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Navigating the challenges of misplaced electrode array in cochlear implant surgery: causes, consequences and solutions

Mohnish Grover[1], Tanmaya Kataria[2], Sunil Samdani[1], Gaurav Gupta[3], Raghav Mehta[4] and Mukesh Dagur[5]

[1]Department of Otorhinolaryngology, SMS Medical College, Jaipur, RJ, India; [2]Department of Otorhinolaryngology, Mahatma Gandhi Medical College, Jaipur, RJ, India; [3]Department of Otorhinolaryngology, SP Medical College, Bikaner, RJ, India; [4]Department of Otorhinolaryngology, RUHS College of Medical Sciences, Jaipur, RJ, India and [5]Department of Otorhinolaryngology, RDBP Jaipuria Hospital, Jaipur, RJ, India

Main Article

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Corresponding author: Tanmaya Kataria; Email: tanmayakataria@gmail.com

Abstract

Objectives. Cochlear implantation is a groundbreaking surgical procedure offering significant benefits to individuals with severe hearing impairments. Correct placement of the electrode array within the cochlea is crucial for optimal device functionality and auditory outcomes. Our study describes four cases of electrode misplacement along with the factors causing it and discusses solutions for the same.

Methods. Eight hundred cochlear implant cases were reviewed in three tertiary care centres in India, spanning 2011 to 2023.

Results. Four cases of electrode misplacement requiring reimplantation were identified.

Conclusion. This paper discusses the implications of electrode misplacement, the factors contributing to it and the critical role of multidisciplinary approaches in managing such complications. By addressing these issues, we aim to improve surgical techniques and outcomes in cochlear implant procedures.

Introduction

Cochlear implantation is a pioneering surgical procedure that has brought hope and a new sense of normality to individuals with severe hearing impairments. As the number of cochlear implantations has increased, so has the number of revision procedures. The most likely reasons reported for revision surgery with reimplantation include wound infection and subsequent device extrusion, device failure and electrode misplacement.[1] Complication rates are low overall, with flap-related complications reported to occur in 0.26 to 2.09 per cent of cases, while electrode array-related problems occur in 0.17 to 2.12 per cent.[2] The success of cochlear implantation does not solely rely on the presence of the implant itself; it hinges on the precise placement of the electrode array within the cochlea. This critical element of the surgery determines the device's effectiveness and the recipient's ability to perceive and interpret sound. In general, the scala tympani is considered the perfect place within the cochlea to accommodate the electrode array.[3] Currently, the placement of the cochleostomy relies largely on the surgeon's real-time evaluation of key anatomical landmarks, such as the round window and its associated relationships. Electrophysiological assessments, including impedance and neural response telemetry (NRT) along with intra-operative C-arm, are used to verify the correct position of the electrode array. Though rare, the misplaced electrode array has been documented in individual case reports by various authors. This potential complication can lead to suboptimal auditory outcomes, harm to nearby vital structures and the need for subsequent revision surgery.

In this paper we will discuss our cases of electrode misplacement, uncover the factors that influence electrode placement, the consequences of misplacement and the ongoing research and advancements aimed at optimising this pivotal aspect of cochlear implant surgery.

Material and methods

This was a retrospective review of 800 cochlear implant recipients implanted from 2011 to 2023 in 3 tertiary care centres in India: SMS Medical College, Jaipur, AIIMS, Bhubaneswar and SP Medical College, Bikaner.

All those patients with congenital hearing loss with normal inner ear anatomy were included in the study, while cases with congenital inner ear malformation and

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cochlear ossification from meningitis were excluded from the study. We examined medical records to collect demographic information, pre-operative and post-operative radiological evaluations, cause of deafness, age at the time of implantation, the type of device used, and the initial number of electrodes inserted in all cases. Four patients were identified with electrode arrays that were either improperly positioned within the cochlea or extended beyond the cochlear boundaries into the surrounding structures. Reimplantation was done for four cases on the same side. The surgery was performed using the classical mastoidectomy and facial recess approach to the round window. The misplacement of the cochlear implant electrode was confirmed by high-resolution computed tomography (HRCT) of the temporal bone.

Case 1

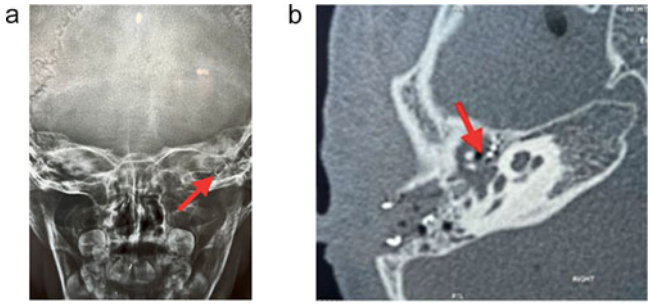


Figure 1. (a) Transorbital view radiograph showing lack of standard spiral configuration of electrode array (red arrow). (b) Axial section of HRCT temporal bone showing presence of electrode array in the middle ear (red arrow).

A 3-year-old female with congenital bilateral severe to profound sensorineural hearing loss underwent cochlear implantation after pre-operative work-up. Pre-operative otoacoustic emissions, auditory brainstem response (ABR), tympanometry, HRCT temporal bone and a magnetic resonance image (MRI) of the brain and temporal bone were done. The patient was evaluated by the Child Development Committee, with psychiatric evaluation in addition to formal speech and language evaluation. A posterior tympanotomy approach was used to the round window. The middle ear mucosa was minimally oedematous, especially on the promontory, therefore, thickened mucosa was removed from the promontory surface to aid visualisation of the round window. An extended round window cochleostomy was done, and electrodes were inserted. During insertion, there was slight resistance at the end. Normal impedance measurement was obtained immediately after implantation. Electrically evoked compound action potential (eCAP) thresholds were recorded, and it was absent in two electrodes. Due to unavailability of the C-arm, no intra-operative imaging was obtained. On post-operative day 1, an X-ray (Stenvers view) was performed, and the electrodes were found extracochlear Figure 1a. On HRCT temporal bone, the electrode was coiled in the middle ear (Figure 1b).

The patient was posted for revision surgery on post-operative day 2, and the electrodes were found to be coiled in the middle ear. The electrodes were reinserted in the cochleostomy site, and full electrode insertion was achieved. Intra-operative impedance measurement was normal, and intra-operative plain film verified the correct placement of the electrode array within the cochlea.

Case 2

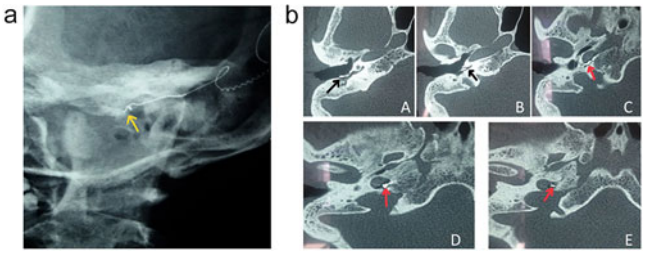


Figure 2. (a) Lack of standard spiral configuration of electrode array (yellow arrow) on modified Stenvers view radiograph of the temporal bone is suggestive of electrode misplacement. (b) Axial sections of HRCT right temporal bone show part of electrode array indicated by black arrow in the middle ear (A) that passed tangentially from cochlear basal turn (B) and then entered into the internal carotid artery canal as shown by red arrow (C, D and E).

A 60-year-old female presented to us after no significant improvement was seen after the switch-on of a cochlear implant and a few sessions of therapy. She was operated upon for right cochlear implantation, and her pre-operative audiogram showed bilateral profound sensorineural hearing loss. Auditory Brainstem Response showed bilateral severe to profound hearing loss with normal pre-operative radiology (HRCT scan of the temporal bone and MRI of the brain and cochlea). As per the operative notes, a standard mastoidectomy and posterior tympanotomy approach was taken. The round window niche was poorly visualised, thus a separate cochleostomy was created. There was suspicion of cochlear ossification; however, radiology was normal. Drilling was done through the ossification. Electrode insertion was performed through this site, and only partial insertion could be achieved. On electrophysiological testing, eCAP thresholds were obtained in only 6 electrodes (from 6 to 11) with high impedance values. Two electrodes were found to be short-circuited. On examination, otoscopy showed a posterior marginal perforation. A modified Stenvers view did not show the standard spiral configuration of the electrode array (Figure 2a).

High-resolution computed tomography of the temporal bone revealed the electrode array in the right internal carotid artery canal (ICA) (Figure 2b).

Coronal and axial sections show the misdirected electrode into the carotid canal. Instead of curving in the cochlea, the electrode passed tangentially through the initial part of the cochlear basal turn in its anterior inferior aspect and entered into the carotid canal. However, no bleeding was encountered intra-operatively or in the post-operative period, confirming no injury to the ICA. On revision surgery, the previous mastoidectomy was further drilled. The electrode array was dissected off from fibrosis and granulations. The posterior tympanotomy was enlarged too. Cochleostomy was found to be slightly inferior than usual, and no major landmarks were visible as quite a bit of promontory had been drilled. A middle-turn cochleostomy was done just inferior to the processus cochleariformis and 2 mm anterior to the oval window. The electrode array was threaded through the posterior tympanotomy and visualised in the middle ear through the elevated tympanomeatal flap, and then gently inserted in the middle turn in a retrograde manner from the middle turn towards the basal turn. An intra-operative radiograph confirmed this. Electrically evoked compound action potential threshold measurements showed responses in 14 electrodes with impedance values of 5 kΩ. Intracochlear

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placement was confirmed on post-operative computed tomography (CT) scan as well.

Case 3

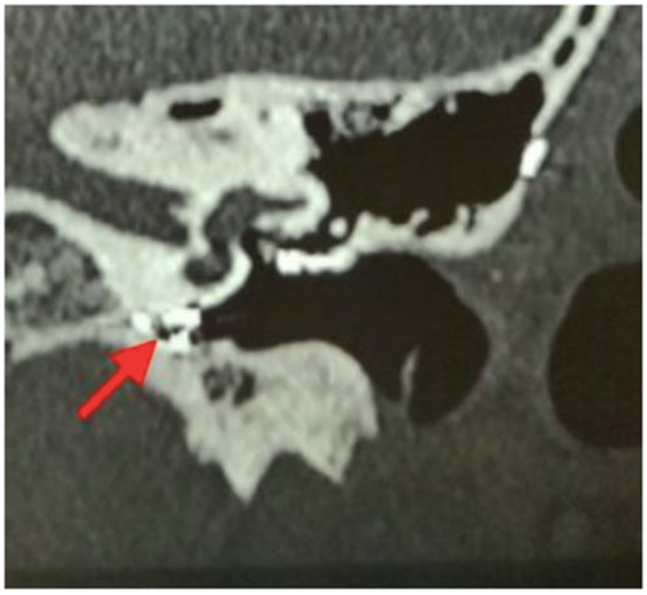


Figure 3. Coronal sections of HRCT left temporal bone show part of electrode array indicated by red arrow coiled in the hypotympanum.

A 3-year-old male was operated on for left cochlear implantation. Pre-operative otoacoustic emissions, ABR and tympanometry were done. High-resolution computed tomography of the temporal bone and MRI of the brain and temporal bone were done and were of normal anatomy. As per the operative notes, standard mastoidectomy and posterior tympanotomy approach were performed. The incudostapedial joint was identified, the round window was identified, an extended round window cochleostomy was done, and electrodes were inserted. During insertion, there was slight resistance at the end. Normal impedance measurement was obtained immediately after implantation. Electrically evoked compound action potential thresholds were measured in all electrodes and were absent in apical two electrodes. On post-operative day 1, a modified Stenvers view was done, and standard spiral configuration of the electrode array was absent. High-resolution computed tomography of the temporal bone was done, and the electrode array was found to be lying in the hypotympanum area (Figure 3).

Case 4

A 4-year-old male patient underwent right cochlear implantation for bilateral congenital profound sensorineural hearing loss. Pre-natal, natal and post-natal history was normal. Pre-operative CT and MRI showed no abnormality. Cochlear implantation was done via the veria approach. As per the operative notes, the round window was identified, and the niche was drilled to maximally expose the round window membrane. The electrode array was instead inserted through the round window membrane after incising it with a fine curved pick, no resistance was encountered while introducing the electrodes. Intra-operative eCAP thresholds were measured in all electrodes. An X-ray in Stenver's view was

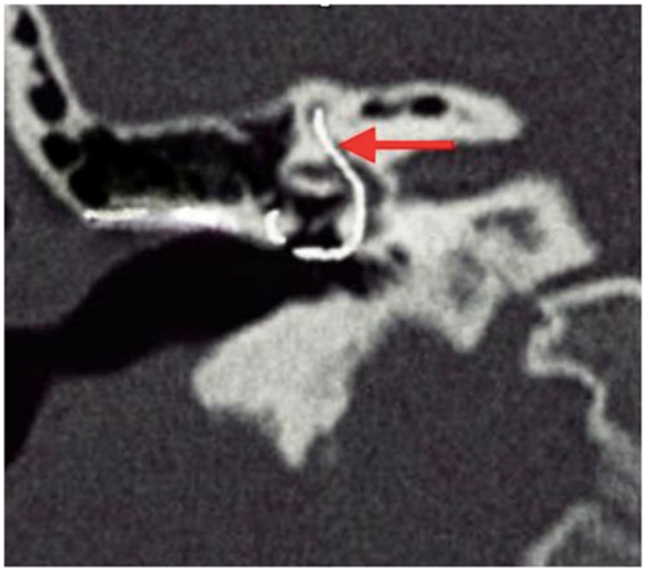


Figure 4. Coronal sections of HRCT right temporal bone show electrode array traversing through the tunnel made in external auditory canal and then deflected into the superior semicircular canal indicated by red arrow.

performed on the second day after surgery, and it showed extracochlear placement of the electrodes, therefore an HRCT temporal bone was done which indicated that the electrode array had been inserted in the superior semicircular canal (Figure 4). The revision surgery with reimplantation was performed with extended round window insertion. The position of the electrodes was confirmed by intra-operative C-arm.

Discussion

The misplacement of the electrode array in cochlear implantation as documented in the existing literature is a critical issue that can significantly impact its outcomes. In the discussion part, we will explore the key findings and insights derived from a review of relevant literature regarding the misplacement of electrode arrays, shedding light on the challenges, consequences and potential solutions. The standard location for insertion of the cochlear implant electrode array is into the scala tympani of the cochlea. As per the complication databases provided by implant manufacturers, incidents of cochlear electrode misplacement have been documented in 64 cases.[4] Additionally, electrode misalignment has been identified as the reason for cochlear implant revisions in approximately 13 to 16 per cent of cases.[5,6]

What are the possible causes?

Firstly, pre-operative radiological investigation is a sensitive tool for identifying abnormal anatomy of the middle or inner ear. Yet, a normal pre-operative scan does not exclude inner ear malformation. In some cases, it can be due to missed or unidentified inner ear malformations, including the possibility of anatomic variation of the basal turn of the cochlea. Some findings, like malformation of the osseous spiral lamina and incomplete ossification of the tympanomeningeal fissure (Hyrtl's fissure), can be missed and serve as a potential space for extracochlear misplacement of the electrode array.

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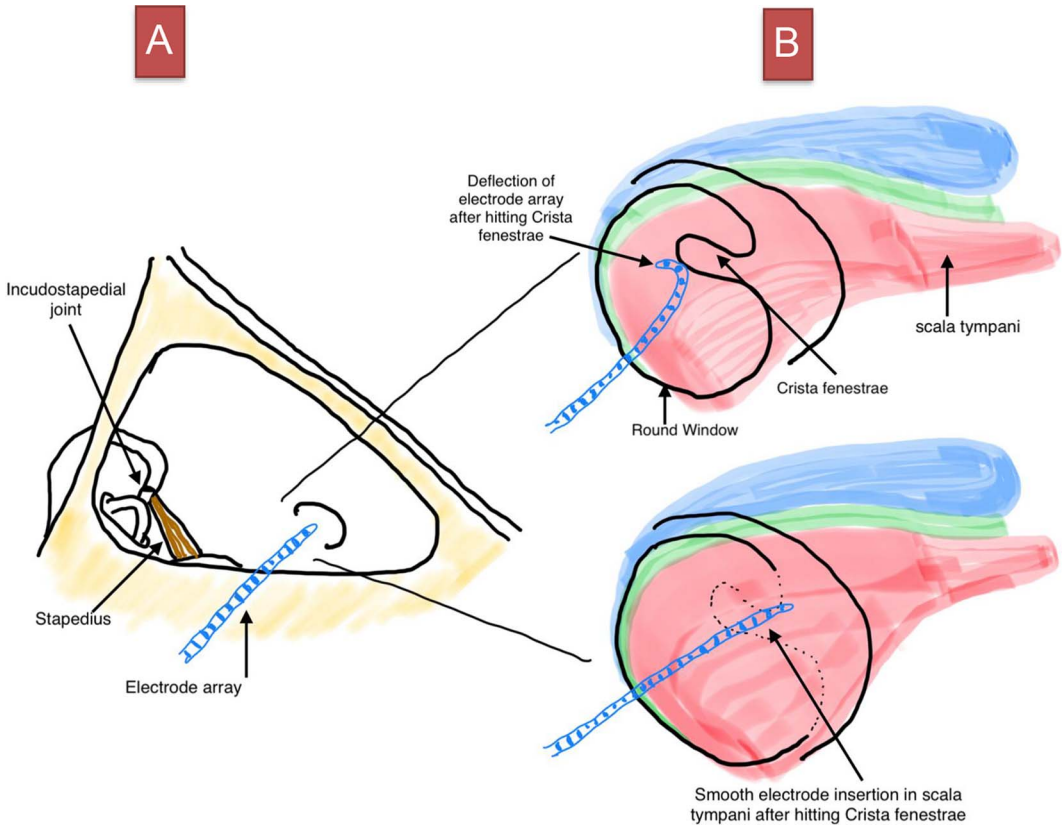


Figure 5. Sketch diagram of a posterior tympanotomy showing electrode insertion through round window. Magnified view of round window shows A) deflection of electrode array towards scala media/vestibuli after hitting crista fenestrae then B) after drilling crista fenestrae straight insertion of electrode array in anteroinferior direction in scala tympani can be seen.

Secondly, surgeons must possess the ability to accurately identify the round window niche and promontory and avoid being misled by the presence of hypotympanic air cells or any other opening because, for a beginner, the most common mistake observed during the procedure is the unintentional implantation in a hypotympanic air cell or any other opening. This can happen in an experienced surgeon's hand also when the round window niche cannot be clearly identified while dealing with fibrous or bony obstructions in the niche. Therefore, it is very important to rely on alternative landmarks, such as the position of the incudostapedial joint and oval window, once the facial recess has been opened.

Thirdly, electrode insertion through an improperly positioned cochleostomy and direction of insertion can also result in incorrect electrode placement. While inserting the electrode, if the direction of insertion is other than anteroinferior or if insertion is being done even after resistance, there is a possibility of rupture of the basilar membrane and Reissner's membrane, leading to electrode insertion into the scala media or scala vestibuli.[7] Therefore, it is important to drill out the crista fenestra region in the round window chamber as it can mislead the electrode (Figure 5).[8]

According to Jain and Mukherji, the electrode array can be unintentionally situated in various locations, including the middle ear cavity, mastoid bowl, cochlear aqueduct, petrous carotid canal, Eustachian tube, or it may only be partially inserted into the cochlea.[9]

What are the possible locations and solutions?

In our study, four cases had electrode array misplacement in the hypotympanum, middle ear, carotid canal and superior semicircular canal. On reviewing the literature, the superior semicircular canal, followed by the vestibule, are the two most common anatomic sites reported for electrode array misplacement.

Superior semicircular canal. Factors contributing to electrode misplacement in the superior semicircular canal can be the direction and angle of the electrode array during insertion and cochleostomy position. This can be due to the improper inclination of the patient's head on the operative table with respect to the surgeon, allowing for adequate visualisation of the round window membrane, and the small dimension for the cochleostomy, which did not allow adequate visualisation of the direction of the electrode array into the labyrinth.

Horizontal semicircular canal. There was one study that identified a misplaced electrode into the horizontal semicircular canal. Surgery was done by the veria technique, and a tight-fitting cochleostomy (<1.2 mm) was created. The insertion of the electrode was hampered because of the narrow anatomical situation in the middle ear. Intra-operative physiological testing showed normal results indicative of the appropriate position and function of the implant. Post-operative imaging showed the tip of the electrode in the horizontal semicircular canal after traversing through the vestibule.[10] In the reimplantation surgery, the cochleostomy was enlarged and reshaped.

Vestibule. A case report of electrode insertion via standard posterior tympanotomy approach, on immediate intra-operative implant-evoked ABR revealed that only electrodes 14 to 22 produced evoked responses, despite NRT indicating that the array was appropriately inserted in its entirety. A post-operative CT scan revealed that the middle electrodes had ended up in the vestibule. The authors put forward a potential explanation for this misplaced

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electrode, suggesting that damage to the basilar membrane during the cochleostomy procedure may have created a weakened area, allowing a portion of the array to protrude through this compromised site into the vestibule. Subsequently, during the initial mapping process, the patient experienced severe vertigo, and there were inconsistent responses to all electrical stimulation.[11] There is another case report of electrode array misplacement into the vestibule via retrofacial approach described by Beltrame *et al.*[12] This approach can create an awkward insertion angle for the electrode array.[13] In a case reported by Mehanna *et al.*, because of difficult visualisation of the round window, cochleostomy was performed superior to the round window, and full electrode insertion was done. Intra-operative electrophysiological events revealed impedance within the range of compliance, while the NRT was measured only in the last channel in the electrode array (basal electrode) and was absent in all other channels. Post-operatively, the patient developed severe vertigo and vomiting which continued overnight, HRCT revealed an electrode array coiled into the vestibule. Explantation and reimplantation of the same electrode on the same side were done on the second day, tympanomeatal flap elevation was performed to overcome the difficulty in round window exposure. Insertion of the electrode array into the vestibule was attributed to the faulty cochleostomy superior and slightly posterior to the post pillar of the round window niche.[14]

Eustachian tube. The opening of the Eustachian tube is situated in the anterior wall of the middle ear. When the round window is positioned posteriorly and facing inferiorly, it can pose a challenge for inexperienced surgeons to visualise properly. Conversely, when an opening is readily visible, it can tempt the surgeon into believing that it can be the round window, and smooth electrode insertion with minimal resistance makes that belief stronger, potentially leading to misguidance in the Eustachian tube. Therefore, it is very important to study cochlear orientation pre-operatively on HRCT temporal bone, as has been described by the authors.[15] A 1995 article from Manchester Royal Infirmary reports that out of 76 cochlear implantation patients on the cochlear implant programme, 3 cases required revision surgery. In one of these cases, a post-operative radiograph revealed the electrode array running in a direction towards the Eustachian tube orifice across the promontory.[16]

Carotid canal. The close anatomic relationship between the cochlea and the carotid artery represents a potential surgical hazard during cochlear implantation. The cochlea lies superior and posterior to the petrous carotid canal in the anterior half of the otic capsule. Carotid–cochlear interval (CCI) is the minimal distance between the petrous segment of the ICA and the basal turn of the cochlea. The small distance between the ICA and the basal turn of the cochlea might lead to potential for injury to the carotid artery during improper placement of the electrode in the cochlear implantation procedure.[17] A small-sized facial recess and then mistaking the presence of an infracochlear air cell for the round window opening can mislead the surgeon, and electrode insertion in this air cell without resistance can justify the surgeon's identification of the round window (Figure 6).

The first case report of a misplaced electrode array within the carotid canal dates to 2002. During the surgical procedure, there were no complications, and all electrodes showed normal impedance values when stimulated, except electrodes 12 and 18. When after switching on, the cochlear implant failed to elicit a response, post-operative HRCT temporal bone was done which confirmed the electrodes in the carotid canal, specifically along the inferior aspect of the basal turn of the cochlea.[18] All the published



Figure 6. Axial section of HRCT right temporal bone shows infracochlear air cell track indicated by the red arrow which can be mistakenly identified as the round window and smooth insertion of electrode can mislead the surgeon.

cases in the literature emphasise widening of the facial recess in the second surgery and obliteration of the old cochleostomy site and a new cochleostomy anterior and inferior to the round window. A comprehensive review of the literature underscores the significance of pre-operative CT scans for evaluating the close anatomical proximity between the cochlea and the carotid artery. The reported thickness of the bony separation between these two structures ranges from 0.2 to 6.2 mm.[19,20] In a study of 40 cadaveric temporal bones, it was found by authors that the CCI studied on HRCT temporal bone (0.48–4.25 mm) was similar to the interval found on dissection (0.85–4.12 mm). It is imperative to make adequate preparations to address potential haemorrhage and therefore should encompass considerations such as possible endovascular management, having a head and neck vascular surgeon readily available for transcervical control of the carotid artery and ensuring the availability of blood products.

Internal Auditory Canal (IAC). Normally, the cochlea and IAC are separated by a bone plate called the lamina cribrosa. However, this bony division may be absent in cases of a few malformations. As per the Sennaroglu classification, these include (1) a few cases of incomplete partition, (2) cochlear hypoplasia and common cavity and (3) all cases of incomplete partition.[21] As per the SMS classification, it would be all cases of congenital vascular malformation (CVM) type IIIb.[22] Whenever the lamina cribrosa is absent, there is a chance of the electrode array getting misplaced into the IAC. In such malformations, it is imperative that after insertion of the electrode array, a check radiograph should be done on the table to confirm the correct positioning. Few such case reports have been published in the literature (Research Excellence Framework: REF). If such misplacement is detected, then reinsertion needs to be done

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with the axis of insertion in a different direction, usually towards a more anterior than anteroinferior direction. Electrode insertion can also be done under fluoroscopic guidance.

Intra-operative tools

Electrophysiological measurement. The assessment of electrode impedance and the electrically evoked compound action potential allow for the evaluation of both the functionality of the implant and the condition of the interface between the electrode and the neural responsiveness of the auditory nerve. While electrical stimulation and the resulting responses from all the stimulated channels can provide valuable information for the surgeon to indirectly assess electrode placement, they do not have the capability to definitively verify the accurate positioning of the electrode array. The action potentials recorded on NRT are usually generated by the cochlear nerve, but it cannot be differentiated whether action potential has been generated from the cochlea or vestibule because they may be similar.[23] It has been reported and hypothesised in the literature that when an electrode is misplaced in the semicircular canals, stimulated channels give a near-normal neural response, which can probably be due to high stimulation intensity for the spread of current.[24]

Intra-operative radiography. Plain film or fluoroscopic imaging can be another tool used to clarify electrode placement. Detecting abnormal electrode positioning during surgery, prior to the patient waking up, provides a significant advantage over discovering malposition after the procedure. This real-time identification allows for immediate correction, thus sparing both the patient and the healthcare system from the burdens of revision surgery or suboptimal implant performance. Copeland *et al.* determined that intra-operative plain radiographs offer minimum utility when it comes to evaluating the correct placement of the electrode array.[25] On the other hand, Dirr, an advocate for intra-operative radiology stated that while electrode misplacements are infrequent, nearly half of the instances of misplacement could have been identified through intra-operative radiological imaging.[26] Intra-operative fluoroscopy plays a significant role in cases involving patients with anatomical malformations.[27] A study revealed that even when the surgeon believed the procedure was trouble-free, there was a 7 per cent likelihood of an abnormal post-operative radiograph. At NYU's specialised cochlear implant centre, where three standard intra-operative testing methods were employed (impedance measurements, NRT levels and plain radiograph), it was observed that solely the radiographic findings influenced intra-operative surgical decisions.[28]

Conclusion

Management of electrode array misplacement in cochlear implant surgery is a multifaceted challenge that demands a comprehensive approach. To ensure successful outcomes and maintain patient satisfaction, it is crucial to emphasise several key aspects of care:

- First and foremost, thorough pre-operative radiological assessment is indispensable, enabling surgeons to anticipate and address anatomical complexities.
- Cadaveric temporal bone dissection is vital for acquiring a deep understanding of the round window and its adjacent structures, facilitating precise electrode placement.
- Pre-operative treatments to manage middle ear mucosal oedema can enhance surgical success.
- Intra-operatively, electrophysiological testing and radiography play pivotal roles in confirming proper electrode positioning and prompt corrective action when needed.
- Furthermore, post-operative radiography and routine follow-up of patients contribute to long-term success.

Effective communication and collaboration with audiologists are essential for optimising cochlear implant outcomes and ensuring the highest level of patient satisfaction. By combining these critical elements, we can significantly improve results and enhance patient experiences.

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Competing interests. The authors declare none.

Ethical statement and informed consent. The study was conducted in accordance with the Declaration of Helsinkin and was approved by the Ethics Committee of the SMS Medical College Jaipur. The requirement for informed consent was waived because of the retrospective design.

References

1 Webb RL, Lehnhardt E, Clark GM, Laszig R, Pyman BC, Franz BK–HG. Surgical complications with the cochlear multiple-channel intracochlear implant: experience at Hannover and Melbourne. *Ann. Otol. Rhinol. Laryngol* 1991;**100**:131–6
2 Tange RA, Grolman W, Maat A. Intracochlear misdirected implantation of a cochlear implant. *Acta Otolaryngolog* 2006;**126**:650–2
3 Gulya AJ, Steenerson RL. The scala vestibuli for cochlear implantation. *Arch. Otolaryngol. Head Neck Surg* 1996;**122**:130–2
4 Waltzman B, Roland JT Jr. *Cochlear Implants*, 3rd edn. New York: Thieme, 2014
5 Lassig AA, Zwolan TA, Telian SA. Cochlear implant failures and revision. *Otol Neurotol* 2005;**26**:624–34
6 Marlowe AL, Chinnici JE, Rivas A, Niparko JK, Francis HW. Revision cochlear implant surgery in children: the Johns Hopkins experience. *Otol Neurotol* 2010;**31**:74–82
7 Li PM, Wang H, Northrop C, Merchant SN, Nadol JB Jr. Anatomy of the round window and hook region of the cochlea with implications for cochlear implantation and other endocochlear surgical procedures. *Otol Neurotol* 2007;**28**:641–8
8 Angeli RD, Lavinsky J, Setogutti ET, Lavinsky L. The Crista Fenestra and its impact on the surgical approach to the scala tympani during cochlear implantation. *Audiol Neurootol* 2017;**22**:50–5
9 Jain R, Mukherji SK. Cochlear implant failure: imaging evaluation of the electrode course. *Clin Radiol* 2003;**58**:288–93
10 Tange RA, Grolman W, Maat A. Intracochlear misdirected implantation of a cochlear implant. *Acta Otolaryngol* 2006;**126**:650–2
11 Pau H, Parker A, Sanli H, Gibson WPR. Displacement of electrodes of a cochlear implant into the vestibular system: intra-and postoperative electrophysiological analyses. *Acta Otolaryngol* 2005;**125**:1116–18
12 Beltrame MA, Frau GN, Shanks M, Robinson P, Anderson I. Double posterior labyrinthotomy technique: results in three Med-El patients with common cavity. *Otol Neurotol* 2005;**26**:177–82
13 Muzzi E, Boscolo-Rizzo P, Santarelli R, Beltrame MA. *J LaryngolOtol* 2012;**126**:414–17
14 Mehanna AM, Gamaleldin OA, Fathalla MF. The misplaced cochlear implant electrode array. *Int J Pediatr Otorhinolaryngol* 2019;**117**:96–104
15 Sharma S, Grover M, Singh S N, Kataria T and Lakhawat RS. Cochlear orientation: pre-operative evaluation and intra-operative significance. *J Laryngol Otol* 2018;**132**:540–3
16 Woolford TJ, Saeed SR, Boyd P, Hartley C, Ramsden RT. Cochlear reimplantation. *Ann Otol Rhinol Laryngol Suppl* 1995;**166**:449–53

https://doi.org/10.1017/S0022215125000222 Published online by Cambridge University Press

17 Cetin MA, Hatipoglu HG, Ikinciogullari A, Koseoglu S, Ozcan KM, Yuksel E, *et al*. The importance of carotid-cochlear interval in the etiology of hearing loss. *Indian J Otolaryngol Head Neck Surg* 2013;**65**:345–9
18 Gastman BR, Hirsch BE, Sando I, Fukui MB, Wargo ML. The potential risk of carotid injury in cochlear implant surgery. *Laryngoscope* 2002;**112**:262–6
19 Muren C, Wadin K, Wilbrand HF. The cochlea and the carotid canal. *Acta Radiol* 1990;**31**:33–5
20 Wysocki J, Skarzynski H. Distances between the cochlea and adjacent structures related to cochlear implant surgery. *Surg Radio Anat* 1998; **20**:267–71
21 Sennaroğlu L, Bajin MD. Classification and current management of inner ear malformations. *Balkan Med J* 2017;**34**:397–411
22 Grover M, Sharma S, Preetam C, Gupta G, Samdani S, Agarwal S, *et al*. New SMS classification of cochleovestibular malformation and its impact on decision-making. *J Laryngol Otol* 2019;**133**:368–75
23 Pau H, Parker A, Sanli H, Gibson WPR. Displacement of electrodes of a cochlear implant into the vestibular system: intra-and postoperative electrophysiological analyses. *Acta Otolaryngol* 2005;**125**: 1116–18
24 Ying YL, Lin JW, Oghalai JS, Williamson RA. Cochlear implant electrode misplacement: incidence, evaluation, and management. *Laryngoscope* 2013;**123**:757–66
25 Copeland BJ, Pillsbury HC, Buchman CA. Prospective evaluation of intraoperative cochlear implant radiographs. *Otol Neurotol* 2004;**25**: 295–97
26 Dirr F, Hempel JM, Krause E, Müller J, Berghaus A, Ertl-Wagner B, *et al*. Value of routine plain x-ray position checks after cochlear implantation. *Otol Neurotol* 2013;**34**:1666–9
27 Fishman AJ, Roland JT Jr, Alexiades G, Mierzwinski J, Cohen NL. Fluoroscopically assisted cochlear implantation. *Otol Neurotol* 2003;**24**:882–6
28 Proops DW, Stoddart RL, Donaldson I. Medical, surgical and audiological complications of the first 100 adult cochlear implant patients in Birmingham. *J Laryngol Otol* 1999;**24**(suppl):14–17

https://doi.org/10.1017/S0022215125000222 Published online by Cambridge University Press