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Various approaches to the round window for cochlear implantation: a systematic review

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Review Article

Dr I Aljazeeri takes responsibility for the integrity of the content of the paper

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Abstract

Objective. Round window approaches are used to insert a cochlear implant electrode array into the scala tympani. This study aimed to review the literature to find the reported round window approaches.

Method. This review was performed according to the Preferred Reporting Items for Systematic Review and Meta-Analyses ('PRISMA') guidelines. Articles that described their surgical approach to the round window were included. The PubMed, Scopus, Web of Science and Cochrane Library electronic databases were searched through to June 2021. The study protocol was registered on Prospero (reference number: CRD42021226940).

Results. A total of 42 reports were included. The following approaches were documented: the standard facial recess, keyhole, retrofacial, modified suprameatal, transaditus, combined posterior tympanotomy and endomeatal, modified Veria, canal wall down approaches, and endoscopically assisted technique.

Conclusion. This review suggested that there are numerous distinct round window approaches, providing alternatives when the round window is inaccessible through the standard facial recess.

Introduction

Cochlear implantation is the definitive procedure used to manage patients with severe-to-profound hearing loss. During cochlear implantation, which is mainly performed using a posterior tympanotomy approach, visualisation of the round window and the round window membrane is needed as these are essential landmarks for successful insertion of the electrode array; otherwise, the electrode may be misplaced in a hypotympanic air cell.[1] The round window membrane is a soft-tissue barrier separating the middle ear and inner ear that can be visualised underneath the round window niche promontory bony overhang.[2]

In some cases, accessing the round window is still challenging and not always possible using the posterior tympanotomy approach. For these cases, the electrode can be inserted through a cochleostomy or extended round window approach as alternative access. In addition, it is difficult to identify the round window in patients with inner-ear malformations.[3,4] A cochleostomy is usually performed by drilling antero-inferior to the round window membrane to access the scala tympani through the outer wall. However, this route is associated with the potential risk of damaging the spiral ligament and basilar membrane.[5] The round window route has been associated with a lower risk of intracochlear trauma, labyrinthitis and perilymph fistula neuronal ganglions injury.[5,6] In addition, electrode insertion through the round window ensures electrode placement in the scala tympani, which is associated with better audiological outcomes than electrodes placed in the scala vestibule.[7] Thus, the round window technique is now the preferred method for electrode array insertion and may result in better hearing preservation. Compared with only 16 per cent of surgeons who reported using the round window approach in 2006, this approach has become increasingly popular.[8]

There are a wide range of anatomical variations in the degree of intra-operative round window membrane visibility, which have been classified into four main groups according to the St Thomas' Hospital classification (type I: 100 per cent of the membrane is exposed, type IIa: more than 50 per cent and less than 100 per cent of the membrane is exposed, type IIb: less than 50 per cent and more than 0 per cent is exposed, and type III: no membrane exposure). Pre-operative high-resolution computed tomography (CT) of the temporal bone provides high-quality radiological images of the inner-ear structures and their relation to the facial nerve as well as the angle of the round window membrane to predict intra-operative round window visualisation[9,10] and thus determine the appropriate surgical approach.

Knowing about the alternative approaches to the round window besides the standard posterior tympanotomy approach can help the surgeon in achieving the highest rates of round window insertion and obtaining the benefits of this. Therefore, studying and reviewing the published works on the possible round window approaches would be helpful. However, to the best of our knowledge, there are no systematic reviews on this topic.

In this study, we aimed to systematically review the different surgical approaches used to access the round window and explore associated intra-operative findings.

Materials and methods

Study design

A comprehensive systematic review of the literature was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses ('PRISMA') guidelines (Appendix 1). Our study protocol was registered and approved by Prospero (reference number: CRD42021226940).

Literature search strategy

In June 2021, the PubMed, Scopus, Web of Science and Cochrane Library electronic databases were searched using the following search strategy: ((round window) OR (scala tympani) OR (approach) OR (insertion))/AND (cochlear implant OR cochlear implantation)).

Selection criteria and screening process

Articles were combined in the main Endnote library, and any repeated references were then removed. Additional articles were retrieved by manually searching the citations of the relevant articles. Found articles were entered into an Endnote library file; through this process, the duplicated articles were removed. The remaining articles were combined into one Excel® spreadsheet to facilitate screening. Two reviewers independently evaluated the articles' titles and abstracts based on the pre-established inclusion and exclusion criteria in Prospero. Articles were considered relevant if they reported cochlear implantation through the round window. There were no restrictions on study design; clinical trials, observational studies, case reports and case series were included. In addition, no limitations were applied regarding patient age, country of origin or year of publication. However, the following articles were not included: (1) conference abstracts or proceedings; (2) comments and letters to editors; (3) overlapped data sets; (4) review articles; (5) book chapters; (6) theses; (7) non-English articles; and (8) non-human studies.

Data extraction and result synthesis

Two authors were assigned to extract the following data from the eligible studies: (1) baseline demographic data including the country where the research was conducted, sample size, age and sex; (2) details of the surgery; and (3) clinical outcomes including audiological assessment outcomes and complications.

Any differences in the data reported by the two authors were resolved through a discussion with a senior investigator. The quality of the eligible articles was assessed by two independent authors using the National Institutes of Health evaluation tool for observational studies[11] and controlled interventions, and using the Case Report ('CARE') checklist for case reports (Appendices 2 and 3).[12]

Statistical analysis

A synthesis of the descriptive data was performed using SPSS® statistical software (version 23) and Excel® spreadsheet software to report numbers, percentages, means and standard deviations.

Results

Search results

A total of 2436 reports were retrieved. After removing duplicates using Endnote software, 875 reports were included in the title and abstract screening. Of these, 53 studies were eligible for full-text screening following our inclusion and exclusion criteria. Finally, 42 reports with a total sample size of 2237 patients were included in this systematic review (Figure 1). The quality assessment scores indicated good quality, regardless of the type of study design used.

Baseline demographic characteristics

The direct round window approach was performed in 1890 ears, with a cochleostomy in 335 ears and an extended round window approach in 27 ears. There were 25 retrospective cohort studies, 9 prospective studies, 1 randomised, controlled trial, 6 case reports and 1 case series.

Among the 32 studies that reported the gender and age of the participants, 63.2 per cent of patients were male (881 of 1394), and the ages varied among infants, children and adults. For all cases, except 29 cases in 6 studies, cochlear implantation was unilateral.[13–18] The most frequent abnormal anatomy reported was otosclerosis (54 patients), followed by abnormal cochleae or vestibules in 11 patients, an enlarged vestibular aqueduct in 10 patients, coloboma, heart defects, atresia choanae, growth retardation, genital abnormalities and ear abnormalities ('CHARGE') syndrome in 5 cases, and Mondini dysplasia in four cases. The facial nerve was located in the anterior and lateral positions in three and two patients, respectively. Patient characteristics, cochlear implantation models and pre-operative assessments are provided in Table 1.

Surgical approaches

After cortical mastoidectomy, the entry approach to the round window was performed through the facial recess in 9 studies[9,15,19–25] (round window, $n = 337$), and the retrofacial approach was used in 3 studies[26–28] (round window, $n = 6$). The modified suprameatal (extended round window, $n = 6$)[29] and modified Veria approaches have been associated with better exposure to the anatomy of the middle ear compared with the posterior tympanotomy approach along with easier localisation of the round window, especially for malformed cochleae.[30] Additionally, external auditory canal mobilisation (in three cases) and the endomeatal approach (in two cases) were used when the round window membrane was not easily accessed.[24] The St Thomas' Hospital classification was used in the majority of studies ($n = 5$ out of 12 articles reporting any classifications); otherwise, the intra-operative visibility of the round window niche or round window membrane was used. According to round window accessibility and visualisation, full insertion of the electrode was performed through the round window membrane, extended round window marginal approach or antero-inferior round window cochleostomy. A summary of the steps of the surgical procedures

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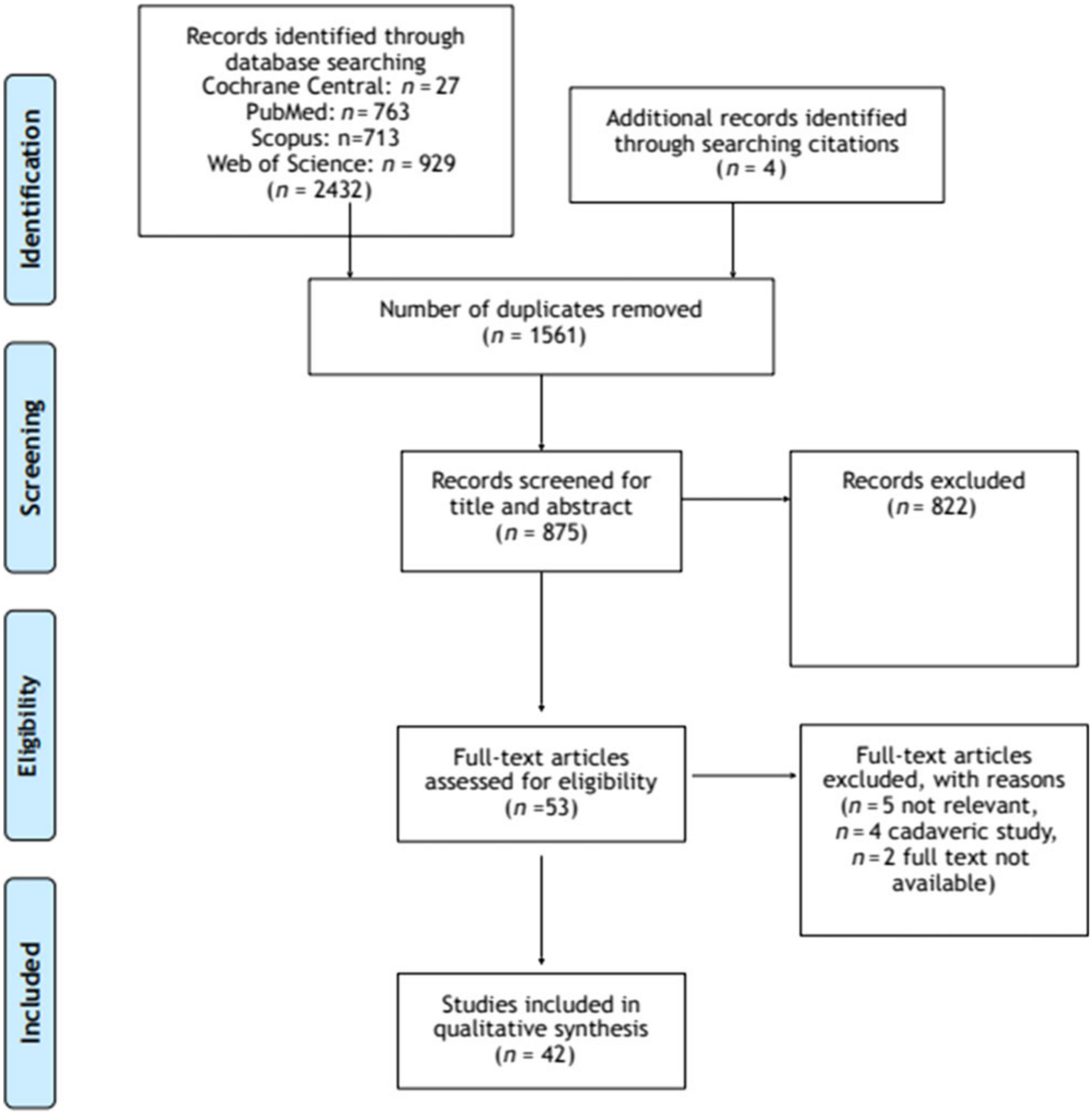

Fig. 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses ('PRISMA') study flow chart.

with intra-operative findings and complications is provided in Appendix 4 and Figure 2.

Standard facial recess or posterior tympanotomy approach

This is the classic and most commonly used approach for cochlear implantation. It was first proposed by William House in 1961. After performing a mastoidectomy, the triangular facial recess is drilled between the chorda tympani anteriorly, facial nerve posteriorly and fossa ambos superiorly. This allows for the visualisation of the round window and direct insertion of the electrode array (Figure 2a).[9,15,19–25,31,32]

Keyhole approach

This approach is a modification of the classic posterior tympanotomy approach. It involves a limited 15-mm mastoidectomy with stepwise identification of the landmarks that lead to the round window. The first landmark is the stalagmite spicules of bone on the medial aspect of the antrum that lead to the next landmark, the lateral semicircular canal. The posterior geniculate artery that is posterolateral-inferior to the lateral semicircular canal defines the superior end of the facial nerve, which is used to perform the posterior tympanotomy approach. This approach allows for the visualisation of the round window; however, in the reported cases, a cochleostomy was performed (Figure 2b).[33]

Retrofacial approach

In cases where the facial nerve is anteriorly displaced or the round window is located more posteriorly, the surgeon may not be able to visualise the round window through posterior tympanotomy. A retrofacial approach can be used in these situations. This approach is limited by the facial nerve anteriorly, lateral semicircular canal superiorly and posterior semicircular canal posteriorly. The inferior crus of the posterior semicircular canal can be followed to reach the round window.

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Table 1. Baseline characteristics of included studies

Author/year	Country	Study design	Sample size (*n*)	Patients with round window approach (*n*)	Mean age (SD)	Gender, male (*n* (%))	Quality assessment score
Allen *et al.*, 2015[26]	USA	RCR	3	3	19.3 years (22.4)	2 (66)	Good
Bae *et al.*, 2019[24]	Korea	RCR	377	372	10 months to 82 years	–	Good
Bhavana & Bharti, 2019[30]	India	RCR	52	52	–	–	Good
Chen *et al.*, 2019[19]	China	RCR	62	62	10.15 years (3.32)	23 (63.9)	Good
Chen *et al.*, 2018[46]	Taiwan	RCR	25	25	11.1 years (17.5)	12 (48)	Good
Cheng *et al.*, 2018[21]	China	RCR	40	20; cochleostomy, 20	40.5 years (18); cochleostomy, 37.7 years (11.6)	12 (60); cochleostomy, 13 (65)	Good
Connor *et al.*, 2012[55]	UK	POS	65	32; cochleostomy, 33	–	–	Good
Dietz *et al.*, 2016[29]	Finland	Case report	7	ERW, 6; cochleostomy, 1	70–84 years	7 (100)	Good
Elzayat *et al.*, 2020[51]	Egypt	RCR	97	97	5.52 years (7.88)	57 (59)	Good
Erixon *et al.*, 2012[56]	Sweden	RCR	21	21	58.6 years (19.6)	11 (52)	Good
Fan *et al.*, 2018[57]	China	RCR	24	15; cochleostomy, 9	Round window & cochleostomy, 2.4 years (0.8–7)	Round window & cochleostomy, 16 (60)	Good
Free *et al.*, 2013[16]	Italy	RCR	31	31	2–72 years	22 (70)	Good
Galal *et al.*, 2019[22]	Italy	RCR	61	61	60.13 years (15.8)	28 (45.9)	Good
Ghonim *et al.*, 2018[48]	Egypt	POS	50	50	34.4 years (23–51)	16 (32)	Good
Gudis *et al.*, 2012[15]	USA	RCR	139	111; cochleostomy, 19	55.5 years	56 (46.6)	Good
Hamerschmidt *et al.*, 2012[60]	Brazil	POS	23	17; cochleostomy, 6	32.25 years (4–84); cochleostomy, 19 years (4–54)	Round window & cochleostomy, 7 (30)	Good
Hasaballah *et al.*, 2014[54]	Egypt	POS	18	–	–	–	Good
Hsieh *et al.*, 2019[49]	Philippines	Case report	1	1	3 years	0 (0)	Good
Huang *et al.*, 2006[28]	Taiwan	Case report	1	1	4 years	1 (100)	Good
Kang & Kim 2013[20]	USA	Case series	143	55; cochleostomy, 88	42.1 years (24.2); cochleostomy, 43.3 years (25)	20 (36); cochleostomy, 43 (48)	Good
Kim *et al.*, 2019[40]	Korea	Case report	1	1	13 years	1 (100)	Good
Kluenter *et al.*, 2010[13]	Germany	POS	52	16; cochleostomy, 36	11–74 years; cochleostomy, 11–74 years	6 (37); cochleostomy, 14 (38)	Good
Jang *et al.*, 2019[23]	Korea	RCR	46	39; cochleostomy, 7	–	–	Good
Jiam & Limb, 2016[58]	USA	RCR	8	4; cochleostomy, 4	50–64 years; cochleostomy, 21–60 years	1 (25); cochleostomy, 1 (25)	Good
Marchioni *et al.*, 2015[4]	Italy	RCR	5	4; cochleostomy, 1	19.6 years (3–71)	2 (40)	Good
Marchioni *et al.*, 2016[50]	Italy	Case report	3	3	40, 49 and 77 years	2 (66.7)	Good

(*Continued*)

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Table 1. (*Continued.*)

Author/year	Country	Study design	Sample size (*n*)	Patients with round window approach (*n*)	Mean age (SD)	Gender, male (*n* (%))	Quality assessment score
Migirov *et al.*, 2014[17]	Israel	RCR	13	13	9 months to 76 years	4 (30)	Good
Mostafa *et al.*, 2014[39]	Egypt	RCR	125	110; cochleostomy, 15	3.4 years	Round window & cochleostomy, 83 (66)	Good
Naderpour *et al.*, 2020[25]	Iran	Double-blind RCT	97	51; cochleostomy, 46	<2 years (10 (20%)) 2–5 years (31 (61%)) 6–10 years (6 (12%)) >10 years (4 (8%)) Cochleostomy: <2 years (14 (30%)) 2–5 years (29 (63%)) 6–10 years (3 (7%)) >10 years (0 (0%))	32 (63); cochleostomy, 23 (50)	Good
Nassif *et al.*, 2020[47]	Italy	RCR	8	8	4–10 years	3 (37)	Good
Park *et al.*, 2015[9]	Canada	POS	57	57	–	–	Good
Pendem *et al.*, 2014[52]	India	POS	37	37	(1–6 years)	–	Good
Quang *et al.*, 2019[14]	Vietnam	POS	94	44; cochleostomy, 50	Round window & cochleostomy: <2 years (6.38%) 2–5 years (52.13%) 6–10 years (24.47%) 10–15 years (13.83%) >15 years (3.19%)	Round window & cochleostomy, 51 (54.26)	Good
Rashad Ghoneim *et al.*, 2021[53]	Egypt	RCR	45	45	2–12	26 (57.8)	Good
Rizk *et al.*, 2015[27]	USA	Case report	2	2	2.5 years, 1 month	2 (100)	Good
Stuermer *et al.*, 2020[62]	Germany	RCR	104	Round window: adult, 74; children 21. ERW: adult, 5; children, 2	–	–	Good
Stuermer *et al.*, 2019[61]	Cyprus	RCR	120	120	44 years (8–82)	57 (47)	Good
Sürmelioğlu *et al.*, 2016[38]	Turkey	RCR	38	38	8.3 years (1–51)	20 (52)	Good
Taibah *et al.*, 2009[18]	Saudi Arabia	RCR	131	131	10–58 years	65 (50)	Good
Todt *et al.*, 2009[59]	Germany	POS					Good
Wang *et al.*, 2017[68]	China	RCR	50	Round window, 35; ERW, 15	–	Round window, 20 (57); ERW, 7 (47)	Good
Wick *et al.*, 2017[44]	USA	RCR	3	1; ERW, 2	2.5 years (1.5–3.8)	–	Good

SD = standard deviation; RCR = retrospective case review; POS = prospective observational study; ERW = extended round window; RCT = randomised, controlled trial

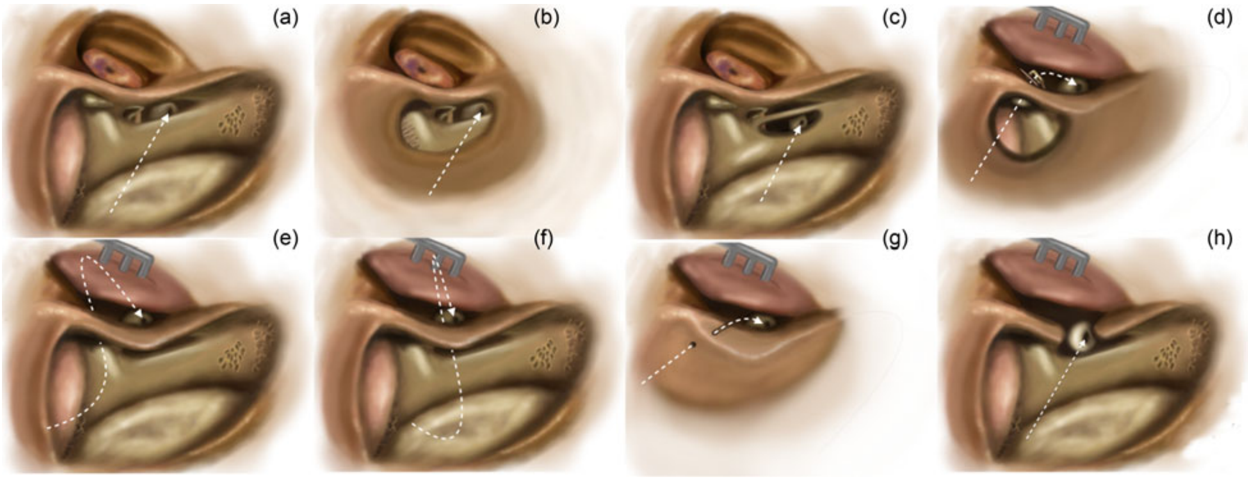

Fig. 2. Diagrams showing the various approaches to the round window: (a) the standard facial recess or posterior tympanotomy approach, (b) the keyhole approach, (c) the retrofacial approach, (d) the modified suprameatal approach, (e) the transaditus or transattic approach, (f) the combined posterior tympanotomy plus endomeatal approach or transcanal approach, (g) the modified Veria approach, and (h) the canal wall down approach.

This approach can be limited by an anteriorly placed sigmoid, which can necessitate sigmoid decompression (Figure 2c).[25–28]

Modified suprameatal approach

For this approach, a small antrostomy is drilled, which allows for the identification of the tegmen, lateral semicircular canal and the short process of the incus. Subsequently, the tympanomeatal flap is elevated. The electrode passes through the antrostomy lateral to the short process of the incus and below the chorda tympani (Figure 2d).[29]

Transaditus or transattic approach

For this approach, the tympanomeatal flap is elevated to widen the exposure anterior to the external auditory canal after performing a cortical mastoidectomy. Using the transcanal view, the incudostapedal joint can be separated, and the incus is then removed. Preservation of the incus is possible if a wide atticotomy is performed. The widened transaditus passage can then be used to insert the electrode into the middle-ear space. The electrode array can either be inserted into the round window directly or the electrode tip can be delivered using the transcanal view to allow for a controlled final insertion of the electrode.

This approach can be used when the round window is not easily accessible even with a well performed posterior tympanotomy. The advantage of the transaditus approach over the retrofacial approach is that the danger of drilling around the vertical segment of the facial nerve can be avoided, which is not possible with the retrofacial approach. Given this advantage, the transaditus approach is easier for less experienced surgeons. This approach also allows for the visualisation of the round window, while a cochleostomy was chosen for electrode insertion by the authors (Figure 2e).[34,35]

Combined approach

Similar to the transaditus approach, the combined posterior tympanotomy plus endomeatal approach, also known as the transcanal approach, provides double views that allow for better visualisation and manipulation. These two views are anterior and posterior to the posterior canal wall. However, in contrast to the transaditus approach, the middle ear is entered using posterior tympanotomy (Figure 2f).[36–38]

Modified Veria approach

For this non-mastoidectomy approach, the tympanomeatal flap is elevated after a postauricular incision. If the round window is not visualised, minimal canaloplasty can be performed. A posterosuperior canal is then drilled into the external auditory canal, starting medially just above the incus. A small bridge of bone can be preserved in the most lateral aspect of the tunnel to cover the electrode and prevent any future displacement. After insertion of the electrode, the bony canal can be either covered with a cartilage graft or glass ionomeric cement to further reinforce the electrode and prevent extrusion through the skin of the external auditory canal (Figure 2g).[24,30,38–41]

The Veria operation or the suprameatal approach was originally described as a cochleostomy technique rather than round window approach. The possibility of round window insertion through this approach was considered difficult because of limited visualisation.[42–44] However, by rotating the head of the patient toward the surgeon, visualisation of the round window and round window niche can be improved, and round window insertion is possible. This solution was first proposed and demonstrated by Bhavana *et al.* and named the modified Veria approach.[30]

The pericanal approach, which does not involve the time-consuming mastoidectomy step that is used in the classic posterior tympanotomy approach, is believed to be faster. Additionally, if the facial recess is narrow, the jugular bulb is high, the round window is inferiorly rotated or there is prominent vessel growth in the mastoid, this approach can allow for access to the round window.[19,40] However, the possibility of electrode extrusion through the thin skin of the external auditory canal and an inability to visualise the round window in all cases remains a concern. A canaloplasty, performed by drilling part of the external auditory canal, can be conducted using this approach if the round window cannot be visualised through the canal.[40,41]

Canal wall down approach or transcanal approach

In the classic mastoidectomy and posterior tympanotomy approach, the posterior auditory canal should be thinned to a ‘paper thin’ thickness. If the round window cannot be visualised after thinning the canal appropriately, the canal wall down or transcanal approach can be used. The tympanomeatal

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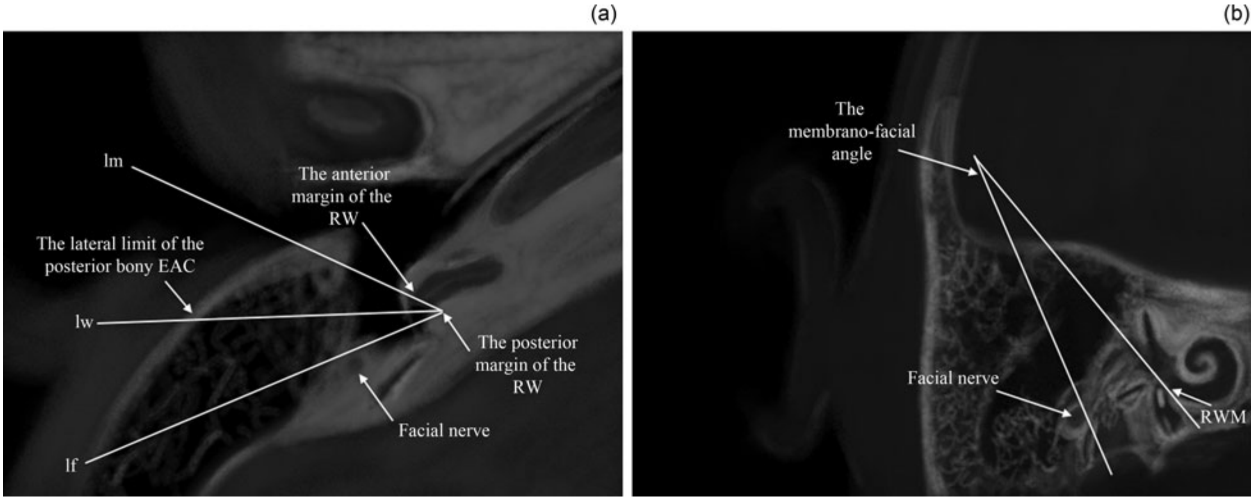

Fig. 3. Images showing computed tomography scan parameters for predicting the ease of round window visualisation through the posterior tympanotomy approach. (a) The axial view and (b) the oblique sagittal reconstruction. *Lw* is a line drawn from the posterior margin of the round window membrane to the intersection point of the posterior wall of the external auditory canal and mastoid cortex; *lf* is a line drawn between the posterior margin of the round window membrane and the lateral margin of the facial nerve; and *lm* is a line drawn from the anterior to the posterior margin of the round window membrane. EAC = external auditory canal; RW = round window; RWM = round window membrane

flap should be elevated to preserve the skin of the canal. The external auditory canal is then drilled laterally to the facial nerve, increasing the access and possibility of visualising the round window. Some authors have recommended the canal wall be reconstructed to protect the electrode array, and others prefer not to perform any reconstruction. One study that used this approach with a cochleostomy for insertion of the electrode array referred to this approach as the transcanal approach.[45] In cases with chronic suppurative otitis media with or without cholesteatoma, canal wall down approach cochlear implantation is performed as a part of subtotal petrosectomy.[16] Performing a blind sac closure would best protect the electrode array in cases of subtotal petrosectomy, particularly as the ear canal would no longer be needed for hearing when the patient has a cochlear implant (Figure 2h).[16,24,38,45]

Endoscopic-assisted surgery

In recent studies, endoscopic surgery has demonstrated better visualisation of the round window niche. In seven studies[4,17,46–50] that reported on microscopic and endoscopic approaches, the round window membrane and round window niche were visualised in spite of the significant difference in round window membrane exposure classifications between the microscopy and endoscopy approaches. The endoscope allowed for full exposure of the features of the round window niche without any associated complications. In two studies,[4,50] a cochleostomy was performed through the round window by drilling on the promontory near the anterior portion of the fustis when the round window could not be accessed. Endoscopic-assisted cochlear implantations were performed either through the classic posterior tympanotomy or endomeatal approach.

Prediction of round window visibility

Pre-operative imaging scans of the temporal bone are an important step in evaluating the anatomy of the round window, including its angulation, the size of the round window niche and the location of the round window in relation to the other anatomical structures (most importantly the facial nerve, sigmoid sinus, external auditory canal and skull base).

In four studies that used pre-operative high-resolution CT, a significant correlation was found between the classification of round window membrane visibility and the angle between *lw* and *lf*, and the angle between *lm* and *lf*,[19] where *lw* is a line drawn from the posterior margin of the round window membrane to the intersection point of the posterior wall of the external auditory canal and mastoid cortex, *lf* is a line drawn between the posterior margin of the round window membrane and the lateral margin of the facial nerve, and *lm* is a line drawn from the anterior to the posterior margin of the round window membrane (Figure 3a).

In addition, there was a significant correlation between round window membrane visibility and the membrano-facial angle[51] (Figure 3b). Furthermore, the high-resolution CT measurements had an overall sensitivity and specificity of 92.3 per cent and 96.2 per cent, respectively, for predicting the round window niche[52] and a sensitivity and specificity of 91.4 per cent and 88.6 per cent, respectively, for predicting round window visibility.[53]

In one study using multislice CT,[22] the prediction of round window membrane visibility through the posterior tympanotomy had a sensitivity of 65.71 per cent and a specificity of 96.15 per cent. In another study that used oblique sagittal-cut CT scanning,[54] the mean distance from the facial bony canal to the round window and from the facial nerve to the round window was longer than the distances observed using the operative view. Table 2 lists all the parameters used and the findings.

Method of detecting the electrode position

Post-operative assessments using either CT or X-ray were performed in all eight studies[14,23,26,55–59] that reported detecting the electrode position. The X-ray images were reported to be performed using the transocular view[23,40] and Stenver's view.[14] Intra-operative imaging might be indicated if there is a high level of uncertainty regarding the electrode positioning, and this imaging was reported in two studies.[14,23]

Table 2. Prediction of round window visibility by computed tomography

Author/ year	Pre-operative round window visibility methods		
	Tool	Parameter used	Findings
Chen *et al.*, 2019[19]	Axial HRCT	1. Angle A° (the angle between *lw* & *lf*) 2. Angle B° (the angle between *lm* & *lf*) 3. Width of the facial recess	1. Significant correlation between the types of round window membrane visibility & the A & B angles 2. An insignificant correlation between the degree of round window membrane visibility & the facial recess width
Elzayat *et al.*, 2020[51]	HRCT	1. Membrano-facial angle 2. Length of the bony overhang of the round window niche	1. Significant correlation between gender & length of the niche (higher in males) & between the membrano-facial angle & the round window membrane visibility (with the membrano-facial angle increasing as the round window membrane became more invisible)
Galal *et al.*, 2019[22]	Multi-slice CT	1. Modified Park's method 2. The proposed method of relating the round window membrane intra-operative visibility to the round window membrane depth	1. Modified Park's method & the proposed method were statistically significant in predicting round window membrane visibility through the round window niche
Hasaballah *et al.*, 2014[54]	Oblique sagittal cuts CT scan	1. Length of tympanic segment of the facial nerve in millimetres 2. Second genu angle in degrees 3. Distance between the bony facial nerve canal & the round window in millimetres 4. Distance between the facial nerve & the round window in millimetres 5. Width of the bony facial nerve in millimetres	1. The mean distance from the facial bony canal to the round window was longer in the operatively viewed round window than in the non-viewed window (4.7 & 4.4 mm, respectively) 2. The mean distance from the facial nerve to the round window was longer in the operatively viewed round window membrane than in the non-viewed window (5.9 & 5.5 mm, respectively) 3. The mean width of posterior tympanotomy was wider in the operatively viewed round window niche than in the non-viewed window niche (3.1 & 3.0 mm, respectively)
Park *et al.*, 2015[9]	CT	1. Degree of mastoid aeration 2. Location of the sigmoid sinus 3. Height of the tegmen 4. The presence of air cells in the facial recess 5. Degree of round window bony overhang	1. Poor mastoid aeration & lower tegmen position are associated with greater difficulty with cortical mastoidectomy 2. The presence of an air cell around the facial nerve was predictive of easier facial recess access 3. The degree of round window bony overhang was not predictive of difficult round window access
Pendem *et al.*, 2014[52]	HRCT	1. The distance between the short process of the incus & the round window niche 2. The distance between the oval window & the round window niche	1. Sensitivity of 92.3% & specificity of 96.2% in determining the actual visualisation of the round window niche
Rashad Ghoneim *et al.*, 2021[53]	HRCT	1. Kashio posterior line 2. Facial recess width 3. Round window location	1. Significant correlation with a combination of Kashio prediction line with cut-off value ≥7.45 mm (sum of facial recess width & round window location) with improvement in the sensitivity & overall accuracy in prediction of round window visibility from 84.2% to 80% up to 91.4% & 88.6%, respectively.

Lw is a line drawn from the posterior margin of the round window membrane to the intersection point of the posterior wall of the external auditory canal and mastoid cortex; *lf* is a line drawn between the posterior margin of the round window membrane and the lateral margin of the facial nerve; and *lm* is a line drawn from the anterior to the posterior margin of the round window membrane. HRCT = high-resolution computed tomography; CT = computed tomography

Audiological and speech outcomes

For the included studies, no significant differences were reported for the audiological and speech outcomes between the round window and cochleostomy approaches. The authors used various measures for evaluation, including: perception of each tone, vowel, consonant, disyllable and sentence;[21] auditory nerve stimulation;[60] speech perception;[20] auditory performance scale and speech intelligibility rating scores;[25] hearing in noise testing; consonant-nucleus-consonant testing; and the Arizona Biomedical sentences test.[15] Performing a meta-analysis was not possible because of the diversity of the reported outcome measures reported.

A slight deterioration in low-frequency thresholds,[56] changes in hearing preservation[23,47,61] and a lower perception of speech scores[20] were reported in some patients after the round window approach between six months and one year after implantation (Table 3).

Discussion

Posterior tympanotomy is the most commonly used approach to the round window. Because it is not always possible to visualise the round window through posterior tympanotomy, it is important for surgeons to know about the alternative approaches to reach the round window. Before considering these alternative approaches, the surgeon needs to ensure that the posterior tympanotomy is well performed and ensure proper skeletonisation of the facial nerve, proper thinning of the external auditory canal, proper widening of the posterior tympanotomy up to the fossa incudes and inferiorly to the bifurcation of the facial nerve and the chorda tympani, and proper rotation and positioning of the microscope and the patient's head.

In this review, we summarised all available clinical evidence regarding the different microscopic and endoscopic approaches to access the round window. Forty-two articles

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Table 3. Audiological and speech outcomes after cochlear implantation

Author/year	Test used	Results
Cheng et al., 2018[21]	Mandarin tone recognition in quiet	No significant difference between the RW & cochleostomy groups for tone perception at 12 months (77.50 vs 80.50%)
	Vowel recognition in quiet	No significant difference between the RW & cochleostomy groups for vowel perception at 12 months (77.70 vs 78.65%)
	Consonant recognition in quiet	No significant difference between the RW & cochleostomy groups for consonant perception at 12 months (75.50 vs 78.25%)
	Disyllable recognition in quiet	No significant difference between the RW & cochleostomy groups for disyllable perception at 12 months (78.60 vs 81.50%)
	Sentence recognition in quiet	No significant difference between the RW & cochleostomy groups for sentence perception at 12 months (50.90 vs 52.50%)
Dietz et al., 2016[29]	Speech reception	Significant improvement from 0%–56% to 76%–100%
Erixon et al., 2012[56]	Audiogram	A slight deterioration of low frequency thresholds occurred in some patients; mean hearing loss at 125–500 Hz was 14.4 dB at 1 month following surgery & 15.6 dB after 1 year
Gudis et al., 2012[15]	Hearing in noise	No significant difference between cochleostomy & RW
	Consonant-nucleus-consonant	No significant difference between cochleostomy & RW
	Arizona Biomedical sentences	No significant difference between cochleostomy & RW
Hamerschmidt et al., 2012[60]	Auditory nerve stimulation	No significant differences between implantation procedures: mean charge units for high frequency sounds for RW approach, 190.4 (± 29.2) & cochleostomy, 187.8 (± 32.7); mean charge units for mid-frequency sounds for RW approach, 192.5 (± 22) & cochleostomy, 178.5 (± 18.5); mean charge units for low frequency sounds for RW approach, 183.3 (± 25) & cochleostomy, 163.8 (± 19.3)
Hsieh et al., 2019[49]	Hearing threshold	Aided threshold decreased to 25 dB
Huang et al., 2006[28]	Hearing threshold	The post-connected hearing threshold was about 30 dB HL
	Monosyllable, trochee, spondee word test	87% correct responses
	Eight-choice spondee word test	50% correct responses
Jang et al., 2019[23]	Pure tone audiometry	Partial hearing preservation with different results among patients over follow-up period. Change in hearing threshold from 87.0 ± 9.4 dB to 101.6 ± 10.6 dB ($n = 28$) at 12 months post-CI
Kang & Kim 2013[20]	Consonant-nucleus-consonant test	No significant differences in post-operative CI speech perception scores were noted between the RW & cochleostomy groups at 12 months post-CI (RW group, 55.28% ± 23.26% vs CI group, 53.19% ± 24.14%)
	Hearing in noise test	
	Northwestern University Children's Perception of Speech	Significant difference between cochleostomy (81.25%) & RW group (64.44%)
Kim et al., 2021[43]	Hearing threshold	The average threshold was 35 dB
Naderpour et al., 2020[25]	Auditory performance scale (CAP)	No significant difference between cochleostomy & RW
	Speech Intelligibility Rating test	Significant difference in improvement in performance between cochleostomy & RW approach with mean Speech Intelligibility Rating score ($p = 1.14 \pm 0.40$) higher in the RW approach group at 3, 6 & 9 months after surgery. There was no significant difference between the cochleostomy & RW groups at the 1-year follow up
Nassif et al., 2020[47]	Audiometric tests	Hearing preservation in 9 ears (RW approach) with mean air conduction threshold (0.5, 1, 2, 4 kHz) at 0, 3 & 6 months within 10 dB. In one ear, the mean air conduction threshold was impaired by 20 dB
Stuermer et al., 2019[61]	Pure tone audiogram	Preservation of residual hearing was achieved in 52 (43.3%) patients: maximum to complete preservation, 27 ears (51.9%), moderate preservation, 8 ears (15.4%), marginal preservation, 17 ears (32.7%) & no preservation of residual hearing, 68 ears (56.7%)

RW = round window; CI = cochlear implantation; CAP = categories of auditory performance

were found to be within the scope of this review, describing eight distinct approaches to the round window, including: the standard facial recess or posterior tympanotomy approach,[1,15,19–25,31,32] the keyhole approach,[33] the retrofacial approach,[25–27] the modified suprameatal approach,[29] the transaditus or transattic approach,[34,35] the combined posterior tympanotomy plus endomeatal approach or transcanal approach,[36–38] the modified Veria approach,[24,30,38–41] and the canal wall down approach.[24,38,45] Endoscopic-assisted techniques were also described for use in the classic posterior tympanotomy or endomeatal approaches.[4,17,46–50]

Prediction of round window visibility using CT was described in seven articles using various radiological parameters,[9,19,22,51–54] with a reported sensitivity of up to 92.3 per cent and specificity of up to 96.2 per cent in determining the actual visualisation of the round window niche (Table 2).[52]

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We also reviewed the audiological and speech outcomes of the included cases with the round window approach. Because of the diversity of reported outcome measures, meta-analysis was not possible.

St Thomas' Hospital classification may provide useful guidance for selecting the appropriate approach for electrode insertion.[3] In one study, the round window membrane could not be visualised in 8 per cent of patients through the posterior tympanotomy approach.[3] Thus, extended round window insertion could be an alternative treatment option for these cases. This could be explained by the fact that the round window membrane is located in the fossula fenestrae rotunda covered with overhanging bony ridges that limit the visibility of the round window membrane during surgery.[6] In a recent study,[62] the authors reported a higher percentage of type I visualisation of the round window, which was explained by sufficient surgical preparation and having experienced surgeons to explore the anatomy.

Moreover, performing a pre-operative CT may allow for a better prediction of round window visualisation, and one study recommended using the Kashio line, which is a facial recess width with a cut-off value equal to or more than 4.75 mm, and round window location with a cut-off value equal to or more than 2.95 mm.[53] Another study[52] found an inverse relationship between round window niche visualisation and the distance between the fossa ambos and round window niche: the shorter the distance, the more difficult visualising the round window niche became. The shorter distance could be explained by the anatomical variation of round window niche displacement either posteriorly or superiorly and the displacement of the tip of the short process of the incus.[52]

A benefit of the round window approach is that it has a low impact on cochlear microenvironments.[63] The soft surgery technique has been applied to the round window approach to reduce intra-cochlear trauma and inflammation.[64] Wanna *et al.* also reported that round window approaches were associated with a lower rate of electrode displacement outside the scalar tympani than the cochleostomy approach.[65]

The retrofacial approach has been used in other ear surgery procedures to reach the sinus tympani and hypotympanum.[66,67] In this review, two of the included studies[26,27] reported using the retrofacial approach to access the round window because visualisation of the round window was not possible using the standard facial recess approach. In the study by Allen *et al.*,[26] the retrofacial approach was performed because of an anterio-laterally displaced facial nerve. These authors suggested considering the retrofacial approach with a high-riding jugular bulb to avoid posterior semicircular canal fenestration.

The extended round window approach is believed to be less traumatic than cochleostomy and is proposed to be used when there is difficulty visualising the round window membrane through the posterior tympanotomy approach.[68] The electrode impedance that is used to evaluate function and reflect the state of the area surrounding the arrays after cochlear implantation can be affected by inflammatory reactions and was found not to be significantly different in the round window approach compared with the extended round window approach.[68]

Conclusion

The findings of the present study suggested that there are numerous approaches to reaching the round window during cochlear implantation. These approaches have been reported to be safe. If the visualisation of the round window cannot be achieved through the standard facial recess approach, the surgeon can try the other approaches. We recommend pre-operative temporal bone CT assessment as certain parameters could provide some important information to predict round window visualisation and possible difficulties during cochlear implantation surgery.

Competing interests. None declared

References

1 Ying Y, Lin J, Oghalai J, Williamson R. Cochlear implant electrode misplacement: incidence, evaluation, and management. *Laryngoscope* 2013;**123**:757–66
2 Goycoolea M, Lundman L. Round window membrane. Structure function and permeability: a review. *Microscopy Res Techniq* 1997;**36**:201–11
3 Leong AC, Jiang D, Agger A, Fitzgerald-O'Connor A. Evaluation of round window accessibility to cochlear implant insertion. *Eur Arch Otorhinolaryngol* 2013;**270**:1237–42
4 Marchioni D, Soloperto D, Guarnaccia MC, Genovese E, Alicandri-Ciufelli M, Presutti L. Endoscopic assisted cochlear implants in ear malformations. *Eur Arch Otorhinolaryngol* 2015;**272**:2643–52
5 Pau HW, Just T, Bornitz M, Lasurashvilli N, Zahnert T. Noise exposure of the inner ear during drilling a cochleostomy for cochlear implantation. *Laryngoscope* 2007;**117**:535–40
6 Roland PS, Wright CG, Isaacson B. Cochlear implant electrode insertion: the round window revisited. *Laryngoscope* 2007;**117**:1397–402
7 Finley CC, Holden TA, Holden LK, Whiting BR, Chole RA, Neely GJ *et al.* Role of electrode placement as a contributor to variability in cochlear implant outcomes. *Otol Neurotol* 2008;**29**:920–8
8 Adunka OF, Buchman CA. Scala tympani cochleostomy I: results of a survey. *Laryngoscope* 2007;**117**:2187–94
9 Park E, Amoodi H, Kuthubutheen J, Chen JM, Nedzelski JM, Lin VYW. Predictors of round window accessibility for adult cochlear implantation based on pre-operative CT scan: a prospective observational study. *J Otolaryngol Head Neck Surg* 2015;**44**:20
10 Xie L-H, Tang J, Miao W-J, Tang X-L, Li H, Tang A-Z. Preoperative evaluation of cochlear implantation through the round window membrane in the facial recess using high-resolution computed tomography. *Surg Radiol Anat* 2018;**40**:705–11
11 Lung NH, Institute B. Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies-NHLBI, NIH. In: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools [25 November 2022]
12 Rison RA, Kidd MR, Koch CA. The CARE (Case Report) guidelines and the standardization of case reports. *BioMed Central* 2013;**7**:261
13 Kluenter HD, Lang-Roth R, Beutner D, Hüttenbrink KB, Guntinas-Lichius O. Postural control before and after cochlear implantation: standard cochleostomy versus round window approach. *Acta Otolaryngol* 2010;**130**:696–701
14 Quang M, Duc NP. Initial outcomes of cochlear implantation: a comparison of round window membrane and conventional bony cochleostomy. *Arch Pharma Pract* 2019;**10**:119–25
15 Gudis DA, Montes M, Bigelow DC, Ruckenstein MJ. The round window: is it the "cochleostomy" of choice? Experience in 130 consecutive cochlear implants. *Otol Neurotol* 2012;**33**:1497–501
16 Free RH, Falcioni M, Di Trapani G, Giannuzzi AL, Russo A, Sanna M. The role of subtotal petrosectomy in cochlear implant surgery—a report of 32 cases and review on indications. *Otol Neurotol* 2013;**34**:1033–40
17 Migirov L, Shapira Y, Wolf M. The feasibility of endoscopic transcanal approach for insertion of various cochlear electrodes: a pilot study. *Eur Arch Otorhinolaryngol* 2015;**272**:1637–41
18 Taibah K. The transmeatal approach: a new technique in cochlear and middle ear implants. *Cochlear Implants Int* 2009;**10**:218–28
19 Chen J, Wu Y, Shi J, Jia H, Wang Z, Zhang Z *et al.* Predictors of round window membrane visibility in pediatric cochlear implant surgery using temporal bone HRCT: a retrospective study. *Int J Pediatr Otorhinolaryngol* 2019;**121**:150–3
20 Kang BJ, Kim AH. Comparison of cochlear implant performance after round window electrode insertion compared with traditional cochleostomy. *Otolaryngol Head Neck Surg* 2013;**148**:822–6

21 Cheng X, Wang B, Liu Y, Yuan Y, Shu Y, Chen B. Comparable electrode impedance and speech perception at 12 months after cochlear implantation using round window versus cochleostomy: an analysis of 40 patients. *ORL J Otorhinolaryngol Relat Spec* 2018;**80**:248–58
22 Galal A, Eldin OG, Baki F, Sanna M. Assessment of the preoperative computed tomographic predictability for round window membrane visibility and accessibility during cochlear implant surgery. *Egypt J Otolaryngol* 2019;**35**:278–87
23 Jang JH, Choo OS, Kim H, Park HY, Choung YH. Round window membrane visibility related to success of hearing preservation in cochlear implantation. *Acta Otolaryngol* 2019;**139**:618–24
24 Bae SC, Shin YR, Chun YM. Cochlear implant surgery through round window approach is always possible. *Ann Otol Rhinol Laryngol* 2019;**128**:38–44
25 Naderpour M, Aminzadeh Z, Moghaddam JY, Pourshiri B, Ariafar A, Akhondi A. Comparison of the pediatric cochlear implantation using round window and cochleostomy. *Iran J Otorhinolaryngol* 2020;**32**:3–10
26 Allen KP, Bartels LJ, Isaacson B. Cochlear implantation requiring a retrofacial approach to the round window. *Otol Neurol* 2015;**36**:e84–6
27 Rizk H, O'Connell B, Stevens S, Meyer T. Retrofacial approach to access the round window for cochlear implantation of malformed ears. *Otol Neurotol* 2015;**36**:e79–83
28 Huang CC, Lin CY, Wu JL. Retrofacial approach of cochlear implantation in inner ear malformation with aberrant facial nerve: a case report. *Auris Nasus Larynx* 2006;**33**:179–82
29 Dietz A, Wüstefeld M, Niskanen M, Löppönen H. Cochlear implant surgery in the elderly: the feasibility of a modified suprameatal approach under local anesthesia. *Otol Neurotol* 2016;**37**:487–91
30 Bhavana K, Bharti B, Vishwakarma R. Round window insertion in veria technique of cochlear implantation: an essential modification. *Indian J Otolaryngol Head Neck Surg* 2019;**71**:1586–91
31 House WF. Cochlear implants. *Ann Otol Rhinol Laryngol* 1976;**85**(suppl 27):1–93
32 House WF. Surgical considerations in cochlear implantation. *Ann Otol Rhinol Laryngol Suppl* 1982;**91**:15–20
33 Black B. Keyhole cochlear implantation: current status. *Otol Neurotol* 2011;**32**:1459–63
34 Al Sanosi A. Trans-aditus approach: an alternative technique for cochlear implantation. *Indian J Otolaryngol Head Neck Surg* 2012;**64**:142–4
35 Vaca M, Gutiérrez A, Polo R, Alonso A, Álvarez F. Long-term results of the transattical approach: an alternative technique for cochlear implantation. *Eur Arch Otorhinolaryngol* 2015;**272**:35–41
36 Volpe AD, Cantore I, Nolè G, Valente P, Varricchio AM, Santandrea M *et al.* Combined posterior tympanotomy/endomeatal access in cochlear implantation. *Eur Arch Otorhinolaryngol* 2013;**270**:2641–8
37 Lavinsky L, Lavinsky-Wolff M, Lavinsky J. Transcanal cochleostomy in cochlear implantation: experience with 50 cases. *Cochlear Implants Int* 2010 Dec;**11**:228–32
38 Surmelioglu O, Ozdemir S, Tarkan O, Tuncer Ü, Çetik F, Kara K *et al.* Techniques in cochlear implantation. *J Int Adv Otol* 2016;**12**:109–12
39 Kiratzidis T, Arnold W, Iliades T. Veria operation updated I. The transcanal wall cochlear implantation. *ORL J Otorhinolarngol Relat Spec* 2002;**64**:406–12
40 Kronenberg J, Migirov L, Dagan T. Suprameatal approach: new surgical approach for cochlear implantation. *J Laryngol Otol* 2001;**115**:283–5
41 Kronenberg J, Migirov L, Baumgartner WD. The suprameatal approach in cochlear implant surgery: our experience with 80 patients. *ORL J Otorhinolaryngol Relat Spec* 2002;**64**:403–5
42 Mostafa BE, Ezzat WF, El Mogui AM. The modified transcanal approach for cochlear implantation: technique and results. *Adv Otolaryngol* 2014;415821
43 Kim H, An JY, Choo OS, Jang JH, Park HY, Choung YH. Cochlear implantation via the transmeatal approach in an adolescent with hunter syndrome-type ii mucopolysaccharidosis. *J Audiol Otol* 2021;**25**:49–54
44 Wick CC, Moore AM, Killeen DE, Isaacson B. The modified ambo transcanal approach for cochlear implantation in CHARGE syndrome. *Otol Neurotol* 2017;**38**:1268–72
45 Carfrae MJ, Foyt D. Intact meatal skin, canal wall down approach for difficult cochlear implantation. *J Laryngol Otol* 2009;**123**:903–6
46 Chen YH, Liu TC, Yang TH, Lin KN, Wu CC, Hsu CJ. Using endoscopy to locate the round window membrane during cochlear implantation: our experience with 25 patients. *Clin Otolaryngol* 2018;**43**:357–62
47 Nassif N, Redaelli de Zinis LO. Endoscopic approach to the round window through posterior tympanotomy for cochlear implantation in children: a study on feasibility. *Int J Pediatr Otorhinolaryngol* 2020;**129**:109781
48 Ghonim MR, Abo-Samra MME, Moneir W, El-Deeb AH. Round window accessibility in transcanal approach. *Egypt J Otolaryngol* 2017;**33**:473–6
49 Hsieh CY, Sun CH, Lin WL, Gotamco GL, Hsu CJ, Wu HP. Modified transcanal cochlear implantation in CHARGE syndrome: a case report. *Medicine* 2019;**98**:e18283
50 Marchioni D, Soloperto D, Bianconi L, Guarnaccia MC, Genovese E, Presutti L. Endoscopic approach for cochlear implantation in advanced otosclerosis: a case report. *Auris Nasus Larynx* 2016;**43**:584–90
51 Elzayat S, Soltan I, Talaat M, Fouad YA. The role of high-resolution computer tomography in prediction of the round window membrane visibility and the feasibility of the round window electrode insertion. *Eur Arch Otorhinolaryngol* 2020;**278**:3283–90
52 Pendem SK, Rangasami R, Arunachalam RK, Mohanarangam VS, Natarajan P. HRCT correlation with round window identification during cochlear implantation in children. *J Clin Imaging Sci* 2014;**4**:70
53 Rashad Ghoneim MM, Ghonim MR, Mohamed Badawy AA, Abdel Razek AAK, Salam Hafez MA, Hamad MS *et al.* Combined preoperative HRCT parameters for prediction of round window visibility in pediatric cochlear implant patient. *Int J Pediatr Otorhinolaryngol* 2021;**140**:110521
54 Hasaballah MS, Hamdy TA. Evaluation of facial nerve course, posterior tympanotomy width and visibility of round window in patients with cochlear implantation by performing oblique sagittal cut computed tomographic scan temporal bone. *Egypt J Otolaryngol* 2014;**30**:317–21
55 Connor SE, Holland NJ, Agger A, Leong AC, Varghese RA, Jiang D *et al.* Round window electrode insertion potentiates retention in the scala tympani. *Acta Otolaryngol* 2012;**132**:932–7
56 Erixon E, Köbler S, Rask-Andersen H. Cochlear implantation and hearing preservation: results in 21 consecutively operated patients using the round window approach. *Acta Otolaryngol* 2012;**132**:923–31
57 Fan X, Xia M, Wang Z, Zhang H, Liu C, Wang N *et al.* Comparison of electrode position between round window and cochleostomy inserting approaches among young children: a cone-beam computed tomography study. *Acta Otolaryngol* 2018;**138**:815–21
58 Jiam NT, Limb CJ. The impact of round window vs cochleostomy surgical approaches on interscalar excursions in the cochlea: preliminary results from a flat-panel computed tomography study. *World J Otorhinolaryngol Head Neck Surg* 2016;**2**:142–7
59 Todt I, Rademacher G, Wagner J, Göpel F, Basta D, Haider E *et al.* Evaluation of cochlear implant electrode position after a modified round window insertion by means of a 64-multislice CT. *Acta Otolaryngol* 2009;**129**:966–70
60 Hamerschmidt R, Schuch LH, Rezende RK, Wiemes GR, Oliveira AK, Mocellin M. A comparison between neural response telemetry via cochleostomy or the round window approach in cochlear implantation. *Braz J Otorhinolaryngol* 2012;**78**:71–5
61 Stuermer KJ, Kluenter HD, Lang-Roth R, Schwarz D, Hüttenbrink KB, Anagiotos A. Preservation of vestibular function and residual hearing after round window cochlear implantation. *Otol Neurotol* 2019;**40**:878–82
62 Stuermer K, Winter T, Nachtsheim L, Klussmann JP, Luers JC. Round window accessibility during cochlear implantation. *Eur Arch Otorhinolaryngol* 2021;**278**:363–70
63 Briggs RJ, Tykocinski M, Xu J, Risi F, Svehla M, Cowan R *et al.* Comparison of round window and cochleostomy approaches with a prototype hearing preservation electrode. *Audiol Neurootol* 2006;**11** (suppl 1):42–8
64 Cohen NL. Cochlear implant soft surgery: fact or fantasy? *Otolaryngol Head Neck Surg* 1997;**117**:214–16
65 Wanna GB, Noble JH, Gifford RH, Dietrich MS, Sweeney AD, Zhang D *et al.* Impact of intrascalar electrode location, electrode type, and angular insertion depth on residual hearing in cochlear implant patients: preliminary results. *Otol Neurotol* 2015;**36**:1343–8
66 Chen B, Yin S, Shen P. The feasibility of the retrofacial approach to the pediatric sinus tympani. *Otolaryngol Head Neck Surg* 2005;**133**:780–5
67 Roland JT Jr, Hoffman RA, Miller PJ, Cohen NL. Retrofacial approach to the hypotympanum. *Arch Otolaryngol Head Neck Surg* 1995;**121**:233–6
68 Wang J, Sun J, Sun J, Chen J. Variations in electrode impedance during and after cochlear implantation: round window versus extended round window insertions. *Int J Pediatr Otorhinolaryngol* 2017;**102**:44–8

Appendix 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses ('PRISMA') 2009 checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Appendix 2. National Institutes of Health tools for quality assessment of studies

Table 1. National Institutes of Health tool for quality assessment of controlled intervention studies

Criteria	Yes	No	Other (CD, NR, NA)
1. Was the study described as randomised, a randomised trial, a randomised clinical trial, or an RCT?			
2. Was the method of randomisation adequate (i.e. use of randomly generated assignment)?			
3. Was the treatment allocation concealed (so that assignments could not be predicted)?			
4. Were study participants and providers blinded to treatment group assignment?			
5. Were the people assessing the outcomes blinded to the participants' group assignments?			
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g. demographics, risk factors, co-morbid conditions)?			
7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?			
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?			
9. Was there high adherence to the intervention protocols for each treatment group?			
10. Were other interventions avoided or similar in the groups (e.g. similar background treatments)?			
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?			
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?			
13. Were outcomes reported or subgroups analysed prespecified (i.e., identified before analyses were conducted)?			
14. Were all randomised participants analysed in the group to which they were originally assigned, i.e. did they use an intention-to-treat analysis?			

CD = cannot determine; NR = not applicable; NA = not reported; RCT = randomised, controlled trial

Table 2. National Institutes of Health Tool for quality assessment tool for observational cohort and cross-sectional studies

Criteria	Yes	No	Other (CD, NR, NA)
1. Was the research question or objective in this paper clearly stated?			
2. Was the study population clearly specified and defined?			
3. Was the participation rate of eligible persons at least 50%?			
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?			
5. Was a sample size justification, power description, or variance and effect estimate provided?			
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?			
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?			
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g. categories of exposure, or exposure measured as continuous variable)?			
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
10. Was the exposure(s) assessed more than once over time?			
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
12. Were the outcome assessors blinded to the exposure status of participants?			
13. Was loss to follow-up after baseline 20% or less?			
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?			

CD = cannot determine; NR = not applicable; NA = not reported

Appendix 3. Case Report ('CARE') checklist of information to include when writing a case report

CARE case report guidelines

CARE Checklist of information to include when writing a case report

Topic	Item	Checklist item description	Reported on Line
Title	1	The diagnosis or intervention of primary focus followed by the words "case report"	
Key Words	2	2 to 5 key words that identify diagnoses or interventions in this case report, including "case report"	
Abstract (no references)	3a	Introduction: What is unique about this case and what does it add to the scientific literature?	
	3b	Main symptoms and/or important clinical findings	
	3c	The main diagnoses, therapeutic interventions, and outcomes	
	3d	Conclusion—What is the main "take-away" lesson(s) from this case?	
Introduction	4	One or two paragraphs summarizing why this case is unique (**may include references**)	
Patient Information	5a	De-identified patient specific information.	
	5b	Primary concerns and symptoms of the patient.	
	5c	Medical, family, and psycho-social history including relevant genetic information	
	5d	Relevant past interventions with outcomes	
Clinical Findings	6	Describe significant physical examination (PE) and important clinical findings.	
Timeline	7	Historical and current information from this episode of care organized as a timeline	
Diagnostic Assessment	8a	Diagnostic testing (such as PE, laboratory testing, imaging, surveys).	
	8b	Diagnostic challenges (such as access to testing, financial, or cultural)	
	8c	Diagnosis (including other diagnoses considered)	
	8d	Prognosis (such as staging in oncology) where applicable	
Therapeutic Intervention	9a	Types of therapeutic intervention (such as pharmacologic, surgical, preventive, self-care)	
	9b	Administration of therapeutic intervention (such as dosage, strength, duration)	
	9c	Changes in therapeutic intervention (with rationale)	
Follow-up and Outcomes	10a	Clinician and patient-assessed outcomes (if available)	
	10b	Important follow-up diagnostic and other test results	
	10c	Intervention adherence and tolerability (How was this assessed?)	
	10d	Adverse and unanticipated events	
Discussion	11a	A scientific discussion of the strengths AND limitations associated with this case report	
	11b	Discussion of the relevant medical literature **with references**.	
	11c	The scientific rationale for any conclusions (including assessment of possible causes)	
	11d	The primary "take-away" lessons of this case report (without references) in a one paragraph conclusion	
Patient Perspective	12	The patient should share their perspective in one to two paragraphs on the treatment(s) they received	
Informed Consent	13	Did the patient give informed consent? Please provide if requested	Yes ☐ No ☐

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Appendix 4. Summary of steps and outcomes of surgical procedures

Author/year	Patients with RW approach (*n*)	Entry approach	RW classification	Surgical procedures	RW exposure finding & complications
Allen *et al.*, 2015[26]	3	Retrofacial	–	Case 1: a large air cell tract was opened to visualise the RW via the sinus tympani (posterior & medial to the facial nerve), then the electrode array was inserted; case 2: full insertion of electrode array through the RW	The RW could not be visualised after opening the facial recess in any of the 3 cases
Bae *et al.*, 2019[24]	377	Posterior tympanotomy	–	Modified mastoidectomy, visualisation of the RWN (the patient's head was turned toward the operator when the RW was not visualised & the posteromedial overlying bone of the facial canal was drilled out). The RWM was exposed by drilling the bony overhangs of the RW & of the posterior-superior angle, using a sharp right-angled pick to make the RWM incision	When the RWM was not exposed, the EAC was mobilised (the tympanomeatal flap was elevated, the facial recess was opened by drilling along the upper & lower limits of the recess, the bony wall was removed, then the electrode was inserted and closure was performed). The endomeatal approach was used when mastoid air cells were undeveloped (postauricular incision, elevation of the tympanomeatal flap, exposure of the middle ear, drilling of the overhanging RWN, electrode insertion through the posterosuperior meatal wall, then EAC reconstruction)
Bhavana & Bharti, 2019[30]	52	Modified Veria approach	–	A suprameatal well was created using an endaural incision & elevation of the tympanomeatal flap; the transcanal tunnel was drilled, the RWN was drilled, the electrode was inserted, followed by closure	
Chen *et al.*, 2019[19]	55	Posterior tympanotomy	Type I: entirely exposed; type II: partially exposed; type III: could not be identified	Mastoidectomy & posterior tympanotomy, followed by drilling of the EAC to allow for a wide view of the RWM, followed by insertion of the electrode using the RW approach, the ERW approach or a cochleostomy	Complete exposure
Chen *et al.*, 2018[46]	25	Endoscope-assisted posterior tympanotomy	St Thomas' Hospital classification (type I: 100%, type IIa: 51–99%, type IIb: 1–50%, & type III: 0% exposure of RWM)	Microscopic mastoidectomy with PT. Microscopic & endoscopic views were used to assess visualisation of the RWM, followed by insertion of the electrode according to the accessibility of the RWM	By microscope: type I in 8 ears, type IIa in 13, type IIb in 5 & type III in 1 ear. Improved visualisation of the RWM by endoscope rather than microscope: 13 ears with type IIa RWM to type I; 5 ears with type IIb RWM to type I ($n = 3$) & type IIa ($n = 2$); 1 ear with type III RWM to type IIa
Cheng *et al.*, 2018[21]	20; cochleostomy, 20	PT	–	Mastoidectomy then tympanotomy. The RWN was removed by drilling, followed by a slow insertion of an electrode through the incision in the RWM by a microsurgical needle or knife. Cochleostomy (anterior-inferior to the RW) was performed using a drill followed by a slow insertion of the electrode	–
Connor *et al.*, 2012[55]	32; cochleostomy, 33	PT	In-house grading system	According to RW accessibility: RWM electrode insertion, the extension of the RWM cochleostomy (antero-inferiorly) or standard bony promontory cochleostomy	–

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Appendix 4. (*Continued.*)

Author/year	Patients with RW approach (*n*)	Entry approach	RW classification	Surgical procedures	RW exposure finding & complications
Dietz *et al.*, 2016[29]	ERW, 6; cochleostomy, 1	Modified suprameatal approach (local anaesthesia)		Elevation of the tympanomeatal flap, removal of the RW bony overhang, drilling of the tunnel lateral to the short process of the incus & electrode insertion via the RWM	One case reported pain during drilling of the antrostomy
Elzayat *et al.*, 2020[51]	97	PT	St Thomas' Hospital classification. Types I (100% of the membrane) & IIa (more than 50% but less than 100%)	–	According to St Thomas' Hospital classification, the visibility of the RWM was found to be type 1, 2a, 2b, & 3 in 34%, 29%, 21% & 17% of the study population, respectively
Erixon *et al.*, 2012[56]	21	Wide exposure of the lateral surface to visualise the major part of the membrane	–	Insertion of the electrode through a vertical incision in the RWM interrupted by corticosteroid middle-ear installation	Resistance of electrode insertion. The RWM was sealed with muscle & fibrin glue around the electrode
Fan *et al.*, 2018[57]	15; cochleostomy, 9	PT	–	A standard PT approach followed by electrode insertion via the RW or cochleostomy (anterior & inferior to the RW)	–
Free *et al.*, 2013[16]	31	Canal wall down as a part of subtotal petrosectomy	–	Mastoidectomy & drilling of the pneumatised cells. Implant insertion was performed through the RWM & drilling-out in ossification cases (n = 5); the cavity was then packed with drill-out fat & antibiotics	Extrusion of the electrode ($n = 1$). Subcutaneous cerebrospinal fluid leakage ($n = 1$)
Galal *et al.*, 2019[22]	61	PT	Visible completely, partially, as a slit & non-visible	PT, detection of RWN, removal of any pseudomembranes or mucosa, localisation of RWM. When the RWN was not visualised, the incus & incus bridge were removed by cutting the chorda tympani nerve	Visible ($n = 10$); partially visible ($n = 16$); slit visible ($n = 14$); not visible ($n = 21$)
Ghonim *et al.*, 2018[48]	50	Transcanal	Visualised microscopically & endoscopically. Type 1: fully visible; type 2: partially visible; type 3: not visible	Step 1: incision in the skin of the EAC deep enough to expose the underlying bone. Step 2: tympanomeatal flap elevation. Step 3: curetting a portion of the posterosuperior bony meatal wall for extended visualisation. Step 4: visualisation of the RW by microscope & otoendoscope (2.7 mm diameter & 30° angle)	By microscope, the RWN was fully visible (type 1) in 48 cases, was partially visible (type 2) in one case, & was not visible (type 3) in one case. By otoendoscope RWN features were fully visible. By endoscope, the RWM was visible in 11 cases (22%)
Gudis *et al.*, 2012[15]	111; cochleostomy. 19	Facial recess	–	Standard cortical mastoidectomy, visualisation of the RWM, removal of the RWN overhang, incision of the RWM using either a sterile 25-gauge needle or a fine-curved pick, followed by insertion of the electrode. Cochleostomy was performed (anterior-inferior to RW) if the RWM was not visualised	RW location too far posterior for atraumatic insertion ($n = 11$, 8.5%), extensive ossification ($n = 3$, 2.3%), extensive adhesions & scar tissue overlying the RW membrane ($n = 2$, 1.5%)
Hamerschmidt *et al.*, 2012[60]	17; cochleostomy, 6	PT	–	Step 1: retroauricular incision & Y-shaped periosteal flap with shifting periosteum. Step 2: mastoidectomy & PT. Step 3: cochleostomy (anterior-inferior to RW). Step 4: in cases where cochleostomy was used for implantation, the upper lip of the RW was drilled & opened with a probe. Step 5: insertion of the electrode & neural response telemetry performed	–

Hasaballah *et al.*, 2014[54]	–	–	–	Not reported	–
Hsieh *et al.*, 2019[49]	1	Endoscopic modified transcanal approach	–	Excision of tragal cartilage, postauricular incision, the elevation of tympanomeatal flap, followed by canaloplasty, use of the otoendoscope to expose the RW, then electrode insertion into the scala tympani	–
Huang *et al.*, 2006[28]	1	PT then retrofacial approach	–	Inverted J-shaped skin incision, osteo-flap creation to expose the mastoid cortex, dissection of the retrofacial air cells, visualisation of the RW & electrode insertion into the scala tympani.	Poor pneumatisation of air cells. The facial nerve was encountered. The round window was obscured by the anteriorly-inferiorly displaced facial nerve
Kang & Kim 2013[20]	55; cochleostomy, 88	PT	–	Step 1: mastoidectomy with PT then removal of any fibrous & mucosal adhesions obscuring the RWM by a fine pick & any bony overhang with a 1.5-mm diamond burr. Step 2: antero-inferior incision in the RWM corner by a fine pick. Step 3: a 0.3-mm footplate rasp was used to enlarge the opening. Step 4: slow insertion of the electrode	–
Kim *et al.*, 2021[43]	1	Transcanal	–	Dissection of the EAC skin, drilling of the posterior EAC wall until the RW pseudomembrane, followed by electrode insertion via the RW, which was fixed with fibrin glue, & then the open tunnel was covered with cartilage	–
Kluenter *et al.*, 2010[13]	16; cochleostomy, 36	PT	–	Mastoidectomy with PT, then either cochleostomy (anterior-inferior to promontorial lip of the RW) or the direct RW approach	–
Jang *et al.*, 2019[23]	39 ears	Transmastoid PT	Leong *et al.* grading system. Grade I (<25%), grade II (25–50%), & grade III (>50%)	RWM exposure through soft surgery with PT & drilling the bony overhang RWN at a low-speed (12 000 rpm) with dexamethasone	Grade I ($n = 27$ ears), grade II ($n = 13$), grade III ($n = 6$)
Jiam & Limb, 2016[58]	4; cochleostomy, 4	PT	–	PT	–
Marchioni *et al.*, 2015[4]	4 cochleostomy through RWN; promontorial cochleostomy, 1	Endoscope-assisted endomeatal approach	–	The endoscope was inserted through the EAC with the tympanomeatal flap to identify the anatomy & RWN, then removal of the tegmen followed by cochleostomy & opening the membrane using a micro-hook. When the RW was not exposed, a promontorial cochleostomy was performed. Microscopic suprameatal steps: drilling of the mastoid tunnel until the exposure of the antrum, the epitympanum & the incus, then removal of incus & insertion of the receiver-stimulator & electrode array via the cochleostomy	RWM in anomalous position ($n = 2$)

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Appendix 4. (*Continued.*)

Author/year	Patients with RW approach (*n*)	Entry approach	RW classification	Surgical procedures	RW exposure finding & complications
Marchioni *et al.*, 2016[50]	3	Endoscope-assisted transcanal approach	–	Retroauricular incision & tympanomeatal flap elevation, then use of an endoscope to identify the anatomy, followed by cochleostomy through the RW by drilling the promontory near the anterior portion of the fustis, drilling the facial recess to create a groove in the posterosuperior aspect of the EAC & intra-mastoid tunnel, then fixation of the receiver-stimulator device & insertion of the electrodes & closure	–
Migirov *et al.*, 2014[17]	6	Endoscope-assisted transcanal approach	–	Cortical mastoidectomy, elevation of the tympanomeatal flap & visualisation of the incus body, then incision on RWM & electrodes insertion medial to the chorda tympani nerve & lateral to the incus in the tunnel from the mastoid to epitympanum ($n = 7$) & into the scala tympani through the RW ($n = 6$)	–
Mostafa *et al.*, 2014[39]	110; cochleostomy, 15	Transcanal	–	Postauricular incision, the elevation of the tympanomeatal flap, canaloplasty if the RW was not exposed; through the posterosuperior meatal wall & bony bridge, the RWN was drilled out & smoothed, the electrode was inserted & RWN was filled with hyaluronic acid & dexamethasone, tucked in the depth of the meatal trough & covered by the strip of cartilage	Difficult exposure of the round window or basal calcification. Partial insertion in 10 patients. Chorda tympani injury in 6 patients
Naderpour *et al.*, 2020[25]	51; cochleostomy, 46	Transmastoid to the scala tympani & RW	–	Mastoidectomy with PT, then after RW identification, the overhang of the niche was removed. The electrode was then inserted through an antero-inferior incision in the membrane or cochleostomy (anteriorly to the RWN)	–
Nassif *et al.*, 2020[47]	8	Postauricular access & transmastoid	St Thomas' Hospital classification	Step 1: microscopic PT view with a 2 mm diamond burr. The tip of a 0°, 1.9 mm diameter & 11 cm long endoscope was positioned at the superior end of the PT. Step 2: using a 1 mm diamond micro-drill & irrigation, the bone overhanging the RW was lowered until the blue line in the anterior-inferior aspect of the promontory. Step 3: using a needle, the anterior-inferior part of the annulus of the RWM was detached from its bone. Step 3: using a microcurette or a very low speed 0.5 mm micro-drill, the corresponding thinned bone was removed until the direction of the canal was clearly visible	Type 1 ($n = 1$), type 2a ($n = 1$), type 2b ($n = 6$), & type 3 ($n = 3$)

Park *et al.*, 2015[9]	57	PT	–	Cortical mastoidectomy with PT	Assessment of difficulties scored according to cortical mastoidectomy, access to the facial recess, & access to RW: 1 = easy, 2 = moderate, 3 = difficult
Pendem *et al.*, 2014[52]	37	PT	Surgical view through PT	PT	Fully visible (*n* = 11), partially visible (*n* = 22), difficult to visualise (*n* = 4). In cases where the RWN was difficult to visualise, deeper drilling into the facial recess was performed & the microscope was adjusted depending on the type of rotation
Quang *et al.*, 2019[14]	44; cochleostomy, 50	PT	St Thomas' Hospital classification	Small retroauricular incision, dissection for the Palva flap, PT & then the RWM was visualised	
Rashad Ghoneim *et al.*, 2021[53]	45	PT	Type I: fully visible RW, type IIa: >50% of RW visible, type IIb: <50% of RW visible, type III: 0% of RW visible	PT then cochleostomy or the extended RW marginal approach were performed for the partially or non-visible RW cases	–
Rizk *et al.*, 2015[27]	2	Retrofacial	–	Case 1: The incus was malformed & the RW was posteriorly displaced & was not visualised despite maximising the facial recess opening. Using a retrofacial approach, the RW was identified, & the electrode was fully inserted via cochleostomy (anterioinferior). Case 2: Poor exposure of the RW through the facial recess, the patient had no stapes, & the course of the facial nerve was aberrant by 6 mm inferomedial to the horizontal semicircular canal. After revision of the CT scan, a subtotal petrosectomy & closure of the EAC were performed, yet RW exposure remained poor. The RWM was identified using the retrofacial approach & the electrode was fully inserted via cochleostomy (antero-inferior)	–
Stuermer *et al.*, 2020[62]	RW: adult, 74; children, 21. ERW: adult, 4; children, 2	PT	St Thomas' Hospital classification	Mastoidectomy with PT, then direct electrode insertion through the RWM. Extension of the RW antero-inferiorly by a few millimetres, cochleostomy (antro-inferior)	Adult: 87% type I, 7% types IIa & IIb, & 6% type III. Paediatric group: 52% type I, 34% types IIa & IIb, & 15% type III
Stuermer *et al.*, 2019[61]	120	–	–	–	
Sürmelioğlu *et al.*, 2016[38]	38	13 suprameatal; 18 transcanal; 7 CWD	–	–	Complications: 4 TM perforations, 3 chorda tympani injuries, 2 electrode extrusions, 1 wound infection & 3 haematomas
Taibah *et al.*, 2009[18]	131	Transmeatal	–	Skin incision, tympanomeatal flap elevation, a small cortical mastoidectomy then drilling using the transcanal approach to access the promontory & the RWN at the annulus away from the facial nerve, with preservation of chorda tympani. A posteriosuperior chorda tympani tunnel was drilled from the annulus to the mastoid cavity underneath the EAC to insert the electrode	–

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Appendix 4. (*Continued.*)

Author/year	Patients with RW approach (*n*)	Entry approach	RW classification	Surgical procedures	RW exposure finding & complications
Todt *et al.*, 2009[59]		PT	–	Mastoidectomy with PT, removal of the promontorial lip, identification & opening of the RW, inferior widening of the RWN, then electrode insertion	In cases with an ossified scala tympani lumen, the scala vestibuli was identified & used for insertion
Wang *et al.*, 2017[68]	RW: 35; ERW: 15	PT	–	Small retroauricular incision, a standard partial mastoidectomy, identification of the facial nerve & opening of the facial recess, then PT in group A; the RWN was drilled off using a 1 mm slow-rotating diamond burr followed by electrode insertion through the RWM & sealing the RW with temporal muscle fascia. In group B (small facial recess, facial nerve malformation, high jugular bulb) the anterior-inferior margin of the RW was exposed & extended to the anterior-inferior margin of the RWM (1.2 mm diameter near the RW) then the electrode was inserted into the scala tympani as in group A	–
Wick *et al.*, 2017[44]	1; ERW, 2	Transcanal	–	A postauricular incision & canaloplasty to access the middle-ear space & identify the RW; if the RW could not be exposed, the expected location away from the facial nerve was selected for the cochleostomy	–

RW = round window; RWN = round window niche; EAC = external auditory canal; ERW = extended round window; PT = posterior tympanotomy; RWM = round window membrane; CT = computed tomography; CWD = canal wall down; TM = tympanic membrane