Citation Key

for more information see: http://open.umich.edu/wiki/CitationPolicy

Use + Share + Adapt

{ Content the copyright holder, author, or law permits you to use, share and adapt. }

Public Domain – Government: Works that are produced by the U.S. Government. (USC 17 § 105)

Public Domain – Expired: Works that are no longer protected due to an expired copyright term.

Public Domain – Self Dedicated: Works that a copyright holder has dedicated to the public domain.

Creative Commons – Zero Waiver

Creative Commons – Attribution License

Creative Commons – Attribution Share Alike License

Creative Commons – Attribution Noncommercial License

Creative Commons – Attribution Noncommercial Share Alike License

GNU – Free Documentation License

Make Your Own Assessment

{ Content Open.Michigan believes can be used, shared, and adapted because it is ineligible for copyright. }

Public Domain – Ineligible: Works that are ineligible for copyright protection in the U.S. (USC 17 § 102(b)) *laws in your jurisdiction may differ

{ Content Open.Michigan has used under a Fair Use determination. }

Fair Use: Use of works that is determined to be Fair consistent with the U.S. Copyright Act. (USC 17 § 107) *laws in your jurisdiction may differ

Our determination **DOES NOT** mean that all uses of this 3rd-party content are Fair Uses and we **DO NOT** guarantee that your use of the content is Fair.

To use this content you should **do your own independent analysis** to determine whether or not your use will be Fair.

Histology of the Ear

M1 – CNS Sequence

Matthew Velkey, Ph.D.

Winter, 2009

University of Michigan
Medical School

Histology of the ear

Matthew Velkey

Learning Objectives

1. Understand the structures and fluid-filled compartments (and their functions) that comprise the membranous vs. the bony labyrinth of the inner ear.

3. Know the structures, locations, and specific cells of sensory areas within the membranous labyrinth (otolith organs, cristae ampullaris, and organ of Corti), and their different functions.

3. Understand how mechanosensory transduction takes place, including how a K+ gradient is set up at the level of the hair cell.

Lecture Outline: Ear

- **Conducting and Sensory Structures**
  - Outer, middle, inner ear
- **Sensory Structures (Vestibulocochlear apparatus):**
  - Bony and Membranous Labyrinths

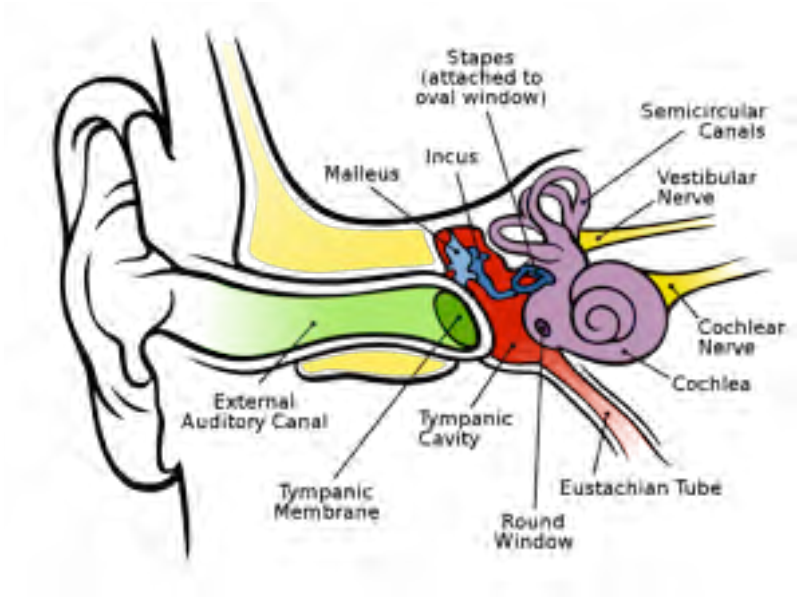
    Vestibular System: utricle & saccule: macula

    semicircular canals: crista

    Auditory System: Cochlea: Organ of Corti

The Ear: equilibrium and hearing

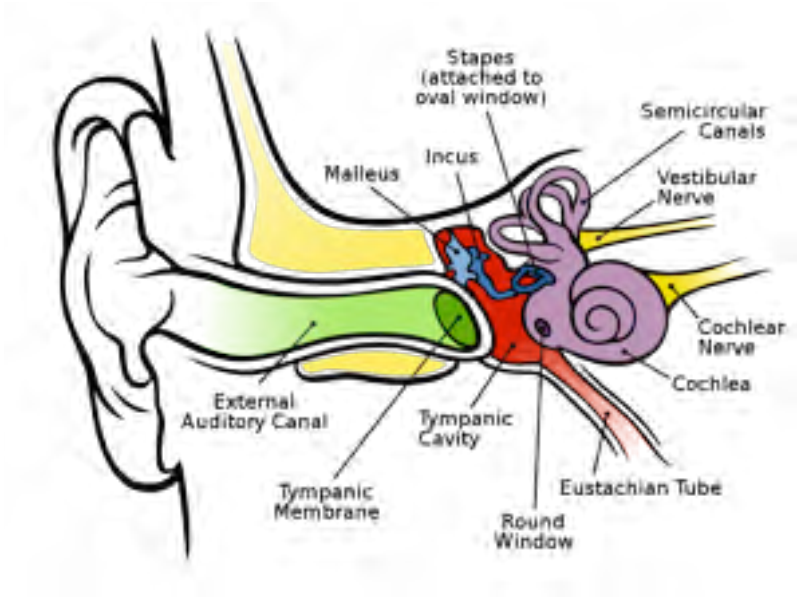
3 parts:



 Chittka L, Brockmann, Wikipedia

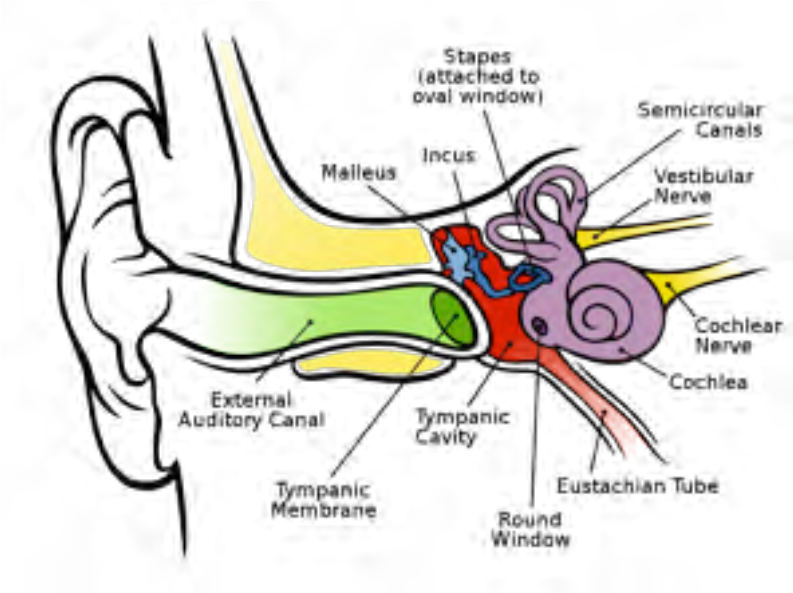
- **External ear**: receives sound waves
- **Middle ear**: transmission from air to bone & bone to inner ear
- **Inner ear**: vibrations transduced to nerve impulses, to acoustic nerve, to CNS

EXTERNAL EAR: transmission of sound waves to ossicles of middle ear



- **Pinna:** elastic cartilage, skin
- **External auditory meatus**: canal to tympanic membrane, lined by skin w/ hair and ceruminous (wax) glands
- **Ear drum**: epidermis, middle ct, inner simple cuboidal epith.

MIDDLE EAR: transmission from ossicles to oval window

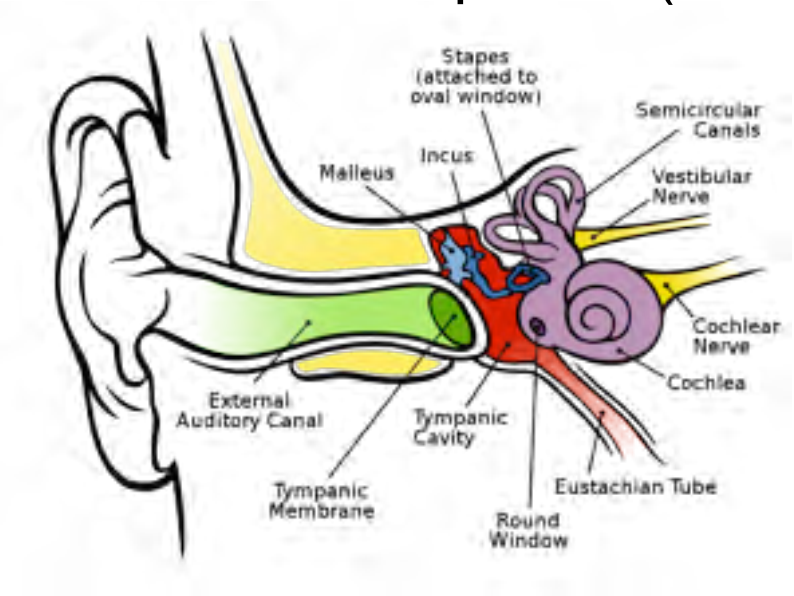


- Aka tympanic cavity (interior of temporal bone)
- S. squamous epith., thin lamina propria, periosteum
- Ossicles: maleus, incus, stapes
- Muscles: tensor tympani (V), stapedius (VII) –responsible for attenuation reflex
- Oval window
- Round window
- Eustachian tube, resp. epith.
- Mastoid sinuses
- Otitis media, mastoiditis

INNER EAR:

Vestibular: perception of body position (utricle and saccule, semicircular canals)

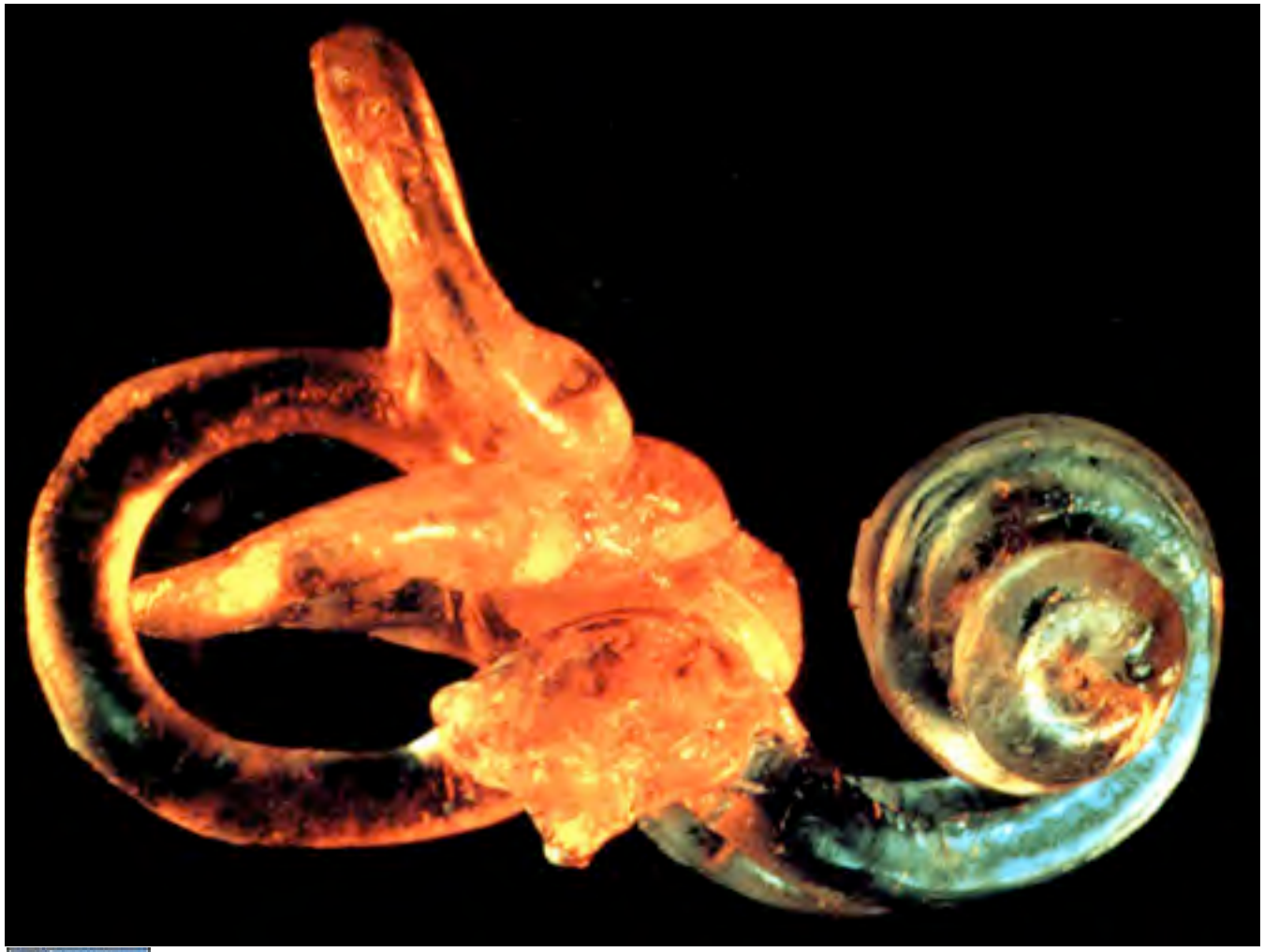
Hearing: vibrations at oval window transduced to fluid, then nervous impulses (cochlea)



Two Labyrinths:

- Bony labyrinth (encased within petrous portion of temporal bone)
- Membranous labyrinth (sac within bony labyrinth)

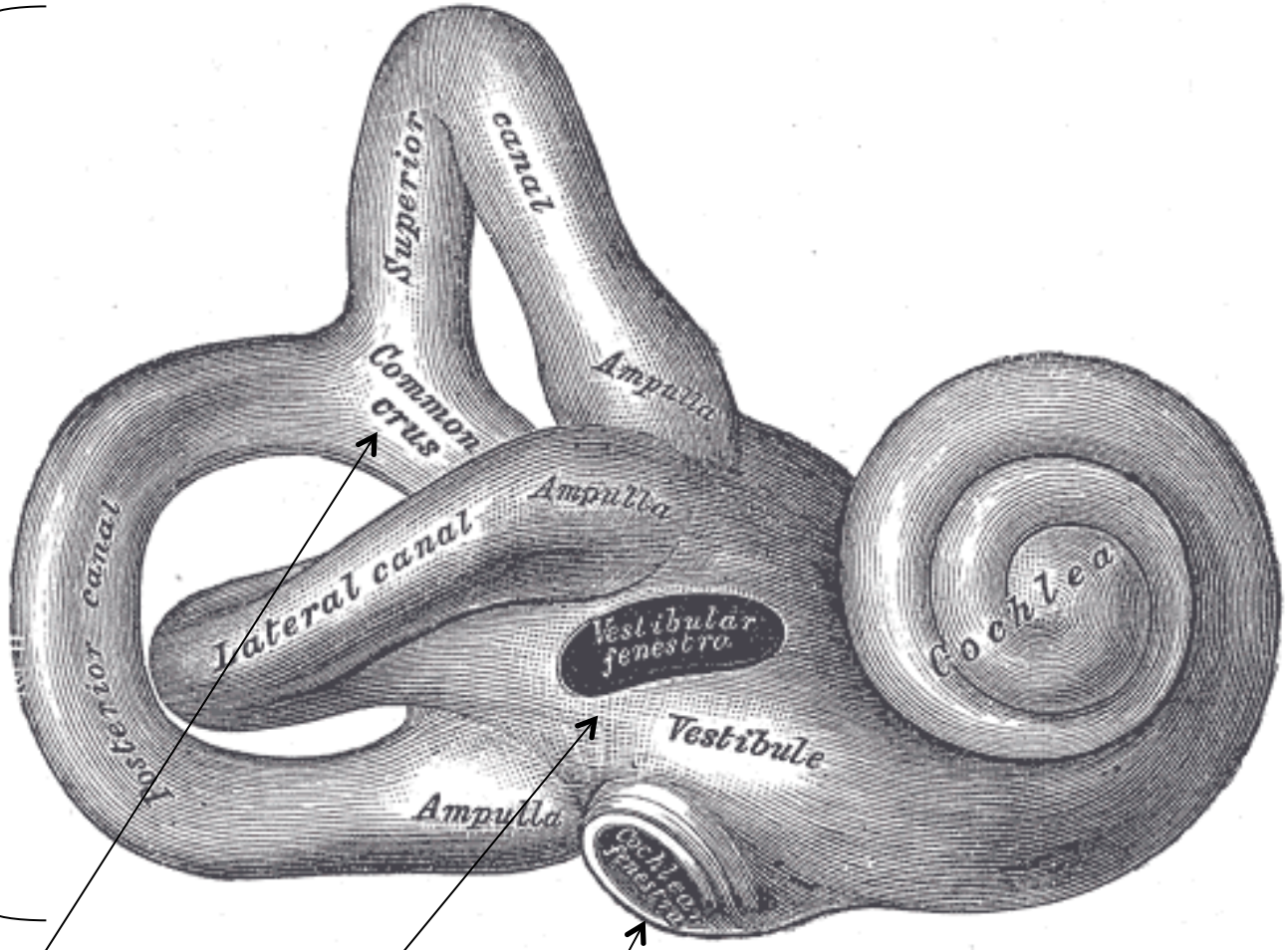
Cast of bony labyrinth



PD-INEL Ross and Pawlina. (2006), *Histology: A Text and Atlas, 5th ed* Figure 25.6

Space in bone

Bony labyrinth: perilymph



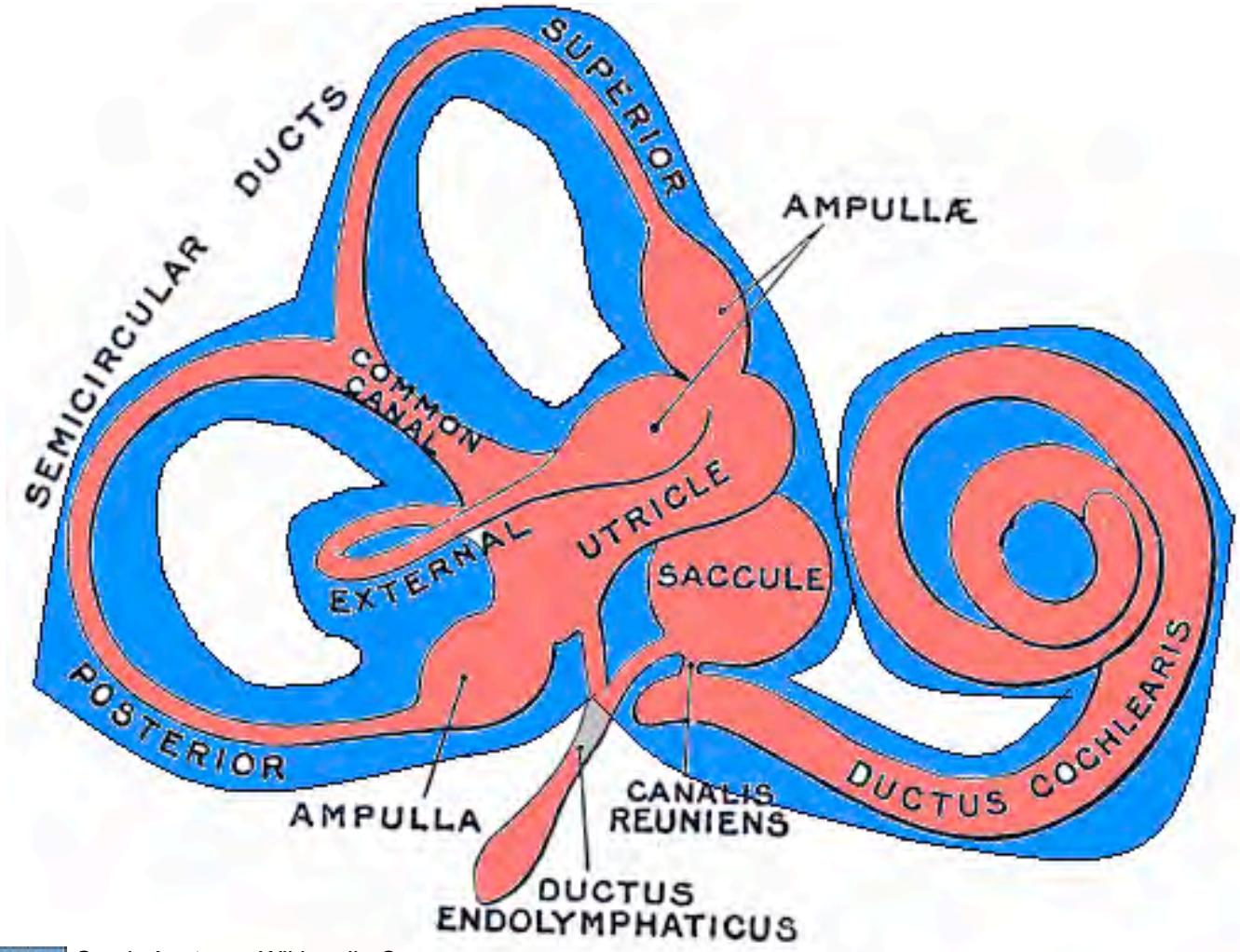
semi-circular canals

common bony limb

oval window

round window

Membranous labyrinth:
endolymph (red) / perilymph (blue)



PD-EXP Gray's Anatomy, Wikimedia Commons

Bony and membranous labyrinths

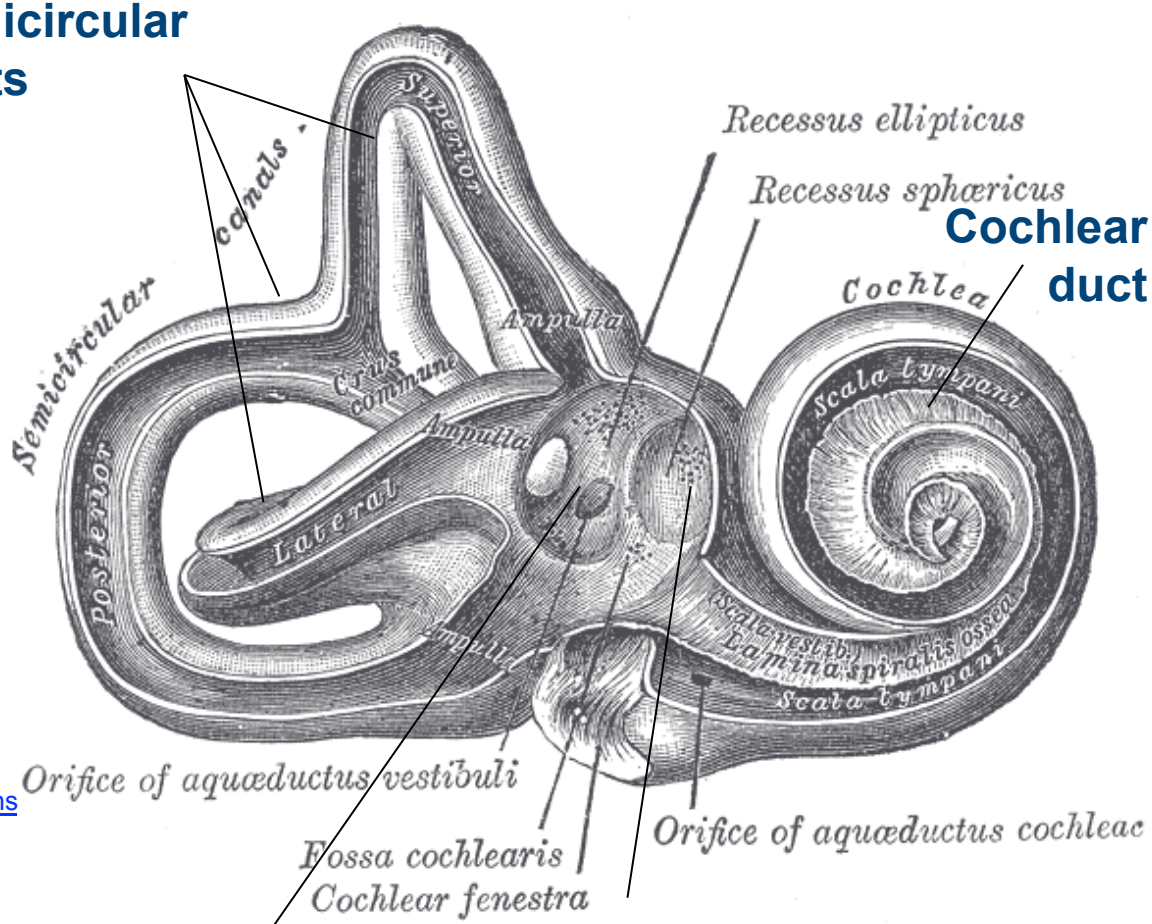
PD-SELF Pearson Scott Foresman, Wikimedia Commons

Semicircular ducts

Cochlear duct

Saccule

Utricle



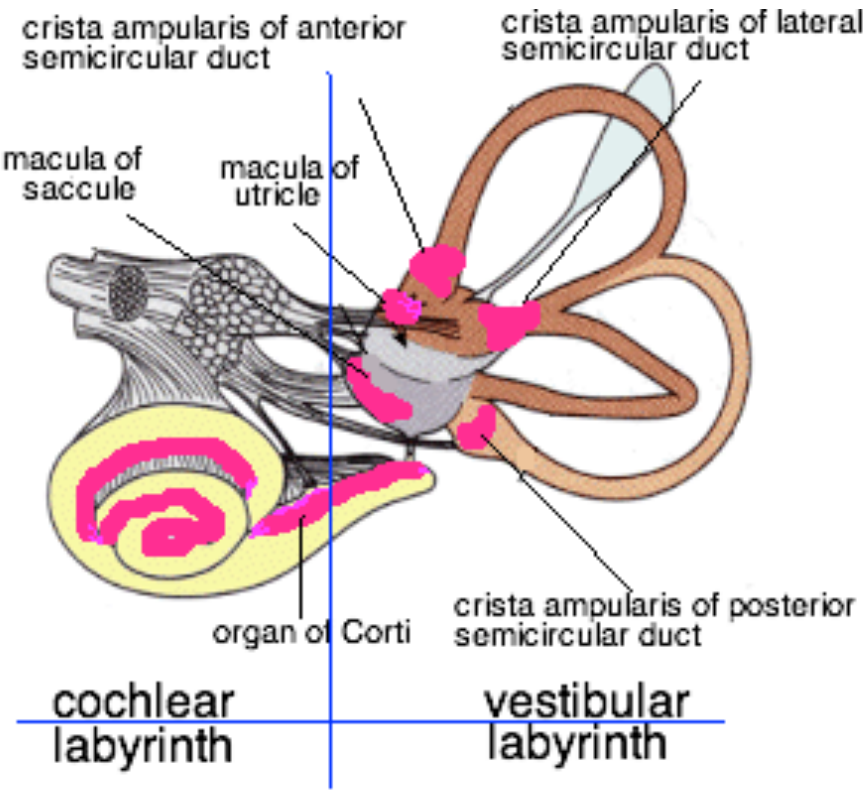
PD-EXP Gray's Anatomy

Perilymph vs endolymph

- Perilymph: bony labyrinth
- Like extracellular fluid
- High sodium,
- Low potassium
- Ultrafiltrate of plasma
- Low protein

- Endolymph: mem. labyrinth
- Like intracellular fluid
- Low sodium
- High potassium
- Produced by stria vascularis
- Low protein

Sensory regions in Membranous Labyrinth

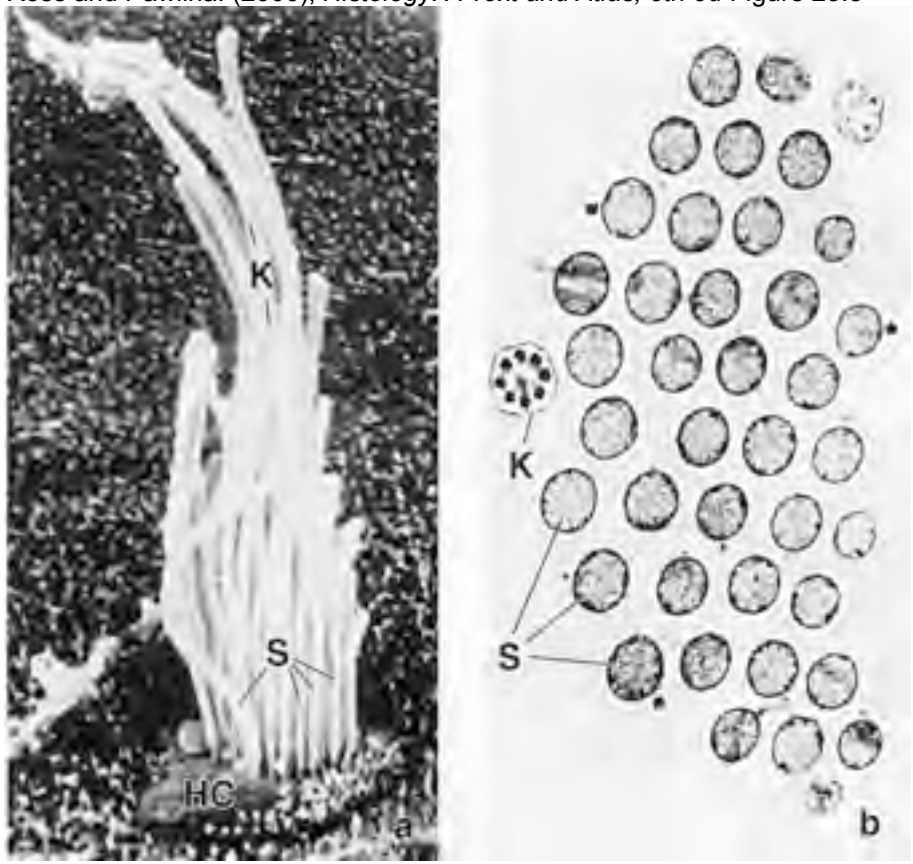


Sensory Regions in Membranous Labyrinth

Sensory regions contain specialized sensory cells, aka “hair cells”

Drawing of Type I and Type II hair cells removed removed

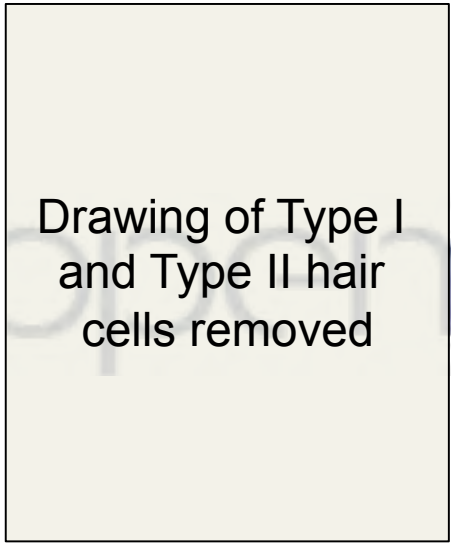
Ross and Pawlina. (2006), *Histology: A Text and Atlas, 5th ed* Figure 25.8



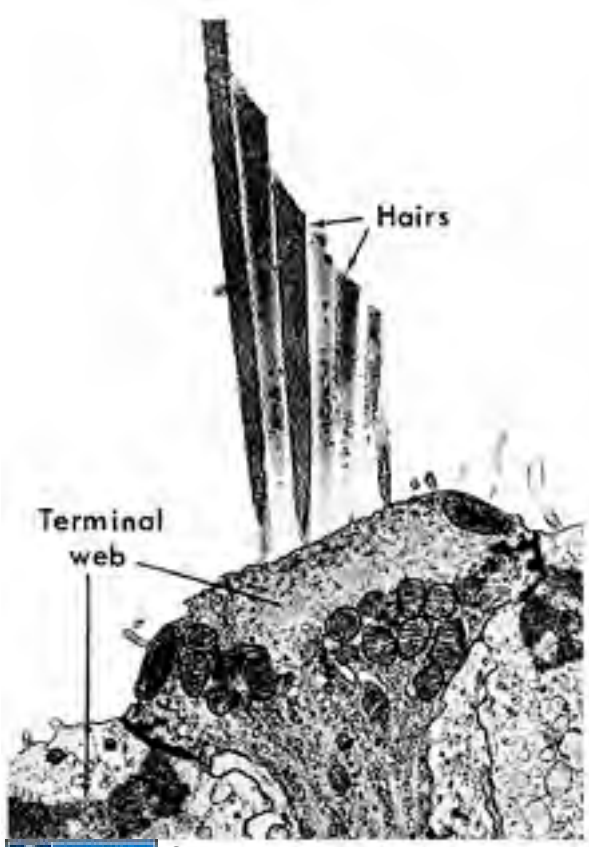
S = stereocilia (about 50-150 per cell) – very long microvilli with actin cores

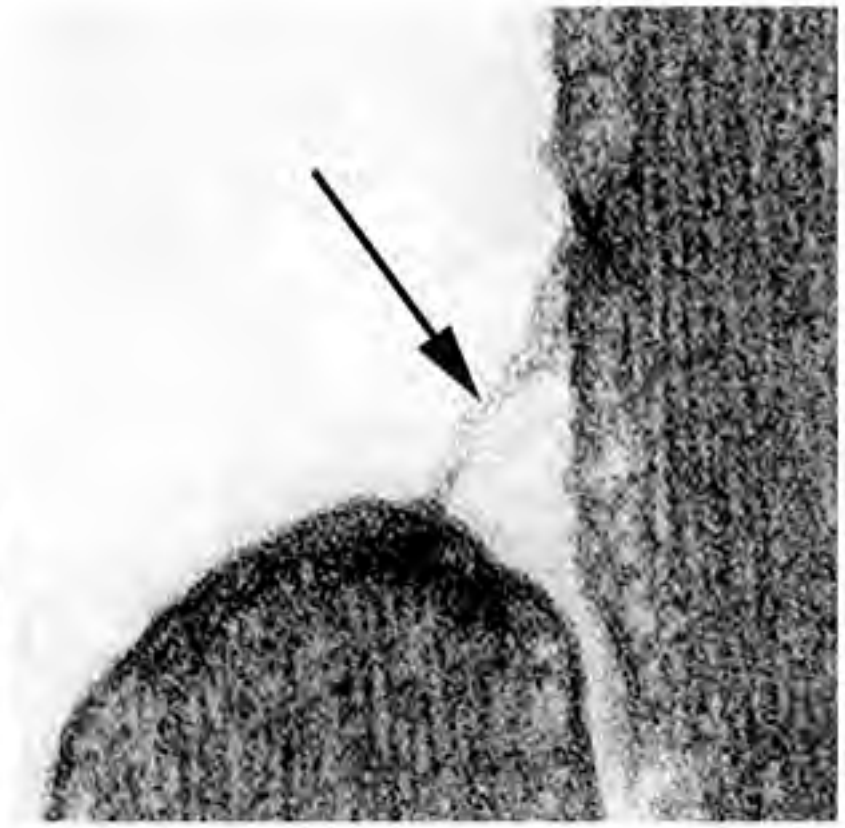
K = kinocilium (1 per cell) – <u>true</u> cilium with 9+2 arrangement of microtubules

Sensory (hair) cells

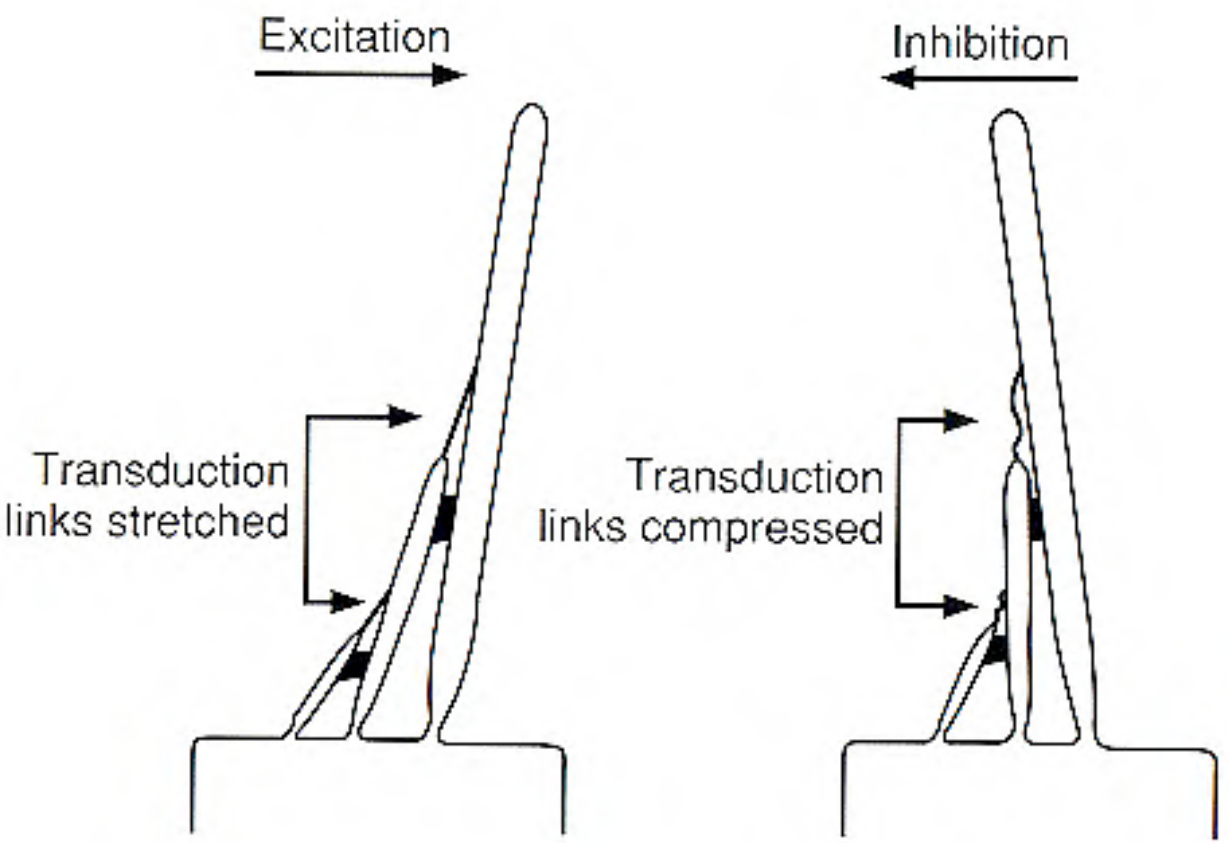


Stereocilia and tip links

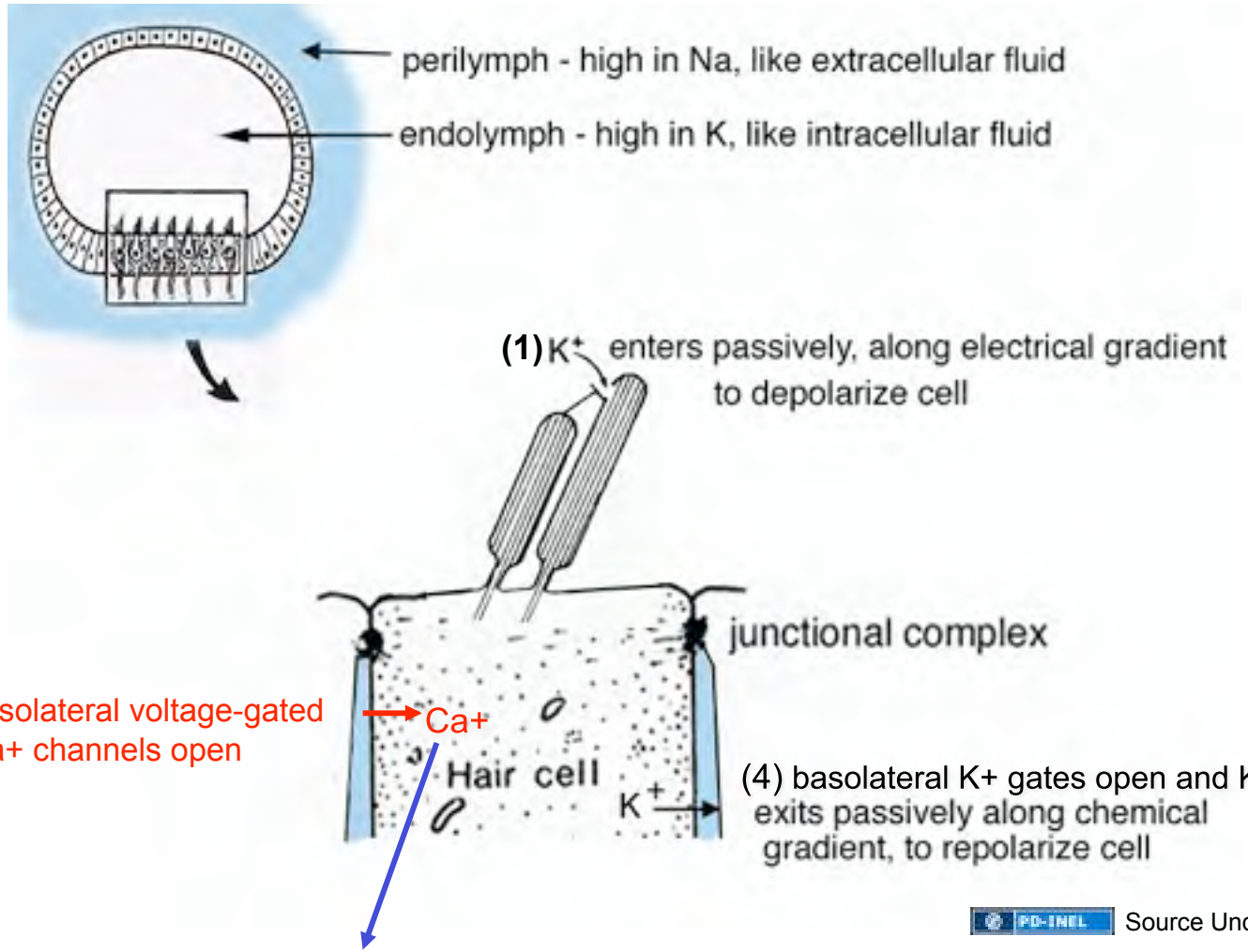




Tip-links open mechanically gated K^+ ion channels

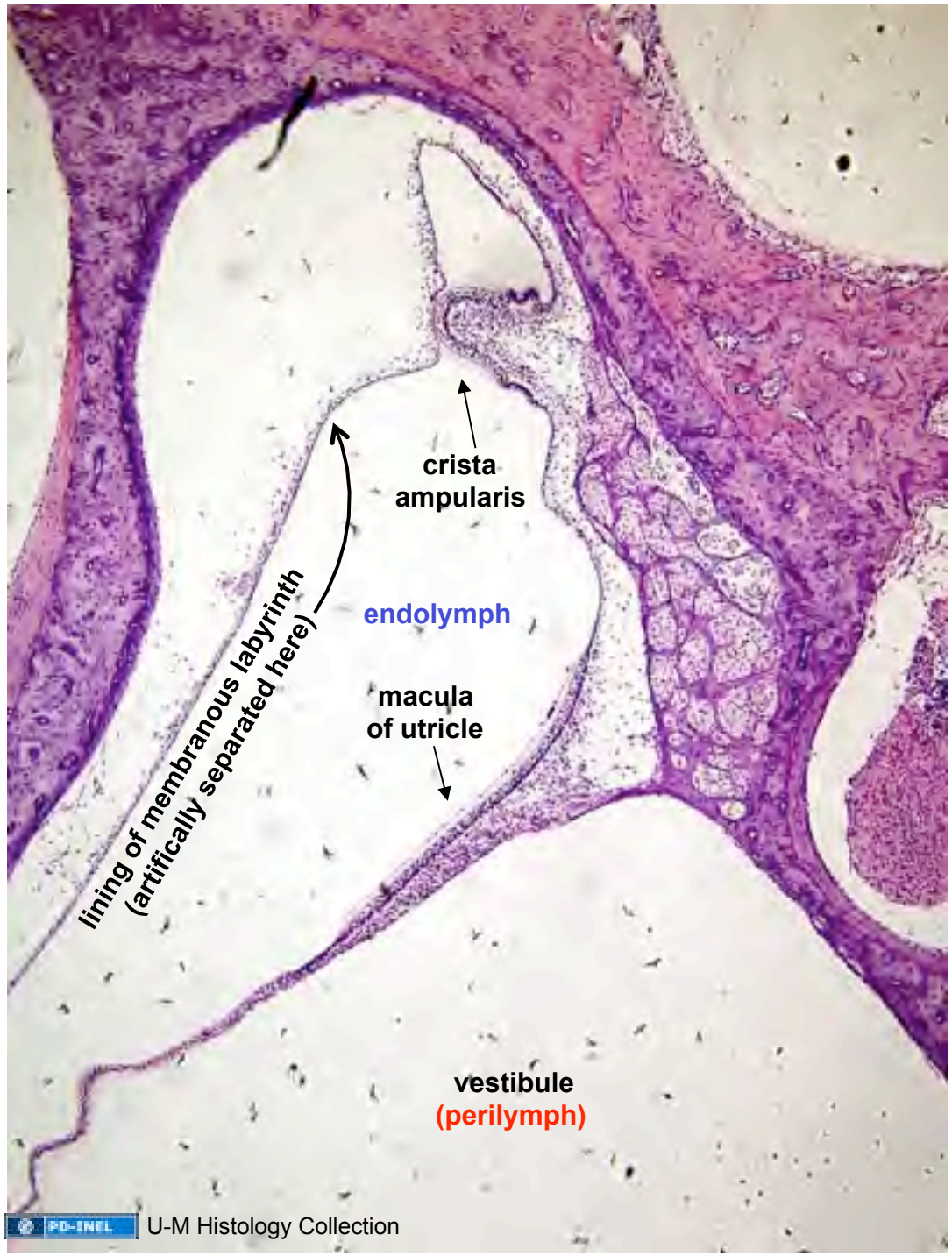


Potassium gradient drives depolarization



PD-INEL Source Undetermined

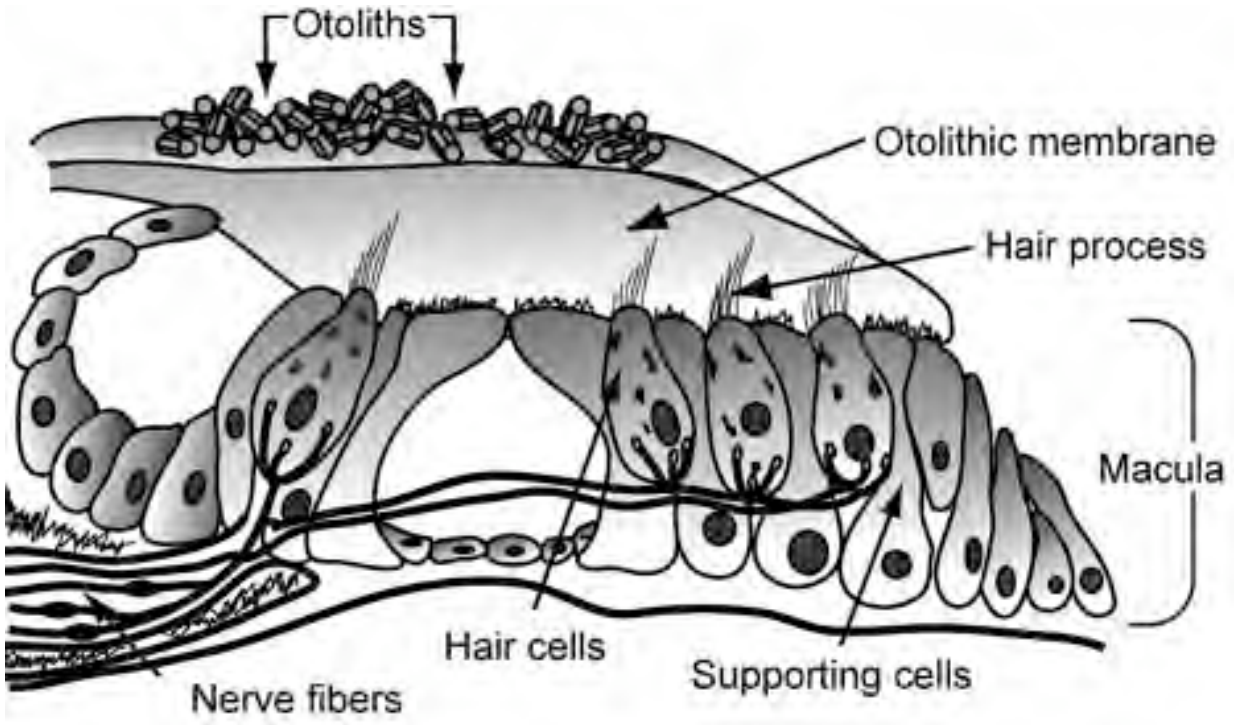
Macula: patch of sensory cells in utricle and saccule



innervated by branches of vestibular nerve

Maculae detect linear acceleration

Inertia causes otoliths and otolithic membrane to lag behind during linear acceleration; shearing effect bends stereocilia



Macula

otoliths & otolithic membrane
(type II collagen, otogelin)

stereocilia

hair cells

sustentacular cells

loose connective tissue:
- nerve fibers
- Schwann cells
- fibroblasts / collagen III
- extracellular fluid
  (similar to perilymph)

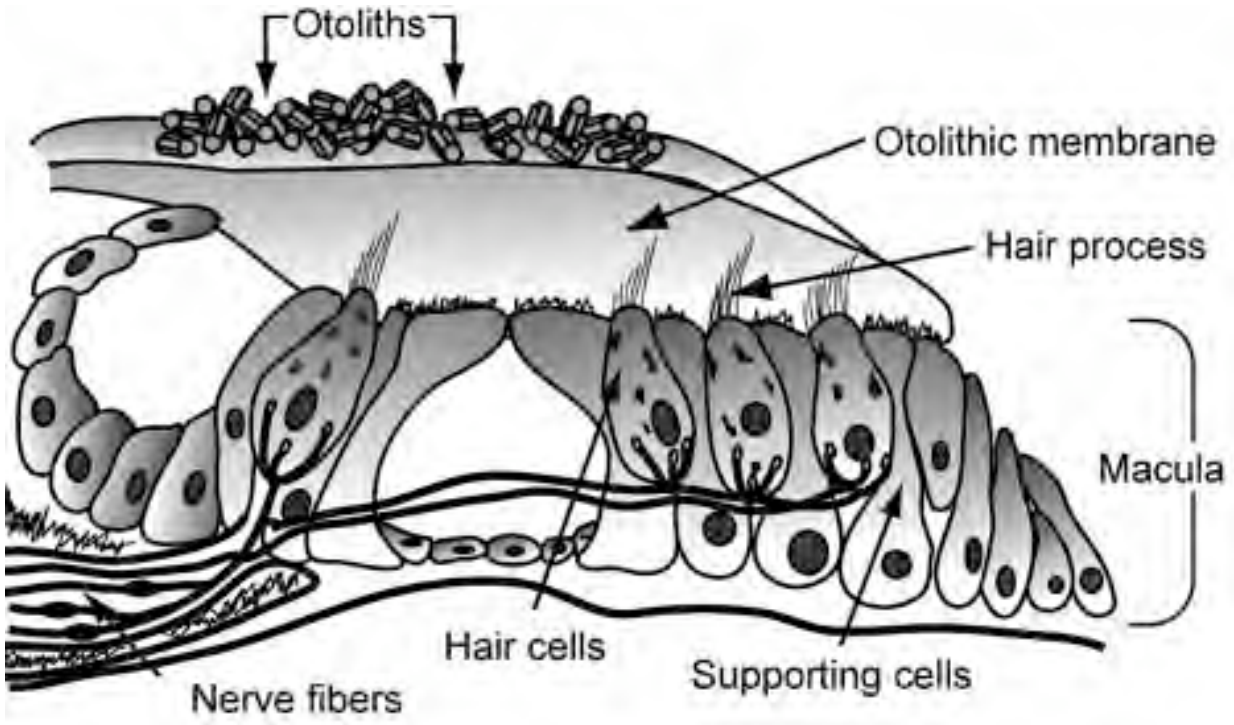
Otoconia/statoconia/otoliths (fish)

calcium carbonate, otoconins

PD-INEL Source Undetermined

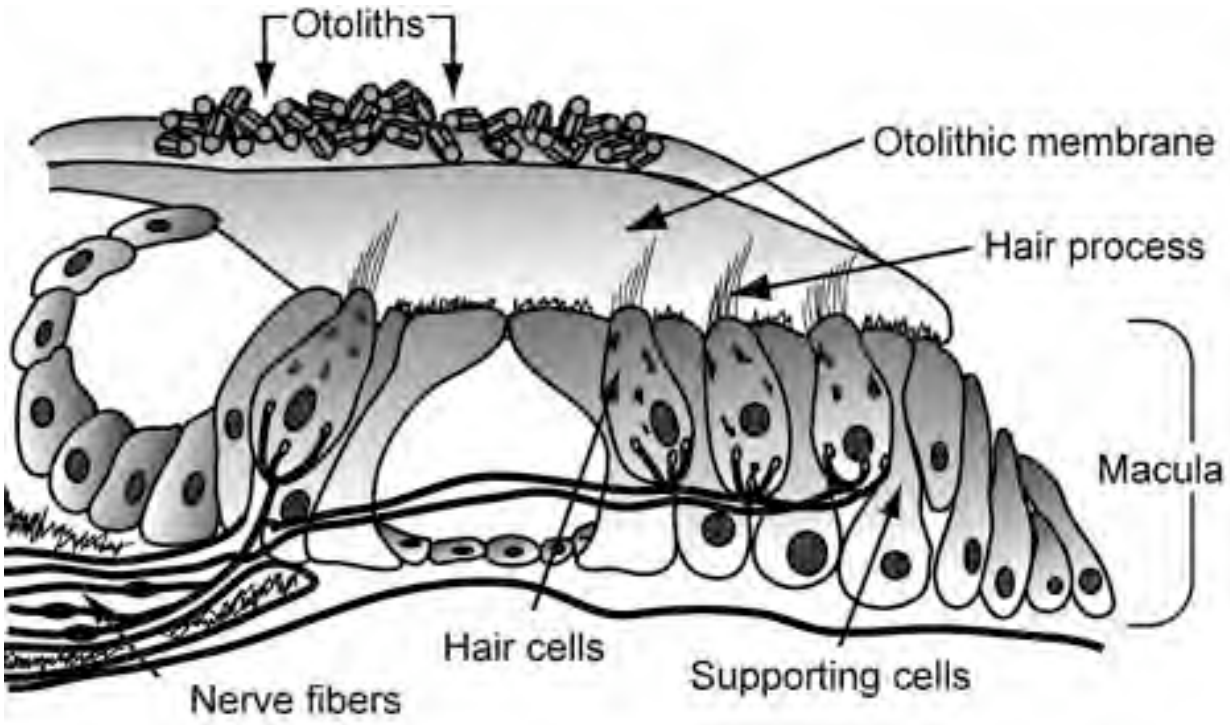
Maculae detect linear acceleration

Inertia causes otoliths and otolithic membrane to lag behind during linear acceleration; shearing effect bends stereocilia

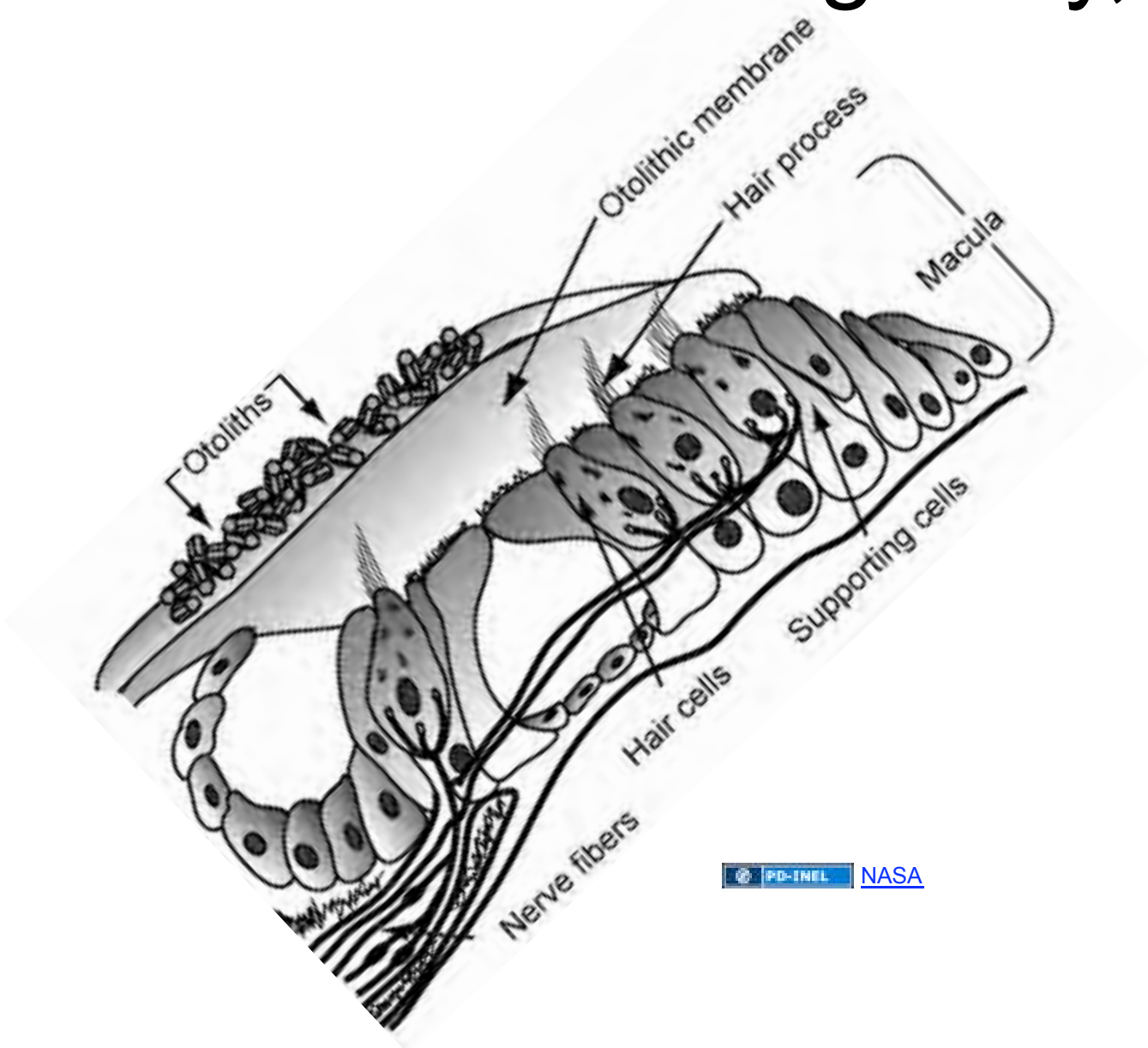


Maculae can also detect deceleration

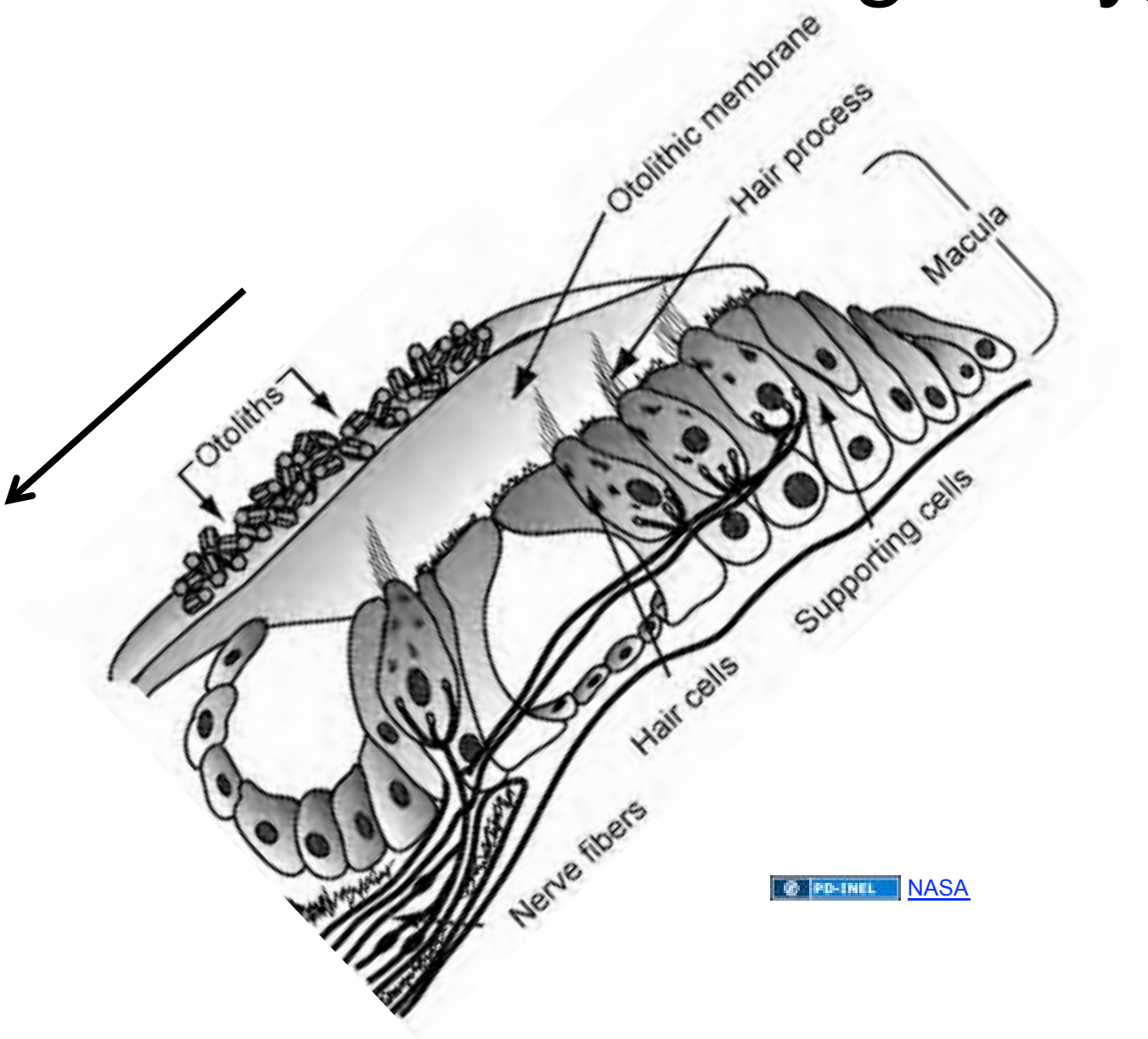
During deceleration, inertia carries otoliths and otolithic membrane forward and bends stereocilia in the other direction. This decreases their firing rate, which the brain interprets as deceleration.



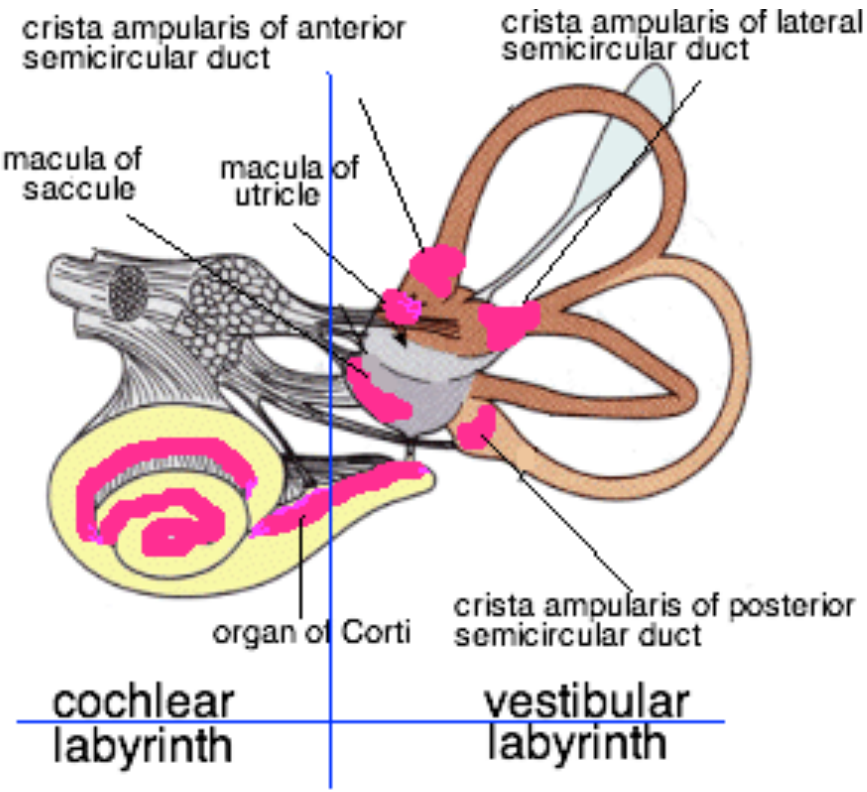
Maculae can detect gravity, too



Maculae can detect gravity, too



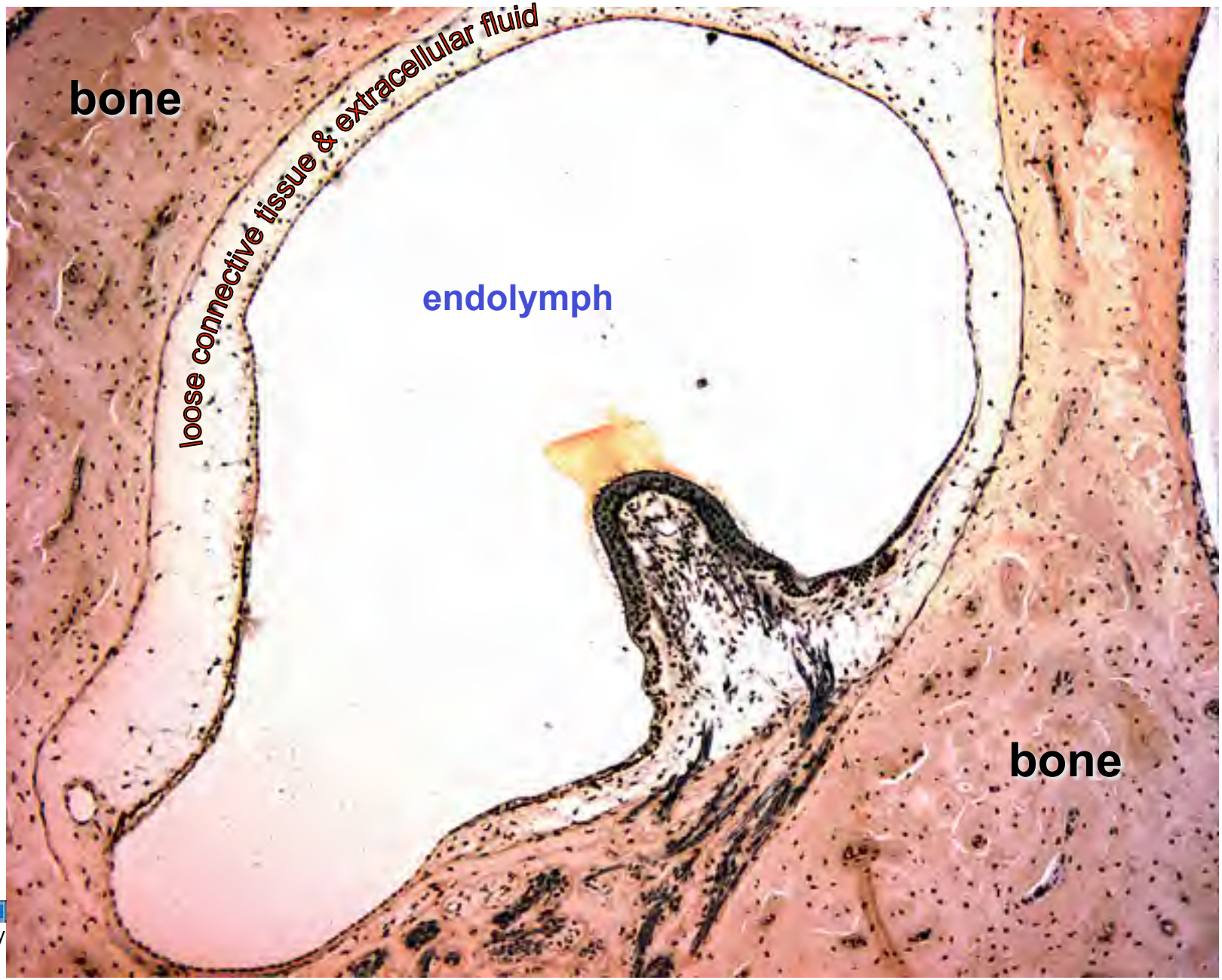
Sensory regions



Semicircular ducts

Crista ampullaris:
ridge of sensory cells in ampulla of each semicircular canal

Crista ampullaris



Crista Ampularis

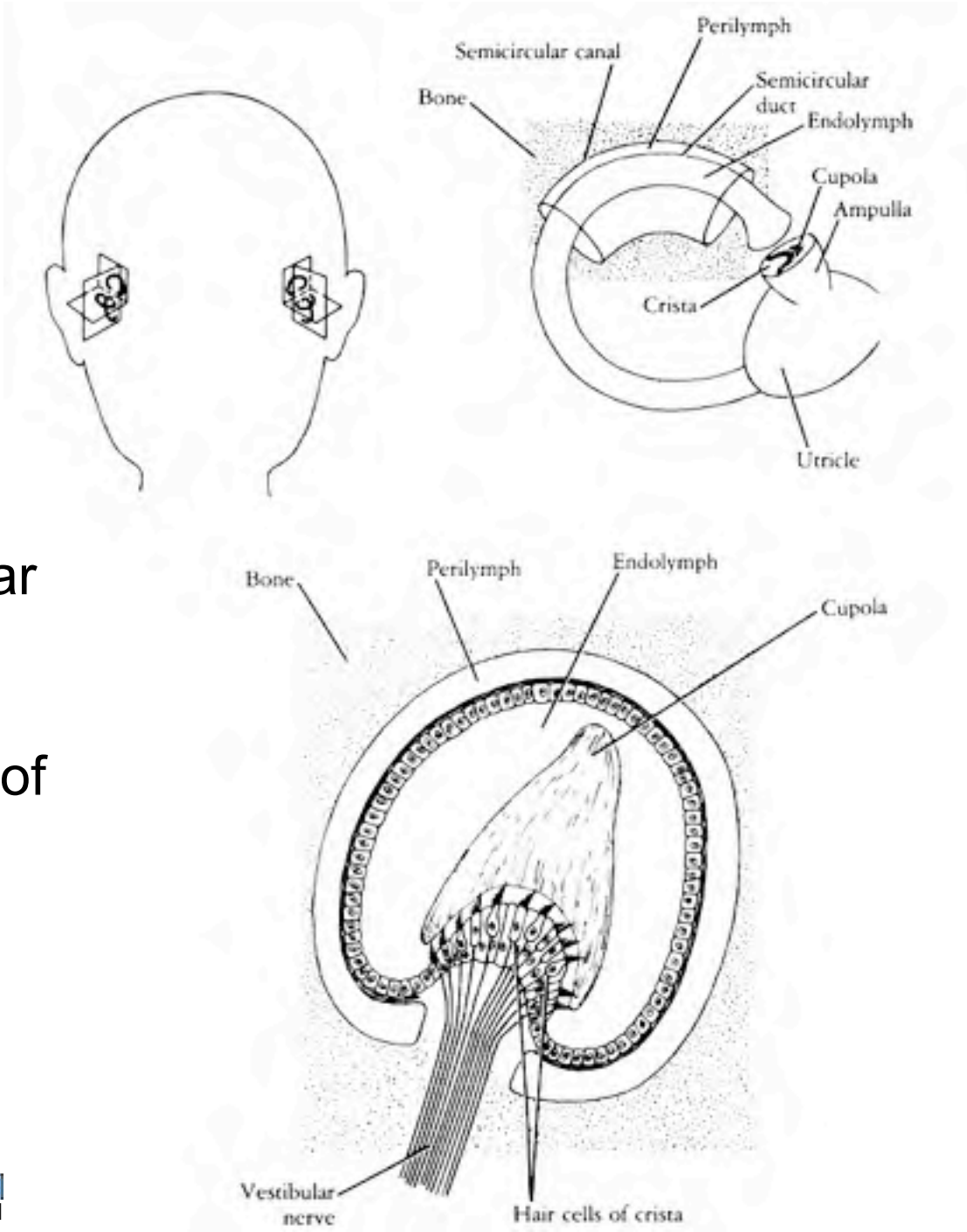
Gelatinous cupula

Hair cells

Sustentacular Cells

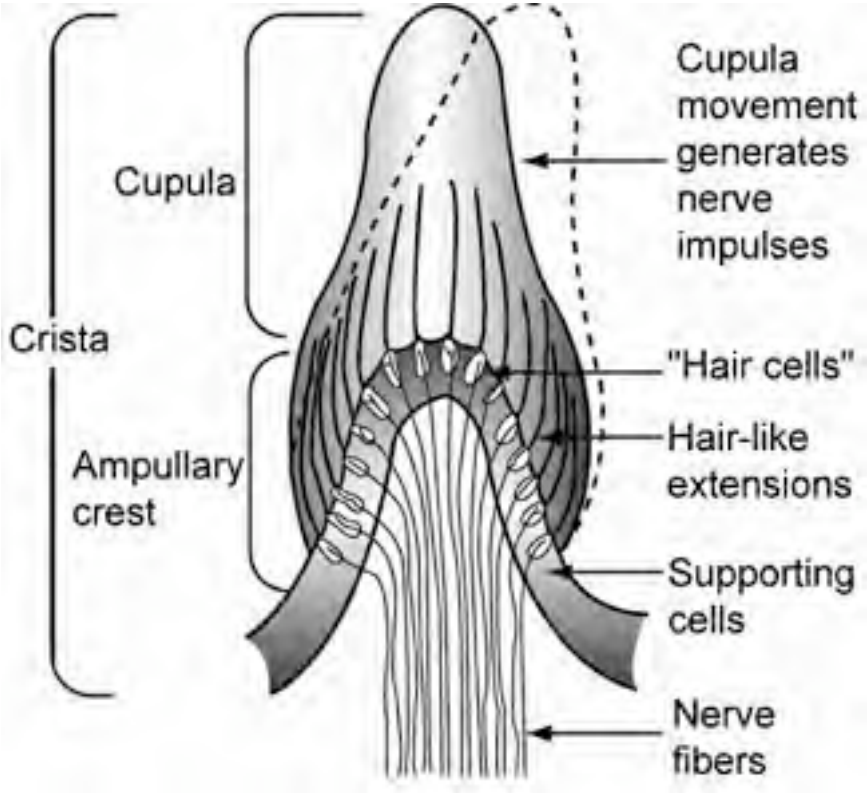
Nerve fibers
(and Schwann cells)

Deflection of stereocilia of crista ampularis hair cells:



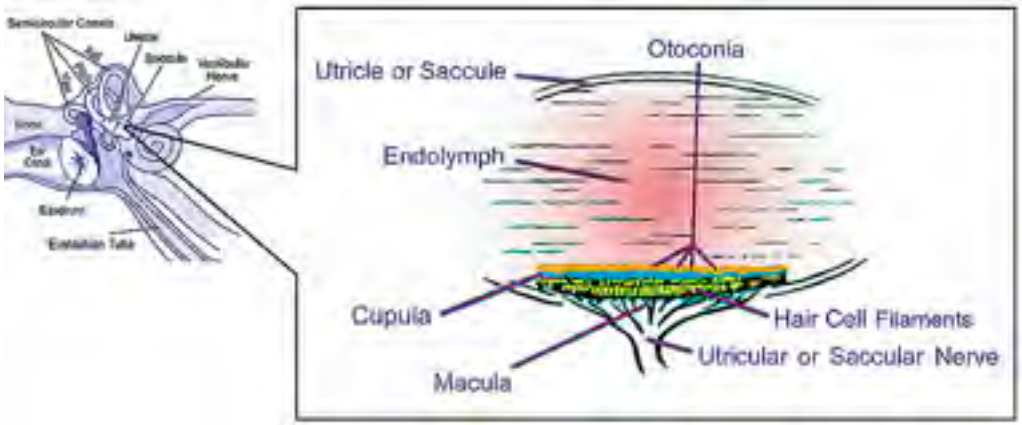
When head is turned, fluid (endolymph) in semicircular canal lags behind causing deflection of cupula which in turn deflects stereocilia of hair cells.

Crista ampularis: angular acceleration



PD-INEL NASA, Wikimedia Commons

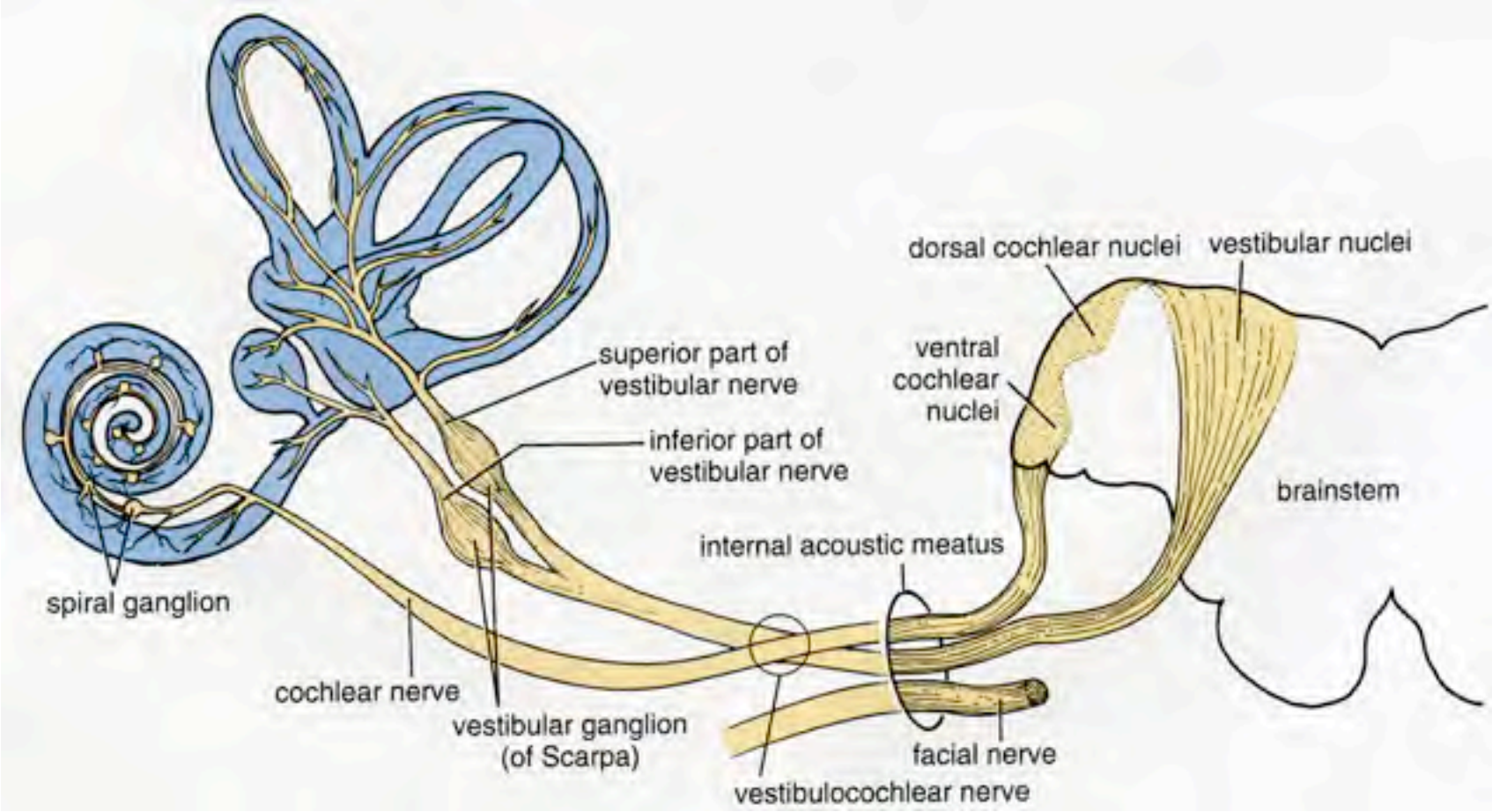
Macula: linear acceleration



PD-GOV U.S. Federal Government

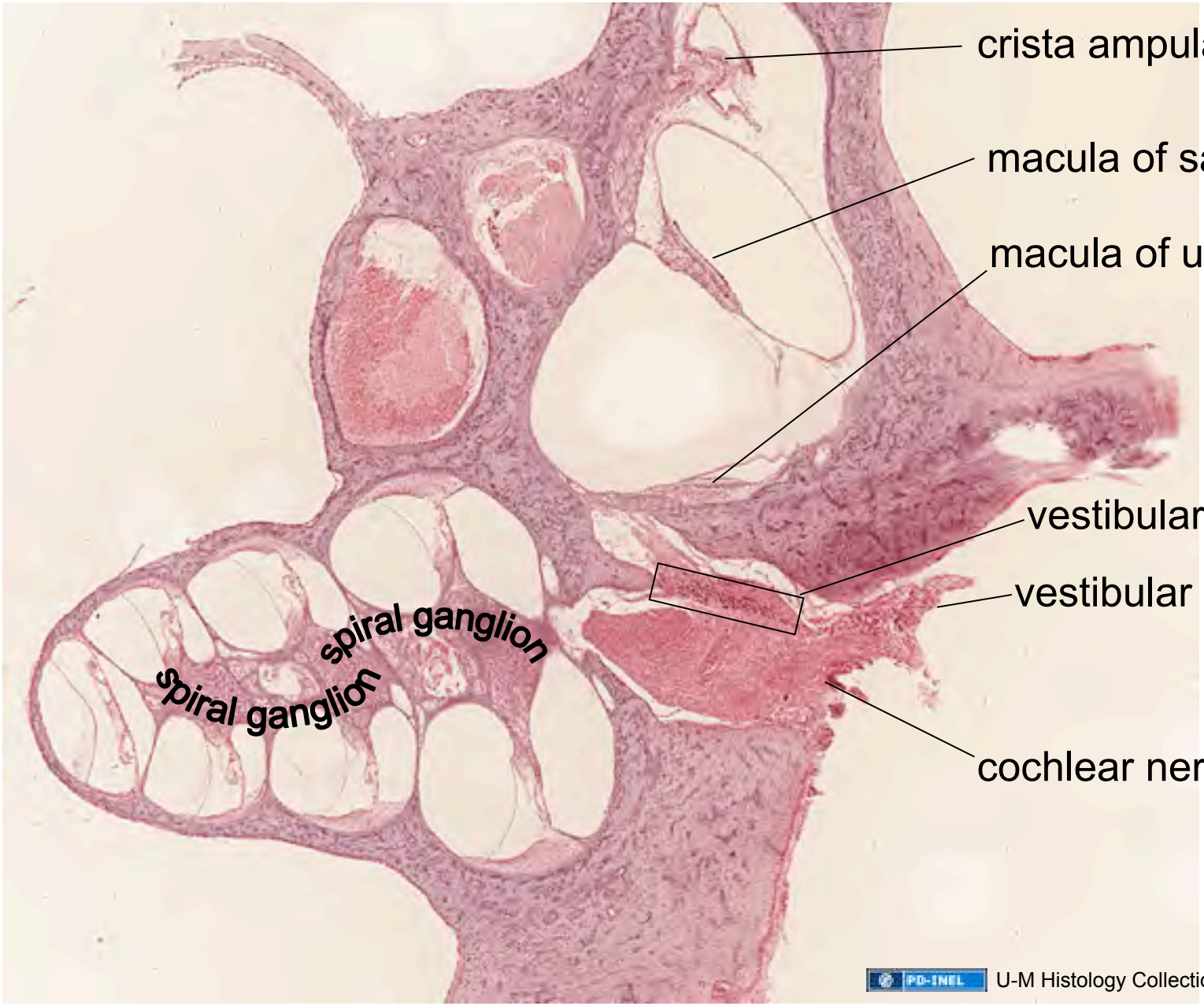
Innervation of vestibular sense organs:

vestibular hair cells innervated by bipolar sensory neurons in vestibular (Scarpa's) ganglion

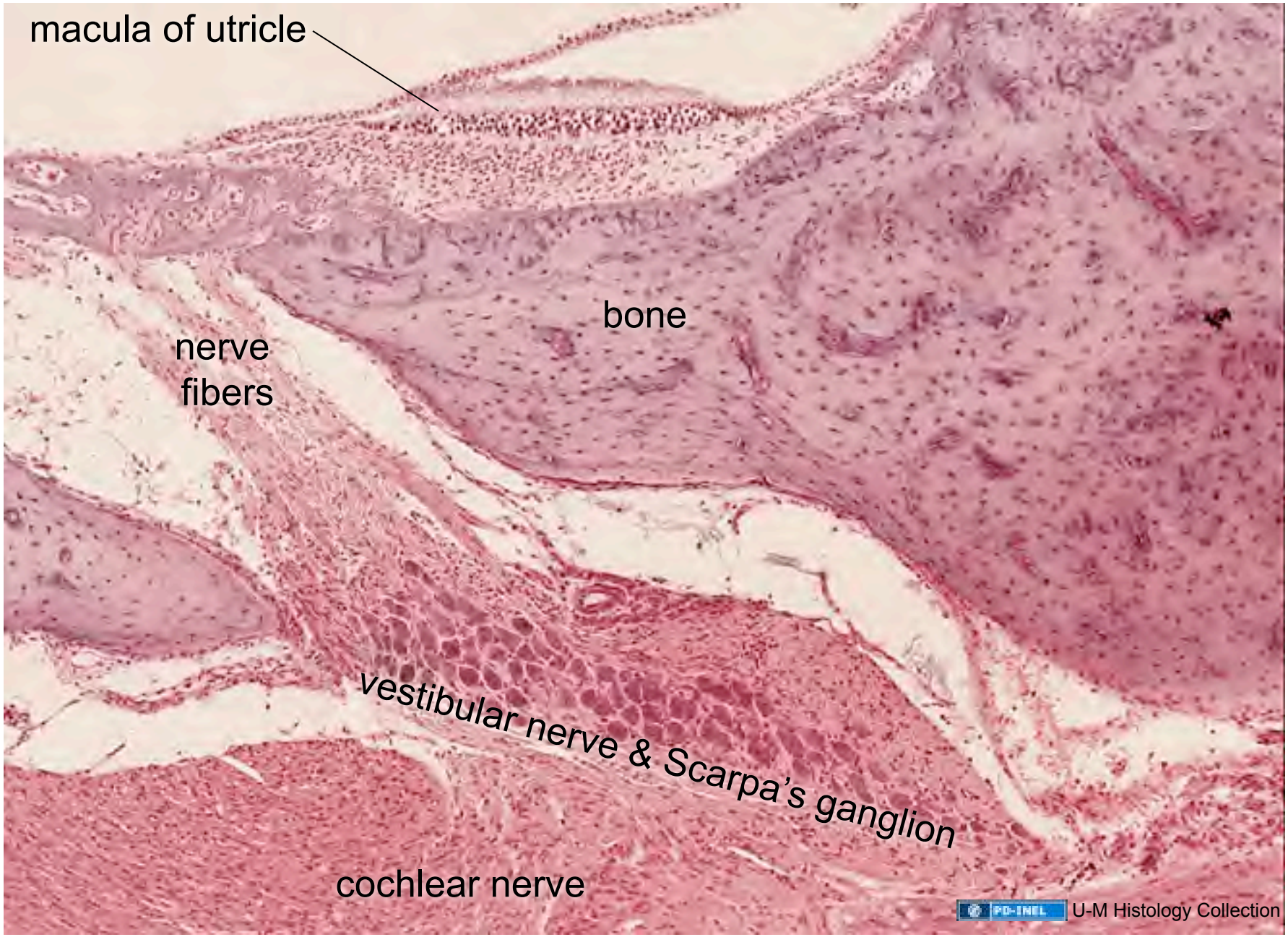


 Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* fig 25.22, pg. 882

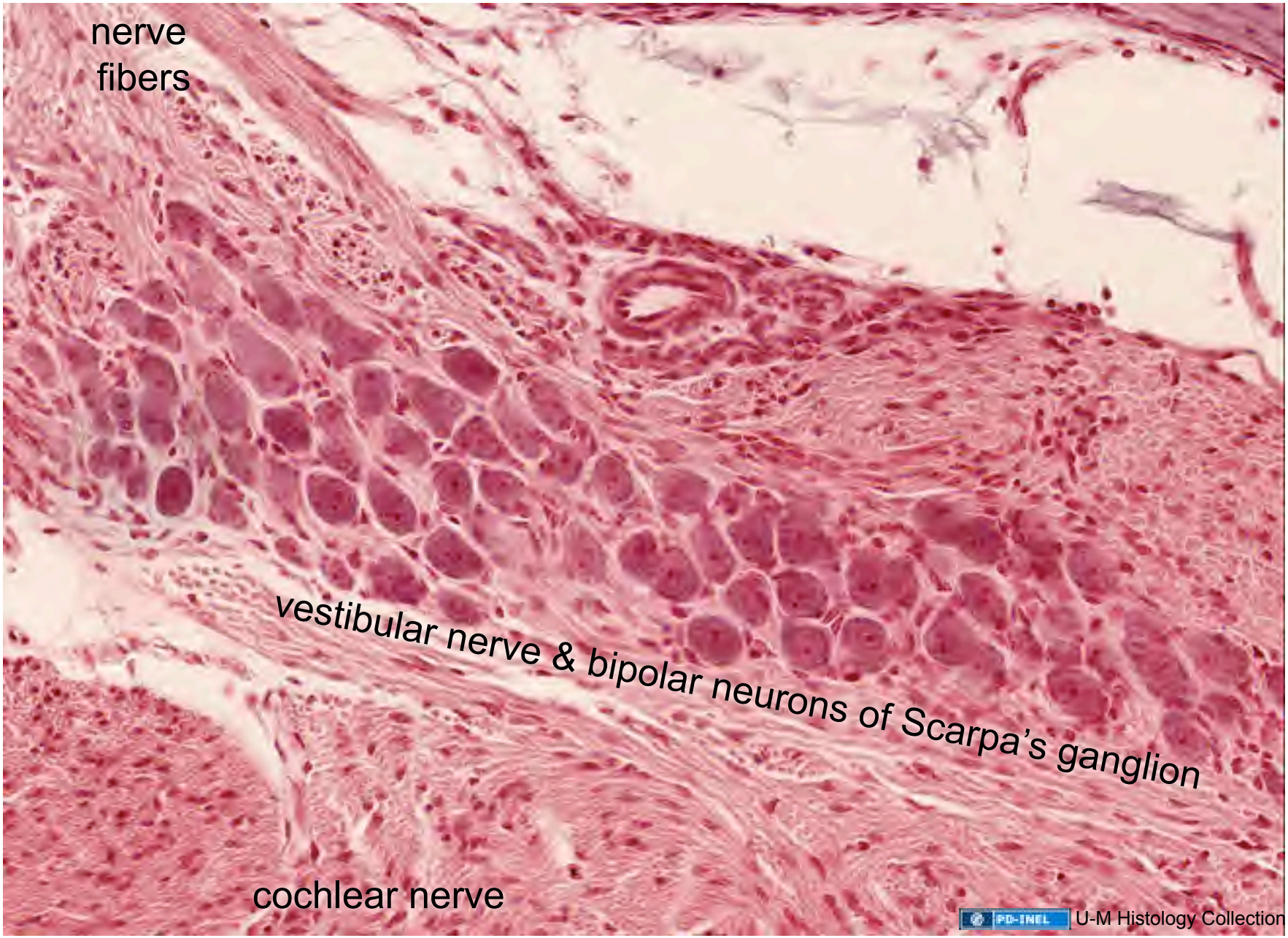
Vestibular (Scarpa's) ganglion



Vestibular (Scarpa's) ganglion



Vestibular (Scarpa's) ganglion

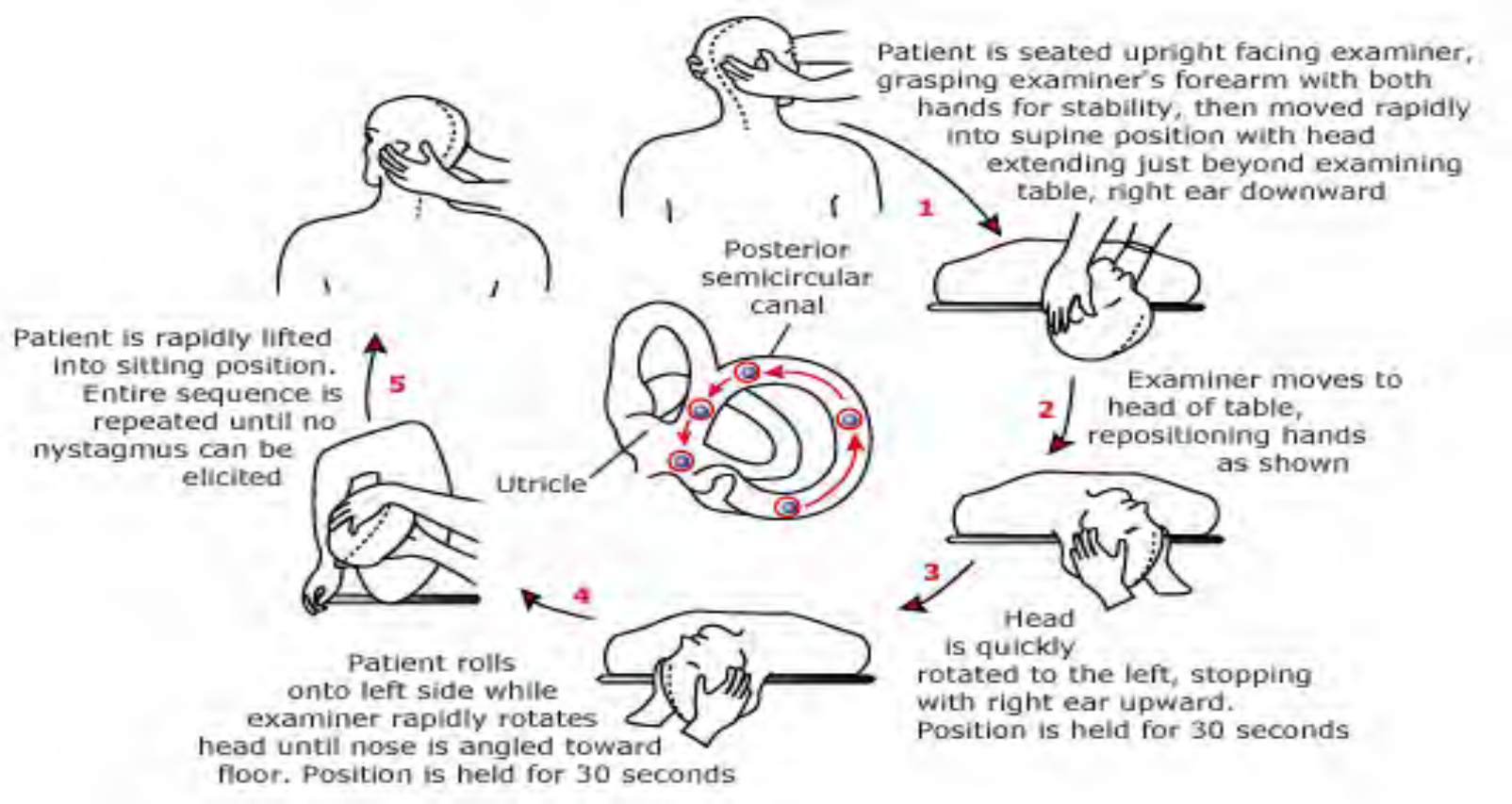


Benign Positional Vertigo:

or, what happens when an accelerometer becomes a gravitometer

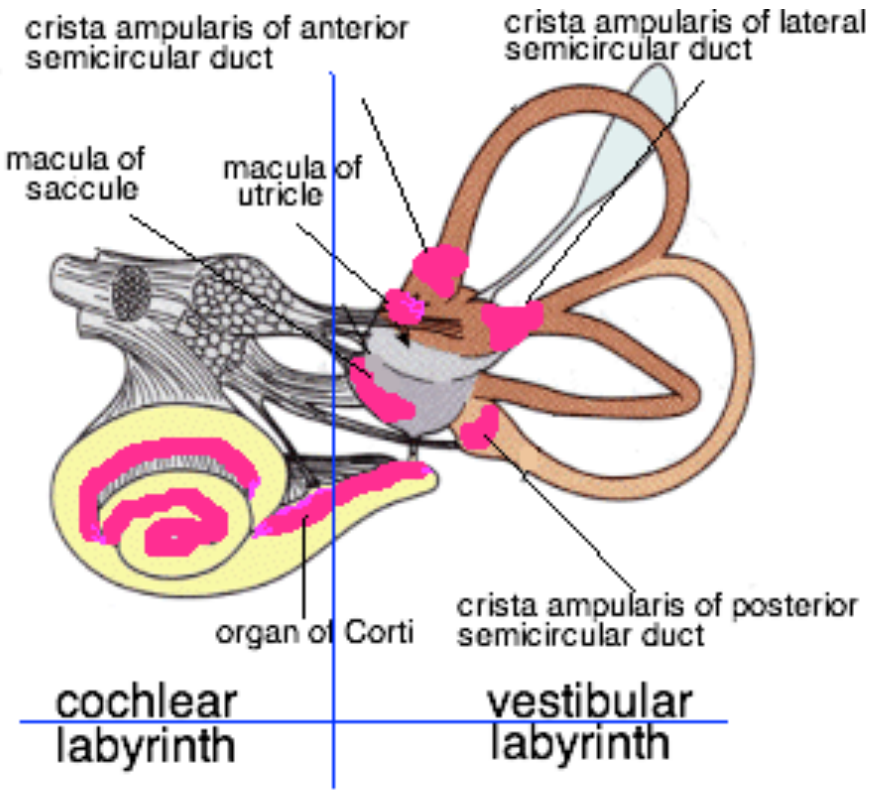
- otoliths dislodged from macula of utricle and become embedded in cupula of a crista ampularis (usually posterior semicircular canal)
- pull of gravity on otoliths deflects cupula stimulating the hair cells
- stimulation of crista hair cells interpreted by brain as angular acceleration –i.e. spinning sensation
- Can be treated by moving the head in such a way to return otoliths to macula (Epley maneuver)

The Epley Maneuver (purely FYI)



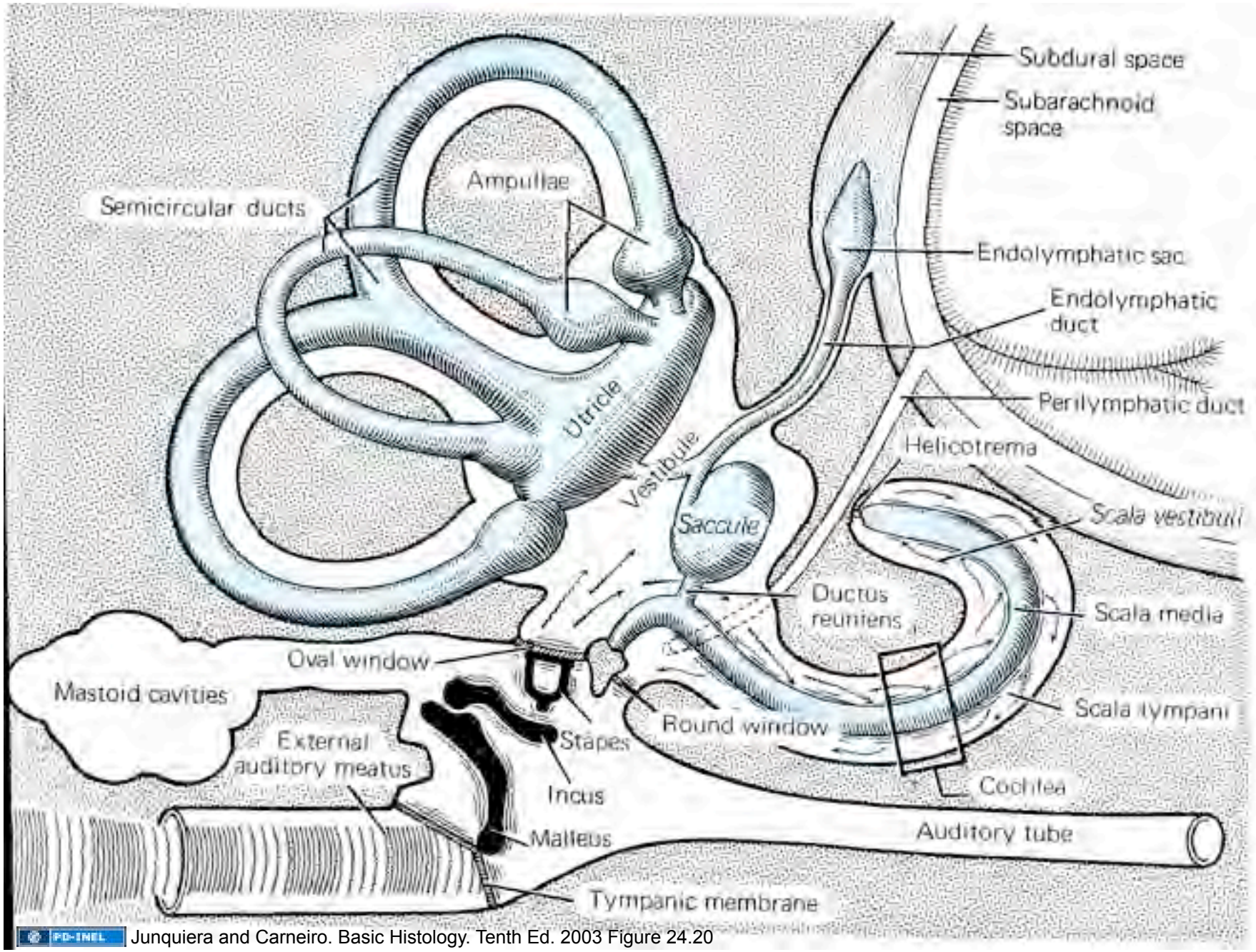
PD-INEL *Up To Date*

Sensory regions



 Thomas.haslwanter, Wikipedia

Cochlear duct: 35 mm, from saccule



PD-INEL Junquiera and Carneiro. Basic Histology. Tenth Ed. 2003 Figure 24.20

Cochlear canal: oval window to round window

The cochlear canal is wound around a central bony shaft (the modiolus)

Three spiraling compartments around a central shaft (the modiolus)

Scala vestibuli (perilymph)

Scala media (endolymph)

Scala tympani (perilymph)

scala = stairway (latin)

Sound waves are converted into mechanical vibrations at tympanic membrane and travel up through perilymph in scala vestibuli…

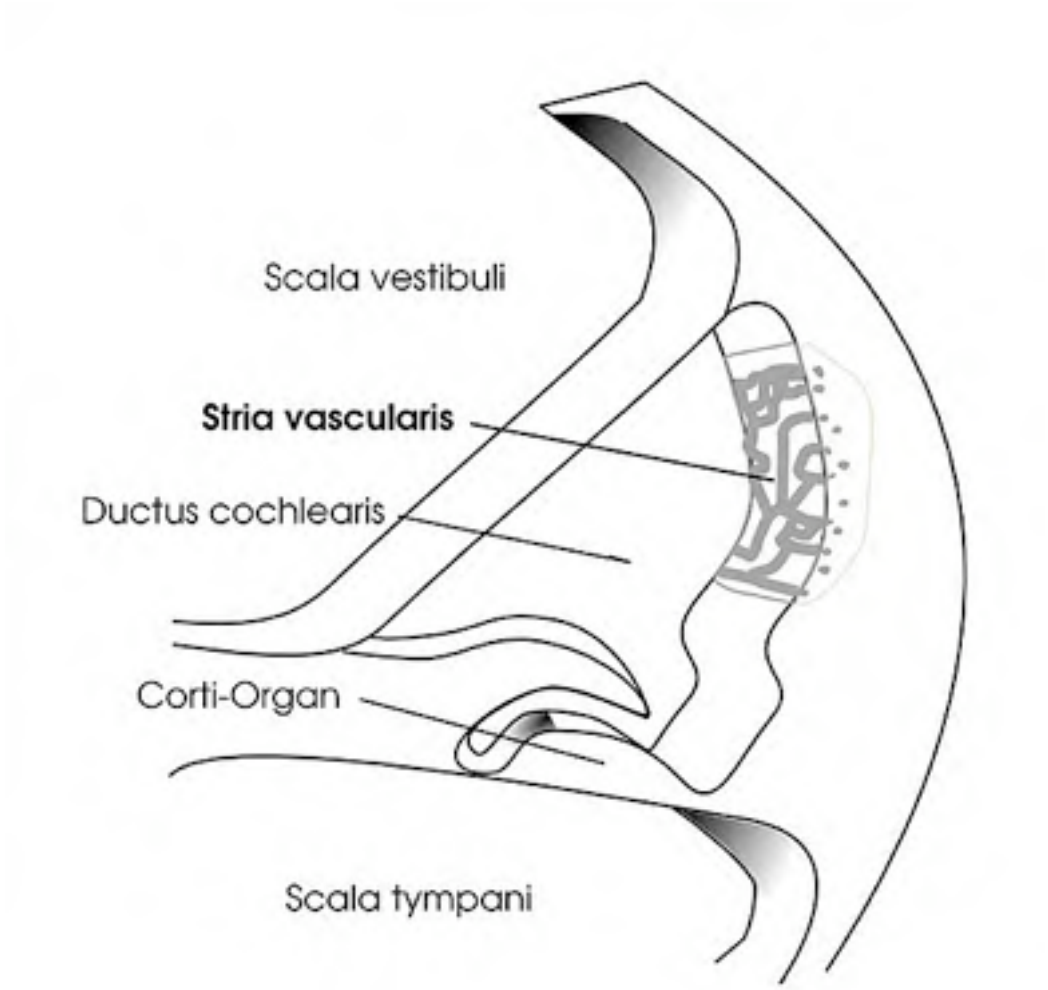
make U-turn at helicotrema…

travel down scala tympani…

and end at round window at the base of the cochlea.

PD-INEL U-M Histology Collection

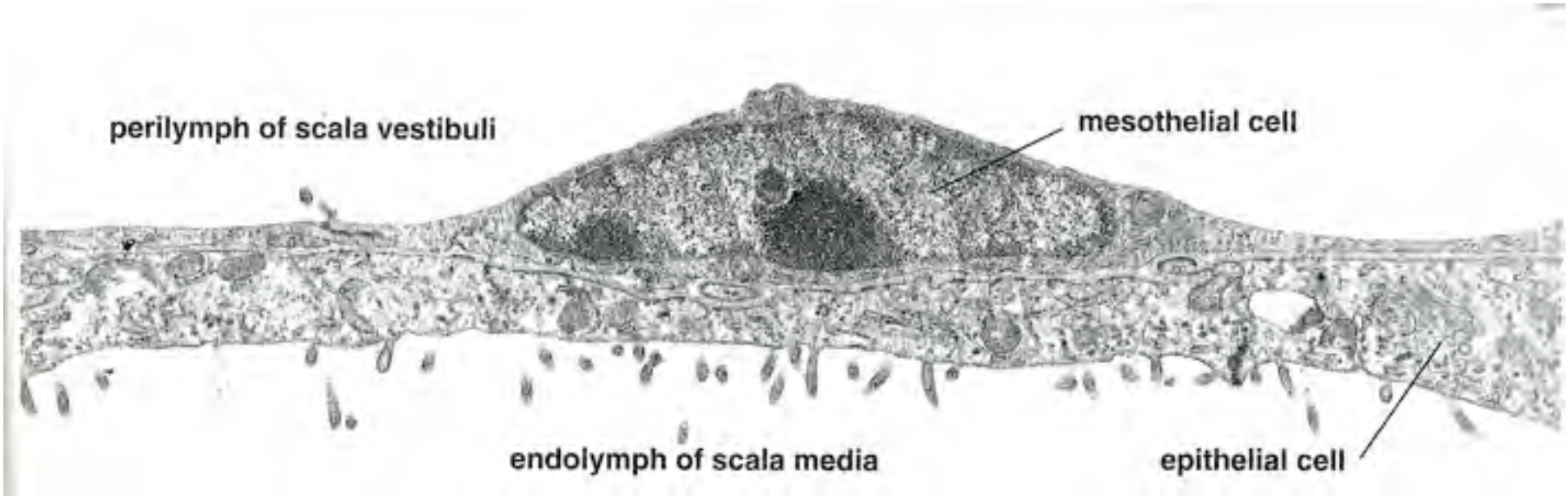
Cochlea



- Vestibular membrane
- Basilar membrane
- Tight Junctions
  isolate endolymph from perilymph
- Stria vascularis**
  ion transport, produces endolymph
- Spiral ganglion cells
  (bipolar sensory neurons)
- Osseous spiral lamina
  (extend from the modiolus like threads of a screw)
- Tectorial membrane (gelatinous)
- Organ of Corti
- "Corticolymph" (like perilymph):
  extracellular fluid within organ of Corti

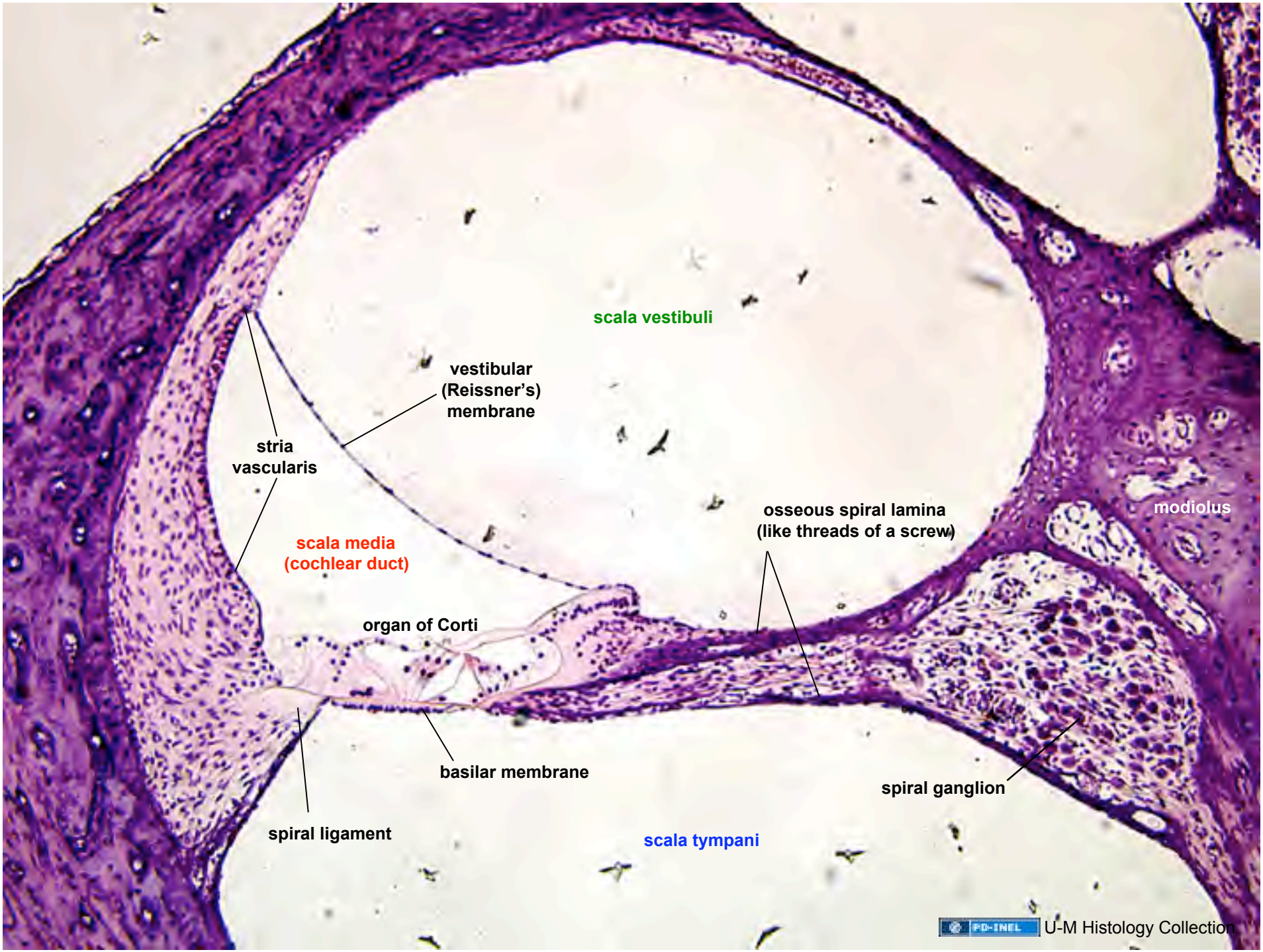
**Meniere's syndrome:
overproduction and/or poor drainage of endolymph –dizziness, tinnitus

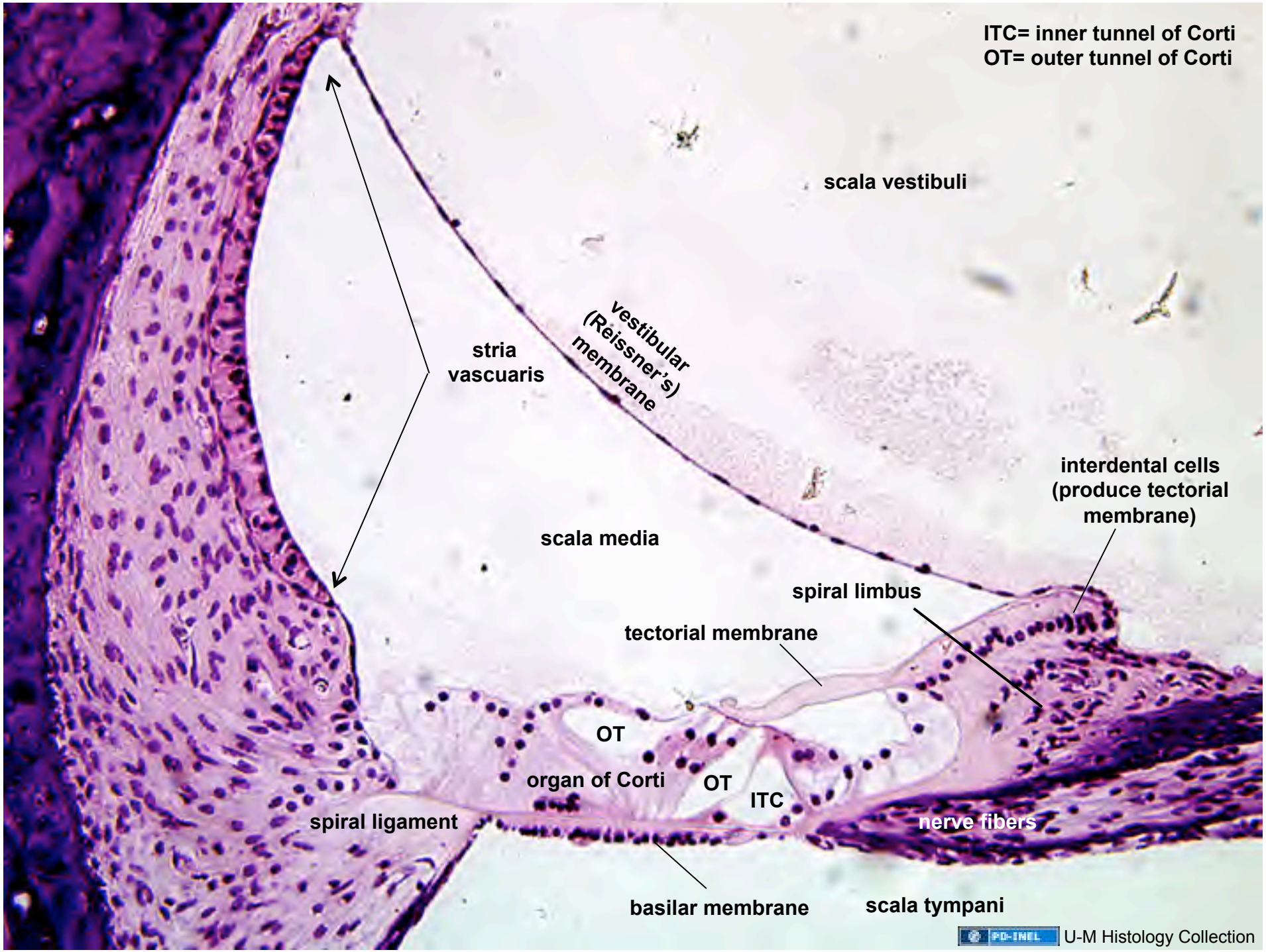
Vestibular Membrane



PD-INEL Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed*. Figure 25.15.

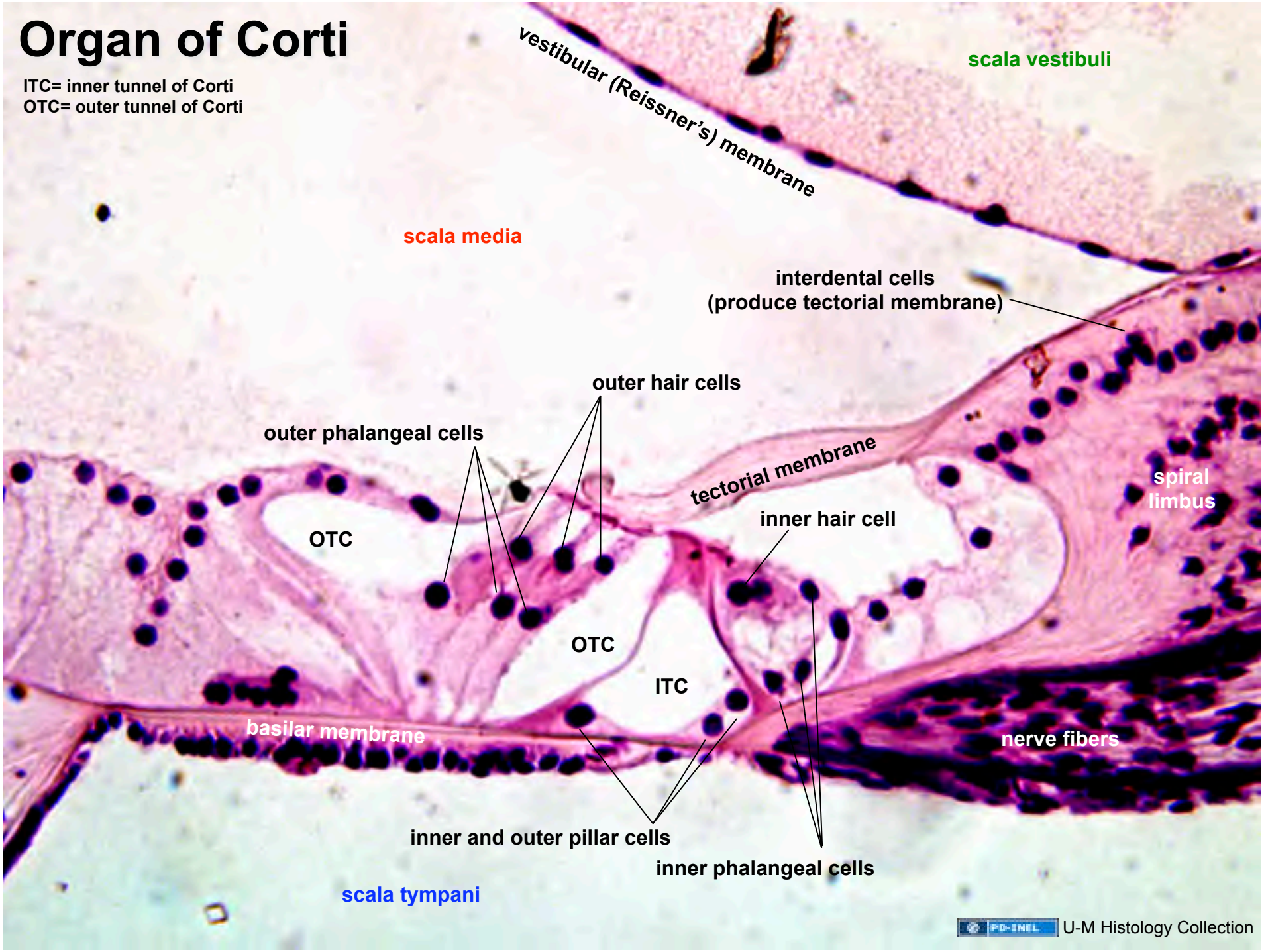
- Double epithelium (common basement membrane)
- Separates endolymph in scala media from perilymph in scala vestibuli (note junctions)




ITC= inner tunnel of Corti
OT= outer tunnel of Corti
scala vestibuli
vestibular (Reissner's) membrane
stria vascuaris
interdental cells (produce tectorial membrane)
scala media
spiral limbus
tectorial membrane
OT
organ of Corti
OT
ITC
spiral ligament
nerve fibers
basilar membrane
scala tympani
PD-INEL
U-M Histology Collection

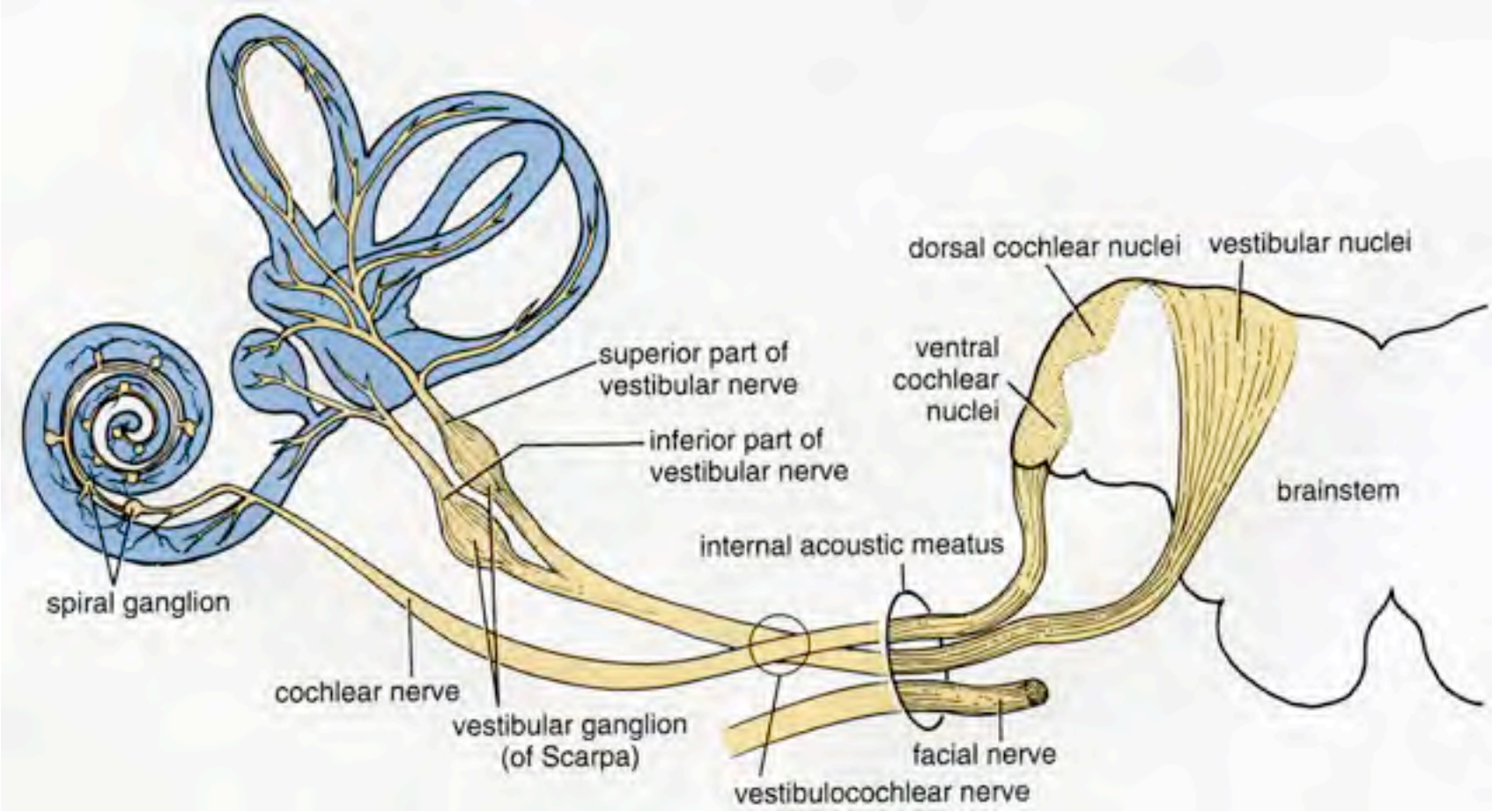
Organ of Corti

ITC= inner tunnel of Corti
OTC= outer tunnel of Corti



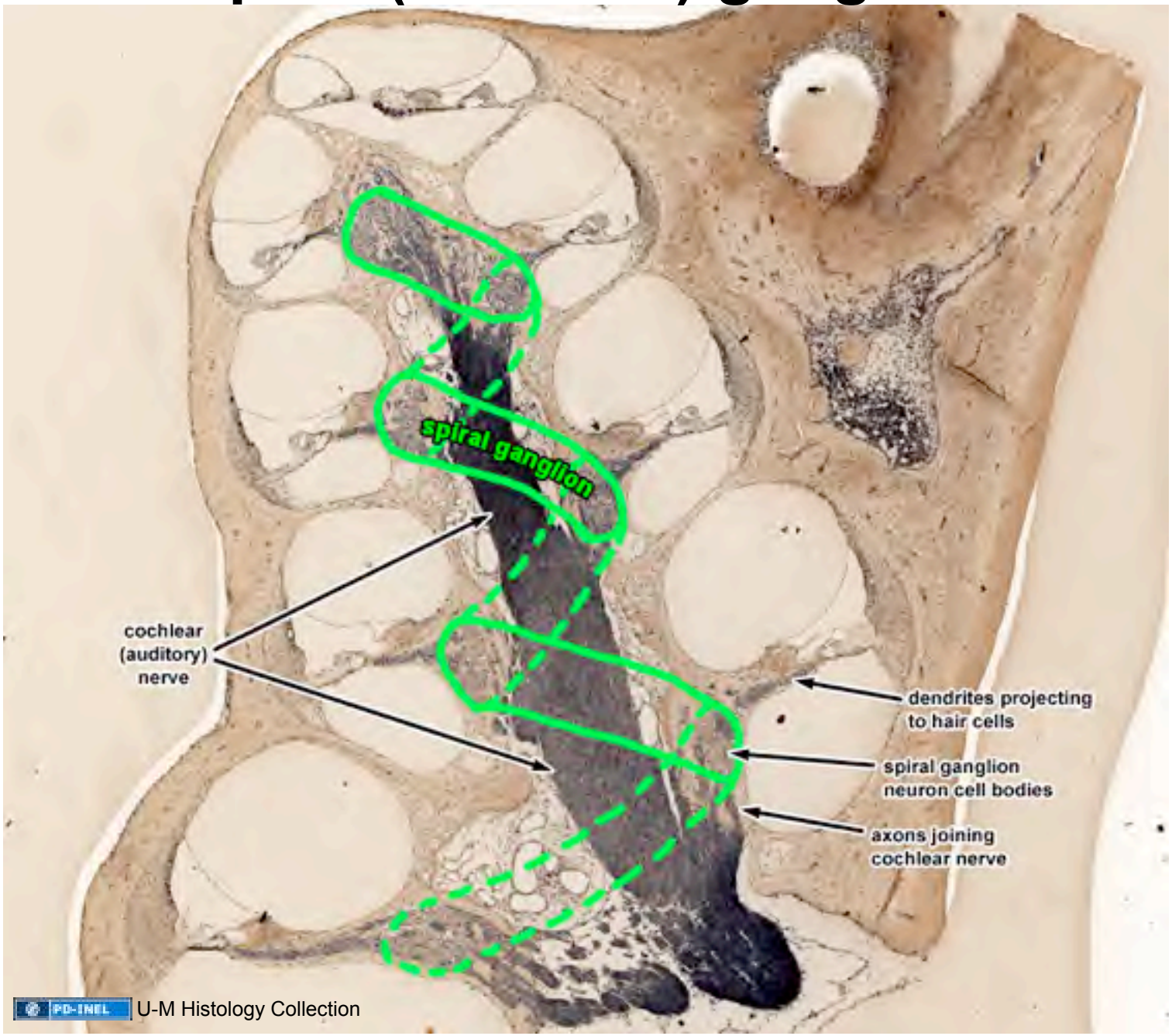
Innervation of the cochlea:

cochlear hair cells innervated by bipolar sensory neurons in spiral (coclear) ganglion

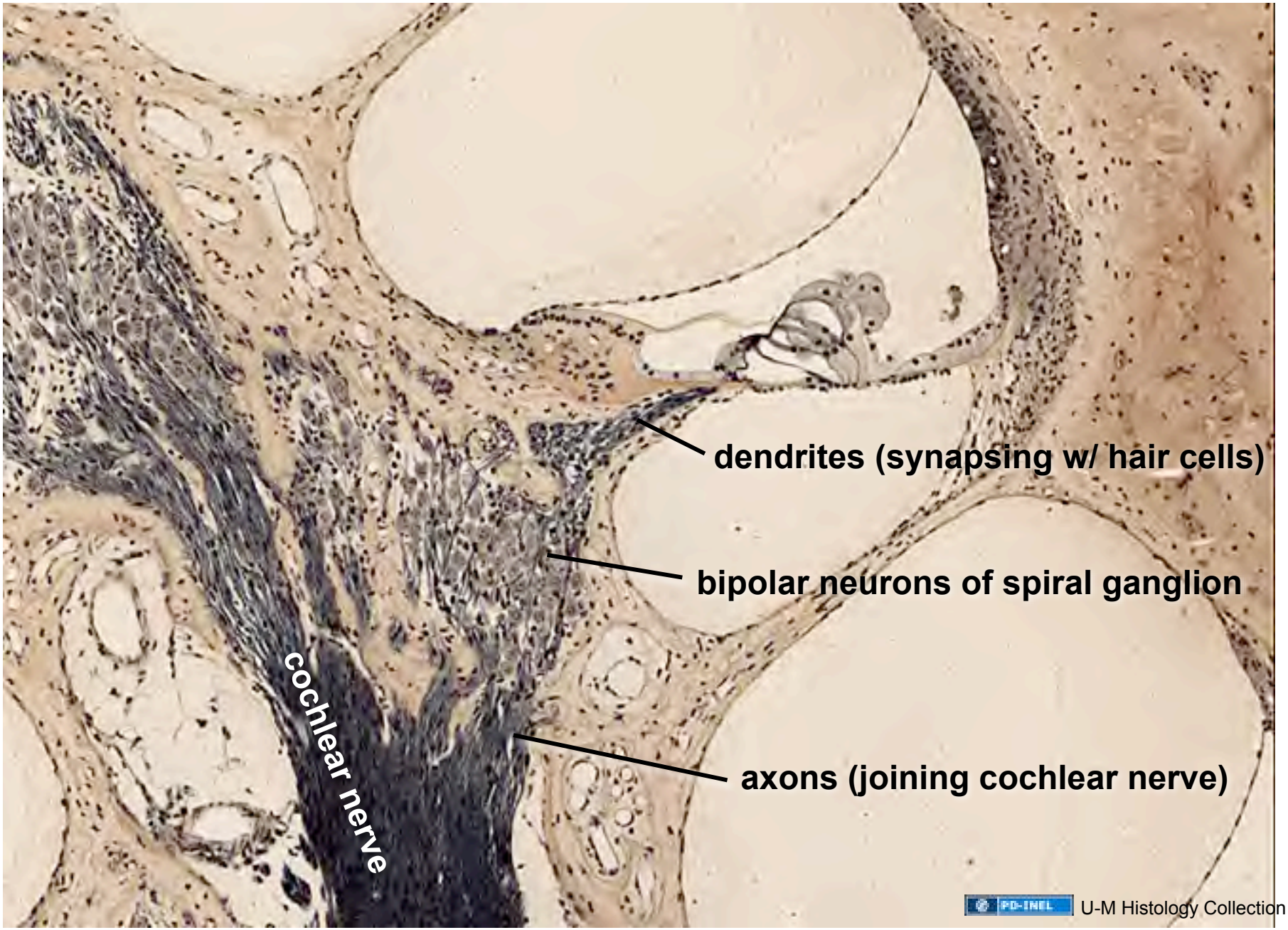


PD-INEL Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* fig 25.22, pg. 882

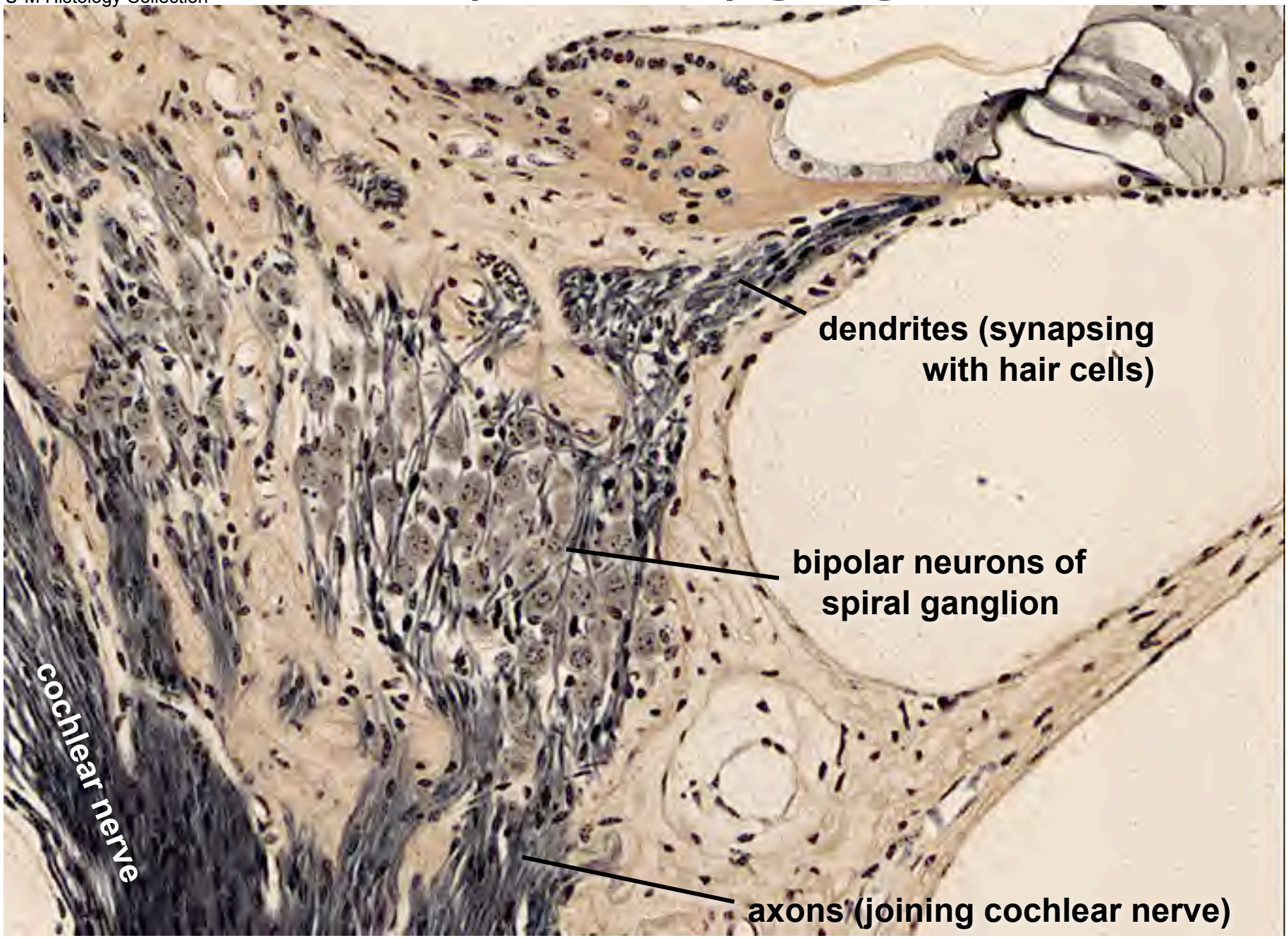
Spiral (cochlear) ganglion



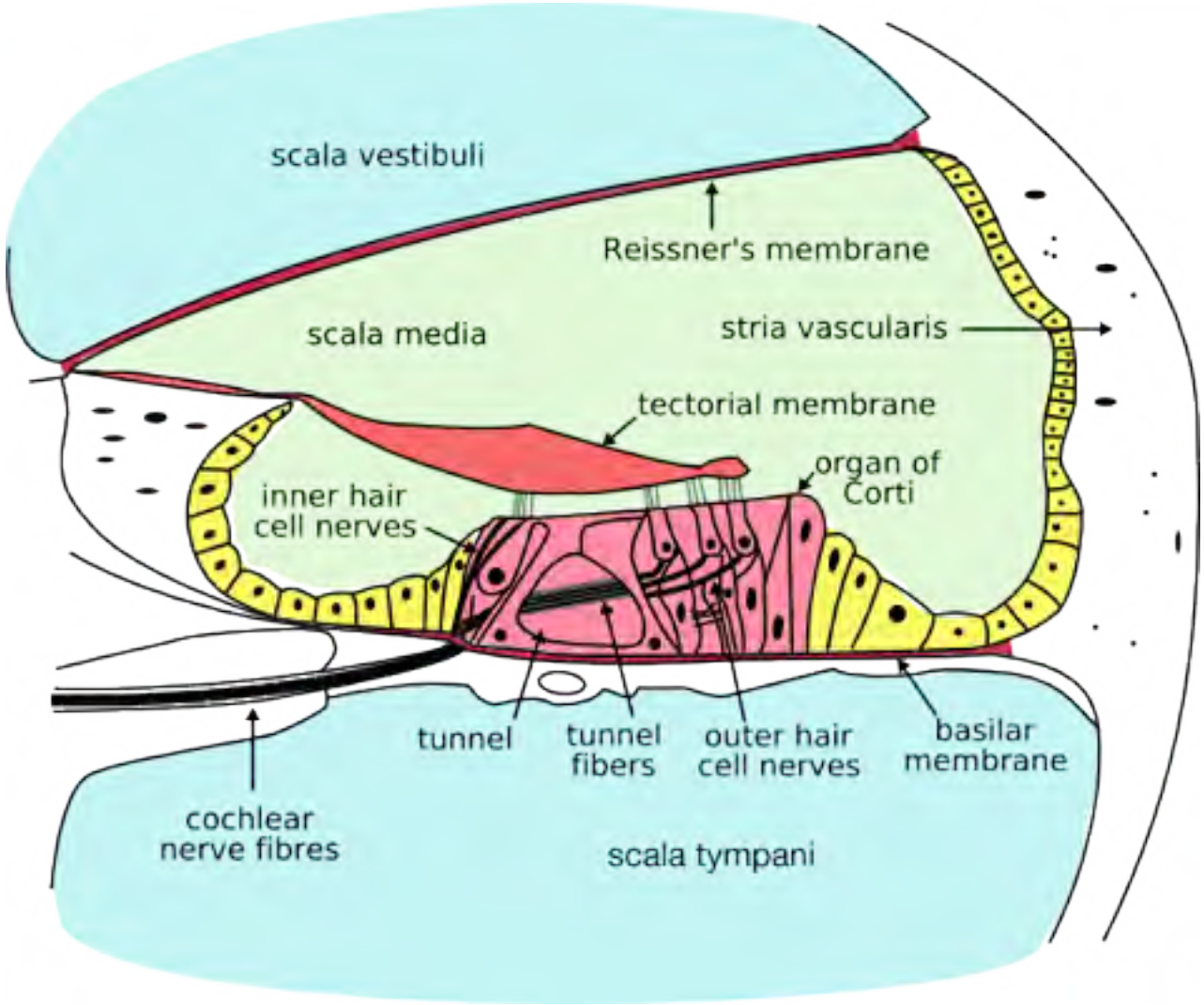
Spiral (cochlear) ganglion

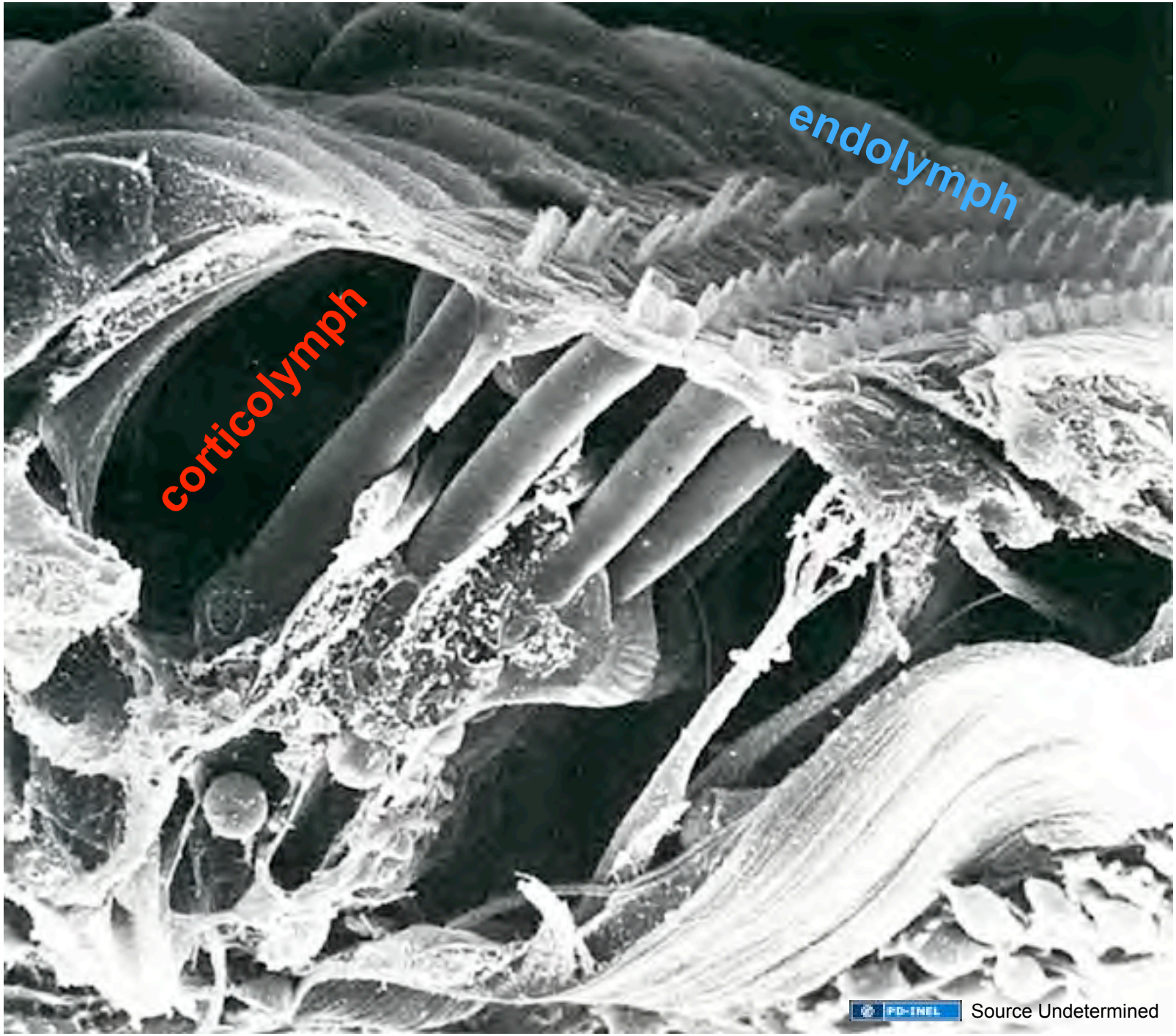


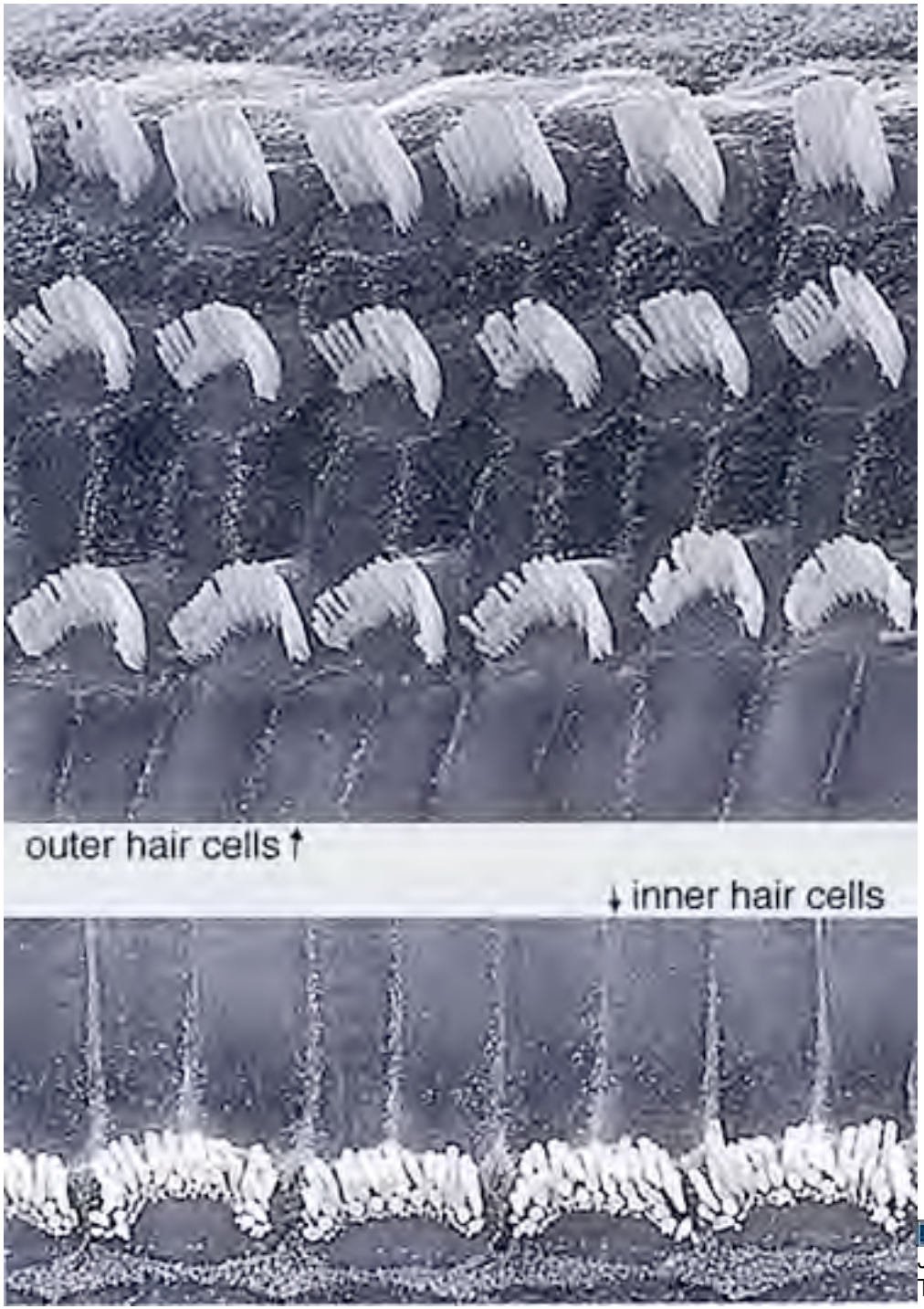
Spiral (cochlear) ganglion



Organ of Corti: Sensory (hair) cells
Supporting cells: phalangeal, pillar




endolymph
corticolymph
PD-INEL
Source Undetermined



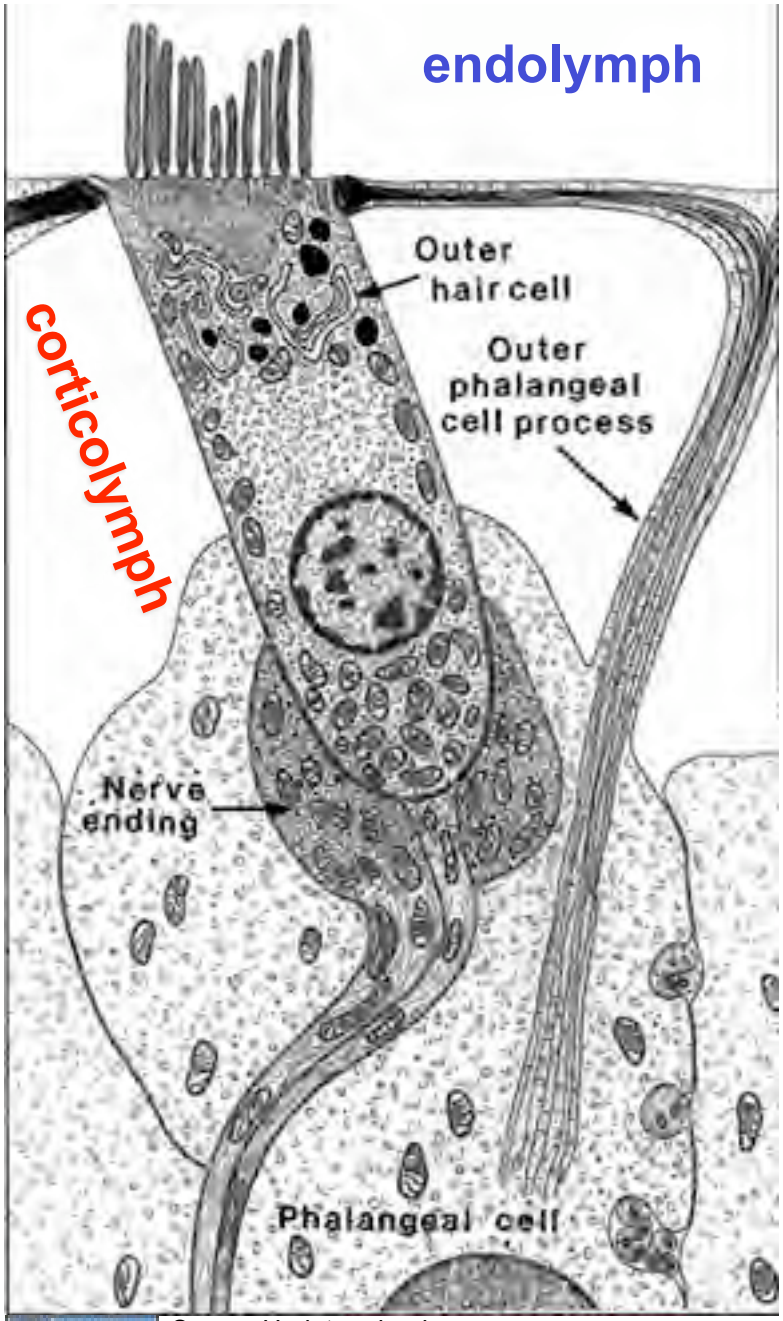
Stereocilia insert into tectorial membrane

OHC stereocilia arranged in a curve

IHC stereocilia arranged in a line

no kinocilum

Junquiera and Carneiro. Basic Histology. Tenth Ed. 2003 Figure 24-25.

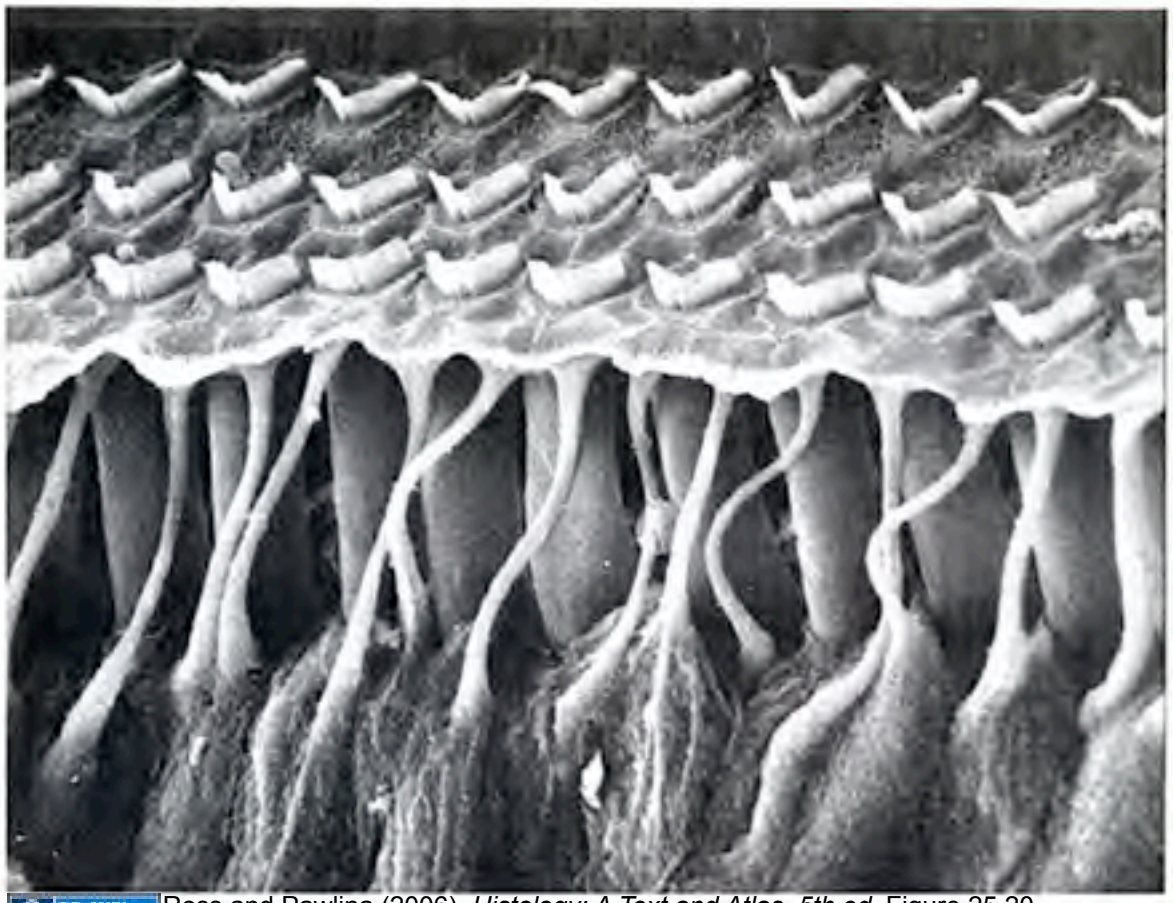


PD-INEL Source Undetermined

Phalangeal Cells

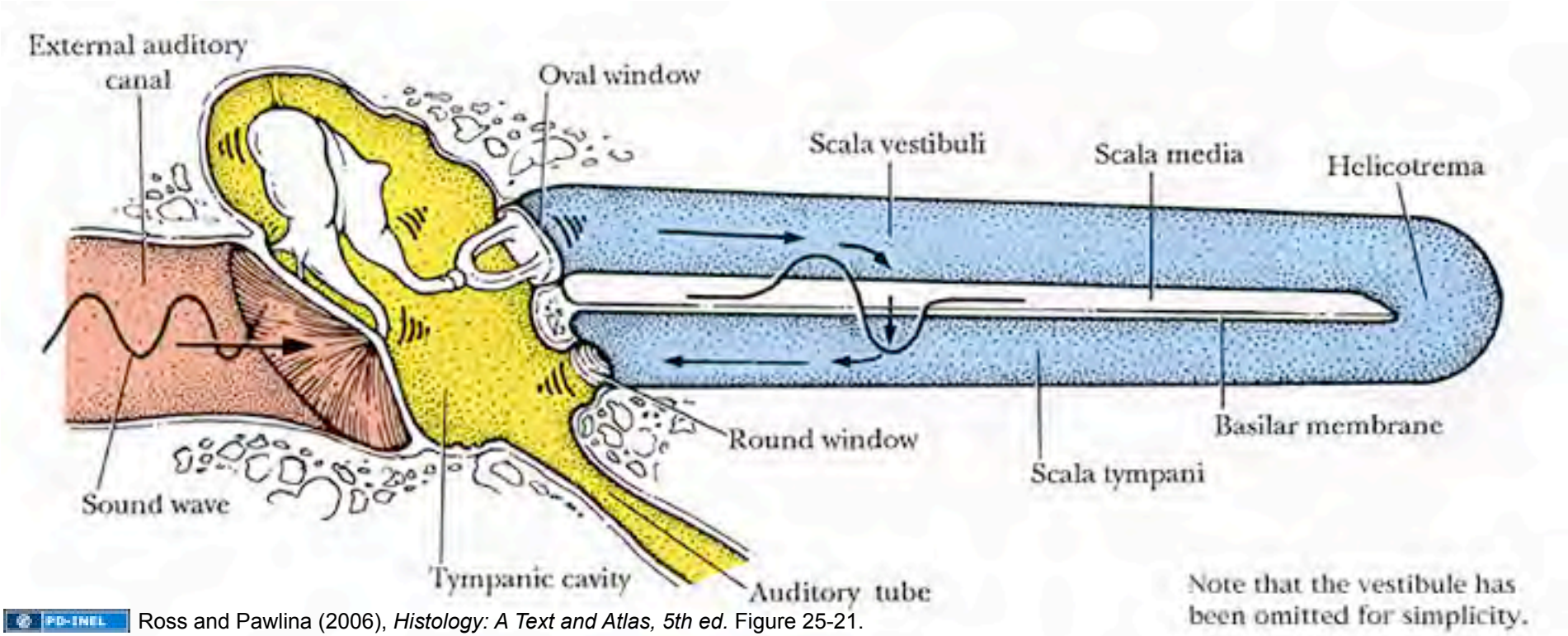
- Stabilize hair cells in reticular plate
- Tight junctions maintain ion gradient between endolymph and corticolymph

Phalangeal and hair cells



PD-INEL Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* Figure 25.20

Sound transduction



PD-INEL Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* Figure 25-21.

- Longitudinal waves: compression & rarefaction.
- Fluids in inner ear nearly incompressible
- Pressure changes transmitted across oval window,
- Resonance frequencies displace basilar membrane at specific locations: high frequency at base, low frequency at apex.

Sound transduction

OHCs — ~10% of auditory input

alter length to “tune” organ of Corti

IHC — ~90% of auditory input

movie found at:

http://www.iurc.montp.inserm.fr/cric/audition/english/corti/fcorti.htm

Outer hair cells are contractile

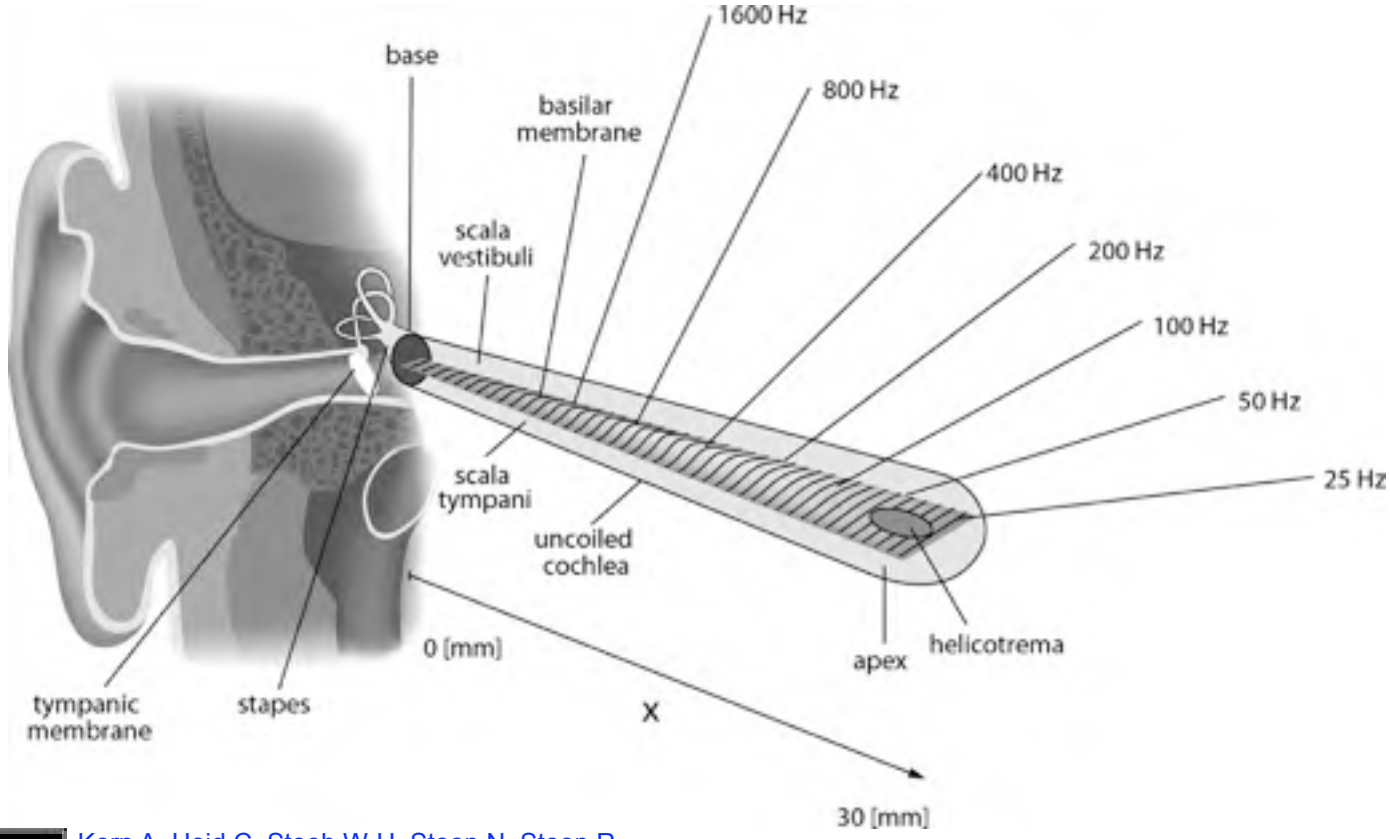
Movie of contracting OHC found at:

http://www.physiol.ucl.ac.uk/ashmore/

The movie shows an outer hair cell which has been patch-clamped using a whole cell recording pipette at its basal end. This allows the membrane potential of the cell to be varied. The low frequency envelope of Bill Haley and the Comet's "Rock Around The Clock" played into the stimulus input socket of the patch amplifier, with a peak-to-peak amplitude of about 100 mV. The hair cell changes length - but at constant volume - because it has a motor molecule in the membrane along the cell sides which responds to membrane voltage by changing area.

Frequency (pitch)

low frequency waves resonate at apex,
high frequency waves resonate at base



Frequency (pitch)

Basilar membrane is shorter at the base and longer at the apex, so…
low frequency waves resonate basilar membrane at the apex,
high frequency waves resonate basilar membrane at the base

Additional Source Information

for more information see: http://open.umich.edu/wiki/CitationPolicy

Slide 6: Chittka L, Brockmann, Wikipedia, http://en.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg CC:BY 2.5 http://creativecommons.org/licenses/by/2.5/
Slide 7: Chittka L, Brockmann, Wikipedia, http://en.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg CC:BY 2.5 http://creativecommons.org/licenses/by/2.5/
Slide 8: Chittka L, Brockmann, Wikipedia, http://en.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg CC:BY 2.5 http://creativecommons.org/licenses/by/2.5/
Slide 9: Chittka L, Brockmann, Wikipedia, http://en.wikipedia.org/wiki/File:Anatomy_of_the_Human_Ear.svg CC:BY 2.5 http://creativecommons.org/licenses/by/2.5/
Slide 10: Ross and Pawlina. (2006), *Histology: A Text and Atlas, 5th ed* Figure 25.6
Slide 11: Gray's Anatomy, Gray's Anatomy, Wikimedia Commons, http://en.wikipedia.org/wiki/File:Gray920.png
Slide 12: Gray's Anatomy, Wikimedia Commons, http://en.wikipedia.org/wiki/File:Gray924.png
Slide 13: Pearson Scott Foresman, Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Ear_4_(PSF).png; Gray's Anatomy
Slide 15: Thomas.haslwanter, Wikipedia, http://en.wikipedia.org/wiki/File:VestibularSystem.gif
Slide 16: U-M Histology Collection
Slide 17: Ross and Pawlina. (2006), *Histology: A Text and Atlas, 5th ed* Figure 25.8
Slide 19: Source Undetermined
Slide 20: Source Undetermined
Slide 21: Source Undetermined
Slide 22: U-M Histology Collection
Side 23: NASA, Fig. 6 http://weboflife.nasa.gov/learningResources/vestibularbrief.htm
Slide 24: Source Undetermined
Slide 25: Source Undetermined
Slide 26: NASA, Fig. 6 http://weboflife.nasa.gov/learningResources/vestibularbrief.htm
Slide 27: NASA, Fig. 6 http://weboflife.nasa.gov/learningResources/vestibularbrief.htm
Slide 28: NASA, Fig. 6 http://weboflife.nasa.gov/learningResources/vestibularbrief.htm
Slide 29: NASA, Fig. 6 http://weboflife.nasa.gov/learningResources/vestibularbrief.htm
Slide 30: Thomas.haslwanter, Wikipedia, http://en.wikipedia.org/wiki/File:VestibularSystem.gif
Slide 31: U-M Histology Collection
Slide 32: U-M Histology Collection
Slide 33: U-M Histology Collection

Slide 34: Source Undetermined

Slide 35: NASA, Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Inner_ear%27s_cupula_transmitting_indication_of_acceleration.jpg; United States Federal Government

Slide 36: Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* fig 25.22, pg. 882

Slide 37: U-M Histology Collection

Slide 38: U-M Histology Collection

Side 39: U-M Histology Collection

Slide 40: U-M Histology Collection

Slide 41: *Up To Date*

Slide 42: Thomas.haslwanter, Wikipedia, http://en.wikipedia.org/wiki/File:VestibularSystem.gif

Side 43: Junquiera and Carneiro. Basic Histology. Tenth Ed. 2003 Figure 24.20

Side 44: U-M Histology Collection

Slide 45: U-M Histology Collection

Slide 46: welleschik, Wikipedia, http://commons.wikimedia.org/wiki/File:Stria_vascularis1.jpg#file

Slide 47: Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed*. Figure 25.15.

Slide 48: U-M Histology Collection

Slide 49: U-M Histology Collection

Slide 50: Source Undetermined

Slide 51: Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* fig 25.22, pg. 882

Slide 52: U-M Histology Collection

Side 53: U-M Histology Collection

Slide 54: U-M Histology Collection

Slide 55: Oarih, Wikipedia, http://en.wikipedia.org/wiki/File:Cochlea-crosssection.png

Slide 56: Source Undetermined

Slide 57: Junquiera and Carneiro. Basic Histology. Tenth Ed. 2003 Figure 24-25.

Slide 58: Source Undetermined

Slide 59: Ross and Pawlina (2006), *Histology: A Text and Atlas, 5th ed.* Figure 25.20

Slide 60: Source Undetermined

Slide 63: Kern A, Heid C, Steeb W-H, Stoop N, Stoop R, http://www.ploscompbiol.org/article/info:doi/10.1371/journal.pcbi.1000161

Slide 64: U-M Histology Collection