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Authors: Katarzyna Amernik, Michał Mielnik, Aleksandra Gawlikowska-Sroka, Edyta A. Dzięciołowska-Baran

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Selected structures of middle ear relevant to cochlear implantation on the basis of computer tomography

Katarzyna Amernik et al., Selected structures of middle ear relevant to cochlear implantation on the basis of CT

Katarzyna Amernik[1], Michał Mielnik[1], Aleksandra Gawlikowska-Sroka[2], Edyta A. Dzięciołowska-Baran[2]

[1]Department of Otolaryngology for Adults and Children and Otolaryngological Oncology, Pomeranian Medical University, Szczecin, Poland

[2]Department of Normal Anatomy, Pomeranian Medical University, Szczecin, Poland

Address for correspondence: Edyta A. Dzięciołowska-Baran, PhD, Department of Normal Anatomy, Pomeranian Medical University, al. Powstańców Wielkopolskich 72, 70-111 Szczecin, Poland, tel: 914661543, e-mail: edyta.dzieciolowska.baran@pum.edu.pl

Abstract

Background: The primary objective of this study was to analyze middle ear structures critical for cochlear implantation using computed tomography.

Materials and methods: Patients who underwent cochlear implantation at the Department of Otolaryngology in Szczecin between 2015 and 2022 were eligible for the study. We analyzed computed tomography images of 57 ears in 52 patients. The following parameters were assessed: mastoid aeration, tegmen tympani height, sigmoid sinus position, posterior tympanotomy width, the distance between the facial nerve and chorda tympani, modified facial recess distance, and the prediction line described by other authors.

Results: In 69% of patients, after the removal of the round window bony overhang, the round window membrane became fully visible. There were no statistically significant correlations found for parameters describing mastoid process anatomy or those rating the width of the posterior tympanotomy concerning round window access. The prediction lines, according to Kashio and Jwair, were found to be relevant. In cases where patients' access to the niche and membrane of the window was rated as good or very good during clinical evaluation, they were more likely to describe the window as being located posteriorly or medially in the radiological evaluation. Using a binary Jwair scale provided a better correlation with the clinical assessment. In cases where the windows were graded as posterior, the clinical assessment indicated better surgical access, especially to the RWM (Round Window Membrane).

Conclusions: Evaluating middle ear anatomy on a computed tomography scan is useful for preparing for middle ear surgery but does not significantly affect the ability to access the round window. For such access, the position of the window in relation to the facial nerve is the most relevant factor, and measurements based on this relationship hold the highest clinical value.

Keywords: cochlear implant, posterior tympanotomy, round window, facial nerve, mastoid process

INTRODUCTION

The treatment of profound hearing loss with cochlear implants has become an established clinical practice, offering an effective solution for both children and adults [3, 21]. As part of the qualification process for cochlear implants, a CT scan is conducted to assess the bone structures of the middle and inner ear and to plan the surgical procedure accordingly [8, 22]. The surgical procedure involves gaining access to the inner ear, necessitating a mastoidectomy, posterior tympanotomy (PT), and the insertion of the implant electrode into the inner ear through either the round window, otherwise called window of Scarpa [1] or cochleostomy [2, 4, 21]. Posterior tympanotomy involves accessing the middle ear cavity located posteriorly from the external auditory canal (EAC) [3, 4, 8]. A crucial requirement for the successful completion of this stage of the procedure is the precise identification of the facial nerve canal in the mastoid area and the chorda tympani nerve (CTN) [12]. The removal of bone within the triangle formed by these structures grants access to the facial nerve recess and the round window, all while safeguarding the posterior wall of the ear canal. This preservation is particularly significant in cochlear implantation, as it enables the placement of a device and electrode—a foreign body within the inner ear structures. The inner part of the implant is positioned beneath the periosteum of the temporalis muscle, with the electrode passing through the mastoid process and posterior tympanotomy to reach the cochlea via the round window. This approach maintains the integrity of the external ear canal and eardrum, positioning the implant within the sterile confines of the middle ear. This serves as protection against potential infections from the external ear and the transmission of infections from the inner ear to the meninges. The diverse anatomy of the middle ear poses a significant surgical challenge [12, 21]. Utilizing a CT scan focused on the temporal bones proves to be an appropriate tool for assessing their anatomical structure. This enables optimal surgical planning and minimizes the risk of complications [6, 8, 15, 17]. It is essential to note that sensorineural hearing loss, the primary indication for cochlear implantation, is typically attributed to damage to the function of the inner ear's hair cells and is not commonly linked to pathological changes in the bone structures' anatomy [7, 11]. This is not applicable to the small subset of patients with inner ear anatomical anomalies or those who have undergone middle ear surgery. The aim of this study was to evaluate the mastoid process's anatomy and critical structures during posterior tympanotomy for implantable otosurgery, underscoring the indispensable role of CT scanning in accurately delineating the bony elements of the middle and inner ear and identifying their anatomical variations with precision [6, 16].

MATERIALS AND METHODS

The study received approval from the Bioethics Committee of Pomeranian Medical University, with approval number KB.006.56.2023.

Patients who underwent cochlear implantation at the Department of Otolaryngology in Szczecin between 2015 and 2022 were considered eligible for inclusion in this study. Patients with obliteration of the round window, inner ear defects, those who had undergone reimplantation, individuals with a history of mastoid process drilling on the implanted side, and those displaying signs of otitis media were excluded from the study.

In high-resolution computed tomography (HRCT), triplanar reconstructions were initially performed. CT images were standardized to eliminate variations arising from differences in the patient's head positioning during the examination. The axial plane was acquired along the orbito-meatal baseline. The oblique sagittal reconstruction was achieved by identifying the sagittal plane until the lateral semicircular canal's view was obtained, marked by two dots representing its anterior and posterior limbs. The axial plane was established by connecting these dots. The axial data were scrolled through until the summit of the superior semicircular canal was visualized [5, 14].

All patients underwent CT scans with 0.6mm increments during the qualification process for cochlear implantation. During the cochlear implant surgery, a clinical assessment was conducted, which involved evaluating the visibility of the round window niche (RWN) in the initial stage and the visibility of the round window membrane (RWM) after removing the bony overhang. Clinical assessment was graded on a five-point scale: a score of 5 indicated full visibility of the entire area under assessment (RWN and RWM), a score of 4 represented visibility of more than 50%, a score of 3 indicated visibility of less than 50%, a score of 2 meant visibility of the upper portion of the window, and a score of 1 indicated that the window was not visible through posterior tympanotomy. The difference between the assessments of accessibility to the round window niche and the round window membrane (RWN - RWM) represented the clinical assessment of the size of the overhang covering the round window.

Computed tomography images from a total of 57 ears in 52 patients were analyzed in a retrospective evaluation. To assess the anatomy of the mastoid, posterior tympanotomy, and predict access to the round window, the following measurements were taken:

Types of Evaluated Parameters:

1. Mastoid Aeration (Proposed by Sarafraz): Classified into three categories - well aerated, moderately aerated, and poorly aerated [19].
2. Tegmen Tympani Height (TTH) (Proposed by Sarafraz [19]): Evaluated by drawing a straight line passing through the axis of the lateral semicircular canal in a subsequently drawn coronal image, followed by drawing a perpendicular line from this axis to determine the height.

3. Sigmoid Sinus Position (SSP): Assessed in axial view. A straight line is drawn from the middle of the round window (RW) and facial nerve (FN), and then another line is drawn perpendicularly from the axis to the front of the sigmoid sinus. The measurement is reported in millimeters.
4. Posterior Tympanotomy Width (According to Kashio): The width of the facial recess is measured perpendicularly from the external auditory canal (EAC) line to the anterolateral part of the FN. The location of the FN is measured perpendicularly from the basal turn line to the anterolateral part of the FN [10].
5. Distance Between FN and CTN (According to Protocol Described by Jwair) [9].
6. Modified Facial Recess Distance (MFRD) (According to Rajati): This parameter is the vertical distance between the line parallel to the coronal axis passing through the middle of the round window niche (RWN) and the anterior portion of the FN [18].
7. Prediction of RW Visibility by Kashio: A prediction line is drawn parallel to the EAC line along the anterolateral part of the FN. The round window membrane (RWM) is traced in the anteroposterior direction and divided into anterior (20% of the RWM), middle (60% of the RWM), and posterior (20% of the RWM) sections [10].
8. Prediction Line by Jwair: A prediction line is drawn from the anterior part of the mastoid course of the FN on the axial planes, towards the lower side of the basal turn of the cochlea, dividing access to the cochlea into anterolateral or posteromedial regions [9].

Figure 1

In the statistical analysis, the main significance level was set at p = 0.05. The p-values were adjusted following Benjamini–Yekutieli corrections, specifically False Discovery Rate (FDR) corrections. These corrections are designed to account for arbitrary independence or autocorrelation between tests. Correlations were assessed using Pearson's and Kendall tests. The assumptions for Pearson's test included: (1) the absence of outliers (tested using the Grubbs test), (2) bivariate homoscedasticity (evaluated with the Breusch-Pagan test), and (3) bivariate normality (checked with the Shapiro-Francia test). The code models used were the Breusch-Pagan test, Shapiro-Francia test, Pearson's correlation test, Kendall test, and Ordinal logistic.

RESULTS

Table 1 presents the results based on the visibility of the round window during surgery. In 69% of patients, following the removal of the bony overhang covering the round window, the round window membrane was fully visible. Whenever the round window was present, access to the round window membrane was consistently achievable (Table 1, Table 2).

There were no statistically significant correlations observed for parameters describing mastoid process anatomy or for those assessing the width of posterior tympanotomy concerning round window access. For the measurements that utilized ranks (such as the prediction line by Kasio and Jwair), the results are presented in Table 3 (Table 3, Figure 2, Figure 3, Figure 4, Figure 5)

For patients whose access to the niche and membrane of the round window was rated as good or very good in the clinical evaluation, they were more likely to describe the window as being located posteriorly or medially in the radiological evaluation. Conversely, when the Kashio radiological evaluation described the niche or membrane of the round window as anterior or medial, it translated into worse access to this anatomical region. Using a binary Jwair scale, rather than the 3-degree scale used in Kashio, resulted in a stronger correlation with the clinical assessment. Specifically, in cases where the round window was graded as posterior on the Jwair scale, the clinical assessment indicated better surgical access, especially to the round window membrane (RWM).

Table 4 presents the results related to the assessment of mastoid process aeration according to the Sarafraz score (Table 4).

Figure 6 shows the correlation between the clinical assessment of RW access and Sarafraz's proposed radiographic assessment of mastoid aeration (Figure 6).

DISCUSSION

The measurements pertaining to posterior tympanotomy width, including those proposed by Kashio [10], Jwair [9], and Rajati [18], did not reveal any significant correlations with the clinical evaluation of round window (RW) access. Notably, in the vast majority of patients, it was necessary to remove the bony overhang located medial to the facial nerve during the procedure. On average, the width of the posterior tympanotomy was 2.9 mm, with the narrowest posterior tympanotomy measuring 1.9 mm. In contrast, the diameter of the round window, as reported in the literature, typically ranges from 1.53 to 1.18 mm [13, 14]. Given this substantial difference, it can be inferred that in patients with a narrow posterior tympanotomy, the procedure may be technically more challenging. However, it is important to note that the width of the posterior tympanotomy itself does not dictate the type of access for electrode placement, as confirmed by the findings of this study.

Contrary to some previous authors, such as Chen and Sarafraz, who did not establish a relationship between window access and posterior tympanotomy width [3, 19], our results align with studies conducted by Kashio, Jwair, and Rajati, which did indicate such a relationship [9, 10, 18]. In terms of measuring posterior tympanotomy width, precise alignment of CT images and accurate intraoperative identification of the facial nerve within the mastoid area emerge as critical factors. These differences in findings among various authors may be attributed to variations in the methodology and techniques employed.

Parameters related to the structure of mastoid anatomy, including mastoid aeration, tegmen tympani height, and sigmoid sinus position [19], were examined in relation to their impact on the clinical assessment of window access. However, no significant correlations were identified between these anatomical parameters and the clinical evaluation of round window (RW) access. Specifically, the position of the sigmoid sinus, the height of the tegmen tympani, and the aeration status of the mastoid cavity did not exert any noticeable influence on the visibility of the round window. Consequently, it can be concluded that these parameters do not need to be taken into account when planning cochlear implantation, either in the selection of access approaches or in determining electrode placement.

It is worth noting that Sarafraz, in relation to mastoid process aeration, primarily demonstrated its relevance to the complexity of performing a mastoidectomy but did not specifically evaluate its impact on the visibility of the round window itself [19]. Hence, based on the available evidence, these structural parameters can be regarded as less influential in the planning and execution of cochlear implantation procedures.

Measurements describing the position of the window - Kashio [10], Jwair prediction line 8 categories. This study evaluated the prediction lines proposed by Kashio and Jwair, which involve radiological assessments of the round window's position relative to specific reference lines. In Kashio's research, 45 ears were radiologically evaluated [10], and the intraoperative assessment was categorized into three grades: fully visible, partially visible, and invisible/nearly invisible. Jwair's study analyzed 153 radiological images [9], and the evaluation of access to the round window membrane (RWM) was binary, classified as either easy access or difficult access.

Both of these studies demonstrated that radiographic assessments indicating the round window as posterior resulted in good visibility of the RWM. Our study's findings are consistent with the results of both Kashio and Jwair, where the best visibility of the round window during the intraoperative assessment was achieved for windows described as posterior in the radiological evaluation. Our measurements yielded similar results, validating the effectiveness of these proposed parameters. The most effective prediction line was Jwair's measurement for assessing access to the RWM. In this assessment, all windows classified radiologically as posterior became fully visible once the bony overhang of the promontory was removed. It seems to be relevant to access separately, to RWN and RWM, due to the bony overhang presence and size, as it be important not only in the classical but also in the endoscopic cochlear implantation [20].

These findings underscore the good predictive value associated with assessing the round window's position based on a reference line describing its relationship with the facial nerve. This information is valuable for planning cochlear implantation procedures, ensuring optimal visibility and access to the round window during surgery.

CONCLUSIONS

Assessing middle ear anatomy via CT scans proves valuable in preoperative planning for middle ear surgery. However, it does not significantly impact the ability to access the round window. In this regard, the positioning of the round window relative to the facial nerve emerges as the most relevant factor. Measurements based on this specific relationship hold the highest clinical value when preparing for cochlear implantation procedures. These findings emphasize the importance of considering the round window's position concerning the facial nerve when planning and executing such surgeries, ensuring optimal outcomes for patients.

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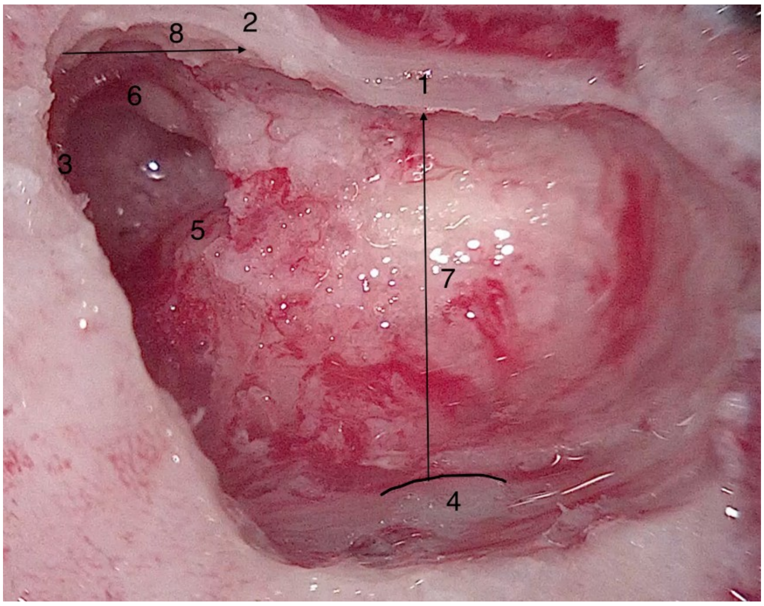

Figure 1. Anatomy of the Mastoid, A. Intraoperative View, B. CT Image, Sagittal View 1 — posterior wall of the external auditory canal, 2 — superior wall of the external auditory canal; 3 — tegmen tympani; 4 — sigmoid sinus; 5 — lateral semicircular canal; 6 — incus; 7 — distance between the sigmoid sinus and the posterior wall of the external auditory canal; 8 — distance between the tegmen tympani and the superior wall of the external auditory canal.

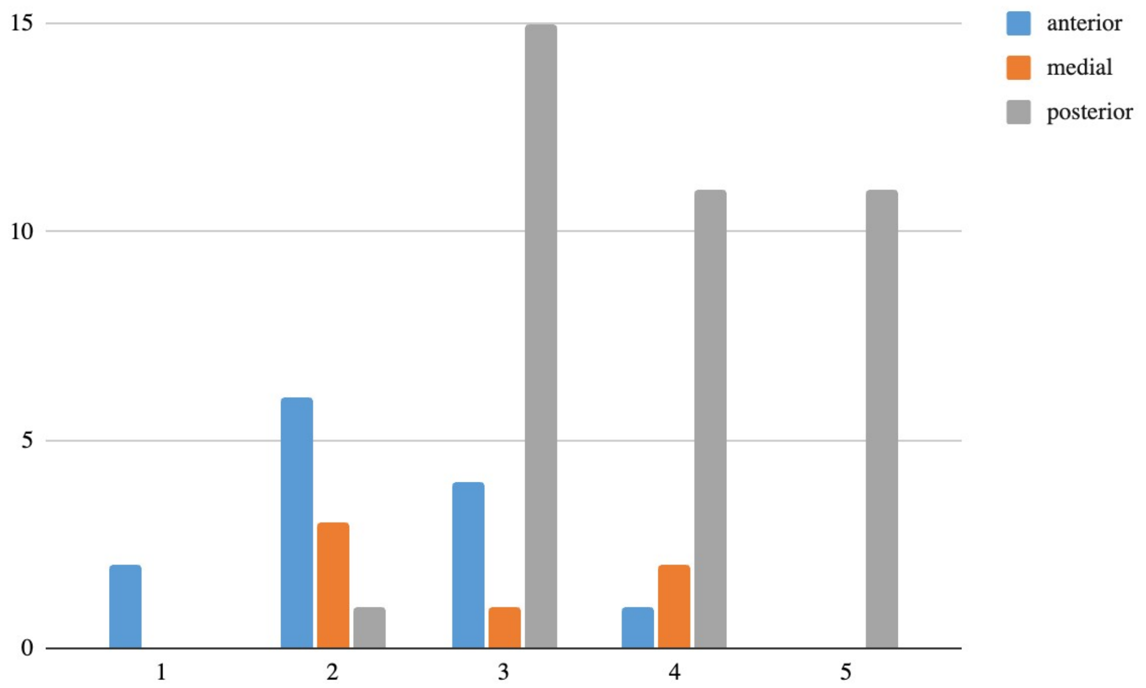

Figure 2. Results for prediction line by Kashio and clinical assessment of the RWM.

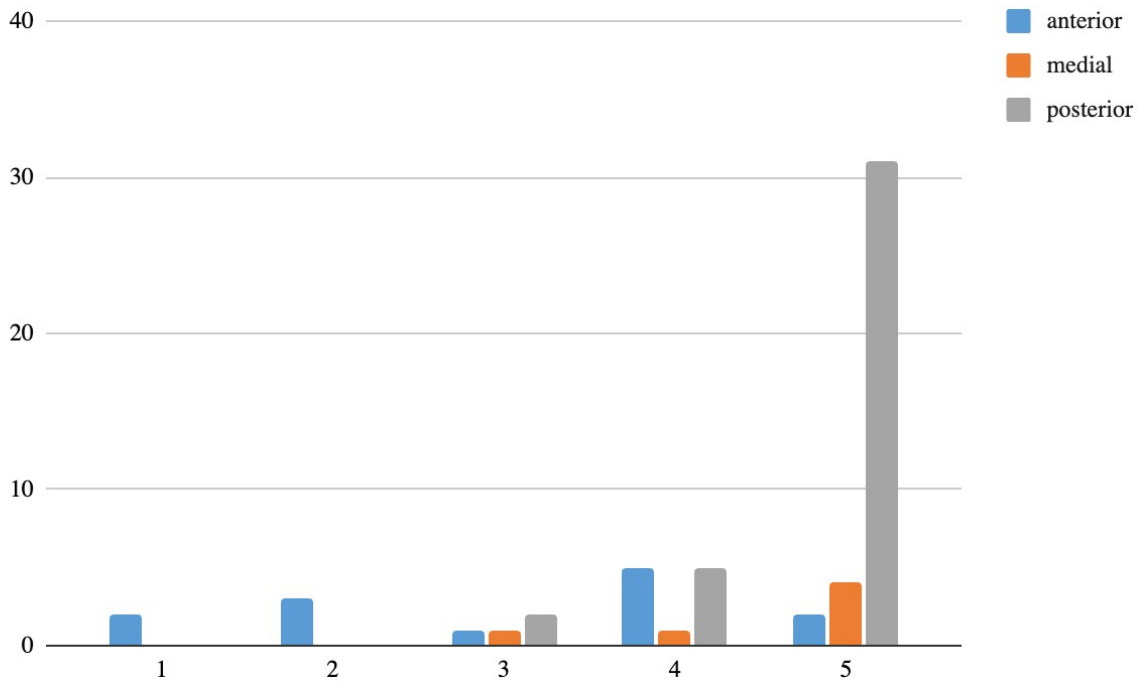

Figure 3. Results for prediction line by Jwair and clinical assessment of the RWN.

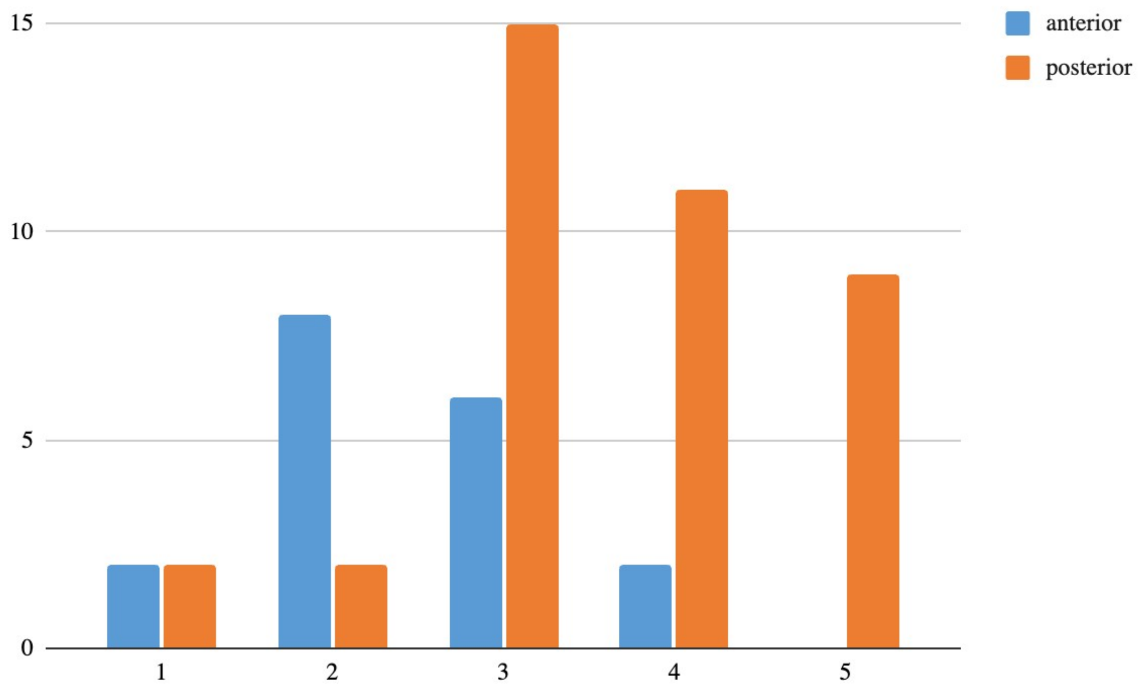

Figure 4 Results for prediction line by Jwair and clinical assessment of the RWM.

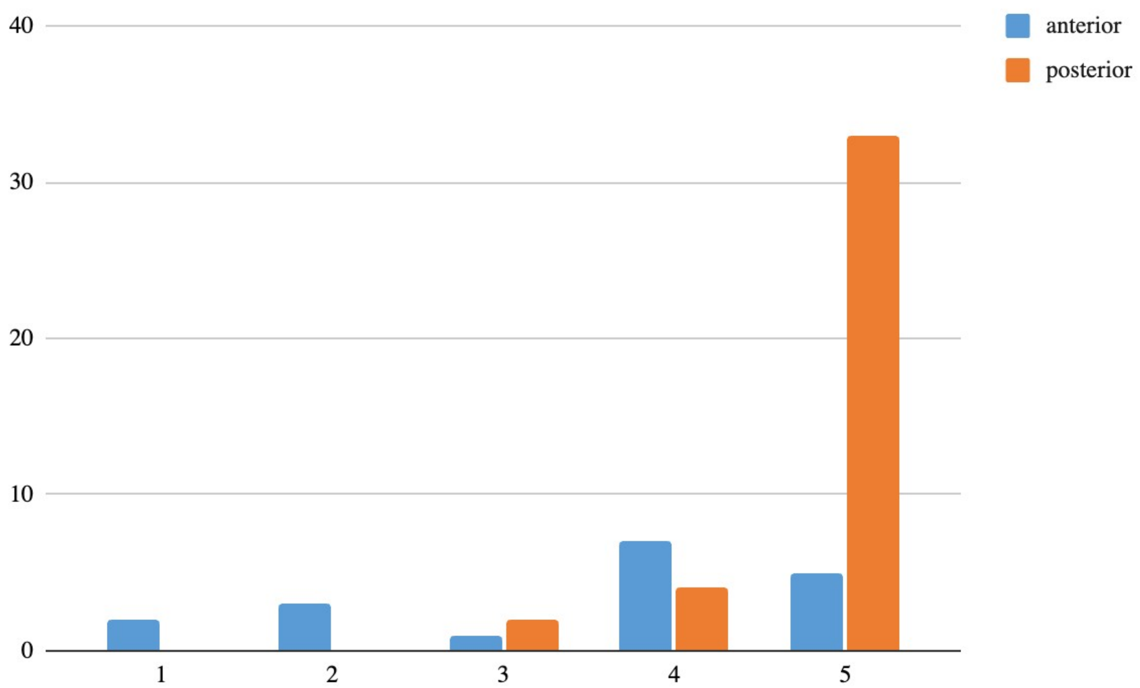

Figure 5. Results for prediction line by Jwair and clinical assessment of the RWM.

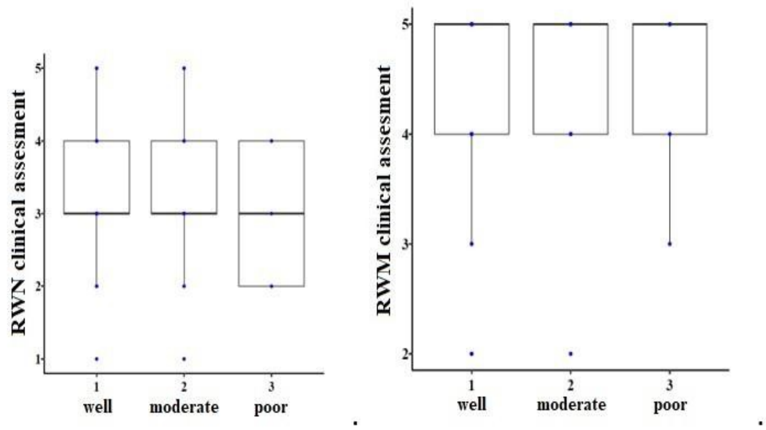

Figure 6. Mastoid aeration by Sarafraz vs RW clinical assessment.

Table 1. Visibility of the round window niche and round window membrane.

Clinical assessment of the visibility	RWN (n = 57)		RWM (n = 57)	
	Number of ears	**[%]**	**Number of ears**	**[%]**
1	2	3%	0	0%
2	11	19%	3	5%
3	21	37%	3	5%
4	13	23%	12	21%
5	10	18%	39	69%

Table 2. Numeric parameters values.

Evaluated parameter	Minimum	Maximum	Mean	Standard deviation	Median		RWN	RWM
PT Kashio [mm]	2,56	7,5	4,6	1,5	4,96	tau	-0.0368	-0.0349
						p	0.933	0.913
FN CT Jwair [mm]	1,71	7,86	2,9	0,93	2,8	tau	0.222	0.142
						p	0.087	0.311
MFRD Rajati [mm]	0,47	5,07	3,01	1,1	2,84	tau	0.19	0.223
						p	0.124	0.0992

TT height Sarafraz [mm]	0,2	8,22	4,,47	1,81	4,68	tau	0.115	-0.0134
						p	0.412	0.928
Sigmoid Sinus position [mm]	2	14	6,31	2,46	5,15	tau	0.0238	0.00447
						p	0.913	0.982

Table 3. Results for prediction lines and clinical access to RWN and RWM.

	Clinical assessment	**1**	**2**	**3**	**4**	**5**
Prediction line Kashio anterior	RWN	2	6	4	1	0
	RWM	2	3	1	5	2
Prediction line Kashio medial	RWN	0	3	1	2	0
	RWM	0	0	1	1	4
Prediction line Kashio posterior	RWN	0	1	15	11	11
	RWM	0	0	2	5	31
Prediction line Jwair anterior	RWN	2	8	6	2	0
	RWM	2	3	1	7	5
Prediction line Jwair posterior	RWN	2	2	15	11	9
	RWM	0	0	2	4	33

Table 4. Mastoid aeration by Sarafraz.

Aeration of the mastoid according to Sarafraz	**Well**	**Moderate**	**Poor**
Number	34	18	5
Percentage	59.65%	31.58%	8.77%

Abbreviations:

FN - facial nerve

FNC - facial nerve canal

CTN - chorda tympani nerve

EAC - external auditory canal

RW - round window

RWN - round window niche

RWM - round window membrane

TTH - tegmen tympani height

SSP - sigmoid sinus position

MFRD - modified facial recess distance

PT - posterior tympanotomy