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Original Article

Cochlear Implantation: Small Cochlear Diameter May Indicate Degree of Abnormality

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BACKGROUND: Cochlear size variation was first reported in 1884, and since then, there have been various reports confirming the same. Yet, there is no single report that has displayed the wide variations in the cochlear size in a single layout capturing the cochlea in the oblique coronal view/cochlear view.

METHODS: Basal turn diameter (*A*-value) was measured in the oblique coronal plane using the OTOPLAN® otological preplanning tool in 104 computed tomography (CT) scans of the temporal bones of cochlear implant (CI) recipients in a tertiary CI center. All CT scans with an image resolution of at least 0.5 mm and identified as having cochleae with normal anatomy were included in this study. A 3-dimensional (3D) segmentation was performed using the 3D slicer and visualized to evaluate the impact of cochlear size on the number of turns studied.

RESULTS: The *A*-value was found to vary between 7.3 mm and 10.4 mm among the studied patients. Three-dimensional segmentation of the inner ear revealed only 2 turns of the cochlea in 4 ears, with *A*-values of 7.3, 8.8, 7.8, and 7.7 mm. One ear had only $1^1/_2$ turns of the cochlea, with an *A*-value of 7.9 mm. As a further advancement in the assessment of cochlear size as determined by the *A*-value, 3D segmentation of the complete inner ear provides a full picture of the number of cochlear turns.

CONCLUSION: Three-dimensional segmentation of the entire inner ear could help improve the preoperative planning of CI surgery and have implications for electrode array selection. Cochlear size could be a predictor of the number of cochlear turns, even in cases that look normal from the radiological findings. The findings of this study could help in improving the preoperative planning for a more successful CI surgery by differentiating between the normal and abnormal cochlea.

KEYWORDS: Anatomy, cochlea, cochlear implant, cochlear size, cochlear turns

INTRODUCTION

The cochlear implant (CI) is the state-of-the-art treatment option for individuals with severe-to-profound sensorineural hearing loss (SNHL) who did not benefit from the use of hearing aids. The CI electrode array is intended to be placed inside the scala tympani (ST) to create an effective implant-neural interface.[1] The length of the ST, or cochlear duct, measured from base to apex of the cochlea, varies between 25 and 45 mm in the human population.[2] Koch et al first observed variation in the cochlear duct length (CDL) in 1884, which ranged between 32 mm and 34 mm.[3] Since then, several reports have investigated different methodologies for studying the measurement or estimation of CDL. This includes histology,[4] indirect estimations of CDL using single cochlear parameters measured from computed tomography (CT) images,[5,6] high-radiation synchrotron phase-contrast images,[7] plastic casts,[8] and direct measurement from the CT scans by following the lateral wall (LW).[9]

The indirect method of estimating the CDL by measuring the basal turn diameter (*A*-value), proposed by Escude et al, has gained popularity owing to its simplicity. The *A*-value is measured in the oblique coronal plane of the basal turn from the

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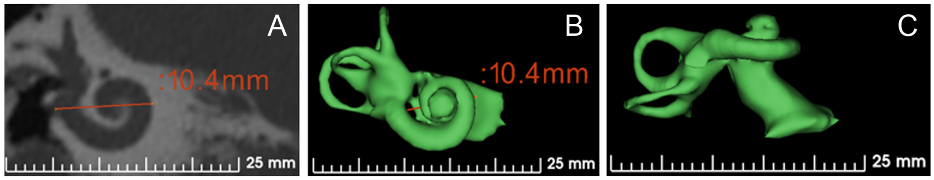

Figure 1. Computed tomography image of the cochlea in the oblique coronal plane showing the *A*-value measurement (A). Three-dimensional view of the cochlea in the oblique coronal plane (B) and axial plane (C).

round window (RW) entrance to the LW end, passing through the center of the cochlea.[5] According to Khurayzi et al,[10] there were 26 publications on *A*-value measurements ranging from 7.1 mm to 11.4 mm between 2007 and 2020, and the prevalence rate of extreme cochlear diameters is approximately 5% among SNHL patients. Despite this, no report has shown wide variations in cochlear size as measured by the *A*-value in a single three-dimensional (3D) illustration to visualize the variation in cochlear size. Recently, Khurayzi et al[10] reported that the *A*-value was similar between normal anatomy cochleae and cochleae with inner ear malformations. Estimation of CDL based on the *A*-value was only validated for normally developed cochleae with 2½ turns not for the malformed inner ear with a cystic apex or underdeveloped cochleae.

Therefore, the primary goal of this study was to examine the variation in cochlear size in a single 3D illustration and relate it to the *A*-value. In addition, we captured the inner ear in 3D to visualize the number of cochlear turns and thus distinguish normal-anatomy cochleae from malformed cochleae.

MATERIAL AND METHODS

Study Design and Participants

On November 16, 2021, Ethics Committee of King Saud Medical City approved this study (Approval No: HIRE-16-Nov 21-02), as well as the use of CT scan images after anonymization. No informed consent was obtained as the data were collected from the hospital database. All CT scan images analyzed in this study were collected retrospectively from January 2020 to December 2021.

Inclusion and Exclusion Criteria

All CT scans with an image resolution of at least 0.5 mm and identified as having normal anatomy cochleae were included in this study, whereas those with inner ear anatomical malformations, as determined by a radiologist, were excluded. Age and sex were not considered when deciding whether to include or exclude subjects.

MAIN POINTS

- This study aimed to display wide variations in cochlear size in a single illustration, in ascending order.
- This study demonstrated that A-Value differ between population and between normal and malformed inner ear.
- A 3D segmentation of the entire inner ear is beneficial and highly recommended in the preoperative evaluation of the inner ear prior to CI surgery, because even if the cochlea appears normal, smaller-sized cochleae with lower A-values (<8.5 mm) might have some degree of anatomical abnormality.

Image Analyses

The high-resolution CT images were analyzed using OTOPLAN® version 3.0 (CAScination AG, Bern, Switzerland, in collaboration with MED-EL GmbH, Innsbruck, Austria) and 3D Slicer, version 4.11.2, freeware (www.slicer.org). The *A*-value was retrospectively measured from preoperative CT scans on the side of implantation in the oblique coronal plane of the cochlea, showing the basal turn as automatically detected by the OTOPLAN®. The *A*-value starts at the entrance of the RW opening and passes through the center of the cochlea to the opposite side of the LW in 'cochlear view,' as described by Escude et al (Figure 1A).[5] The 3D segmentation of the complete inner ear was performed in the 3D slicer according to the steps reported by Dhanasingh et al[11] Figures 1B and 1C show the inner ear in 3D in both the oblique coronal and axial planes.

Statistical Analysis

All statistical analyses were performed using Microsoft Excel 365 (Microsoft Corp.; USA). The mean, SD, and range (i.e., minimum and maximum values) were used to describe the participants' characteristics. The *A*-values were normally distributed using a normal distribution function by applying probability density.

RESULTS

A-Value Distribution

Computed tomography scans of 104 ears were included and analyzed for the *A*-value measurement. The average *A*-value was 8.7 ± 0.6 mm, with values ranging from 7.3 mm to 10.4 mm. The *A*-value was 8 mm in 14 ears, >8.0 mm and ≤8.5 mm in 38 ears, >8.5 mm and ≤9 mm in 23 ears, >9 mm and ≤9.5 mm in 20 ears, and >9.5 mm in 9 ears. Figure 2 shows the normal distribution curve of the measured *A*-values.

Cochleae with Less than 2½ Turns

The 3D segmentation of the inner ear revealed only 2 turns of the cochlea in 4 ears, with *A*-values of 7.3 (Figure 3, sample 1), 8.8, 7.8, and 7.7 mm. One ear had only 1½ turns of the cochlea, with an *A*-value of 7.9 mm (Figure 3, sample 3).

Display of Cochleae in Size Ascending Order

Figure 3 displays the right-sided cochleae of 7 CI candidates in size ascending order, with *A*-values ranging from 7.3 mm to 10.4 mm. Column 1 shows images of cochleae in the oblique coronal view with the *A*-value measurement; column 2 shows the 3D segmented inner ear in the oblique coronal view; and column 3 shows the 3D segmented inner ear in the axial view. Our observation on the 3D image showed that cases 1 and 3 with *A*-values <8 mm had less than 2½ turns of the cochlea, with no other abnormalities.

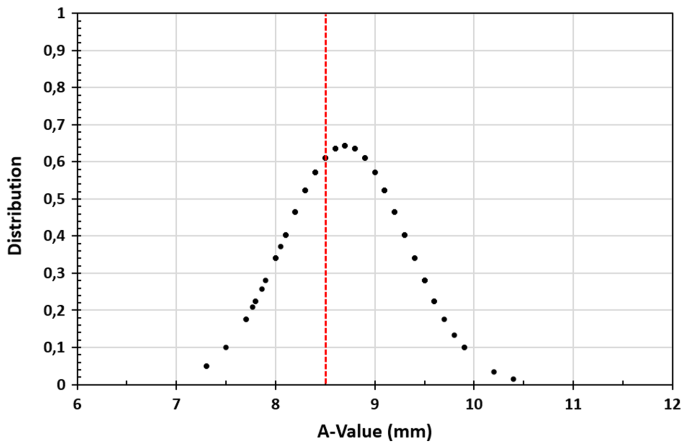

Figure 2. The distribution curve of *A*-values which have been measured in 104 ears. The threshold *A*-value of ≤8.5 mm indicates smaller-sized cochleae. The vertical dotted line in red separates the cochlear size above and below the *A*-value of 8.5 mm.

DISCUSSION

This study reports cochlear size variation in our population as measured in relation to the *A*-value in the oblique coronal plane. Khurayzi et al[10] recently reported on the range of cochlear size measured by *A*-values between 7.4 and 11.4 mm through a literature review of prior studies on cochlear size variations. In the current study, the reported cochlear size ranged between 7.3 and 10.4 mm. Pelliccia et al[12] in Italy reported the largest cochlear size of 11.4 mm in 2014.

The *A*-value was 8.5 mm in 52 of the 104 ears analyzed in the current study, accounting for half of the population, whereas only 9 ears had an *A*-value greater than 9.5 mm. This supports Alanazi et al's[6] early findings of smaller-sized cochleae in some ethnic populations.

Cases 1 and 3 in the current study (Figure 3) showed less than 2½ turns of the cochlea, with *A*-values of <8 mm. According to Khurayzi et al,[10] the *A*-value can be similar between cochleae with normal and malformed anatomies. This raises the concern that smaller-sized

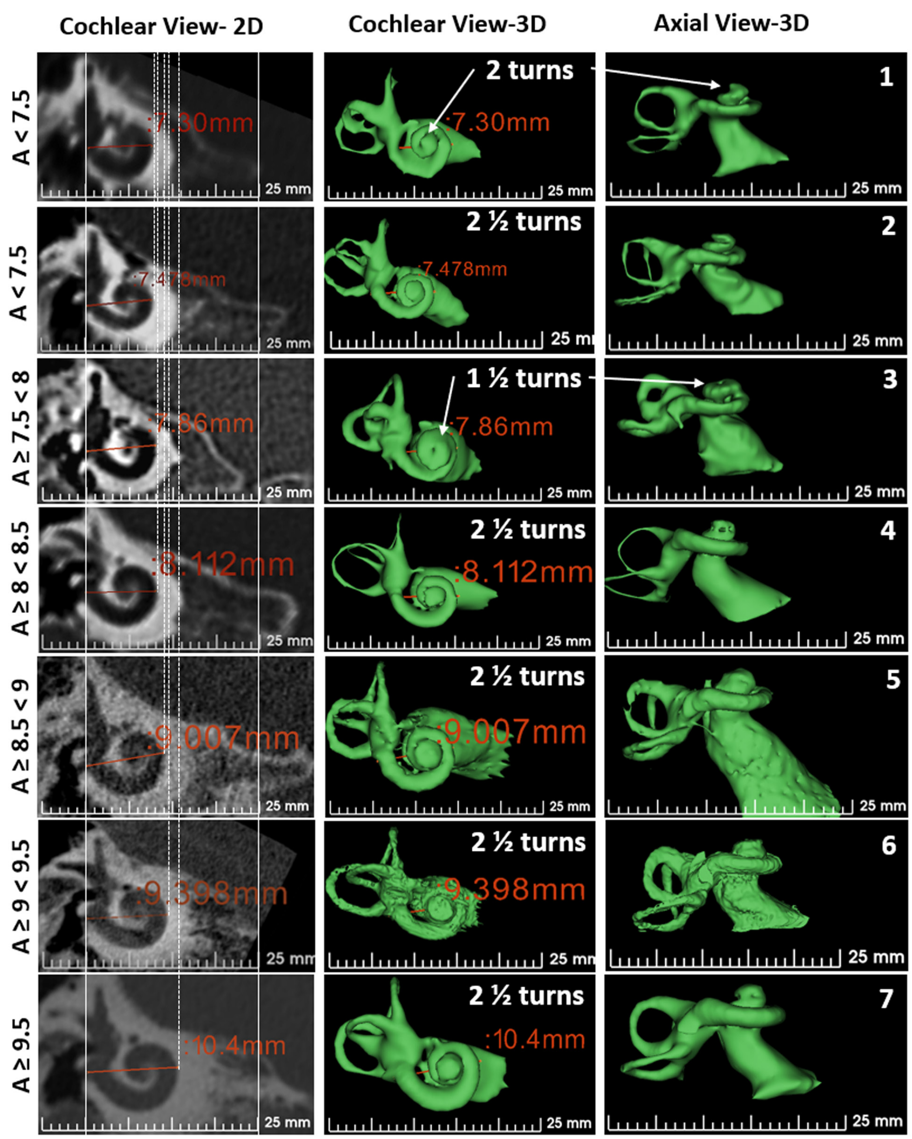

Figure 3. Oblique coronal view of cochlear basal turn as seen in CT scan (column A). Three-dimensional-segmented image of the inner ear in the oblique coronal view (column B) and axial view (column C). The white vertical lines serve as a reference to visualize the variations in cochlear size in the ascending order. CT: computed tomography.

cochleae may have some abnormalities, which need to be investigated in detail during preoperative image analyses. Therefore, the current study might be helpful for the preoperative planning process. This could be a good starting point for differentiating between normal and abnormal cochleae (in terms of the number of turns) by doing a simple measurement of the *A*-value. More proper planning could henceforth help surgeons in selecting the most suitable electrode array and deciding the proper surgical steps accordingly.

While the *A*-value has become a widely accepted cochlear parameter in assessing the cochlear size prior to CI surgery and choosing the electrode array length, the *A*-value alone cannot predict the number of cochlear turns. This raises awareness of the importance of 3D segmentation in addition to routinely measuring the cochlear size prior to CI surgery in order to select an electrode array with a proper length. According to this study, cochlear size measured by an *A*-value of ≤ 8.5 mm requires a thorough preoperative image analysis to find any abnormalities in the number of cochlear turns. The accuracy of the *A*-value measurement depends on how accurately the cochlear view is created. The advantage of OTOPLAN is that it automatically measures the *A*-value from the cochlear view, removing any human errors involved in getting the optimal cochlear view and in the *A*-value measurement. Literature has evidenced measuring the cochlear size in a suboptimal cochlear view, as shown in Figure 4, which could lead to wrongly measuring the cochlear size,[13,14] which further leads to choosing suboptimal electrode array lengths, creating wrong frequency maps, and ineffective fitting of the audio processors.

One of the limitations of this study is the small number of datasets (n = 104) capturing the cochlear size of our national population in comparison to earlier studies that have used more than 300 datasets to report the variations in *A*-value, with n = 670 in the Netherlands,[15] n = 314 in Singapore,[16] n = 310 in China,[17] n = 482 in Italy,[12] and n = 325 in Sweden.[18] Systematic preoperative cochlear size measurement has numerous advantages and clinical implications, including a better understanding of the inner ear anatomy, CI electrode array selection, and surgical planning in difficult or malformed inner ear anatomy.

The findings of this study and 3D illustrations confirmed that the size of the human cochlea varies between individuals. The cochlear diameters (*A*-values) ranged from 7.3 to 10.4 mm. Furthermore, even if the cochlea appears normal, smaller-sized cochleae with lower *A*-values (<8.5 mm) might have some degree of anatomical abnormality. As a result, 3D segmentation of the entire inner ear is beneficial and highly recommended in the preoperative evaluation of the inner ear prior to CI surgery. More research with a larger sample size is needed to determine the statistical relationship between *A*-values and the number of cochlear turns.

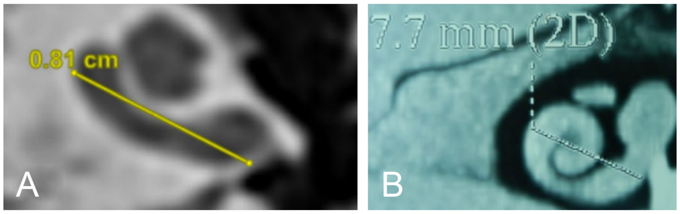

Figure 4. Suboptimal plane in which the *A*-value measurement was made. Axial view which is away from the mid-modiolar section in which the *A*-value is measured (A). Coronal view in which the *A*-value is measured away from the center of the round window entrance (B).

Ethics Committee Approval: This study was approved by Ethics Committee of King Saud Medical City (Approval No:HIRE-16-Nov 21-02), Date: November 21,2021).

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