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High-Resolution Computed Tomographic Appearance of Normal Cochlear Aqueduct

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Computed tomographic (CT) scans of 37 patients with normal adult cochlear aqueducts were selected for retrospective analysis. Usually, only the inferomedial part of the cochlear aqueduct could be seen on axial CT. The sizes of the external cochlear aqueduct opening were tabulated, and they did not vary significantly with age or gender. The average width was 2.9 mm. Of the configurations found, the most common was the funnel (22 cases).

The cochlear aqueduct, a small canaliculus located along the inferior petrous pyramid, provides a potential communication between the subarachnoid space and the perilymph (fig. 1). Although the functional significance of the cochlear aqueduct is unknown, this entity has been the subject of numerous histomorphologic studies. To our knowledge, only two articles in the radiographic literature have been devoted solely to the cochlear aqueduct [1, 2]; both were before the advent of computed tomography (CT). In view of the ease with which high-resolution CT defines the external opening of the cochlear aqueduct and some of its course, we performed a retrospective study to determine the size and morphology of this structure on CT.

Anatomy

Developmental

According to Anson et al. [3, 4] *cochlear aqueduct* refers to the bony canal, while the *perilymphatic* (periotic) *duct* refers to its contents. In this communication, we will adhere to this terminology.

The cochlear aqueduct anlage can be distinguished as a tissue-filled gap in the cartilaginous otic capsule in the 30 mm human embryo [3]. This gap enlarges until at the 40 mm stage it can be easily discernible connecting the otic capsule to the cranial cavity. During this period, it is filled by loose connective tissue, which merges with the denser connective tissue surrounding the glossopharyngeal nerve, cochlear vein, round window niche, and scala tympani. At the 50 mm stage (10 weeks), these structures become clearly separated by a bar of cartilage arising from the ampulla of the posterior semicircular canal, so that each of the above-mentioned structures will be in its own separate compartment.

Thus, by 20 weeks gestation, when ossification has occurred in the otic capsule, the embryonic cochlear aqueduct has been formed, which at this early stage resembles the adult cochlear aqueduct in configuration. The length of the cochlear aqueduct increases from 0.8 mm at 10 weeks to 4.5 mm at term [4]; that is, its growth parallels that of the otic capsule. In the adult it is about 6–10 mm in length [5, 6].

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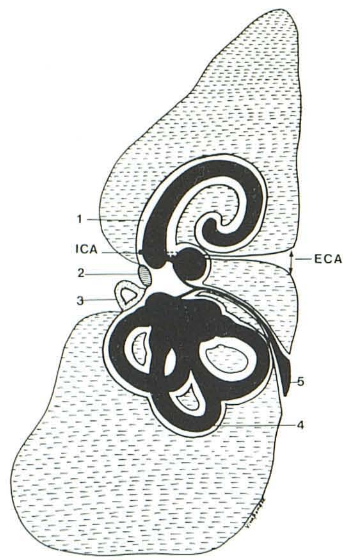


Fig. 1.—Course of cochlear aqueduct. Cochlear aqueduct provides potential communication between subarachnoid space at external opening of cochlear aqueduct (ECA) and perilymph in scala tympani (1) at its internal opening (ICA), slightly anterior to round window membrane (2). 3 = stapes; 4 = semicircular canal; 5 = endolymphatic sac.

Adult

In the adult human, the cochlear aqueduct internal orifice is located along the anteroinferior edge of the scala tympani [4] immediately anterior to the crest for the attachment of the round window membrane [3]. Here it usually follows a direct posteromedial course through the petrous bone to open along its inferior aspect at the lateral border of the endocranial opening of the jugular fossa. Its posterior course subtends an angle 11°–45° with respect to the coronal plane (see Materials and Methods), along which the internal auditory canal is usually oriented. Its inferomedial course forms about a 60° angle with respect to the axial plane. The lateral part of the cochlear aqueduct is its narrowest part; about 1 mm from the scala tympani, the cochlear aqueduct lumen reaches its minimal diameter of about 0.1 mm, gradually enlarging to more than 1 mm in caliber at the medial external (endocranial) opening. Hence, the cochlear aqueduct resembles an hourglass.

Immediately anterior (0.1–0.3 mm) to the cochlear aqueduct is a small accessory canal (canal of Catugno), which houses the inferior cochlear vein. It is considerably smaller than the cochlear aqueduct but may be larger than the cochlear aqueduct at its isthmic portion. This structure occasionally can be visualized on conventional tomography [7].

The lumen of the cochlear aqueduct is elliptic, and its largest diameter lies in the horizontal plane [6]. For the most part, it is filled by loose fibrous connective tissue, which is similar to that surrounding the endolymphatic sac [8]. This layer of connective tissue is continuous laterally with the endosteal covering of the scala tympani and medially with the dura and arachnoid, which extends into the canal to a variable length. Therefore, unlike the vestibular aqueduct, the cochlear aqueduct does not contain a true epithelium-lined duct [8].

Because the external cochlear aqueduct is situated along the inferomedial ridge of the petrous pyramid, it has a complex relation to the structures along the medial and inferior aspects of the pyramid (fig. 2), most of which can be seen on CT.

Along the medial aspect of the petrous bone, several foramina and recesses can be observed. The porus acusticus is located almost centrally in this wall, anterosuperior to the external cochlear aqueduct. Therefore, it is separated from the external cochlear aqueduct by a bar of bone about 4–6 mm wide (fig. 2A). A ridge of bone is present along the medial aspect of the petrous pyramid (figs. 2A and 2B), which runs from the petrooccipital synchondrosis to form the medial wall of the external cochlear aqueduct and then passes upward to interconnect the external cochlear aqueduct with the fossa for the endolymphatic sac and subarcuate fossa. This upward extension of the inferomedial ridge can be seen on CT (see Materials and Methods). Immediately posteroinferior to the external cochlear aqueduct, this ridge projects medially into the jugular fossa to form the jugular spine, thereby separating the fossa into two compartments: pars nervosa anteriorly and pars vascularis posteriorly [9, 10]. The external cochlear aqueduct itself is located within a small notch bounded anteriorly by a small beaklike projection from the petrous bone, similar to the jugular spine.

Along the inferior aspect of the petrous pyramid, the external cochlear aqueduct is continuous with the caroticojugular spine, which is a bar of bone that bridges the external cochlear aqueduct medially to the vaginal process of the tympanic bone and styloid process laterally. These ridges can occasionally be seen on CT as compact bone densities following the contour of each vascular canal separated by cancellous bone. Within the caroticojugular spine is found a small canaliculus (or canaliculi) (fig. 2B) called the *tympanic canaliculus*, which transmits a branch of the glossopharyngeal nerve (Jacobson nerve) and a small branch of the ascending pharyngeal artery (inferior tympanic). In one specimen, this canaliculus was large (2 mm in diameter), while in several specimens, it was barely discernible. In another specimen there were two canaliculi (fig. 2B). Its importance lies in the fact that occasionally this canaliculus lying anteroinferior to the cochlear aqueduct may be visible on CT.

Materials and Methods

CT scans of 80 patients with normal temporal bones were collected, and 37 cases were selected for retrospective study. Scans of poor quality or those that were technically inadequate to demonstrate the anatomy of the cochlear aqueduct were rejected. The scans were obtained either on Pfizer 0200 or GE CT/T 8800. The former had been modified for high-resolution scanning. A detailed account of the scanning techniques has been published [11]. Most scans were obtained in the axial projection.

The configuration and size of the external cochlear aqueduct were evaluated. The size was determined by using routine track-ball measurement (fig. 1). The course of the cochlear aqueduct within the petrous bone in live patients was difficult to evaluate, not only because of its minute diameter more laterally (so that it was impossible to see on CT), but also because we anticipated that minor changes in beam angulation would result in considerable inaccuracies. As the lumen of the cochlear aqueduct tapered to an isthmus, only the external opening was measured.

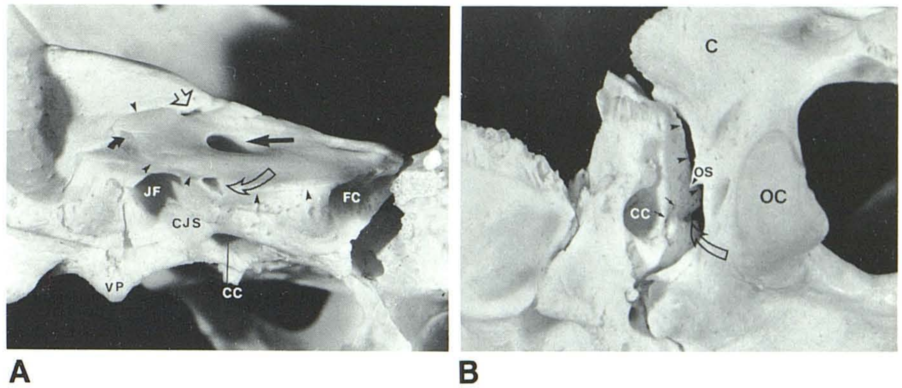


Fig. 2.—**A**, Left petrous pyramid, inferior oblique view. Triangular opening of cochlear aqueduct (*curved open arrow*) between jugular fossa (JF) and internal opening of carotid canal (CC). Internal auditory canal (*straight black arrow*) lies anterosuperior to cochlear aqueduct opening. Subarcuate fossa (*straight open arrow*); foveate impression for endolymphatic sac (*solid curved arrow*); inferomedial ridge and its superior continuation anterior to foveate impression and subarcuate fossa (*arrowheads*). CJS = caroticojugular spine; FC = foramen lacerum; VP = vaginal process of tympanic bone. **B**, Inclined inferior view of external cochlear aqueduct (*curved open arrow*) in another disarticulated dry skull demonstrating its relation to carotid canal (CC) and tympanic canaliculi (*solid black arrows*). Inferomedial ridge of petrous bone (*arrowheads*) can be seen extending anteriorly into petrooccipital fissure. C = clivus; OC = occipital condyle; OS = occipital spine.

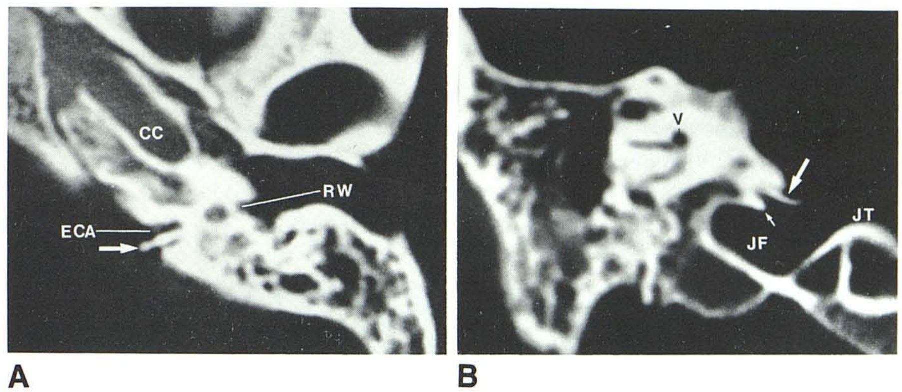


Fig. 3.—**A**, Axial CT scan of dry skull. Wire in lumen of cochlear aqueduct (*arrow*). CC = carotid canal; ECA = external orifice of the cochlear aqueduct; RW = round window. **B**, Coronal CT scan of same skull. Metallic wire in cochlear aqueduct (*large arrow*). Jugular spine (*small arrow*) is continuous with lower lip of cochlear aqueduct opening. Course of wire is directed toward vestibule (V) laterosuperiorly. Directly inferior to jugular spine is jugular fossa (JF). (Jugular tubercle [JT] is inferomedial to external cochlear aqueduct.)

In another report, we found that the accuracy of such measurement varied inversely with the length [12]. In the range of 2–3 mm the accuracy of GE CT/T 8800 scanner was about 93%.

In an attempt to visualize the course of cochlear aqueduct on CT, a dry skull was scanned in axial and coronal projections with a metallic wire inserted through the external opening of the aqueduct (fig. 3). It was impossible to pass such a wire through the entire length of the aqueduct laterally for reasons mentioned above.

Because of the discrepancies in the recommended anteroposterior angulation of head (5°, Hemingsson and Lindgren [1]; 37°, Dorph et al. [2]; and 0°, Rask-Anderson et al. [7]), we attempted to measure the posteromedial course of the cochlear aqueduct on CT with respect to the coronal plane as well as to the longitudinal axis of the petrous bone.

Results

Size and Configuration of the External Cochlear Aqueduct

The opening of the external cochlear aqueduct was 2.0–5.3 mm; there was no age correlation (fig. 4A), and the average size of the external cochlear aqueduct was about equal in males and females (2.9 mm) (fig. 4B). This dimension is considerably larger than that measured by Palva and Dammert [6] (1.8 mm) and Anson et al. [3, 4] (0.8 mm), both of whom measured the external aperture of the cochlear aqueduct inside the funnel opening. Rask-Anderson et al. [7], on the other hand, found the mean width of the funnel opening itself to be 4.2 mm.

The cochlear aqueduct assumed several configurations (fig. 5). In most instances it had a small opening. When the opening was large, it usually had a large, funnel-shaped configuration (fig. 6). Other configurations accounted for about 30%; the two that were irregular presumably were from the numerous excrescences of bone projecting into the cochlear aqueduct lumen reported by Keleman et al. [13]. In 80%, only the medial one-third of the cochlear aqueduct was seen, while in 6% the medial two-thirds was seen. In 14% we were able to visualize the entire course of the cochlear aqueduct on CT (fig. 6). This is in contradistinction to the work of Hemmingson and Lindgren [1], who claimed that they were able to visualize the entire course of the cochlear aqueduct with conventional tomography in 50% of their cases. However, their study was performed in two projections, which is probably ideal for the study of the temporal bone. Ours was done primarily in the axial projection because of limited scanning time.

Course of the Cochlear Aqueduct

The posteromedial course of the cochlear aqueduct was found to vary from 11° to 45° (average, 33°) with respect to the coronal plane and 30° to 76° (average, 64°) with respect to the longitudinal axis of the petromastoid. Thus, it can be inferred that should visualization of its entire course in the coronal plane be required, rotation of the head at about 30°

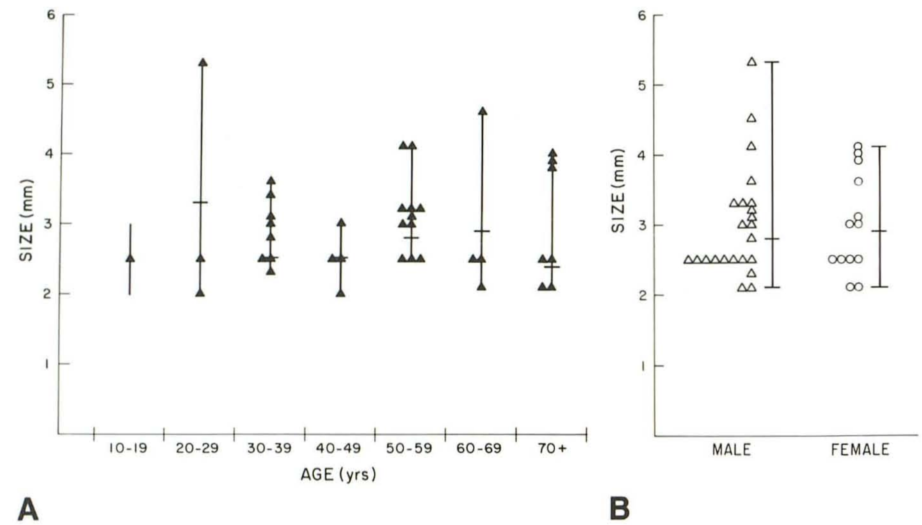


Fig. 4.—Relation between size of external cochlear aqueduct to age (**A**) and gender (**B**). Triangles in **A** denote subjects; crossed bars in **A** and **B** denote averages.

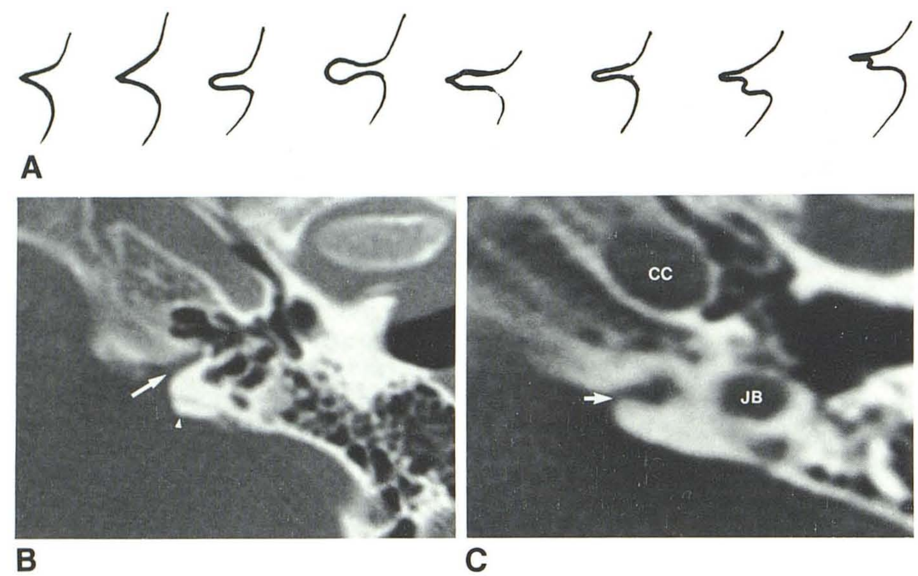


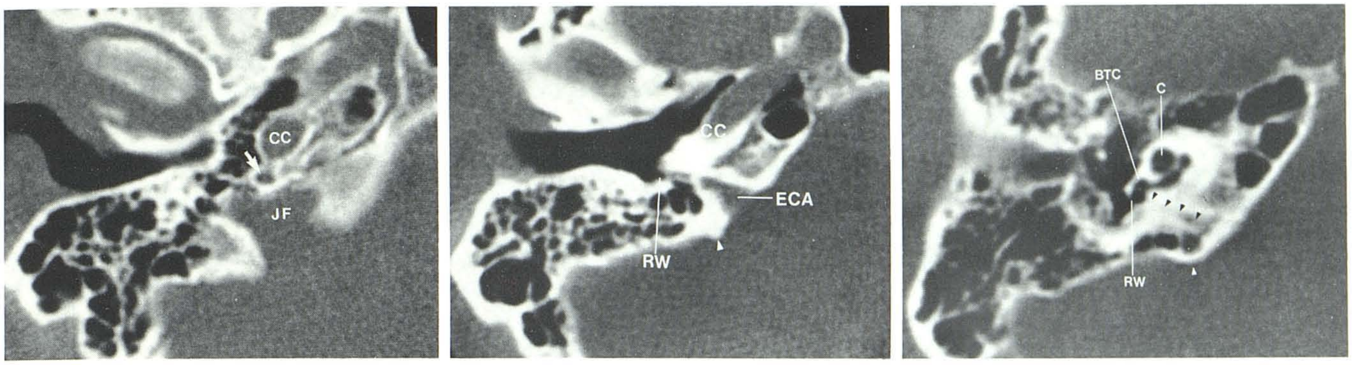
Fig. 5.—**A**, Various configurations of the cochlear aqueduct. From left to right: small funnel (22 cases), large funnel (five), tubular (five), ampullar (one), tapered (one), slit (one), irregular tubular (one), and tubular and slit (one). **B**, Axial CT scan of left petrous bone showing tubular cochlear aqueduct (*arrow*). Prominent inferomedial ridge (*arrowhead*). **C**, Axial CT scan showing ampullar cochlear aqueduct (*arrow*). CC = carotid canal; JB = jugular bulb.

to the ipsilateral side is recommended to bring the cochlear aqueduct parallel to the plane of section. This is more in keeping with the angulation postulated by Dorph et al. [2] (37°).

Relation of the Cochlear Aqueduct to Other Structures

On axial CT, the cochlear aqueduct visualized on "low" sections through the hypotympanum and external auditory canal as a tubular or funnel-shaped bony dehiscence along the medial petrous bone. The cochlear aqueduct lies directly above the jugular fossa, which is varied in configuration [8, 9]. Anteriorly, its apex is bordered by bone surrounding the carotid canal, which is continuous with the caroticojugular spine below. The latter may be perforated by the tympanic canaliculus (fig. 6A), which appears as a small, rounded, soft-tissue density surrounded by bone; care, however, must be taken to distinguish this structure from partial-volume averaging of a petrous air cell. Posterior to the cochlear aqueduct, the superior dome of the jugular bulb may be observed at a higher section (fig. 5C), which can be confused with an intrapetrosal lesion. When the entire course of the cochlear aqueduct is visualized, the cochlear aqueduct enters the basal turn of the cochlear along its medial aspect (fig. 6C). Posterolateral to this, the round window niche can be seen.

Along the inner aspect of the petrous pyramid posterior to the external cochlear aqueduct, a sharp angulation of the petrosal wall may be seen, so that the petrous bone almost appears to be oriented in the coronal direction (fig. 6B). This change in angulation probably is from the upward extension of the inferomedial ridge of the petrous bone, which runs from the external cochlear aqueduct to the opening of the endolymphatic sac (figs. 5B and 6B) (see Anatomy section). Thus, the plateau lying dorsal to it becomes continuous with the foveate impression superiorly. The latter then merges with the concave bone along the posterior aspect of the pyramid forming the groove for the sigmoid sinus.



A B C

Fig. 6.—Axial CT scans of right temporal bone in patient from inferior to superior. **A**, Below cochlear aqueduct through carotid canal (CC) and jugular fossa (JF). Interposed between two structures is caroticojugular spine, occupied by widened tympanic canaliculus (*arrow*). **B**, Through external cochlear aqueduct (ECA). In this patient, aqueduct is patulous, forming wide funnel. Cochlear aqueduct is also enlarged, allowing better visualization of its course. Note its course directed toward round window niche (RW). Change in angulation of medial petrous wall is probably caused by superior continuation of inferomedial ridge (*arrowhead*). **C**, Through superolateral part of cochlear aqueduct (*black arrowheads*). Laterally, it merges with basal turn of cochlea (BTC). Inferomedial ridge continuation (*white arrowhead*). C = cochlea; RW = round window.

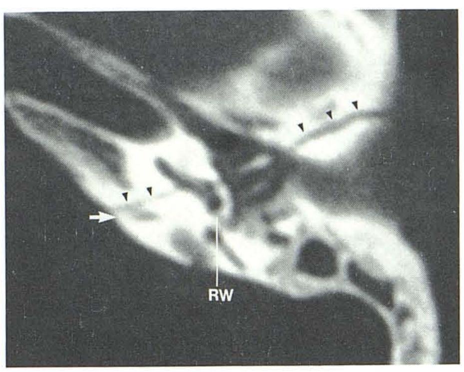


Fig. 7.—Axial CT scan of left temporal bone. Course of transverse fracture (*arrowheads*) is distinguished from cochlear aqueduct (*arrow*). Fracture passes through basal turn of cochlea about 5 mm ventral to round window niche (RW), while cochlear aqueduct is coursing toward niche. In addition, fracture has vertical component (passing through internal auditory canal) and courses through middle ear into temporal squama.

In trauma, the cochlear aqueduct occasionally can be seen throughout its entire length, making it difficult to distinguish from a fracture (fig. 7). However, its funnel-shaped opening, varying caliber, course, and internal opening ventral to the round window niche should make this distinction easier.

Discussion

While functional significance of the cochlear aqueduct in man has not been established several observations are noteworthy:

1. The fact that a patent cochlear aqueduct provides a channel of communication between the subarachnoid space and the perilymph has been established experimentally in laboratory animals [14]. As yet, no satisfactory proof has been offered in humans. In man, red blood cells frequently have been found trapped within the fibrous (or arachnoid) network of the duct, and in some instances, entering the labyrinth; the cochlear aqueduct seems otherwise almost impervious to other entities such as microorganisms [6, 15, 16]. According to Schuknecht [17], the greater the size of the cochlear aqueduct, the more viable it is to the passage of red blood cells.

2. In man, the patent cochlear aqueduct has been implicated in patients who developed severe labyrinthitis secondary to meningitis [15, 16].

3. The patent cochlear aqueduct may be the source of the continuous gush of cerebrospinal fluid (CSF) ("perilymph" otorrhea) during stapedectomy for otosclerosis [5]. In some instances, this could be persistent enough as to force early termination of the surgery. In fact, it is believed the first description of the cochlear aqueduct in 1760 by Catugno (who named it) was from his observation that fluid escaped from the cochlear aqueduct when the stapes was depressed [18]. In vivo experimentation by Ritter and Lawrence [5] demonstrated that tracer compounds injected into the spinal CSF before such procedures were not recovered in the perilymph aspirated from the oval window.

4. It seems reasonable to assume that a relation exists between the perilymphatic and CSF compartments, as the two are similar biochemically and immunologically [6].

5. Morphologically, it appears that the cochlear aqueduct is wide and patent in mammals other than human and nonhuman primates, in whom it has become extremely narrow [5, 19]. Also, the cochlear aqueduct is wider in children than in adults [20].

The latter observation leads to the tempting conclusion that this once functional organ may be evolving into a vestigial functionless structure in primates, a theory propounded by Lempert et al. [21]; this process is repeated in human ontogeny. In vitro direct and indirect injections of chemical stains by Wlodyka [22] further support this hypothesis, in that lack of patency of the cochlear aqueduct seems to increase with age, the earliest occurrence being in the neonate. This opinion is supported by Rask-Anderson et al. [7], who claim that the gradual bony obliteration may be related somehow to the growth of the jugular fossa and the infra- and perilabyrinthine pneumatization.

The cochlear aqueduct may function as a pressure-regulating mechanism equalizing CSF pressure with perilymph pressure [5, 21, 23], an attractive hypothesis similar to that proposed for the endolymphatic sac, but this has not been demonstrated in humans. In rabbits, who have wider cochlear aqueducts than do humans, it appears to have this function [5]. However, can one assume that those with wide and perhaps patent cochlear aqueducts (i.e., "variants" as in fig. 7) are vulnerable to the foregoing complications? Perhaps the ease with which CT allows this structure to be visualized, although usually not in its entirety, may be instrumental in solving this puzzle.

Reviewing the literature, we found only one simultaneous in vivo human morphologic and functional correlation study to determine the relation between the size of the cochlear aqueduct and its patency [14]. CT may render such a study possible. The question arises as to which measurement is the more relevant to this problem: the size of the external opening (as in our study) or the degree of visualization of the cochlear aqueduct length [1]. We are somewhat skeptical of the results of Hemingsson and Lindgren [1], who report 50% visualization of the cochlear aqueduct in their series of 41 patients, considering that usually the normal cochlear aqueduct can narrow to 0.1 mm or less and that conventional tomography has poor contrast resolution. Rask-Anderson et al. [7] reported 60% visualization of their in vitro temporal bone specimens with conventional tomography. They claim that failure of visualization may be caused by a high jugular fossa, particularly directed cochlear aqueduct, and bony obliteration. The low yield of total visualization in our study probably is because many scans were obtained at 2-mm-thick slices (Pfizer 0200FS), which may have resulted in partial-volume averaging of adjacent bone.

According to Crowe [15] and Palva and Dammert [6], soft-tissue barriers that may prevent microorganisms from reaching the labyrinth via the cochlear aqueduct include those found at the funnel of the external orifice, and in 10% of cases a membrane is situated across the internal orifice. During meningitis, tissues swell at the funnel, plugging up the cochlear aqueduct orifice. Our study may be useful in predicting the relation between the amount of soft tissue and the size of the funnel. We believe an inverse relation would exist: the larger the mouth, the more likely the patency.

Despite the recommendations of Dorph et al. [2] and Hemingsson and Lindgren [1] to obtain various projections on conventional tomograms to place the plane of the cochlear aqueduct parallel to the plane of section, we believe that CT has the superior contrast resolution necessary to obviate these cumbersome manipulations. Hence we believe that routine axial and coronal projections should be adequate for examination of this structure.

In view of our own results, we cannot agree with the findings of Dorph et al. [2] that in most cases of chronic otitis the cochlear aqueduct cannot be seen because of excessive bone deposition in the petrosa. Currently, a study is underway to determine the relation of the size of the cochlear aqueduct to various diseased states.

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