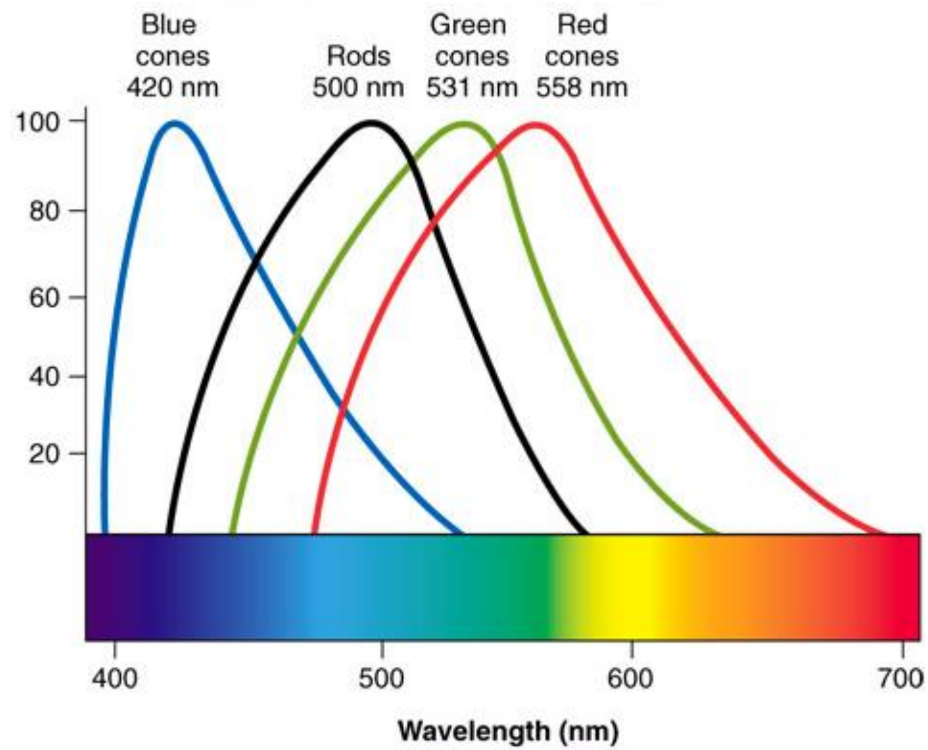


Color Vision

3 types of Cones have 3 different photopigments with 3 distinct absorption peaks:

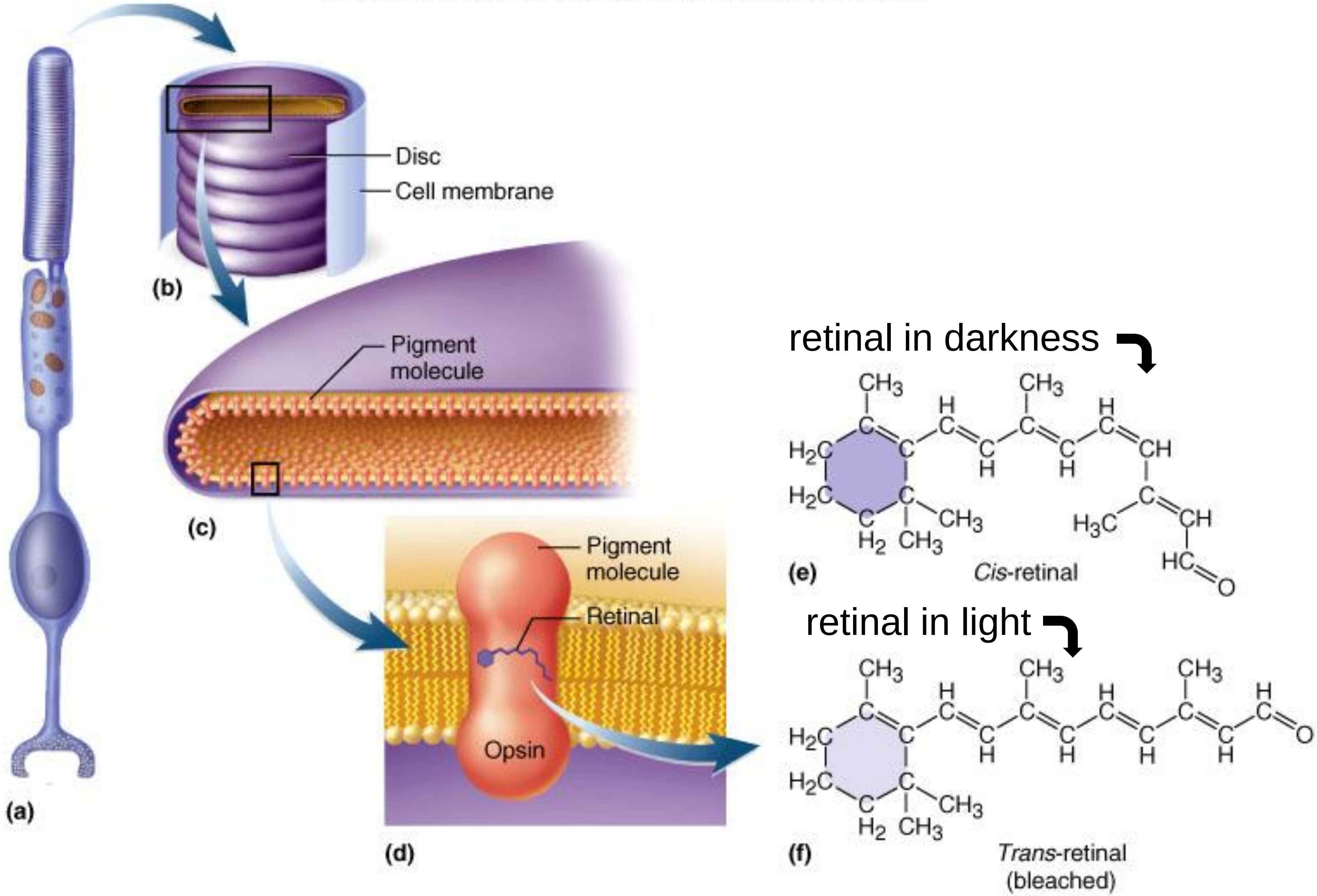
- red
- green
- blue

- Color perception is based on a complex mixture of signals from the three types of cones



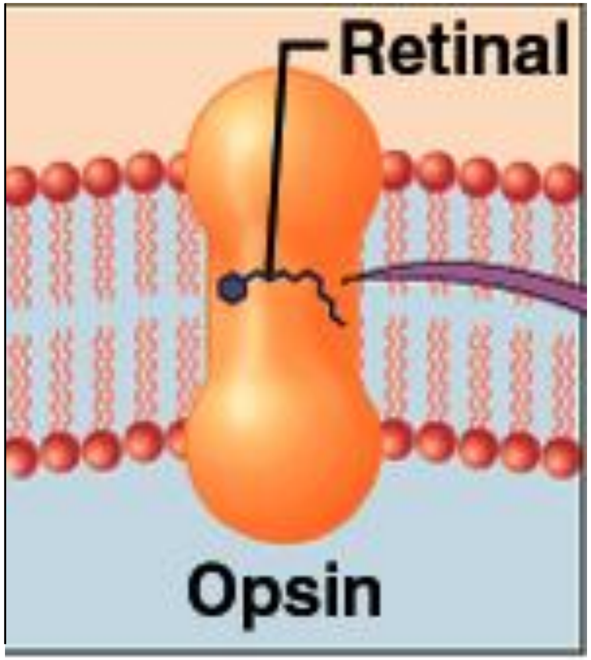
Wavelength (nm)	Percent of maximum cone response (red:green:blue)	Perceived hue
400	0 : 0 : 50	Violet
450	0 : 30 : 72	Blue
500	60 : 82 : 20	Blue-green
550	97 : 85 : 0	Green
625	35 : 3 : 0	Orange
675	5 : 0 : 0	Red

Location of Visual Pigments



Visual Pigments

- Visual pigment of the rod cells is called rhodopsin (visual purple)
- 2 major parts to rhodopsin:
  1) protein called opsin
  2) vitamin A derivative called retinal
- Rod cells contain single kind of rhodopsin with an absorption peak at wavelength of 500 nm

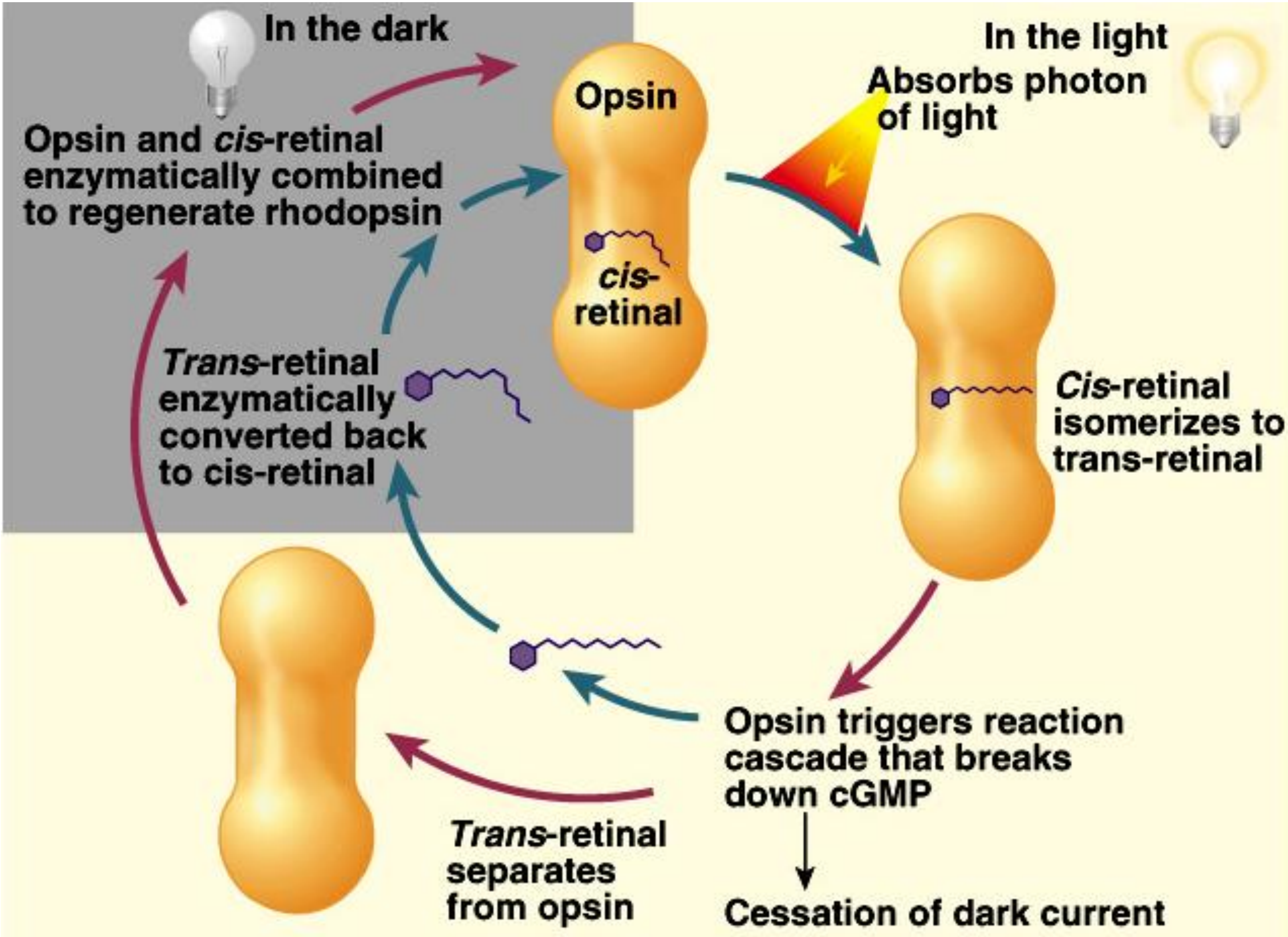


- Cones contain photopsin
  - the opsin part of photopsin contains different amino acids that determine which wavelengths of light are absorbed
  - 3 kinds of cones absorbing different wavelengths of light produce color vision

The Photochemical Reaction in Rod Cells

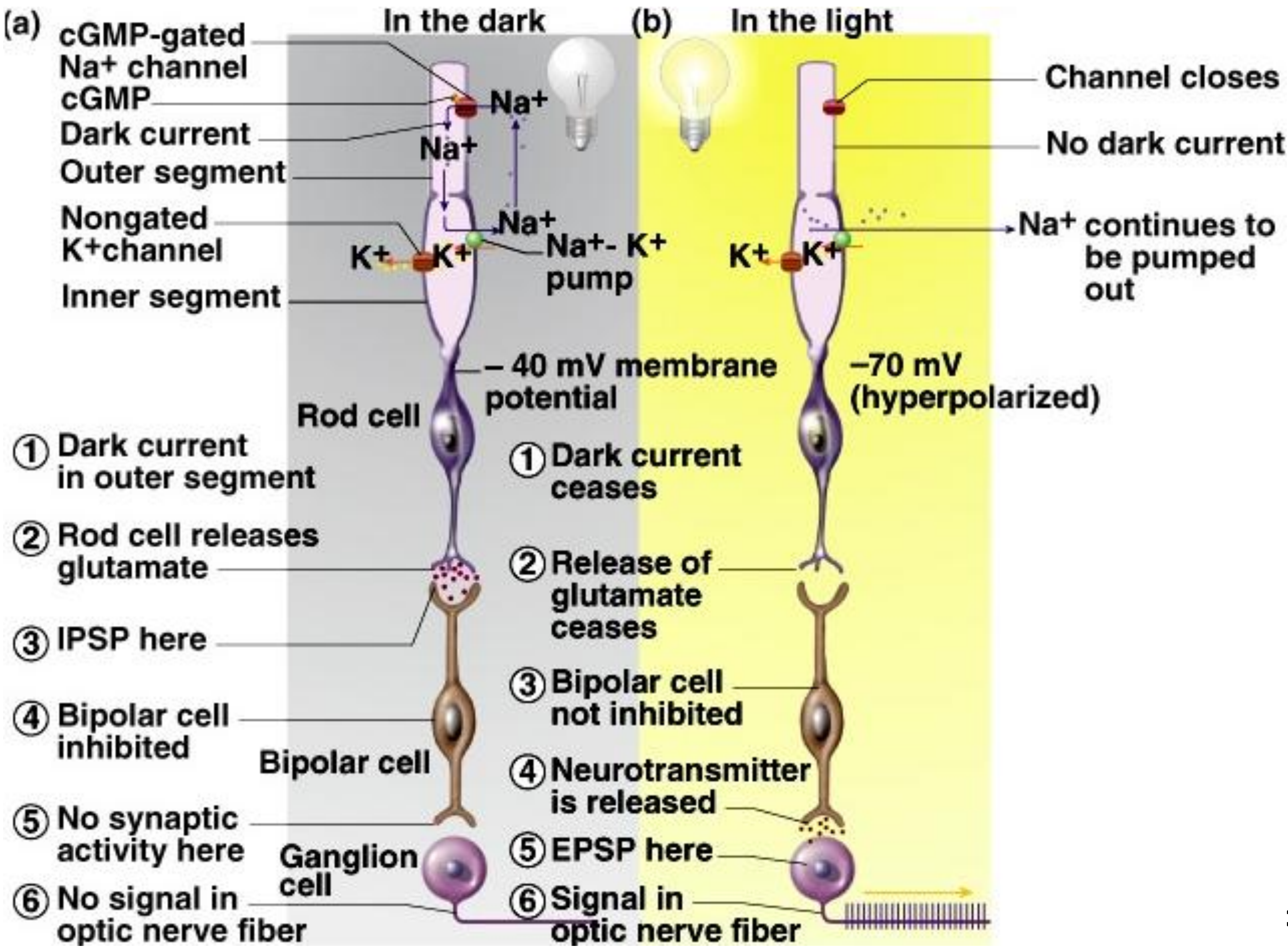
- When rhodopsin absorbs light, the bent cis-retinal is converted into straight trans-retinal
- Trans retinal dissociates from the opsin (bleaching)
- Opsin starts a reaction that breaks down cGMP
- Without cGMP, Na^+ channels close, stopping the “dark current”
- Rods hyperpolarize and stop releasing the inhibitory neurotransmitter, glutamate, onto bipolar cells
- Uninhibited bipolar cells stimulate ganglion cells that send signals through optic nerve to brain.
- Takes 5 minutes to regenerate 50% of bleached rhodopsin as trans-retinal is converted to cis-form and reunited with opsin

The Photochemical Reaction in Rod Cells



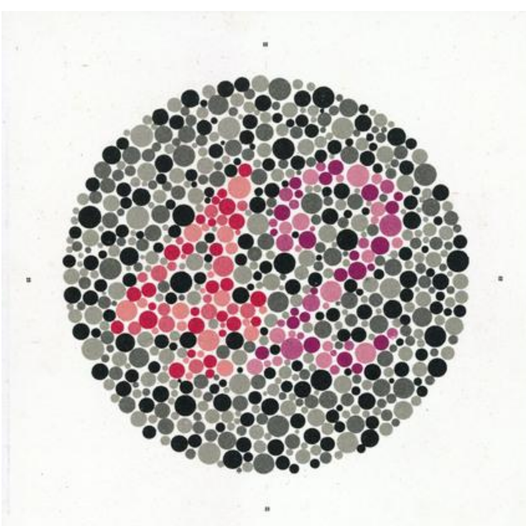
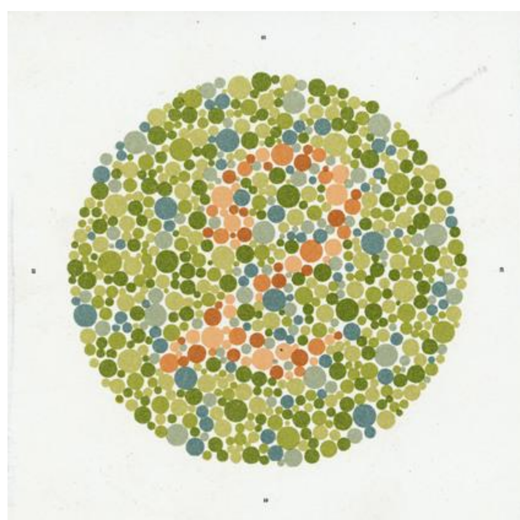
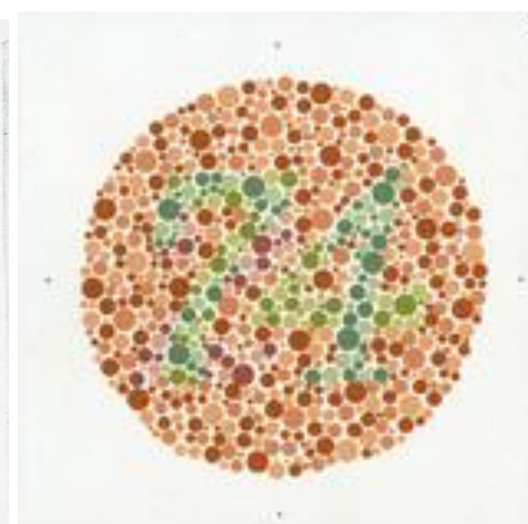
Generating the Visual Signal

- **In darkness, a steady flow of Na^+ into rods depolarizes the rods which causes them to release the inhibitory neurotransmitter glutamate onto bipolar cells resulting in no signal in optic nerve.**
- **cGMP-gated Na^+ channels open when bound to c-GMP.**
  - **cGMP is abundant in rods in the dark**
  - **Na+ inflow depolarizes the rods**
  - **depolarized rods release inhibitory glutamate**
- **When a rod absorbs light, the dark current ceases and uninhibited bipolar cells stimulate ganglion cells that send signals to the optic nerve and brain.**
  - **dark current ceases because photons trigger the separation of retinal from opsin, and the opsin begins a reaction cascade that breaks down cGMP.**


(a)
In the dark
(b)
In the light
cGMP-gated
Na+ channel
cGMP
Dark current
Outer segment
Nongated
K+channel
Inner segment
Na+
Na+
Na+
K+
K+
Na+- K+
pump
– 40 mV membrane
potential
Rod cell
① Dark current
in outer segment
② Rod cell releases
glutamate
③ IPSP here
④ Bipolar cell
inhibited
Bipolar cell
⑤ No synaptic
activity here
Ganglion
cell
⑥ No signal in
optic nerve fiber
Channel closes
No dark current
Na+ continues to
be pumped
out
K+
K+
–70 mV
(hyperpolarized)
① Dark current
ceases
② Release of
glutamate
ceases
③ Bipolar cell
not inhibited
④ Neurotransmitter
is released
⑤ EPSP here
⑥ Signal in
optic nerve fiber

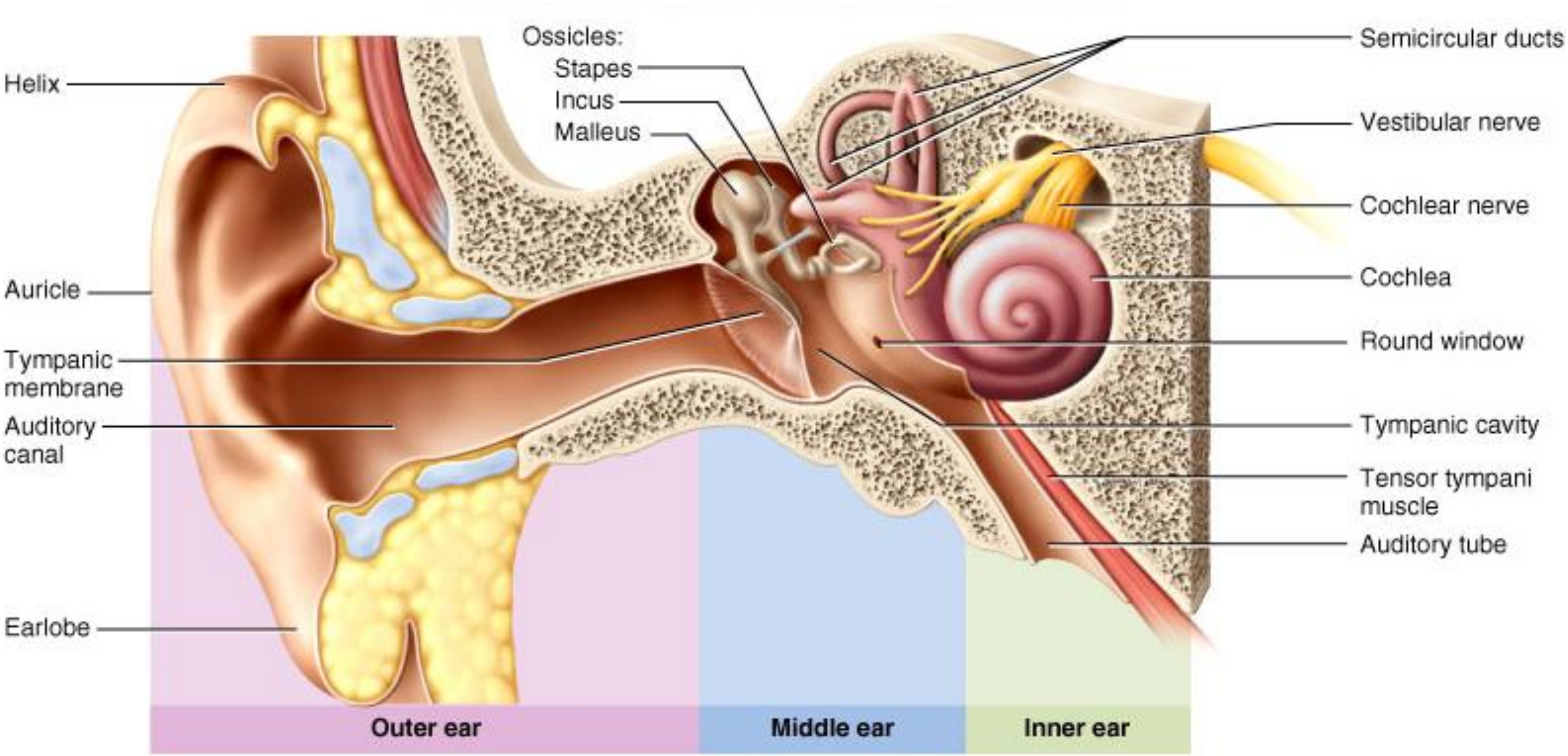
Color Blindness

- Hereditary lack of one photopigment
  - red-green color blindness is the most common form of color blindness which results in a lack of either red or green cones.
    - Affected individuals can not distinguish red from green
    - Color blindness is a sex-linked recessive trait that is observed in about 8% of males

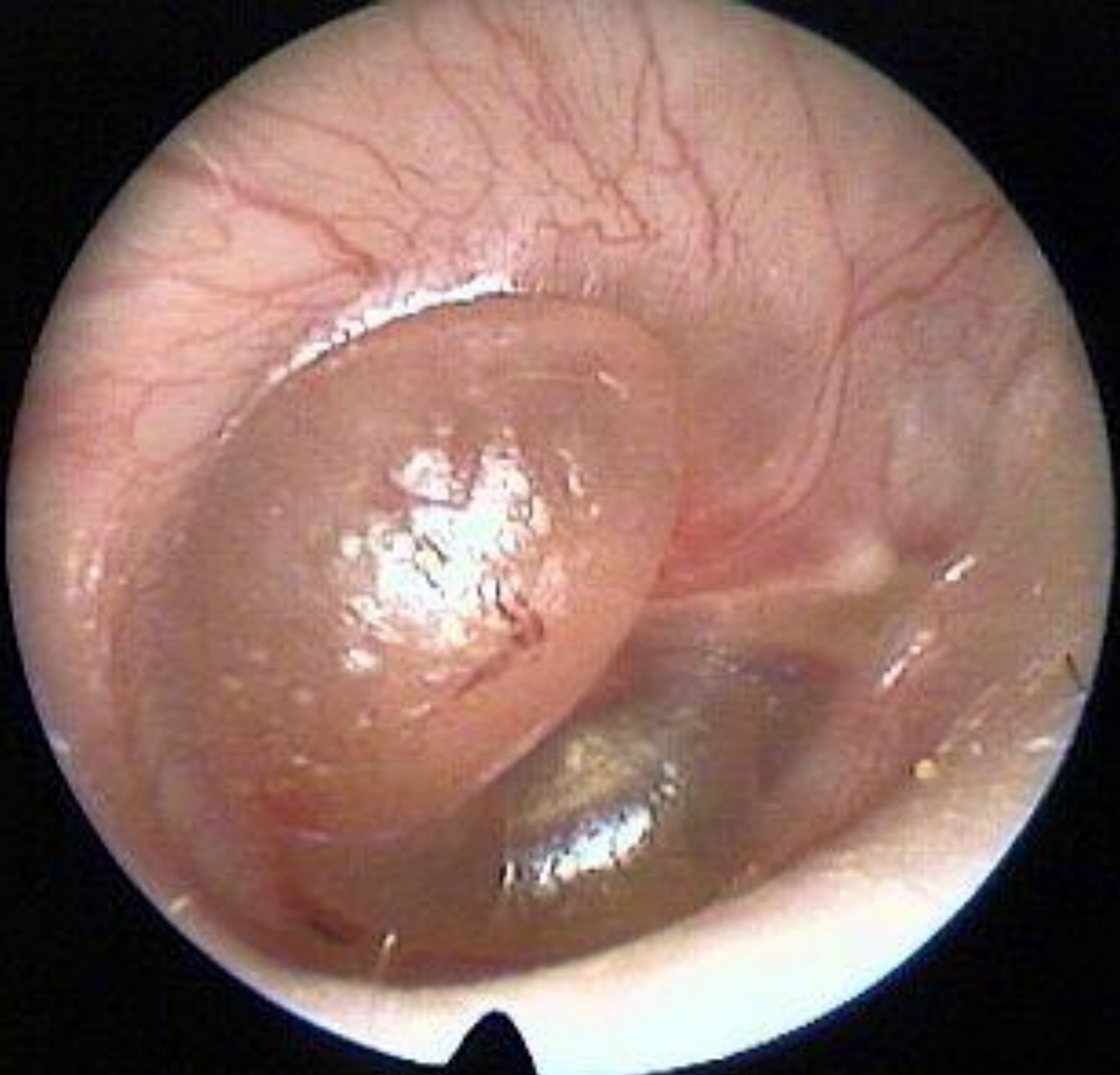
The Ear

Sound is the audible vibration of air molecules created as a vibrating object pushes air molecules. The vibrating object could be the string of a guitar, a tire spinning on asphalt, the vocal cords of a bird…



The normal Tympanic Membrane is shiny, translucent and pearlescent pink/grey. A “cone of light” should be prominent at 7 o'clock in the left ear and 5 o'clock in the right. Dilated blood vessels such as those shown do not necessarily indicate *Otits Media*. This vascular dilation often occurs following crying, coughing or a even a hard sneeze.


Normal Tympanum as viewed with a pneumatic otoscope
http://rnceus.com/otitis/otidx.htm



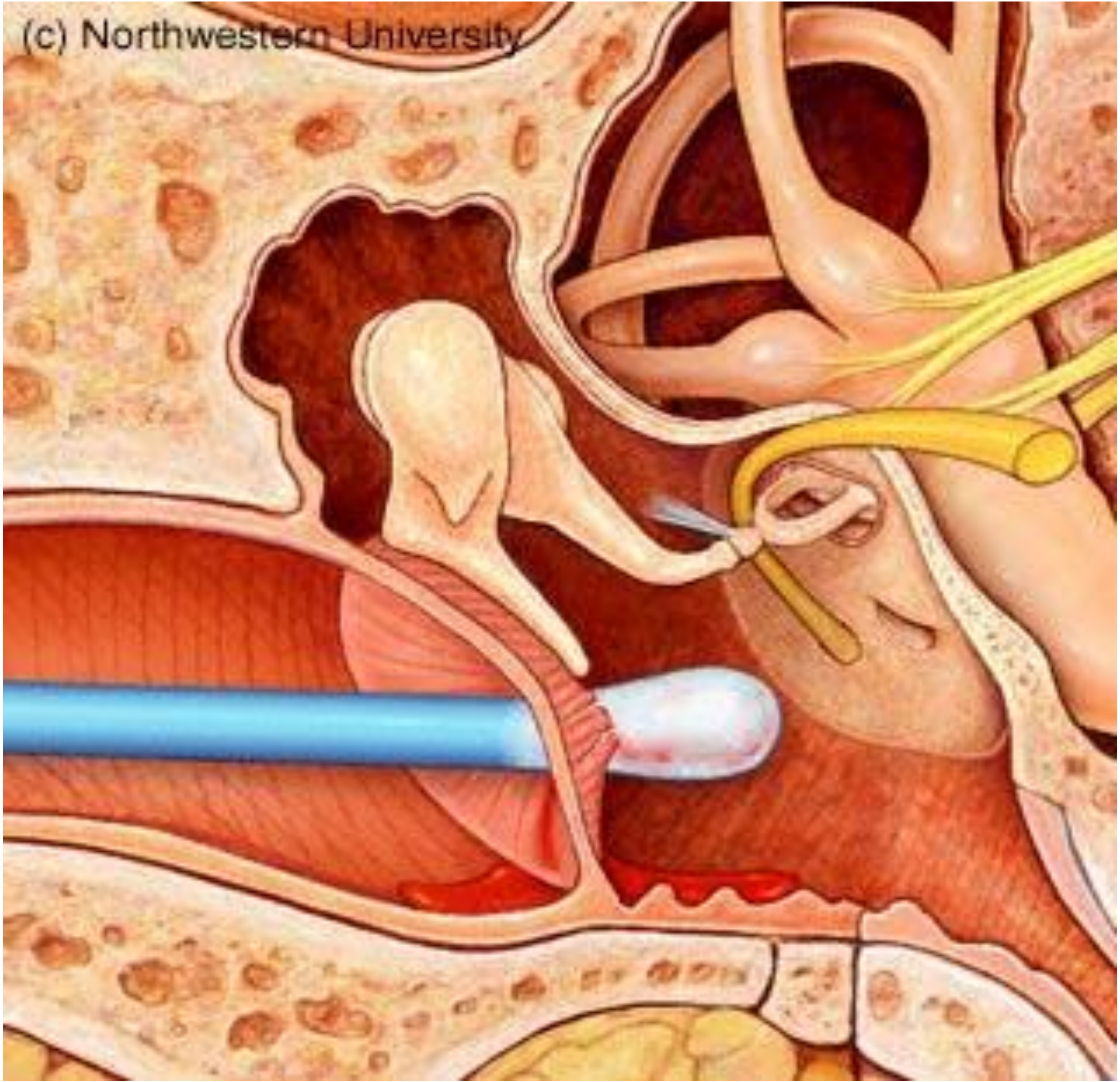
Acute Otitis Media

Acute Otitis Media

Ventillation Tube

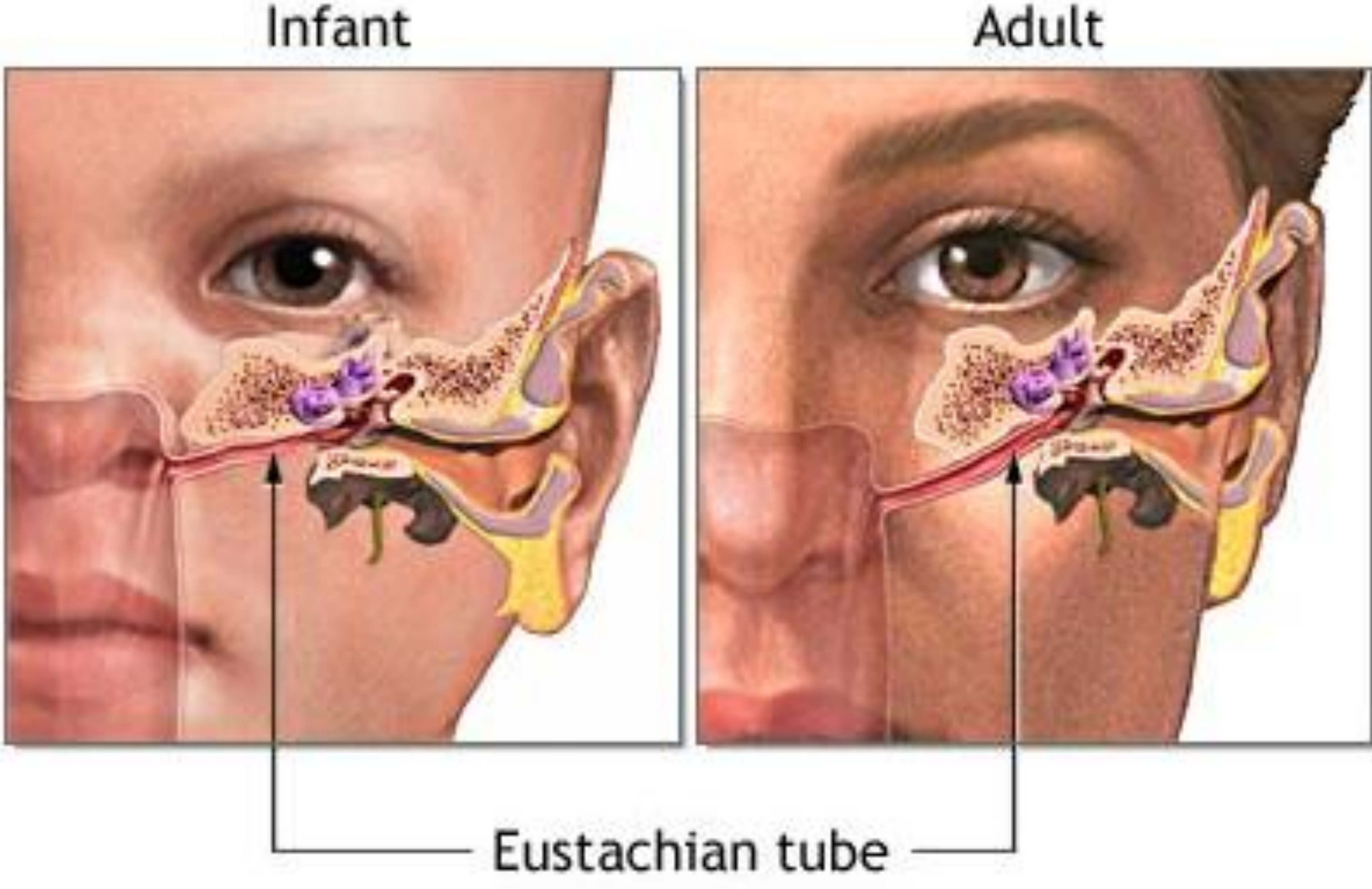
Traumatic perforation from a blow to the head

Subtotal Perforation

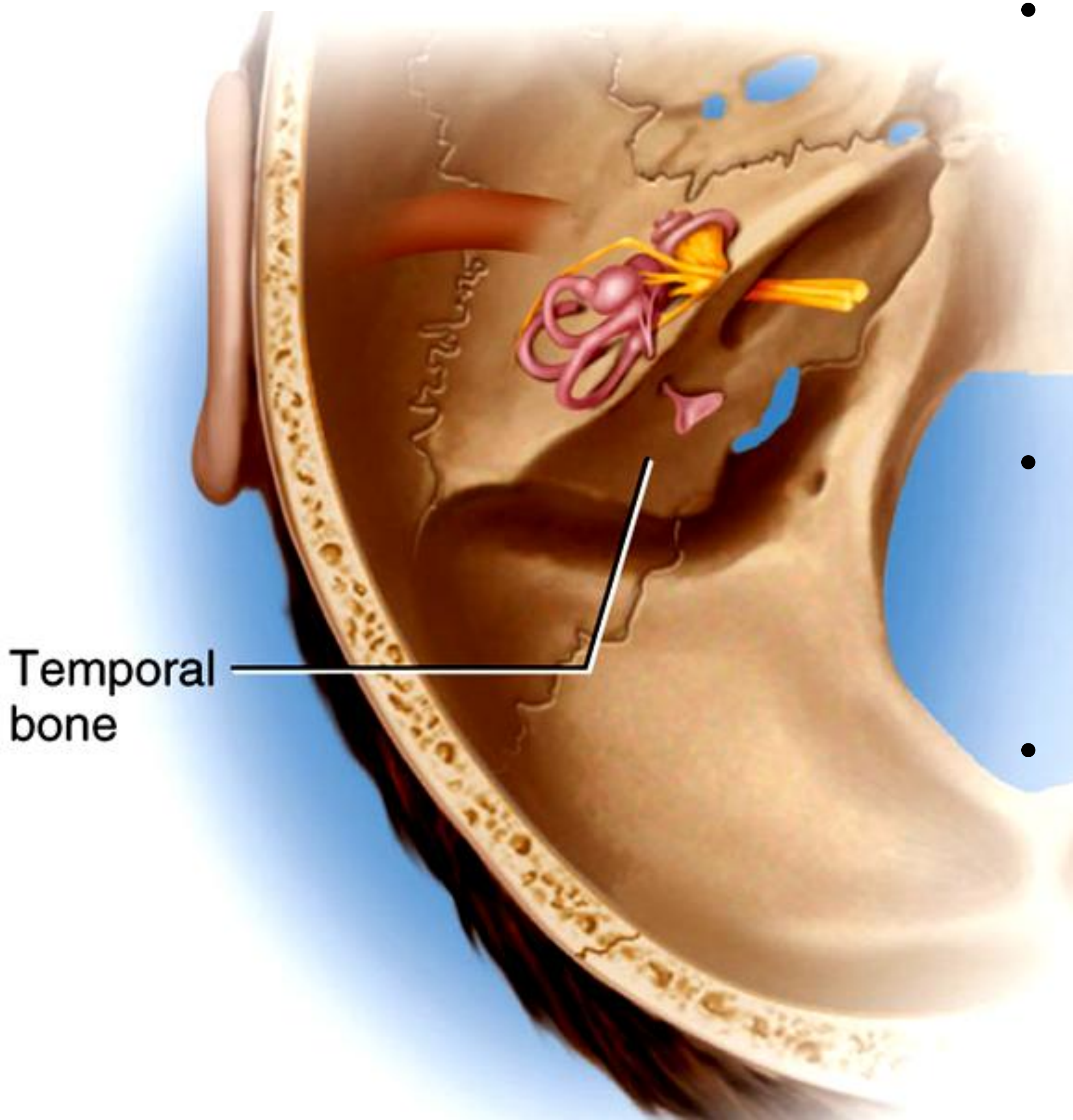

(c) Northwestern University

Middle Ear

- Air-filled cavity in temporal bone
- Contains:
  - ear ossicles
    - malleus
    - incus
    - stapes
  - auditory tube (eustachian tube) connects middle ear and nasopharynx
    - equalizes air pressure on tympanic membrane
  - tensor tympani muscle attaches to the malleus and contracts in response to potentially damaging volume


Infant
Adult
Eustachian tube

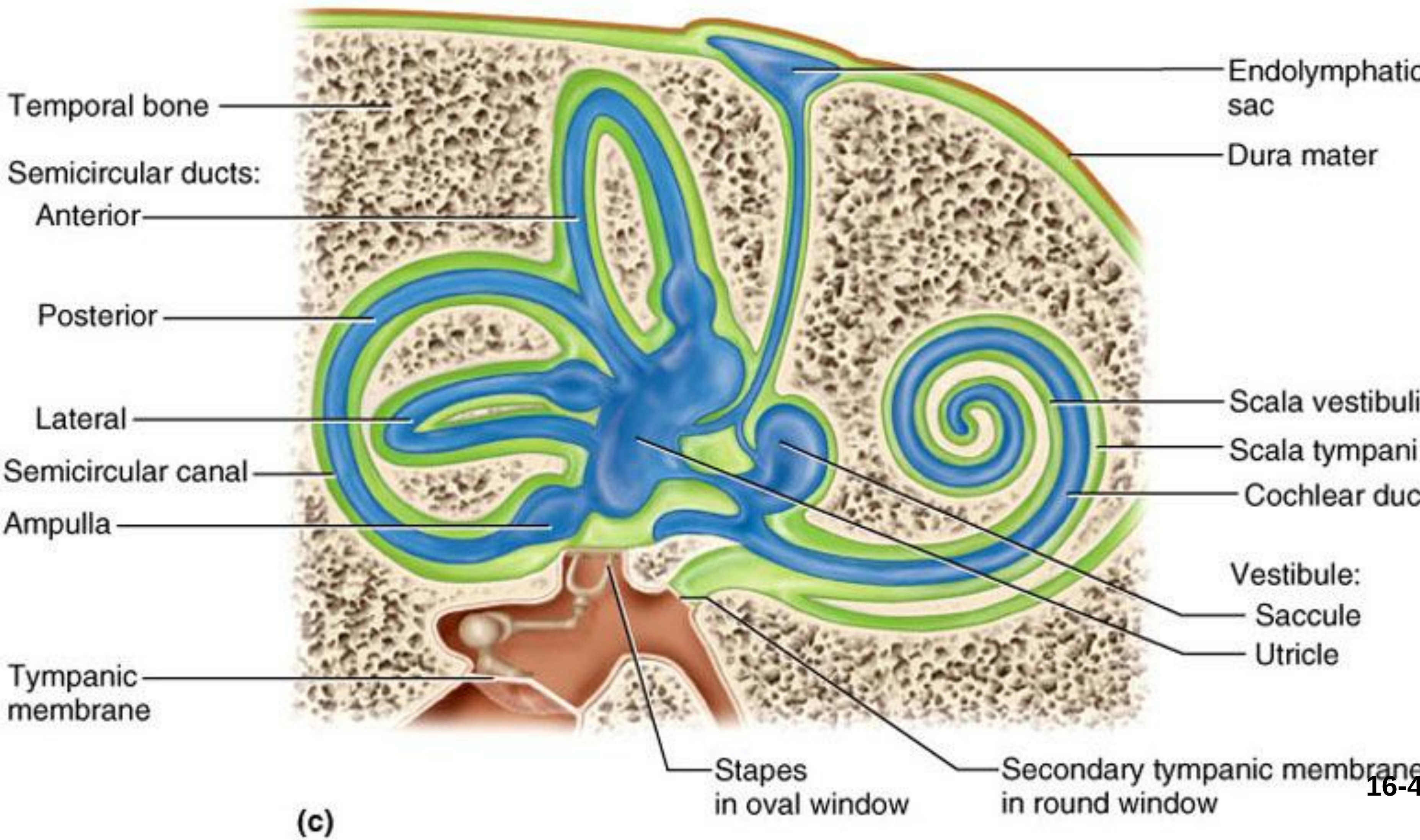
Inner Ear



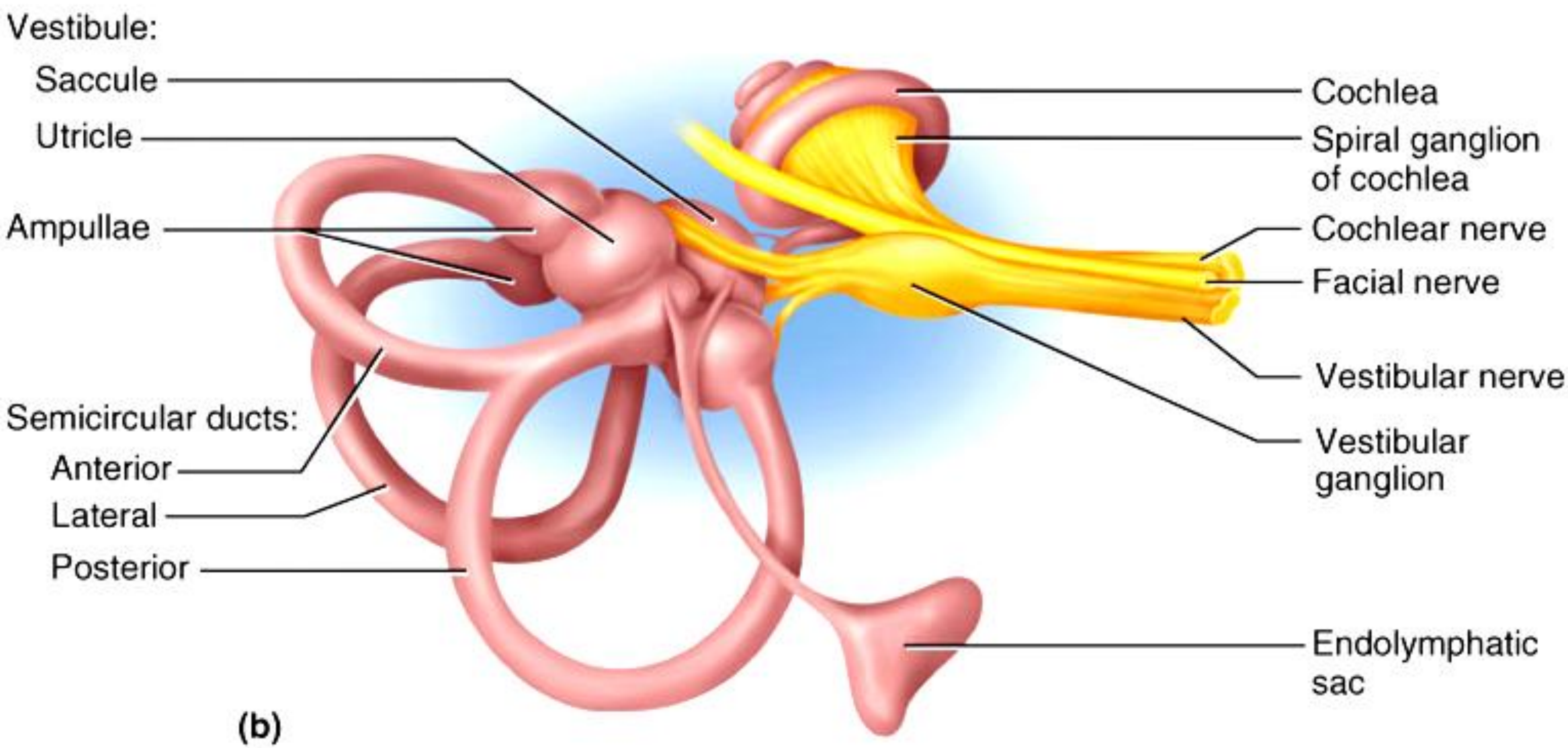
- Inner Ear is composed of a network of membranes called the “Membranous Labyrinth” located in petrous portion of temporal bone
- Membranes make up the cochlea, vestibule, semicircular canals (semicircular ducts)
- Membranes are filled with endolymph and surrounded by perilymph (similar to cerebrospinal fluid)

Inner Ear

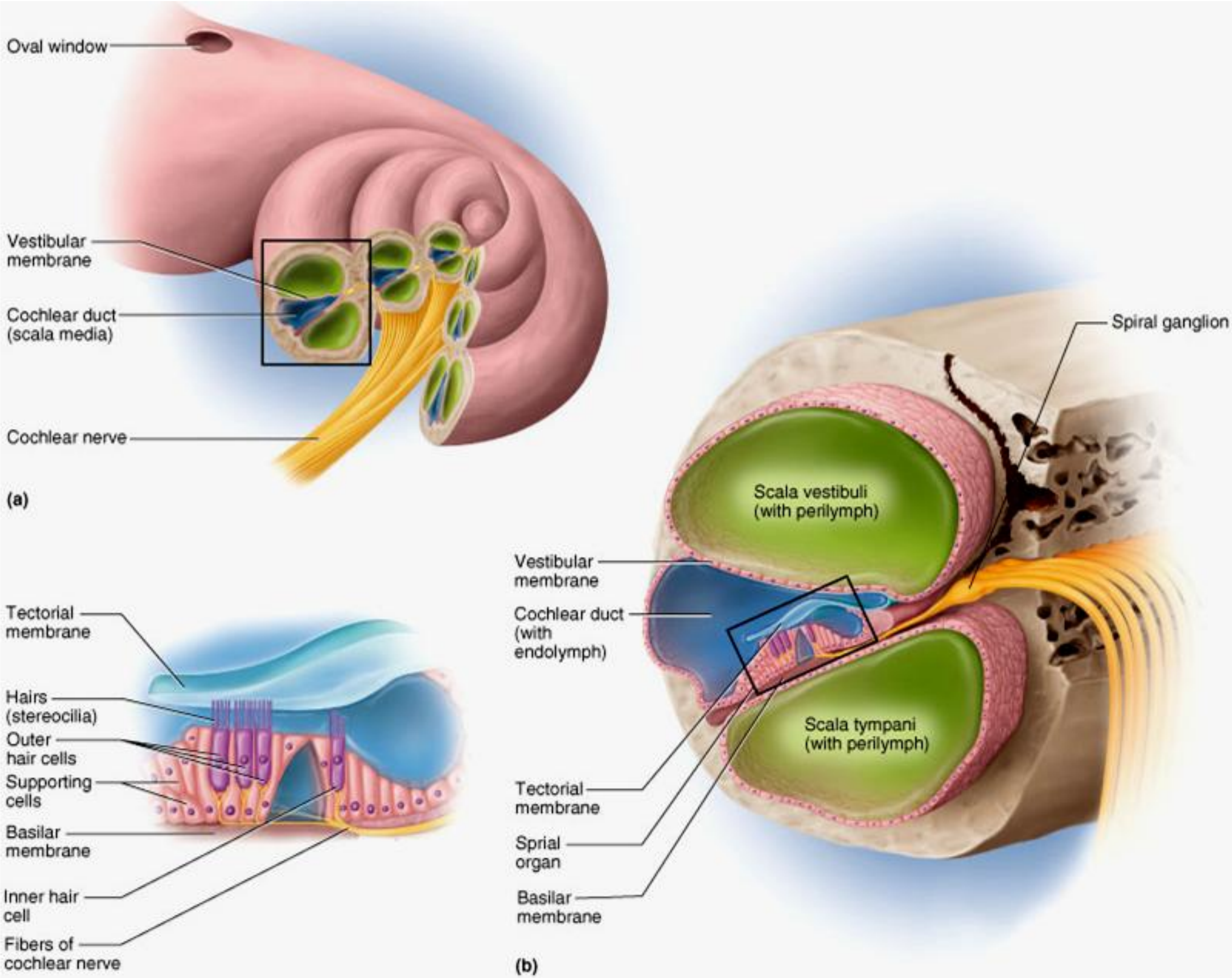
- **Membranous Labyrinth - tubes of thin epithelia that line bony tunnels are filled with endolymph (similar to intracellular fluid) and surrounded by perilymph (similar to cerebrospinal fluid)**



Organs and Innervation of the Inner Ear

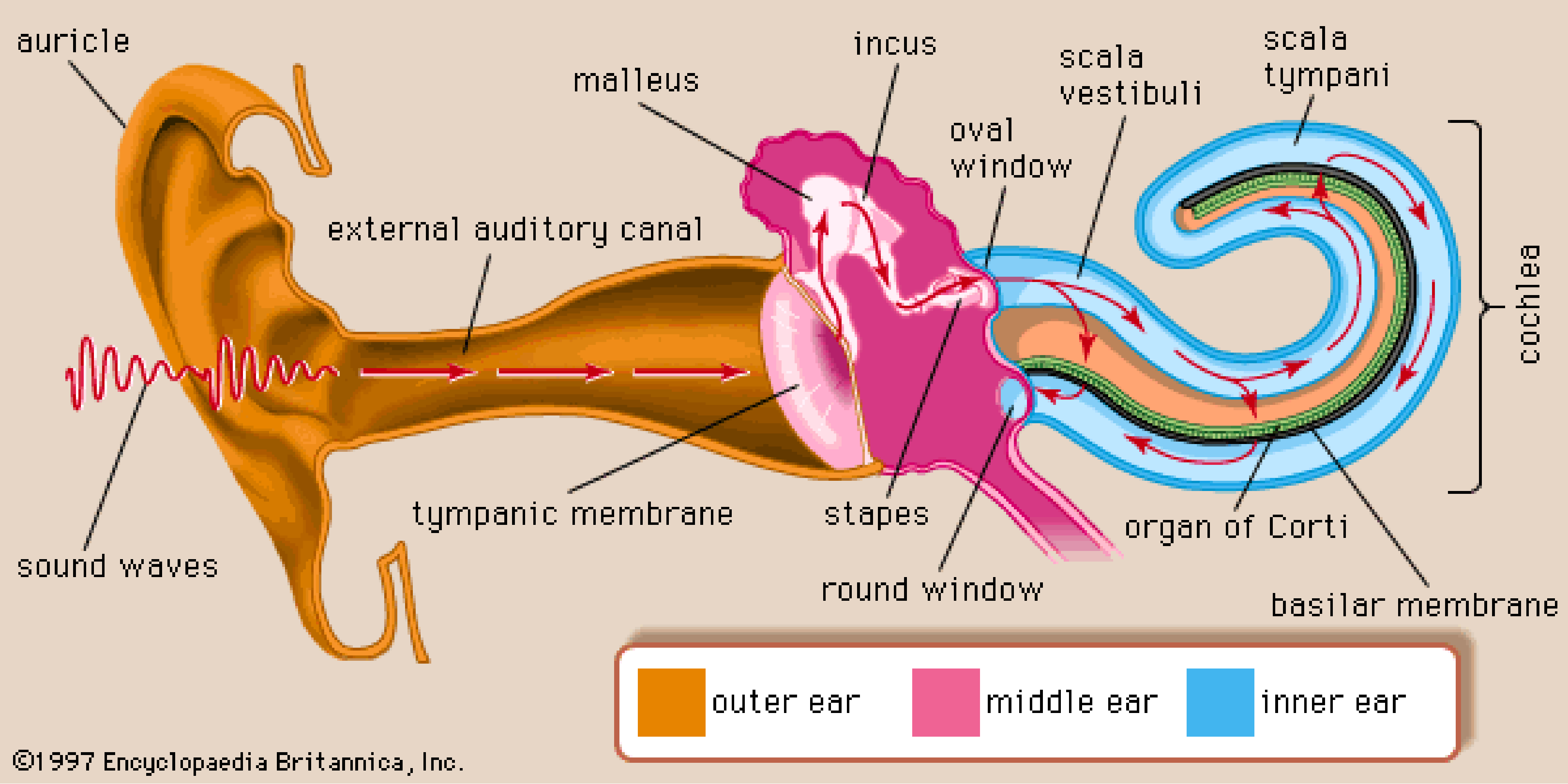


- **Vestibular branch of Cranial Nerve VIII innervates vestibule and semicircular canals**
- **Cochlear branch of Cranial Nerve VIII innervates the cochlea**



Oval window
Vestibular membrane
Cochlear duct (scala media)
Cochlear nerve
(a)
Spiral ganglion
Scala vestibuli (with perilymph)
Vestibular membrane
Cochlear duct (with endolymph)
Scala tympani (with perilymph)
Tectorial membrane
Sprial organ
Basilar membrane
(b)
Tectorial membrane
Hairs (stereocilia)
Outer hair cells
Supporting cells
Basilar membrane
Inner hair cell
Fibers of cochlear nerve

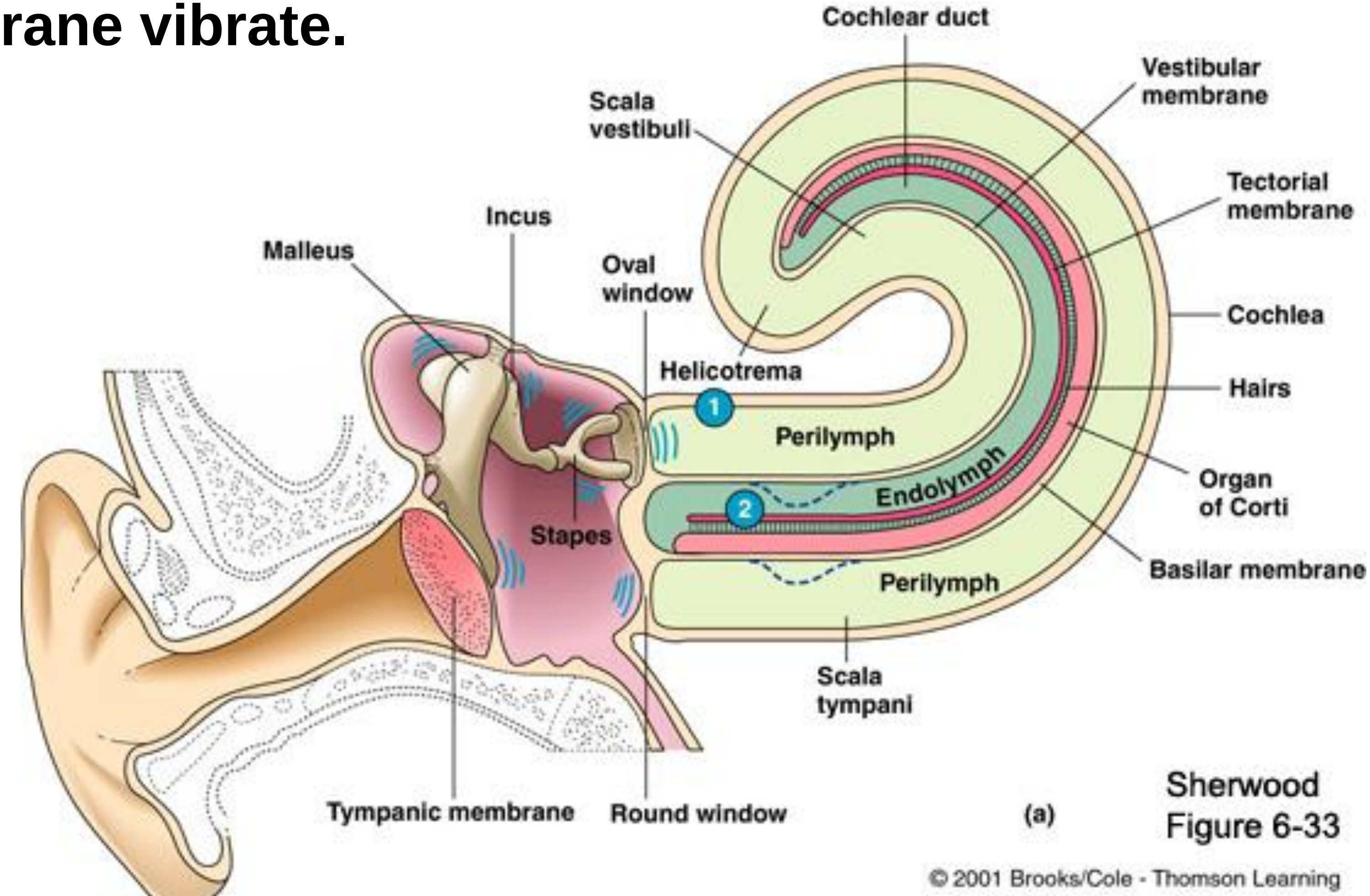
Sound Conduction Through the Ear



The Organ of Corti is a strip of sensitive “hair cells” on the basilar membrane in the cochlea.

Cochlea

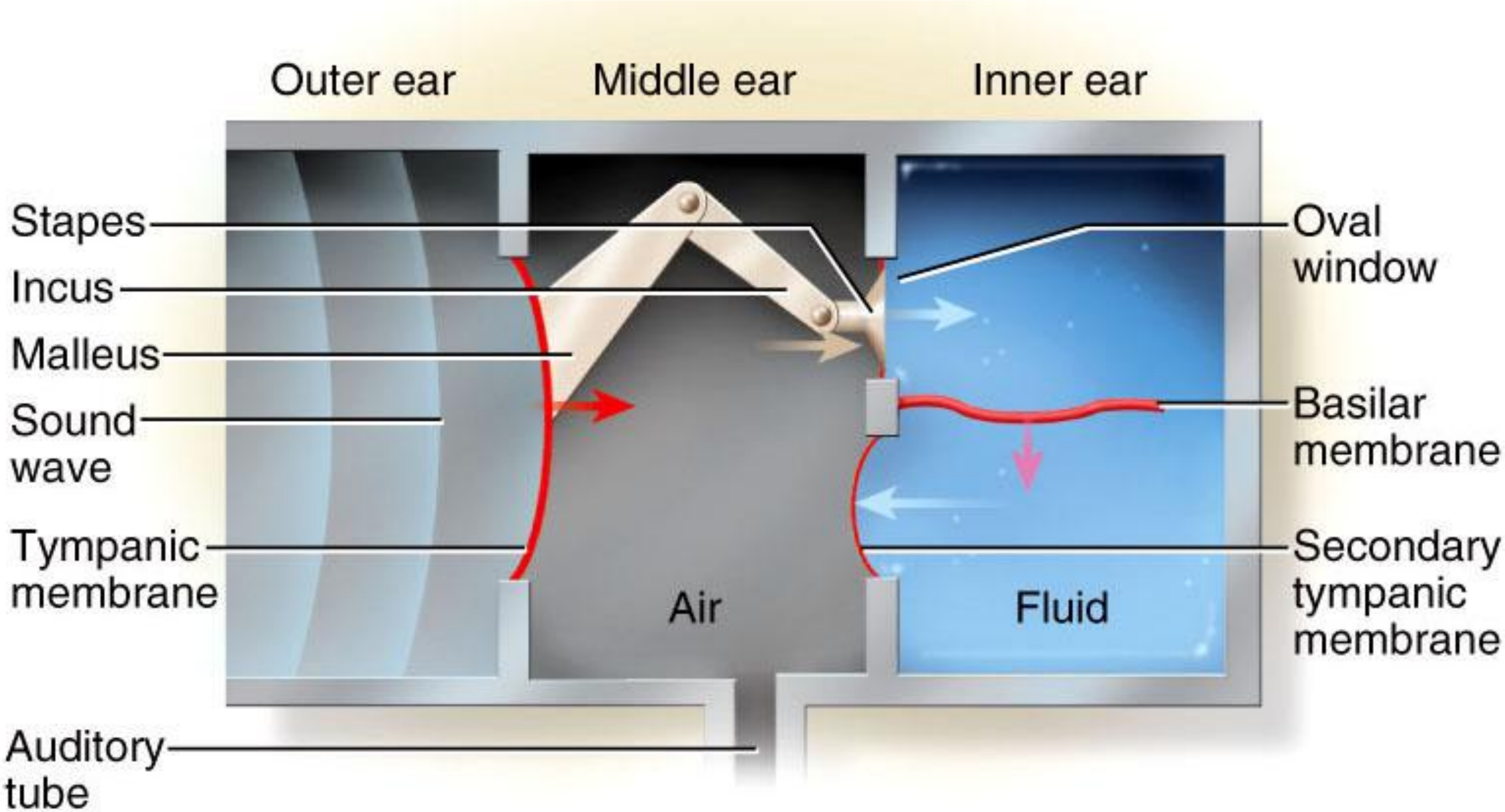
- **Cochlear Duct (scala media) contains endolymph and sensory hair cells anchored to the basilar membrane.**
- **Vibrations of ossicles are carried by perilymph in canals surrounding the cochlear duct that make the basilar membrane vibrate.**



Sherwood Figure 6-33

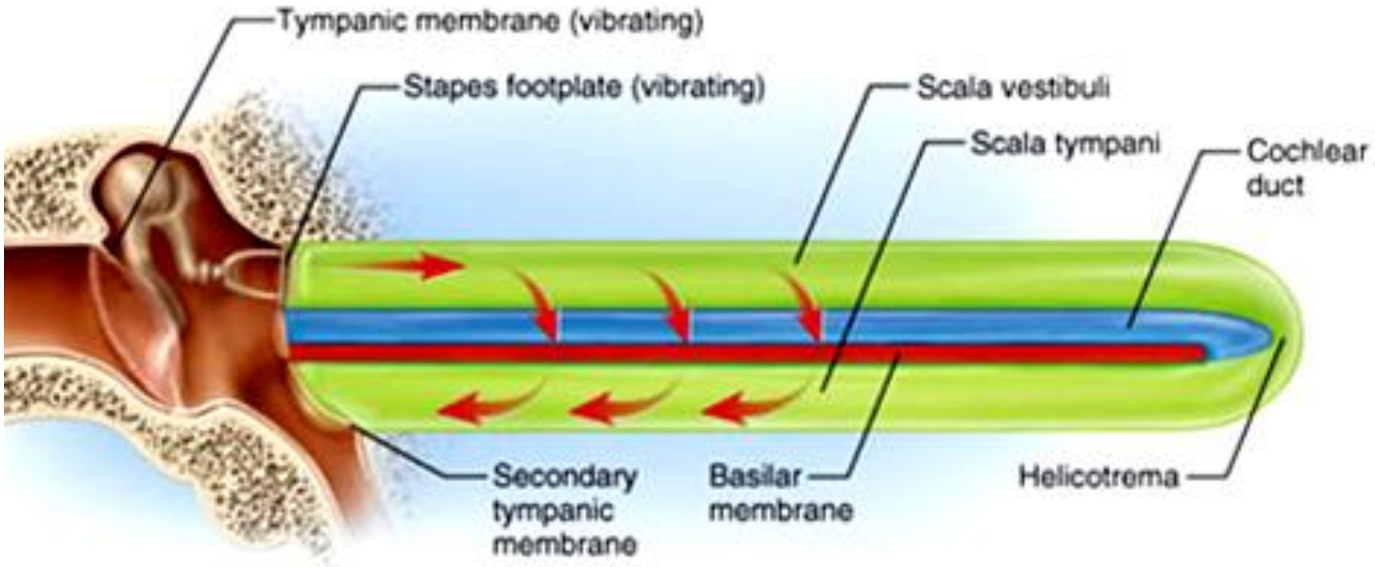
Sound Wave Transduction Through the Ear

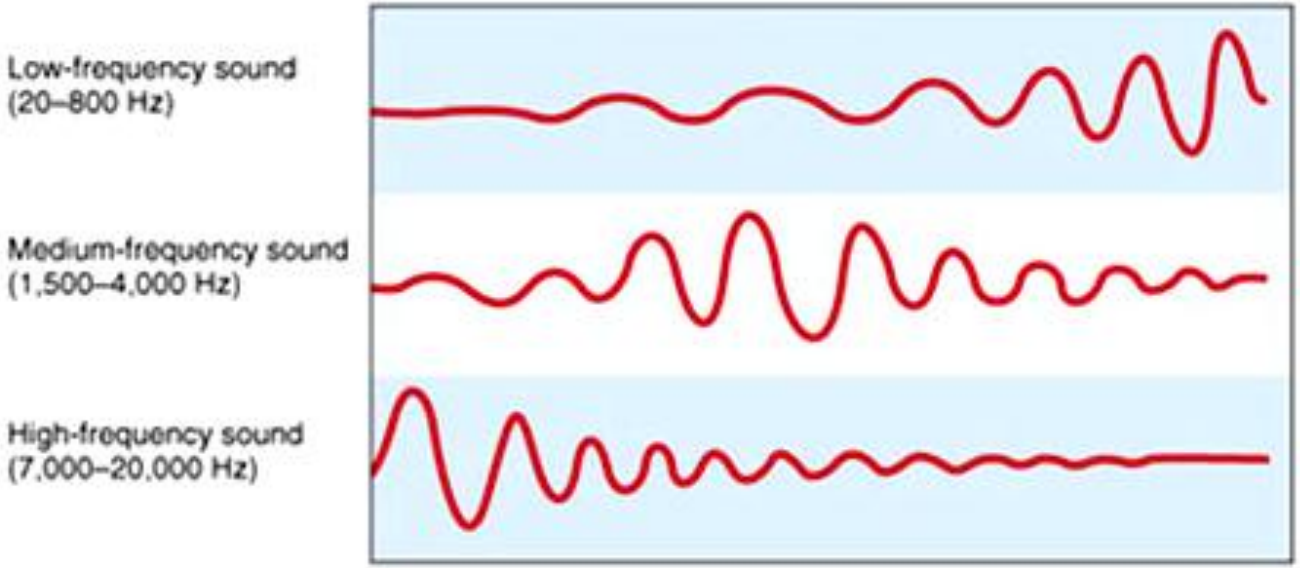
- **Vibration of the tympanum, ossicles and oval window send shock waves into the cochlear fluid that vibrates the basilar membrane supporting the hair cells. Vibrations are dampened by the secondary tympanic membrane of the round window.**



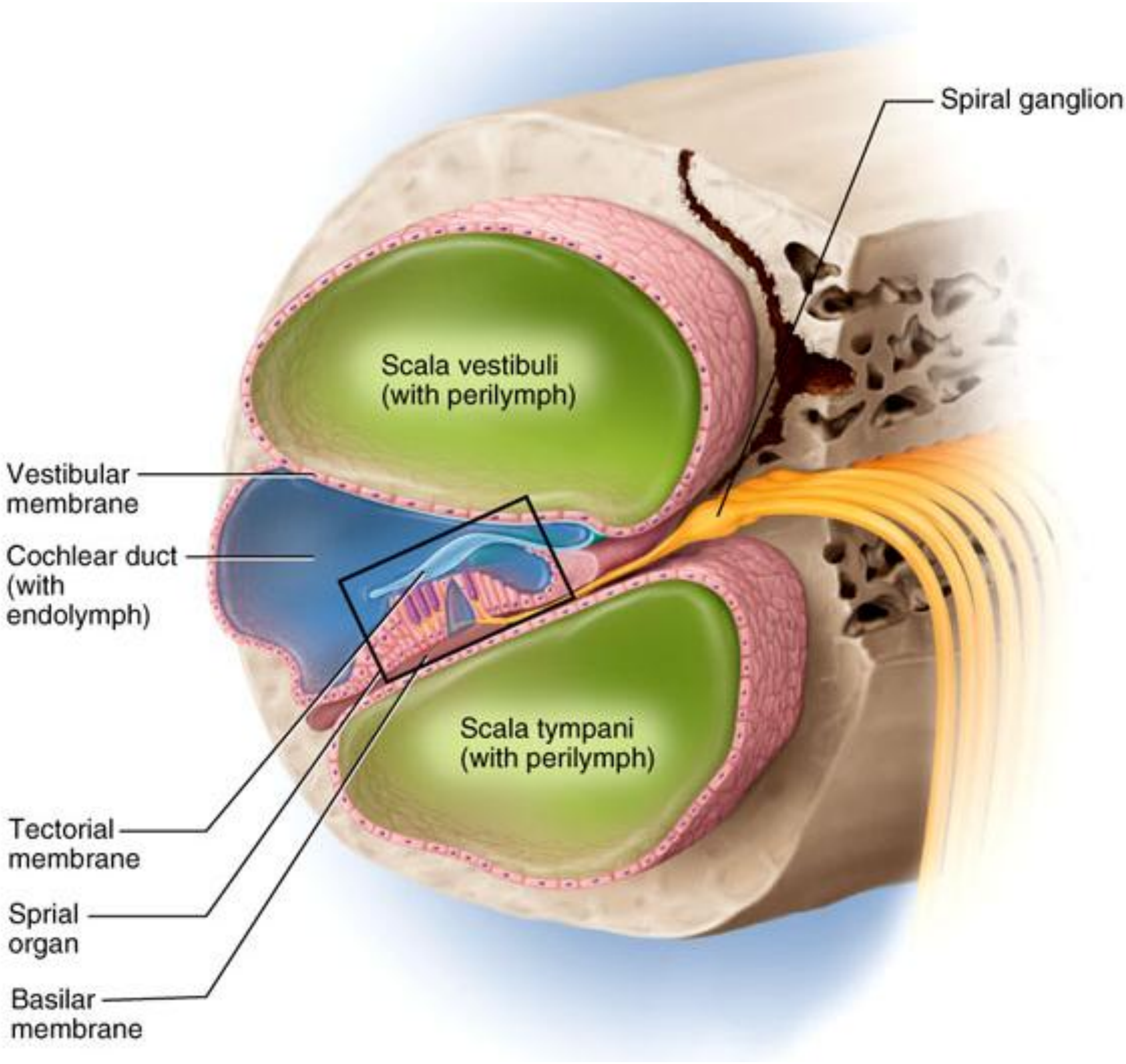
Basilar Membrane Frequency Response

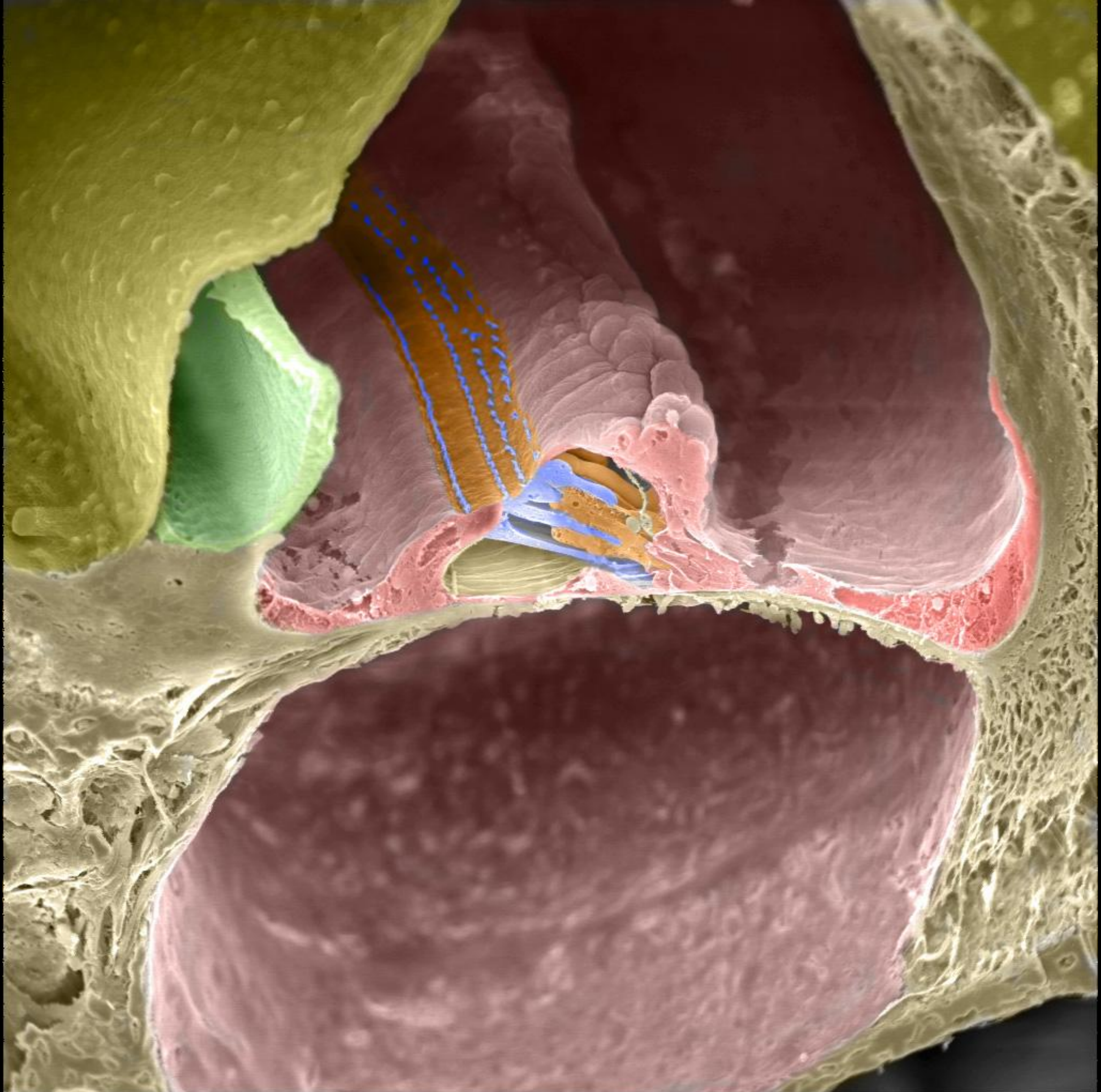
The basilar membrane is tuned for frequencies in the range of 20-20,000 Hertz





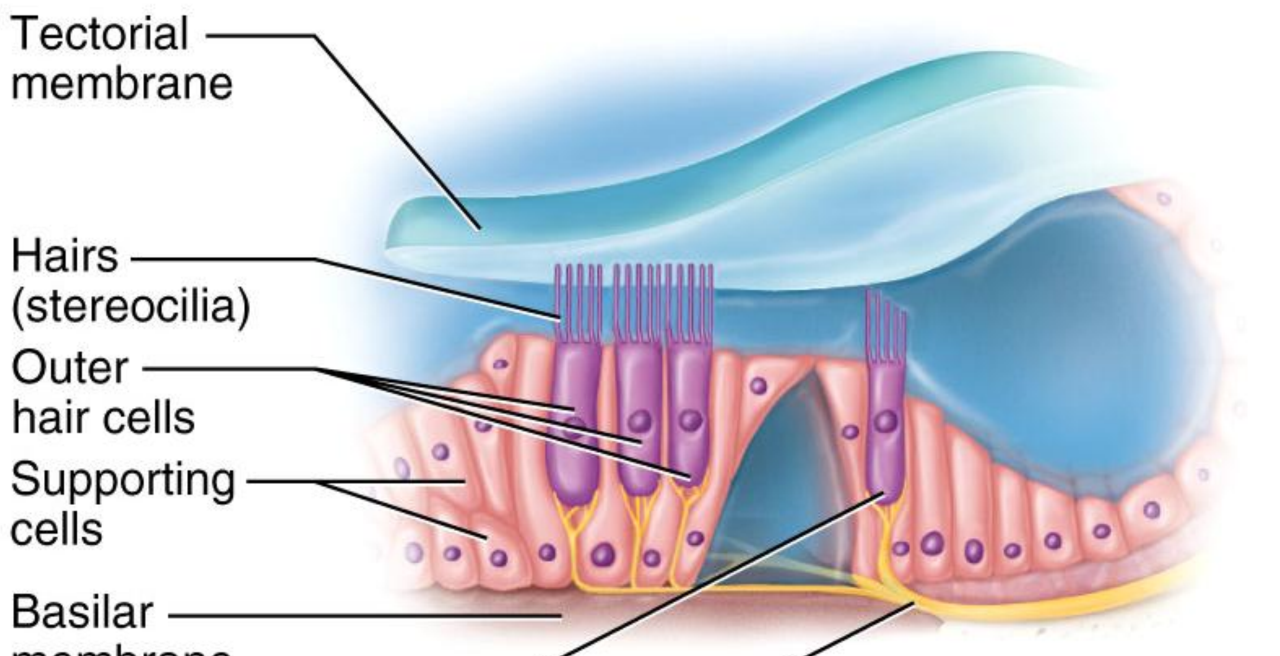
http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter46/animations.html#

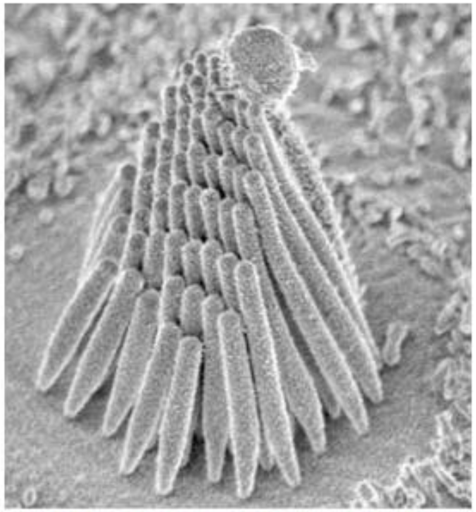

Spiral ganglion
Scala vestibuli
(with perilymph)
Vestibular
membrane
Cochlear duct
(with
endolymph)
Scala tympani
(with perilymph)
Tectorial
membrane
Sprial
organ
Basilar
membrane



Hair Cells of the Cochlea

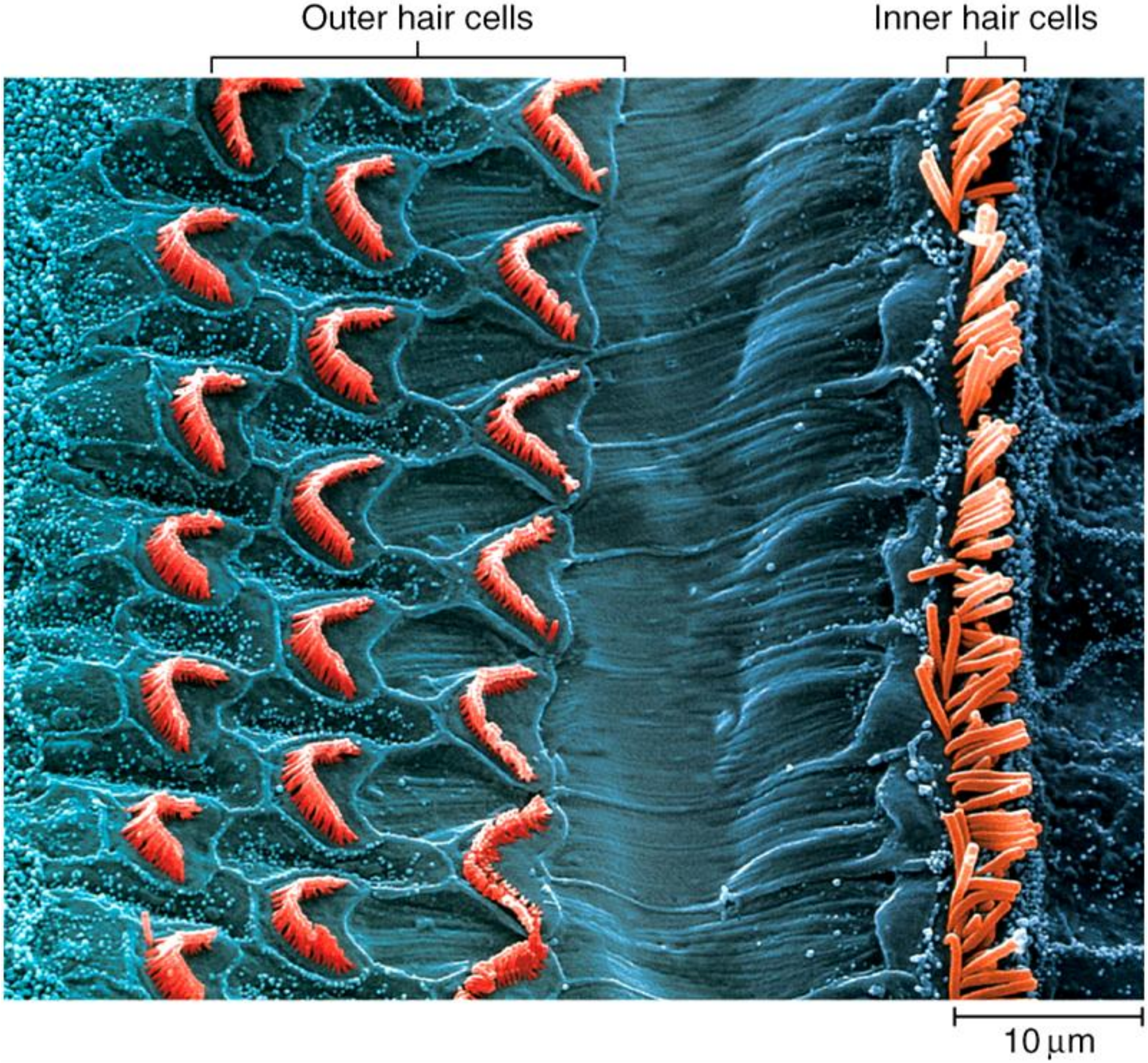
- **Stereocilia of hair cells bump into the gelatinous tectorial membrane as the basilar membrane vibrates.**
- **Inner Hair Cells are for hearing.**
- **Outer Hair Cells adjust the tectorial membrane to increase precision of perception of specific frequencies.**



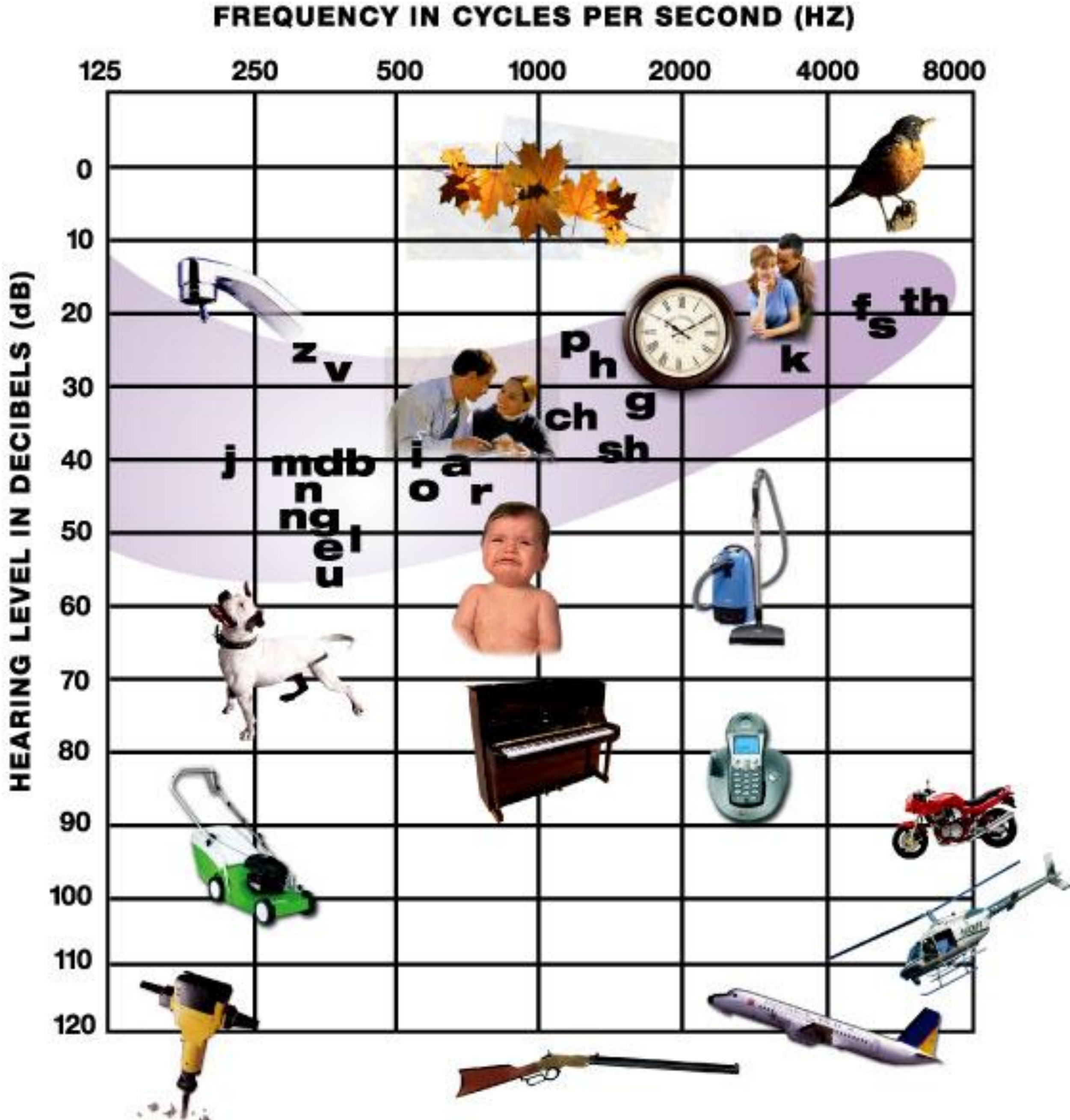


SEM of hair cell bundle from a bullfrog; longest cilia are 8um

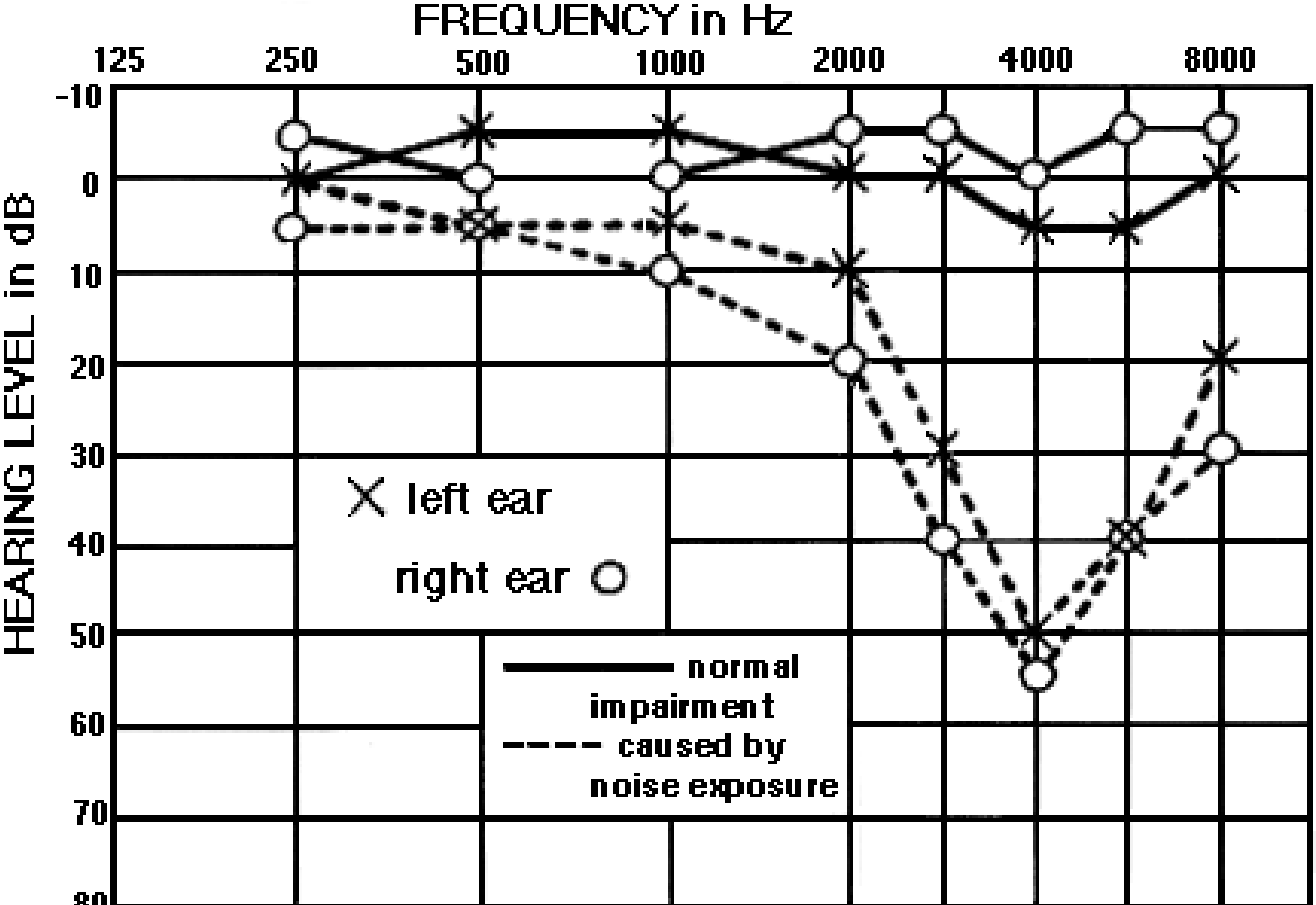
Cochlear Hair Cells on the Basilar Membrane



This audiogram has been filled in with illustrations to show where common sounds and parts of speech fit in. Frequency, or tone pitch is measured on the x-axis (horizontal axis) and sound intensity, or loudness is measured on the y-axis (vertical axis) in decibels (dB). The purple shaded area on the audiogram shows the pitch and loudness where most common speech sounds occur. An "s" sound is high in pitch, yet quiet, whereas the "u" sound is lower in pitch but louder.



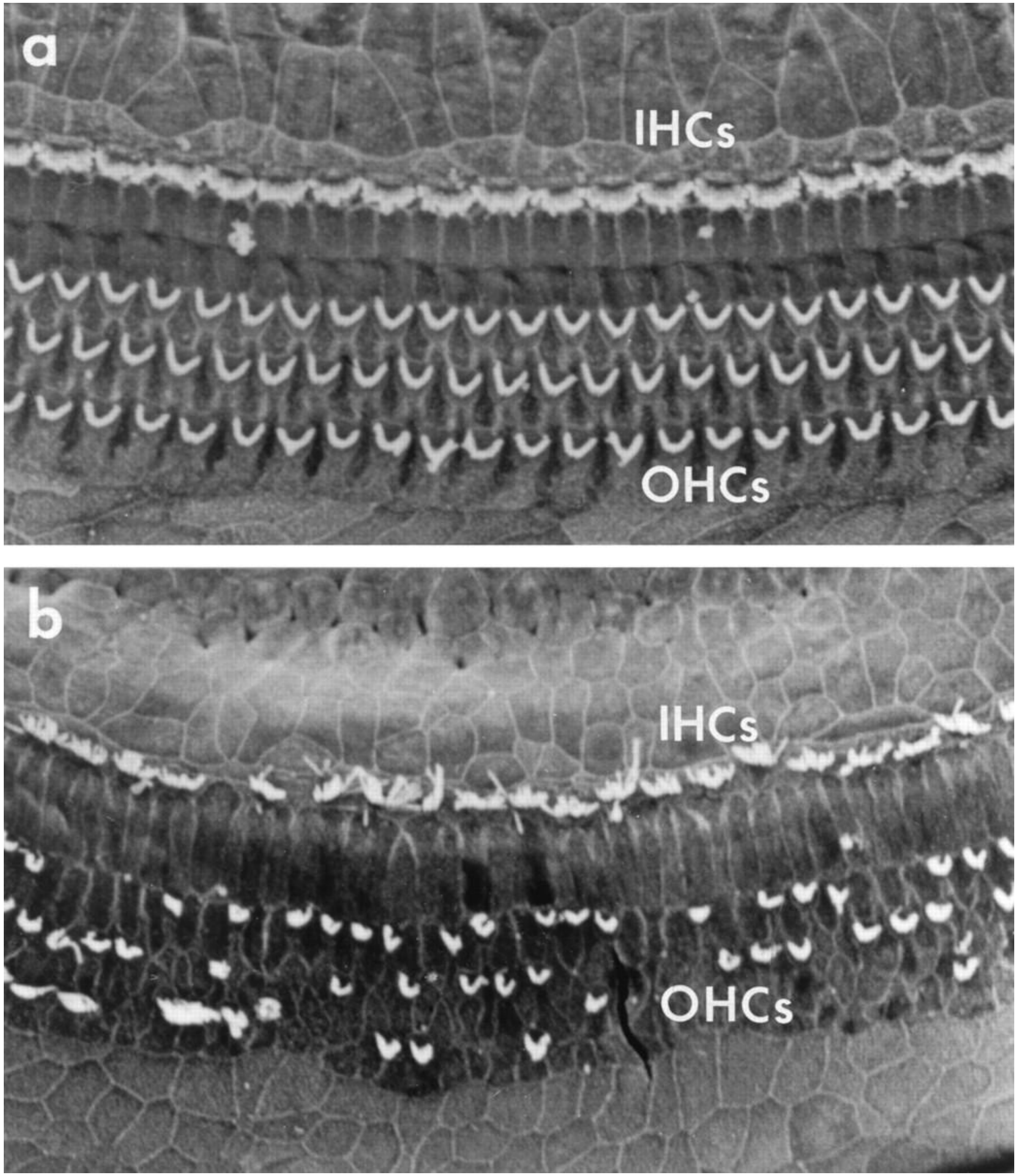
www.amherstaudiology.com/resources/audiogram.html



A typical audiogram comparing normal and impaired hearing. The dip or notch at 4 kHz as shown, or at 6 kHz, is a symptom of noise-induced hearing loss.

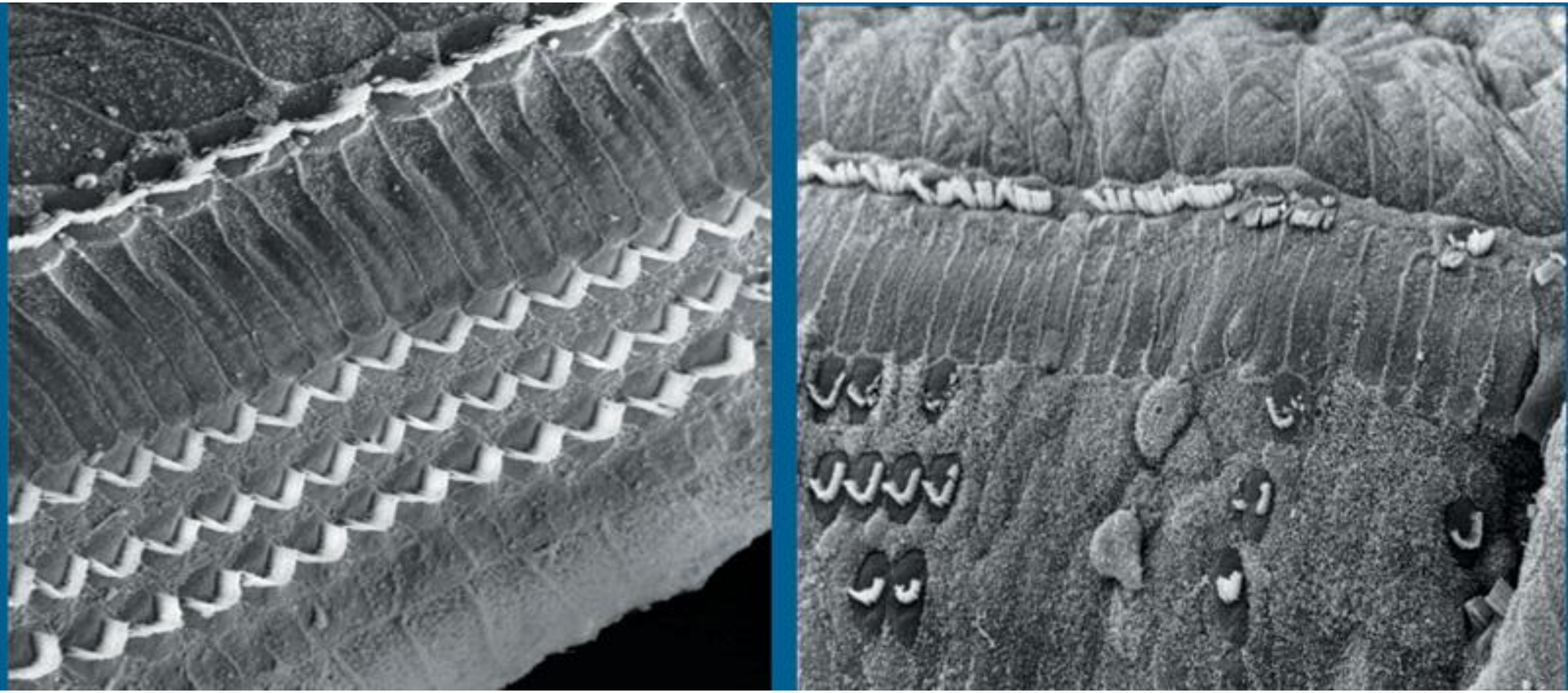
www.sfu.ca/sonic-studio/handbook/Audiogram.html

Scanning electron micrographs of the normal (a) and damaged (b) cochlear sensory epithelium



Ryan A F PNAS 2000;97:6939-6940

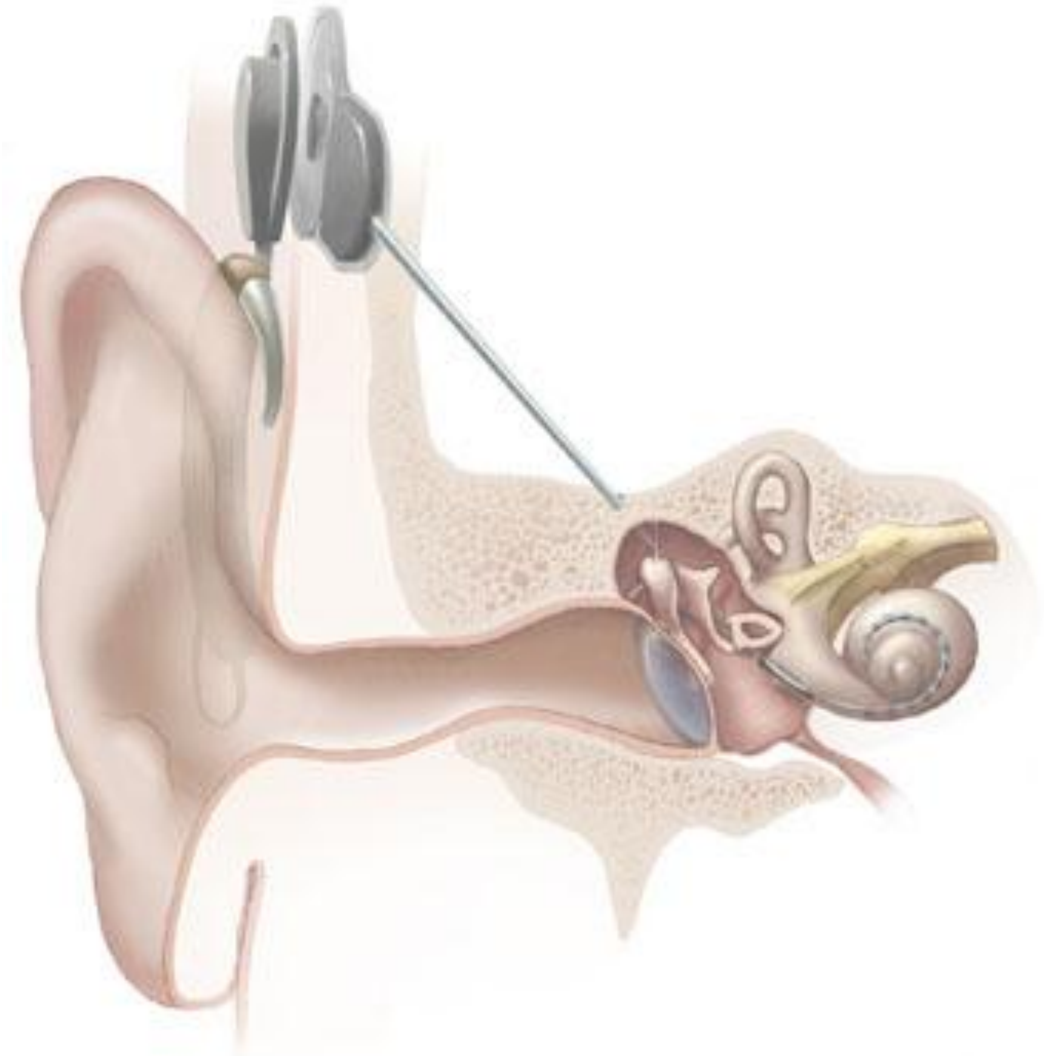
PNAS



Left - An undamaged mouse organ of Corti, showing rows of inner and outer hair cells.
Right – A damaged mouse organ of Corti showing significant loss of sensory hair cells

http://www.bcm.edu/cmb/?pmid=9497

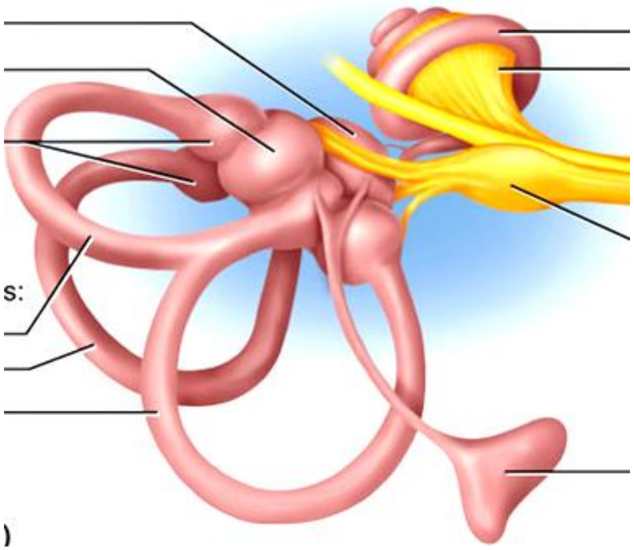
Cochlear Implant

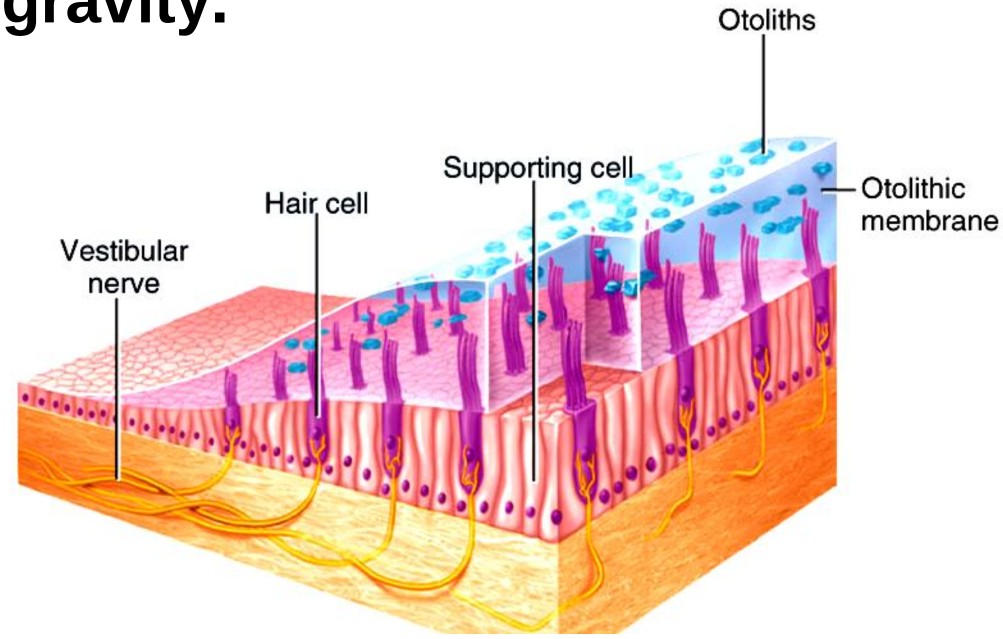


http://www.thehearinginstitute.org/Default.aspx?tabid=866

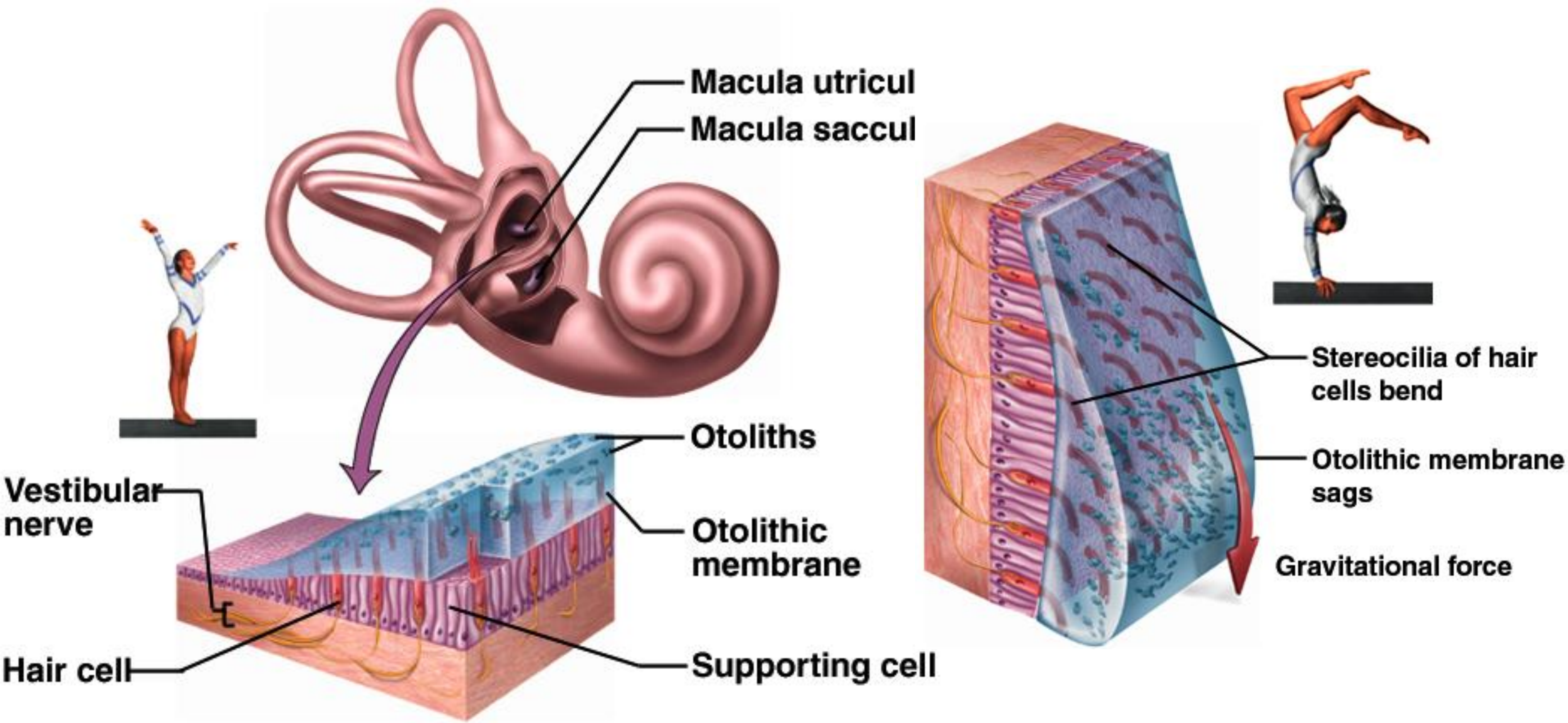
Vestibule: Saccule and Utricle

- Vestiblue provides a sense of position relative to gravity.
- Saccule and Utricle are the two sensory pouches of the Vestibule.
- Stereocilia of hair cells are buried in a gelatinous membrane.
- The membrane contains otoliths (crystals of calcium carbonate) that add density to the membrane and enhance the sense of gravity.
- Changes in position of the head are sensed as the otolithic membrane is pulled by gravity.



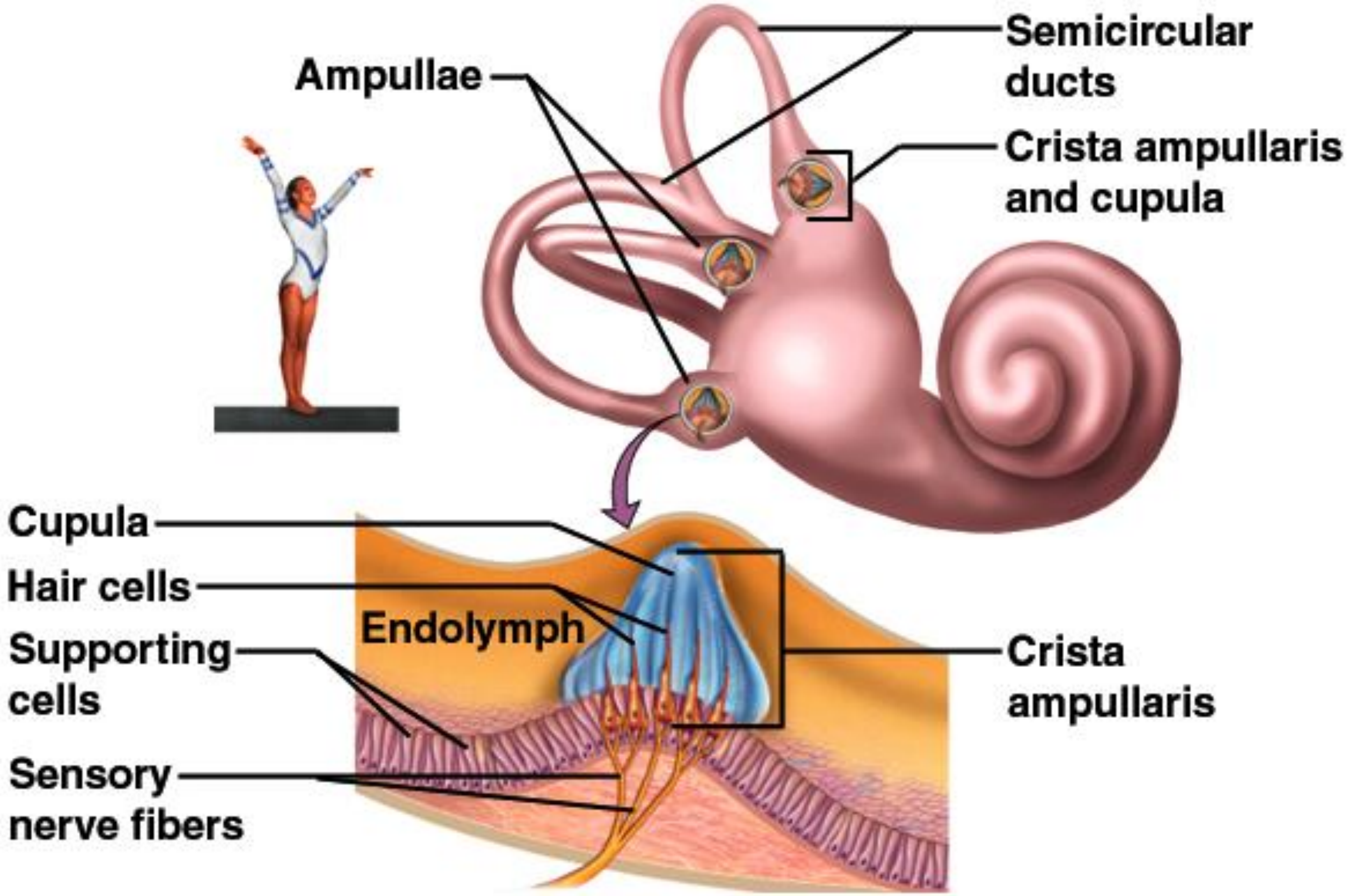


Saccule and Utricle



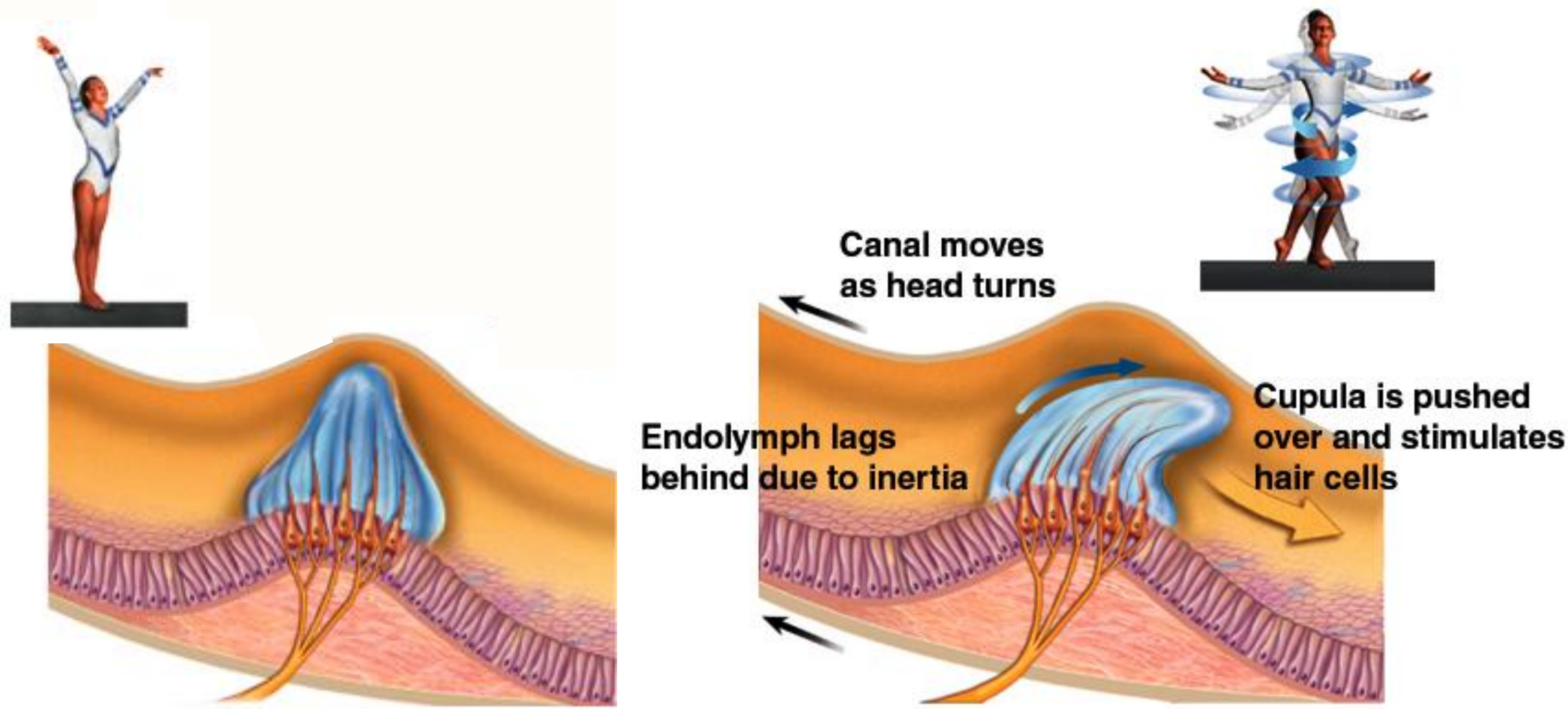
- With the head erect, stimulation is minimal, but when the head is tilted, weight of membrane bends the stereocilia (static equilibrium)
- When head is tilted down, or during acceleration, weight of otolithic membrane bends the stereocilia down and activates the hair cells (one type of dynamic equilibrium).

Semicircular Canals (Ducts)



Each semicircular canal has a crista ampularis that is a tuft of hair cells buried in a cupula (a mound of gelatinous membrane).

Crista Ampullaris and Head Rotation



Head rotation causes endolymph circulation that pushes the cupula and the hairs of the hair cells in the direction of the motion providing a sense of acceleration or deceleration.