Coronal Computed Tomography of the Normal Vestibular Aqueduct in Children and Young Adults

L. Nicole Murray, MD; G. Javier Tanaka, MD; David S. Cameron; Gerard J. Gianoli, MD

Objective: To characterize the appearance of the normal vestibular aqueduct on coronal computed tomography (CT).

Design: Retrospective evaluation of routine CT images of the temporal bones.

Setting: Private tertiary care center.

Patients: Twenty-four children and young adults (14 females and 10 males), aged 2 to 24 years (average age, 10 years).

Main Outcomes Measures: Axial CT images were evaluated for the size of the vestibular aqueduct as previously described. On coronal CT images the vestibular aqueduct was evaluated for shape, dimensions, and angle. These measurements were made posteriorly, at the first point of vestibular aqueduct definition, and anteriorly, where the vestibular aqueduct abuts the posterior semicircular canal.

Results: We were able to measure the vestibular aqueduct on 100% of the anterior coronal views, 77% of the midisthmus axial CT images, and 53% of posterior coronal CT images, (P<.001). The shape of the vestibular aqueduct on coronal CT scans varied posteriorly to anteriorly from being a slit to being an oval or round. The dimensions (mean±SD) of the isthmus on the anterior coronal views were 3.1±1.8 mm long by 1.6±0.8 mm wide. The upper limits of normal, as defined by the mean + 2 SDs, are 6.8 × 3.3 mm.

Conclusions: We have easily and consistently identified the vestibular aqueduct on coronal CT images; in fact, we found the vestibular aqueducts more consistently measurable on coronal CT scans than on axial CT scans. The addition of these views may improve the sensitivity of the CT scan in the evaluation of sensorineural hearing loss in children.


SENSORINEURAL hearing loss in children and young adults is often evaluated by computed tomographic (CT) imaging of the temporal bones. Although temporal bone abnormalities are uncommon, abnormalities such as enlarged vestibular aqueducts, Mondini-type deformities, and other types of deformities of the otic capsule may be found in up to 25% of young patients with unexplained hearing loss. Many otolaryngologists routinely image the temporal bones in children and young adults with unexplained sensorineural hearing loss. The most common congenital abnormality found on CT imaging is the enlargement of the vestibular aqueduct. The size of the vestibular aqueduct has, to date, been evaluated with axial CT. The vestibular aqueduct, however, is a 3-dimensional tubular structure with a largely horizontal path. As such, it is well suited to evaluation in the coronal plane. Additionally, the vestibular aqueduct is often in close approximation to the jugular bulb; on an axial CT scan, it can be difficult to delineate the vestibular aqueduct from the bulb. For these reasons, we began to evaluate the vestibular aqueducts on routine coronal CT scans. We found that the vestibular aqueduct could be easily identified at its posterior aperture and traced anteriorly to the vestibule (Figure 1). The anterior portion visualized is the isthmus segment, and is well seen traveling horizontally. The posterior portion widens out into a funnel shape as it opens into the posterior fossa.

To our knowledge, no one has determined the characteristics of the normal vestibular aqueduct on coronal CT imaging. Our purposes for this study were to (1) establish the reliability of the coronal CT imaging for evaluation of the vestibular aqueduct, (2) define the shape and size...
PATIENTS AND METHODS

Twenty-four patients (14 females and 10 males, aged 2–24 years [average age, 10 years]) who underwent routine CT scanning of the temporal bones at Tulane University Medical Center, New Orleans, La, were studied. Patients were included who were younger than 30 years at the time of the CT imaging and who had high-resolution CT scans of the temporal bones during the study period of May 1, 1996, to August 31, 1998, for chronic ear disease, unexplained hearing loss, trauma, or facial nerve abnormalities. Any finding of congenital temporal bone abnormalities or other bony deformities of the skull necessitated the patient’s exclusion from the study. This allowed us to evaluate 48 ears. Scans were performed using commercially available CT scanners (HiSpeed Advantage and ProSpeed CT Scanners; General Electric Medical Systems, Milwaukee, Wis). Computed tomographic images were obtained with 1-mm collimation at 1-mm intervals using a bone algorithm. As this was a retrospective review, informed consent was not obtained. This study was approved by the Tulane University Medical Center Institutional Review Board.

Computed tomographic scans were evaluated by a senior otolaryngology resident (L.N.M.) and a staff otologist (G.J.G.). Prior to collecting measurements, all CT scans were reviewed by the evaluators and any discrepancies of opinion regarding the presence or position of the structures in question were addressed. Discrepancies were few and were either resolved through a second scrutiny or were left in dispute. Measurements were then made independently by the 2 investigators (L.N.M. and G.J.G.) by projecting films with a standard overhead projector onto a large surface and calculating the rate of enlargement from the calibration marks on the CT scan. Measurements could be reliably made using this system on structures as small as 0.3 mm. Structures identifiable but smaller than 0.3 mm were recorded as “too small to measure” and structures unidentifiable were recorded as such.

Axial CT images were evaluated for the diameter of the right and left vestibular aqueduct as measured at the midpoint of the isthmus, as described by Valvassori and Clemis (Figure 2). Coronal CT images were evaluated for characteristics of the vestibular aqueduct at the following 2 regions: posteriorly, at the first point of vestibular aqueduct definition, and anteriorly, where the vestibular aqueduct abuts the posterior semicircular canal. Our requirements for recording measurements were well defined at each point. Posteriorly, we took measurements at the posterior-most image where a bony septum could be seen between the vestibular aqueduct and the posterior fossa (Figure 3A). This allowed the width and length of the aperture to be clearly defined. We then followed the vestibular aqueduct anteriorly and took the anterior measurements at the posterior-most image where the vestibular aqueduct was seen against a portion of the posterior semicircular canal (Figure 3B). This allowed the measurement of the diameter of the isthmus. Variables recorded at each position included the right and left width and length or diameter, angle to the horizontal axis, and shape. Angles were measured as follows: a line was drawn along the long axis of the vestibular aqueduct that could be intersected with a horizontal line to yield an angle. A line parallel to the horizontal axis of the head was most readily available by connecting 2 analogous points on the skull base (ie, the foramen magnum); if this was unavailable then analogous points on the first cervical vertebra were used. The shape was determined by obtaining an integer ratio of length to width: this resulted in the ability to categorize shapes as round (ratio = 1), oval (ratio = 2–3), or slit (ratio >4). Measurements were then collected and analyzed using a standard spreadsheet software program Microsoft Excel Version 5.0 (Microsoft Corp, Seattle, Wash).

RESULTS

The study of these 14 female and 10 male patients allowed the evaluation of 48 ears. There appeared to be good correlation between the measurements of the 2 evaluators (Pearson product moment correlation coefficient, \( r = 0.99 \)).

Axial CT scans were evaluated for the presence and the width of the vestibular aqueduct at the midisthmus segment. The image containing the image of the left vestibular aqueduct was missing for 1 patient, allowing 47 ears to be evaluated. The vestibular aqueduct was identifiable in 43 (91%) of 47 ears and measurable in 36 (77%) of 47 ears. Seven vestibular aqueducts were too small to measure on axial CT scans. Average width was 1.0 mm (vestibular aqueduct range, 0.3–1.5 mm).

Coronal CT scans were evaluated for the presence and character of the vestibular aqueduct first posteriorly (aperture) and then anteriorly (isthmus). Computed tomographic scans were technically inadequate for posterior evaluation in 3 (0.06%) of 48 ears because the images did not go back far enough toward the posterior fossa. Thus, the technical adequacy rate for posterior scans was 94%. The vestibular aqueduct was identified and measured in 24 (53%) of the 45 technically adequate CT scans. Those that were unidentifiable or unmeasurable were such because the vestibular aqueduct did not become well defined until it was seen abutting the posterior semicircular canal. By our convention, these were recorded as “anterior” measurements. Posterior length, width, and angle are given in the Table. Shape posteriorly was a slit in 14 ears (38%) and an oval in 10 ears (42%).

Anterior coronal CT evaluation was technically impossible for 1 ear due to a failure to image the posterior semicircular canal; therefore, 47 of 48 ears were evaluated (98% technical adequacy). The vestibular aqueduct was identifiable and measurable in all 47 (100%) of these ears. Anterior length, width, and angle are shown in the Table. Shape anteriorly was a slit in 3 ears (6%), an oval in 27 ears (56%), and round in 17 ears (33%).

Results for technical adequacy, identifiability, and measurability for each view of the vestibular aqueduct are summarized in Figure 4. The difference between axial limits of the normal vestibular aqueduct on coronal CT imaging, and (3) correlate the coronal findings with those on axial CT imaging.
and anterior coronal measurability was statistically significant (P < .001, t test).

Finally, we looked for correlation of our axial isthmus diameter with our coronal isthmus diameter (ie, anterior coronal width measurements). There was no correlation (Pearson product moment correlation coefficient, r = −0.058).

COMMENT

The course of the vestibular aqueduct has been well described, based on both imaging and temporal bone dissection studies. It arises from the medial wall of the vestibule and extends in an inverted J shape to the posterior surface of the petrous pyramid (Figure 5). The vestibular aqueduct initially travels medially and parallel to the common crus (isthmus). Posterior to the common crus, the distal portion of the vestibular aqueduct turns inferiorly and becomes triangular with its apex at the isthmus and its base (aperture) at the posterior fossa. The distal segment has been described as oval with a diameter of 0.5 to 5 mm at the aperture.²

The large vestibular aqueduct syndrome has been recognized clinically since 1978.³ Although large vestibular aqueduct syndrome was initially believed to be characterized by a congenital, nonprogressive, nonfluctuating high-frequency sensorineural hearing loss, current evidence suggests that the enlarged vestibular aqueduct is simply an anatomic variant that may predispose affected individuals to fluctuating, progressive hearing loss often associated with minor head trauma.²,⁴

The enlarged vestibular aqueduct has been defined radiologically in several ways, all of which involve examination of an axial CT image. Most published articles use the midpoint of the isthmus as the point of measurement. Valvassori and Clemis² defined an enlarged vestibular aqueduct as one having a diameter greater than 1.5 mm, whereas Wibrand et al⁵ had a more stringent requirement of greater than 2.0 mm for the same segment. Urman and Talbot⁶ defined an enlarged vestibular aqueduct as any one with this segment twice the size of the width of the adjacent posterior semicircular canal. This rule is useful as it is easy to recall and apply. Swartz et al⁷ based their size evaluation on the size of the aperture as measured on axial CT scan; the upper limit of normal in their series was 2.0 mm. Little has been published regarding the appearance of the vestibular aqueduct on coronal CT scan. Some authors⁸,⁹ have reported the ability to detect the vestibular aqueduct on coronal CT, but others¹⁰ report that it is “nearly impossible” to image the vestibular aqueduct in the coronal plane. Some textbooks suggest a sagittal or lateral view if the vestibular...
lar aqueduct is to be visualized, but these views are excluded from a routine CT series of the temporal bones and are not generally obtained.

We initiated this study because we became aware that we could, indeed, find the vestibular aqueduct on our routine coronal CT images, and we could trace its course nicely from posterior to anterior. Prior studies have not investigated the ability to routinely find the vestibular aqueduct using coronal CT scans, and, to our knowledge, there is no description in the literature of the nor-

Figure 2. Axial computed tomographic scan and line drawing of the bony vestibular aqueduct (arrow) where measurements are made. Width is measured at the midpoint of the isthmus. PSCC indicate posterior semicircular canal; HSCC, horizontal semicircular canal; VA, vestibular aqueduct; VEST, vestibule; and IAC, internal auditory canal.

Figure 3. Coronal computed tomographic scan (A) and line drawing (B) of bony vestibular aqueduct (arrow) where posterior measurements are made. C. Coronal computed tomographic scan and line drawing (D) of bony vestibular aqueduct (arrow) where anterior measurements are made. Length and width are measured as indicated from points a, b, c, and d. A horizontal line is formed by connecting 2 analogous points on the skull base and this is intersected with the line ab to yield the angle. VA indicates vestibular aqueduct; JB, jugular bulb; SB, skull base; and PSCC, posterior semicircular canal.
Measurability

The technical adequacy of the routine CT scans to allow evaluation of the vestibular aqueduct was high for both axial and coronal views. The rates of vestibular aqueduct identifiability and measurability were not equally high for all views. The axial CT scans allowed the identification of the vestibular aqueduct in 43 (91%) of the 47 ears but allowed its actual measurement in only 36 (77%) of the 47 ears. The vestibular aqueducts that were categorized as “identifiable” but not “measurable” on axial CT scans were simply too small at the midpoint of the isthmus to accurately measure (generally <0.3 mm). Those that were unidentifiable were either so small as to not even be visible or, perhaps, were best defined at a point between the actual CT slices and thus not seen. The coronal posterior view (aperture) had the poorest rates of identifiability and measurability at 53% (25 of 47 ears). The reasons for this stemmed from our strict requirements for taking measurements. If the vestibular aqueduct was not seen as separate from the posterior fossa by a bony bridge, it was judged as unidentifiable or unmeasurable. Also, if the first point of vestibular aqueduct definition involved the segment next to the posterior canal, it was recorded as an anterior and not a posterior view. Thus, about half of the vestibular aqueducts were thin and ill-defined on posterior views. Here, when measurable, the vestibular aqueduct averages 8 × 1.8 mm, is oval or slitlike, and is oriented at 147° to the horizontal axis. This aperture width correlates with that described by Swartz et al. The anterior coronal view (isthmus) was the most reliable for evaluating the vestibular aqueduct: identification and measurement rates were each 100%. This view was as technically adequate for evaluating the vestibular aqueduct size as the axial views (98%), and more reliable. The isthmus on coronal CT averages 3.1 × 1.6 mm, is round to oval, and is oriented at 131° to the horizontal axis. If we define an abnormally large vestibular aqueduct as one larger than the mean +2 SDs, then the upper limit of normal on coronal CT at the isthmus is 6.8 × 3.3 mm. Although we did not measure the posterior canal in this study, we believe that a modification of the Urman and Talbot rule will likely hold when evaluating coronal CT scans: the vestibular aqueduct at the isthmus is generally no wider than twice the adjacent posterior canal.

In this study we have measurements of the width of the isthmus from 2 different perspectives: axial and anterior coronal. These measurements did not correspond well; this is likely owing to (1) the manner in which we made our anterior coronal measurements and (2) the manner in which CT slices are obtained. We measured our anterior coronal widths at the point where the vestibular aqueduct was first seen next to the common crus; however, this was not necessarily at the midpoint of the isthmus segment and, therefore, not necessarily the same anatomic point as that measured by a bony bridge, it was judged as unidentifiable or unmeasurable.
on axial scan. Perhaps more importantly, our coronal measurements were true diameters, whereas our axial measurements were possibly tangentially sliced segments. These tangential segments would by definition be shorter than the true diameter of the duct. This is demonstrated in Figure 6, and likely accounts for the lack of correlation between axial and coronal views of the isthmus. Because of the potential for tangential sectioning of the vestibular aqueduct with axial CT scans, it is more anatomically sound to assess the vestibular aqueduct width on coronal CT scans. In fact, we found 2 patients in this series with normal vestibular aqueducts on axial CT scan but enlarged vestibular aqueducts by the coronal CT scan criteria (ie, $6.8 \times 3.3$ mm). These may be examples of underestimation of the true size of the vestibular aqueduct by axial CT imaging. Evaluation of a series of patients with large vestibular aqueduct syndrome using coronal and axial CT scans will help to determine the true use of the coronal CT scan in large vestibular aqueduct syndrome. We are undertaking such a study.

In our experience, the coronal CT image has been useful not only for evaluating the size of the vestibular aqueduct but also in distinguishing a high-riding jugular bulb from an enlarged vestibular aqueduct by the coronal CT scan criteria (ie, $>6.8 \times 3.3$ mm). These may be examples of underestimation of the true size of the vestibular aqueduct by axial CT imaging. A high-riding jugular bulb may be mistaken for an enlarged vestibular aqueduct (Figure 7). We have seen several cases where a high-riding jugular bulb would have been misdiagnosed as an enlarged vestibular aqueduct if axial CT scans alone are used for evaluation, the proximity of the jugular bulb to the path of the vestibular aqueduct may cause the bulb to be mistaken for the vestibular aqueduct (Figure 7). We have seen several cases where a high-riding jugular bulb would have been misdiagnosed as an enlarged vestibular aqueduct if the coronal views had not been evaluated. Clinicians who are experienced in reading CT scans of the temporal bone may never make this mistake, but we have seen some confusion here by those less comfortable with these details of temporal bone anatomy. Evaluation of the coronal views or careful evaluation of all slices of the axial CT scan will usually clarify this situation.

**CONCLUSIONS**

We have established the usefulness of routine coronal CT imaging for evaluation of the vestibular aqueduct. These views are almost always available but the vestibular aqueduct is not generally evaluated. The vestibular aqueduct may be identified on coronal views initially by examining posterior scans and noting the aperture of the duct as it opens into the posterior fossa. Although the vestibular aqueduct may not become well defined at this posterior point, it can almost always be identified and followed anteriorly to its isthmus, adjacent to the common crus.

Axial CT scans, which have been used for measuring the size of the isthmus to date, allowed measurement in only 77% (36 of 47 ears) of technically adequate scans. Routine coronal CT scans were technically adequate for evaluation of the isthmus 98% of the time and the isthmus size was measurable in 100% of these. The upper size limits of the normal isthmus on coronal CT scans are $6.8 \times 3.3$ mm. The lack of correlation of coronal isthmus measurements with axial measurements may indicate that axial CT scans underestimate the true width of the vestibular aqueduct. This is supported by the finding of 2 patients in this series with normal-appearing vestibular aqueducts on the axial CT scan but enlarged vestibular aqueducts on the coronal CT scan. Coronal views seem to provide a more ana-
atomically sound measurement of the size of the isthmus; further evaluation of both normal and enlarged vestibular aqueducts on coronal CT scans will be necessary to confirm this.

We believe that the evaluation of the coronal CT image will be valuable in assessing children and young adults with unexplained sensorineural hearing loss. Sensitivity in detecting the most common temporal bone abnormality, enlarged vestibular aqueducts, may be improved; therefore, prophylactic measures or treatment measures may be more readily enacted.

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Corresponding author: Gerard J. Gianoli, MD, Tulane University Medical Center, Department of Otolaryngology–Head and Neck Surgery, 1430 Tulane Ave, Box SL59, New Orleans, LA 70112 (e-mail: ggianol@mailhost.tcs.tulane.edu).

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