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Original Article

Cochlear Implantation: Predicting Round Window Niche Visibility Using One Measurement in High-Resolution Temporal Bone Computed Tomography

Laila Telmesani[1,2], Mona Al-Ramah[1], Yassin Abdelsamad[3], Lena Telmesani[2,4]

[1]Cochlear Implant Unit, King Fahad University Hospital, Al-Khobar, Saudi Arabia
[2]Department of ENT, Imam Abdulrahman bin Faisal University, Dammam, Saudi Arabia
[3]Department of Research, MED-EL GmbH, Riyadh, Saudi Arabia
[4]Department of ENT, King Fahad University Hospital, Al-Khobar, Saudi Arabia

ORCID iDs of the authors: L.T. 0000-0001-7237-4923, M.Al-R. 0000-0002-4266-2526, Y.A. 0000-0001-8281-5825, L.T. 0000-0003-0519-0344.

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BACKGROUND: To evaluate the accuracy of a single measurement in temporal bone computed tomography in predicting the round window niche (RWN) visibility during cochlear implantation.

METHODS: A prospective study was conducted on 148 patients (165 ears) who had a cochlear implant (CI) from January 2010 to December 2018 at a tertiary CI center. The measurement was done for the angle of the basal turn of the cochlea (ABTC), which we defined as the angle formed by the cochlear basal turn and the cranium mid-sagittal plane, by 2 readers blindly from the axial images of computed tomography. The RWN visibility was classified according to the observation during surgery (through posterior tympanotomy) into full visibility, partial visibility, and invisibility. The measured angle was then correlated to the intra-operative visibility of the RWN.

RESULTS: The average ABTC was 57.48° ± 4.05° (range: 45.0-68.0), and the RWN was found to be fully visible in 85%, partially visible in 11%, and invisible in 4% of the studied ears. The receiver operating characteristic analysis revealed a significant discriminating ability in predicting RWN visibility ($P < .001$) at a threshold ABTC angle of 58.5°. The mean ABTC was 56.71° ± 3.74°, 61.00°, and 63.86° ± 2.67° for fully visible, partially visible, and invisible RWN, respectively. A statistical significant difference was found ($P = .0002$) when comparing the ABTC in patients with partially visible/invisible RWN (61.80° ± 2.87°) with the fully visible RWN (56.71° ± 3.74°).

CONCLUSION: Round window niche visibility could be predicted by measuring the ABTC in relation to the cranium's mid-sagittal plane in CT preoperatively. An ABTC bigger than 58.5° could be an indication of poorly visible RWN.

KEYWORDS: Cochlear implantation, round window niche, hearing loss, anatomy, computed tomography, inner ear malformation

INTRODUCTION

A cochlear implant (CI) is the primary modality for treating severely/profoundly sensorineural hearing-loss individuals. The standard approach is transmastoid-posterior tympanotomy (TM-PT), as described by the House. Electrode-array (EA) placement inside scala tympani could be achieved via the bony cochleostomy or round window membrane (RWM).

The membrane is concealed beneath the round window niche's (RWN) bony overhang. However, recent studies showed that RWM insertion ensures scala tympani insertion and is less traumatic to the intra-structure of the cochlea. Compared to cochleostomy, RWM insertion showed better outcomes in terms of language acquisition, speech outcomes, and speech production, and was superior in situations where hearing preservation seems to be a priority.[1-5]

Nevertheless, the proper insertion of the array through the RWM might pose several difficulties in some cases. Therefore, RWN is considered an important anatomical landmark in CI surgery. For CI surgery to be effective, it is essential to understand the variations in the shape and anatomical correlations of the RWN presurgery.[6] The RWN has anterior pillar (postis anterior), tegmen, and

Corresponding author: Laila Telmesani, e-mail: telmesanilaila@hotmail.com

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posterior pillar (postis posterior).[7] In 15%, 40%, and 45% of cases, the RWN was found to be oriented inferiorly, posterior inferiorly, and posteriorly.[6] High-resolution computed tomography provides sufficient anatomical details on the inner and middle ear. Furthermore, it improves dependent correlation and RWN studying.[8]

Numerous studies have attempted to estimate the RWN visibility using radiological data, that mostly depends on different anatomical landmarks. Kashio et al used the external ear canal.[9] While RWN together with facial nerve (FN) were used by Fouad et al[10] FN, external auditory canal, and RWM were used by many authors.[3,11] Others used the short process of incus, RWN, beside the oval window.[12] Some correlation was found between the measured angles or distances and the visibility of the RWN except for the external auditory canal.[9,10,12]

Researchers believed that throughout postnatal development, the cochlea's location and orientation could alter often.[13-16] Recently, other researchers[14-16] studied cochlear orientation in space by computing the angle between the cochlear basal turn long axis and sagittal plane and discovering a negative correlation with age. Therefore, this angle has been used as an indicator for changes in cochlear angulation in space.

We hypothesize that a bigger angle between the basal turn of the cochlea (BTC) and the mid-sagittal plane (we call it "the angle of the basal turn of the cochlea (ABTC)" can reflect a more posterior rotation of the cochlea in space. This rotation is between the long axis of the basal turn of the cochlea and the sagittal plane around a fixed point (the intersection between the 2 lines). The smaller ABTC reflects more anterior rotation. Therefore, this could be related to the position of the RWN and hence the visualization of the RWN through posterior tympanotomy.

To test our hypothesis, we measured the ABTC in high-resolution temporal bone CT (HRCT-TB) for cochlear implant recipients and then correlated it with RWN visualization through posterior tympanotomy, route of EA insertion, inner ear malformations (IEMs), and patient's age.

MATERIAL AND METHODS

This prospective observational research was carried out on CI patients operated on from January 2010 to October 2018 in our tertiary referral CI center. This work was approved by the institutional ethical committee at Imam Abdulrahman Bin Faisal University (Approval No: 2020-01-170) and the patients/guardians consented and signed before undergoing the CI surgery. The preoperative medical imaging and the surgery were done following the clinical routine of the hospital without any unordinary steps.

Participants

The inclusion criterion of the current study was all patients who underwent CI surgery by 1 otology consultant in King Fahad University Hospital. The exclusion criteria were patients with morphological alternation of RWN between slit-like niche and absent niche, narrow facial recess, an anteriorly or laterally displaced FN mastoid segment, cochlear ossification, or any bone diseases involving the temporal bone.

Imaging and Measurements

Preoperative HRCT-TB of 0.6 mm slice thickness was obtained by CT scanner SOMATOM Definition Flash 128 multislice and SOMATOM definition as 64 multislice machines (Siemens Healthineers, Erlangen, Germany). Two independent otologists followed the same steps to do all measurements blindly, and the reliability of both readings was verified. All measurements were also blinded to the intraoperative findings. In cases of big discrepancies (low agreement) between the 2 observers, the measuring method was examined, and the discrepancies were consulted with an experienced observer.

The ABTC was measured by drawing 2 lines in the axial slice, which represent the longest axis of the cochlear basal turn, as mentioned by Lloyd et al [11]. The first line is a mid-sagittal vertical line passing between the nasal septum and the face of the

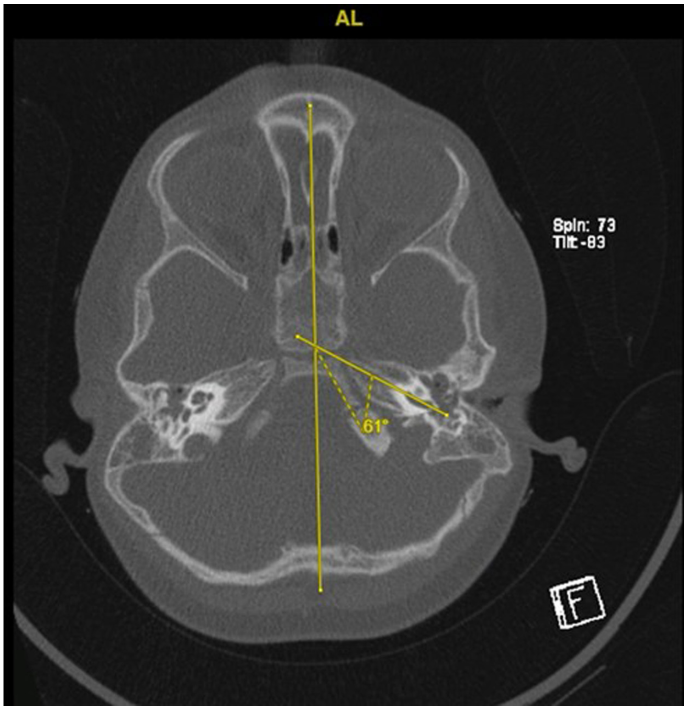

Figure 1. The angle between the long axis of the basal turn of the cochlea and the mid-sagittal plane of the cranium on the left side.

MAIN POINTS

- The angle between the basal turn of the cochlea and the mid-sagittal plane in the axial film (the cut that demonstrate the RWN & maximum length of the basal turn) of HRCT-TB, as described is easily measured by ear surgeons.
- The current study suggests that the value equal or greater than 58.5° of ABTC can be a predictor of difficulty of RWN visibility through posterior tympanotomy during CI surgery.
- Adding measuring the ABTC to the routine pre-operative assessment of cochlear implant patients will help in proper more smooth surgery and less stressful situations.
- Measuring the proposed angle pre-operatively could enable the surgeon to perform RWM insertion in almost all patient by using the simple modifications suggested in this research.

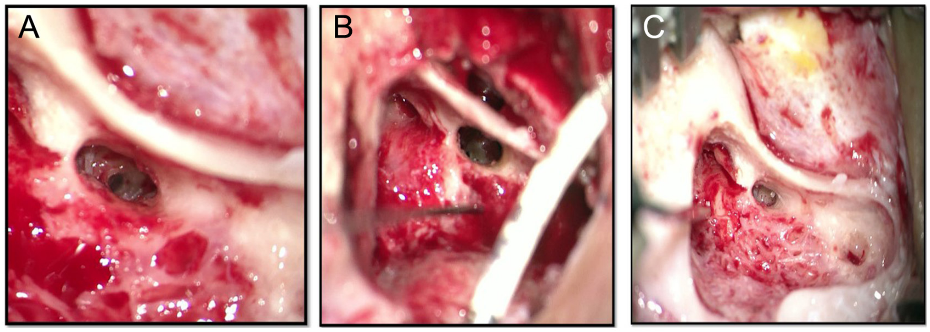

Figure 2. Fully visible round window niche (A), partially visible round window niche (B), and invisible round window niche (C).

sphenoid rostrum anteriorly and posteriorly positioned occipital protuberance.

The second line represents the longest axis of BTC drawn between the uppermost bony border of RWN posterolateral and the most prominent point of the medial bony wall of BTC anteromedially (Figure 1). The angle has been determined by using a built-in tool in the software utilized in our tertiary center (GE web version).

A single senior neurotologist surgeon performed the cochlear implantation for all patients included in this study. The surgery technique used was cortical mastoidectomy, an adequately wide PT that included thinning the bony posterior meatal wall, maximum drilling on the lateral and anterior bony walls of the facial nerve mastoid segment, and proper positioning of patient's head and microscope. All surgeries have been planned to be RWM insertions. Extended RWM (ERWM) or cochleostomy was used if needed in partially visible or invisible RWN.

Data Collection

Data collection was done for ABTC, patient's age, presence or absence of IEMs, intraoperative notes about RWN visibility through PT, and the surgical approach utilized for RWN accessibility, whether PT alone or combined with transcanal. Additionally, the route used for EA insertion is either through RWM, ERWM**,** or cochleostomy.

Round window niche visibility is determined by visualizing the anterior and posterior pillars through an adequate posterior tympanotomy. It was divided into fully visible when both posterior and anterior pillars can be seen completely, partially visible if the anterior pillar can only be seen, and invisible when the surgeon cannot see the anterior pillar through widely adequately performed posterior tympanotomy (Figure 2A, B, and C).

Statistical Analysis

Analyses were done by specialized software GraphPad Prism version 9.0 (GraphPad Prism TM, Boston, Massachusetts, USA). All categorical variables (i.e., gender, surgical approaches, radiological findings, mode of insertion, and type of RWN) were presented as frequencies and percentages, and the descriptive analysis was presented for the quantitative variables (i.e., age and angle of BTC). The ABTC readings from the 2 observers/readers were in numerical data form. So, Cronbach's alpha test was used to assess the degree of agreement (inter-rater reliability) between the 2 readings. Receiver operating characteristic (ROC) analysis was used to find the ABTC threshold, which predicts round window visibility or non-visibility. Furthermore, the mean ABTC values were compared between 2 groups of RWN visibility (fully visible versus partially visible & invisible). The steps of this comparison were done as follows: (i) the normality test was done on the data of the 2 groups; (ii) the results showed a normal distribution for both groups; (iii) the unpaired *t*-test was then performed to compare the means of both groups. To assess the strength and direction of the relationship between ABTC and the patient's age, Spearman's correlation coefficient has been chosen. This test was chosen because the normality test showed non-normal distribution for the patients' ages.

RESULTS

The medical records of 148 patients (165 ears), 155 pediatrics, and 10 adults who underwent cochlear implants met the inclusion criteria. Age at implantation ranged from 1 to 68 years, where 126 ears were below the age of 4 years, 29 ears between 4 and 18, and 10 ears above 18 years, with a mean age of 5.49 years ± 9.84. Among 165 cases, 92 (55.6%) were male and 73 (43.4%) were female.

There was very good inter-rater reliability (0.88) among the 2 readers who evaluated the computed tomography of the included patients.

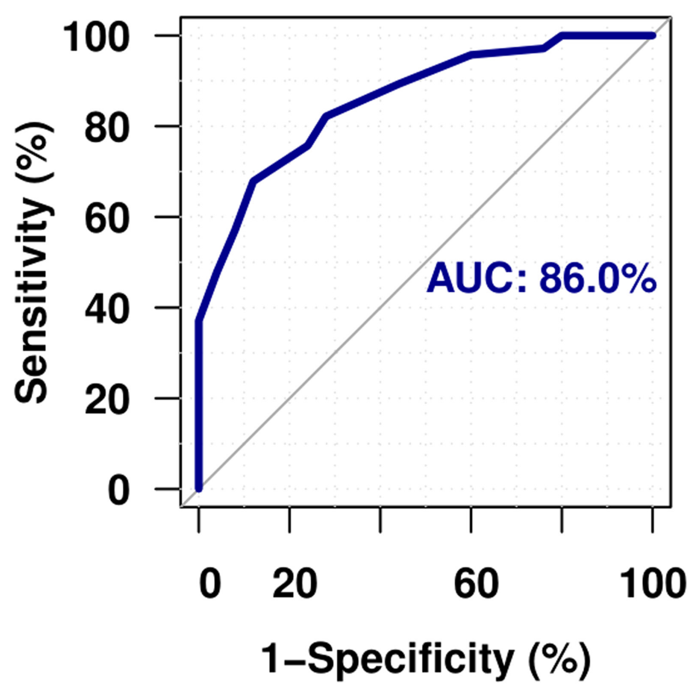

Figure 3. Receiver operating characteristic analysis of angle of the basal turn of the cochlea angles to predict the round window niche visibility.

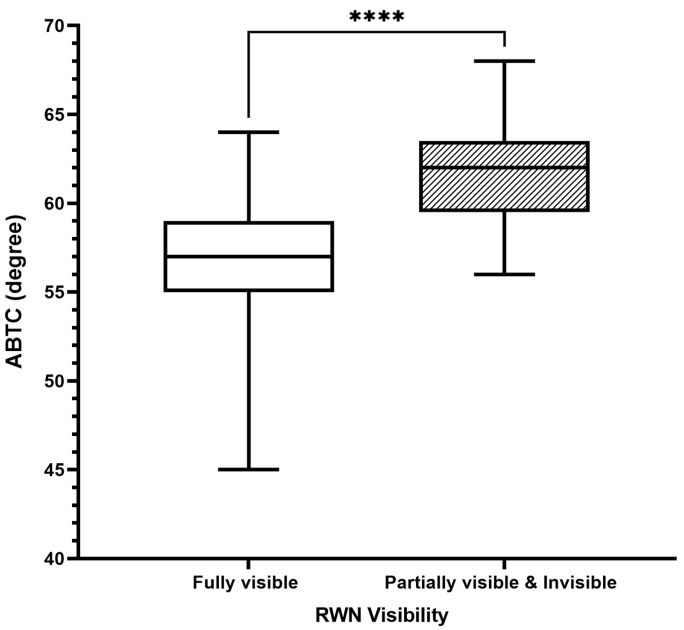

Figure 4. Statistical comparison between angle of the basal turn of the cochlea in ears with normally rotated (fully visible) RWN and posteriorly rotated (partially/invisible) RWN. RWN, round window niche.

The mean ABTC was found to be 57.48° ± 4.05 with a range between 45° and 68°. Among the included patients, the RWN was found to be fully visible in 85% (140/165), partially visible in 11% (18/165), and invisible in 4% (7/165). The computed mean value of the ABTC was 56.71° ± 3.74° in patients with fully visible RWN, 61.00° ± 2.59 in the partially visible RWN, and 63.86° ± 2.67° in the invisible RWN individuals.

As illustrated in Figure 3, the ABTC showed 86% area under the ROC curve, indicating its significant discriminating ability in predicting the round window visibility ($P < .001$) at a threshold ABTC angle of 58.5° with 70.9% accuracy, 67.9% sensitivity, 32.8% negative predictive value, 88% specificity, and 96.9% positive predictive value. Therefore, about 97% of patients having ABTC < 58.5 were confirmed to have fully visible RWN.

The analyses revealed a strong association between ABTC and RWN visibility ($r = 0.46$, $P < .0001$). Also, a substantial discrepancy ($P = .0002$) has been found among ABTC in patients who have partially visible/invisible RWN (61.80° ± 2.87°) compared to fully visible RWN (56.71° ± 3.74°) as demonstrated in Figure 4.

We found that patients with wider angles, specifically ≥58.5° (the threshold ABTC), are more likely to have poorer visibility of the RWN.

Table 1. Different Types of Round Window Niche Visibility and the Correspondence Cochlear Angles

Round Window Niche Visibility	Number of Ears	Cochlear Angle	
		<58.5°	≥58.5°
Fully visible	140	95 (67.9%)	45 (32.1%)
Partially visible	18	3 (16.6%)	15 (83.3%)
Invisible	7	0 (0%)	7(100%)

Only 45/140 (32.1%) of patients with fully visible RWN have an angle ≥58.5°, while 15/18 (83.3%) ears with partially visible RWN have an angle ≥58.5°, and in all 7 (100%) cases with invisible RWN, the ABTC was ≥58.5°, as illustrated in Table 1.

When we looked at the size of the ABTC in relation to the patient's age, we found a positive weak ($r = 0.25$) significant ($P = .001$) direct correlation where the mean angle was bigger in the older age groups.

Regarding the cases with IEMs, we had 39 ears with IEMs [15 IP II, 21 Mondini, and 3 IP I]. The average angle among these cases was 58.28° ± 3.48°, while it was 57.2° ± 4.21° in ears with normally developed inner ear. Regarding the visibility of the RWN, partially or invisible RWN was found in 5/39 (12.8%) ears with IEMs and 20/126 (15.9%) ears with normally developed inner ear. Therefore, no statistically significant association is found between IEMs and both the size of the ABTC and the visibility of the RWN.

In all cases with partially visible RWN (18 ears), electrode array insertion was done through RWM or ERWM after drilling the tegmen and anterior pillar through the ear canal, as in Figure 5A, B, and C. Cochleostomy was the route of insertion in only 4/7 of the cases with invisible RWN, while ERWM insertion was used in 2/7, and in the seventh case, the RWN could be visualized only by using a transcanal endoscope; therefore, RWM insertion was achieved endoscopically, as in Figure 6A, B, and C. It has been noted from the intraoperative videos that there were differences in the electrode trajectory between the RWN with full visualization and the partial visualization/invisible as in (Figure 5C).

DISCUSSION

Despite the anatomical differences in cochlear architecture/orienta tion, RWM electrode array insertion enables complete and precise placement into the scala tympani. Round window membrane implantation was therefore believed to enhance auditory results and lessen intracochlear damage.[1,17] On the other hand, some authors

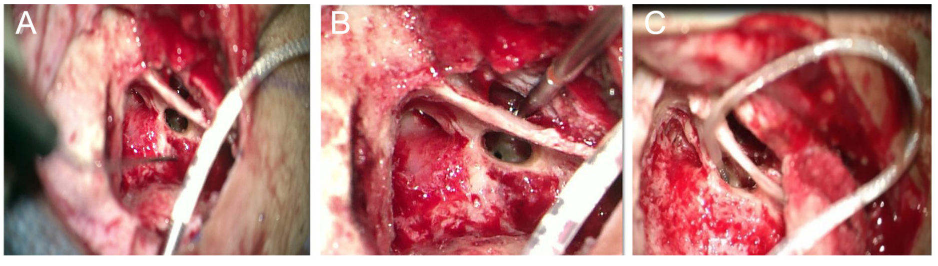

Figure 5. The surgical technique used in partially visible RWN. View through the posterior tympanotomy (A), transcanal approach to access RWN and drill the tegmen and the anterior pillar (B), and insertion of the electrode array through the PT (C).

assert that a crucial element in maintaining hearing is the implantation of the electrode under observation.[17,18]

Toward performing RWM insertion, the otologists need to have a direct vision and good access to the RWN through posterior tympanotomy. Many authors reported cases where, with the widest possible posterior tympanotomy and repositioning of patients' heads and the microscope, only part of the RWN could be seen or was even invisible. [10,16,19]

Most surgeons first believed that a bigger facial recess (FR) might improve RWN visibility. However, many authors[3,19] reported that intraoperative RWN visibility is not related to FR width and concluded that it is not a predictor of RWN exposure.

Recently, many studies have been published about different CT-based measurements for anticipating RWN visibility via the PT. Lloyd et al[16] published that ABTC decreases with age and RWN visualization becomes better in older individuals. Yasser A et al[10] reported CT measures according to RWM, facial nerve (FN), and coronal plane.

The angle formed by RWM, FN, and coronal axis from the first measurement demonstrated a strong connection to RWM visualization. In the other measure, the vertical distance from RWM and FN has been shown to be substantially connected with the RWM visualization. But its drawback was the difficulty in accurately measuring this distance due to its typical narrowness. Kashio et al[19] measured the angulation from the cochlear axis to the EAC to predict the RWN visualization through PT and reported a significant correlation. As opposed to Yasser et al[10] who revealed no correlation between the same angle and the visibility of the RWN. Jianqing Chen et al[3] draw 3 lines using the following landmarks: (i) EAC posterior wall, RWM posterior margin, and FN; (ii) intersection of EAC posterior wall; and (iii) mastoid cortex. Then, they measured the 2 angles between the 3 lines, and they reported a significant correlation between the measured 2 angles and the visibility of the RWM.

The distances between RWN, the short process of incus, and the oval window in the axial HRCT-TB were used by other researchers and found to have a good correlation with the RWN visibility via PT.[20]

In the current study, the RWN visualization was correlated to the ABTC in HRCT-TB, and a significant association was found. We noted that an ABTC of 58.5° had a significant predictive value. Since the angle was found to be ≥58.5° in 83.3% of cases with partial visibility and in all the cases with invisible RWN (Figure 6). On the other hand, about 97% of patients with ABTC less than 58.5° showed fully visible round windows. Our findings agree with Li-Hong et al[21] as they reported poorer visibility when the value of the angle is bigger, but they did not define a predictor value of the ABTC, which we found to be 58.5°.

The cochlea's spatial orientation in relation to the cranial base is only briefly discussed in a few articles. Jeffery and Spoor[22] discovered no substantial postnatal alterations; however, there was a considerable age decline in ABTC throughout the gestation period. Recently, some researchers have reported a significant postnatal change in the spatial cochlear orientation as well as a substantial decrease in the angle formed by BTC and sagittal plane with age.[13,14,16,23] However, Hui-Ying Lyu et al[13] used a conventional three-dimensional coordinate system to compute the cochlea's spatial position and angulation inside the cranial base and then examined its interactions with surrounding structures in different age groups (1-6/7-18/above 18 years) and discovered a minor age-related propensity of the angle formed by cochlea's central axis and sagittal plane.

Moreover, the cochlear orientation during postnatal development did not vary significantly. In our study, analyzing the value of the ABTC in relation to the patient's age, we found a positive weak significant direct correlation ($P = .001$), where the mean angle was bigger in the older age group. We can't conclude in this respect since the number of adult cases is very limited (10 out of 165).

In our study, a significant association between ABTC and RWN visibility was found. As the angle increases, more difficulty will be encountered to visualize the RWN through PT. This can be explained by the rotation of the long axis of the basal turn of the cochlea around the intersection point with the mid-sagittal plane. As the RWN is part of the BTC. So, the variation in its position and visibility could be dependent on the rotation of the cochlea in space, where a bigger ABTC represents a more posteriorly rotated cochlea and therefore a poorly visible or invisible RWN through the facial recess, and a smaller angle reflects a more anteriorly rotated cochlea and easily visible RWN.

Looking at the cases with IEMs, in 39 ears with IEMs, we found that it does not affect both the size of the ABTC and the visibility of the RWN, where the mean size of ABTC was 57.2° ± 4.21° in ears with IEMs and 58.28° ± 3.48° in patients with the normally developed inner ear. There were 5 (12.8%) cases with poor to invisible RWN out of 39 and 20 (15.9%) out of 126 in ears with IEMs and normally developed inner ears, respectively. To our knowledge, other similar research did not include cases with IEMS.

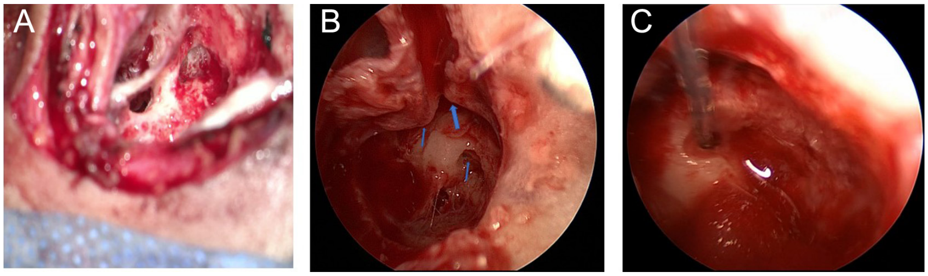

Figure 6. The surgical technique used for endoscopic RWM insertion in the seventh case with invisible RWN. The RWN could not be seen through PT or microscopic transcanal (A). The RWN was seen only by a transcanal endoscope [handle of the malleus, stapes, and RWN] (B), and Endoscopic RWM insertion of the electrode array (C). RWN: round window niche, RWM: round window membrane.

As a result of our hypothesis, the findings of this work revealed that the surgeon succeeded to do RWM and ERWM insertion in all 18 cases with partial RWN visibility, 3 ears with invisible RWN, 1 endoscopic RWM insertion, 2 ERWM, and only 4 cases through cochleostomy, with no complications in all cases. The surgeon modified the surgical technique to combine trans-canal/posterior tympanotomies to get access to the RWN whenever it was needed.

To our knowledge, this study has the largest number of cases among other reported similar studies; it includes all age group**s** and ears with IEMs and uses only 1 measurement that can be easily used by surgeons.

This 1 angle measured in the preoperative HRCT-TB was found to be applicable, measurable for all age groups, reliable, and significantly correlated with RWN visibility through PT during CI surgery. The Value of ABTC of 58.5° can be used as a good predictor value of the difficulty to visualize RWN. In the event that the RWN's visibility is expected to be challenging, a more experienced surgeon can be consulted, and planned modifications of the surgical technique can be used which will reduce surgery time, decrease complications, and increase the chances of RWM or ERWM insertion.

The ABTC could be of great benefit in predicting RWN visibility. Preoperative measurement of the angle between the BTC and midsagittal plane in HRCT-TB is a valuable tool to assess the possible difficulty of RWN visualization during CI. The current study proposed a threshold ABTC angle of 58.5° to predict round window visibility or non-visibility. Patients with ABTC bigger than 58.5° could have poorer visibility of the RWN during the CI surgery. We suggest adding this angle as an additional parameter for a proper preoperative planning of cochlear implantation.

Data Availability: The datasets used and analyzed in the current study are available from the corresponding author upon request.

Ethics Committee Approval: This study was approved by Ethics Committee of Imam Abdulrahman Bin Faisal University University (Approval No: IRB. 2020-01-170).

Informed Consent: Informed consent was obtained from the patients and guardians who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – L.T.; Design – L.T., M.A., Y.A.; Supervision – L.T.; Resources – M.A., Le.T.; Materials – L.T., M.A.; Data Collection and/or Processing – L.T., M.A.; Analysis and/or Interpretation – Y.A., Le.T.; Literature Search – L.T., Le.T.; Writing – L.T., M.A., Y.A., Le.T.; Critical Review – L.T., Y.A.

Declaration of Interests: The authors have no conflict of interest to declare.

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