Assessment of the preoperative computed tomographic predictability for round window membrane visibility and accessibility during cochlear implant surgery

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Objectives
The aim of the present study was to assess the preoperative predictability of multi-slice computed tomography for round window membrane (RWM) visibility and accessibility through round window niche (RWN) intraoperatively.
Patients and methods
Computed tomographic scans of 61 adult cochlear implant patients with otherwise normal temporal bone anatomy were studied for RWN extent using two methods. The first was a modification of a method by Park and colleagues and another simple method proposed by our group. The visibility of the RWN through RWN was assessed intraoperatively after performing the posterior tympanotomy and good exposure of the RWN. Statistical analysis was then performed.
Results
Modified Park and colleagues method was statistically significant in predicting RWM visibility (P=0.018) and a cutoff point was detected at more than or equal to 0.7 with a specificity of 69.23% for low or no visibility of RWM. Our proposed method was also statistically significant (P=0.001) with a cutoff point of more than or equal to 1.43 mm with a specificity of 96.15%.
Discussion
RWN depth has been studied repeatedly in the literature with only rarely correlation to intraoperative findings. These methods were also frequently either cadaveric or radiological with complex reconstruction, thus were with doubtful clinical value. In the present study, two methods were used and were found to be significant to predict the degree of visibility of RWN visibility through RWM.
Conclusion
The modified Park's and our proposed methods can statistically significantly predict RWM visibility through RWN. However, our proposed method had higher specificity and smaller P value.

Keywords:
cochlear implant, computed tomography, round window niche

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Introduction

Cochlear implantation (CI) is the established treatment for patients with bilateral and sometimes unilateral severe to profound hearing loss [1,2]. The classical transmastoid facial recess approach stood the test of time for the most commonly performed approach for CI till the present day [3,4]. Regardless of the approach, the purpose of CI is inserting the electrode array into the scala tympani.

The round window (RW) is the gate connecting the middle and the inner ear [5]. It originates from the otic capsule [6]. The development of the bony round window niche (RWN) begins in the 16th fetal week. Anterior, superior, and posterior walls are to appear first while the inferior wall is completely absent at this time and is formed by the cartilage bar [7].

Different parts of the RWN do not grow neither at the same rate nor at the same time resulting in variable phenotypes of RWN anatomy. This can affect the accessibility of the round window membrane (RWM) and the extent of drilling needed to expose it [7].

The walls of the RWN consist of: superiorly the tegmen, inferiorly the fustis, and area concamerata, anteriorly the funiculus and the anterior pillar, and posteriorly the posterior pillar and the subiculum.

Round window versus promontory cochleostomy

It is very hard to compare between different types of cochleostomy. CI started initially with RW insertion. Then there was a shift to promontory cochleostomy because of the need of a straighter course. Later on, there was a shift back toward RW insertion [8,9].

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The role of imaging

The surgeon has to be familiar with the anatomy and imaging and the correlation between them [10].

Multi-slice computed tomography (MSCT) is known to expose patients and especially children to radiation to which they are more sensitive [11]. To overcome this, many authors perform MRI as their routine preoperative assessment for CI and CT is used on an as needed basis [11–13].

However, CT is still used in many centers especially for adults. It serves as a surgical road map, for instance, dural height and sigmoid sinus position, for reaching the final destination RWM and also its status itself. It helps the decision on which ear to implant, cochlear patency, and on the types of inner ear anomalies. Even in normally looking temporal bones, subtle anomalies can be detected by various measurement and non-measurement methods [14–16]. These might affect technical decisions and improve preoperative counseling especially regarding hearing preservation [17]. Postoperatively CT can confirm correct insertion of the electrode and its angular depth of insertion [1].

Cone beam CT (CBCT) is a relatively new tool in the assessment of the middle and the inner ear. Some authors suggest a comparable resolution for CBCT in relation to MSCT with significantly less radiation dose [1,18,19].

The visibility of RWN through posterior tympanotomy (PT) has been previously assessed and classified in the literature and correlated with multiple methods to preoperative imaging [12,17,20,21]. However, the visibility of RWM through RWN has been less discussed in the literature. It was either classified solely intraoperatively [22] or only radiologically [23]. The aim of the present study was to assess the preoperative predictability of MSCT for RWM visibility and accessibility through RWN intraoperatively.

Patients and methods

Sixty-one cochlear implantation patients performed at Gruppo Otologico Center, Piacenza, Italy in the period from February 2016 to February 2017. Written informed consent was obtained from all patients and the research was approved by the ethical committee of Alexandria university.

(1) No age limit.
(2) No sex limit.
(3) No specific audiologic criteria.
(4) RW intended implantation.

Exclusion criteria

(1) Previous middle ear surgeries.
(2) Middle ear disease as chronic suppurative otitis media, cholesteatoma.
(3) Congenital anomalies within the middle ear or cochlear duct on MSCT.
(4) Gross anomalies within the course of facial nerve (FN) on MSCT.
(5) Major trauma or fractures to the skull.

Demographic distribution

Demographics of the adult group are shown in Table 1.

Of the 64 patients 34/ (55.7%) patients had it on the right side and the remaining 27/61 (44.3%) were left. Absence of one side predominance is explained by the fact that the most common cause of implantation in Gruppo Otologico Center was single-sided deafness.

Preoperative radiological assessment with 0.5 mm cut MSCT to predict the accessibility of the RWM through RWN (two methods):

(1) Modified Park *et al.* [24] ratio method: the original method was to identify how many of four axial cuts where the RWM was detected was completely covered by bony niche to develop a ratio Figure 1. We modified this method. We considered all cuts with RWM as the denominator and how many covered as the numerator. This is because we observed that the number of cuts where RWM shows varied greatly from one CT scan to the other (3–8). We speculate that omitting that many cuts could affect the value and its clinical correlation.
(2) RWN depth (our proposed method): in coronal view, we chose the cut with the deepest RWN detectable Figure 2. We passed a line through the intersection of the RWM with the bone of the RWN medially and laterally. We passed another line parallel to that one, touching the edge of the

Table 1 Distribution of the studied cadavers according to demographic data (*N*=61)

	n (%)
Sex	
Male	28 (45.9)
Female	33 (54.1)
Age (years)	
Minimum–maximum	18.0–83.0
Mean±SD	60.13±15.8
Median	61.0

RWN. We measured the distance between them by a perpendicular line (mm).

Measurements on CT were assessed by our radiologist preoperatively, and so was blinded to operative findings.

Intraoperative assessment

A transmastoid facial recess approach was performed. RWN was detected through PT. Any pseudomembranes or mucosal folds covering the RWN were removed. RWM location confirmed by RW reflex by means of fine ossicular movement. In case of invisible RWN through PT, additional measures were taken to visualize the RWN, for example removing the incus and the incus bridge, cutting the chorda tympani nerve (CTN). The RWM visibility was classified into four categories namely: completely, partially, slit, and nonvisible. Intraoperative assessment was done by one surgeon (M. S.), who was blinded to preoperative CT measurements (Figs 3–6).

Results

We statistically analyzed the predictability of each of these two methods to the intraoperative:

(1) Modified Park's ratio method (Table 2) and its degree of agreement (Table 3).
Modified Park's method was statistically significant in predicting RWM visibility through RWN (*P*=0.018). The cutoff point for low or absent visibility was detected at more than 0.7 (*P*=0.014) with a sensitivity of 60% and a specificity of 69.23%.

(2) Our proposed method (Table 4) and its degree of agreement (Table 5):
Our proposed method was statistically significant in predicting RWM visibility through RWN (*P*=0.001). The cutoff point for low visibility was detected at more than 1.43 mm, with a sensitivity of 65.71% and a specificity of 96.15% (Figs 7–14).

Table 2 Relation between round window membrane intraoperative visibility and modified Park's method (*N*=61)

	RWM visibility (IO)				*F*	*P*
	Visible (*N*=10)	Partial visible (*N*=16)	Slit visible (*N*=14)	Invisible (*N*=21)		
Park's method						
Minimum–maximum	0.50–0.75	0.50–1.0	0.33–1.0	0.50–1.00		
Mean±SD	0.64±0.09	0.68±0.16	0.68±0.21	0.88±0.17	7.183*	<0.001*
Median	0.66	0.66	0.61	1.0		

F, *P*, *F* and *P* values for analysis of variance test; IO, intraoperative; RWM, round window membrane. *Statistically significant at a *P* value less than or equal to 0.05.

Table 3 Agreement (sensitivity, specificity) for modified Park's method to predict slit visible/invisible round window membrane patients

	AUC	*P*	95% CI	Cut off	Sensitivity	Specificity	PPV	NPV
Park's method	0.686*	0.014*	0.552–0.820	>0.7	60.0	69.23	72.4	56.2

AUC, area under a curve; CI, confidence intervals; NPV, negative predictive value; PPV, positive predictive value. *Statistically significant at a *P* value less than or equal to 0.05.

Table 4 Relation between round window membrane intraoperative visibility and round window membrane depth (*N*=61)

	RWM visibility (IO)				*F*	*P*
	Visible (*N*=10)	Partial visible (*N*=16)	Slit visible (*N*=14)	Invisible (*N*=21)		
RWN depth (mm)						
Minimum–maximum	0.79–1.38	0.96–1.61	1.18–1.94	1.18–1.90		
Mean±SD	1.13±0.21	1.28±0.17	1.51±0.25	1.58±0.20	14.149*	<0.001*
Median	1.15	1.30	1.46	1.63		

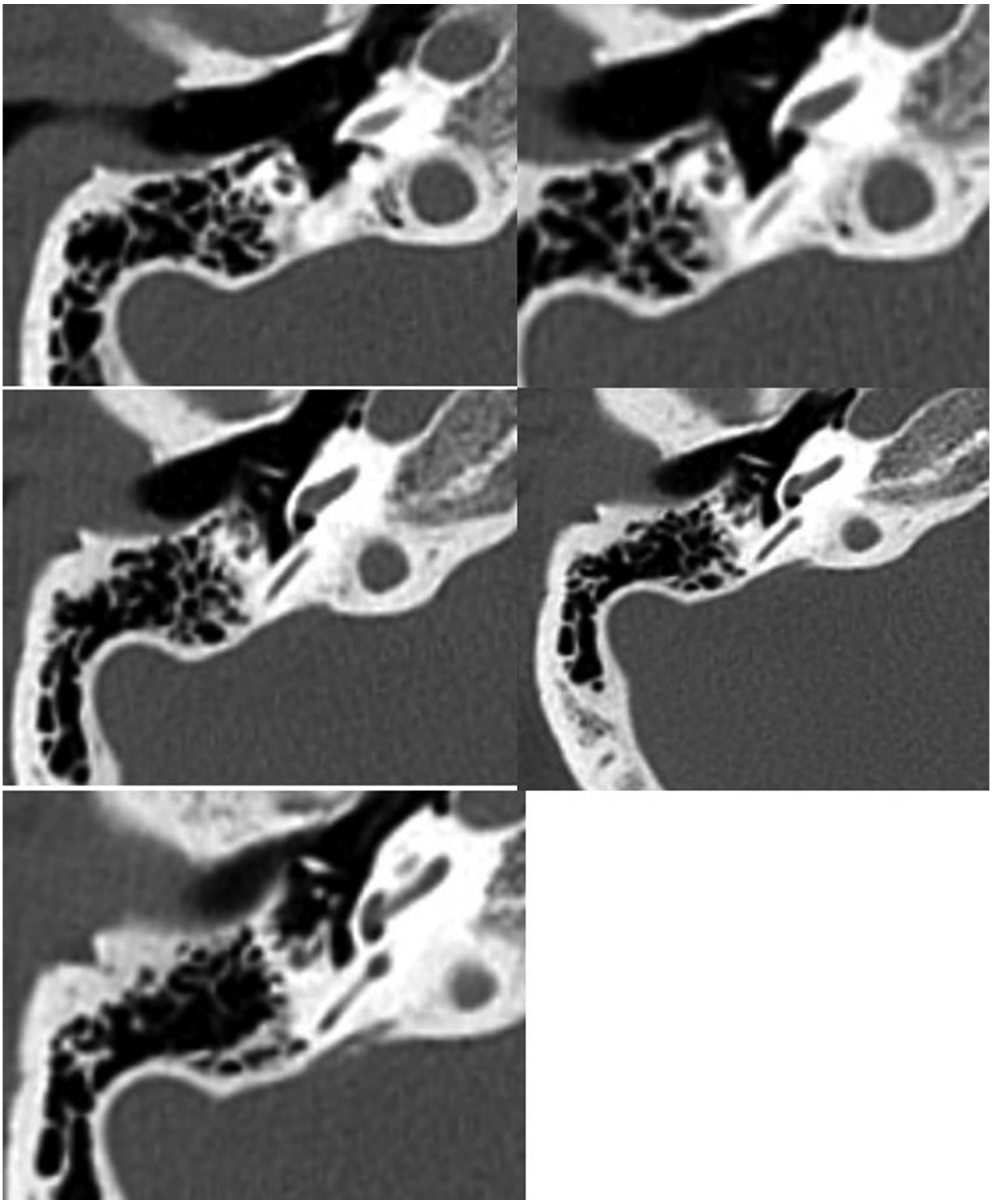
F, P, *F* and P values for analysis of variance test; IO, intraoperative; RWM, round window membrane; RWN, round window niche. *Statistically significant at a *P* value less than or equal to 0.05.

Table 5 Agreement (sensitivity, specificity) for round window niche depth (mm) to predict slit visible/invisible round window membrane patients

	AUC	*P*	95% CI	Cut off	Sensitivity	Specificity	PPV	NPV
RWN depth (mm)	0.853*	<0.001*	0.760–0.945	>1.43	65.71	96.15	95.8	67.6

AUC, area under a curve; CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value; RWN, round window niche. *Statistically significant at a *P* value less than or equal to 0.05.

Figure 1



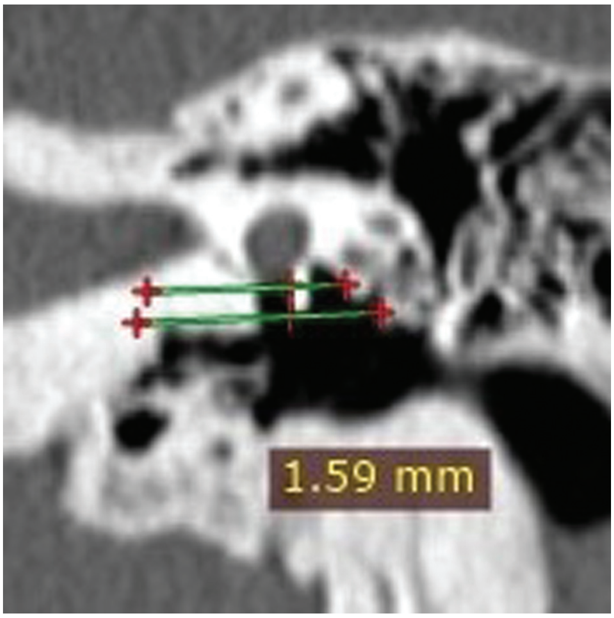
Modified Park *et al*. [24] ration method; two of five cuts RWM were completely covered by RWN=0.4.RWM, round window membrane; RWN, round window niche.

Discussion

The RW is a 2–3 mm long and about 1.5 mm wide channel connecting the middle and inner ears. The walls of the niche are formed by both membranous and chondral bones, which results in different phenotypes. The floor of the RWN on the other hand is a constant area due to its purely chondral ossification which occurs in the cartilaginous otic capsule [7]. Thus, the postnatal RWN configuration is variable due to its complex embryological development [6].

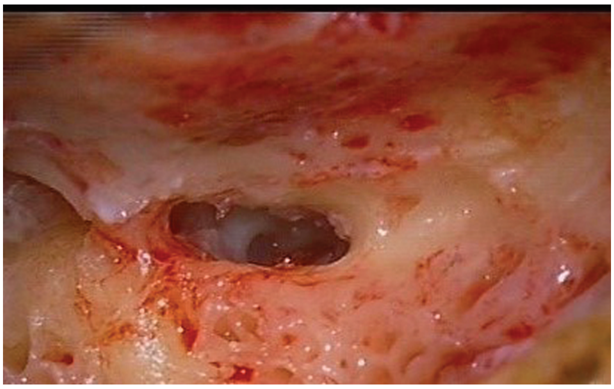
Takahashi found in three of six (50%) temporal bones studied that RWM was not seen through RWN and in the rest less than 30% of the RWM was visible [5]. Nomura reported that it can be seen without drilling [25]. We agree with all these authors. In the present study, the RWM varied

Figure 2



RWN depth according to our proposed method. RWN, round window niche.

Figure 3

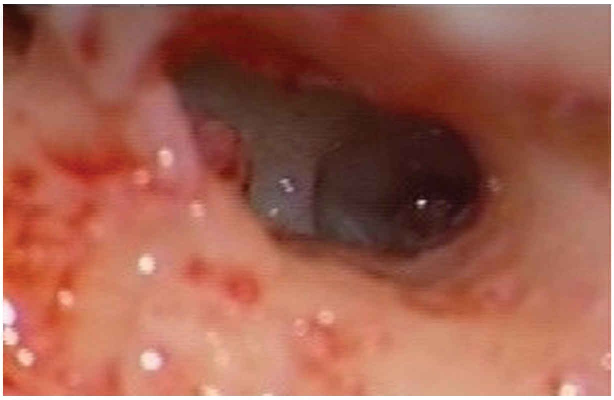


RWM fully visible through RWN. RWM, round window membrane; RWN, round window niche.

Figure 4

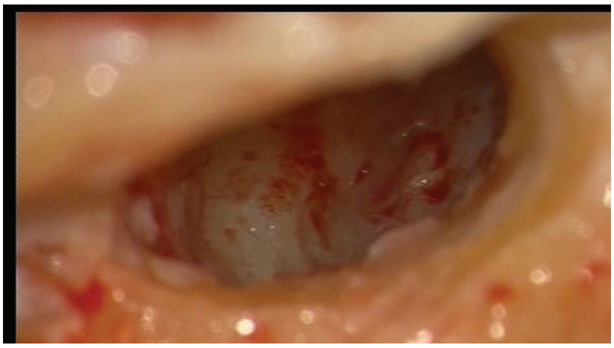
RWM partially visible. RWM, round window membrane.

Figure 5



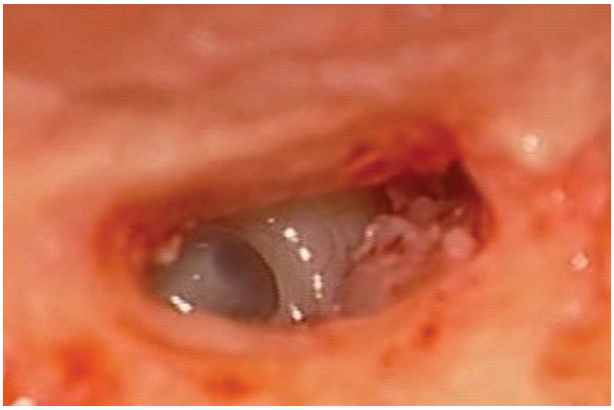
RWM slit visible. RWM, round window membrane.

Figure 6



RWM nonvisible. RWM, round window membrane.

Figure 7

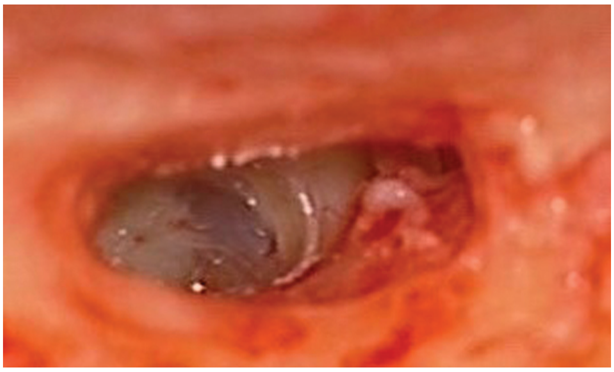


RWM almost fully visible. RWM, round window membrane.

from completely invisible to completely visible with minimal drilling needed.

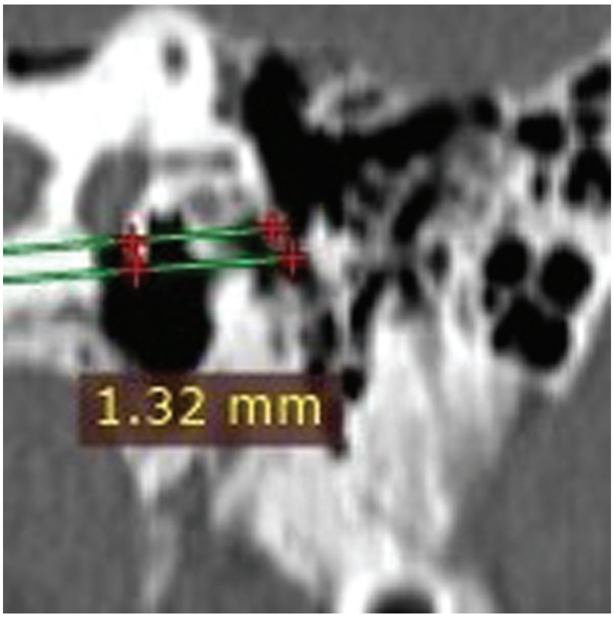
Roland observed a gain in RWM visibility after drilling a niche of 1.5–3 times that could reach up to 13 times. Another reason to drill the RWN would be to direct the electrode toward the axis of the scala tympani and not the modiolus. This is expected to make the

Figure 8



RWM after minimal RWN drilling (same patient). RWM, round window membrane; RWN, round window niche.

Figure 9



RWN depth according to our proposed method 1.32 mm (same patient). RWN, round window niche.

insertion less traumatic to the intracochlear fine structures [26].

Intraoperatively, Panda *et al.* [22] suggested a classification to assess the depth of the RWN by assessing how much of the RWM is visible through the RWN.

This study had two points worth discussing. First, they did not do any preoperative radiological assessment that could help predict the classification before surgery.

Second, they divided the visibility of RWM through RWN into four grades. Namely, visible, partially visible, slit visible, and invisible [22]. The fourth grade had confused visibility of RWN through PT with a visibility of RWM through RWN. RWN can be 100% visible through PT but has an extensive RWN, through which RWM cannot be seen and needs extensive drilling. On the other hand, an invisible RWN through PT, after taking necessary measures to improve exposure we might find an RWM that is visible through RWN and may need minimal or no drilling.

One method was suggested by Cohen *et al.* [23] to assess RWN depth on MSCT. They used oblique reconstruction in the plane of the posterior semi circular canal (PSCC). It was too complicated to apply. Additionally, they used two measures to assess the depth of RWN namely RWN air depth and RWN length. Both of which could be used as RWN depth, it was not clear which one to use or is of more clinical significance. These measures were not compared with intraoperative findings.

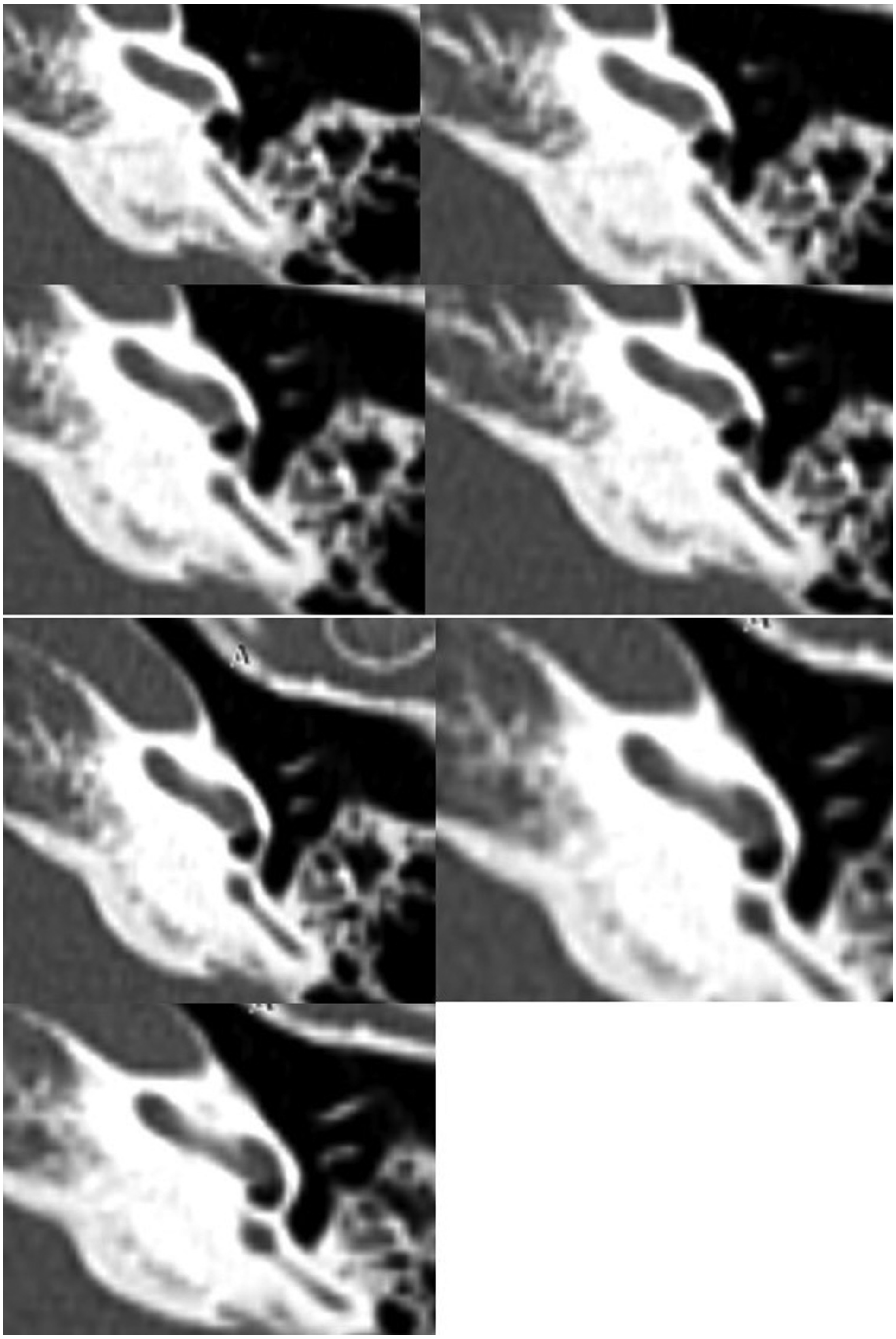
We applied two methods to assess the extent of RWN preoperatively on CT in the present study and compared them with intraoperative visibility according to the grades of Panda *et al.* [22].

The first method we applied was a ratio method by Park *et al.* [24] which we modified. In the original study, they found no effect of RWN extent on the difficulty of surgery. We compared this method with intraoperative visibility of the RWM because difficulty is a subjective entity. In the present study, this method could predict the visibility of RWM through RWN with a statistical significance of P value 0.018. A cutoff point for low or no visibility was detected at 0.7.

The second method we performed was not according to our knowledge published elsewhere. We used the coronal cut with the deepest RWN and simply measured the distance (mm) from free edge to the first point of RWM. It ranged from 0.79 to 1.94 mm with a mean of 1.41 mm.

Two reference points appeared to us to be of more clinical significance than the ones used by Cohen *et al.* [23], who measured the distance from the middle of the operculum of the RWN which would not correlate to drilling starting point which is the edge of the RWN. The other references were the middle and the deepest part of the RWM. We chose the shallowest point of the RWM as it would relate to the earliest visibility, and the fact that the whole RWN does not need to be drilled completely in order to have good exposure and a proper angle of insertion. RWN length gave results in that study of 1.66±0.26 mm with a range of 1–2.7 mm. RWN air depth gave the exact

Figure 10



Modified Park's ratio method (4/7 covered)=0.57 (same patient).

same values [23]. This proves the confusion between the two measurements and their clinical purpose. Their results were close to ours, but there was a difference in the methodology. For instance, the difference in views oblique versus coronal and reference points were used. This study did not correlate their findings to intraoperative views either.

An anatomical study reported RWN depth to have a mean of 2.1 mm with a range of 1.9–2.4 mm [27]. The mean was somehow larger than our patients, and the range was much narrower. This study, nevertheless, was purely anatomical with no intraoperative observations nor radiological correlation. It was performed on only 14 temporal bones using molds and with no definition of age or sex. So, its clinical usefulness is rather limited.

Our proposed method was statistically significant in predicting the visibility of RWN (P=0.001). A cutoff

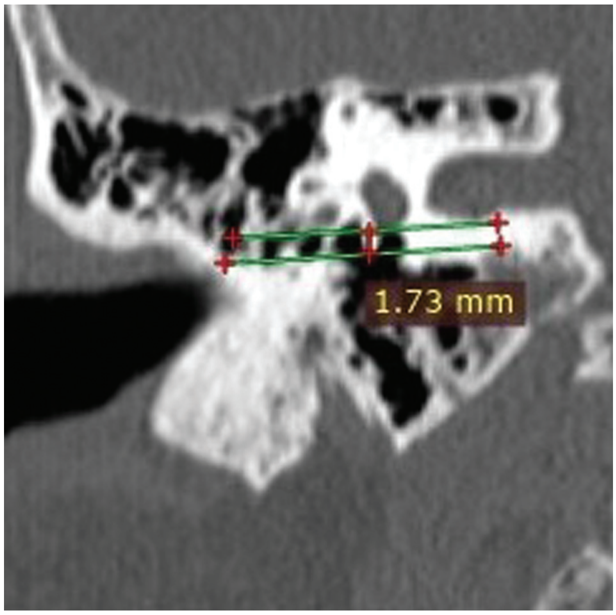
Figure 11

Slit visible RWM in another patient. RWM, round window membrane.

Figure 12

Same patient with RWM exposed after extensive drilling. RWM, round window membrane.

Figure 13



Same patient with an RWN depth of 1.73 mm according to our method. RWN, round window niche.

point was detected at more than 1.43 mm having low visibility. This cutoff point had a higher sensitivity (65.7 vs. 60%) and specificity (96.15 vs. 69.23%) than the modified Park and colleagues method and a better *P* value (0.001 vs. 0.018). Our method obtained a good specificity to confirm low visibility for values below 1.43 mm. All our patients had a successful RWM insertion confirmed by intraoperative neural response telemetry (NRT), stapedial reflex, and C-arm.

The measures used in the present study could help predict the accessibility of the RWM and the extent of drilling needed for RWN to expose it. Some authors mentioned that the RWN might be so small that drilling can be omitted though this was rare [22,26]. Others disagreed and concluded that RWN always needed at least some drilling [28,29]. All our patients needed at least some drilling of the RWN. Nevertheless, we agree that no drilling can be a possibility specially with newer thinner electrodes.

The weakness about this study was that measurement methods on CT might have interobserver and intraobserver variability and also would be affected by the thickness of cuts during the acquisition of the scan from one device and setting to the other. Also, our assessment was focused on RWM intended insertions not cochleostomy, so wider exposure was needed.

Drilling of the RWN can usually be accomplished starting with the anterior–inferior lip of the niche until the annulus of the RWM is visualized. It is ill advised to drill the poster superiorly [5,26] based on the finding that at the posterosuperior margin the distance between RWN and osseous spiral lamina (OSL) is 0.1 mm [30].

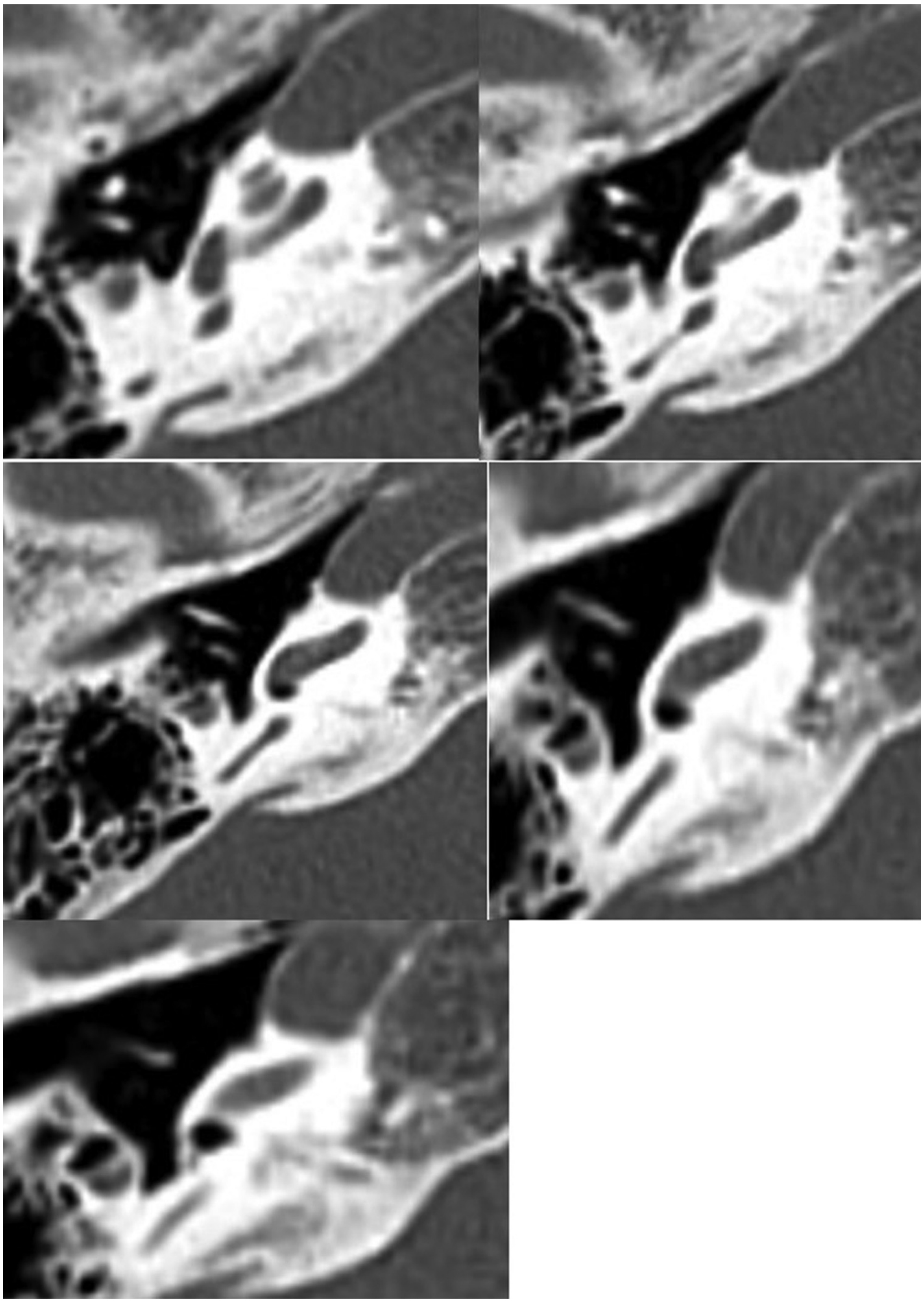
Conclusion

RWN accessibility and visibility can be predicted preoperatively using MSCT. We propose a new simple method to measure depth of RWN on CT with good intraoperative predictability and good specificity to anticipate no or low visibility of RWM through RWM at more than or equal to 1.43 mm. We also modified a method Park and colleagues with good statistical significance, but low specificity at 0.7.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

Figure 14



Modified Park's ratio method 5/5 covered=1 (same patient).

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