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Optimizing Cochlear Implant Position for Magnetic Resonance Imaging of Vestibular Schwannoma

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Correspondence: In Seok Moon (ismoonmd@yuhs.ac)**Received:** 14 October 2025 | **Accepted:** 15 November 2025**Keywords:** Cochlear implants | inner ear | internal auditory canal | magnetic resonance imaging | vestibular schwannoma

ABSTRACT

Objectives: This study aimed to determine the optimal placement of the cochlear implant (CI) magnet to ensure the visibility of the inner ear and internal auditory canal (IAC) on postoperative magnetic resonance imaging (MRI) scans in patients treated for vestibular schwannoma (VS).

Methods: Nine patients who underwent CI either simultaneously with VS resection or sequentially after gamma knife surgery between January 2021 and June 2024 were retrospectively reviewed. Three patients had the CI placed in the conventional position, while six had it positioned farther from the external auditory canal (EAC) at a more vertical angle (alternative positioning). Postoperative temporal MRI scans were analyzed for inner ear and IAC visibility. Postoperative brain computed tomography (CT) scans underwent three-dimensional reconstruction to measure the distances from the CI magnet to the EAC and IAC, and the nasion–EAC–magnet angle.

Results: Among the six patients in the alternative positioning group, five showed unobstructed IAC visibility, with both magnet-to-EAC and magnet-to-IAC distances exceeding 90 mm. The remaining patient in this group, whose distances were below 90 mm, showed obscured IAC structures due to artifacts. All three patients in the conventional positioning group had distances less than 90 mm and exhibited obscured IAC visibility. A strong correlation was observed between the magnet-to-EAC and magnet-to-IAC distances.

Conclusion: Optimal positioning of the CI magnet, particularly maintaining a distance greater than 90 mm from the EAC, is crucial for achieving clear postoperative MRI visualization of the IAC in patients undergoing VS treatment.

Level of Evidence: 3.

1 | Introduction

Vestibular schwannomas (VS) are benign tumors that originate from the Schwann cells of the eighth cranial nerve [1]. Treatment strategies for VS include a “wait-and-see” approach with serial magnetic resonance imaging (MRI), surgical resection of the tumors, or stereotactic radiation therapy [2–4]. The most frequent presenting symptom is unilateral hearing loss

(99%–100%), which may result either directly from the tumor or as a consequence of treatment [4]. Hearing preservation is challenging across all treatment modalities. Regardless of the tumor management strategy, over 75% of patients experience unserviceable hearing loss at the last follow-up [5].

Cochlear implantation (CI) is the most effective method for restoring binaural hearing in patients with single-sided deafness

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(SSD) [6, 7]. However, the risk of compromised vascular supply and cochlear ossification following the surgical resection of VS suggests that implantation should be performed shortly after tumor resection [8–10]. Recently, simultaneous CI during schwannoma resection has been attempted [11–13]. Although simultaneous CI shows promising auditory performance [14], monitoring for residual or recurrent tumors through follow-up MRI presents challenges due to patient safety concerns, discomfort, and degraded image quality [15, 16]. The introduction of rotatable magnets has significantly alleviated safety concerns, including pain, magnet displacement, and demagnetization, allowing certain implants to be compatible with MRI magnetic field intensities up to 3.0 T [17–19]. However, CI magnet-related artifacts remain a problem. These artifacts can significantly degrade MRI image quality, particularly near critical structures such as the internal auditory canal (IAC) and labyrinth, which require long-term surveillance in this patient population. Several strategies have been investigated to reduce the severity of artifacts, including the removal of internal magnets [20], the selection of MRI sequences [21], adjustments to head orientation [22], and the positioning of CI [23]. A preclinical experimental study demonstrated optimal visibility of the IAC and labyrinth on 3 T MRI when the implant magnet was positioned at a nation–external auditory canal (EAC) angle of 90° or 160°, with a distance of 90 mm from the EAC [23]. To our knowledge, no previous study has assessed magnet positioning and its impact on the visibility of the IAC on postoperative MRI scans in patients who have undergone CI with VS resection. This study aimed to assess the MRI visibility following CI in patients with VS, with a focus on the optimal positioning of the CI magnet.

2 | Materials and Methods

2.1 | Study Population

This retrospective study included patients who underwent CI either simultaneously with surgical resection of the VS or sequentially following gamma knife surgery (GKS) between January 2021 and June 2024. All included patients had postoperative imaging available, including brain computed tomography (CT) and temporal MRI, which were used to assess implant positioning and visibility. A senior author performed all CI operations and surgical tumor resection. In April 2023, a change in surgical protocol was implemented: patients who underwent surgery before this date received CI with conventional positioning, without specific consideration for postoperative MRI visibility. In contrast, for patients who underwent surgery after this date, the CI magnet was positioned using an alternative strategy, guided by previous studies suggesting that MRI artifacts can be minimized by placing the implant at least 90 mm away from the EAC and at either a more vertical (90°) or horizontal (160°) angle [23, 24].

Among these options, a more vertical orientation was selected based on practical surgical considerations. Achieving a horizontal angle would have required dissection of the neck musculature from its insertion on the posterior skull base to create an adequate receiver well, increasing intraoperative bleeding and postoperative pain. Additionally, the horizontal orientation raised concerns regarding implant stability and potential migration. Although a 90° orientation would be ideal from an imaging

standpoint, it was avoided due to cosmetic concerns and anticipated difficulties, such as discomfort when wearing hats. Therefore, a 110° orientation—slightly more vertical than the commonly used 120°—was selected as a feasible compromise. The target distance from the EAC was maintained at a minimum of 90 mm, based on findings from previous studies [23, 24].

The final implant positioning was determined intraoperatively, considering individual anatomical constraints and the available length of the lead wire, which connects the receiver/stimulator to the intracochlear electrode array. Implants were positioned in the most posterosuperior location permitted by the lead wire, ensuring both secure fixation and proper electrode insertion.

This study was approved by the Institutional Review Board (IRB number: 4-2023-1367), and all procedures were conducted in accordance with relevant guidelines and regulations, including the Declaration of Helsinki. The same institution waived the requirement for written informed consent due to the retrospective design of this study.

2.2 | Image Study Protocol and Analysis

Postoperative imaging evaluation was conducted within 6 months following CI to assess the volume of any residual tumor tissue. All postoperative temporal MRI scans were performed using a 1.5 T scanner (Achieva, Philips Medical Systems, Best, NL) to minimize imaging artifacts. The standard institutional protocol involved removing the external speech processor and applying an external pressure bandage around the patient's head. Two sequences were evaluated for each postoperative MRI: T1-weighted turbo spin-echo (TSE) with gadolinium enhancement, and three-dimensional (3D) T2-weighted volume isotropic turbo spin-echo acquisition (VISTA). Images were independently evaluated by three reviewers: a board-certified neuroradiologist and two otologic surgeons. Each reviewer qualitatively assessed the visibility of the ipsilateral and contralateral inner ears and the IAC. Visual assessment was descriptively scaled in each sequence as follows: distinct artifact completely obscuring the target structure, making evaluation impossible (–); artifact present, with partial or distorted visualization of the target structure, allowing only limited evaluation (+); and no artifact visible in the target area, with target structure clearly visualized without limitation (++) [20, 25]. All assessments were performed independently, with perfect inter-rater agreement ($\kappa = 1.0$), indicating excellent consistency in the qualitative evaluation of MRI visibility.

Postoperative brain CT scans were collected and loaded into 3D Slicer (version 5.2.2, The Slicer Community, www.slicer.org). Three-dimensional models were generated from the CT images, and the distances from the CI magnet to the EAC and IAC were measured (Figure 1). The distance from the magnet to the EAC was measured in the superficial plane of the 3D reconstructed head, from the surface center of the magnet to the distal surface of the posterior border of the orifice of the cartilaginous EAC, to reflect the actual intraoperative measurement. In contrast, the distance from the magnet to the IAC was measured in the bone plane, from the surface center of the magnet to the fundus of the IAC. Additionally,

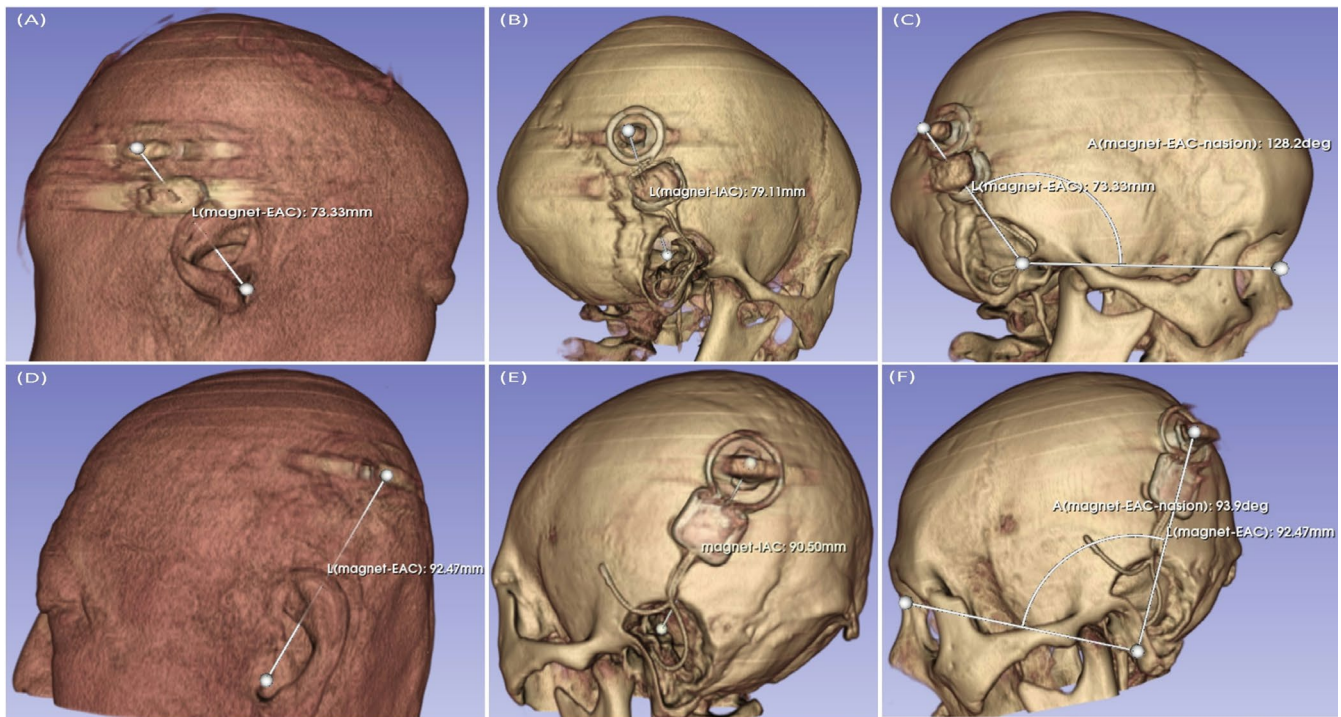


FIGURE 1 | Assessment of cochlear implant (CI) magnet position through 3D reconstruction of postoperative brain computed tomography (CT) scans using 3D Slicer. (A–C) Conventional positioning; (D–F) alternative positioning. (A, D) Lateral head view showing the distance from the CI magnet to the external auditory canal (EAC) in the superficial plane. (B, E) Oblique skull view showing the distance from the CI magnet to the internal auditory canal (IAC) in the bone plane. (C, F) Lateral skull view illustrating the distance from the CI magnet to the EAC and the angle between the magnet, EAC, and nasion.

the nasion–EAC–magnet angle was measured using 3D reconstructed lateral-view CT images of the bone plane. This angle was defined by two lines: one connecting the nasion to the EAC and the other extending from the EAC to the center of the magnet. All measurements were performed by a single reviewer using consistently defined anatomical landmarks and were reviewed for consistency in collaboration with the senior author.

Statistical analysis was performed using IBM SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized using medians and interquartile ranges (IQRs) due to the small sample size. To compare measurements between groups, the Mann–Whitney *U* test was used. The correlation between the distance from the magnet to the EAC and IAC was analyzed using Spearman's correlation. A *p* value of <0.05 was considered statistically significant.

3 | Results

Nine patients were included in this study. Among them, three patients underwent CI with conventional positioning, and six with alternative positioning (Table 1). The three patients with conventional positioning were diagnosed with unilateral sporadic VS and underwent simultaneous tumor resection. Among the six patients with alternative positioning, five underwent simultaneous tumor resection, while one underwent GKS followed by sequential CI. Two types of CI devices were implanted: the Nucleus CI622 (Cochlear, Sydney, Australia) and the Mi1250

Synchrony 2 FORM24 (MED-EL, Innsbruck, Austria). In the conventional group, two patients received the Synchrony 2, and one received the Nucleus CI622. In the alternative group, one patient received the Synchrony 2, and five received the Nucleus CI622. Both conventional and alternative positioning methods were performed without any intraoperative or postoperative complications, and all implants remained stable during the follow-up period. None of the patients reported pain, heating sensations, or other discomfort, and no adverse events occurred during postoperative MRI scans.

Each patient had a distinct CI magnet position (Table 2). In the three cases with conventional positioning, the distance from the magnet to the EAC ranged from 71.49 to 73.33 mm, and the distance from the magnet to the IAC ranged from 74.24 to 79.11 mm. The nasion–EAC–magnet angle ranged from 122.7° to 128.2°. By contrast, in the six cases with alternative positioning, the distance from the magnet to the EAC ranged from 85.52 to 95.53 mm, and the distance from the magnet to the IAC ranged from 89.52 to 95.58 mm, both of which were significantly greater than those in the conventional cases. The nasion–EAC–magnet angle ranged from 98.2° to 110.7°, which was significantly smaller than in the conventional cases. Correlation analysis between the distance from the magnet to the EAC and the distance to the IAC showed a significant positive correlation (Spearman's correlation coefficient = 0.717, *p* = 0.03) (Figure 2).

The visibility of inner ear structures on postoperative MRI also showed distinct differences between the conventional

TABLE 1 | Clinical characteristics of enrolled patients.

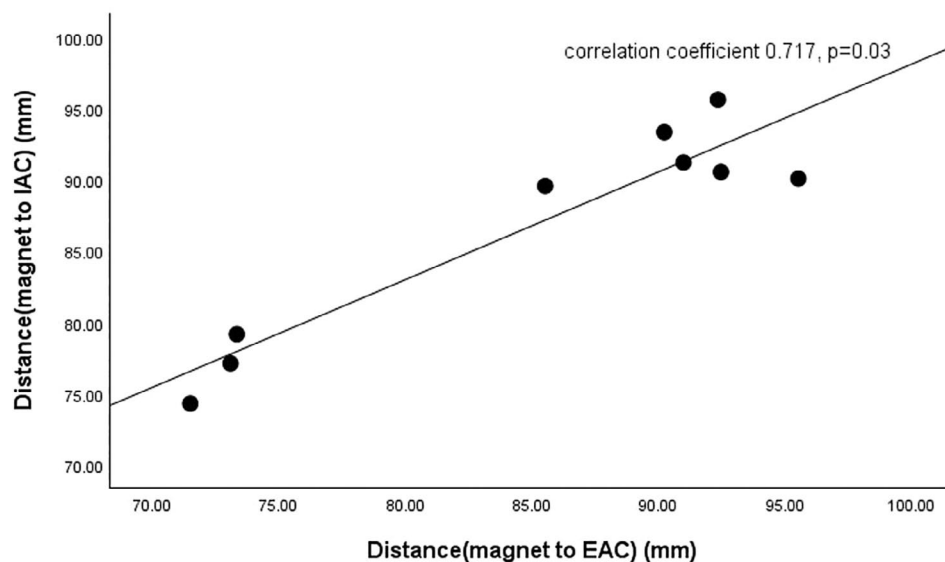
Group	Number	Sex	Age	Diagnosis	Side	Tumor size (mm)	Tumor position	Preoperative PTA4 (ipsi-/contralateral)	Approach for tumor resection	Implant
Conventional positioning group	1	F	54	Sporadic	Right	4	Intrameatal	60/85	Middle cranial fossa approach	Medel FORM Mil250
	2	F	36	Sporadic	Right	6	Intrameatal	Deaf/16	Translabryrinthine approach	Medel FORM Mil250
	3	M	40	Sporadic	Left	4	Intrameatal	88/32	Endoscopic transpromontrial approach	Cochlear Nucleus 622
Alternative positioning group	4	F	69	Sporadic	Left	8	Intrameatal	Deaf/38	Translabryrinthine approach	Cochlear Nucleus 622
	5	F	45	Sporadic	Right	10	Intrameatal	Deaf/10	Translabryrinthine approach	Medel FORM Mil250
	6	F	61	NF2	Bilateral	2	Intrameatal, Cochlea	85/Deaf	Endoscopic transpromontrial approach	Cochlear Nucleus 622
	7	M	35	NF2	Bilateral	16	Intrameatal	85/41	Gamma-knife radiation	Cochlear Nucleus 622
	8	M	36	NF2	Bilateral	9	Intrameatal	55/Deaf	Retrolabryrinthine approach	Cochlear Nucleus 622
	9	M	64	Sporadic	Left	10	Intrameatal	39/59	Translabryrinthine approach	Cochlear Nucleus 622

Abbreviations: NF2, neurofibromatosis type 2; PTA4, average pure-tone audiometry (0, 5, 1, 2, and 4 kHz).

TABLE 2 | Location of cochlear implant magnet and visibility of inner ear structures on postoperative MRI.

Group	Number	Distance EAC–magnet (mm)	Distance IAC–magnet (mm)	Angle nasion– EAC–magnet (°)	Visibility of the inner ear			
					Ipsilateral		Contralateral	
					T1	T2	T1	T2
Conventional positioning group	1	71.49	74.24	122.7	–	–	++	++
	2	73.33	79.11	128.2	+	–	++	++
	3	73.08	77.06	123.2	–	–	++	++
Alternative positioning group	4	85.52	89.52	106.1	+	–	++	++
	5	95.53	90.04	106.3	++	++	++	++
	6	90.99	91.17	98.2	++	++	++	++
	7	90.23	93.30	109.9	++	++	++	++
	8	92.35	95.58	110.7	++	++	++	++
	9	92.47	90.50	93.9	++	++	++	++

Abbreviations: EAC, external auditory canal; IAC, internal auditory canal.

**FIGURE 2** | Correlation between the distance from the cochlear implant (CI) magnet to the external auditory canal (EAC) and the distance from the CI magnet to the internal auditory canal (IAC). Each point represents an individual measurement point. Spearman's correlation coefficient was 0.717, indicating a strong positive correlation between the two distances ($p=0.03$).

and alternative groups (Table 2). In all cases, the contralateral side was visible without interference from artifacts on postoperative MRI. In patients with conventional positioning, the ipsilateral inner ear and IAC were not visible on postoperative MRI in either T1- or T2-weighted sequences (Figure 3A). In contrast, most patients who underwent CI with alternative positioning had clear visibility on MRI (Figure 3B). Visibility of the IAC was determined based on a distance of 90 mm from the magnet to the EAC and IAC. Although six patients underwent CI with alternative positioning, one with a distance of less than 90 mm had distorted and obscured inner ear structures due to artifacts, particularly in T2-weighted sequences. In the other five patients with distances greater than 90 mm, the visual assessment of the structures of interest was not limited by implant-related artifacts in either T1- or T2-weighted

sequences. All three patients in the conventional group had distances less than 90 mm from the magnet to the EAC and IAC.

When the enrolled patients were grouped according to the IAC visibility (fully visible, $n=5$; partially or not visible, $n=4$), the distances from the magnet to both the EAC and the IAC were significantly greater in the fully visible group. Specifically, the median distance from the magnet to the EAC was 92.35 mm (IQR 90.61–94.0) in the fully visible group, compared to 73.21 mm (IQR 71.89–82.47) in the partially or not visible group ($p=0.016$). Similarly, the median distance from the magnet to the IAC was 91.17 mm (IQR 90.27–94.44) in the fully visible group, compared to 78.09 mm (IQR 74.95–86.92) in the partially or not visible group ($p=0.016$). However, the

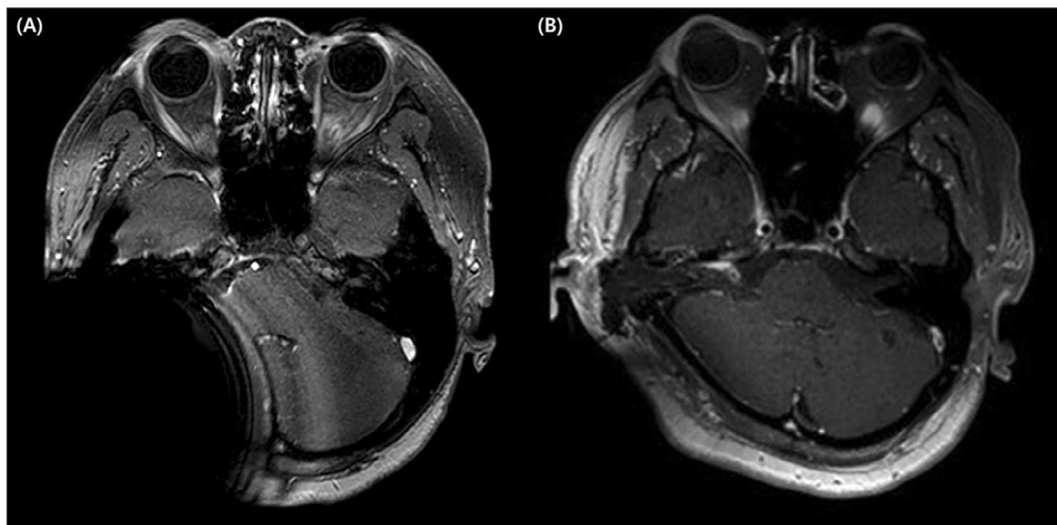


FIGURE 3 | Postoperative magnetic resonance image of patients. Axial turbo spin echo (TSE) T1 with gadolinium enhancement images were obtained at 1.5T at the level of the original tumor for each patient. (A) Magnetic artifact obscured the inner ear and internal auditory canal in a patient with the conventional positioning (Patient No. 1). (B) Inner ear and internal auditory canal are fully accessible without any interference from magnetic artifacts, with the alternative positioning (Patient No. 5).

nasion–EAC–magnet angle did not differ significantly between the two groups (median 106.3°, IQR 96.05–110.3 vs. 122.95°, IQR 110.25–126.95; $p = 0.111$).

4 | Discussion

Simultaneous or sequential CI with VS resection is considered the most effective approach for restoring hearing in cases of SSD resulting from either tumor resection or the tumor itself [14]. However, this approach presents two challenges: assessing cochlear nerve conduction and enabling postoperative surveillance using MRI. Manufacturers have addressed safety concerns related to MRI compatibility by incorporating rotational magnets that self-align within the implant housing, thereby reducing pain, displacement, and demagnetization during MRI scans [26]. However, the extent of artifacts produced by CI requires further resolution. Artifact-induced obscuration of the IAC on postoperative MRI is particularly concerning, as it may hinder the early detection of residual or recurrent tumors following VS resection. Several studies have reported that MRI artifacts can impair the assessment of vestibulocochlear structures when the CI magnet is in place [20, 27]. One study reported that 12%–14% of scans failed to provide an adequate view of the IAC or cerebellopontine angle [28]. Similarly, another study found that among 14 scans, the ipsilateral IAC was fully visible in four cases, partially visible in nine, and not visible in one [29]. In our study, IAC visibility was impaired in all patients with conventional CI positioning, indicating that such artifact-related limitations are relatively common.

The location of the implant is a key factor influencing the assessment of the IAC and labyrinth on MRI. Several studies have focused on positioning the implant at an optimal location for IAC visibility, which is at least 90 mm away from the EAC and at a more vertical (90°) or horizontal (160°) angle [23, 30]. These studies were conducted in preclinical settings, where implants were fixed onto the heads of participants using tight dressings

in various positions, and the heads were scanned using MRI. To our knowledge, few studies have investigated the interference of CI magnets with MRI surveillance of schwannomas in actual patients. Because external magnet placement on the skin surface can differ from implanted magnets due to variations in scalp thickness, measurements conducted in patients who have received CI can provide more accurate evidence. Furthermore, the angles previously proposed as alternatives in preclinical studies (90° and 160°) may pose practical challenges to implementation in patients, leading to cosmetic concerns, difficulties in detecting sound direction, and discomfort when wearing headgear or lying down. Additionally, such positioning may increase surgical complexity and raise concerns about implant stability and the risk of migration. The available length of the electrode lead must also be considered, as it limits how far the receiver can be positioned. Therefore, this study is valuable because it provides implant locations that can be feasibly applied to patients.

In this study, positioning the CI magnet at least 90 mm away from the EAC and IAC, and adopting a more vertical angle, enabled visualization of the IAC and labyrinth structures on 1.5T MRI scans. The resultant image quality of the postoperative MRI was deemed suitable for monitoring residual or recurrent schwannomas. Because the magnet-to-IAC distance could not be measured during surgery, we analyzed the correlation between the magnet-to-EAC distance and the magnet-to-IAC distance and found a strong positive correlation. Therefore, ensuring a magnet-to-EAC distance greater than 90 mm is likely sufficient. Additionally, previous studies evaluating MRI artifacts after magnet removal have shown that the artifact size caused by electrode and receiver components is minimal, typically with a maximum diameter of 1.0 cm on 1.5T MRI, affecting only peripheral regions such as the lateral parietal and occipital lobes [20, 31]. These findings suggest that, for postoperative MRI visualization, proper magnet placement alone may be sufficient, without the need for additional consideration of receiver or electrode positioning.

In the alternative group, the magnet-to-EAC distance and nasion–EAC–magnet angle were initially set at 90 mm and 110°, respectively, based on findings from previous studies [23, 30]. However, actual placement varied slightly due to skull curvature and limitations on lead wire length. Patients with full IAC visibility had significantly greater distances, whereas the angles showed no significant difference. Although angle was included in our analysis due to its potential relevance reported in earlier studies, it has limited clinical utility in practice. In real-world CI surgery, the skull surface is often curved and irregular, making it difficult to maintain a specific angle intraoperatively. Therefore, while angle optimization may offer some benefit, our findings suggest that ensuring sufficient distance is a more critical and feasible factor for improving postoperative MRI visibility.

The two types of CI magnet systems used in this study—Nucleus (Cochlear) and Synchrony 2 (MED-EL)—feature rotatable, self-aligning magnets compatible with MRI scans at 1.5 and 3.0 T. Although the proportion of CI types differed between the two groups and the sample size was insufficient for statistical analysis, IAC visibility did not vary by magnet type. The 90 mm distance threshold consistently determined IAC visibility, regardless of CI type. This finding is consistent with that of a previous study [32]. However, further studies are required to confirm these observations.

Regarding the differences between sequences, reports have shown that T2-weighted non-3D sequences provide better visibility of the IAC and labyrinth [21, 30, 33]. However, because the routine protocol in our institution for temporal MRI adopts 3D VISTA for T2-weighted sequences, we analyzed 3D T2-weighted sequences along with T1-weighted gadolinium-enhanced sequences in this study. Nevertheless, if the distance condition was fulfilled, visibility of the IAC and labyrinth was ensured, even with this sequence.

MRI artifacts at 3 T, caused by conventionally inserted CI magnets, have been reported to make it highly difficult to assess inner ear structures [27]. Therefore, our institution currently opts for a 1.5 T MRI for postoperative imaging after CI. However, Todt et al. demonstrated that with strategic positioning of the implant, visual assessment of the inner ear could be ensured even with 3 T MRI [23]. With the continuing trend toward higher-field-strength MRI, the compatibility of CI with 3 T MRI is becoming increasingly essential. Further clinical studies are necessary to ensure the visibility of inner ear structures with strategic CI positioning on 3 T MRI.

This study had certain limitations. First, the number of included patients was limited due to the low incidence of this disease and the recently adopted concept of simultaneous CI. Although statistical analyses were performed and revealed significant associations, the small sample size may limit the generalizability of the findings. Future studies with larger cohorts are needed to validate and expand upon these results. Second, due to its retrospective clinical design, various distances and angles could not be examined as in preclinical studies. However, the distances and angles documented in this study can feasibly be applied to actual patients. Third, we did not perform quantitative measurements of artifact size or shape, as no standardized methodology currently exists, and the extent of the artifact can vary

considerably depending on the MRI sequences and parameters used. Instead, our assessment focused on the clinical visibility of key anatomical regions.

In conclusion, monitoring residual or recurrent VS using 1.5 T MRI is feasible with optimal magnet placement. The magnet should be positioned at least 90 mm away from the EAC.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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