The shape and function of the inner ear in mammals

Dr. Swati Yadav[1], Dr. Shweta Chaudhary[2]*

1.   Assistant Professor, Department of Anatomy, Santosh Medical College & Hospital, Santosh Deemed to be University, Ghaziabad.

2.   Associate Professor, Department of Anatomy, Santosh Medical College Hospital, Santosh Deemed to be University, Ghaziabad.

*Dr. Shweta Chaudhary- Corresponding Author

ABSTRACT

Mammals' inner ears are made up of the vestibule and three semicircular canals, which are involved with balance, and the cochlea, which is involved with hearing. The bone chambers and membranous ducts remain morphologically continuous even though distinct parts of the inner ear are responsible for various functions. The development of internal cochlear structures, including the primary and secondary bony laminae, the morphology of the spiral nerve ganglion, and the nature of cochlear coiling, including the total number of turns completed by the cochlear canal and the relative diameters of the basal and apical turns, are all included in the gross anatomy of the cochlea that has been related to auditory physiologies. The semicircular canals' general sizes, shapes, and orientations are connected to their sensitivity to head rotations and perhaps to locomotor movements. We may be able to learn more about the form and function of the inner ear by examining intraspecific variation, particularly in the size and positioning of the semicircular canals.

Key words: cochlea; inner ear; semicircular canals; vestibule.

Introduction

The vertebrate nervous system's unique sensory division includes the otic (ear) region. The cochlea in the ear's cochlea serves as the organ of hearing, and the vestibule and semicircular canals serve as the organ of balance. The inner ear's balancing and hearing organs are tiny structures housed in chambers that range in size from less than 1 mm3 in shrews to more than 1000 mm3 in baleen whales (1). Humans have an inner ear that is about 150 mm3 in size. Despite their diminutive size, the inner ear organs are biologically very strong. It is incredible that such tiny objects can result in a wide range of issues, including tinnitus, motion sickness,

and a general lack of balance. The ear area has been one of the most thoroughly investigated systems of vertebrate anatomy and physiology in part because of this phenomena.

The auditory and vestibular systems are important components in vertebrate biology just based on their functions. Early tetrapod evolution, when newly terrestrial creatures switched from perceiving water-borne to air-borne sounds, undoubtedly involved hearing (2). Early mammals, who were probably nocturnal (3,4), would have needed to rely on non-visual senses to move through the Mesozoic world.

For phylogenetic research at both more- and less-inclusive taxonomic levels, the inner ear's anatomy is instructive. For instance, the cochlea in live therian mammals (marsupials and placentals) makes at least one full 360-degree turn, but less so in monotremes and more basally positioned species (5-7). It is possible to see ancestral morphologies in the bony labyrinths of marsupial and placental mammals from the Mesozoic epoch, such as the fusion of the posterior and lateral semicircular canals to produce a secondary common crus. Many crown Therian clades, including primates, rodents, some carnivorous mammals, and a number of marsupial clades, lack the secondary common crus, and most extant mammals have posterior and lateral canals that are distinct over their entire lengths (8-10). Primates' inner ear measurements vary between great apes and other primates (11), as well as between humans and chimpanzee subspecies (12). Squamate reptiles' inner ears can include additional phylogenetic data (13-16).

Anatomy and function of the inner ear

Mammals have three distinct parts to their ears: the outer, middle, and inner ears. The external acoustic meatus connects the outer surface of the head to the tympanic membrane, or eardrum, through the pinna, which directs sound from the environment into the ear region of the head. The three ear ossicles (malleus, incus, and stapes) are located within the tympanic cavity of the middle ear, which extends from the tympanic membrane to the lateral surface of the skull.

The bony labyrinth, or inner ear in mammals, is a network of interconnected cavities within the petrosal bone. The membranous labyrinth, a network of interconnecting soft tissue sacs and channels, is located inside the bone labyrinth. The term "canal" is only used to describe elements of the bone labyrinth in traditional ear terminology; membrane channels are referred to as "ducts." The membrane labyrinth is divided into two sections: a superior section that contains the utricle of the vestibule and the three semicircular ducts and related ampullae, and an inferior section that contains the cochlear duct and the saccule of the membranous vestibule.

The membranous labyrinth is both filled with and encircled by lymphatic fluid. Perilymph fills the gaps around the membranous labyrinth within the bone labyrinth. Similar to extracellular fluid in composition, perilymph is high in sodium but low in potassium (18).

Endolymph is present in the membranous vestibular apparatus and cochlear duct. In contrast to perilymph, endolymph has a pH close to blood plasma, a composition similar to intracellular fluid, and is rich in potassium ions but lacking in sodium ions (19-20).

Vibrations in the endolymph, caused by the stapes dial or head motions, stimulate the vestibular system's motion receptors and the cochlea's auditory receptors. Despite the fact that the cochlea's sensory function is hearing and the vestibule's sensory function is balance, endolymph from one region can flow into the other and alter the function of the other. For instance, variations in the volume and pressure of the vestibular endolymph have an impact on both the auditory and vestibular systems.

Cochlea

All living animals have a bone cochlea that is coiled around a central axis known as the modiolus, with the exception of monotremes, in which the canal is twisted toward its end but does not fully turn (21-23). The cochlear branch of cranial nerve VIII travels through the hollow middle of the modiolus. The cochlear spiral's basal end begins close to the fenestra vestibuli for the stapedial footplate, and its apex is known as the tip.

Most of the cochlear spiral's length is occupied by the cochlear duct, which divides the scalae tympani and vestibuli. However, at the spiral's tip, the helicotrema allows communication between the two outer scalae.

Within the cochlear duct, the basilar membrane's vestibular surface is where the spiral organ of Corti rests. Cochlear hair cells in the organ of Corti translate auditory perceptions. Along the axial edge of the basilar membrane, a longitudinal row of flask-shaped inner hair cells can be seen. Within the organ of Corti, columnar cells known as outer hair cells are located more radially. Over 75% of the sensory cells in the cochlea come from the outer hair cells (24).

The cranial nerve VIII, which leaves the cranium by the internal acoustic meatus on the endocranial surface of the petrosal, innervates the outer and inner hair cells. A cochlear branch descends into the modiolus of the cochlea, while a vestibular branch extends posteriorly to innervate the vestibular end organs. The cribriform walls of the modiolus serve as a bone sieve for a number of tiny nerve passageways leading from the ganglion to the spiral auditory nerve.

Vestibular system

All jawed vertebrates, including cartilaginous fishes, bony fishes, amphibians, reptiles, and mammals, have three semicircular canals in the bony vestibule. Jawless vertebrates have two semicircular canals, whereas modern hagfish only have one. These include live lampreys and many extinct "ostra- coderms" (25).

The vestibular crus, a minor constriction of the bony vestibule, separates the elliptical and spherical recesses, which do not precisely depict the shapes of the membrane structures (26). The spherical saccule is typically smaller than the membrane vestibule's oblong utricle.

The cristae within the ampullae of the semicircular ducts and the maculae within the utricle and saccule are two different types of vestibular end organs found in the membranous vestibule. Otolithic organs, which recognize linear accelerations, are the maculae of the utricle and saccule taken together.

ANATOMICAL AND FUNCTIONAL VARIATION

All anatomical systems are subject to morphological variation, a phenomena that occurs in nature. The most common correlation between morphological diversity and locomotor and auditory function is found in the inner ear. For instance, the number and length of inner and outer hair cell cilia within the cochlea vary amongst mammalian species (26). In particular, the lengths of the outside hair cells are inversely associated with the frequency at which sensitivity is highest, resulting in an increase in outer hair cell length as the upper frequency limit falls (27). Along with a downward shift in peak sensitivity along the length of the cochlear organ, the lengthening of the cells also occurs from the basilar membrane's base to its apex within a single cochlea.

Variations in the cochlea

It has been theorized that cochlear volume in primates corresponds to auditory physiology in that a rise in cochlear cavity volume relative to body mass denotes a decrease in both low and high frequency sensitivity thresholds (28). Conversely, compared to their close cousins, such as rodents, colugos (also known as "flying lemurs"), and tree shrews, primates' cochleae tend to be more voluminous in relation to body mass (29).

The size and rigidity of the basilar membrane are possibly the characteristics of the cochlea that have drawn the most attention in regards to their relevance to hearing physiology. Observations support the hypothesis that mammals susceptible to the highest frequency sound waves have the thickest and stiffest basilar membranes. The stiffness of the membrane is positively correlated with the frequencies at which the cochlea is most sensitive (30). (31-32).

The main and secondary bony laminae can be found in the fossil record easily, but since they

are such delicate structures, they are rarely completely preserved. The laminar gap has been used as a proxy for basilar membrane width, although caution has been urged in doing so because estimates using the laminae may be incorrect by as little as 25% or as much as over 100% of the true membrane width for whales (33). On the other hand, the distal edge that opposes the main bony lamina is significantly more fragile than the proximal end of the secondary bony spiral lamina, which connects to the radial wall of the auditory canal. As a result, the proximal end has a better potential for preservation.

Variations in the semicircular canals

Variations in the vestibular system have received a lot of attention recently. Semicircular canals and rotating perceptions have been linked for almost 150 years (34), and current research in evolutionary biology is focused on the relationships between canal structure, orientation, sensitivity, behavior, and phylogeny. Numerous studies have inferred the agility and locomotor skills of numerous extinct and living species, including primates, whales, ungulates, and sloths, based on the size and structure of the semicircular canals (35-37).

Variations in semicircular canal morphology as they relate to locomotor differences across a wide range of mammals representing a spectrum of behaviors have not yet been thoroughly and methodically studied. Additionally, the sensitivity of a semicircular canal arc has not been clearly associated with the form of the canal. However, neurophysiological evidence suggests a relationship between the semicircular canal circuit's size, which is commonly described as the semicircular canal's arc's radius (38–40), and the canal's sensitivity (41).

In marine mammals, a complete loss of vestibular function may indicate a fully aquatic existence. For instance, it is well known that the semicircular canals of cetaceans are smaller than the cochlea (42) and that the fossil record reveals this pattern throughout the history of cetaceans (43).

The intraspecific diversity in the shapes and orientations of vestibular parts is a fascinating and potentially significant pattern that has lately emerged. Three-toed sloths showed more intraspecific variation in semicircular canal orientation than faster moving species like tamanduas and armadillos, according to a study on the bone labyrinths of xenarthrans (45). Additionally, mice bred for high levels of voluntary wheel running compared to a non-selected control group do not differ in the widths of their semicircular canals, but they do in their forms (46).

CONCLUSION

One of the most well researched areas of the nervous systems in vertebrates is the inner ear.

The coiled cochlea, which is involved in hearing, and the loops of the semi-circular canals, which are involved in balance, appear to be the basic structure and function of the inner ear. Vertebrate morphologists are learning more about the extent of morphological variation within and across species, and these differences very certainly correspond with the enormous range of hearing and locomotor physiologies reported across Mammalia. The degree and kind of coiling inside the cochlear spiral, as well as the forms and orientations of the semicircular canals, all require more research in the area of intra-specific variation. There may be particularly intriguing links between how intraspecific variations in anatomy and physiology translate to relationships between interspecific shape and function.

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