NORMATIVE CT MEASUREMENTS OF VESTIBULAR AQUEDUCT WIDTH IN MALAYSIAN PAEDIATRIC POPULATION

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ABSTRACT: Enlarged vestibular aqueduct (EVA) is the most common inner ear malformation associated with sensorineural hearing loss (SNHL), often presenting in childhood with fluctuating or progressive hearing loss. However, the normal range of vestibular aqueduct (VA) size in paediatric populations, particularly in Malaysia, remains lacking. This study aims to establish reference values of VA width using CT imaging in Malaysian paediatric population without hearing loss. We retrospectively evaluated eighty-five CT scans of brain, face, and paranasal sinuses with bone algorithm reconstruction done for reasons other than hearing loss from January 2022 to December 2024 at Hospital Canselor Tuanku Muhriz (HCTM). The VA widths were measured in both axial and 45° oblique (Pöschl) planes using Horos/Osirix software by two experienced head and neck radiologists. The upper limit of normal VA width was 1.0mm in the axial plane and 0.9mm in the 45° oblique (Pöschl) plane. The 45° oblique (Pöschl) plane demonstrated stronger interobserver consistency, with moderate correlation for the right ear ($r = 0.429$, $p = 0.000$) and good correlation for the left ear ($r = 0.538$, $p = 0.000$). The mean VA midpoint width in the axial plane was 0.44mm (SD 0.18; range 0.10–0.90mm). In the 45° oblique plane, the mean midpoint width was 0.49mm (SD 0.17; range 0.10–0.88mm). Measurements in the 45° oblique plane were more reliable and accurate than the axial plane. Our findings help define localized diagnostic thresholds for diagnosing EVA in Malaysian children.

***KEYWORDS**: vestibular aqueduct width, paediatric, CT, Pöschl plane, Malaysia*

1.0 INTRODUCTION

Enlarged vestibular aqueduct (EVA) is the most frequently identified congenital inner ear malformation associated with paediatric sensorineural hearing loss (SNHL) [1-3]. Accurate radiologic assessment of vestibular aqueduct (VA) size is critical in the diagnosis of EVA, particularly in children presenting with progressive or fluctuating hearing loss [4].

In 1978, Valvassori and Clemis reported that a midpoint VA width of more than 1.5mm is enlarged based on hypocycloidal polytomography [3]. With advances in multidetector CT, the Cincinnati criteria defined EVA based on axial CT, using thresholds of >0.9mm at the midpoint or >1.9mm at the operculum [5].

Due to the VA anatomic obliquity, the 45° oblique (Pöschl) demonstrates better visualisation of the VA in its entire length, which allows it to yield more precise and reliable measurements of VA size compared to the axial plane [6, 7]. Juliano et al. in 2016 reported that the mean VA midpoint width measured in the 45° oblique (Pöschl) plane was 0.5mm, with a range of 0.3–0.9 mm [6].

To date, no published studies have established normal VA width measurements in the Malaysian paediatric population. Given ethnic and anatomical variation, establishing a population-specific reference range may enhance diagnostic accuracy of EVA. Hence, this study aims to define normative CT-based measurements of VA width in Malaysian paediatric population, using both axial and 45° oblique (Pöschl) planes. This study will also compare the reproducibility of the VA width measurements between the axial plane and 45° oblique (Pöschl) plane to determine which plane offers greater measurement reliability.

2.0 METHODOLOGY

2.1 Study Design

This is a retrospective study conducted in the Radiology Department of Hospital Canselor Tuanku Muhriz (HCTM). CT scans of brain, face, and paranasal sinuses with bone reconstruction done from 1st January 2022 to 31st December 2024 are retrieved from PACS (Pictures Archiving and Communication System) via convenient sampling method. Each CT indication was then screened for inclusion and exclusion criteria (refer Table 1) via the available clinical data on C-HetS (Caring Hospital Enterprise System). The VA width measurements are made with the use of current workstation software (Osirix/Horos) by two experienced head and neck radiologists. All selected cases also demonstrated no radiographic evidence of inner ear abnormality.

Table 1: Study Criteria

Inclusion criteria:	Exclusion criteria:
1. CT examination performed for indications other than hearing loss. 2. Normal inner ear structures.	1. Age 21 years old and above. 2. History or clinical evidence of hearing loss. 3. Inner ear abnormality. 4. Temporal bone fracture.

2.2 Research Objectives

The objective of this study is to establish normative CT-based measurements of VA width in the axial plane and 45° oblique (Pöschl) plane for Malaysian paediatric population. This study will also compare the reproducibility of the VA width measurements between the axial plane and 45° oblique (Pöschl) plane, in order to determine which provides greater measurement reliability.

2.3 Statistical Analysis

All data were analysed using SPSS version 27. The minimum sample size required is approximately 82 patients to ensure adequate power to detect a statically significant difference in VA width between groups, if exists. This was calculated using the formula for comparing two means:

$$n = \frac{2\sigma^2}{\Delta^2}\left(z_\alpha + z_\beta\right)^2$$

In Ozgen et al. study [7]:

The standard deviations for the two groups were $\sigma_1 = 0.098$ and $\sigma_2 = 0.133$

The expected mean difference (Δ) between the groups was 0.616 – 0.482 = 0.134

A 99% confidence level ($\alpha = 0.01$) and 90% power ($\beta = 0.10$) were selected, giving $z\alpha = 2.58$ and $z\beta = 1.28$

Substituting into the formula:

$$n = \frac{2(0.098^2 + 0.133^2)}{(0.134)^2} \times (2.58 + 1.28)^2 = 81.7$$

Thus, a sample size of 85 patients (N=85; 170 ears) was taken in this study.

2.4 Research Procedures

VA midpoint in the axial plane is defined as the part of the VA located in the petrous bone, in between the distance from its origin in the labyrinth to its aperture in the epidural space [8]. The posterior wall of the vestibule defines the vestibular plane (V). The posterior petrous bone defines the operculum plane (O). The midpoint plane (M) is equidistant from the vestibular (V) and operculum (O) planes, where the VA width will be measured across its walls (white line) subjectively. The procedure to measure VA midpoint width in axial plane is as follows, illustrated in Figure 1:

Step 1: Identify the posterior wall of the vestibule (V) and the operculum (O) planes.

Step 2: The midpoint plane (M) is equidistant from the vestibular (V) and operculum (O) planes.

Step 3: The VA width (white line) is subjectively measured across its walls at the midpoint (M).

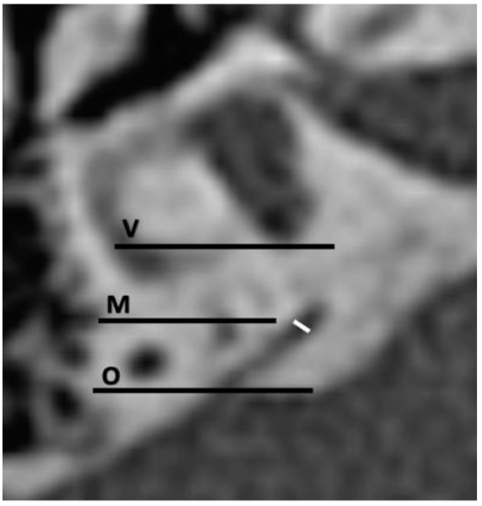

Figure 1: Measurment of VA midpoint width in axial plane

The VA midpoint width in the 45° oblique (Pöschl) plane is measured by using commercially available 3D reformatting software (Osirix/Horos). Images in the 45° oblique plane are produced for each temporal bone by selecting the plane parallel to the superior semicircular canal (SCC) [6]. The image slice that shows the entire length of the VA is selected. The midpoint of the VA is identified, and the width is measured across this line subjectively.

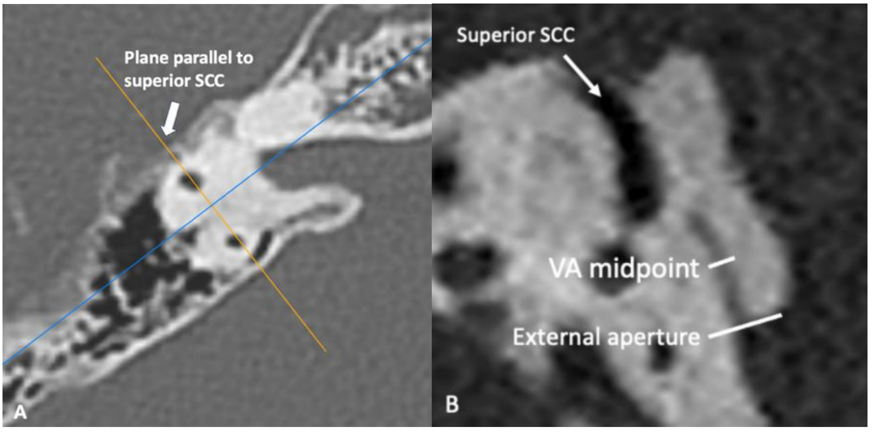

Figure 2: Measurement of VA midpoint width in the Pöschl plane using 3D reformatting software. A) The Pöschl plane is produced by selecting the plane parallel to the superior semicircular canal (SCC). B) The image section demonstrating the entire VA length is selected. VA midpoint is identified, and the width is measured subjectively across its walls.

3.0 RESULTS

A total of eighty-five patients who met the inclusion criteria were selected. The age range for the patients in this study were between 2 to 20 years old. The demographic data and CT indication were shown in Table 2. Non-trauma indications include fitting, headache, nasal discharge, eye swelling, altered behaviour or altered mental status. The age groups were divided according to the Eunice Kennedy Shriver National Institute of Child Health and Human Development in the United States [9].

Table 2: Demographic Data

Criteria	Group	Number (n = 85)
Gender	Male	50
	Female	35
Age	1 to <3yo toddler	4
	3 to <6yo early childhood	8
	6 to <12yo middle childhood	10
	12 to <19yo early adolescence	51
	19 to <21yo late adolescence	12
CT Indication	Trauma	33
	Non-trauma	52

Table 3: Normal Values of VA width in Axial plane

	Mean	Std. Deviation	Minimum	Maximum
Right ear VA width in Axial plane (mm)	0.47	0.18	0.10	0.88
Left ear VA width in Axial plane (mm)	0.40	0.18	0.10	0.96
Both ears VA width in Axial plane (mm)	0.44	0.18	0.10	0.96

Table 4: Normal Values of VA width in 45° Oblique (Pöschl) plane

	Mean	**Std. Deviation**	**Minimum**	**Maximum**
Right ear VA width in *Pöschl* plane (mm)	0.49	0.17	0.10	0.88
Left ear VA width in *Pöschl* plane (mm)	0.49	0.17	0.10	0.79
Both ears VA width in *Pöschl* plane (mm)	0.49	0.17	0.10	0.88

Table 5: Upper Ranges of Normal VA width in Axial plane and 45° Oblique (Pöschl) plane

Percentile (N=85)	**Size (mm)**			
	50th	**75th**	**90th**	**95th**
Right ear VA width in Axial plane	0.47	0.61	0.72	0.75
Left ear VA width in Axial plane	0.40	0.51	0.66	0.74
Both ears VA width in Axial plane	0.43	0.58	0.69	0.75
Right ear VA width in *Pöschl* plane	0.51	0.61	0.69	0.78
Left ear VA width in *Pöschl* plane	0.44	0.55	0.65	0.72
Both ears VA width in *Pöschl* plane	0.49	0.59	0.67	0.75

Table 6: Paired Sample Test between Right and Left Ears VA width in Axial plane and 45° Oblique (Pöschl) plane.

			95% Confidence Interval of the Difference		
	Mean	**Std. Deviation**	**Upper**	**Lower**	**t**
Right & Left ears VA width in Axial plane	0.0720	0.176	0.033	0.110	3.762
Right & Left ears VA width in *Pöschl* plane	0.0617	0.159	0.027	0.096	3.578

Table 7: Paired Samples Correlation Tests between Radiologist 1 (R1) and Radiologist 2 (R2)

Paired Samples	**N**	**Correlation (r)**	**Significance (p)**
R1 & R2 Right ear VA width in Axial plane	85	0.128	0.242
R1 & R2 Left ear VA width in Axial plane	85	0.270	0.013
R1 & R2 Right ear VA width in Pöschl plane	85	0.429	0.000
R1 & R2 Right ear VA width in Pöschl plane	85	0.538	0.000

The overall results of our study highlights that:

i. In the axial plane: the mean VA width is 0.44mm (range 0.10–0.96mm). The maximum VA width reached up to 0.96mm, otherwise remained below 1.0mm. This supports the Cincinnati criteria of defining EVA as ≥ 1.0 mm at the midpoint [5], which is applicable for Malaysian population.

ii. In the Pöschl plane: the mean VA width is 0.49mm (range 0.10–0.88mm), with no cases exceeding 0.9mm. These findings suggest that VA widths in Malaysian paediatric population are slightly smaller than those reported by Juliano et al. [6], who found a mean midpoint width of 0.5mm (range 0.3–0.9mm).

iii. In both the axial and Pöschl planes: the 95th percentile VA widths are almost the same (range 0.72 to 0.78mm). These findings reinforce that VA widths rarely exceed 0.75mm in a normal Malaysian paediatric population.

iv. Consistent asymmetry observed in the paired sample test suggests that mild right-left variation in VA width is likely a normal anatomical variant in Malaysian population.

v. Inter-observer correlation was significantly higher in the Pöschl plane, confirming superior reliability.

4.0 DISCUSSION

The vestibular aqueduct (VA) is a slender bony conduit located within the petrous part of the temporal bone. It houses the endolymphatic duct, which extends from the vestibule and terminates at the endolymphatic sac situated against the dura in the posterior cranial fossa [10, 11]. Developmentally, the VA attains its adult form by around three years of age, assuming an inverted "J" configuration with a short proximal (isthmic) limb and a longer distal descending limb [12-16]. It was reported in this histopathologic series that VA enlargement associated with large vestibular aqueduct syndrome (LVAS or EVAS) reflects aberrant continued growth rather than developmental arrest during early embryogenesis [17]. Radiologically, enlargement of the VA is a frequently identified marker in children with SNHL, particularly in the context of Pendred syndrome [4, 7, 18]. Diagnostic accuracy depends critically on imaging technique and measurement plane. To date, no published data exists on the normative measurements of VA width in the paediatric population of Southeast Asia, particularly Malaysia.

In the axial plane, the VA typically appears as a teardrop- or funnel-shaped structure posterior to the vestibule [12-16]. Because the canal courses obliquely, axial sections often intersect it at an angle, which may result in partial visualization and potential overestimation of its width due to oblique sectioning. Traditional Valvassori criteria define EVA as a VA midpoint diameter of ≥1.5mm on axial CT [3, 19, 20], whereas the Cincinnati criteria define EVA as ≥ 1.0mm at the midpoint or ≥ 2.0mm at the operculum [10]. In our study, the normal values of VA width in the axial plane for the right ear, left ear and both ears respectively are shown in Table 3. The mean VA width for the right ear was 0.47mm, while the left ear showed a slightly lower mean of 0.40mm, both with a standard deviation of 0.18mm. The overall mean VA width when combining both ears was 0.44mm, with values ranging from 0.10mm to 0.9mm. The maximum VA width reached up to 0.96mm, but remained below 1.0 mm. These results support the Cincinnati criteria of defining EVA as ≥ 1.0 mm at the midpoint in the axial plane.

The Pöschl plane is a 45° oblique reformat aligned parallel to the superior semicircular canal and perpendicular to the long axis of the petrous bone. This allows almost complete visualization of the VA within a single CT slice (refer Figure 3B), enabling more accurate midpoint measurement and reduces the risk of over- or underestimation due to partial volume effects [6, 7]. It was demonstrated that the 45° oblique (Pöschl) plane is superior as it improves reproducibility and has an upper-normal midpoint diameter of about 0.9 mm [6, 7]. In our study, the normal values of VA width in the 45° oblique (Pöschl) plane for the right ear, left ear and both ears respectively are shown in Table 4. The mean VA width was 0.49mm for both the right and left ears, with a standard deviation of 0.17mm. The measurements ranged from a minimum of 0.10mm to a maximum of 0.88mm, with no cases exceeding 0.9mm. When combining both ears, the overall mean VA width was 0.46 mm, consistent with a narrow range of normal values in this population.

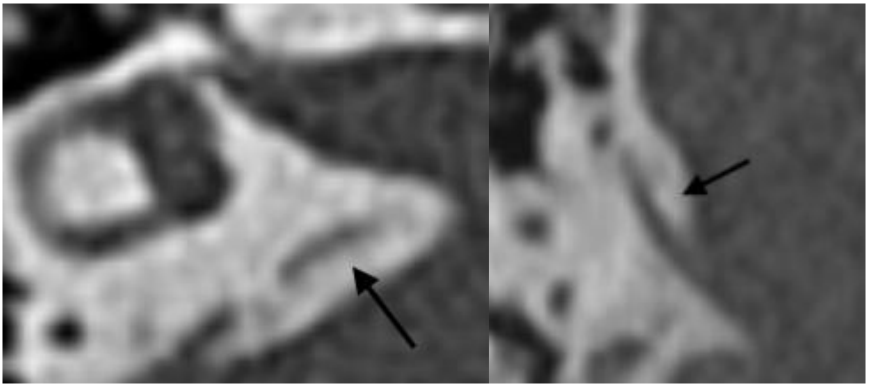

Figure 3: VA (black arrow) of the same patient. A) On the axial plane, it appears wider, and its length can only be seen partially due to its oblique orientation. B) On the Pöschl plane, the VA can be seen along its entire length

Table 5 further showed the upper ranges of normal VA width in the axial plane and 45° oblique (Pöschl) plane for the right ear, left ear and both ears respectively. In the axial plane, the 95th percentile VA width reached 0.75 mm for the right ear and 0.74 mm for the left ear, with the overall 95th percentile for both ears combined at 0.75 mm. Similarly, in the 45° oblique (Pöschl) plane, the 95th percentile measurements were 0.78 mm (right ear), 0.72 mm (left ear), and 0.75 mm overall. The 50th percentile (median) values ranged from 0.40 mm to 0.51 mm across all planes and sides. These findings indicate that VA widths in normal Malaysian children seldom exceed 0.75

mm, supporting 1.0 mm (axial) and 0.9 mm (oblique) as appropriate upper diagnostic limits. A paired sample t-test was done to compare the VA widths between the right and left ears in both the axial and 45° oblique (Pöschl) planes (Table 6). The results showed that the right ear VA was slightly larger than the left in both planes, with a mean difference of 0.072 mm in the axial plane and 0.062 mm in the oblique plane. These differences were statistically significant ($p = 0.000$ and $p = 0.001$, respectively). Despite the small magnitude of the differences, the consistent asymmetry observed suggests that mild right-left variation in VA width is likely a normal anatomical variant in Malaysian population. This finding underscores the need for cautious interpretation of asymmetry, particularly when measurements remain within normal thresholds. Interobserver correlation between the two radiologists (R1 and R2) was evaluated for each ear and imaging plane (Table 7). In the axial plane, correlation was low for the right ear ($r = 0.128$, $p = 0.242$) and weak but statistically significant correlation for the left ear ($r = 0.270$, $p = 0.013$), indicating limited measurement agreement. In contrast, the 45° oblique (Pöschl) plane demonstrated stronger interobserver consistency, with moderate correlation for the right ear ($r = 0.429$, $p = 0.000$) and good correlation for the left ear ($r = 0.538$, $p = 0.000$). These results emphasize the greater reliability and reproducibility of VA measurements in the oblique plane compared to the axial plane.

5.0 CONCLUSION

Accurate measurement of the vestibular aqueduct is important in paediatric hearing loss workup. Our results propose a localized and more detailed reference range of VA widths in both the axial and 45° oblique (Pöschl) planes for Malaysian children. Furthermore, we advocate for the routine use of multiplanar reformation (MPR) with the 45° oblique (Pöschl) plane for improved reliability, particularly when evaluating borderline or equivocal cases of potential EVA in children.

It is important to note that this single-center retrospective study findings may not fully represent the entire Malaysian paediatric population. Image resolution and thin-slice reconstruction artefacts may cause minor variability in measurement accuracy.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare and are in agreement with the contents of the manuscript.

ETHICS STATEMENT

This retrospective study utilized available scans retrieved from the PACS system. This research was executed in adherence to the ethical principles outlined in the Declaration of Helsinki and Malaysian Good Clinical Practice Guideline. Patients remained anonymous and all data collected were kept confidential.

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