Systematic Review

Magnet and receiver-stimulator displacement after cochlear implantation

Clinical characters and management approaches

Asma Alahmadi, MD, Saad Alenzi, MD, Mohammed Alsheikh, MD, Saeed Alghamdi, MD, Mostafa E. Morra, MBBch, Khalid M. Badr, MD.

ABSTRACT

الأهداف: أجرينا مراجعة منهجية لحدوث إزاحة المغناطيس أو المستقبل / المحفز بعد مضاعفات وضع غرسة القوقعة الصناعية (CI) وتقييم الأدبيات الموجودة حول هذا الموضوع.

المنهجية: أجرينا دراسة منهجيه في الأدب باستخدام قاعدة بيانات بب ميد، وسكوبس، و Web of Science، وقاعدة (VHL) ومكتبة كوكرين. تضمنت على أبحاث عن حالات إزاحة المغناطيس أو جهاز الاستقبال الذي يحدث كمضاعفات بعد غرس القوقعة الصناعية CI. قيمنا كذلك جودة الدراسات المشمولة باستخدام أداة تقييم المعاهد الوطنية لجودة الصحة للدراسات القائمة على الملاحظة وقائمة مراجعة CARE لدراسات الحالة.

النتائج: تضمنت الدارسة على 36 دراسة منشورة، بما في ذلك 6469 مريضا. ظهرت حالة الانزحاج المغناطيس في 82 (1.3%) مريضًا، بينما تم الإبلاغ عن جهاز الاستقبال/المحفز في 4 (0.1%) حالات. قمنا بتحديد سبب هجرة المغناطيس في 78 حالة؛ كانت الحركة التي يسببها التصوير بالرنين المغناطيسي هي السبب الأكثر شيوعًا (العدد=43، 55.1%)، تليها صدمة الرأس (العدد=25، 32.1%). وقد أجرت 20 دراسة اشتملت على 35 مريضًا يعاني من إزاحة المغناطيس تصويرًا شعاعيًا للجمجمة لتشخيص الانزحاح. كانت الجراحة المراجعة / الاستكشافية مع إعادة الوضع الجراحي أو الإستبدال هي الإجراء العلاجي الأكثر شيوعًا (العدد=46).

الخلاصة: تظهر الحاجة إلى مزيد من البحث حول تصميم الجيب المغناطيسي والبروتوكولات القياسية للتصوير بالرنين المغناطيسي في مستخدمي CI. يعد التشخيص المبكر لانزحاج المغناطيس والإحالة الفورية إلى مراكز CI المتخصصة أمرًا ضروريًا للعلاج والوقاية من المضاعفات الرئيسية.

Objectives: To systematically review the occurrence of magnet or receiver/stimulator displacement following cochlear implant (CI) placement complication and evaluate the existing literature on this topic.

Methods: A systematic literature search was conducted using PubMed, Scopus, Web of Science, Virtual Health Library (VHL), and Cochrane Library. Original studies reporting cases of magnet or receiver-stimulator migration occurring as a complication after CI placement were included. The quality of the included studies was evaluated using the National Institutes of Health Quality Assessment Tool for observational studies and CARE checklist for case studies.

Results: A total of 36 studies, including 6469 patients, were included. Magnet migration was reported in 82 (1.3%) patients, while receiver/stimulator was reported in 4 (0.1%) cases. The cause of magnet migration was identified in 78 cases; MRI-induced movement was the most frequently reported cause (n=43, 55.1%), followed by head trauma (n=25, 32.1%). A total of 20 studies involving 35 patients with magnet migration performed skull radiography to diagnose magnet migration. Revision/exploratory surgery with surgical repositioning or replacement was the most frequent management procedure (n=46).

Conclusions: Further research on magnet pocket design and standard protocols for MRI in CI users is needed. Early diagnosis of magnet migration and instant referral to specialized CI centers is necessary for proper management and prevention of major complications.
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Keywords: magnet, receiver-stimulator, cochlear implant, migration, displacement

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From the Department of Otolaryngology Head & Neck Surgery (Alahmadi), Ministry of Health, from the Head and Neck Skull Base Health Centre (Alghamdi), from the Department of Otology and Skull Base Surgery (Badr), King Abdullah Medical City, Makkah; from the Department of Otolaryngology, Neurotology & Skull Base Surgery (Alenzi), King Abdullah Ear Specialist Center, King Saud University, Riyadh, from the Department of Otolaryngology, Neurotology & Cochlear Implant (Alsheikh), Royal Commission Hospital, Jubail, Kingdom of Saudi Arabia; and from the Faculty of Medicine (Morra), AlAzhar University, Cairo, Egypt.

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Address correspondence and reprint request to: Dr. Asma Alahmadi, Department of Otolaryngology Head & Neck Surgery, Ministry of Health, Makkah, Kingdom of Saudi Arabia. E-mail: asma0alahmadi@yahoo.com
ORCID ID: http://orcid.org/0000000166031596

Cochlear implants (CIs) are effective and safe for patients with moderate and severe hearing loss. Approximately half a million patients have received CI over the last decade.[1] However, with their increasing use, several complications have been shown to contribute to CI failures and revision surgeries or re-implantation. The major complications include receiver-stimulator protrusion, electrode array migration, flap necrosis, otitis media, persistent perilymph leakage, and permanent facial nerve paresis.[2,3]

The number of imaging studies, especially magnetic resonance imaging (MRI), for examining neural structures, including the spinal cord and joints, has considerably increased over the last decade.[4] Of note, MRI scans of CI users have been reported to jeopardize the magnet by causing displacement of the magnet out of its lodging.[5-7] Magnet migration can lead to difficulties with fixation of the internal part of the implant, causing discomfort as well as skin infection and necrosis.[5-7] Some protective measures have been recommended by implant manufacturers, such as wearing head bandages during MRI; however, these measures may be insufficient since the reports of displacement have been increasing.[8,9] Also, other many manufacturers implemented the features of a freely rotating and self-aligning magnet in CI devices in which no complication was reported with a total of 19 MRI scans.[8] A recent review concluded a superior effect for rotatable magnet during MRI scans with no need for device removal or head wrap.[10]

Migration of the CI magnet may also occur because of head trauma, which is commonly reported in children[11] and has been reported in adults.[12] Of note, redness and swelling on the receiver-stimulator site were found to be associated with magnet displacement even in the absence of a clear history of trauma or MRI scan.[13]

If magnet displacement is suspected, confirmation of the diagnosis through radiological studies is essential, and it is usually followed by revision surgery to re-fix the implant. Since migration of the CI magnet or receiver-stimulator is considered a rare complication, no previous studies have clearly reported the prevalence of this complication, performed systematic qualitative studies of the pooled evidence, or established standard practices and management protocols for the patients. Therefore, this report aimed to systematically review the occurrence of magnet or receiver-stimulator migration after CI and conduct a full evaluation of this complication. Further, this study aimed to outline the clinical presentations, diagnostic approaches, and surgical interventions for these rare complications.

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Methods. The present systematic review followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

In August 2020, the following search terms were used to search for relevant articles: (migration, displacement, or dislocation) AND (cochlear or cochlea) AND (implant or implantation). Electronic databases including PubMed, Scopus, Web of Science, Virtual Health Library (VHL), and Cochrane Library, without language or year restrictions, were used. Additionally, a manual search of potentially eligible studies was performed. Articles were collected in a single library through Endnote, and all duplicate references were omitted. Two authors blindly screened all articles based on the predetermined inclusion and exclusion criteria. Papers were deemed included if they reported original data of magnet or receiver-stimulator migration as a complication after CI. There were no restrictions on study design, country of research, or year of publication. However, we excluded (i) posters, commentaries, letters, review articles, theses, conferences, and book chapters; (ii) studies with overlapped data sets; (iii) non-English articles; and (iv) in vitro studies.

Data extraction. Two authors independently extracted data from the eventually included studies. Pilot extraction was initially performed using 5 articles to prepare a consistent extraction form to fit the data and reduce heterogeneity. The extraction form covered 3 main domains: (i) the baseline demographics of the included studies, including patients' age, gender, and sample size, (ii) patients' clinical presentations and device type, and (iii) patient outcomes, including the number of cases showing migration, causes of migration, investigations, and management approaches. The outcomes were classified on the basis of the cause of migration as either post-MRI, post-head trauma, or unexplained migration. All discrepancies were resolved through discussion among the authors and with a third senior author.

Quality assessment and data analysis. All included studies were evaluated by 2 separate authors using the National Institutes of Health Quality Assessment Tool for observational studies[14] and the CARE checklist for case studies.[15] Descriptive data analysis was performed using Microsoft Excel to calculate numbers, proportions, means, and standard deviations (SD).

Results. Our electronic search retrieved 1657 studies, of which only 972 were left after removing duplicated references. On the basis of title and abstract screening, 902 references were excluded, while 70 references were assigned for further full-text screening. Finally, 36 studies were included for qualitative synthesis in the systematic review (Figure 1).

Baseline characters of included studies. A total of 18 retrospective case reviews and 18 case studies including 6469 patients were included (34 studies on magnet displacement, one study on receiver-stimulator migration, and one study evaluating both magnet and receiver-stimulator displacement). Magnet migration was reported in 82 (1.3%) patients, while receiver/stimulator was reported in 4 (0.1%) cases. The average quality assessment score was 10 for case reports and 8 for observational studies. The basic characteristics of individual studies, including country, device type, and causes of hearing loss, are shown in Table 1.

Clinical characteristics of patients showing magnet displacement according to the reasons for migration. Of the 82 cases involving magnet migration, the cause of migration was identified in 78 cases. Magnetic resonance imaging examination was the most frequently reported cause (n=43, 55.1%), followed by head trauma (n=25, 32.1%). In addition, magnet migration due to unexplained reasons (no history of apparent trauma or MRI) or no apparent cause was identified in 7 cases (9%). Playing with magnetic toys was also reported in 2 cases. Chronic suppurative otitis media was associated in one case (Figure 2).

A total of 13 (30.2%) patients with post-MRI magnet migration experienced pain and discomfort during the MRI scan. A head bandage was applied in 14 patients during the MRI scan. All patients were exposed to 1.5 T MRI, except for one patient who was exposed to 3 T MRI. Clinical examination revealed redness, swelling, or a bulge over the magnet site; a bulge in the receiver-stimulator site was demonstrated in the majority of cases. In patients with head trauma, clinical examination relieved diffuse swelling with a visible or palpable magnet over the internal receiver-stimulator coil. However, cases without an apparent history of trauma or MRI presented with deterioration of sound and auditory skills (Table 2).

Management of reported cases with magnet displacement. A total of 20 studies involving 35 patients with magnet migration used skull radiographs to diagnose magnet migration, and 2 studies used both radiography and computed tomography (CT).[16,17] The magnet was shown to be outside the receiver-stimulator container, outside the antenna coil, and migrated from

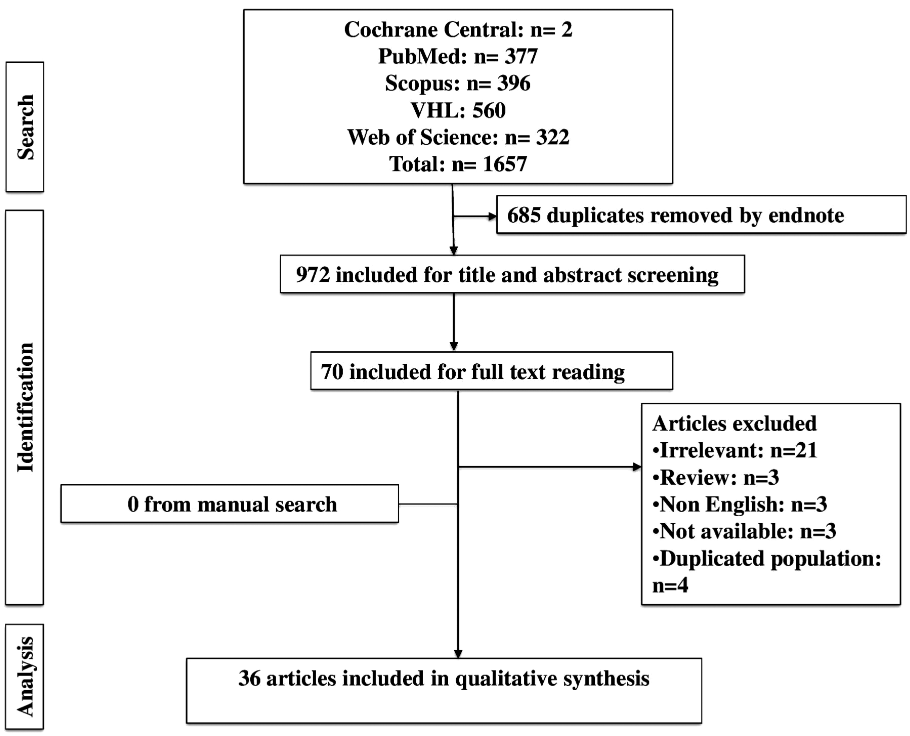

Figure 1 - Flow diagram of studies' screening and inclusion. VHL: Virtual Health Library

Table 1 - Basic characteristics of patients in our included studies.

Author, year	Country	Study design	Sample size	Number of MM/RSM cases	Device type	Etiology of hearing loss	QA score
Bawazeer et al 2019[18]	Saudi Arabia and France	Case series	6	1	CI422	Congenital deafness	10
Broomfield et al 2018[23]	Australia	Case report	1	1	Nucleus CI512	Advanced otosclerosis from the age of 15 years.	11
Chan & Wu 2011[13]	Taiwan	Case report	1	1	Nucleus freedom, Cochlear limited, Australia	-	7
Cuda et al 2013[26]	Italy	Case report	1	1	Nucleus 5, CI512; Cochlear LTD	Bilateral SNHL	10
Demir et al 2019[32]	Turkey	Case report	1	1	Nucleus, CI24RE,	Bilateral profound SNHL	10
Deneuve et al 2008[6]	France	Case report	1	1	CI24RCS	Bilateral SNHL	9
Di Nardo et al 2012[31]	Italy	Case report	1	1	Advanced Bionics Hi-Res 90K array with Harmony speech processor	Bilateral SNHL	11
Epperson et al 2019[16]	USA	Case report	1	1	Cochlear 532	Bilateral SNHL	11
Keereweer et al 2014[33]	Netherlands	Case report	1	1	-	-	11
Leong & Yeon 2018[9]	Singapore	Case report	1	1	HiRes 90 K	SNHL	10
Mickelson & Kozak 2008[34]	Canada	Case report	1	1	Nucleus contour 24R device	SNHL	10
Nichani et al 2006[35]	UK	Case series	4	4	Nucleus 24 Contour Softip implant	SNHL	10
Özgür et al 2019[36]	Turkey	Case report	1	1	Nucleus freedom straight CI24RE	SNHL	10
Raghunandhan et al 2010[37]	India	Case report	1	1	-	Congenital bilateral hearing loss	10
Stokroos & Dijk 2007[12]	Netherlands	Case report	2	2	Nucleus CI24R	Bilateral SNHL	9
Wild et al 2010[38]	Switzerland	Case report	3	3	Nucleus Freedom, CI24RECA, Cochlear Corporation	Bilateral profound hearing loss (n=1), Profound hearing loss due to a mutation in gene 26 (n=2)	10
Wilkinson et al 2004[39]	USA	Case report	1	1	Nucleus CI24RCS device (Cochlear Corporation, Englewood, CO, USA).	Bilateral profound SNHL	10
Yun et al 2005[11]	USA	Case report	3	3	Nucleus CI24R	-	9
Bhadania et al 2018[40]	India	RCR	250	2	(MedEl, Cochlear, Advanced Bionics) and underwent surgery via	-	7
Brown et al 2009[41]*	USA	RCR	44	3	-	-	8
Cullen et al 2008[42]	USA	RCR	93	2	-	-	7
Hashemi & Bahrani 2012[19]	Iran	RCR	11	2	-	-	8

Table 1 - Basic characteristics of patients in our included studies (continued).

Hassepass et al 2014[28]	Germany	RCR	2027	22	(6) CI512, (5) Cochlear Nucleus Freedom, (1) CI422	-	7
Jiang et al 2016[43]	China	RCR	1,065	1	-	-	7
Sefein 2018[44]	Egypt	RCR	112	1		-	8
Kim et al 2008[45]	South Korea	RCR	720	2	CI24R	-	8
Loundon et al 2010[46]	France	RCR	434 (43 compli-cation)	3	-	-	7
Migirov et al 2010[47]*	Israel	RCR	320	3/1*	-	-	7
Orhan et al 2012[48]	Turkey	RCR	344	2	Nucleus (Cochlear Limited, Lane Cove, Australia)	-	8
Qiu et al 2011[49]	China	RCR	416	1		-	8
Leinung et al 2020[17]	Germany	RCR	9	9	(5) CI 512, (2) CI 24RE, (1) CI 532, (1) HiRes 90 k	-	8
Tam et al 2020[50]	Australia	PCR	76	2	-	-	9
Tarkan et al 2013[51]	Turkey	RCR	475	1	-	-	8
Kim et al 2015[7]	South Korea	RCR	18	1	-	-	8
Young et al 2016[52]	USA	RCR	12	1	-	-	8
Brian et al 2013[20]	USA	RCR	12	1	-	-	10

Receiver-stimulator migration cases. MM/RSM: magnet migration/receiver-stimulator migration; SNHL: sensorineural hearing loss; RCR: retrospective cohort review; PCR: prospective cohort review; CI: cochlear implant; MRI: magnetic resonance imaging; (-): data were not available.

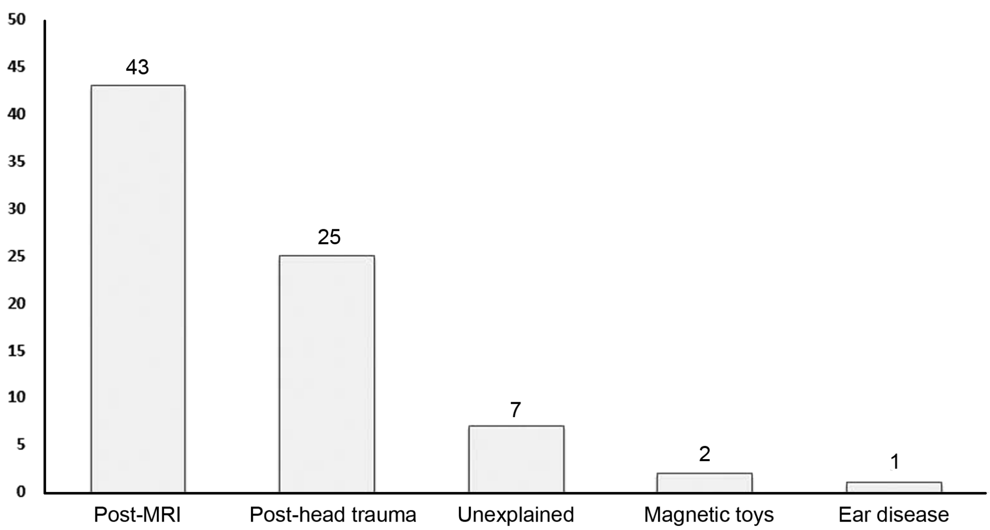

Figure 2 - Reasons for magnet migration in accordance with the authors' reporting.

Table 2 - Clinical characteristics of magnet displacement according to the reason of migration.

Author, year	Cause of migration	Cases (n)	Gender	Mean age (SD) (years)	MRI dose/indication	Head bandage/ pain during the MRI	Clinical presentation	Clinical examination
Bawazeer et al 2019[18]	MRI	1	-	28	1.5T	-/Y	Progressive neurological illness	-
Brian et al 2013[20]	MRI	1	Male	4	1.5 T/Spine and brain tumor	Y/Y	-	-
Broomfield et al 2013[23]	MRI	1	Female	64	1.5 T/spinal cord compression suspection	-/Y	Gait disturbance upper limb weakness	Bilateral skin reactions
Cuda et al 2013[26]	MRI	1	Male	72	1.5 T/biliary duct pathology	Y/ -	Pain and hotness	Focal skin alteration over the left inner coil
Demir et al 2019[32]	MRI	1	Female	7	1.5 T/congenital scoliosis follow up	N/Y	Inability to use the implant due to a wound	Redness, wound scarring and edema on the implant body and magnet site
Deneuve et al 2008[6]	MRI	1	Male	8	1.5 T/neurologic disorder progression	Y/Y	local erythema with edema and tenderness	local erythema, edema, tenderness, the magnet was outside the SR
Di Nardo et al 2012[31]	MRI	1	Female	31	1.5 T/64-MHz brain MRI/mitochondrial myopathy sudden detorioation	N/Y	Pain and a burning sensation	Bulge in the receiver-stimulator
Epperson et al 2019[16]	MRI	1	Female	10	1.5 T/central hypothyroidism suspection	Y/Y	Intermittent fever and tenderness over the processor/ magnet site.	-
Leinung et al 2020[17]	MRI	9	Male (22%)	37.2 (21.7)		Y (n=6) / -	Pain (4), swelling (5), redness (2), palpable displacement (3), inability to wear the CI processor (7)	
Leong et al 2018[9]	MRI	1	Male	67	1.5 T/suspected cervical and lumbar radiculopathy	Y/Y	Discomfort and a bulge	-
Kim et al 2015[7]	MRI	1	Female	25	1.5 T/malignant ependymoma	Y/Y	-	-
Özgür et al 2019[36]	MRI	1	Male	4	3 T/suspected diabetes insipidus	Y/Y	Swelling over the magnet site	The magnet had turned upside down, the external part was reversed (inside facing out) and still attracting the internal part.
Tam et al 2020[50]	MRI	2	Female	36 and 74	-	-	-	-
Young et al 2016[52]	MRI	1	Female	11.6	1.5 T	Y/ -	Discomfort and swelling of the soft tissue overlying the portion of the device.	-
Hassepass et al 2014[28]	3 cases post-head trauma, 19 cases post-MRI	22	-	-	-	-	-	-

Table 2 - Clinical characteristics of magnet displacement according to the reason of migration (continued).

Loundon et al 2010[46]	1 case post-MRI, 2 cases post-head trauma	3	-	-	-	-/Y	-	-
Bhadania et al 2018[40]	Head trauma	2	-	-	-	-	-	-
Jiang et al 2016[43]	Head trauma	1	-	-	-	-	-	-
Keereweer et al 2014[33]	Head trauma	1	Male	1.5	-	-	The sound processor could no longer connect to the CI	Diffuse swelling without erythema of the skin overlying the CI.
Kim et al 2008[45]	Head trauma	2	Female	4 and 6	-	-	-	-
Mickelson et al 2008[34]	Head trauma	1	Male	1.8	-	-	-	The magnet was palpable anteroinferiorly.
Migirov et al 2010[47]	Head trauma	3	-	-	-	-	-	-
Nichani et al 2006 [35]	2 cases post head trauma 2 unexplanied reasons, without history of apparent trauma	4	Male (100%)	3 (82)	-	-	(2) erythema and swelling of the scalp over the RS site	(1) swelling over the magnet site (3) erythema and swelling of the scalp over the RS site.
Orhan et al 2012[48]	Head trauma	2	-	-	-	-	-	-
Stokroos et al 2007[12]	Head trauma	1	Female	44 y	-	-	Known to have seizures	A slight bulge over the processor part of the implant and some local tenderness with a small, firm, palpable but less-well-defined mass.
	Head trauma	1	Male	3 y	-	-	Loss of the function of the implant	A slight bulge of the skin was visible over the implant site, and a small, firm swelling was felt over the processor part.
Tarkan et al 2013[51]	Head trauma	1	-	-	-	-	-	-
Wilkinson et al 2004[39]	Head trauma	1	Male	13 m	-	-	No response in the external coil	-
Chan et al 2011[13]	No apparent trauma	1	Male	4 y	-	-	Poor response to sound	Small and firm bulge over the processor part of the implant.
Qiu et al 2011[49]	Unexplained reasons	1	-	-	-	-	-	-
Raghunandhan et al 2010[37]	Unexplained reasons	1	Female	13 y	-	-	Rapid deterioration in auditory verbal skills	A small boggy swelling in the mastoid region over the internal RS coil site.
Sefein et al 2018[44]	Associated with chronic suppurative otitis media	1	Male	-	-	-	-	-

Table 2 - Clinical characteristics of magnet displacement according to the reason of migration (continued).

Yun et al 2005[11]	Head trauma	1	Male	70 m	-	-	-	Magnet was external to the SR by palpation.
	No apparent cause	1	Male	31 m	-	-	Swelling precludng use of the external device.	Ridge was palpable over the anterior body of the SR. Erythema without fluctuance
	Head trauma	1	Male	28 m	-	-	Tender knot over the RS	Magnet was found to be freely mobile under the flap
Wild et al 2010[38]	No apparent cause	1	Male	34 m	-	-	-	Skin irritation over the implant site
	Playing with magnetic toys	1	Female	67 m	-	-	-	Dislocated magnet lateral to the receiver aerial
	Playing with magnetic toys	1	Female	56 m	-	-	Dislocated magnet	-

Y, yes; N, no; y, years; m, months; CI, cochlear implant; RS, receiver-stimulator MRI; magnetic resonance imaging.

Table 3 - Investigation and management of magnet migration cases.

Author, year	Cases (n)	Investigation		Management
		Tool	Finding	
Post MRI				
Bawazeer et al 2019[18]	1	CT	Magnet rotation without total implant displacement within the cochlea	Emergency surgery
Walker et al 2013[20]	1	-	-	Spontaneous reduction
Broomfield et al 2013[23]	1	Radiography	Left magnet displaced	Magnet replacement with titanium spacers.
Cuda et al 2013[26]	1	Radiography	Partial magnet migration on the left side	Surgical exploration and magnet repositioning
Demir et al 2019[32]	1	Examination	There was a hard spot consistent with the contour of the magnet under the scar.	The magnet was excised from the s ubcutaneous tissue without compromising the integrity of the skin.
Deneuve et al 2008[6]	1	Examination	Magnet was palpable	Removal under local anesthesia followed by repositioning after 5 days
Di Nardo et al 2012[31]	1	Radiography	Magnet displacement	Manual maneuver for repositioning
Epperson et al 2019[16]	1	Radiography and CT	Normal findings after the initial examination, but magnet angulation was noted on re-evaluation	Repositioning of the magnet with a CI 500 series replacement
Leinung et al 2020[17]	9	4 Radiography 5 CT	Magnet displacement	Surgical repositioning
Leong et al 2018[9]	1	Radiography	Dislocated from its slot in the receiver stimulator	Endoscopic repositioning
Kim et al 2015[7]	1	Radiography	The internal magnet was displaced outside the receiver container	Reinsertion of the magnet into the retainer using a microelevator and repositioning

Table 3 - Investigation and management of magnet migration cases. (continued).

Özgür et al 2019[36]	1	Radiography	Magnet displacement	Surgical repositioning
Tam et al 2020[50]	2	-	-	Surgical revision and magnet repositioning; subsequent infection led to device loss in one case
Young et al 2016[52]	1	Radiography	90-degree rotation of the magnet	Surgical replacement
Post head trauma				
Bhadania et al 2018[40]	2	Radiography	Magnet displacement	Surgical replacement
Jiang et al 2016[43]	1	-	-	Surgical replacement
Keereweer et al 2014[33]	1	Radiography	Magnet displacement (on top of the titanium housing of the receiver-stimulator)	Surgical replacement
Kim et al 2008[45]	2	Radiography	Floating magnet from the device well	Revision surgery and surgical repositioning
Mickelson et al 2008[34]	1	Radiography	Magnet displacement	Surgical magnet repositioning Recurrence after 3 yr and treated by surgical lasso technique
Orhan et al 2012[48]	2	Radiography	Magnet displacement	Reinsertion of the magnet by (1) sub-periosteal temporal pocket technique, (2) standard technique
Stokroos et al 2007[12]	2	Radiography	Luxation and anterior displacement of the magnet	Surgical exploration and magnet repositioning
Tarkan et al 2013[51]	1	-	-	Revision surgery
Wilkinson et al 2004[39]	1	Radiography	Magnet migration outside the antenna coil to a position compromising normal function of the device.	Surgical replacement
Nichani et al 2006*[35]	4	Radiography	Magnet displacement	Surgical repositioning
Yun et al 2005[11]	2	Examination	Magnet was palpable	Surgical replacement
Unexplained reasons and other conditions				
Chan et al 2011[13]	1	Radiography	Magnet migration from the silicon pocket toward the antenna	Surgical exploration
Cullen et al 2008[42]	2	-	-	Revision surgery
Hashemi et al 2012[19]	2	Neuroresponse telemetry	Poor response	-
Qiu et al 2011[49]	1	Radiography	Magnet displacement	Revision surgery without re-implantation
Raghunandhan et al 2010[37]	1	Radiography	Magnet migration from its socket in the receiver-stimulator coil	Surgical exploration and repositioning
Sefein et al 2018[44]	1	-	-	Surgical repositioning
Wild et al 2010[38]	3	-	-	Revision surgery and surgical replacement
Yun et al 2005[11]	1	Examination	Magnet was palpable	Magnet reduction

*Two cases were due to unexplained reasons, without a history of apparent trauma the silicon pocket. Using a CT scan in a case report, magnet rotation was observed without total implant displacement.[18] Furthermore, in one study, magnet migration was diagnosed by a poor response through neuroresponse telemetry.[19] Revision/exploratory surgery with surgical repositioning or replacement was the most frequent procedure for magnet migration management (n=46). Emergency surgery was indicated in a patient who experienced pain during an MRI scan.[18] Moreover, spontaneous reduction was reported in another case.[20] Table 3 summarizes the radiological findings and management in cases with magnet migration.

Discussion. Magnet or receiver/stimulator displacement following CI surgery is a rare complication; however, it is a serious event and may be underestimated. This systematic review summarizes the evidence from original studies to report the prevalence, clinical characteristics, and management of magnet or receiver-stimulator migration following CI. The current study identified that MRI scans and a history of head trauma are the main causes of magnet migration, but this condition may also occur without apparent reasons. The static and dynamic magnetic fields generated by MRI scanners can affect the magnet of the CI, leading to its displacement. The literature suggested that 1.5 T MRI is a safe and efficacious imaging method for patients with CI.[21,22] Newer and better CI devices may show reduced influence of the adverse events induced by the electromagnetic field of MRI machines; however, several patients showed magnet migration following 1.5 T imaging.[18,20,23] It is therefore important to consider magnet problems if patients present with tenderness or pain in the temporal region after an MRI scan.[24] The data extracted in our systematic review revealed that a head bandage was applied in almost all included studies with individual data. Although the use of Cochlear® is advised while performing MRI in CI users with a compression bandage as well as a "splint" being directly placed above the magnet,[25] magnet displacement has also been reported even in studies that used head bandage and followed all precautions.[16,20,26] Moreover, it is difficult to quantify the success rate of head bandages in the absence of large data. Therefore, the need for an MRI scan must be carefully assessed and discussed with CI users and their families.[27] More importantly, the position of the patients in the MRI machine and the imaging protocol may influence the magnet status. Previous reports have recommended that MRI scans should be performed at specialized CI centers where otorhinolaryngologists can guide the patients about proper precautionary measures and carefully monitor them after MRI imaging for possible clinical signs of magnet migration.[17]

The main challenge after magnet migration is to promptly perform and confirm the diagnosis. Of note, many patients presented with redness, swelling, or bulging over the magnet site bulge in the receiver-stimulator site. In addition, the majority of patients with post-MRI magnet displacement experienced pain and discomfort during the MRI procedure. However, there were no consistent presenting features. While radiological methods including radiography, CT, and cone-beam CT (CBCT) can confirm the diagnosis, radiography may be recommended because of the low radiation risks. Notably, Hassepass et al recommended performing radiography immediately after MRI scans in CI users who experienced pain or any problems during MRI without magnet removal to exclude possible magnet displacement and prevent further complications.[28] Recently, the diagnostic ultrasound has been utilized as one of the diagnostic tools for identifying magnet dislocation.[29]

Once the diagnosis of magnet dislocation has been proven, most cases would require surgical repositioning or replacement of the magnet. A literature search revealed that the procedure can be conducted under general anesthesia or local anesthesia.[17] A commonly followed incision approach is the incision of a semicircular cut around the antenna of the CI.[17] A larger incision may affect the long-term wound outcomes; therefore, Leong et al recommended an endoscopic fixation technique through a smaller access.[9] Leinung et al preferred an open surgical technique along with a small semicircular incision of the skin, between the magnet and the antenna parts.[17] However, some cases, which can be recognized as grade one displacement in accordance with the Gubbels and McMenomey classification, can be managed through manual fixation from outside.[22,30,31] Notably, patients who underwent manual repositioning should be instructed about the potential recurrence of magnet migration because of the physical impact close to the CI. In these cases, a skin incision line is recommended so that a repositioning procedure can be converted into a replacement operation.[27]

The significance of this study lies in the fact that it is the first systematic review to provide qualitative evidence regarding these rare complications after CI.

Study limitations. The first is the relatively small number of included participants and studies, although 5 major databases were selected for the literature search. The second limitation is that the inferences from our study relied on data from case reports and cohort analysis, and the lack of randomized trials and controlled studies may affect the generalization of study conclusions. Lastly, the included patients were of different ages, received various device types, and underwent different implantation techniques. Therefore, larger studies are needed to compare different types of CI devices, patients' basic demographics, exact causes of migration, best diagnostic approach, and effective management.

In conclusion, magnet or receiver-stimulator displacement are critical complications of CI and may not be as rare as previously perceived. This systematic review revealed that MRI and head trauma were the most frequently responsible factors for magnet displacement. Patients may present with redness and swelling at the implant site, and skull radiography is usually performed to confirm the diagnosis. Further research is needed on magnet pocket design, and standard protocols for MRI in CI users are required to lessen magnet or receiver-stimulator migration. Therefore, the necessity of an MRI scan must be carefully assessed and discussed with CI users and their families. In addition, healthcare providers should carefully evaluate CI users after MRI scans and head trauma. Early diagnosis and instant referral to specialized CI centers for appropriate management are extremely important for the prevention of partial or complete explantation of the implant.

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