THE SPECIAL SENSES PART 2 SMELL, TASTE

Chemical Senses

- Taste and smell (olfaction)
- Their chemoreceptors respond to chemicals in aqueous solution

Sense of Smell

- The organ of smell—olfactory epithelium in the roof of the nasal cavity
- Olfactory receptor cells—bipolar neurons with radiating olfactory cilia
- Bundles of axons of olfactory receptor cells form the filaments of the olfactory nerve (cranial nerve I)
- Supporting cells surround and cushion olfactory receptor cells
- Basal cells lie at the base of the epithelium

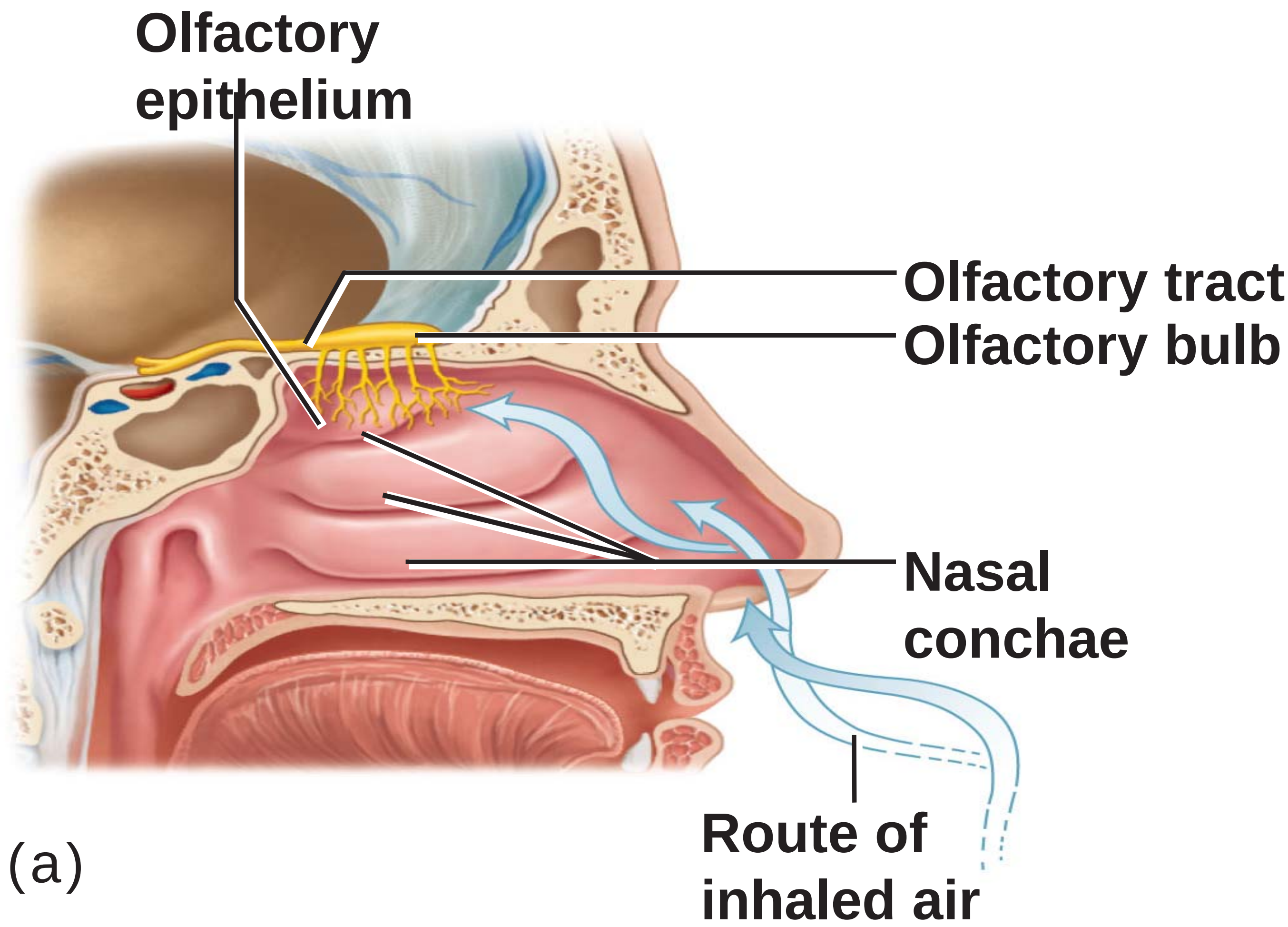


Figure 15.21a

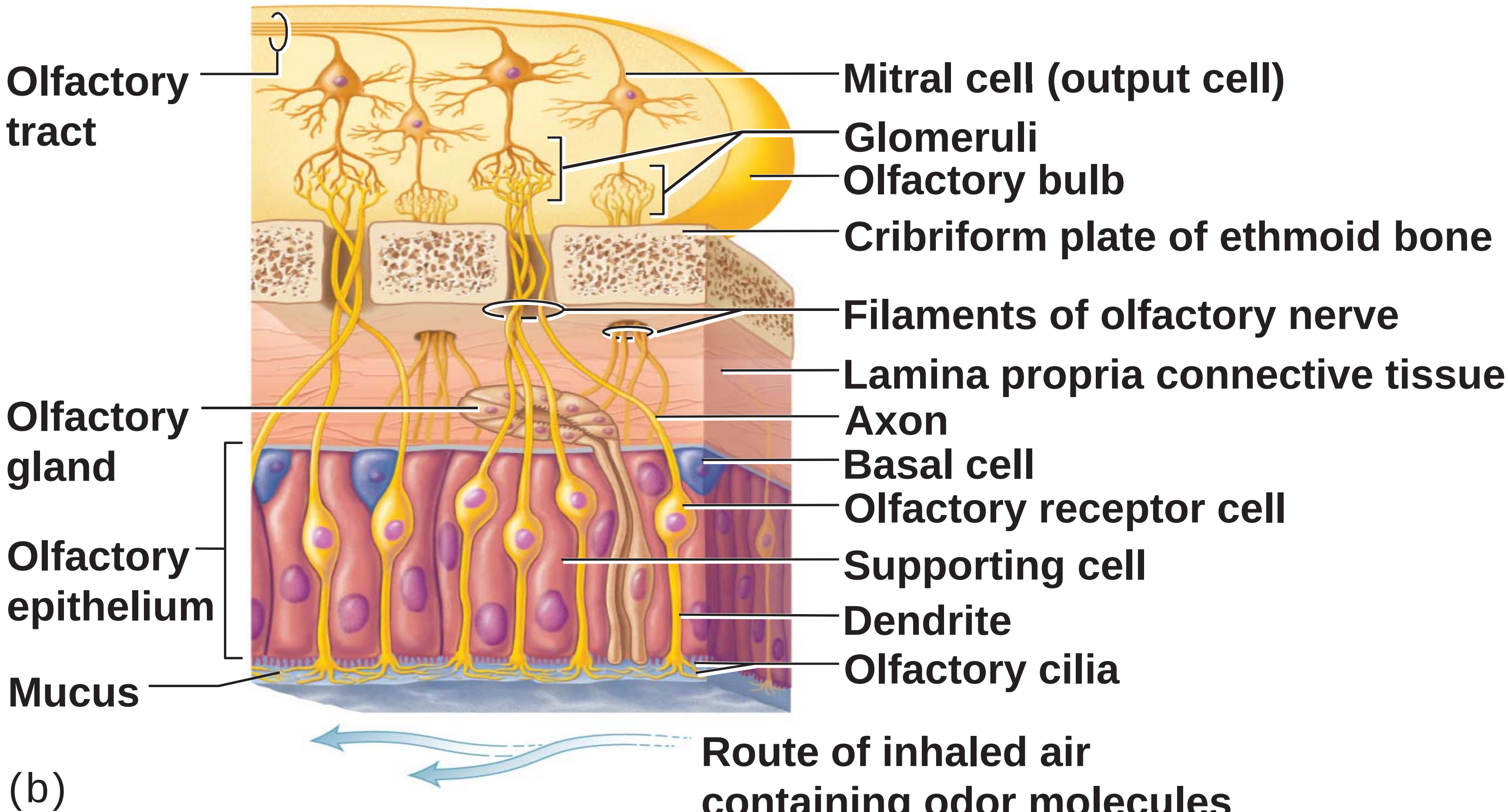


Figure 15.21a

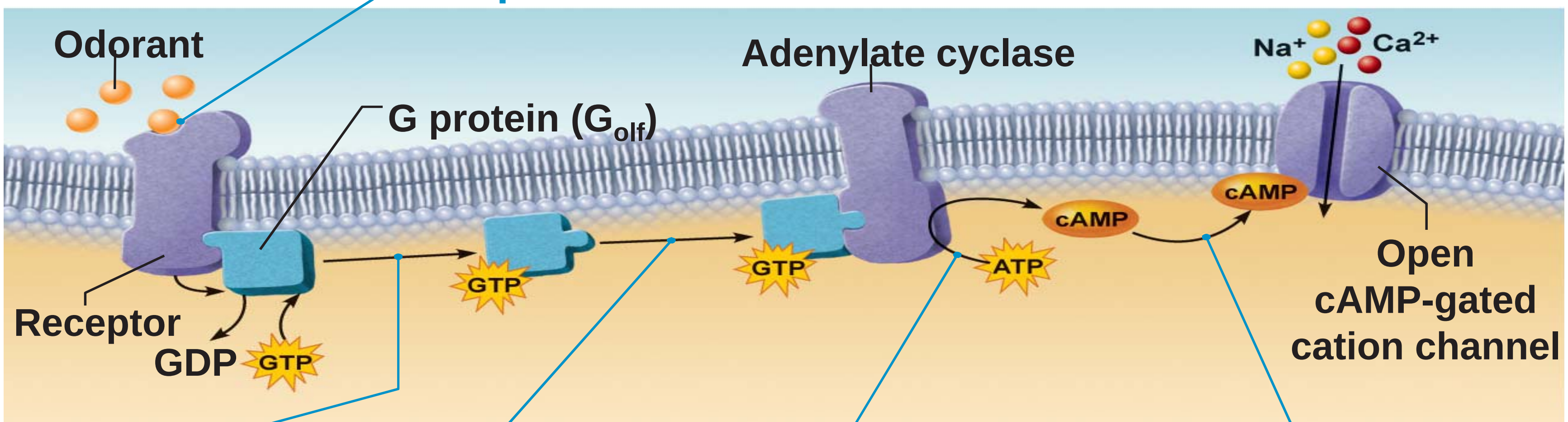
Physiology of Smell

- Dissolved odorants bind to receptor proteins in the olfactory cilium membranes
- A G protein mechanism is activated, which produces cAMP as a second messenger
- cAMP opens Na^{+} and Ca^{2+} channels, causing depolarization of the receptor membrane that then triggers an action potential

Olfactory Pathway

- Olfactory receptor cells synapse with mitral cells in glomeruli of the olfactory bulbs
- Mitral cells amplify, refine, and relay signals along the olfactory tracts to the:
  - Olfactory cortex
  - Hypothalamus, amygdala, and limbic system

① Odorant binds to its receptor.



② Receptor activates G protein (G_{olf}).

③ G protein activates adenylate cyclase.

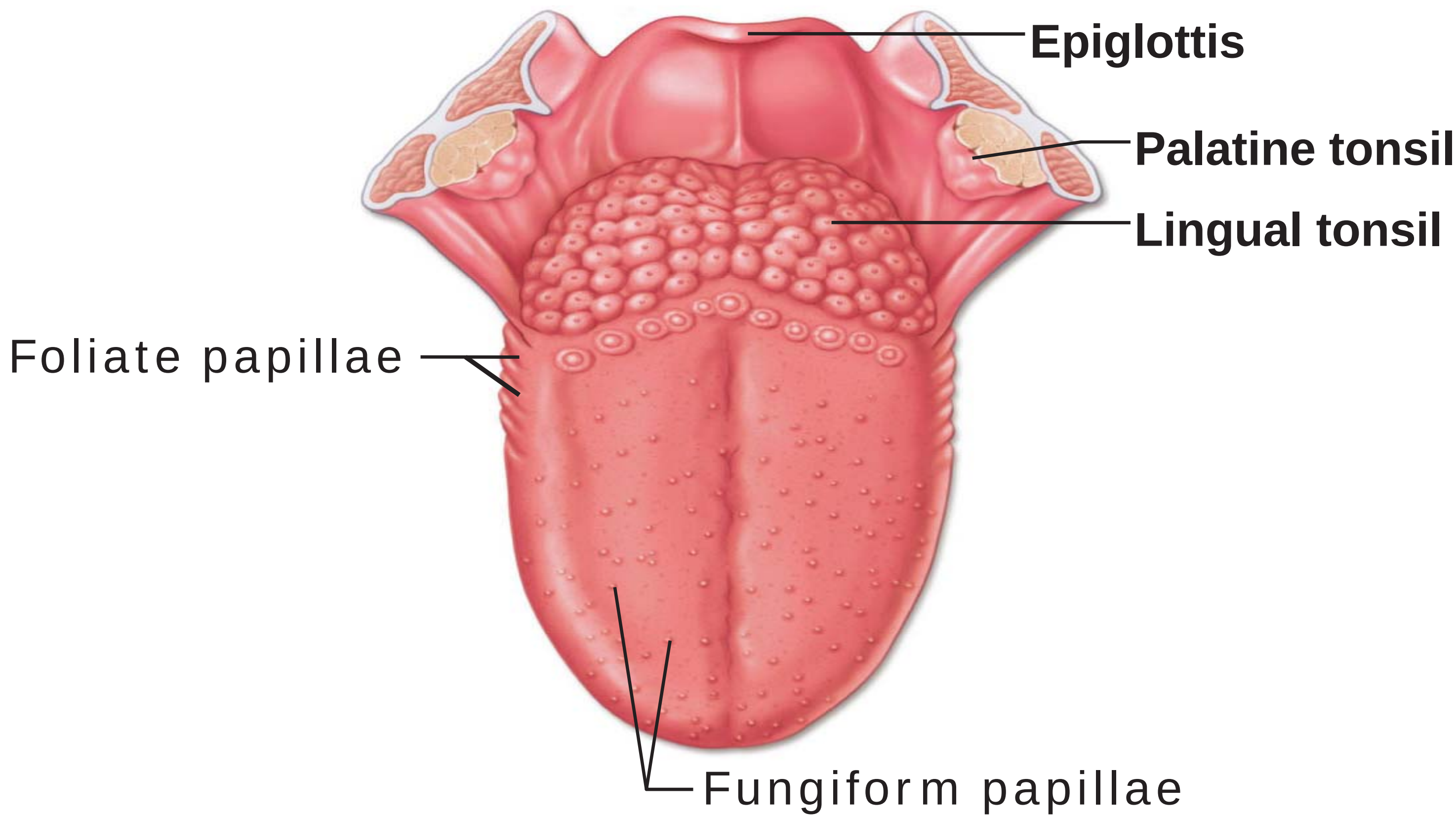
④ Adenylate cyclase converts ATP to cAMP.

⑤ cAMP opens a cation channel allowing Na^+ and Ca^{2+} influx and causing depolarization.

Figure 15.22

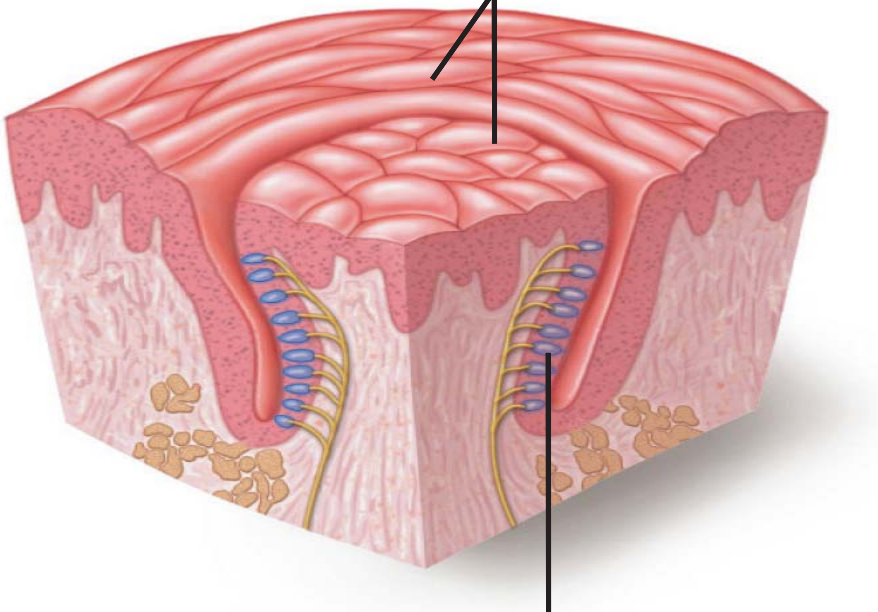
Sense of Taste

- Receptor organs are taste buds
  - Found on the tongue
    - On the tops of fungiform papillae
    - On the side walls of foliate papillae and circumvallate (vallate) papillae



(a) Taste buds are associated with fungiform, foliate, and circumvallate (vallate) papillae.

Figure 15.23a

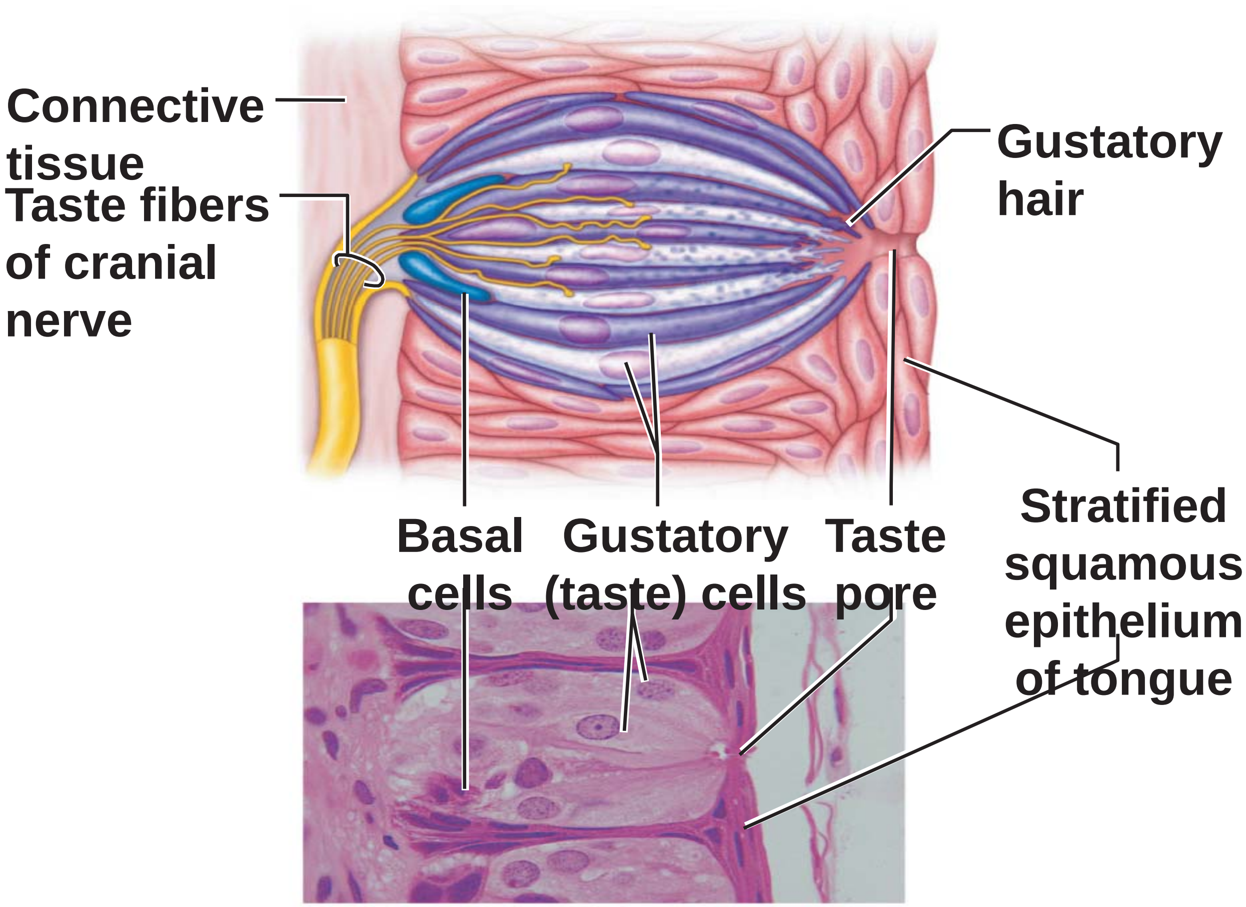


(b) Enlarged section of a circumvallate papilla.

Figure 15.23b

Structure of a Taste Bud

- Flask shaped
- 50–100 epithelial cells:
  - Basal cells—dynamic stem cells
  - Gustatory cells—taste cells
    - Microvilli (gustatory hairs) project through a taste pore to the surface of the epithelium



(c) Enlarged view of a taste bud.

Figure 15.23c

Taste Sensations

- There are five basic taste sensations
  1. Sweet—sugars, saccharin, alcohol, and some amino acids
  2. Sour—hydrogen ions
  3. Salt—metal ions
  4. Bitter—alkaloids such as quinine and nicotine
  5. Umami—amino acids glutamate and aspartate

Physiology of Taste

- In order to be tasted, a chemical:
  - Must be dissolved in saliva
  - Must contact gustatory hairs
- Binding of the food chemical (tastant)
  - Depolarizes the taste cell membrane, causing release of neurotransmitter
  - Initiates a generator potential that elicits an action potential

Taste Transduction

- The stimulus energy of taste causes gustatory cell depolarization by:
  - Na^+ influx in salty tastes (directly causes depolarization)
  - H^+ in sour tastes (by opening cation channels)
  - G protein gustducin in sweet, bitter, and umami tastes (leads to release of Ca^{2+} from intracellular stores, which causes opening of cation channels in the plasma membrane)

Gustatory Pathway

- Cranial nerves VII and IX carry impulses from taste buds to the solitary nucleus of the medulla
- Impulses then travel to the thalamus and from there fibers branch to the:
  - Gustatory cortex in the insula
  - Hypothalamus and limbic system (appreciation of taste)

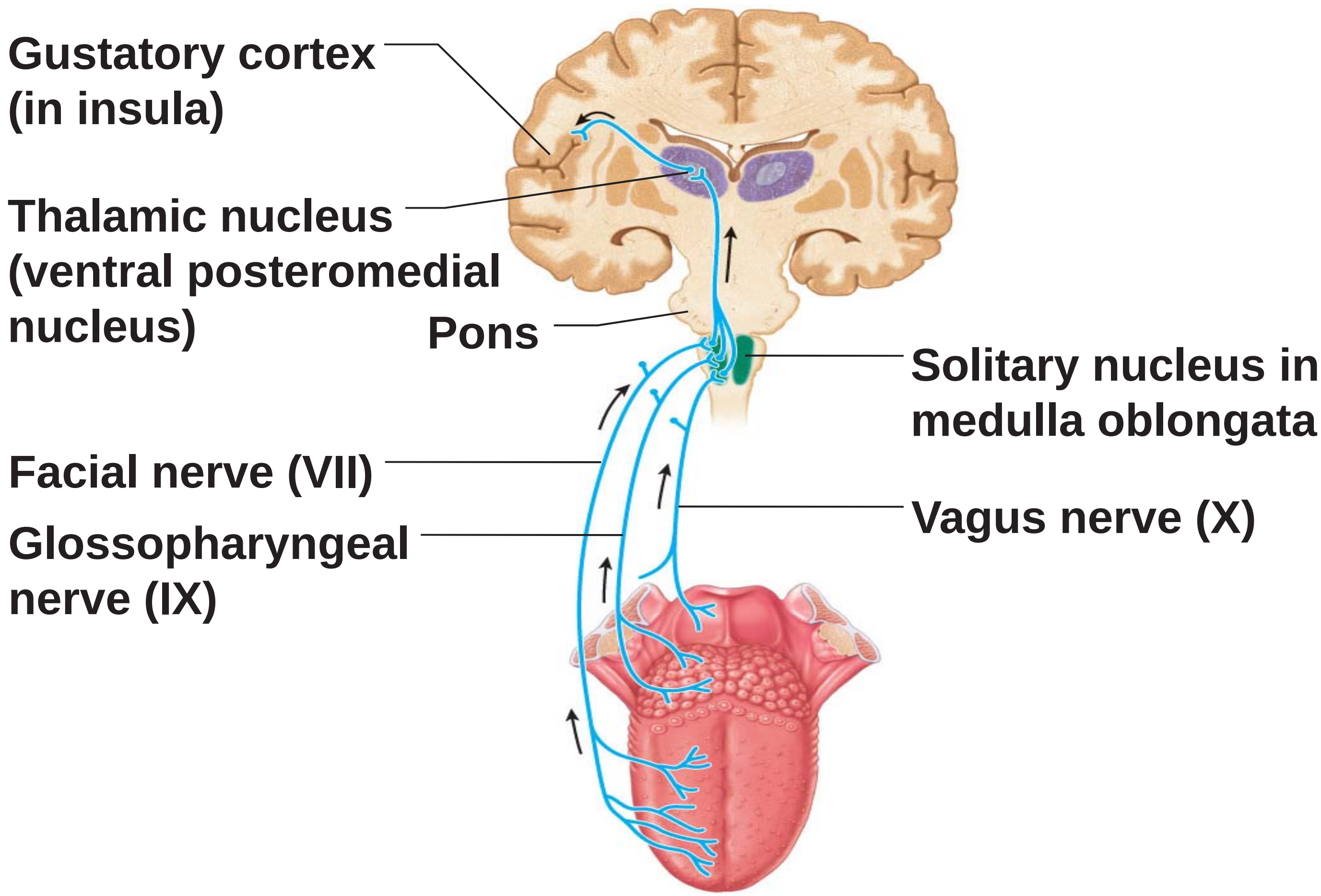

Gustatory cortex
(in insula)
Thalamic nucleus
(ventral posteromedial
nucleus)
Pons
Solitary nucleus in
medulla oblongata
Facial nerve (VII)
Glossopharyngeal
nerve (IX)
Vagus nerve (X)

Figure 15.24

Influence of Other Sensations on Taste

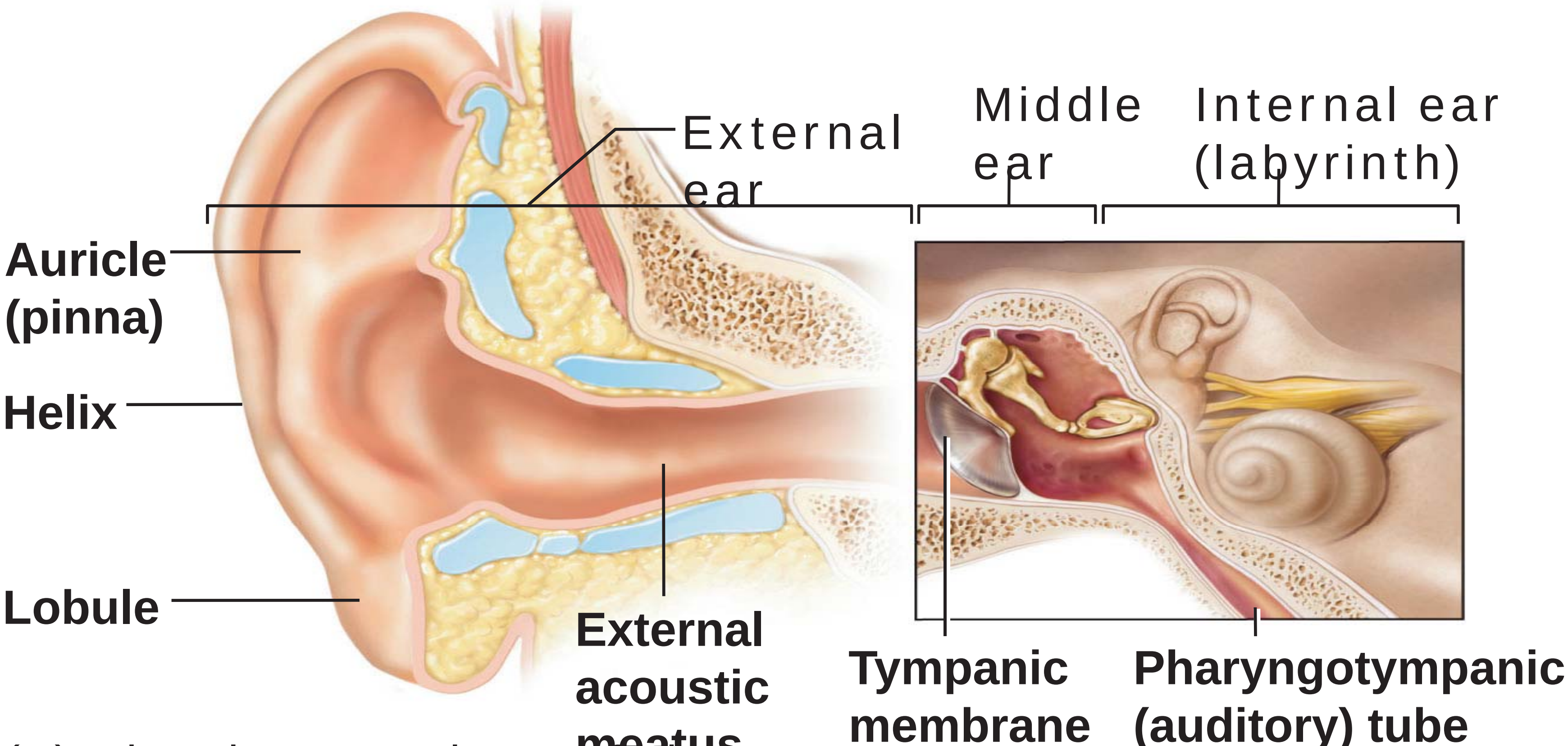
- Taste is 80% smell
- Thermoreceptors, mechanoreceptors, nociceptors in the mouth also influence tastes
- Temperature and texture enhance or detract from taste

The Ear: Hearing and Balance

- Three parts of the ear
  1. External (outer) ear
  2. Middle ear (tympanic cavity)
  3. Internal (inner) ear

The Ear: Hearing and Balance

- External ear and middle ear are involved with hearing
- Internal ear (labyrinth) functions in both hearing and equilibrium
- Receptors for hearing and balance
  - Respond to separate stimuli
  - Are activated independently



(a) The three regions of the ear

Figure 15.25a

External Ear

- The auricle (pinna) is composed of:
  - Helix (rim)
  - Lobule (earlobe)
- External acoustic meatus (auditory canal)
  - Short, curved tube lined with skin bearing hairs, sebaceous glands, and ceruminous glands

External Ear

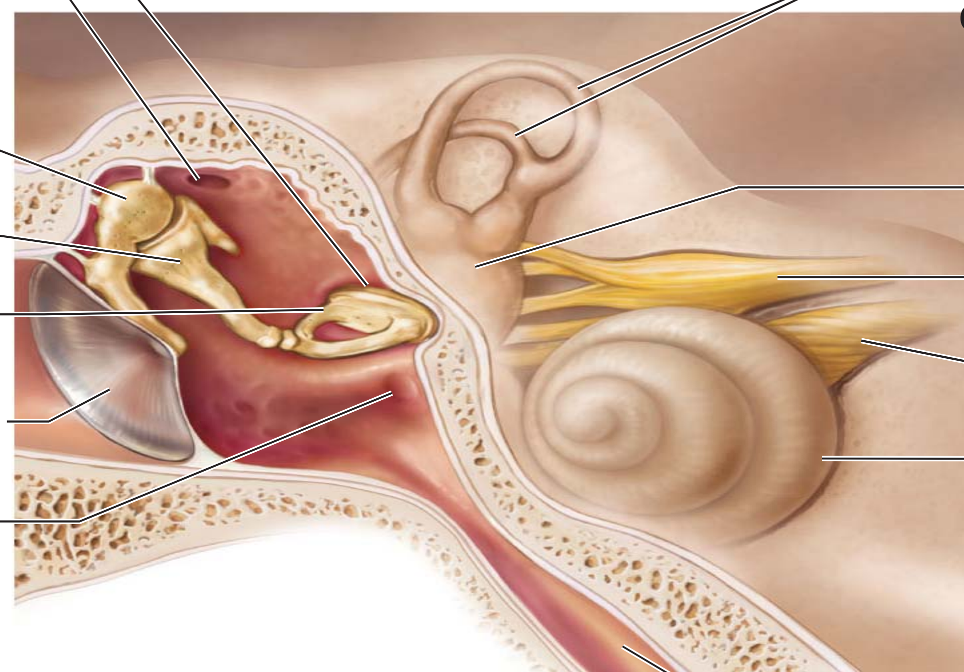
- Tympanic membrane (eardrum)
  - Boundary between external and middle ears
  - Connective tissue membrane that vibrates in response to sound
  - Transfers sound energy to the bones of the middle ear

Middle Ear

- A small, air-filled, mucosa-lined cavity in the temporal bone
  - Flanked laterally by the eardrum
  - Flanked medially by bony wall containing the oval (vestibular) and round (cochlear) windows

Middle Ear

- Epitympanic recess—superior portion of the middle ear
- Pharyngotympanic (auditory) tube—connects the middle ear to the nasopharynx
  - Equalizes pressure in the middle ear cavity with the external air pressure



(b) Middle and internal ear

Figure 15.25b

Ear Ossicles

- Three small bones in tympanic cavity: the malleus, incus, and stapes
  - Suspended by ligaments and joined by synovial joints
  - Transmit vibratory motion of the eardrum to the oval window
  - Tensor tympani and stapedius muscles contract reflexively in response to loud sounds to prevent damage to the hearing receptors

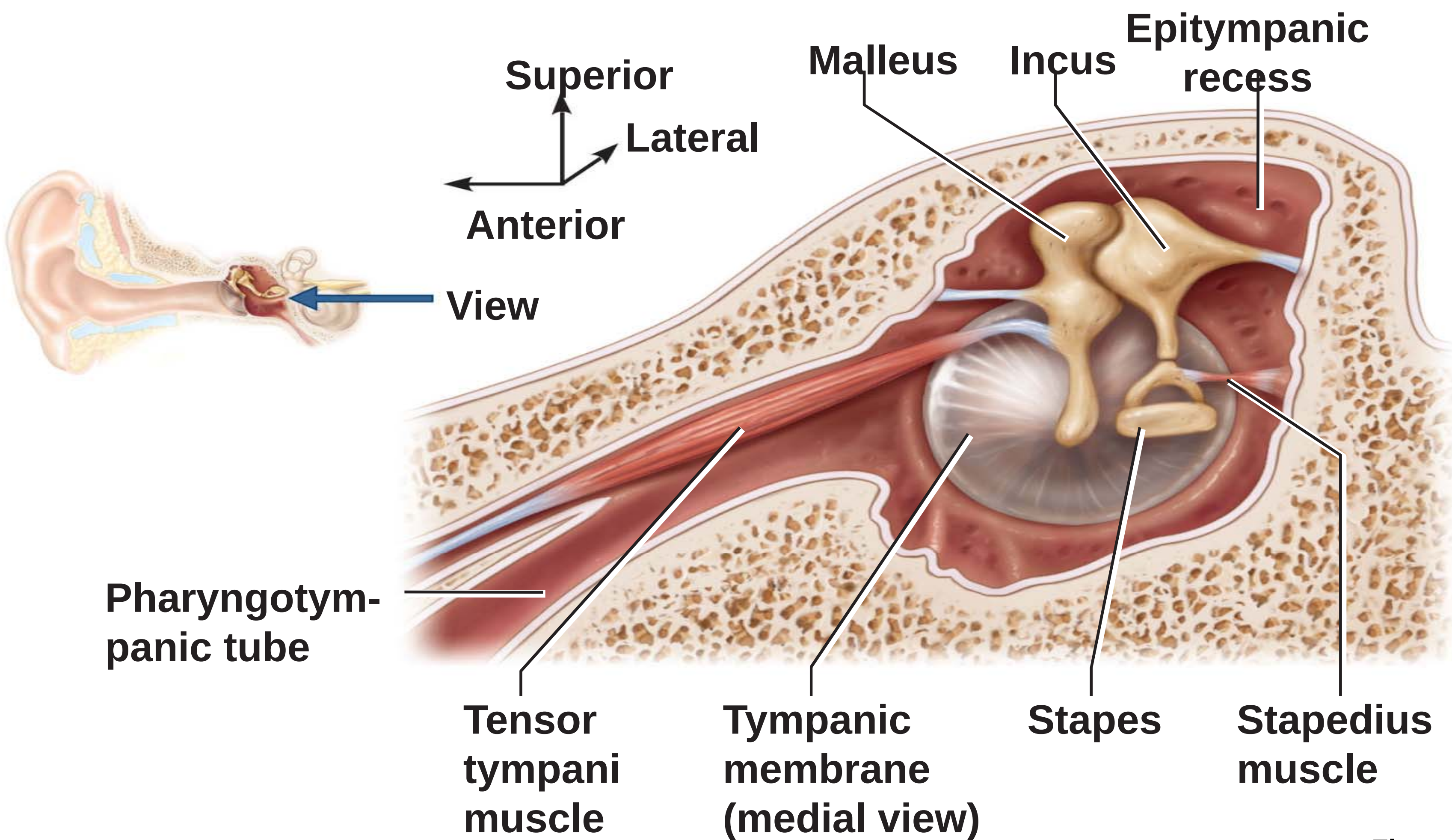

Superior
Lateral
Anterior
View
Malleus
Incus
Epitympanic recess
Pharyngotym-panic tube
Tensor tympani muscle
Tympanic membrane (medial view)
Stapes
Stapedius muscle

Figure 15.26

Internal Ear

- Bony labyrinth
  - Tortuous channels in the temporal bone
  - Three parts: vestibule, semicircular canals, and cochlea
- Filled with perilymph
  - Series of membranous sacs within the bony labyrinth
  - Filled with a potassium-rich endolymph

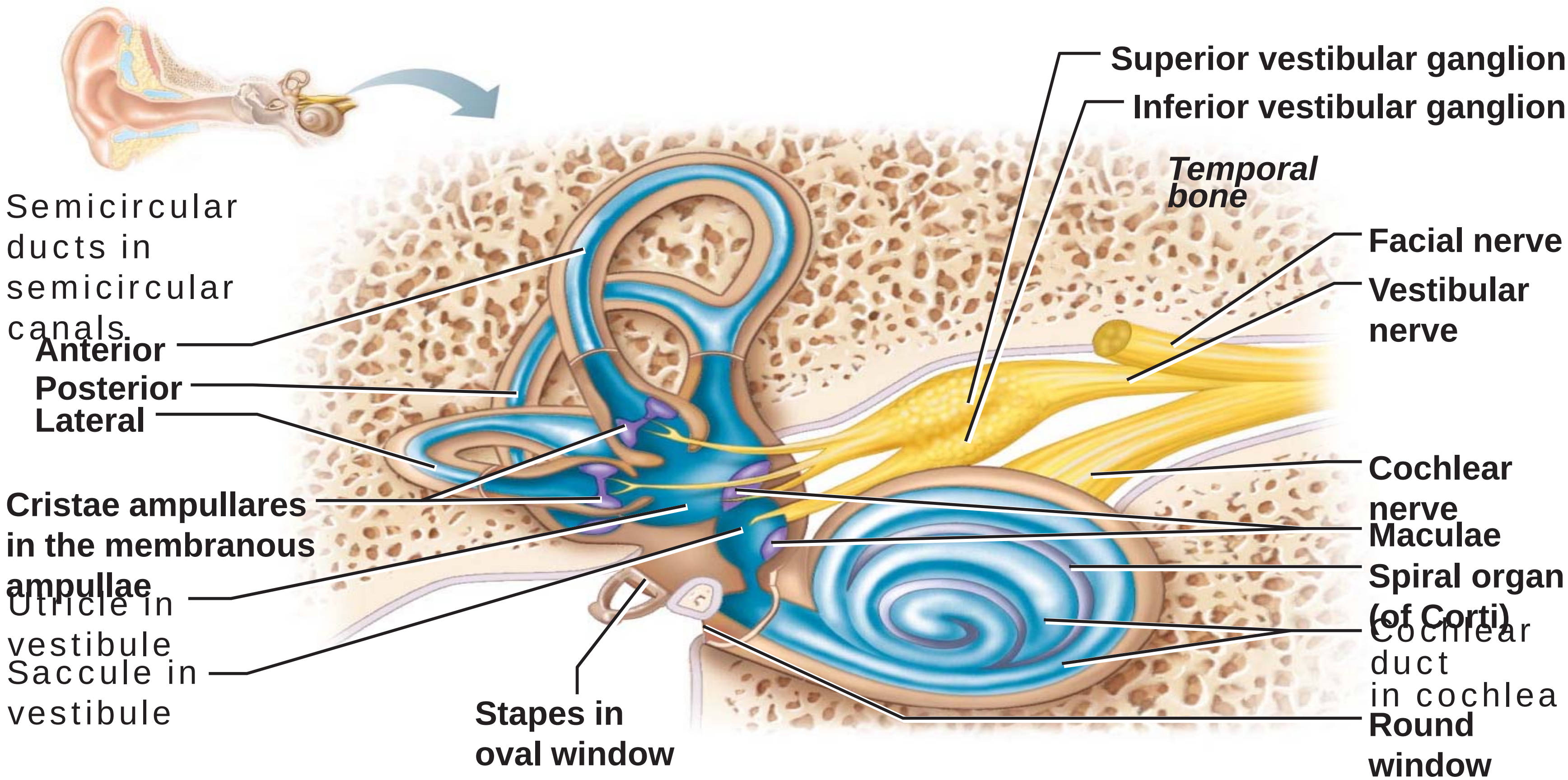

Superior vestibular ganglion
Inferior vestibular ganglion
Temporal bone
Facial nerve
Vestibular nerve
Semicircular ducts in semicircular canals.
Anterior
Posterior
Lateral
Cristae ampullares in the membranous ampullae
Utricle in vestibule
Saccule in vestibule
Stapes in oval window
Cochlear nerve
Maculae
Spiral organ (of Corti)
Cochlear duct in cochlea
Round window

Figure 15.27

Vestibule

- Central egg-shaped cavity of the bony labyrinth
- Contains two membranous sacs
  1. Saccule is continuous with the cochlear duct
  2. Utricle is continuous with the semicircular canals
- These sacs
  - House equilibrium receptor regions (maculae)
  - Respond to gravity and changes in the position of the head

Semicircular Canals

- Three canals (anterior, lateral, and posterior) that each define two-thirds of a circle
- Membranous semicircular ducts line each canal and communicate with the utricle
- Ampulla of each canal houses equilibrium receptor region called the crista ampullaris
- Receptors respond to angular (rotational) movements of the head

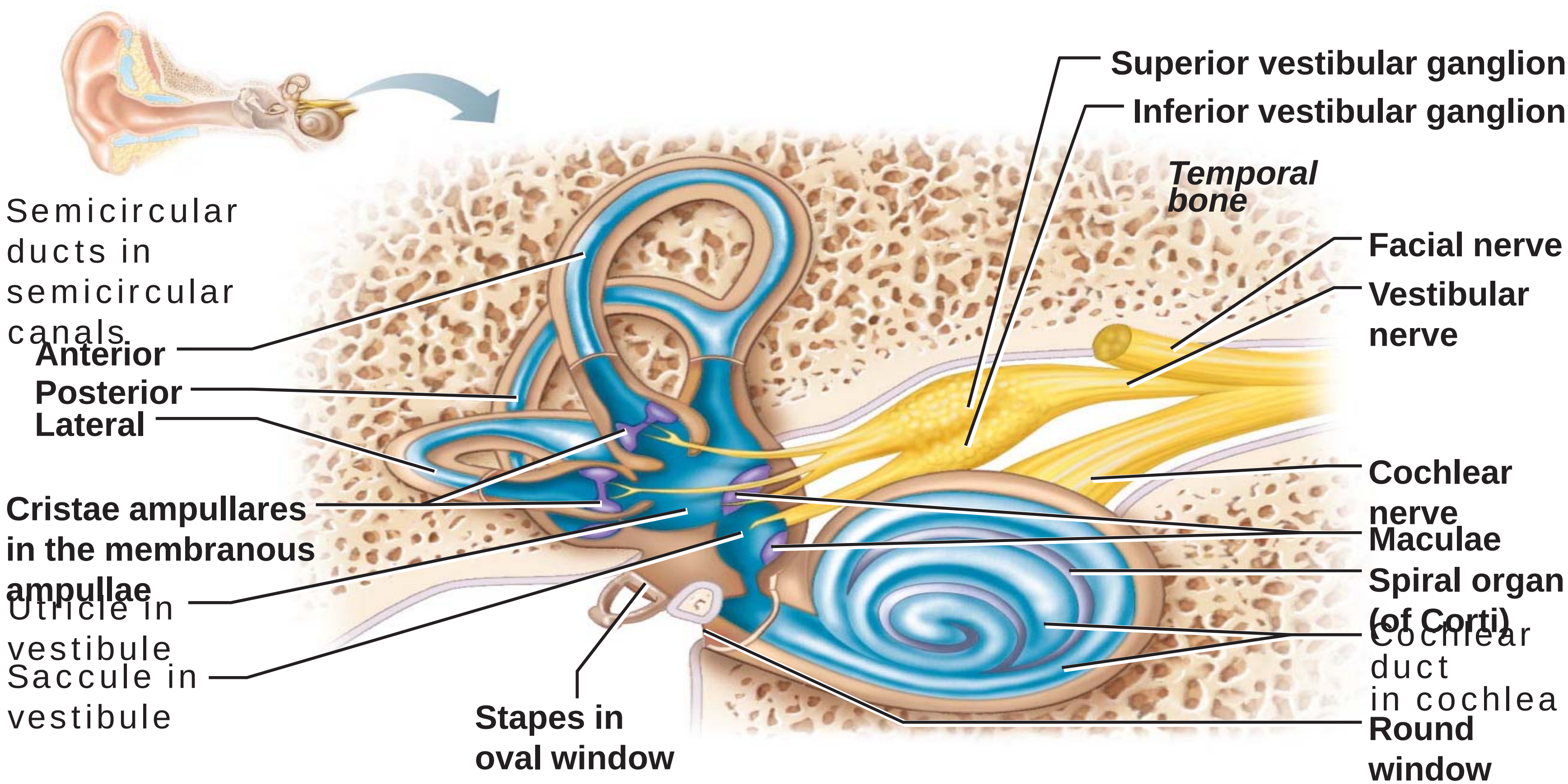

Superior vestibular ganglion
Inferior vestibular ganglion
Temporal bone
Facial nerve
Vestibular nerve
Semicircular ducts in semicircular canals
Anterior
Posterior
Lateral
Cristae ampullares in the membranous ampullae
Utricle in vestibule
Saccule in vestibule
Stapes in oval window
Cochlear nerve
Maculae
Spiral organ (of Corti)
Cochlear duct in cochlea
Round window

Figure 15.27

The Cochlea

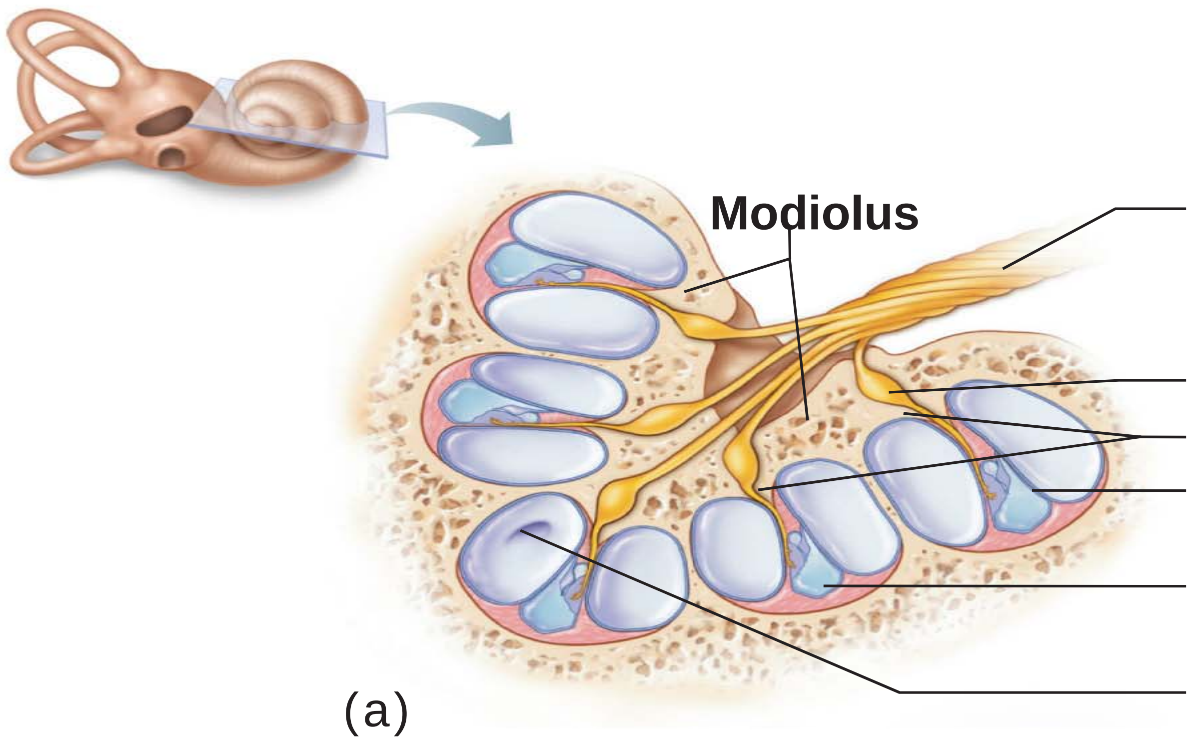
- A spiral, conical, bony chamber
  - Extends from the vestibule
  - Coils around a bony pillar (modiolus)
  - Contains the cochlear duct, which houses the spiral organ (of Corti) and ends at the cochlear apex

The Cochlea

- The cavity of the cochlea is divided into three chambers
  - Scala vestibuli—abuts the oval window, contains perilymph
  - Scala media (cochlear duct)—contains endolymph
  - Scala tympani—terminates at the round window; contains perilymph
- The scalae tympani and vestibuli are continuous with each other at the helicotrema (apex)

The Cochlea

- The “roof” of the cochlear duct is the vestibular membrane
- The “floor” of the cochlear duct is composed of:
  - The bony spiral lamina
  - The basilar membrane, which supports the organ of Corti
- The cochlear branch of nerve VIII runs from the organ of Corti to the brain



(a)

Figure 15.28a

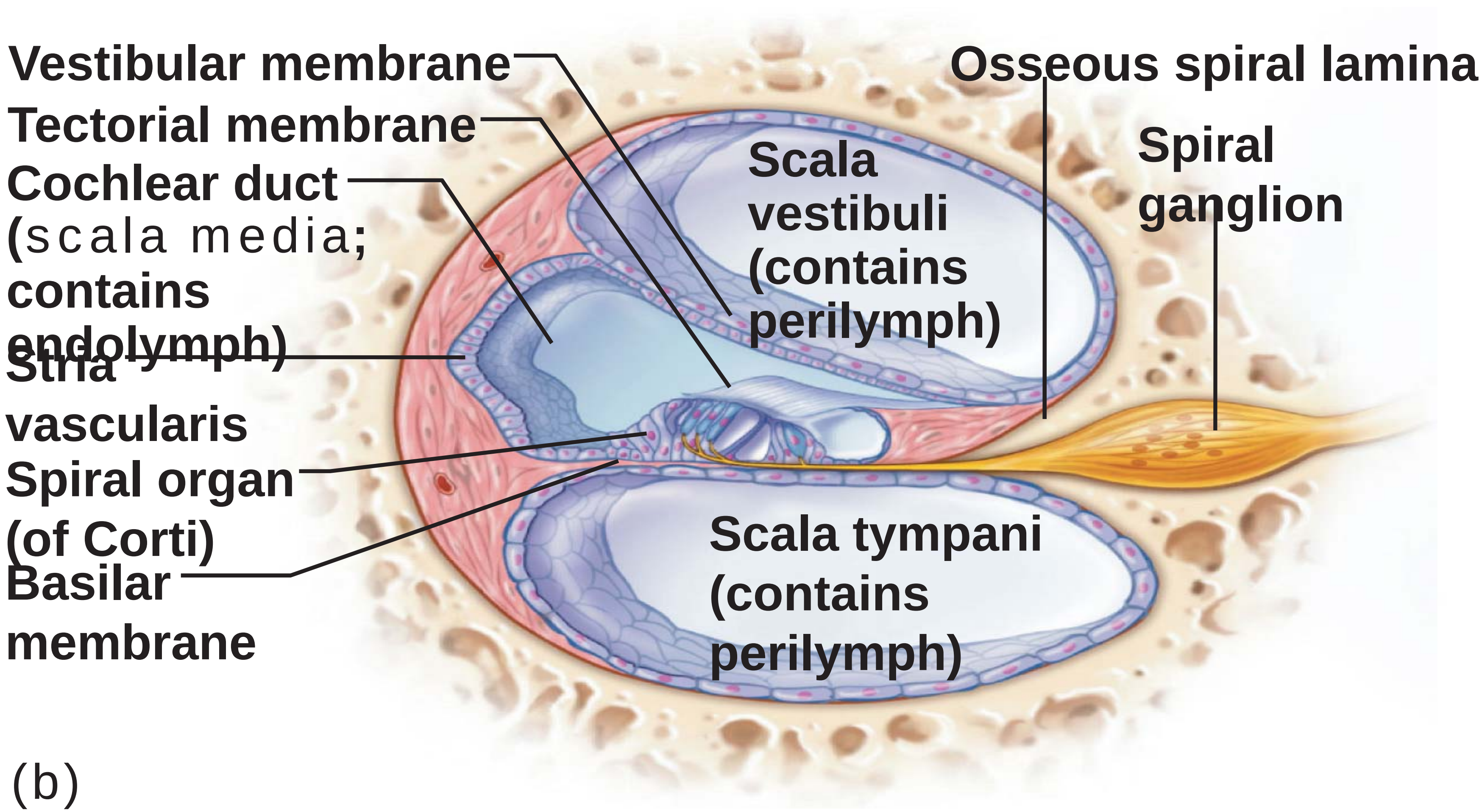


Figure 15.28b

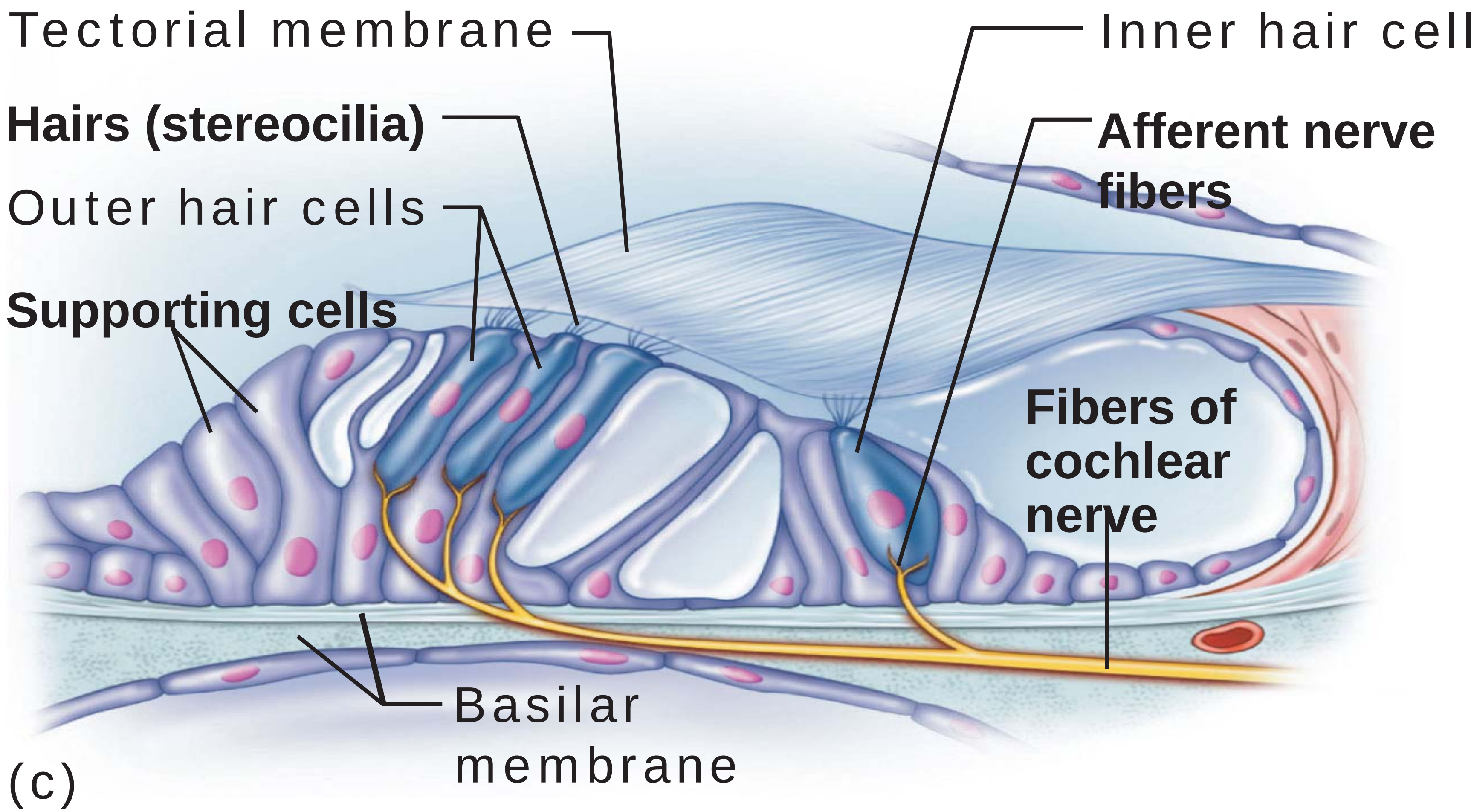
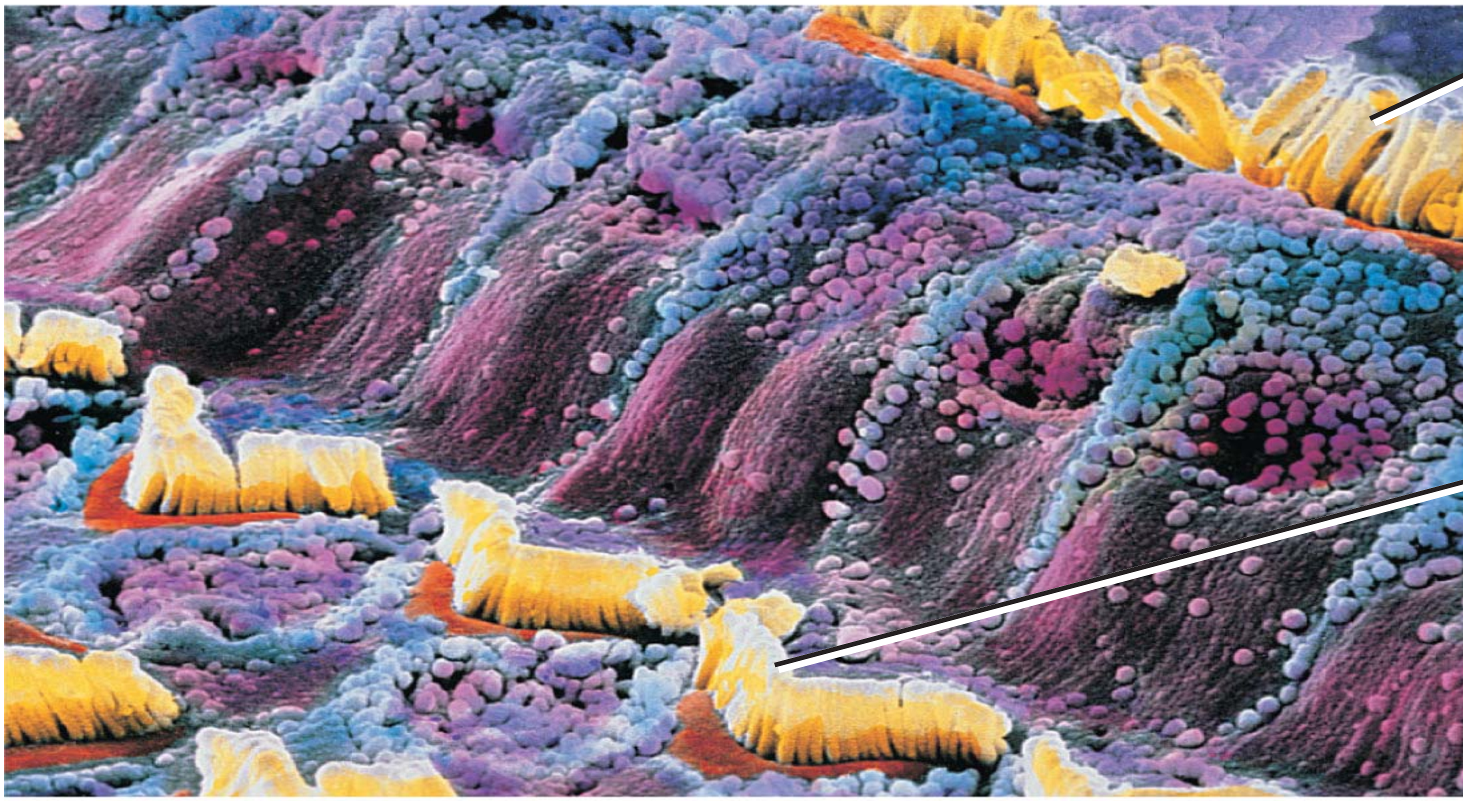


Figure 15.28c

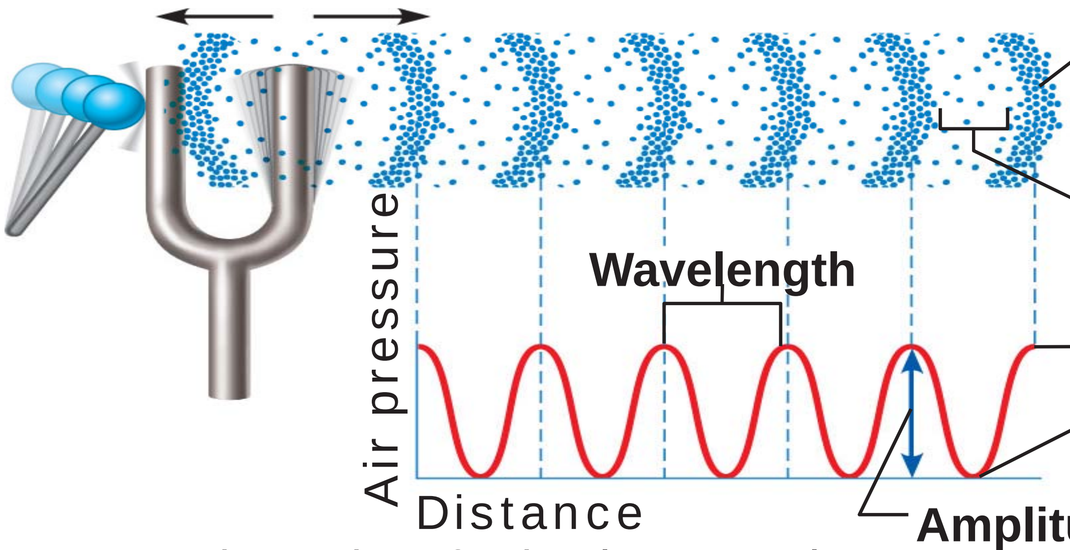


(d)

Figure 15.28d

Properties of Sound

- Sound is
  - A pressure disturbance (alternating areas of high and low pressure) produced by a vibrating object
- A sound wave
  - Moves outward in all directions
  - Is illustrated as an S-shaped curve or sine wave



A struck tuning fork alternately compresses and rarefies the air molecules around it, creating alternate zones of high and low pressure.

(b) Sound waves radiate outward in all directions.

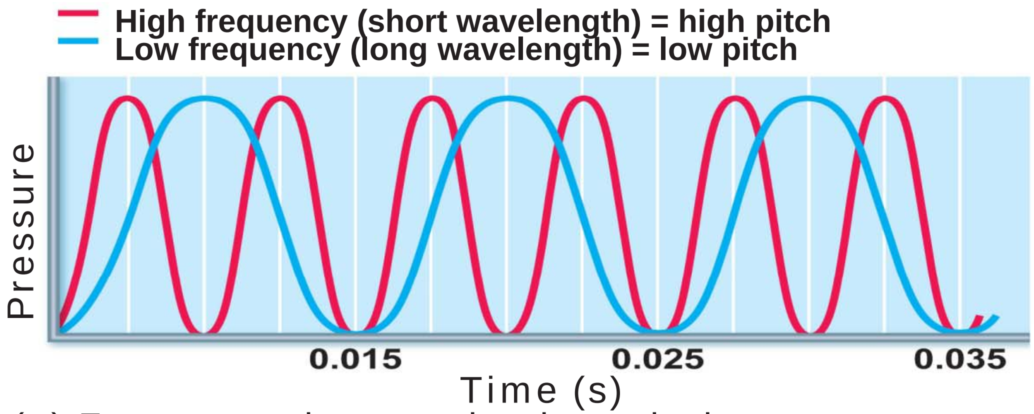
Figure 15.29

Properties of Sound Waves

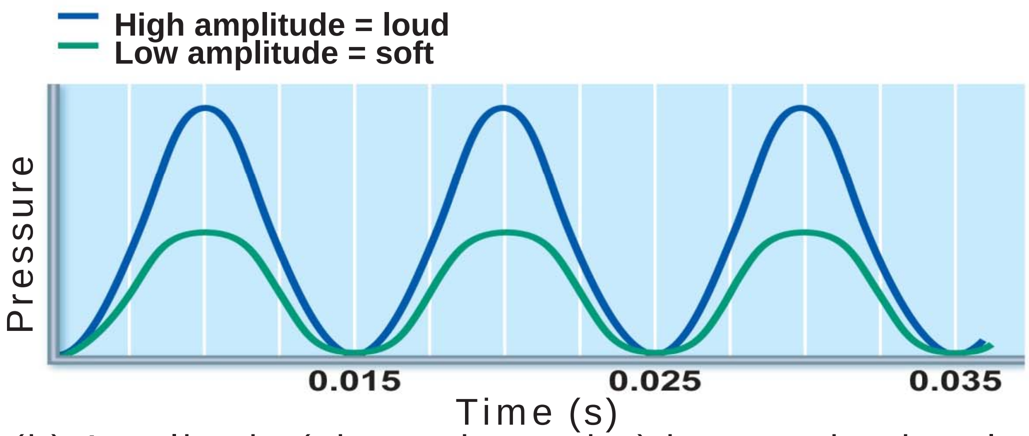
- Frequency
  - The number of waves that pass a given point in a given time
- Wavelength
  - The distance between two consecutive crests
- Amplitude
  - The height of the crests

Properties of Sound

- Pitch
  - Perception of different frequencies
  - Normal range is from 20–20,000 Hz
  - The higher the frequency, the higher the pitch
- Loudness
  - Subjective interpretation of sound intensity
  - Normal range is 0–120 decibels (dB)



(a) Frequency is perceived as pitch.



(b) Amplitude (size or intensity) is perceived as loudness.

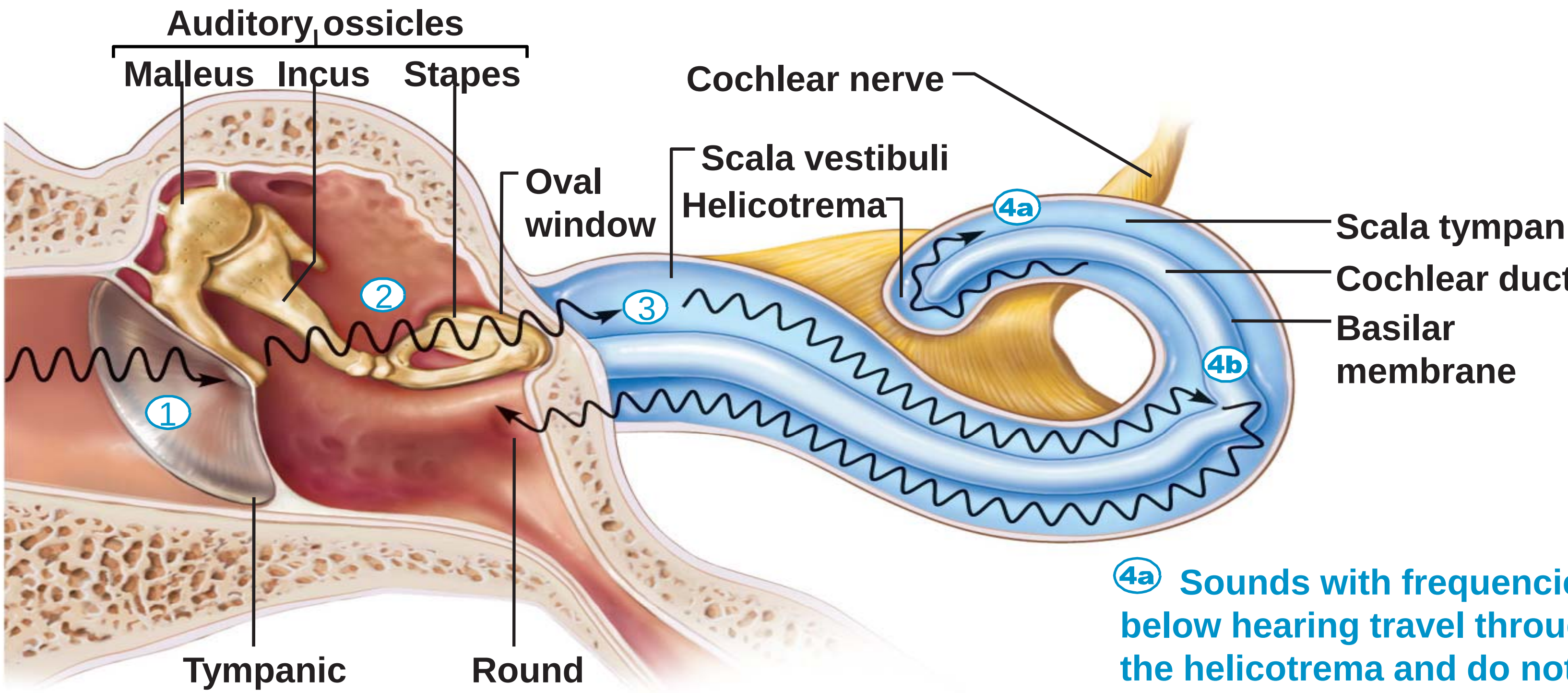
Figure 15.30

Transmission of Sound to the Internal Ear

- Sound waves vibrate the tympanic membrane
- Ossicles vibrate and amplify the pressure at the oval window
- Pressure waves move through perilymph of the scala vestibuli

Transmission of Sound to the Internal Ear

- Waves with frequencies below the threshold of hearing travel through the helicotrema and scali tympani to the round window
- Sounds in the hearing range go through the cochlear duct, vibrating the basilar membrane at a specific location, according to the frequency of the sound



(a) Route of sound waves through the ear

1 Sound waves vibrate the tympanic membrane.

2 Auditory ossicles vibrate. Pressure is amplified.

3 Pressure waves created by the stapes pushing on the oval window move through fluid in the scala vestibuli.

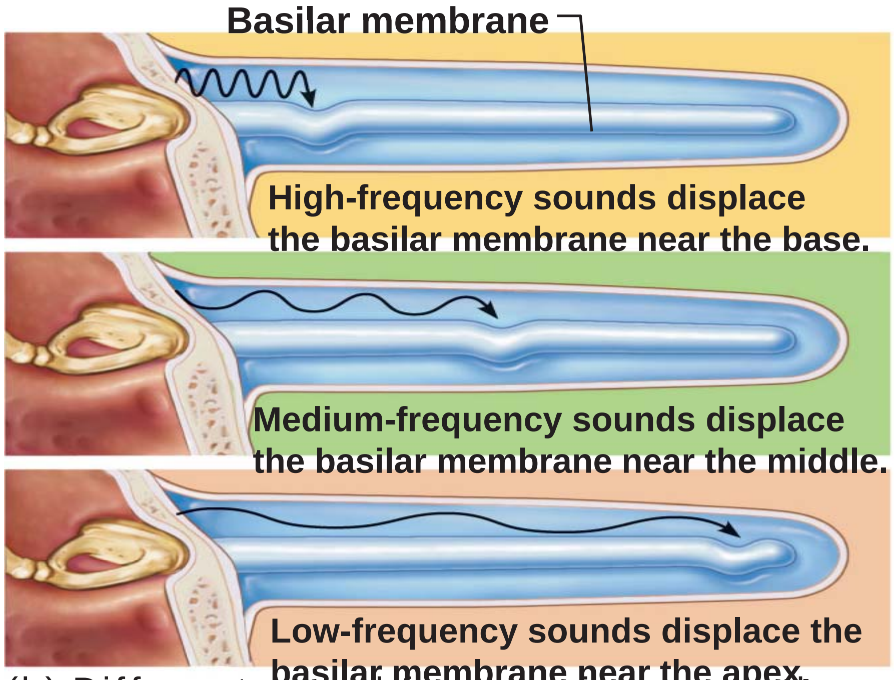
4a Sounds with frequencies below hearing travel through the helicotrema and do not excite hair cells.

4b Sounds in the hearing range go through the cochlear duct, vibrating the basilar membrane and deflecting hairs on inner hair cells.

Figure 15.31a

Resonance of the Basilar Membrane

- Fibers that span the width of the basilar membrane are short and stiff near oval window, and resonate in response to high-frequency pressure waves.
- Longer fibers near the apex resonate with lower-frequency pressure waves



(b) Different sound frequencies cross the basilar membrane at different locations.

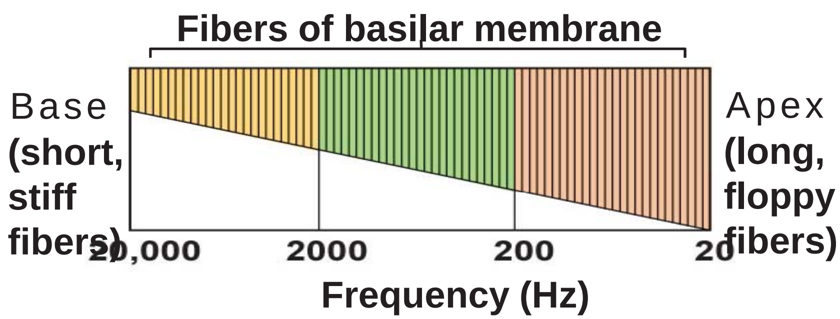


Figure 15.31b

Excitation of Hair Cells in the Spiral Organ

- Cells of the spiral organ
  - Supporting cells
  - Cochlear hair cells
    - One row of inner hair cells
    - Three rows of outer hair cells
- Afferent fibers of the cochlear nerve coil about the bases of hair cells

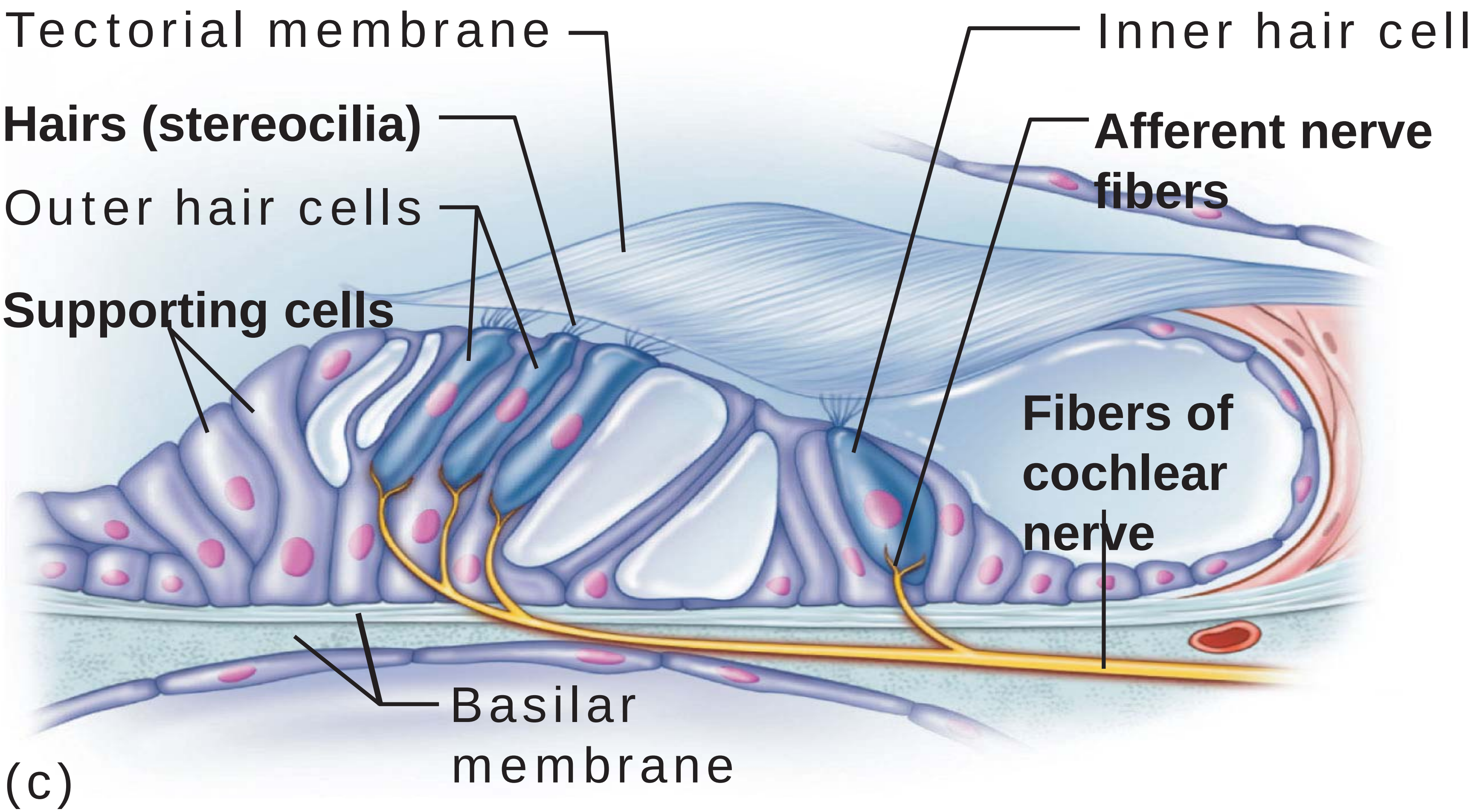


Figure 15.28c

Excitation of Hair Cells in the Spiral Organ

- The stereocilia
  - Protrude into the endolymph
  - Enmeshed in the gel-like tectorial membrane
- Bending stereocilia
  - Opens mechanically gated ion channels
  - Inward K^+ and Ca^{2+} current causes a graded potential and the release of neurotransmitter glutamate
- Cochlear fibers transmit impulses to the brain

Auditory Pathways to the Brain

- Impulses from the cochlea pass via the spiral ganglion to the cochlear nuclei of the medulla
- From there, impulses are sent to the
  - Superior olivary nucleus
  - Inferior colliculus (auditory reflex center)
- From there, impulses pass to the auditory cortex via the thalamus
- Auditory pathways decussate so that both cortices receive input from both ears

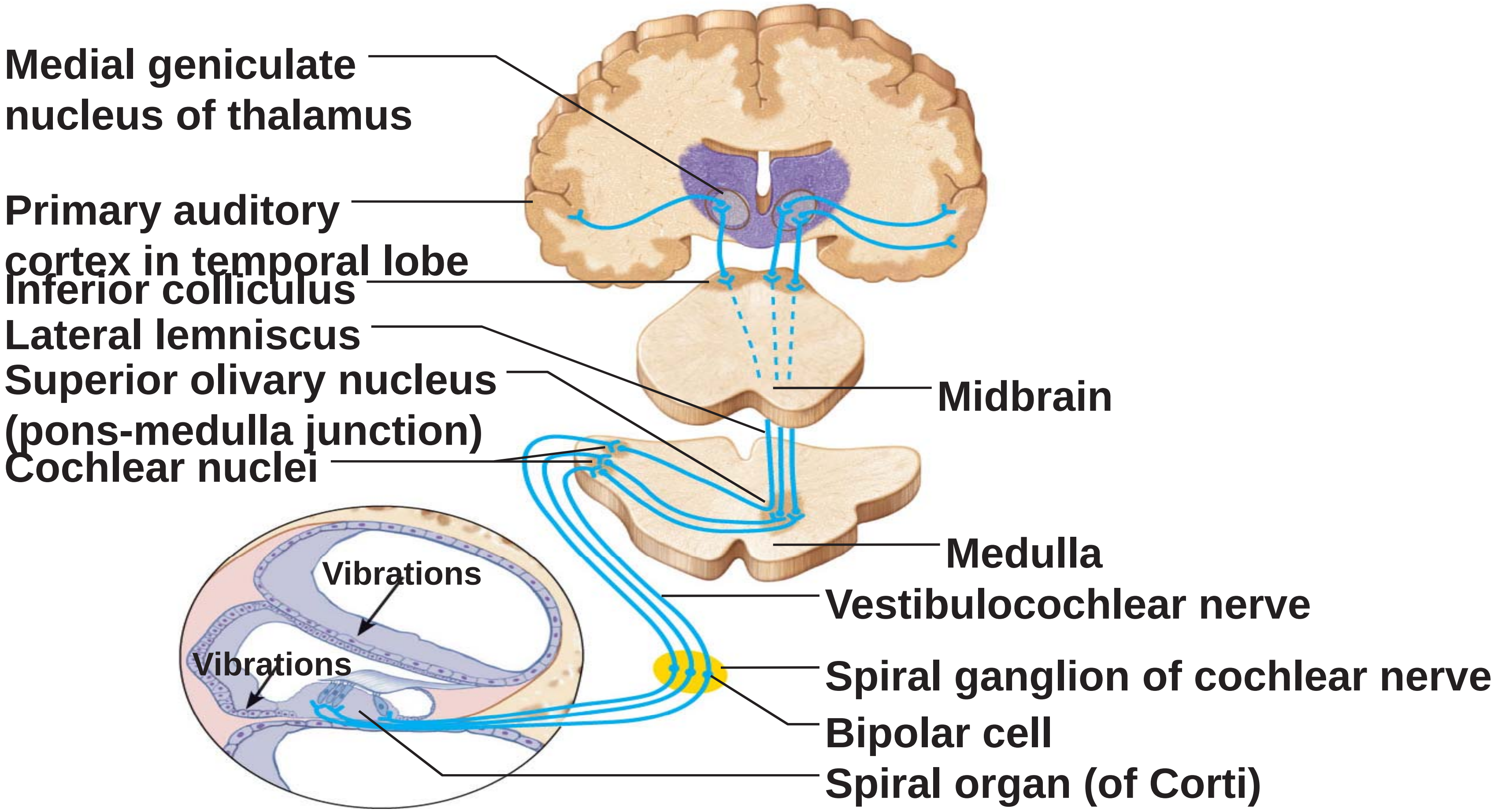

Medial geniculate nucleus of thalamus
Primary auditory cortex in temporal lobe
Inferior colliculus
Lateral lemniscus
Superior olivary nucleus (pons-medulla junction)
Cochlear nuclei
Midbrain
Medulla
Vestibulocochlear nerve
Spiral ganglion of cochlear nerve
Bipolar cell
Spiral organ (of Corti)
Vibrations
Vibrations

Figure 15.33

Auditory Processing

- Impulses from specific hair cells are interpreted as specific pitches
- Loudness is detected by increased numbers of action potentials that result when the hair cells experience larger deflections
- Localization of sound depends on relative intensity and relative timing of sound waves reaching both ears

Homeostatic Imbalances of Hearing

- Conduction deafness
  - Blocked sound conduction to the fluids of the internal ear
    - Can result from impacted earwax, perforated eardrum, or otosclerosis of the ossicles
- Sensorineural deafness
  - Damage to the neural structures at any point from the cochlear hair cells to the auditory cortical cells

Homeostatic Imbalances of Hearing

- Tinnitus: ringing or clicking sound in the ears in the absence of auditory stimuli
  - Due to cochlear nerve degeneration, inflammation of middle or internal ears, side effects of aspirin
- Meniere's syndrome: labyrinth disorder that affects the cochlea and the semicircular canals
  - Causes vertigo, nausea, and vomiting

Equilibrium and Orientation

- Vestibular apparatus consists of the equilibrium receptors in the semicircular canals and vestibule
  - Vestibular receptors monitor static equilibrium
  - Semicircular canal receptors monitor dynamic equilibrium

Maculae

- Sensory receptors for static equilibrium
- One in each saccule wall and one in each utricle wall
- Monitor the position of the head in space, necessary for control of posture
- Respond to linear acceleration forces, but not rotation
- Contain supporting cells and hair cells
- Stereocilia and kinocilia are embedded in the otolithic membrane studded with otoliths (tiny $CaCO_3$ stones)

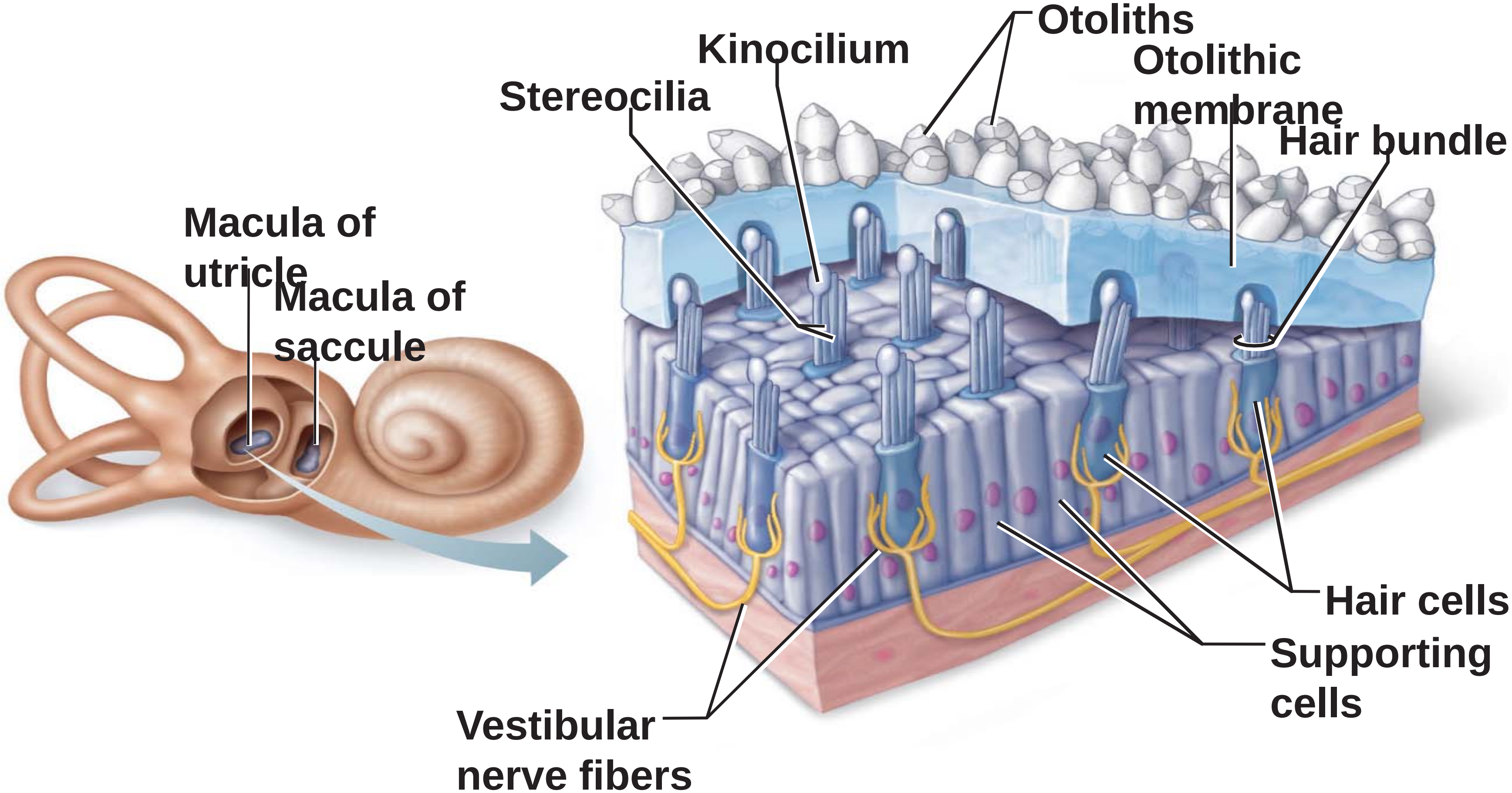

Otoliths
Kinocilium
Otolithic membrane
Stereocilia
Hair bundle
Macula of utricle
Macula of saccule
Hair cells
Supporting cells
Vestibular nerve fibers

Figure 15.34

Maculae

- Maculae in the utricle respond to horizontal movements and tilting the head side to side
- Maculae in the saccule respond to vertical movements

Activating Maculae Receptors

- Bending of hairs in the direction of the kinocilia
  - Depolarizes hair cells
  - Increases the amount of neurotransmitter release and increases the frequency of action potentials generated in the vestibular nerve

Activating Maculae Receptors

- Bending in the opposite direction
  - Hyperpolarizes vestibular nerve fibers
  - Reduces the rate of impulse generation
- Thus the brain is informed of the changing position of the head

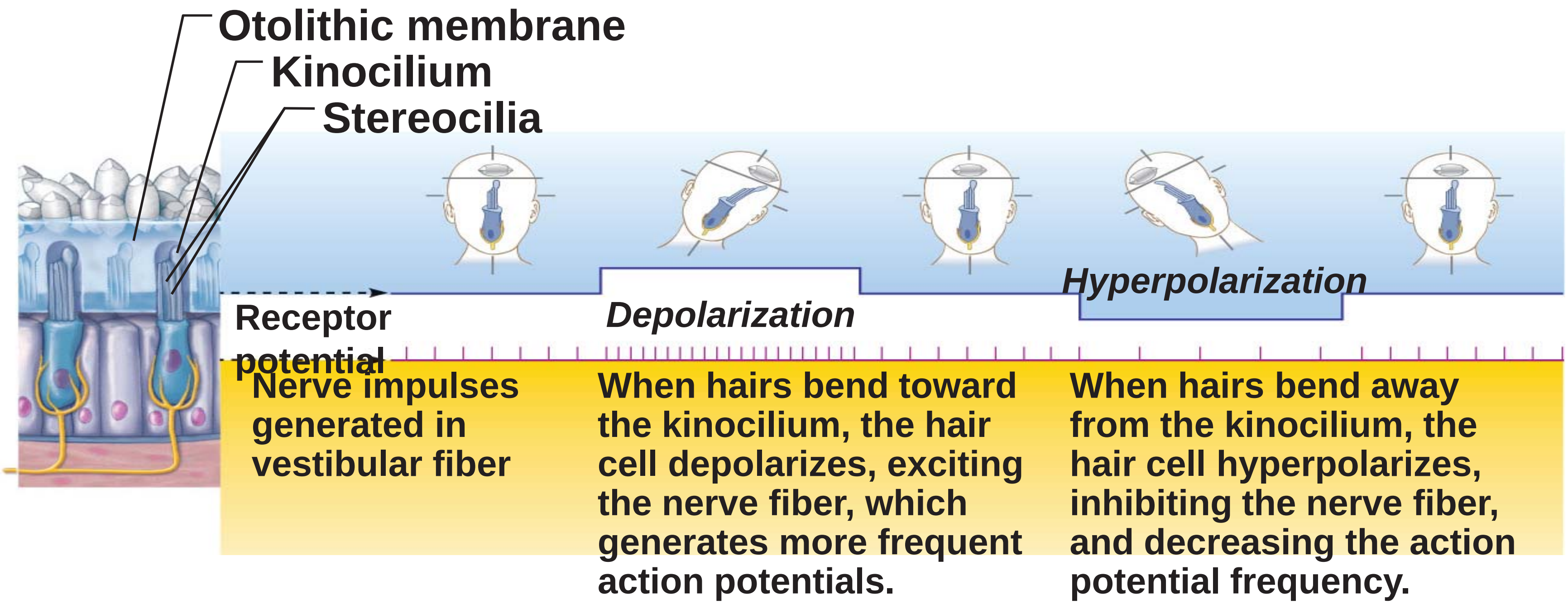
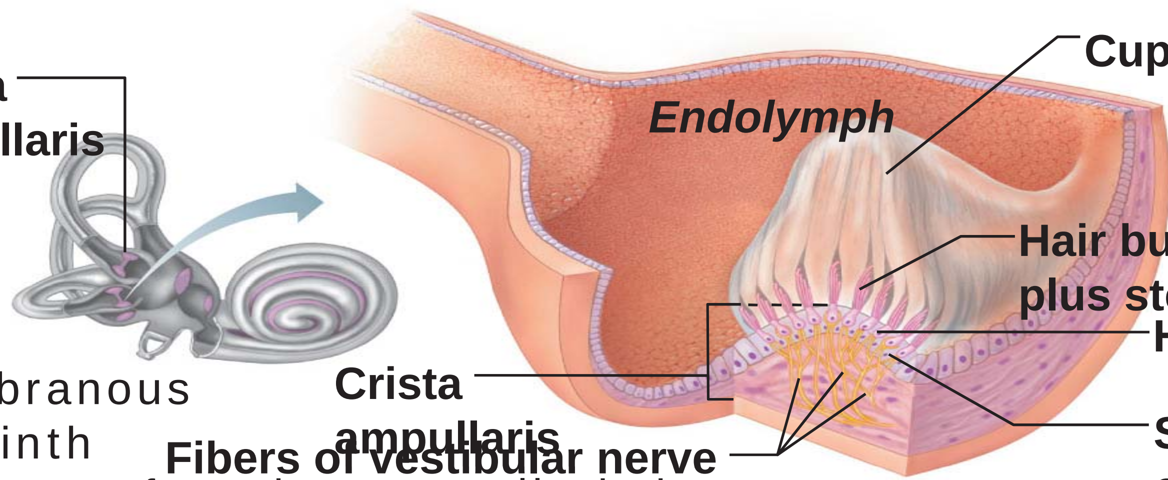

Otolithic membrane
Kinocilium
Stereocilia
Receptor potential
Depolarization
Hyperpolarization
Nerve impulses generated in vestibular fiber
When hairs bend toward the kinocilium, the hair cell depolarizes, exciting the nerve fiber, which generates more frequent action potentials.
When hairs bend away from the kinocilium, the hair cell hyperpolarizes, inhibiting the nerve fiber, and decreasing the action potential frequency.

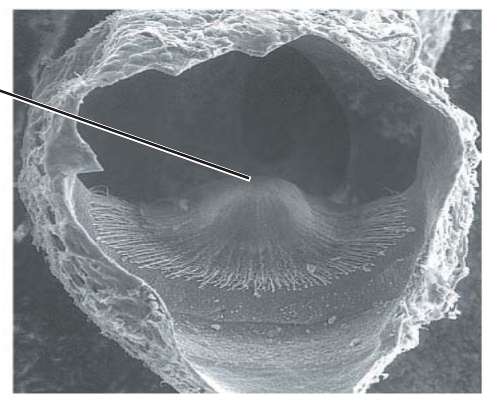
Figure 15.35

Crista Ampullaris (Crista)

- Sensory receptor for dynamic equilibrium
  - One in the ampulla of each semicircular canal
  - Major stimuli are rotatory movements
- Each crista has support cells and hair cells that extend into a gel-like mass called the cupula
- Dendrites of vestibular nerve fibers encircle the base of the hair cells



(a) Anatomy of a crista ampullaris in a semicircular canal



(b) Scanning electron micrograph of a crista ampullaris (200x)

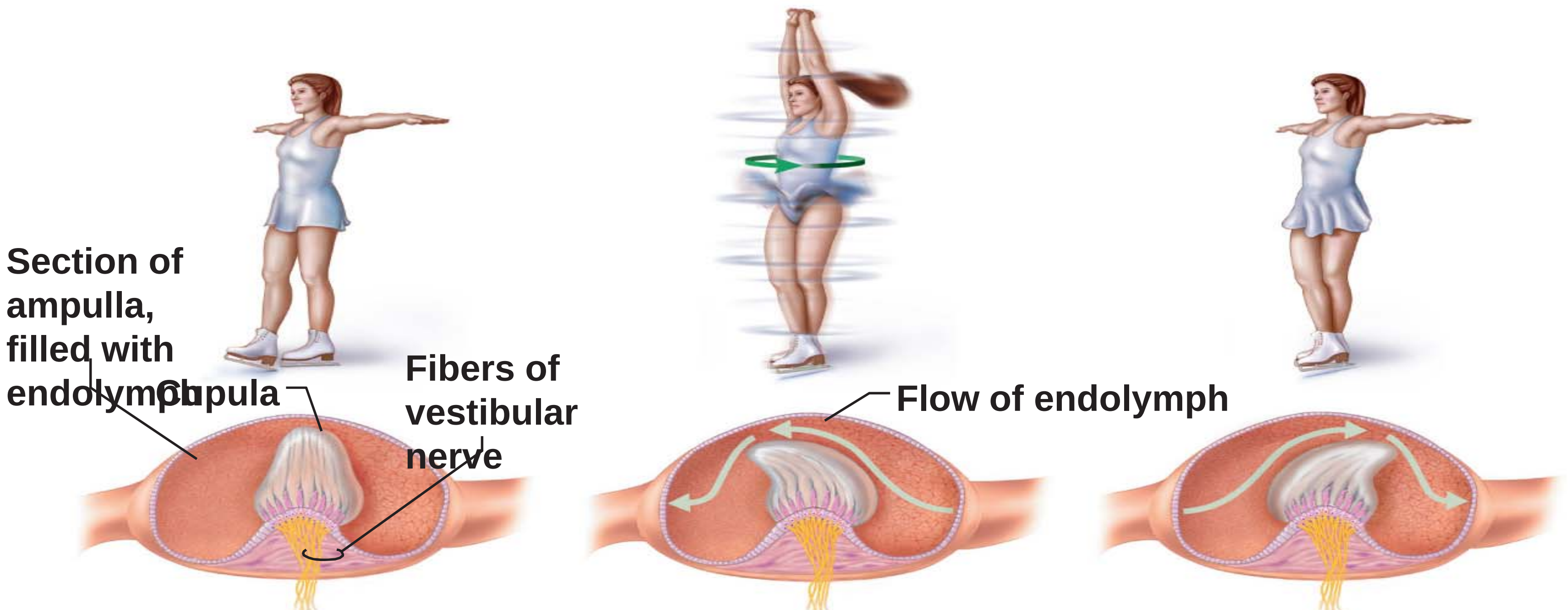
Figure 15.36a–b

Activating Crista Ampullaris Receptors

- Cristae respond to changes in velocity of rotatory movements of the head
- Bending of hairs in the cristae causes
  - Depolarizations, and rapid impulses reach the brain at a faster rate

Activating Crista Ampullaris Receptors

- Bending of hairs in the opposite direction causes
  - Hyperpolarizations, and fewer impulses reach the brain
- Thus the brain is informed of rotational movements of the head



At rest, the cupula stands upright.

During rotational acceleration, endolymph moves inside the semicircular canals in the direction opposite the rotation (it lags behind due to inertia). Endolymph flow bends the cupula and excites the hair cells.

As rotational movement slows, endolymph keeps moving in the direction of the rotation, bending the cupula in the opposite direction from acceleration and inhibiting the hair cells.

(c) Movement of the cupula during rotational acceleration and deceleration

Figure 15.36c

Equilibrium Pathway to the Brain

- Pathways are complex and poorly traced
- Impulses travel to the vestibular nuclei in the brain stem or the cerebellum, both of which receive other input
- Three modes of input for balance and orientation
  - Vestibular receptors
  - Visual receptors
  - Somatic receptors

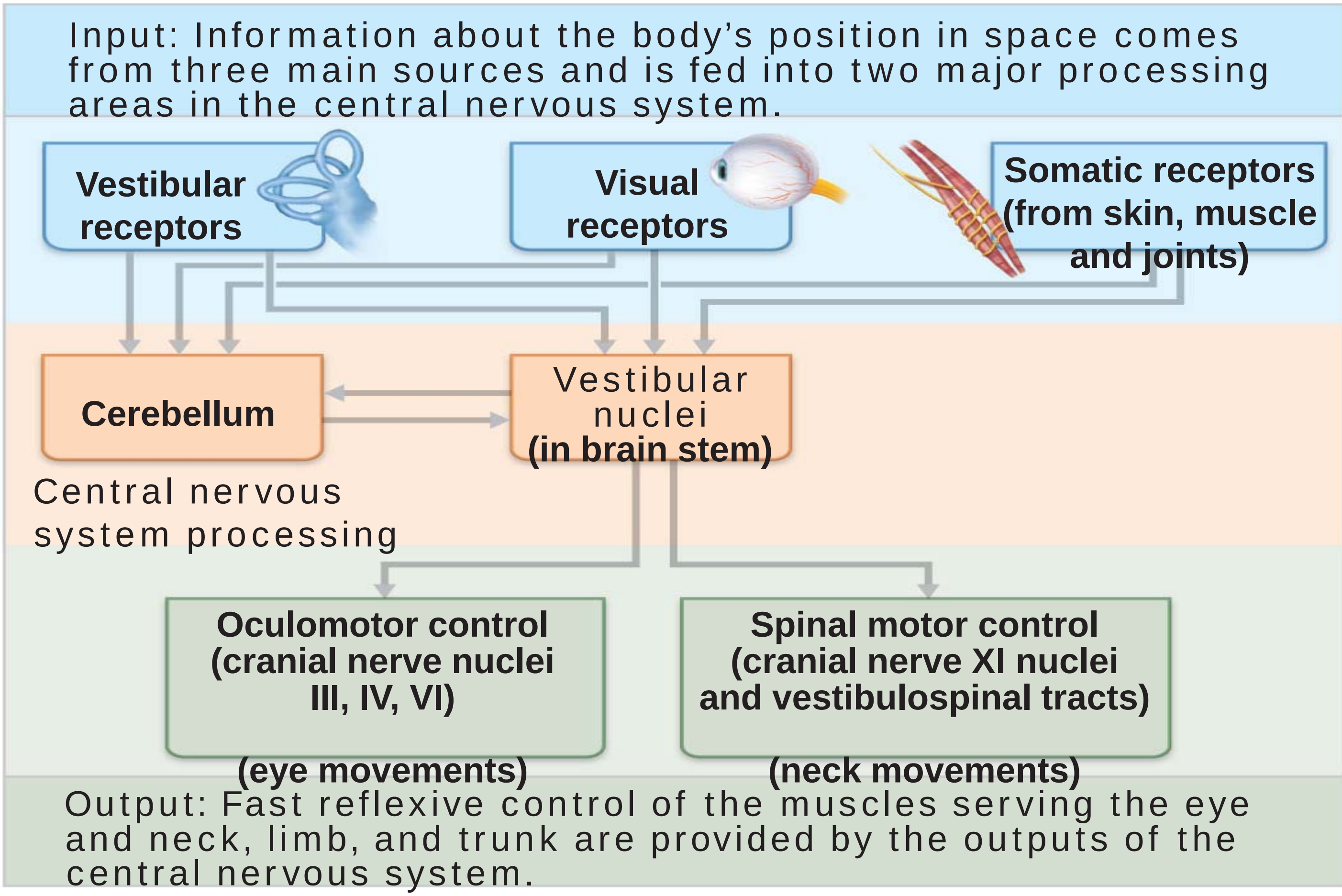

Input: Information about the body's position in space comes from three main sources and is fed into two major processing areas in the central nervous system.
Vestibular receptors
Visual receptors
Somatic receptors (from skin, muscle and joints)
Cerebellum
Vestibular nuclei (in brain stem)
Central nervous system processing
Oculomotor control (cranial nerve nuclei III, IV, VI)
(eye movements)
Spinal motor control (cranial nerve XI nuclei and vestibulospinal tracts)
(neck movements)
Output: Fast reflexive control of the muscles serving the eye and neck, limb, and trunk are provided by the outputs of the central nervous system.

Figure 15.37

Developmental Aspects

- All special senses are functional at birth
- Chemical senses—few problems occur until the fourth decade, when these senses begin to decline
- Vision—optic vesicles protrude from the diencephalon during the fourth week of development
  - Vesicles indent to form optic cups; their stalks form optic nerves
  - Later, the lens forms from ectoderm

Developmental Aspects

- Vision is not fully functional at birth
- Babies are hyperopic, see only gray tones, and eye movements are uncoordinated
- Depth perception and color vision is well developed by age five
- Emmetropic eyes are developed by year six
- With age
  - The lens loses clarity, dilator muscles are less efficient, and visual acuity is drastically decreased by age 70

Developmental Aspects

- Ear development begins in the three-week embryo
- Inner ears develop from otic placodes, which invaginate into the otic pit and otic vesicle
- The otic vesicle becomes the membranous labyrinth, and the surrounding mesenchyme becomes the bony labyrinth
- Middle ear structures develop from the pharyngeal pouches
- The branchial groove develops into outer ear structures