OTOLOGY

Anatomical landmarks for cochlear implantatıon in ossifıed cochleas

Rasim Yilmazer[1,5] · Emrah Karatay[2] · Sevtap Akbulut[3] · Zeynep Alkan[3] · Basar Sarikaya[4]

Abstract

Purpose In this study, we aimed to introduce the facial nerve as a new anatomical landmark which can be used in ossified cochleas during cochlear implantation. We also set out to define a safe line to preserve the internal auditory canal (IAC) while drilling the basal turn of the cochlea.

Methods Thirty patients who had temporal computed tomography (CT) were studied. The distances from the facial nerve and the round window to the IAC, carotid artery, and jugular bulb were measured in the reformatted CT images. We have created a line in the direction of the stapedial tendon from the round window to the IAC and called it ROWIAC (Round window–IAC) line. We have investigated whether this line intersects the IAC and measured the distances from this line to the IAC.

Results Fifty-four temporal CT scans were included to the study. The mean distances from the facial nerve to the IAC, carotid artery, and jugular bulb were 8.8 ± 0.9, 15.0 ± 2.0, and 12.2 ± 2.9 mm, respectively. The mean distances from the round window to these structures were 3.8 ± 0.7, 9.4 ± 2.2, and 8.3 ± 2.9 mm, respectively. ROWIAC line did not intersect the IAC in any of the patients. The mean distance between this line and the IAC was 0.8 ± 0.4 mm.

Conclusion We propose that facial nerve and ROWIAC line can be used as potential landmarks during cochlear implantation in ossified cochleas to protect the adjacent neurovascular structures.

Keywords Cochlea · Cochlear implant · Facial nerve · Round window · Internal auditory canal

Introduction

Cochlear ossification is the formation of new bone within the cochlea. Several diseases and trauma have been associated with cochlear ossification (Table 1) [1–3]. The most common cause of cochlear ossification is infection which may reach the inner ear by hematogenous, tympanic, or meningeal routes. Most bacteria and toxins use the round window membrane (tympanic route) and/or the cochlear aqueduct (meningeal route) to enter the inner ear, so pathologic bone growth most commonly occurs in the scala tympani near the round window membrane [1, 4, 5].

Cochlear ossification results in sensorineural hearing loss in all of the cases [6]. They benefit from cochlear implantation and, in those patients with partially ossified cochleas, many perform as well as patients with patent cochleas [7–9]. Smullen and Balkany [3] classified the ossified cochleas as: stage I, ossification limited to the round window area; stage II, inferior segment of basal turn up to 180°; and stage III, more than 180° of the basal turn. Stage I and II ossification are the most frequently encountered ones [10]. In stage I, new bone can often be picked away or drilled open to expose the patent scala. In stage II, inferior segment of basal turn ossification requires a drill-through procedure. The area of the round window is identified, and drilling is performed anteriorly for up to 8 mm or until a patent lumen is visualized [3, 10]. During these commonly performed procedures in ossified cohleas, there is a risk of damaging the nearby neurovascular structures such as internal carotid artery, jugular bulb, and internal auditory canal (IAC) [11–14].

✉ Rasim Yilmazer
ryno78@gmail.com

1   Department of Otolaryngology, Demiroglu Bilim University Hospital, Istanbul, Turkey

2   Department of Radiology, Kartal Dr. Lutfi Kirdar Education and Research Hospital, Istanbul, Turkey

3   Department of Otolaryngology, Yeditepe University Hospital, Istanbul, Turkey

4   Department of Radiology, University of Washington, Seattle, WA, USA

5   Florence Nightingale Atasehir Hastanesi, Kulak Burun Bogaz Anabilim Dali, Kuçukbakkalkoy Mahallesi, Isiklar Cd. 35/A, 34750 Atasehir/Istanbul, Turkey

Table 1 Common causes of cochlear ossification

Meningitis
Otosclerosis
Chronic otitis media
Ototoxic agents
Idiopathic deafness
Autoimmune disorders
Congenital deafness
Trauma
Iatrogenic injury
Viral infections

Round window has been used as a landmark in ossified cochleas to preserve the neurovascular structures lying within millimeters to the basal turn of the cochlea [11, 12]. However, while drilling the ossified round window membrane through the facial recess, this important landmark could be obscured and surgeons can lose their orientations. Inadvertant drilling of the medial side of the basal turn can result in damages to the IAC. Hence, identifying alternative landmarks would be helpful to avoid this possible and potentially devastating complication. In this study, we aimed to introduce the facial nerve to be used as a potential landmark in ossified cochleas during the cochlear implantation. We also set out to define a safe line to preserve the IAC while drilling the basal turn of the cochlea.

Materials and methods

Subjects

The methods used in this study were approved by the local ethics committee of Yeditepe University School of Medicine. Data of all patients who underwent Computed Tomography(CT) imaging at the Yeditepe University. Hospital were reviewed from January 2016 to January 2018. A total of 30 subjects who are older than 18 years of age were selected for the study. Patients with anomalies of the cochlea and second genu of the facial nerve and patients with unrecognized pyramidal eminence and stapedial tendon due to chronic otitis media or surgery were excluded from the study. All CT images of bilateral temporal bones were evaluated by one radiologist. As the ossification of the cochlea does not influence the distances which we have planned to measure, it was deemed appropriate to evaluate temporal bones with non-ossified cochleas.

Computed tomography protocol

All CT images were obtained with a 64-detector multi-slice CT (Revolution HD/GSI, GE Healthcare, Chalfont

St Giles, UK). The scanning technique was the standard temporal bone CT imaging protocol containing tube voltage of 120 kVp, tube current of 180 mA, slice thickness of 0.625 mm, matrix of 512×512, and FOV of $22\,cm \times 22\,cm$. Multiplanar reconstruction (MPR) images were obtained from high-resolution computed tomography data. The typical display included the three orthogonal CT scans (axial, coronal, and sagittal) and a fourth one for self-set oblique CT image whose changes were followed by the three orthogonal ones. The four images could be viewed at the same time and it was possible to switch to each image at the same time.

Parameter measurements

The multislice CT images were assessed in a dedicated workstation program of GE Volume Viewer v13.0 (GE Healthcare, LLC, Waukesha WI). The shortest distances to the neurovascular structures near the cochlea were measured using the facial nerve and the round window membrane as landmarks (Figs. 1, 2). We have used the inferomedial border of the round window membrane as the starting point of the measurements. We have also created a line in the direction of the stapedial tendon from the round window to the IAC and called it ROWIAC (Round window–IAC) line (Fig. 3). First, in the axial oblique cut, we have identified the stapedial tendon. Subsequently, we have moved the reference line on the same direction of the stapedial tendon (Fig. 3a). We have scrolled down to the level of the round window membrane and moved the line to the inferomedial border of the round window membrane (Fig. 3b). Then, we scrolled up to the level of the IAC and evaluated whether this line intersects the IAC. We have also measured the distances from this line to the IAC (Fig. 3c).All distances were recorded at the hundredth millimeter and then rounded to the nearest millimeter. To demonstrate the application of ROWIAC line in a real patient, we have shown the direction of this line in an adult cadaveric temporal bone (Fig. 4). The definition of the distances measured on the reformatted CT images is shown in Table 2.

Statistical analysis

Statistical analyses were performed using SPSS software (IBMSPSS statistic 25.0). Descriptive analyses were presented using means, standard deviations, and minimum and maximum values for continous data and frequecies and percentages for categorical data. The variables were investigated using Kolmogorov–Smirnov test to determine whether or not they were normally distributed. For normally distributed data, independent sample *t* test was used, and for
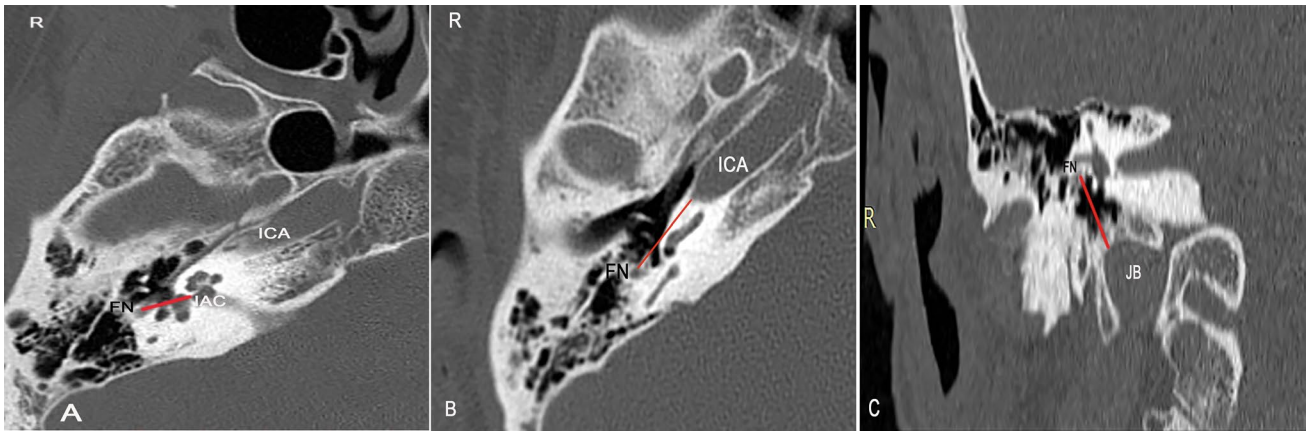
Fig. 1 The distances (red lines) from the Facial nerve (FN) to the Internal auditory canal (IAC), Internal carotid artery (ICA), and Jugular bulb (JB) are shown on the reformatted computed tomography images in figures **a** (D1), **b** (D2), and **c** (D3), respectively. *R* right, *D*1 distance 1, *D*2 distance 2, *D*3 distance 3
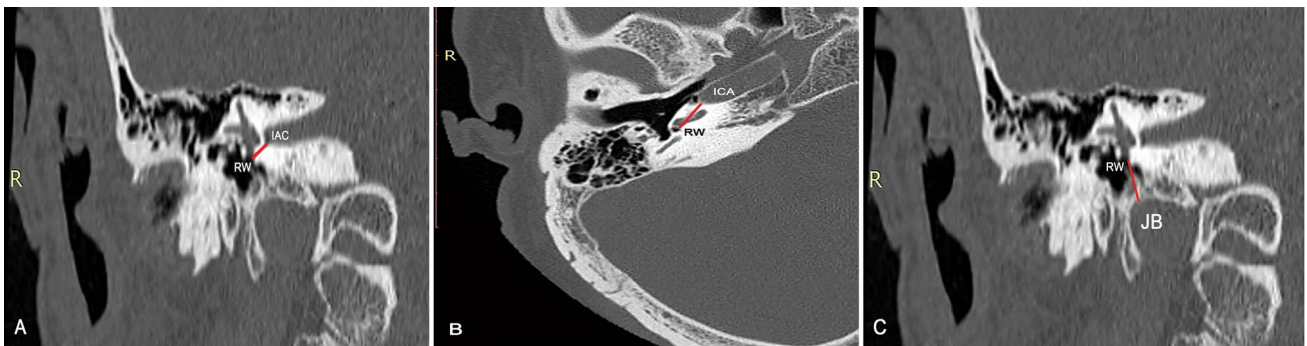

Fig. 2 The distances (red lines) from the Round window (RW) to the Internal auditory canal (IAC), Internal carotid artery (ICA), and Jugular bulb (JB) are shown on the reformatted computed tomography images in figures **a** (D4), **b** (D5), and **c** (D6), respectively. *R* right, *D*4 distance 4, *D*5 distance 5, *D*6 distance 6
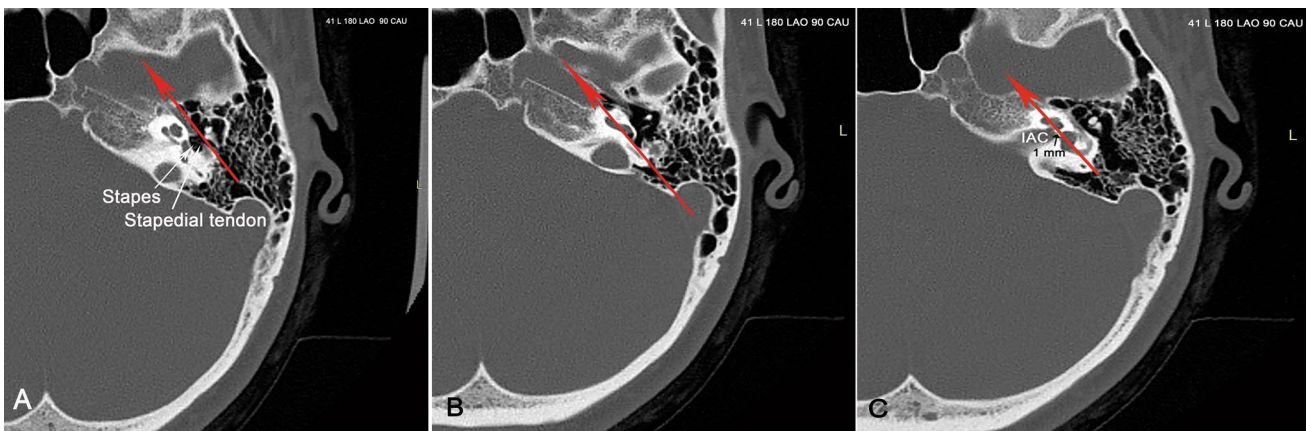

Fig. 3 The Round window–Internal auditory canal (ROWIAC) line (red arrows) is created in the direction of the stapedial tendon on the axial cut of the computed tomography images (**a**). This line is moved to the medial edge of the round window membrane (**b**). After scroll-ing the images and reference line up, the distance from the ROWIAC line to the Internal auditory canal (IAC) (D7) is shown (**c**) (Black arrow). *L* left, *D*7 distance 7
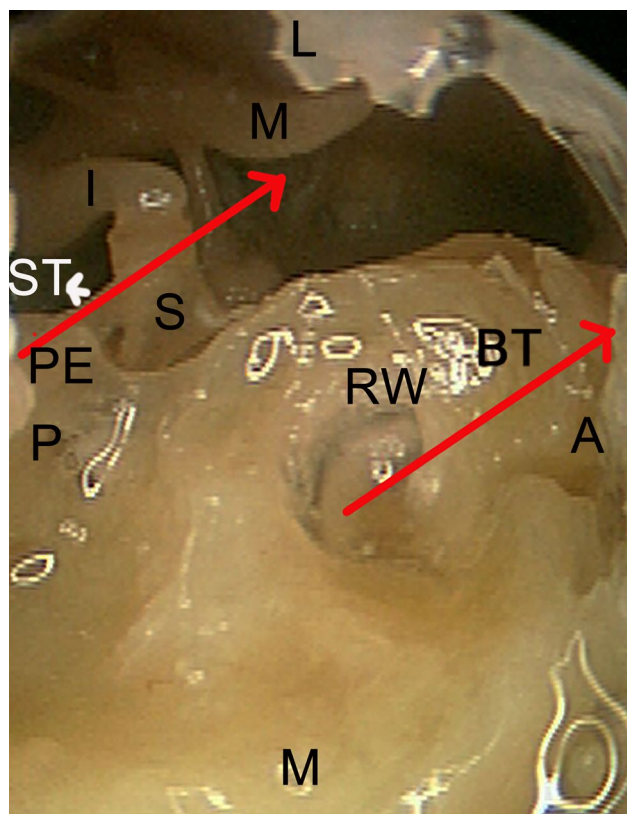
Fig. 4 The endoscopic inferior view of a right tympanic cavity from the retrofacial recess approach of an adult cadaveric temporal bone. Superior red arrow shows the direction of the stapedial tendon. Inferior red arrow shows the Round window–Internal auditory canal (ROWIAC) line. *L* lateral, *M* medial, *P* posterior, *A* anterior, *ST* stapedial tendon (White arrow), *PE* pyramidal eminence, *S* stapes, *I* incus, *M* malleus, *RW* round window, *BT* basal turn of the cochlea

not normally distrubuted data, Mann–Whitney *U* test was used to compare the differences between sexes and laterality. $p < 0.05$ was considered as statistically significant.

Results

Thirty patients and sixty temporal CT scans were evaluated. Of the 30 patients, 16 (53%) were female and 14 (47%) were male, with a mean age of 44.7 years (range 29–71). Six of the temporal bones were excluded, because stapes and/or stapedial tendon were not identifiable due to chronic otitis media or surgery. Fifty-four temporal CT scans were included to the study. The mean distances from the facial nerve to the IAC, carotid artery and jugular bulb were 8.8 ± 0.9, 15.0 ± 2.0, and 12.2 ± 2.9 mm, respectively. The mean distances from the round window to these structures were 3.8 ± 0.7, 9.4 ± 2.2, and 8.3 ± 2.9 mm, respectively. ROWIAC line did not intersect the IAC in any of the patients. The mean distance between this line and the IAC was 0.8 ± 0.4 mm. The descriptive statistics of the distances are shown in Table 3.

No statistical difference could be found between right and left sides. Males were found to have a longer D3 (Facial nerve-Jugular bulb, $p = 0.017$) and D6 (Round window-Jugular bulb, $p = 0.023$) in comparison to females. The distances from the facial nerve and round window to the jugular bulb were 13.2 ± 2.9 (range 7.4–20.1 mm), and 9.3 ± 3.0 (range 5.3–15.5 mm) in males, respectively. Same distances in females were 11.3 ± 2.7 (range 6.6–18.9 mm) and 7.5 ± 2.7 (range 2.0–13.1 mm), respectively.

Discussion

Cochlear implantation in ossified cochleas can be challenging to the surgeon depending on the degree of ossification within the cochlea. Since ossification mainly involves the round window area and the inferior segment of basal turn of the cochlea, a thorough understanding of the nearby anatomical structures is crucial for a safe cochlear implantation [4, 10]. Cochlea is related anteriorly to the internal carotid artery, inferiorly to the jugular bulb, and medially

Table 2 The distances measured between the landmarks and the neurovascular structures

D1	The shortest distance from the second genu of the FN to the internal auditory canal (measured in the axial oblique cut where the pyramidal eminence is most prominent)
D2	The shortest distance from the second genu of the FN to the internal carotid artery (measured in the axial oblique cut where the pyramidal eminence is most prominent)
D3	The shortest distance from the second genu of the FN to the jugular bulb (measured in the coronal oblique cut where the pyramidal eminence is most prominent)
D4	The shortest distance from the round window to the internal auditory canal (measured in the coronal oblique cut)
D5	The shortest distance from the round window to the internal carotid artery (measured in the axial oblique cut)
D6	The shortest distance from the round window to the jugular bulb (measured in the coronal oblique cut)
D7	The shortest distance from the ROWIAC line to the internal auditory canal (Measured in the axial oblique cut)

D Distance, *FN* facial nerve, *ROWIAC* Round Window-Internal Auditory Canal

Table 3 Descriptive statistics of the distances

	N	Mean	Std. deviation	Minimum	Maximum
D1 (FN-IAC)	54	8.8	0.9	6.3	11.0
D2 (FN-ICA)	54	15.0	2.0	10.7	22.1
D3 (FN-JB)	54	12.2	2.9	6.6	20.1
D4 (RW-IAC)	54	3.8	0.7	2.4	5.6
D5 (RW-ICA)	54	9.4	2.2	6.6	17.3
D6 (RW-JB)	54	8.3	2.9	2.0	15.5
D7 (ROWIAC-IAC)	54	0.8	0.4	0.0	1.6

All measurements are in millimiters (mm)

D Distance, *FN* facial nerve, *IAC* internal auditory canal, *ICA* internal carotid artery, *JB* jugular bulb, *RW* round window, *ROWIAC* Round Window-Internal Auditory Canal

to the internal auditory canal. While drilling the cochlea to open a patent scala, the surgeon is not able to visualize the adjacent neurovascular structures during the procedure as they are covered by bone. Round window is considered as an important surgical landmark to know the minimum distances of these neurovascular structures from the cochlea [3, 11, 12]. Singla et al. [11] reported the distances from the round window niche to the carotid canal and jugular fossa as 8.03 ± 1.55 and 2.98 ± 1.68, respectively. In a cadaveric study, Wysocki and Skarzynski [15] found the distance between the round window niche and the carotid canal as 8.08 ± 1.55 mm. In our study, the mean distance between the round window and the internal carotid artery was 9.4 ± 2.2 and similar to the previous studies. This distance may help to avoid internal carotid artery injury or misplacement of electrode array into carotid canal, which has been reported previously in the literature [16, 17]. The mean distance between the round window and the jugular bulb was 8.3 ± 2.9 mm, which was higher than the prior studies [11, 18]. This difference may be due to fact that the starting point of their measurements was from the inferior border of the round window niche in the cadavers. We have used the inferomedial border of the round window membrane as the starting point of the measurements in CT images. The mean distance between the round window and the IAC was 3.8 ± 0.7 mm. To the best of our knowledge, this distance has not been reported in the literature. Since this is a very short distance, the surgeon should be aware of it and keep in mind that drilling medial to the round window can cause injury to the IAC and/or misplacement of electrode array into the IAC [16, 19].

During cochlear implantation in ossified cochleas, if the surgeon fails to adequately distinguish the round window or drills the entire round window which is an important landmark, he/she may have difficulty to decide the direction of the further drilling to open a patent scala. Since no landmark had been defined other than the round window so far, we have introduced the second genu of the FN as an adjunctive

landmark in ossified cochleas. Jiang et al. [20] have reported the shortest distance between the mastoid segment of FN canal and the vertical segment of the petrous internal carotid artery as 13.33 ± 1.25 mm. However, they have not used the second genu of the FN which can be seen through the facial recess approach during cochlear implantation. We have found the distance between the second genu of the FN and the internal carotid artery as 15.0 ± 2.0 mm. Since the mastoid segment and second genu of the FN are close to each other, we have found similar results. In case of the absence of the round window as a landmark, the second genu of the FN can help the surgeon as a second landmark to protect the internal carotid artery. This landmark can also be used to avoid any inadvertent damage to the jugular bulb and IAC.

We have defined the ROWIAC line as a safe guide to prevent injury to the IAC. While creating the ROWIAC line, initially, we have determined the line according to the direction of the stapedial tendon in the axial oblique cut of CT images (Fig. 3a). Then, we have moved this line by scrolling down to the starting point which is the inferomedial edge of the round window. The direction of the ROWIAC line from the round window to the possible IAC only intersected the basal turn of the cochlea and the IAC remained superiorly (Fig. 3b). Subsequently, to investigate whether it intersects the IAC, we have scrolled this line up to the level of the IAC. It did not intersect the IAC again (Fig. 3c). If the surgeon preserves the inferomedial edge of the round window as a landmark in an ossified cochlea, and draws an imaginary line in the axial direction of the stapedial tendon from the inferomedial edge of the round window to the possible IAC anteriorly, he/she can stay away from the IAC by drilling inferolateral to this ROWIAC line. Using this line, the surgeon can prevent any injury to the IAC and/or misplacement of electrode array into the IAC even in normal cochleas [19]. Nevoux et al. [17] reported that the stapedial tendon is an important landmark to assess the proper axis for the cochleostomy. They recommend to drill for the cochleostomy in a vertical line to avoid any injury to the carotid canal. They believe that the stapedial tendon is helpful in finding the proper axis. However, in our study, we have used the stapedial tendon to avoid any injury to the IAC.

The major strength of the present study is providing a new landmark and line for protecting the neurovascular structures during cochlear implantation in normal and ossified cochleas. The major limitation of this study is that it has been performed on non-ossified cochleas. However, we do believe that these results could be sufficiently translated to the patient population with cochlear ossification as ossification should not interfered with the measurements. One of the limitations of the measurements is that if the round window membrane and niche cannot be identified clearly due to the new bone formation, our measurements cannot be used. Another important limitation of our study was the

limited sample size. Yet, we believe that as a pilot study, we hope this study paves way for further studies to be performed with larger sample sizes. Patient sample has been solely consisted of adults; therefore, applicability of these parameters in pediatric age group is uncertain.

Conclusion

In this study, the second genu of the facial nerve has been introduced as a novel anatomical landmark that can be used during cochlear implantation of adult patients with ossified cochleas to protect nearby neurovascular structures. We have also defined the ROWIAC line that can be used to preserve the IAC both in normal and ossified cohleas during cochlear implantation.

Compliance with ethical standards

References

1. Paparella MM, Sugiura S (1967) The pathology of suppurative labyrinthitis. Ann Otol Rhinol Laryngol 76:554–586
2. Suga F, Lindsay JR (1977) Labyrinthitis ossificans. Ann Otol Rhinol Laryngol 86:17–29
3. Smullen JL, Balkany TJ (2005) Implantation of the ossified cochlea. Oper Tech Otolaryngol Head Neck Surg 16:117–120
4. Kaya S, Paparella MM, Cureoglu S (2016) Pathologic Findings of the Cochlea in Labyrinthitis Ossificans Associated with the Round Window Membrane. Otolaryngol Head Neck Surg 155(4):635–640
5. deSouza C, Paparella MM, Schachern P, Yoon TH (1991) Pathology of labyrinthine ossification. J Laryngol Otol 105:621–624
6. Roland JT Jr, Coelho DH, Pantelides H, Waltzman SB (2008) Partial and double-array implantation of the ossified cochlea. Otol Neurotol 29(8):1068–1075
7. Balkany TJ, Gantz B, Nadol JB (1988) Multichannel cochlear implants in partially ossified cochleas. Ann Otol Rhinol Laryngol 97:3–7
8. Gantz BJ, McCabe BF, Tyler RS (1988) Use of multi-channel cochlear implants in obstructed and obliterated cochleas. Otolaryngol Head Neck Surg. 98:72–81
9. Hodges AV, Balkany TJ, Gomez-Marin O et al (1999) Speech recognition after implantation of the ossified cochlea. Am J Otol 20:453–456
10. Yan T, Zong F, Ma X et al (2019) Cochlear implantation in patients with ossified cochleas. Am J Otol 40(2):183–186
11. Singla A, Sahni D, Gupta AK, Loukas M, Aggarwal A (2014) Surgical anatomy of round window and its implications for cochlear implantation. Clin Anat 27:331–336
12. Singla A, Gupta T, Sahni D, Gupta AK, Aggarwal A (2017) Topography of neurovascular structures in relation to round window and how it relates to cochlear implantation. Surg Radiol Anat 39(12):1309–1316
13. Coelho DH, Roland JT Jr (2012) Implanting obstructed and malformed cochleae. Otolaryngol Clin North Am 45(1):91–110
14. Leal Mde C, Caldas Neto Sda S (2015) The anatomical orientation of the middle turn of the cochlea: importance during surgical implantation of the ossified cochlea. Otol Neurotol 36(3):406–408
15. Wysocki J, Skarzynski H (1998) Distance between the cochlea and adjacent structures related to cochlear implant surgery. Surg Radiol Anat 20:267–271
16. Ying YL, Lin JW, Oghalai JS, Williamson RA (2013) Cochlear implant electrode misplacement: incidence, evaluation, and management. Laryngoscope 123:757–766
17. Nevoux J, Loundon N, Leboulanger N, Roger G, Ducou Le Pointe Garabedian HEN (2010) Cochlear implant in the carotid canal. Case report and literature review. Int J of Pediatr Otorhinolaryngol 74:701–703
18. Jain S, Gaurkar S, Deshmukh PT et al (2019) Applied anatomy of round window and adjacent structures of tympanum related to cochlear implantation. Braz J Otorhinolaryngol 85(4):435–446
19. Mehanna AM, Gamaleldin OA, Fathalla MF (2019) The misplaced cochlear implant electrode array. Int J Pediatr Otorhinolaryngol 117:96–104
20. Jiang Y, Chen Y, Yao J, Tian Y, Su L, Li Y (2015) Anatomic assessment of petrous internal carotid artery, facial nerve, and cochlea through the anterior transpetrosal approach. J Craniofac Surg 26(7):2180–2183

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.