
ANATOMY

HEARING & BALANCE

The human ear contains two components: auditory (cochlea) & balance (vestibular).

ARTICLE

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Anatomy of the Ear & Glossary of Terms

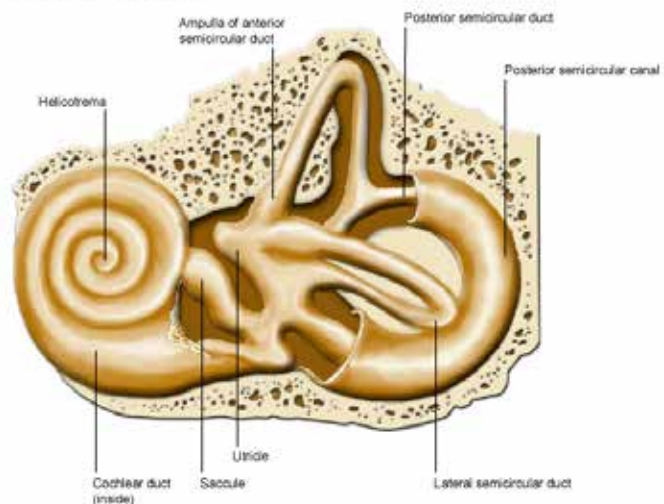
By Brian Keith, BS, Habib Rizk, MD

OVERVIEW

There are three anatomical components to the human ear: the external, middle, and inner ear. The inner ear is a complex system found within a hollow cavity of the temporal bone of the human skull known as the bony labyrinth. In this bony labyrinth, there are several structures responsible for both our sense of hearing as well as our sense of balance and position collectively forming the membranous labyrinth. The bony labyrinth can be thought of as a shell surrounding and protecting the membranous labyrinth. The auditory (hearing) component of the inner ear is driven by the cochlea, a spiral-shaped, fluid-filled organ. The vestibular (balance and position) component of the inner ear is directed by the semicircular ducts, the utricle, and the saccule.

The fluid within the inner ear's membranous labyrinth is called endolymph (endo-: inside or within). The fluid contained between the bony labyrinth and the membranous labyrinth is perilymph (peri-: around or about). These two fluids contain similar chemicals such as potassium, calcium, sodium, and magnesium, but the concentration of chemicals varies substantially between the two. When the composition of these fluids is disturbed, normal function of hearing and balance may be affected.

Inner ear showing membranous labyrinth inside bony labyrinth



SEMICIRCULAR DUCTS

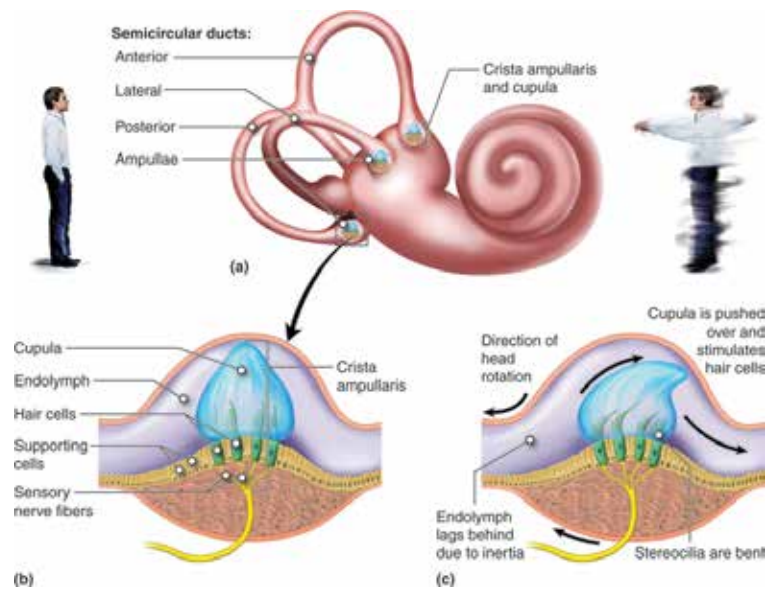
With head movement in the plane or angle in which a canal is positioned, the semicircular ducts are fluid-filled tubes deep within the bony semicircular canals that detect the rotational movement of the head about the axes of motion (X, Y, and Z). There are three semicircular ducts: superior, lateral, and posterior. Each semicircular duct detects the motion of the head around a different axis. The superior semicircular duct detects rotational movement around the frontal, or X, axis (e.g. nodding your head to indicate "yes"). The lateral semicircular duct detects movement around the vertical, or Y, axis (e.g. shaking of the head to indicate "no"). The posterior semicircular duct detects movement around the anterior-posterior, or Z, axis (e.g. touching your ear to your shoulder).

Located at the base of each semicircular duct is a widened area referred to as the ampulla. The ampulla contains the cupula and hair cells. The cupula is a gelatinous structure that spans the entire duct, and its motion is coupled to the hair cells. The hair cells are receptor cells that have hairlike projections called hair bundles that extend into the cupula. When the head moves, the endolymph lags behind due to inertia, which creates a fluid wave that collides with the cupula. The deflection of the cupula, and the hair bundles, activates the hair cells which sends a signal to the brain via the vestibular nerve, a branch of the vestibulocochlear nerve (cranial nerve eight).

This is how the semicircular ducts detect and transmit rotational movement information to the central nervous system to maintain balance and position. In addition, this information is used by our brain to carry out corresponding eye movements as our head turns to maintain forward vision. Each ear has a matching set of semicircular ducts and canals, and they work in tandem. Vestibular symptoms (e.g. dizziness, vertigo, imbalance, etc.) may be seen in semicircular duct disturbances such as benign paroxysmal positional vertigo (BPPV), superior canal dehiscence syndrome (SCDS), and alcohol positional nystagmus.

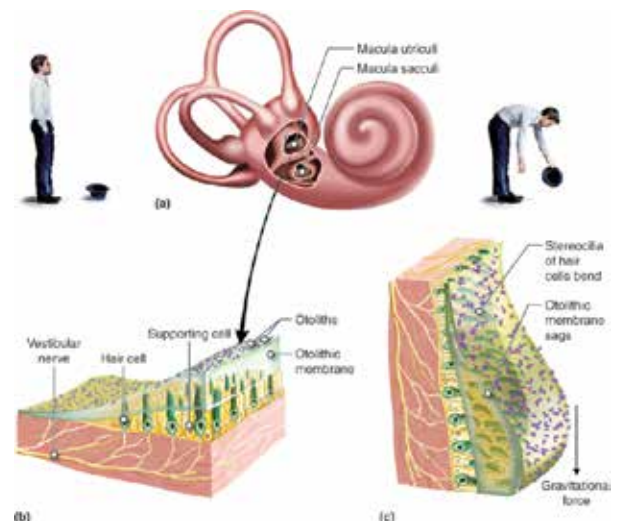
UTRICLE & SACCULE

The utricle and the saccule are involved with linear motion of the head. These two membranous structures, referred to as the otolithic organs, are the sole residents of the vestibule, a hollow cavity located between the cochlea and the semicircular canals. The utricle detects linear motion in the horizontal plane (e.g. accelerating/decelerating in



a car) and the saccule detects linear motion in the vertical plane (e.g. movement in an elevator).

The otolithic organs each contain a single curved structure called the macula that contains receptor cells known as hair cells and additional supporting cells. Similar to the mechanism of the semicircular ducts, these hair cells contain tiny hairlike projections. These projections extend into a gelatinous membrane called the otolithic membrane. Resting on top of this membrane are microscopic crystals made of calcium carbonate called otoconia. These are commonly referred to as "ear rocks" or "ear stones." Upon linear motions of the head, these tiny crystals will drag along the otolithic membrane and deflect the hairlike projections of the hair cell. This deflection allows the hair cells of the otolithic membranes to fire off a signal to the vestibular nerve and communicate with the brain that the head is moving in the horizontal and/or vertical plane.



Dysfunctions of the otolithic organs may lead to vestibular disorders such as BPPV or persistent postural-perceptual dizziness (PPPD).

OTHER STRUCTURES

The endolymphatic sac is a pouch that connects to the vestibule via the endolymphatic duct. The endolymphatic sac is believed to maintain the volume and composition of endolymph as it circulates through the inner ear. If this regulatory system is disrupted, endolymph may accumulate within the inner ear resulting in a condition known as endolymphatic hydrops. In this condition, the excessive volumes of endolymph cause the structures containing endolymph to swell up and may result in vestibular and/or auditory symptoms. Disruption of the endolymphatic sac is only one potential cause of endolymphatic hydrops. Commonly, this condition is associated with Ménière's disease.

The oval window is a kidney-shaped opening connecting the middle ear to the inner ear and this opening is covered with connective tissue. The footplate of the stapes, one of the middle ear bones, sits on top of the connective tissue. The function of the oval window is to transmit vibrations from the stapes to the inner ear fluid, sending a fluid wave through the cochlea and generating sound through specialized cells. Although its role is primarily related to the auditory system, compromise of the oval window's seal may result in vestibular problems. A perilymphatic fistula is an abnormal connection between the perilymph-filled inner ear and the middle ear. This undesirable communication between the inner and middle ear may change the perilymph composition and volume which can lead to vestibular and auditory symptoms.

The round window is another connective tissue-covered opening between the middle and inner ear. This membrane is on the receiving end of the fluid wave generated by the oval window. When the oval window bulges inward towards the inner ear, the round window bulges outwards towards the middle ear. Like the oval window, disruption of the round window's connective tissue membrane can result in a perilymphatic fistula.

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GLOSSARY

auditory: related to the sense of hearing.

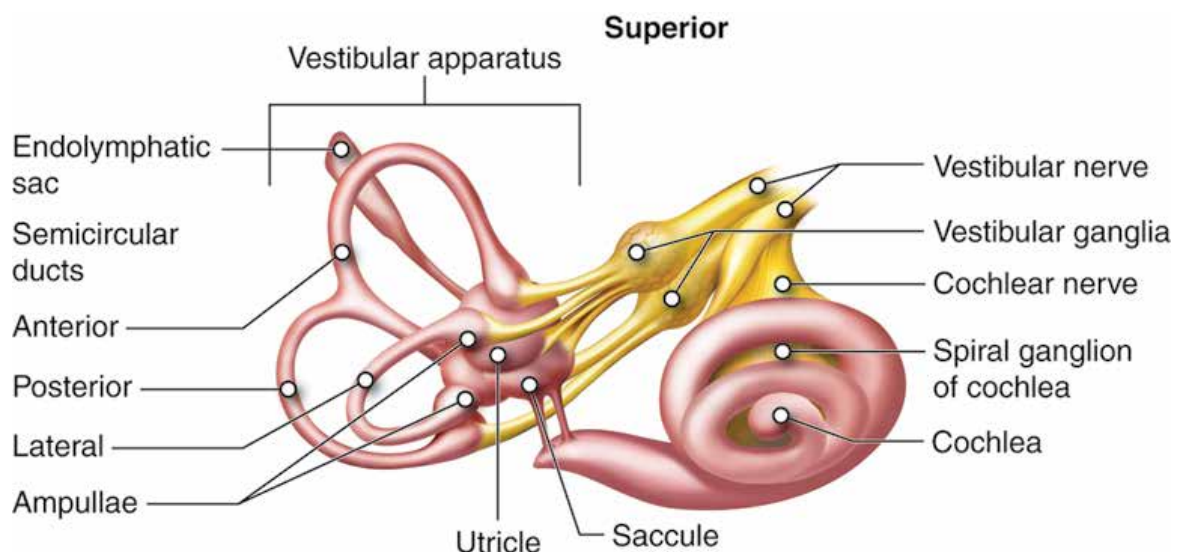
canalithiasis: the theory of BPPV (*Benign Paroxysmal Positional Vertigo*), where free-floating debris can migrate into a semicircular canal and cause short episodes of vertigo when it moves within the canal.

central vestibular system: parts of the central nervous system (brain and brainstem) that process information from the peripheral vestibular system about balance and spatial orientation.

cochlea: portion of the inner ear concerned with hearing.

cochlear implant: a prosthetic device that, unlike hearing aids which amplify sound, bypass the outer, middle, and inner ear and directly stimulate auditory nerve fibers.

conductive hearing loss: hearing loss produced by abnormalities of the outer ear or middle ear. These



abnormalities create a hearing loss by interfering with the transmission of sound from the outer ear to the inner ear.

cupulolithiasis: a variant of BPPV in which the debris is stuck to the cupula of a semicircular canal rather than being loose within the canal.

disequilibrium: unsteadiness, imbalance, or loss of equilibrium; often accompanied by spatial disorientation (a sensation of not knowing where one's body is in relation to the vertical and horizontal planes).

dizziness: lightheadedness; does not involve a rotational component (see vertigo).

endolymph: the fluid within the semicircular canals and vestibule (utricle and saccule).

Eustachian tube: connects the middle ear space with the throat; maintains equal air pressure on both sides of the tympanic membrane (eardrum).

labyrinth: complex system of chambers and passageways of the inner ear; includes both the hearing and balance portions of the inner ear.

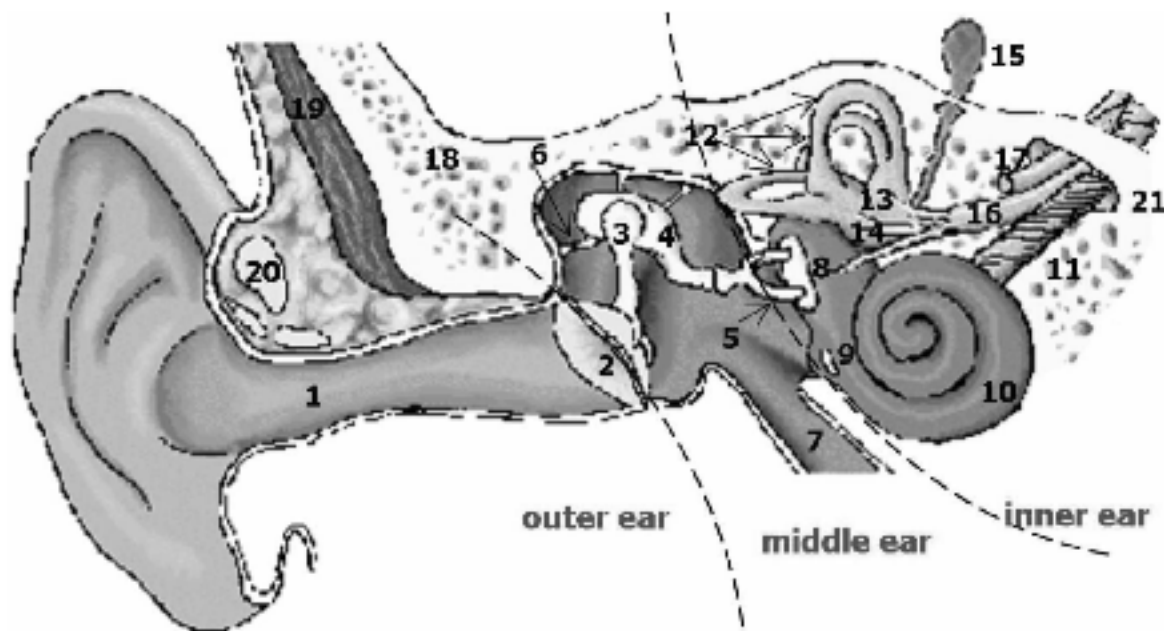
labyrinthitis: an inflammation of the labyrinth.

middle ear: air-filled cavity containing the ossicles and tympanic membrane, the function of which is to transfer sound energy from the outer ear to the cochlea of the inner ear.

mixed hearing loss: hearing loss produced by abnormalities in both the conductive and sensorineural mechanisms of hearing.

Ear Anatomy

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- | | | |
|--------------------------------|-------------------------|--------------------------------------|
| 1. external auditory canal | 8. oval window | 15. endolymphatic sac |
| 2. tympanic membrane (eardrum) | 9. round window | 16. vestibular nerve |
| 3. malleus | 10. cochlea | 17. facial nerve |
| 4. incus | 11. cochlear nerve | 18. temporal bone |
| 5. stapes | 12. semicircular canals | 19. muscle |
| 6. ligament | 13. utricle | 20. cartilage |
| 7. Eustachian tube | 14. saccule | 21. internal auditory canal to brain |

nystagmus: *involuntary, alternating, rapid and slow movements of the eyeballs.*

ossicles (*incus, malleus, stapes*): *tiny bones of the middle ear that conduct sound from the tympanic membrane to the oval window of the inner ear.*

otoliths: *calcium carbonate crystals found in the utricle and saccule of the inner ear. Damage to the otoliths may lead to BPPV.*

oval window: *oval-shaped opening from the middle ear into the inner ear. The footplate of the stapes fits into the oval window.*

perilymph: *the fluid that fills the space between the semicircular canals and vestibule (utricle and saccule) and the surrounding bone.*

peripheral vestibular system: *parts of the inner ear concerned with balance and body orientation; consists of the semicircular canals, utricle, and saccule. Peripheral in this context means outside the central nervous system (brain and brainstem), to which the peripheral system sends information.*

perilymph fistula: *abnormal opening that permits perilymph from the inner ear to leak into the middle ear.*

pinna: *external, visible portion of the ear. Its primary function is to carry sounds to the middle ear. Also called the auricle.*

round window: *membrane-covered opening between the inner ear and the middle ear.*

saccule: *sac-like inner ear organ containing otoliths; senses vertical motion of the head.*

sensorineural hearing loss: *hearing loss produced by abnormalities of the cochlea or the auditory nerve or of the nerve pathways that lead beyond the cochlea to the brain.*

temporal bone: *part of the skull in which the inner ear is located.*

tinnitus: *noise or ringing in the ears.*

tympanic membrane: *eardrum; separates the external ear canal from the middle-ear air cavity.*

utricle: *sac-like inner ear organ containing otoliths; senses forward, backward, and side-to-side motion of the head.*

vertigo: *perception of movement (either of the self or surrounding objects) that is not occurring or is occurring differently from how it is perceived.*

vestibulo-cochlear nerve: *nerve that carries information from the inner ear to the brain. Also called the eighth cranial nerve, auditory nerve, or acoustic nerve.*

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