Original Investigation

Adverse Events and Discomfort During Magnetic Resonance Imaging in Cochlear Implant Recipients

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IMPORTANCE Patients with cochlear implants (CIs) should be fully informed before undergoing magnetic resonance imaging (MRI) about the possibility of discomfort or pain. Prior to an MRI scan, patients need to fully understand not only the potential complications but also the potential discomfort that they may experience during the scan.

OBJECTIVE To assess the adverse events during MRI in patients with CIs and to investigate the safety and diagnostic efficiency of MRI in patients with CIs with internal magnets.

DESIGN, SETTING, AND PARTICIPANTS Retrospective review of the medical records of 18 patients with CIs undergoing MRI between September 2003 and February 2014 at a single tertiary referral center.

INTERVENTIONS Sixteen patients underwent MRI in a 1.5-T scanner, and 2 patients underwent MRI in a 3.0-T scanner. Twelve brain MRI scans were performed, and 18 MRI scans were performed in areas outside the brain.

MAIN OUTCOMES AND MEASURES Discomfort or pain, adverse events, and auditory performance after MRI were evaluated using medical records or interviews.

RESULTS Thirteen of 18 patients completed their MRI scans (25 of 30 scans). Five patients with head bandages were unable to complete their MRI scans owing to pain; one of these patients experienced magnet displacement, and another underwent surgery for magnet removal and reinsertion. Finally, 1 patient experienced polarity reversal of the magnet. Artifacts induced by the CI internal magnet compromised the diagnosis of ipsilateral brain lesions under 1.5-T MRI. Auditory performance in the CI recipients who had major events was unaffected.

CONCLUSIONS AND RELEVANCE Even with protective head bandages, 1.5-T MRI in patients with CIs led to a variety of adverse events, including discomfort or pain and displacement of the internal magnet. Therefore, sedation and careful head positioning may be appropriate for some patients with CIs who undergo MRI, and these patients should be carefully monitored to decrease the likelihood of such adverse effects.

Invited Commentary

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A cochlear implant (CI) can be an effective means of rehabilitation for patients with severe to profound sensorineural hearing loss. The number of CI recipients now exceeds 300 000 worldwide and is rapidly increasing.[1] However, undergoing magnetic resonance imaging (MRI), which is used during the evaluation of a variety of conditions, can pose significant concerns for CI recipients. Developments in MRI technologies have enabled the generation of high-resolution images, which generally require the use of instruments with 1.5-T to 3.0-T field strengths. In the past, CIs were thought to be incompatible with MRI because the internal magnet located within the CI receiver can generate significant torque when placed in a strong electromagnetic field, which can dislodge the implant.[2] Additionally, these internal magnets can induce artifacts in MRI scans, which is also true for the receiver coil and electrode, albeit to a lesser extent. Therefore, the primary issue for patients with CIs who undergo MRI is exposure of the internal magnet to a strong electromagnetic field, which can induce significant magnetic forces and cause serious problems.

However, the US Food and Drug Administration (FDA) has allowed the use of MRI on patients with CIs in specific cases under certain conditions of use.[3] For example, MED-EL implants (Sonata, Pulsar, Concert, and Concert Pin; MED-EL GmbH) were approved for use with MRI instruments involving field strengths up to 1.5 T, as long as head dressings were used. Furthermore, CIs with removable magnets, such as the Nucleus Freedom, Nucleus 24, certain Nucleus 22 models (Cochlear Ltd), and Clarion HiRes 90K (Advanced Bionics AG) were approved for use with MRI systems up to 1.5 T following removal of the internal magnet.

There have been several reports of adverse events, such as magnet displacement and polarity changes, following MRI in patients with CIs. Hassepass et al[4] also described a series of revision surgeries involving magnet removal or replacement, and they suggested that the use of compressive bandages during 1.5-T MRI does not eliminate the risk for dislocation of the internal magnet. In contrast, Crane et al[5] reported that 16 patients with CIs and head bandages safely underwent 1.5-T MRI and that the images obtained were adequate. A separate case report detailed another CI recipient who safely underwent 1.5-T MRI without adverse effects.[6] Therefore, the safety of MRI for patients with CIs has yet to be definitively demonstrated, and the compatibility of MRI with CIs is becoming an increasingly important topic.

The present study was conducted to assess the various problems that may occur during MRI in CI recipients with internal magnets. Furthermore, we investigated the safety and diagnostic efficiency of MRI in patients with CIs with internal magnets.

Methods

This retrospective medical record review was approved by the institutional review board of Severance Hospital, Yonsei University Health System. Written informed consent was obtained from all patients.

Study Participants

Between September 2003 and February 2014, 18 patients (7 male and 11 female) with CIs who underwent MRI were included in this study (mean [SD] age, 33.4 [24.2] years; range, 1-77 years). The mean age at which the patients received their CIs was 28.7 (24.1) years (range, 1-66 years). All patients had received their CIs at the authors' institution between 1992 and 2013, and the CI devices were from 3 major companies: Cochlea, MED-EL, and Advanced Bionics. All of the implants had been immobilized using double-stitch sutures. The characteristics of patients and reasons for MRI are summarized in **Table 1**. Discomfort or pain registered at the receiver site during the event was evaluated using medical records and/or interviews with the patients or their parents.

Head Bandage and MRI

All 18 patients underwent MRI following CI, and a total of 30 MRI examinations were performed. Patients 5 and 9 did not visit the authors' office but instead underwent MRI in a 3.0-T scanner without head bandaging. Patients 13 and 18 visited the authors' office, where they were informed about head bandaging for 1.5-T MRI scans, but then they subsequently underwent MRI with gauze bandages at a local clinic. The other 14 patients underwent their MRI scans with head bandages placed over the implants at the authors' institution. In 7 cases (patients 1, 2, 4, 11, 12, 14, and 16), gauze and an elastic bandage were wrapped around the head (gauze bandage group); in the other 7 cases (patients 3, 6, 7, 8, 10, 15, and 17), gauze, an elastic bandage, and a mold were used (mold + gauze bandage group). In all cases, the speech processor of the CI was removed. For the gauze bandage group, the gauze was attached to the area surrounding the internal magnet. For the mold + gauze bandage group, molding material used in hearing aids was applied to the area surrounding the internal magnet and covered with gauze, and an elastic bandage was tightly wrapped around the head to compress the mold. Adhesive tape was then used to affix the mold + gauze bandage (**Figure 1**).

The MRI examinations were performed using 1.5-T MRI systems for 16 patients and a 3.0-T scanner for 2 patients (patients 5 and 9, who did not visit the otolaryngologist). The MRI machines used were the Philips Achieva (Philips Medical Systems), the GE Discovery MR750 and SIGNA HDxt (GE Healthcare), and the Siemens Magnetom Essenza (Siemens Corporation).

Five patients (patients 4, 10, 12, 14, and 16) underwent MRI under general anesthesia with intravenous propofol, 1%, at a rate of 6 mg/kg/h because they were too young to tolerate the MRI scans. Following the MRI scans, the head bandages were removed. Modified Stenvers views or skull anteroposterior-lateral views were obtained in case patients had discomfort or pain.

Results

Events and Complications

Thirteen of the 18 patients completed their MRI scans (25 of 30 scans). Among this group, 2 patients (patients 5 and 9) underwent 3.0-T MRI with no bandaging, and no major adverse events or complications were observed for either patient. Pa-

Table 1. Characteristics of the CI Recipients

Patient No./ Sex/Age at CI, y	CI Device[a]	MRI Site	Reason for MRI	MRI Machine[b]	MRI Field Strength
1/M/24	Nucleus CI 24RE(CA)	Knee	Degenerative osteoarthritis	Philips Achieva	1.5 T
2/F/25	Nucleus CI 24RE(CA)	Lumbar spine (×2)	Malignant ependymoma, spinal cord	Philips Achieva	1.5 T
3/M/17	Nucleus CI 24RE(CA)	Knee (×3)	Ruptured anterior cruciate ligament	Philips Achieva	1.5 T
4/M/1	Nucleus CI 24RE(CA)[c]	Brain	Bacterial meningitis	Philips Achieva	1.5 T
5/F/17	Nucleus CI22M	Knee	Tear of discoid lateral meniscus	Discovery MR750	3.0 T
6/F/66	Nucleus CI 24RE(CA)	Brain	Traffic crash	Philips Achieva	1.5 T
7/F/54	Nucleus CI 24RE(CA)	Cervical spine	Traffic crash	Philips Achieva	1.5 T
8/F/66	Nucleus CI 24RE(CA)	Brain	Optic neuritis	Philips Achieva	1.5 T
9/F/38	Nucleus CI22M	Shoulder	Chronic pain	Philips Achieva	3.0 T
10/F/11	Nucleus CI512	Whole spine	Thoracic scoliosis	Philips Achieva	1.5 T
11/F/25	Clarion CII	Thigh	Degenerative osteoarthritis	Philips Achieva	1.5 T
12/M/2	Clarion CII	Brain	Preoperative evaluation before ABI	Philips Achieva	1.5 T
13/F/65	Clarion HiRes 90K	Right knee Left knee Lumbar spine	Degenerative osteoarthritis	Magnetom Essenza	1.5 T
14/M/4	Clarion HiRes 90K[c]	Brain	Preoperative evaluation before ABI	Philips Achieva	1.5 T
15/M/2 (R) 15/M/9 (L) 15/M/12 (R)	Clarion CII Clarion HiRes 90K Nucleus CI422	Brain (×3)	Diabetes insipidus Langerhans cell histiocytosis	Philips Achieva	1.5 T
16/F/6	MED-EL Combi 40+	Brain (×4) Lumbar spine (×2)	Medulloblastoma	Philips Achieva	1.5 T
17/F/60	MED-EL FLEXsoft	Thoracolumbar spine	Lumbar pain	Philips Achieva	1.5 T
18/M/35	MED-EL Pulsar	Wrist	Chronic pain	SIGNA HDxt	1.5 T

Abbreviations: ABI, auditory brainstem implant; CI, cochlear implant; L, left-side implant; MRI, magnetic resonance imaging; R, right-side implant; T, tesla.

[a] All Clarion implants are from Advanced Bionics AG; MED-EL implants, MED-EL GmbH; and Nucleus implants, Cochlear Ltd.

[b] Discovery and SIGNA machines are from GE Healthcare; Philips Achieva, Philips Medical Systems; and Magnetom Essenza, Siemens Corporation.

[c] Patient 4 had bilateral simultaneous CIs due to meningitis, and patient 14 had bilateral sequential CIs.

tient 5 underwent 3.0-T MRI of the knee, an area far from the head. In contrast, patient 9 underwent 3.0-T MRI of the shoulder and reported discomfort during the procedure, likely due to the greater proximity of the scanned area to the head.

Five patients (patients 2, 3, 6, 10, and 15) could not complete the MRI scans owing to extreme pain, despite the fact that all had gauze bandages applied, with or without a mold. Patient 2 completed 1 MRI scan with a gauze bandage and reported no pain or adverse events; however, the patient then reported pain while approaching the MRI machine and was unable to undergo the second MRI scan, despite having the same protective measures as before. From the lateral view of the skull of this patient (head turned to left side 15°), it appeared that the internal magnet had been displaced outside the receiver container (**Figure 2**A). During subsequent surgical intervention, the internal magnet was found to be displaced from the retainer. The magnet was reinserted into the retainer using a microelevator (Figure 2B) and repositioned within the container (Figure 2C). Patients 3, 6, 10, and 15 were unable complete any MRI scans owing to pain during the scanning process, even with use of molds and gauze bandages.

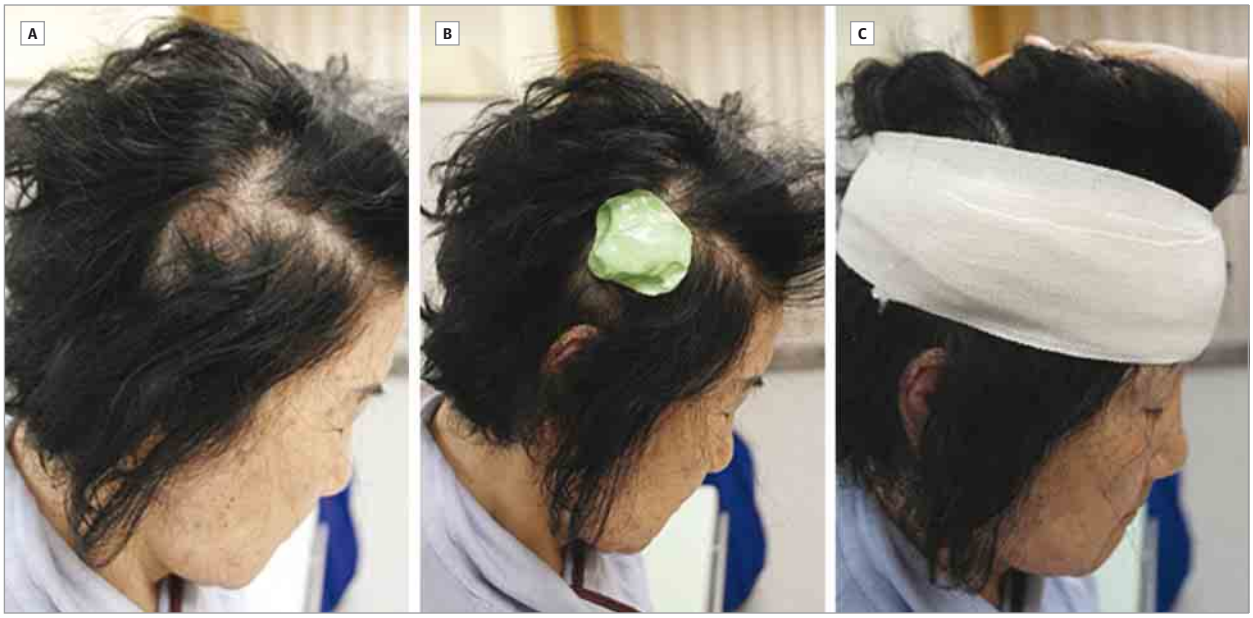
One patient (patient 13) with gauze bandaging tolerated pain and discomfort during her third MRI scan, although as previously reported,[7] the patient's CI experienced a polarity reversal of the internal magnet. **Table 2** summarizes the adverse events and complications that occurred in the patients with CIs during MRI. All patients reported that pain was localized to the implantation site of the magnet and/or antenna.

Image Quality and Artifacts

Of the 30 total attempted MRI examinations, 12 were brain scans (1 brain scan with no image in patient 6), and the remaining 18 involved other body areas. No artifacts were observed in the nonbrain MRI scans, whereas various artifacts were observed in the brain MRI scans (**Table 3**). The mean (SD) artifact size was 7.43 (2.03) cm (range, 4.55-9.87 cm) along the long axis and 4.16 (1.19) cm (range, 3.00-6.80 cm) along the short axis.

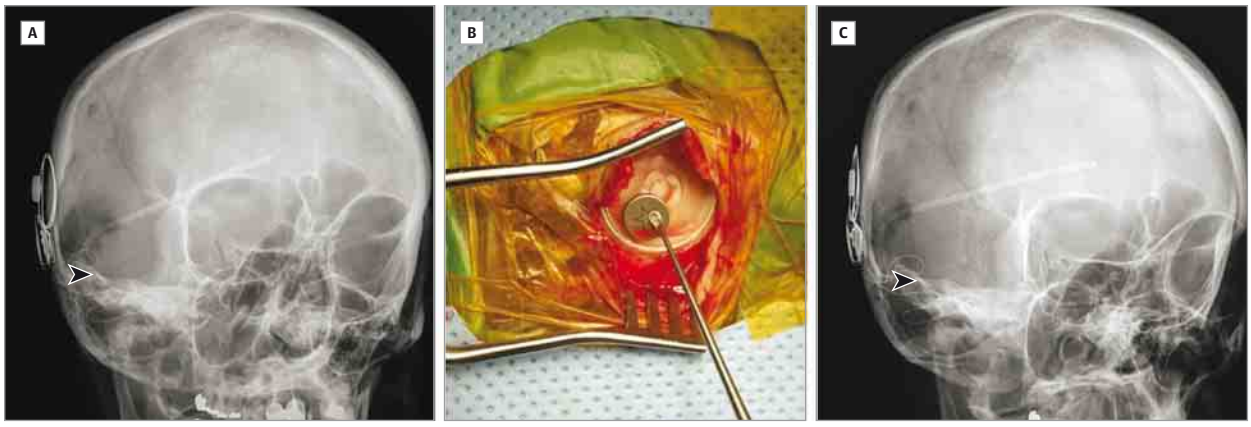
Patient 4, who had bilateral simultaneous CIs with internal magnets, showed large artifacts in the regions surrounding both implants, which compromised the diagnostic value of the scan (**Figure 3**A). Patient 15 had a Clarion HiRes 90K CI in the left side with an internal magnet, and this patient underwent a 1.5-T MRI scan with mold + gauze bandage. However, because he was unable to tolerate the MRI scans, only partial images were acquired. Following removal of the internal magnet from the Clarion HiRes 90K CI, another set of MRI scans were completed, which showed smaller artifacts than those in the previous scan. In particular, there was a large dif-

Figure 1. Applying Mold, Gauze, and Bandage Prior to Magnetic Resonance Imaging of Patient With Cochlear Implant (CI)



A, Area over CI is identified. B, Mold is applied to the scalp directly over the internal magnet of the CI. C, Elastic bandage is then tightly wrapped around the head.

Figure 2. Radiographic and Intraoperative Views of Patient Undergoing Cochlear Implant (CI) Internal Magnet Repositioning After Displacement by Magnetic Resonance Imaging (MRI)



A, Radiographic skull lateral view shows displacement of the CI internal magnet (arrowhead) caused by MRI. B, Intraoperative photograph showing repositioning of the CI internal magnet. C, Radiographic skull lateral view shows CI internal magnet (arrowhead) repositioned within the receiver container.

ference in artifact size between the left-side scans with and without the internal magnet (9.80 × 6.80 cm with magnet; 5.54 × 3.16 cm without magnet) (Figure 3B).

Auditory Performance After the MRI Scans

We examined auditory performance in 3 patients who experienced major adverse events. In particular, we compared the results of auditory function tests performed before and after the MRI scans for patients 2, 13, and 15 (**Table 4**). The sound field was checked at 250, 500, 1000, 2000, 4000, and 6000 Hz in patients 2 and 15. The average results from the hearing tests at 250, 500, 1000, and 2000 Hz were not significantly different after MRI in either patient. Patient 13 showed the same cap score before and after undergoing MRI. Overall, none of the patients showed displaced electrodes, demagnetized magnets, or any significant changes in auditory performance. However, due to several procedures involving magnet removal, magnet insertion, and CI reimplantation, patient 15 developed a postoperative wound infection requiring treatment with antibiotic medication and aseptic dressing.

Discussion

Recent studies have reported that 1.5-T MRI scans involving patients with CIs with head bandages were safe. A retrospective review of 16 patients with CIs concluded that 1.5-T MRI

Table 2. Adverse Events and Complications Observed During the MRI Scans in Patients With CIs

Patient No.	MRI Site	CI Head Protection	CI Device[a]	Pain or Discomfort	Event
1	Knee	Gauze bandage	Nucleus CI 24RE(CA)	NR	NR
2	Lumbar spine (×2)	Gauze bandage	Nucleus CI 24RE(CA)	Pain at second MRI	Incomplete MRI and magnet displacement at second MRI
3	Knee (×3)	Mold + gauze bandage	Nucleus CI 24RE(CA)	Pain at second MRI	Incomplete MRI at second MRI
4[b]	Brain	Gauze bandage	Nucleus CI 24RE(CA)	NR	NR
5	Knee	NR	Nucleus CI22 M	NR	NR
6	Brain	Mold + gauze bandage	Nucleus CI 24RE(CA)	Pain	Incomplete MRI
7	Cervical spine	Mold + gauze bandage	Nucleus CI 24RE(CA)	Discomfort	NR
8	Brain	Mold + gauze bandage	Nucleus CI 24RE(CA)	NR	NR
9	Shoulder	NR	Nucleus CI22M	Discomfort	NR
10[b]	Whole spine	Mold + gauze bandage	Nucleus CI512	Pain	Incomplete MRI
11	Thigh	Gauze bandage	Clarion CII	NR	NR
12[b]	Brain	Gauze bandage	Clarion CII	NR	NR
13	Right knee Left knee Lumbar spine	Gauze bandage	Clarion HiRes 90K	Pain at third MRI	Reversing the polarity of magnet at third MRI
14[b]	Brain	Gauze bandage	Clarion HiRes 90K	NR	NR
15	Brain (×3)	Mold + gauze bandage	Clarion CII Clarion HiRes 90K Nucleus CI422	Pain at first MRI	Incomplete MRI at first MRI
16[b]	Brain (×4) Lumbar spine (×2)	Gauze bandage	MED-EL Combi 40+	NR	NR
17	Thoracolumbar spine	Mold + gauze bandage	MED-EL FLEXsoft	NR	NR
18	Wrist	Gauze bandage	MED-EL Pulsar	NR	NR

Abbreviations: CI, cochlear implant; MRI, magnetic resonance imaging; NR, none reported.

[a] All Clarion implants are from Advanced Bionics AG; MED-EL implants, MED-EL GmbH; and Nucleus implants, Cochlear Ltd.

[b] MRI performed with patient under general anesthesia (intravenous propofol, 1%, at a rate of 6 mg/kg/h).

Table 3. Artifacts Observed in Patients With CIs Who Underwent MRI Scans That Included the Head Region

Patient No.	Artifact Size, cm		CI Device[a]	MRI	
	Long Axis	Short Axis		Intensity, T	Site
4	R 9.87 L 9.73	R 6.43 L 4.76	Nucleus CI 24RE (R)	1.5	Brain
8	R 5.67	R 3.70	Nucleus CI 24RE (R)	1.5	Brain
12	R 8.42	R 4.02	Clarion CII (R)	1.5	Brain
14	L 9.40	L 5.98	Clarion HiRes 90K (L)	1.5	Brain
15[b]	L 9.80 L 5.54 R 4.55 L 5.75	L 6.80 L 3.16 R 2.48 L 3.00	Clarion HiRes 90K (L) Clarion HiRes 90K (L) (magnet removed) Nucleus CI422 (R) (magnet removed) Clarion HiRes 90K (L) (magnet removed)	1.5 1.5 1.5	Brain Brain Brain
16	R 8.57 R 6.54 R 6.54 R 7.09	R 5.14 R 4.10 R 4.19 R 3.96	MED-EL Combi 40+ (R)	1.5	Brain Brain Brain Brain

Abbreviations: CI, cochlear implant; L, left; MRI, magnetic resonance imaging; R, right; T, tesla.

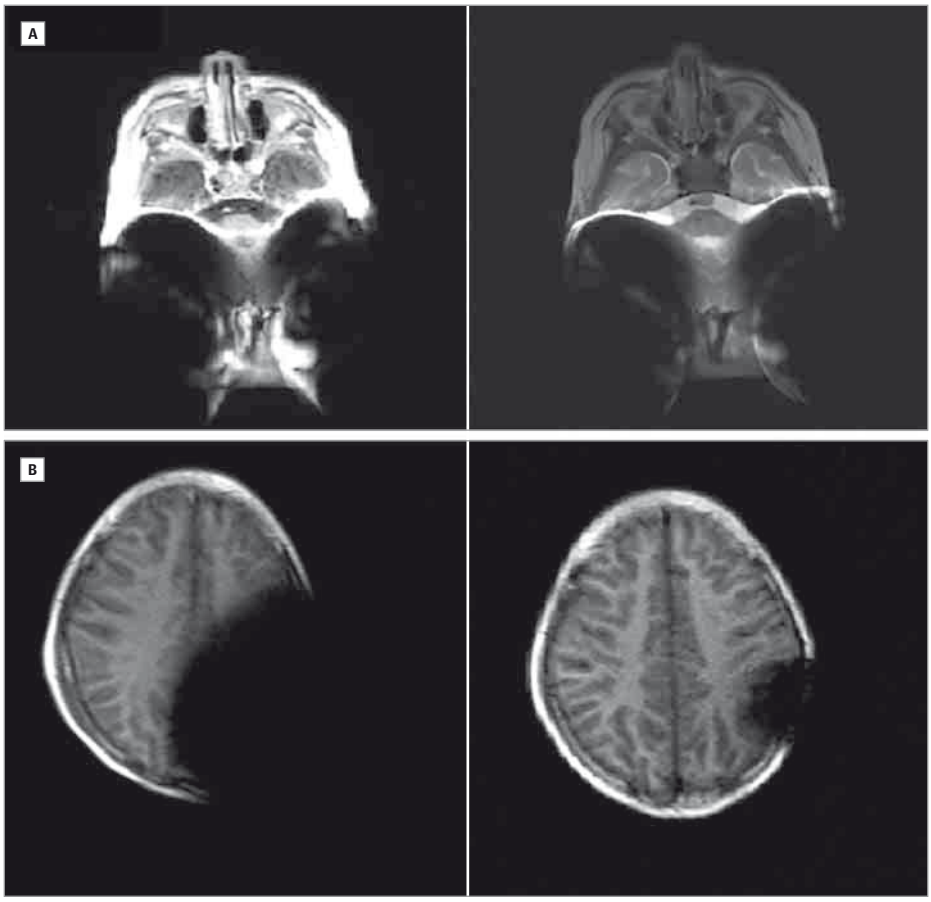
[a] All Clarion implants are from Advanced Bionics AG; MED-EL implants, MED-EL GmbH; and Nucleus implants, Cochlear Ltd.

[b] Patient 15 underwent the first MRI scan with a Clarion HiRes 90K (magnet inserted) in the left side following removal of a Clarion CII from the right side. The second MRI scan was performed with a Clarion HiRes 90K (magnet removed) in the left side. The third MRI scan was carried out following revision surgery of a Nucleus CI422 inserted into the right side and was performed with both internal magnets removed.

scans were safe if the implants were tightly bound with a head dressing.[5] In human calvarial studies, it was shown that the force generated by 1.5-T MRI was not sufficient to damage the CI bed.[8,9] Moreover, device displacement and demagnetization of the internal magnet were not observed in a cadaver study involving 1.5-T MRI.[10] Furthermore, in Europe, a broader range of CIs is approved for use with 3.0-T MRI and head bandaging in CI recipients.[3]

In the present study, however, we found that 7 of the 13 patients who had not undergone general anesthesia (7 of 19 MRI scans) experienced discomfort or pain during the MRI scans. Indeed, 1 patient who had undergone general anes-

Figure 3. Magnetic Resonance Images (MRIs) of the Brains of Patients With Cochlear Implants (CIs)



A, T1 (left) and T2 (right) axial images of a patient with bilateral CIs with internal magnets; both images show large artifacts in the regions surrounding the CIs. B, T1 axial images of a patient before (left) and after (right) removal of left-side CI internal magnet; with the magnet in place, the artifact is much larger than with the magnet removed.

Table 4. Auditory Function After MRI Scans in Patients With CIs Who Experienced Major Adverse Events

Patient No.	MRI Auditory Performance, dB		Complication After MRI	Event
	Before MRI	After MRI		
2	28.3[a]	26.7[a]	NR	Magnet displacement
13	CAP 4	CAP 4	NR	Reversing the polarity of magnet
15	R 30.8[a] L 31.7[a]	R 26.7[a] L 35.8[a]	Postoperative wound infection	CI device removal

Abbreviations: CAP, category of performance; CI, cochlear implant; L, left ear; MRI, magnetic resonance imaging; NR, none reported; R, right ear.

[a] Pure tone average at 250, 500, 1000, and 2000 Hz.

thesia was awakened by pain during the MRI scan and could not complete the MRI. Our data clearly demonstrate that a significant proportion of patients experienced discomfort or pain during the MRI process and were unable to complete the scans. Therefore, in addition to device safety and image quality, patient comfort should be considered when performing MRI procedures.

We observed individual variations between the CI recipients who underwent MRI based on individual patient differences, MRI scan site, and CI device. For example, several patients (patients 2, 3, and 13) who had previously undergone MRI without problems experienced pain during subsequent MRIs, despite using the same protective measures as previously when the same sites were scanned. On the other hand, 2 patients (patients 5 and 9) underwent 3.0-T MRI without bandaging and experienced no adverse events or complications during the MRI scans. However, the sites of the MRI scans in these cases were distant from the head region; therefore, the internal magnets were likely less affected than those in patients undergoing MRI scans of the brain region.

Our research group[7] previously reported that a CI recipient who underwent a 1.5-T knee MRI scan with a head bandage experienced a reversal of the polarity of the CI internal magnet. In addition, Deneuve et al[11] published a case report showing magnet displacement during a 1.5-T cerebral MRI scan with a compressive head dressing. Dubrulle[12] suggested that the position of the head during MRI can affect demagnetization of the implant. Specifically, the tilt angle between the magnetic field of the implant and the primary magnetic field is particularly important, and if this angle is greater than 90, the chance of demagnetization is increased, generally at a level of approximately 60%. Majdani et al[13] also reported that if the

angle between the MRI magnet and the CI magnet is greater than 80, demagnetization reaches unacceptable levels under 3.0-T MRI. In the present study, no patient implants showed demagnetization, although the position of the patient's head during the MRI scan may also be important for displacement of the internal magnet or the induction of pain by the magnetic field. Indeed, magnet dislocation due to MRI procedures in patients with CIs is a major cause of revision surgery.[4]

Those MRI scans of areas outside the brain in the present study showed no artifacts, indicating that the diagnostic value of MRI scans is not affected by CIs in other body areas. In contrast, the brain MRI scans were subject to large artifacts around the implant receivers. We found that the presence of an internal magnet dramatically increased artifact size, to the extent that when the magnet was in place, the ipsilateral side of the brain around the internal magnet became nearly invisible.

Patient 15 in our study underwent revision surgery in which a CI model without a removable magnet was replaced with a Nucleus CI422 with a removable magnet; as a consequence, a diagnosis of Langerhans cell histiocytosis could be made from his brain MRI scans without large artifacts following removal of the bilateral internal magnets (from Nucleus CI422 and HiRes 90K CIs). Patient 2, a young child, had bilateral CIs and underwent a brain MRI scan to assess for bacterial meningitis. However, the CIs caused bilateral artifacts that were very large compared with the patient's relatively small head, making the diagnosis difficult to confirm.

Baumgartner et al[14] have suggested that 1.0-T MRI is safe for patients with CIs and is effective for diagnosis owing to minimal artifacts.[14] However, 1.0-T MRI is not commonly used. Crane et al[5] reported artifacts that were approximately 6.6 cm long in the anterior-posterior dimension and 4.8 cm long in the lateral dimension, centered around the device, and that the contralateral internal auditory canal could be visualized using 1.5-T MRI. A similar artifact size of approximately 7 cm maximum, centered around the internal magnet, was reported in another study.[15] However, in the case of ipsilateral or midline brain lesions, MRI scans can be hard to interpret owing to shadows induced by internal magnets, which is especially true for bilateral CI recipients, as shown in our present study. In a study involving 3.0-T MRI of human cadavers, CI-based artifacts compromised the image quality of nearby brain regions, and detection of lesions of the contralateral hemisphere was also limited.[16]

One limitation of our study is the small number of patients for statistical analysis. Study groups were divided by the binding method, device type, and MRI strength, thus resulting in small numbers of patients for comparison. However, the following 3 major adverse events were experienced by 3 different patients during this study: magnet displacement, magnetic polarity reversal, and required revision of the CI. However, these adverse events did not affect auditory performance following MRI. The protective head bandaging was applied appropriately prior to each MRI scan. Furthermore, mold size, number of gauze pieces, location of the internal magnet, and tightness of the head bandage were all carefully considered to avoid harming the patients. As described in other studies,[5,10] we performed at least 3 circumferential turns with a compressive dressing (elastic bandage) at maximal stretch. These protective measures did not appear to contribute to the adverse events.

Besides assessing the technical compatibility between MRI and CIs, we confirmed that some CI recipients experienced discomfort or pain during the MRI procedure and were unable to complete the scanning process owing to these adverse events. Crane et al[5] have reported that only 4 of 16 patients did not have pressure or pain during their MRI scans. Previous studies did not give serious consideration to the discomfort or pain of patients with CIs but mainly focused on complications.

Conclusions

Patients with CIs may not be fully informed before undergoing MRI scans about the possibility of discomfort or pain, and they may be frightened when they feel discomfort or pain during the scan. Prior to an MRI scan, patients with CIs must fully understand not only the potential complications but also the potential discomforts that they may experience during the scan. Appropriate sedation and head positioning can alleviate patient discomfort or pain during MRI scans. Therefore, patients with CIs who undergo MRI scans should be carefully monitored, and measures should be taken to minimize the likelihood of adverse events.

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Drafting of the manuscript: B. G. Kim, Choi.
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