Chapter 8

Cochlear Anatomy

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Although the middle ear is important for enhancing one's sensitivity to airborne sound, you can hear loud sounds even if part of the middle ear is missing or blocked (see Chapter 17). In contrast, the **cochlea** (i.e., hearing portion of the inner ear) is absolutely essential for hearing. It contains the sensory cells (i.e., inner [IHC] and outer **hair cells** [OHC]) responsible for converting mechanical waves into electrical activity that is transmitted to the brain and perceived as sound. Sensory cells can be destroyed by excessive exposure to noise (see Chapter 18), certain drugs (see Chapter 19), infections in the inner ear, or aging (see Chapter 21). Permanent loss of sensory cells is manifested functionally as a sensorineural hearing loss. This chapter describes the basic structure of the cochlea, the complicated hearing organ (i.e., **organ of Corti**), the specialized sensory cells and their innervation, and the fluids and fluid spaces in the cochlea.

GROSS STRUCTURE OF THE INNER EAR

The temporal bone is one of the major bones of the skull. It forms part of the floor and lateral side of the skull (Figure 8-1). Both the middle and inner ears are completely contained within the petrous (i.e., rock hard) portion of the temporal bone (see Figure 8-1, black dashed line).[1]

The temporal bone must be removed from the skull and dissected open, or decalcified, embedded in a support medium, then cut into thin slices (i.e., sections) using a precision sectioning machine called a *microtome* to view middle- and inner-ear structures. The sections are stained to show various

[1]Within the inner ear, there are eponyms for a number cell types and structures based on the descriptions of early anatomists, including Boettcher, Claudius, Corti, Deiters, Hensen, Huschke, Nuel, Reissner, and Rosenthal. An excellent history of the discoveries pertaining to the inner ear and the changes in nomenclature over time can be found in articles by Hawkins (2004a, b) and Schacht and Hawkins (2004).

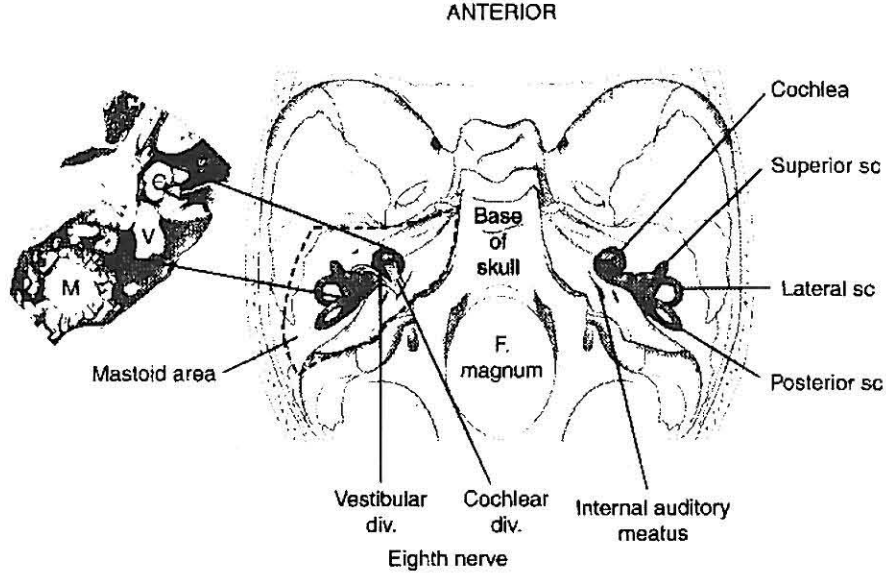

FIGURE 8-1 View of the base of the human skull with silhouettes of the left and right inner ears superimposed on the petrous portion of the temporal bone (outlined by *black dashed line*). C, cochlea; F. magnum, hole (foramen) in basal part of skull through which the spinal cord joins the brainstem; M, mastoid air cells; sc, semicircular canal; V, vestibule. The anatomical relations of key structures are indicated on the horizontal section through the left temporal bone.

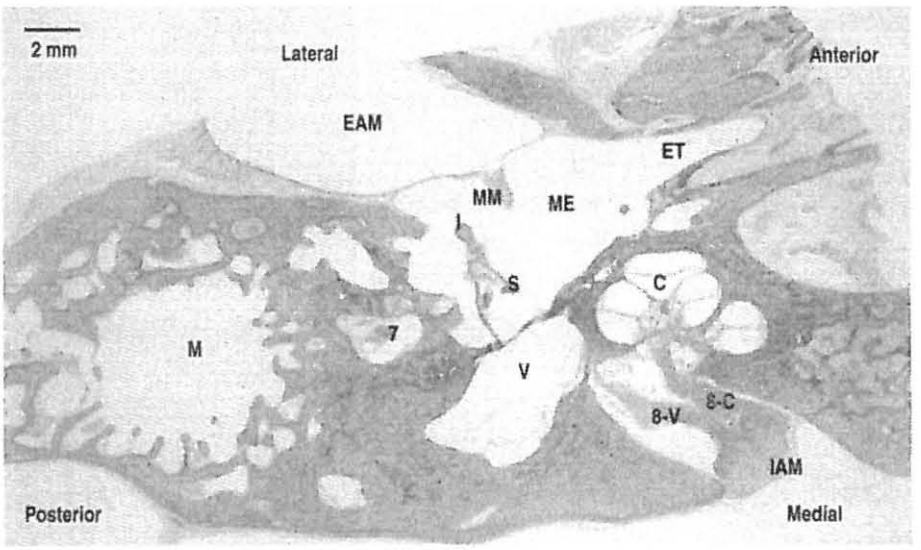

FIGURE 8-2 Horizontal section (20-μm thick) through the middle of the human temporal bone (same section as in Figure 8-1). C, cochlea; EAM, external auditory meatus; ET, Eustachian tube; I, incus; IAM, internal auditory meatus; M, mastoid; ME, middle-ear cavity; MM, manubrium of malleus; S, stapes; V, vestibule; 7, facial nerve; 8-C, cochlear division of vestibulocochlear nerve; 8-V, vestibular division of vestibulocochlear nerve.

tissues and cells, mounted on glass slides, and examined by light microscopy. An overview of the relations among the external, middle, and inner ears can be obtained by examining a horizontal section through the middle of the temporal bone. Figure 8-2 shows a section through a normal human temporal bone at the level of the external auditory meatus (EAM) and **internal auditory meatus** (IAM). The three-dimensional appearance of the middle-ear cavity is comparable with a rectangular box. The top is formed by the tegmen tympani, a thin plate of bone that separates the middle-ear cavity from the brain in the middle cranial fossa. The bottom is formed by the bone of the hypotympanum, separating the middle-ear cavity from the jugular bulb. The four walls are formed, respectively, by the tympanic membrane laterally, the cochlea (C) and vestibule (V) medially, the mastoid air cells (M) posteriorly and the Eustachian tube (ET) anteriorly. The most posterior portion of the mastoid appears as a bump behind the auricle. In the middle-ear cavity (ME), portions of the ossicles (i.e., manubrium of the malleus [MM] attached to the tympanic membrane, long process of the incus [I] and stapes [S]) are visible. The vertical descent of the seventh cranial nerve (i.e., **facial nerve** [7]) through the temporal bone is visible in the posterior wall of the middle-ear cavity. Both the cochlear division (8-C) and vestibular division (8-V) of the eighth cranial nerve (i.e., **vestibulocochlear nerve**) are seen in the IAM.

The cochlea (Latin meaning "snail shell") consists of a spiral canal that, in humans, makes two and a half turns around a spongy central core termed the **modiolus.** Dividing the cochlea in half shows the centrally placed modiolus (M) and five radial sections through the cochlear turns and fluid spaces (i.e., **scala vestibuli** [SV], **scala tympani** [ST], **scala media** [Figure 8-3, box]). The bodies of the **spiral ganglion cells** (i.e., primary auditory neurons) are found in **Rosenthal's canal** (rc), a spiral canal located at the periphery of the modiolus (M).

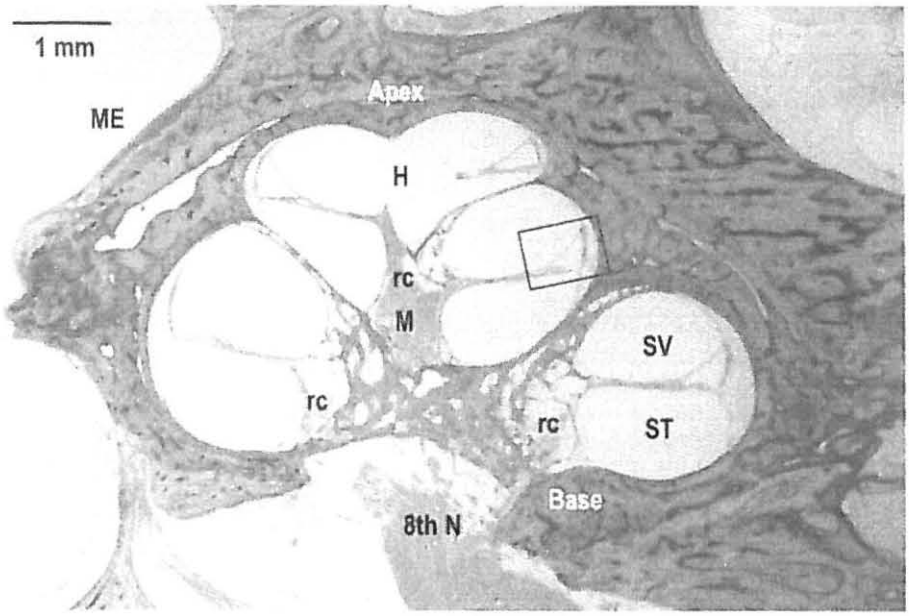

FIGURE 8-3 High-power photomicrograph of a midmodiolar section through the human cochlea. *Box* denotes the boundaries of one turn of the membranous cochlea that is shown at a higher power in Figure 8-4. 8th N, cochlear division of vestibulocochlear nerve; H, helicotrema; M, modiolus; ME, middle-ear cavity; rc, Rosenthal's canal; ST, scala tympani; SV, scala vestibuli.

The central processes (i.e., axons) of the ganglion cells form the cochlear division of the vestibulocochlear nerve (8th N) that exits the temporal bone at the base of the cochlea.

FLUID SPACES IN THE COCHLEA

Scala vestibuli and scala tympani are both filled with **perilymph,** a fluid that has a low concentration of potassium ions and a high concentration of sodium ions. This fluid is similar in ionic composition to cerebrospinal fluid (CSF). At the base of the cochlea, the oval and round windows provide openings from the middle ear into the vestibule and scala tympani, respectively. The stapes footplate is tightly held in the oval window by the annular ligament. The round window is closed by the relatively thin, semipermeable round-window membrane. Near the base of scala tympani, the cochlear aqueduct connects scala tympani to the CSF space in the cranium. Scalae vestibuli and tympani are in communication with one another at the cochlear apex via the **helicotrema** (H) (see Figure 8-3).

Scala media is a triangular-shaped space that is located between scala vestibuli and scala tympani. Its boundaries are **Reissner's membrane,** the **basilar membrane,** and the **stria vascularis** (Figure 8-4). The boundaries of the **cochlear duct** or **endolymphatic space** are the epithelial covering on the superior surface of the basilar membrane, the superior surface of the **spiral limbus,** the inferior layer of Reissner's membrane, and the inner surface of the stria vascularis. The endolymphatic space is filled with **endolymph,** a fluid that has a low concentration of sodium ions and a high concentration of potassium ions, making it similar in ionic concentration to intracellular fluid.

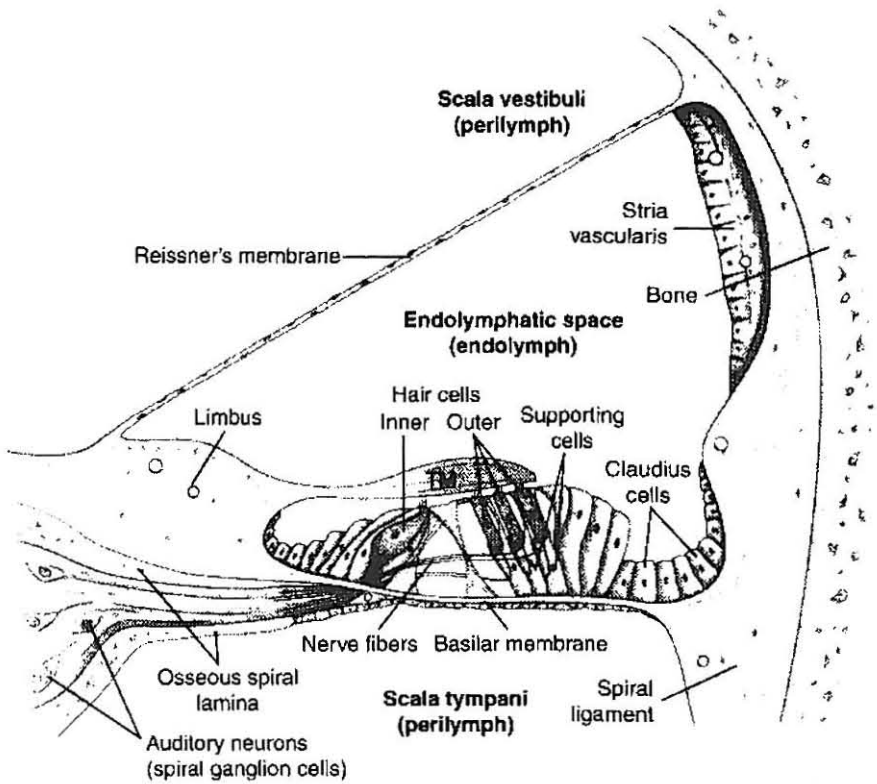

FIGURE 8-4 (See Color Plate) Schematic view of a portion of the membranous cochlea. C, Claudius cell; TM, tectorial membrane. (Adapted from Davis and Associates, 1953, by B.A. Bohne, 2004.)

COCHLEAR DUCT

The cochlear duct spirals around the modiolus from the base to the apex of the cochlea. A radial view of one turn of the cochlear duct is shown diagrammatically in Figure 8-4. All cells that form the endolymphatic boundary are derived from the embryonic cell layer called the *neuroectoderm* and are joined at their apical ends by tight junctions (i.e., **zonulae occludens**). Tight junctions prevent the passage of ions between the different fluid compartments in the cochlea.

The superior boundary of the endolymphatic space is formed by Reissner's membrane. This membrane is composed of two layers of squamous (i.e., flattened) cells. The cells in the inferior layer are joined by tight junctions. The lateral boundary of the endolymphatic space is formed by the stria vascularis. The cells on the surface of the stria vascularis facing the modiolus are joined by tight junctions. The inferior boundary of the endolymphatic space is formed by the superior surface of the organ of Corti, Claudius cells, inner sulcus cells, and the epithelial cells on the superior surface of the limbus. Boettcher cells (not shown in Figure 8-4) are found laterally on the basilar membrane in the basal turn. Their apical surfaces are entirely covered by

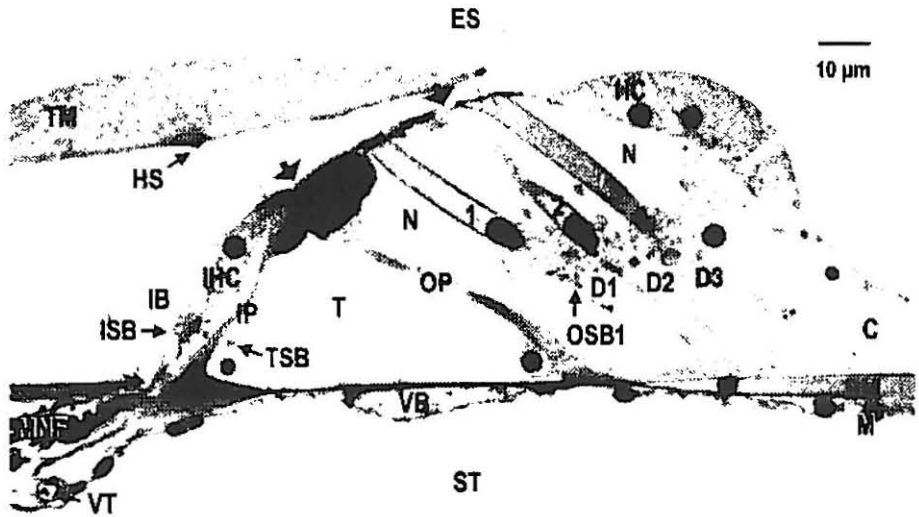

FIGURE 8-5 Radial section of the organ of Corti from the second turn of a control chinchilla. 1, 2, 3, outer hair cells in the first, second, and third rows, respectively; BM, basilar membrane; C, Claudius cell; D1, D2, D3, Deiters' cell in first, second, and third rows, respectively; ES, endolymphatic space; H, habenula perforata (between *arrows*); HC, Hensen's cell; HS, Hensen's stripe; IB, inner border cell; IHC, inner hair cell; IP, inner pillar cell; ISB, inner spiral bundle of nerve fibers; M, mesothelial cell; MNF, myelinated nerve fibers; N, Nuel's space; OP, outer pillar cell; OSB1, first outer spiral bundle of nerve fibers; ST, scala tympani; T, tunnel; TM, tectorial membrane; TSB, tunnel spiral bundle of nerve fibers; VB, vessel of the basilar membrane; VT, vessel of the tympanic lip of the osseous spiral lamina.

Claudius cells. The exact function of the Boettcher cells is unknown, but it may involve ion or fluid transport, or both.

The limbus is attached to the superior lip of the **osseous spiral lamina** (i.e., double layer of thin bone projecting from the modiolus). The limbus consists of a network of fibrocytes, capillaries, and numerous filaments. The epithelial cells on the superior surface of the limbus are called *interdental cells*. These cells are separated from one another by the teeth of Huschke, short projections of the connective tissue of the limbus. The medial edge of the **tectorial membrane** (TM) is attached to the interdental cells of the limbus. These latter cells are thought to be responsible for maintaining the structure of the TM. The TM is a gelatinous matrix, with embedded fibrils, that is about 96% water. It overlies the superior surface of the organ of Corti. In the living ear, the lateral edge of the TM is attached to the apical surfaces of **Hensen's cells** (HC) (Figure 8–5).

The peripheral processes of spiral ganglion cells and efferent fibers enter or leave the organ of Corti by passing between the two lips of the osseous spiral lamina. Innervation of the organ of Corti is discussed in a later section.

ORGAN OF CORTI

The organ of Corti (see Figure 8–4) is a lacy network of sensory and supporting cells with interposed fluid spaces. The sensory cells, called IHCs and OHCs, occupy the superior half of the organ of Corti. Hair cells were named for the small "hairlike" projections (i.e., **stereocilia**) from their apical surfaces. In the organ of Corti, the supporting cells extend from its superior to its inferior surface.

Because fixation of human temporal bones is generally not optimal and because all mammalian organs of Corti have substantially the same appearance, detailed structure of the organ of Corti can best be seen in sections of animal cochleas. Figure 8-5 is a photomicrograph of a radial section through the organ of Corti from a normal chinchilla. The thin, flexible basilar membrane (BM) is covered on its superior surface by the organ of Corti, inner sulcus cells medially, and Claudius cells (C) laterally, whereas mesothelial cells (M) and blood vessels (i.e., vessel of the basilar membrane [VB]; vessel of the tympanic lip of the osseous spiral lamina [VT]) are found on its inferior surface. The basilar membrane itself is composed of extracellular matrix material in which heavy, radially oriented fibrils are embedded. Scala tympani (ST) is inferior to the basilar membrane.

Extending from the cochlear base to apex, the organ of Corti contains two types of sensory cells: a single row of IHCs and three rows of OHCs. Supporting cells are found medial to and in between adjacent IHCs (i.e., inner border [IB]; inner phalangeal [p]; Figure 8-6), inferior and lateral to the OHCs (i.e., Deiters' cells [D1, D2, D3]; HC], and at the margins of the **tunnel** (T) (i.e., inner pillar cell [IP]; outer pillar cell [OP]). The **pillar** and **Deiters' cells** contain parallel, intracellular bundles of microtubules that extend from the bases of the cells on the basilar membrane up to their heads or phalangeal processes, respectively, at the superior surface of the organ of Corti. The inner and outer pillar cells have a triangular relation in the radial direction. The inner pillars are offset such that the thin head plate that projects from each inner pillar head generally overlaps part of two outer pillar heads. In the apical-basal (i.e., spiral) direction, the outer pillar feet are slightly apical to their heads and Deiters' cell processes angle basally across three to four OHCs before reaching the superior surface of the organ of Corti and forming phalangeal processes. These supporting cell relations provide stiff, yet lightweight, connections between the basilar membrane and endolymphatic surface of the organ of Corti.

A view of the endolymphatic surface of the organ of Corti in the first turn of a chinchilla cochlea is shown in Figure 8-6. The apical surface of each hair cell is separated from neighboring hair cells by phalangeal processes from different supporting cells. Adjacent IHCs are separated by phalangeal processes (p) from inner phalangeal cells. OHCs in the first row (see Figure 8-6, region 1) are separated by phalangeal processes from the outer pillar head (pop). OHCs in the second row (see Figure 8-6, region 2) are separated by phalangeal processes (D1) from the first row of Deiters' cells. OHCs in the third row (see Figure 8-6, region 3) are separated by phalangeal processes (D2) from the second row of Deiters' cells. Phalangeal processes (D3) from the third row of Deiters' cells are lateral to the third row of OHCs. Figure 8-6 shows that third-row OHCs are on a straight line directly lateral to the first-row OHCs. In contrast, second-row OHCs are offset in a spiral direction by half the diameter of an OHC.

The tunnel (T) and the **spaces of Nuel** (N) are fluid-filled spaces within the organ of Corti. The latter spaces surround the body of each OHC. All fluid spaces in the organ of Corti communicate with one another. The superior surface of the organ of Corti is termed the **reticular lamina** (see Figure 8-5, heavy arrows). It is composed of the head plates of the inner pillar cells and the apices of the hair cells alternating with phalangeal processes from the inner phalangeal cells, Deiters' cells, and outer pillar cells (see Figure 8-6). Tight junctions exist between all cells that form the reticular lamina. Therefore, the tunnel and Nuel's spaces are not in communication with the endolymphatic space (ES). A number of studies have shown that the fluid in the organ of Corti is perilymph or is similar to perilymph in its ionic composition.

The peripheral processes (myelinated nerve fibers [MNF]) of the spiral ganglion cells are myelinated until they enter the organ of Corti through a series of small holes in the basilar membrane called **habenulae perforata** (H; see Figure 8-5, small opposing arrows) that are located inferior to the IHCs. Within the organ of Corti, the nerve fibers form nonmyelinated bundles inferior to the

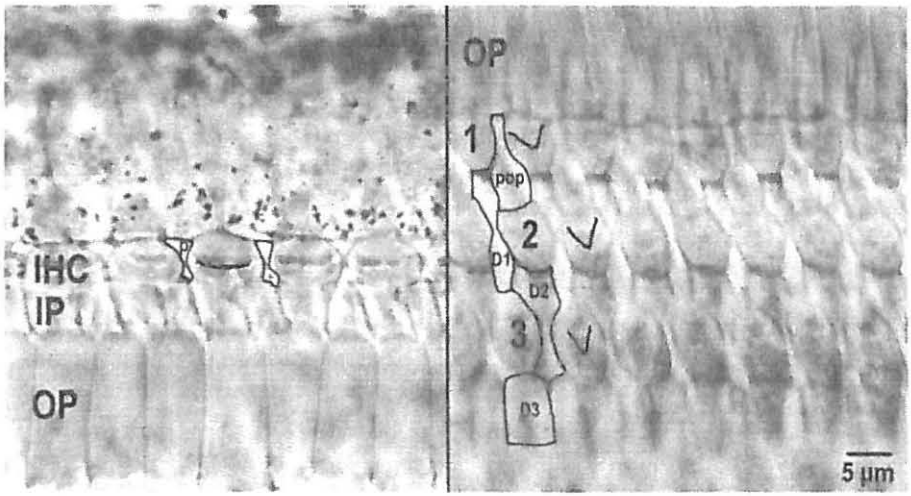

FIGURE 8-6 Horizontal view of the reticular lamina of the organ of Corti as seen from the direction of Reissner's membrane. 1, 2, 3, outer hair cell in first, second, and third rows, respectively; D1, D2, D3, phalangeal process from Deiters' cell in first, second, and third rows, respectively; IHC, inner hair cell; IP, inner pillar head; OP, outer pillar head, p, phalangeal process from inner phalangeal cell; pop, phalangeal process from outer pillar head. Arrangement of stereocilia on the hair cells is drawn in black.

IHC (i.e., inner spiral bundle [ISB]), within the tunnel space (i.e., tunnel spiral bundle [TSB]), and inferior to each row of OHCs (i.e., outer spiral bundles [e.g., OSB1]) (see Figure 8-5).

In most histologic preparations, the TM is shrunken and displaced from its *in vivo* location because of dehydration. Even with preparation artifacts, several features of the TM are visible, including its tapering lateral edge and **Hensen's stripe** (HS), which appears as a small, dark protrusion from its inferior surface (see Figure 8-5).

INNER AND OUTER HAIR CELLS

The intracellular organelles and surface specializations on IHCs and OHCs can best be appreciated in transmission electron micrographs (Figure 8-7). The IHC (I) has a flask-shaped body, a centrally located nucleus with organelles, such as mitochondria and lysosomes, scattered in the cytoplasm. Just inferior to the apical surface of the cell is an electron-dense structure called the *cuticular plate* (cp). The specializations on the apical surface [i.e., stereocilia (st)] of the cell that project into the endolymphatic space (ES) are similar to elongated, parallel microvilli. Rootlets project into the cuticular plate from each stereocilium. On the IHCs, three to four rows of stereocilia are arranged in nearly a straight line, which is oriented in an apical-basal direction (see Figure 8-6). The stereocilia are graded in length with the shortest on the medial side and the tallest on the lateral side of the cell. *In vivo*, the tallest stereocilia are in contact with the lateral side of HS. Tight junctions (see Figure 8-6, arrows) are found between the inner pillar (IP) and the apex of the IHC, as well as the inner border cell (IB) and the IHC. Cross-sectioned nerve fibers (nf) are visible where the nerve fibers synapse on the hair cell base. The tunnel space (T) is visible lateral to the inner pillar body (see Figure 8-7A).

The OHC (O1) is long and cylindrical with its nucleus located near the base of the cell. The base of each OHC and its nerve endings (E) sit in the cup region (D) of a Deiters' cell. Intracellular organelles (i.e., mitochondria, lysosomes, and microbodies) are clustered in the region inferior to the cuticular plate (cp). A group of mitochondria inferior

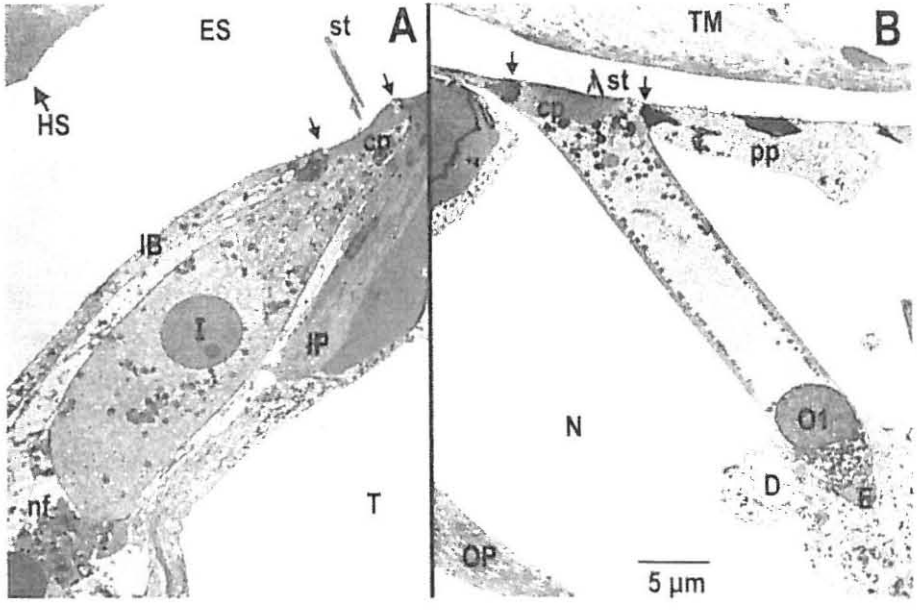

FIGURE 8-7 Transmission electron micrographs of (A) third-turn inner hair cell and (B) first-turn outer hair cell from a control chinchilla. cp, cuticular plate; D, cup region of Deiters' cell; E, nerve ending; ES, endolymphatic space; HS, Hensen's stripe; I, inner hair cell; IB, inner border cell; IP, inner pillar cell; N, Nuel's space; nf, nerve fibers; O1, first row outer hair cell; OP, outer pillar body; pp, phalangeal process from supporting cell; st, stereocilia; T, tunnel; TM, tectorial membrane.

to the nucleus fills the region where the nerve endings (E) synapse. A single row of mitochondria is found adjacent to the lateral plasma membrane of the cell. On the OHCs, three to five rows of stereocilia (st) are arranged in a "W-" or "V-shaped" pattern on the cell surface with the points facing laterally (see Figure 8-6). The stereocilia on the OHCs are also graded in length from the medial to the lateral side of the cell. *In vivo*, the tips of the tallest (i.e., lateralmost) stereocilia are embedded in the TM. Tight junctions (see Figure 8-7, arrows) are found between the hair cell apex and the phalangeal process (pp) of the adjacent supporting cells. Nuel's space (N) surrounds the OHC body (see Figure 8-7B).

HAIR CELL INNERVATION

The hair cells in the organ of Corti have both **afferent** and **efferent** innervation (Figure 8-8). The bipolar spiral ganglion cells, the bodies of which are located in Rosenthal's canal, provide afferent innervation to the hair cells. The central (i.e., axonal) processes of these cells traverse the modiolus, exit the temporal bone via the IAM, and synapse in the cochlear nuclei of the brainstem. Their peripheral processes traverse the osseous spiral lamina, pass through the holes in basilar membrane (i.e., habenulae perforata; see Figure 8-5), and enter the organ of Corti to synapse on the hair cells.

Type I spiral ganglion cells have large bodies and large, round nuclei. In some species other than humans, the bodies of type I ganglion cells and their peripheral processes (as far as the habenulae perforata) are myelinated. Depending on species, type I cells comprise 85% to 95% of the spiral ganglion cell population and exclusively innervate IHCs. The peripheral process of each type I ganglion cell exits a habenula perforata, runs directly to the nearest IHC, and forms a small bouton ending on the base or basolateral side of the hair cell. These fibers are called

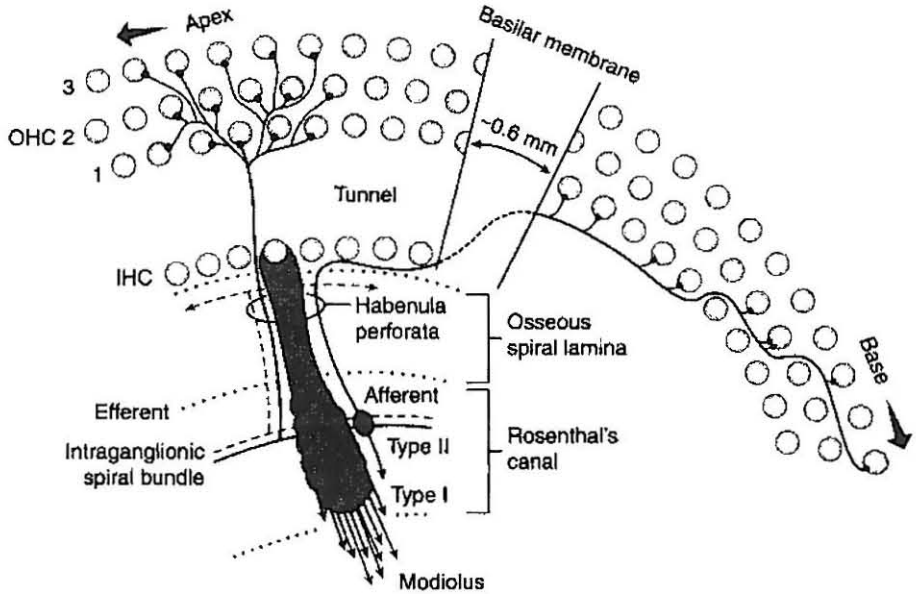

FIGURE 8-8 Summary of hair cell innervation in the organ of Corti. IHC, inner hair cells; OHC 1, 2, 3, outer hair cells in first, second, and third rows, respectively. (Adapted from Spoendlin, 1984, by B.A. Bohne, 2004.)

radial afferents, and depending on species and cochlear location, each IHC synapses with about 10 to 20 of these fibers. Within the IHC adjacent to afferent nerve endings, it is common to find synaptic bodies surrounded by synaptic vesicles.

Type II spiral ganglion cells have small bodies and lobular, eccentrically located nuclei, and they are thinly myelinated or not myelinated at all. Type II cells comprise 5% to 15% of the spiral ganglion cell population and exclusively innervate OHCs. These cells are located laterally in Rosenthal's canal near the origin of the osseous spiral lamina. Their peripheral processes exit the habenulae perforata, travel a short distance in the inner spiral bundle, pass between adjacent inner pillar feet, and then cross near the floor of the tunnel as basilar fibers. The fibers enter one of the outer spiral bundles, turn in a basal direction, and travel as much as 0.6 mm before forming bouton nerve endings on a variable number of OHC bases (e.g., 6–60) in one or more rows. Each OHC synapses with multiple (but an unknown number) afferent fibers. Within the OHC adjacent to the afferent nerve endings, synaptic bodies are found in some species (e.g., human, guinea pig, and chinchilla), but not others (e.g., cat).

The neurons that provide efferent innervation to the hair cells are located in the brainstem (see Chapter 14). These neurons are found in both the ipsilateral and contralateral superior olivary complexes. The efferent fibers exit the brainstem with the vestibular division of the vestibulocochlear (8th) nerve, then cross (via Oort's anastomosis) to the cochlear division within the IAM. In all mammals, the number of efferent fibers innervating the cochlea is considerably smaller than the number of afferent fibers, although the exact number has been reported for only one species. In the cat, about 500 efferent fibers (crossed [i.e., contralateral] and uncrossed [i.e., ipsilateral]) enter each IAM. The efferent fibers then enter the intraganglionic spiral bundle that runs at the periphery of Rosenthal's canal. From their point of entry, these fibers run both apically and basally. Many of the

fibers in the intraganglionic spiral bundle are nonmyelinated. At various points, individual or small groups of fibers turn laterally to enter the osseous spiral lamina. These fibers pass through the habenulae perforata together with the afferent fibers and enter the organ of Corti. Efferent fibers to the IHCs turn and enter the inner spiral or tunnel spiral bundle, traveling for a variable distance before synapsing on the radial afferent fibers that, in turn, are synapsing on the IHC bases. Efferent fibers to the OHCs are myelinated before crossing the habenulae perforata. Once in the organ of Corti, these fibers may spiral in the inner spiral bundle for a short distance, pass to the tunnel spiral bundle, and then cross the tunnel as upper tunnel crossing fibers in most species. Lateral to the tunnel, the fibers immediately divide into multiple branches that run both apically and basally in the outer spiral bundles. On the bases of the OHCs, the efferent fibers form large endings that contain many synaptic vesicles and large mitochondria. A flattened cisterna of smooth endoplasmic reticulum (i.e., subsynaptic cisterna) is adjacent to each efferent nerve ending on OHCs.

SPIRAL LIGAMENT AND STRIA VASCULARIS

The **spiral ligament** (SpL) is positioned lateral to the cochlear duct, between the cochlear bone and the lateral side of the stria vascularis (see Figure 8-4). It contains fibrocytes, extracellular matrix material, and blood vessels (Figure 8-9). Perilymph fills its intercellular spaces. The spiral ligament thus provides a second route of communication between scalae tympani and vestibuli, in addition to the helicotrema. Reissner's membrane is attached to the spiral ligament near its superior end where the superior end of the stria vascularis is located. The basilar membrane inserts into the spiral ligament near its inferior end.

The stria vascularis (i.e., vascular stripe) consists of three cell layers (i.e., marginal [M], intermediate [I], and basal [B]) and an intraepithelial network of capillaries (C) (see Figure 8-9). The marginal (M) cells are known as chromophils because they stain

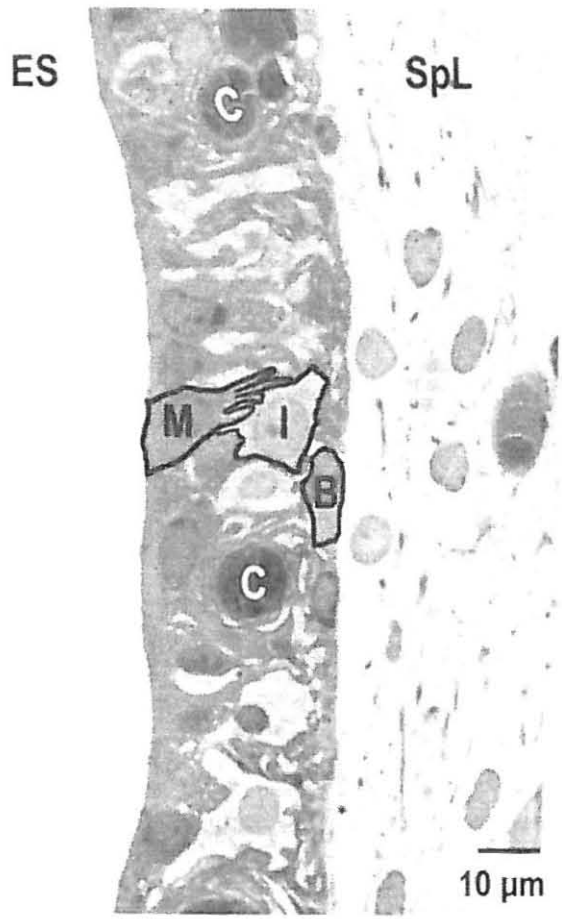

FIGURE 8-9 Radial section of stria vascularis and spiral ligament (SpL). B, basal cell of the stria vascularis; C, capillary; ES, endolymphatic space; I, intermediate cell of the stria vascularis; M, marginal cell of the stria vascularis.

darkly. They abut the endolymphatic space (ES) and are joined by tight junctions at their luminal margins. Their basolateral surfaces are deeply infolded and the folds contain numerous mitochondria. The marginal cells are thought to secrete potassium that is found in a high concentration in endolymph.

Intermediate (I) cells are known as chromophobes because they stain lightly. These cells are melanocytes because in all pigmented mammals they contain a variable number of melanin granules.

TABLE 8-1 Cochlear Parameters in Selected Species

Cochlear Parameter	Human	Chinchilla	Mouse
Organ of Corti (OC) length	Mean (male): 37.11 mm[a] Mean (female): 31.9 mm[a] Range: 28–40 mm[c]	Mean (male and female): 18.4 mm[b] Range: 16–21.6 mm[b]	Mean (male and female): 6.06 mm[b] Range: 5.66–6.43 mm[b]
Frequency range of hearing	20–20,000 Hz[d]	90–22,800 Hz[e]	1,000–100,000 Hz[e]
Total inner hair cells	Mean: 3,480[f] Range: 3,035–4,390[f]	Mean: 1,800[b] Range: 1,600–2,030[b]	Mean: 705[b] Range: 684–746[b]
Inner hair cell density	Mean: 109/mm OC[f] Range: 93–125[f]	Mean: 100/mm OC[b] Range: 96–103[b]	116/mm OC[b] Range: 109–123[b]
Total outer hair cells	Mean: 13,345[f] Range: 11,220–16,040[f]	Mean: 7,150[b] Range: 6,300–8,280[b]	Mean: 2,398[b] Range: 2,331–2,483[b]
Outer hair cell density	Mean: 415/mm OC[f] Range: 387–459[f]	Mean: 405/mm OC[b] Range: 391–416[b]	Mean: 395/mm OC[b] Range: 371–419[b]
Total spiral ganglion cells	Mean: 30,500[g]–33,600[h] (cell bodies in Rosenthal's canal)	Mean: 23,550[i] (myelinated fibers in cochlear nerve)	Mean: 12,600[j] (myelinated fibers in cochlear nerve)

[a]Sato, Sando, & Takahashi, 1991.
[b]Bohne and Harding, 2004, unpublished data.
[c]Wright, Davis, Bredberg, Ulehlova, & Spencer, 1987.
[d]Dallos, 1986.
[e]Fay, 1988.
[f]Bredberg, 1968.
[g]Rasmussen, 1940.
[h]Hinojosa, Seligsohn, & Lerner, 1985.
[i]Boord & Rasmussen, 1958
[j]Ehret, 1979.

These cells are thought to generate the positive potential (i.e., +80 to +100 mV) in the endolymphatic space.

The basal (B) cells are flat and overlapping and form a continuous layer that separates the interior of the stria vascularis from the spiral ligament. These cells are joined to one another by tight junctions. They form a sleeve around each capillary entering and leaving the stria vascularis. Because of the tight junctions between adjacent marginal cells and between overlapping basal cells, the interior of the stria vascularis is separated from perilymph in the spiral ligament and endolymph in the endolymphatic space.

BLOOD SUPPLY OF THE INNER EAR

The arterial blood supply to the inner ear comes from the labyrinthine artery that enters the temporal bone through the IAM along with the seventh and eighth cranial nerves. This artery is a branch of the anterior inferior cerebellar artery that, in turn, is a branch of the basilar artery. Within the modiolus, the artery divides into arterioles that supply capillary beds in Rosenthal's canal, the spiral ligament, stria vascularis, limbus, and osseous spiral lamina. To supply capillaries in the stria vascularis and spiral ligament, the arterioles radiate over scala vestibuli before entering the superior portion of the spiral ligament.

The only capillaries near the organ of Corti are the vessel of the tympanic lip of the osseous spiral lamina and the vessel of the basilar membrane (see Figure 8-5). These latter vessels form discontinuous arcades inferior to the basilar membrane. The capillary beds in the spiral ligament and stria vascularis join collecting venules that run radially within the

bone around scala tympani. These venules ultimately join the labyrinthine vein in the modiolus that, in turn, exits the temporal bone via the IAM. The labyrinthine vein drains into the transverse or inferior petrosal sinus.

VARIATIONS IN COCHLEAR PARAMETERS

Both within and across species, considerable variability exists in cochlear parameters such as the length of the organ of Corti/basilar membrane complex, the total number of sensory and spiral ganglion cells, and the density of hair cells per millimeter of the organ of Corti. Some of these variations have functional consequences for hearing, such as the range of audible frequencies and the difference limen for frequency. Table 8-1 shows some of these parameters for the human, chinchilla, and mouse. The latter two animals are often used to study normal and abnormal hearing.

CLINICAL RELEVANCE

At birth, the normal human organ of Corti contains approximately 3,400 IHCs and 13,000 OHCs. These numbers are considerably less than the 110 million rods and 5.5 million cones in the retina. A variety of external agents result in the death of cochlear hair cells, including excessive exposure to noise (i.e., military, industrial or recreational), systemic treatment with certain drugs (e.g., aminoglycoside antibiotics, anticancer agents), and physical trauma to the temporal bone. Hair cells are also lost with advancing age. Because there are relatively few sensory elements in the cochlea, small losses of these cells can result in a permanent sensorineural hearing loss. The high-frequency portion (i.e., base) of the cochlea is more vulnerable to damage from drugs, noise, and aging than the low-frequency portion (i.e., apex). This accounts for the progressive loss of high-frequency hearing that is found in many older humans.

SUMMARY

The inner ear consists of the *cochlea*, which contains the sensory organ responsible for hearing, and the *vestibule*, which contains the sensory organs for balance and equilibrium. This chapter describes the morphological structure of the cochlea, including the *organ of Corti*, the end organ for hearing, which contains sensory cells (i.e., *inner and outer hair cells*), supporting cells, and *spiral ganglion cells* (i.e., primary auditory neurons); the *basilar membrane*, which is set in motion by movement of the tympanic membrane and ossicular chain; and fluid spaces (i.e., *scalae vestibuli, media*, and *tympani*). The inner and outer hair cells are responsible for transducing the mechanical waves of the basilar membrane into electrical impulses that are transmitted by the spiral ganglion cells to the brain for the perception of sound.

KEY TERMS

Afferent nerve
Basilar membrane
Cochlea
Cochlear duct
Deiters' cell
Efferent nerve
Endolymph
Endolymphatic space
Facial nerve
Habenula perforata
Hair cell
Helicotrema
Hensen's cell
Hensen's stripe
Internal auditory meatus
Spiral limbus
Modiolus
Organ of Corti
Osseous spiral lamina
Perilymph
Pillar cell
Reissner's membrane
Reticular lamina
Rosenthal's canal
Scala media
Scala tympani
Scala vestibuli
Spaces of Nuel
Spiral ganglion cells
Spiral ligament
Stereocilium
Stria vascularis
Tectorial membrane
Tunnel
Vestibulocochlear nerve
Zonula occludens

STUDY QUESTIONS

1. Describe the gross structure of the inner ear and how it relates to the middle ear.
2. Describe the three fluid compartments and their boundaries and the two fluids of the cochlea.
3. Describe the cochlear duct and its boundaries. What is special about its boundaries?
4. Name the cells of the organ of Corti. Describe their relation to one another, as well as to the basilar membrane and TM.
5. Describe the afferent innervation of IHCs and OHCs. How does it differ?

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