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## Article

# A Concept for MRI-Based Cholesteatoma Detection in Cochlea Implant Recipients

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## Abstract

**Introduction:** Cochlear implantation is the treatment of choice for severe hearing loss and deafness. Cholesteatomas can cause this deafness. A frequently used procedure in the course of surgical rehabilitation is a subtotal petrosectomy combined with a cochlear implant. The follow-up of residual cholesteatomas is related to the combination of a cochlear implant and the blind sac closure, which is more difficult due to cholesteatoma sequence magnet artefacts. Recent developments in combining cochlea implants and necessary MRI examinations enable the assessment of the internal auditory canal and cochlea. The study aimed to develop a procedure for detecting cholesteatomas in patients with cochlear implants using magnetic resonance imaging (MRI). **Methods:** Ex vivo MRI examinations were performed on five subjects with fixed cochlear implants (Medel Synchrony) and swim caps. MRI examinations were performed at 1.5 T and 3 T using EPI, HASTE, and RESOLVE sequences (Siemens). The position of the implant was 12 cm distal to the external auditory canal, with anteversional head position of the volunteers in the MRI. **Results:** Due to artefact effects, assessment of the ipsilateral and contralateral mastoid is not possible with EPI sequences and a cochlear implant. The combination of cholesteatoma-detecting MARS sequences (HASTE, RESOLVE), a distal implant position, and a specific head position allows the assessment of the ipsilateral mastoid. **Conclusion:** Postoperative cholesteatoma assessment after CI implantation and subtotal petrosectomy appears to be possible under 1.5 T and 3 T, considering the MRI sequence, implant position, and head position.

**Keywords:** CI; MRI; Cholesteatoma

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## 1. Introduction

Given the importance of MRI as a routine diagnostic tool in many clinical pathways, the likelihood of needing a scan at some point in a lifetime is high. This finding holds even for cochlear implant recipients (van de Heyning et al., 2021).

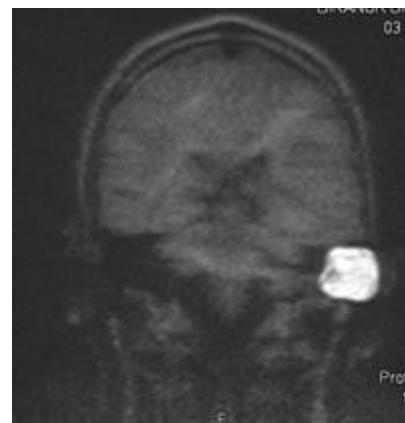
Developments of the CI magnet to bipolar diametral magnets, which align to the applied magnetic field, allow a painless procedure without complications (Todt et al., 2017). The position of the implant at the head (Todt et al., 2015), the position of the head inside the MRI scanner (chin to chest) (Ay et al., 2021), and a proper sequence allow the routine assessment of the internal auditory canal and the cochlea.

These findings allow the routine follow-up of vestibular schwannoma and intralabyrinthine schwannoma in combination with a cochlear implant (Sudhoff et al., 2020; 2021). Further development and application of MARS sequences enable the reduction of artifacts around the implant and improved visualization of central structures (Edmonson et al., 2018; Canzi et al., 2023; Winchester et al., 2025).

The introduction of MRI into the field of cholesteatoma detection allowed a non-surgical visual second look (Tran ban Huy et al., 1986) for the first time. Besides the initial single-shot echo planar imaging (EPI) DWI detection sequence (Fitzek et al., 2002), non-EPI echo planar imaging DWI was developed, achieving higher sensitivity and specificity of 91% and 97%, respectively (Jindal et al., 2011; De Foer et al., 2006). The disadvantage of most cholesteatoma detection sequences is their high susceptibility to magnetic fields. Therefore, significant distortive artifacts can be generated by an implant (Nassiri et al., 2024), which makes the evaluation of cholesteatoma impossible. Although modified cholesteatoma sequences, such as multishot EPI DWI RESOLVE and single-shot non-epi DWI HASTE (Figure 1), are assumed to be less susceptible to magnets with acceptable rates of cholesteatoma detection (Bozer et al., 2024)

Subtotal petrosectomy (SP) contains the complete exenteration of pneumatized cells of the mastoid, removal of epithelialized cells, and removal of the posterior wall. Closure of the eustachian tube and a blind sac closure of the EAC is performed after filling the cavity with fat. This technique, developed in the late 1950s (Rambo et al., 1958), was combined with a cochlear implant in the late 1990s (Bendet et al., 1998) as a surgical solution for many pathologies. It is described as being performed in cases of COM, cholesteatoma, temporal bone fractures, otosclerosis, vestibular schwannomas, and inner ear malformations, in combination with a cochlear implant (Morelli et al., 2025). Related to the assumed good safety profile, the SP is widely used. Caused by the closure of the blind sac, a follow-up of the underlying etiological disease is based on clinical observation, and usually involves a CT scan. Since CT is not the radiological tool of choice for detecting cholesteatoma, knowledge about residual or recurrent cholesteatoma is primarily based on clinical observation and is therefore limited. Different authors have described the rate of cholesteatoma in the groups of PS and CI as ranging from 9.3% to 20% (Yan et al., 2020; Aristigue et al., 2022; Gray et al., 1999). It can be assumed that the rate of undetected cholesteatoma is different. Recently, Macielak et al. described the rate of cholesteatoma in patients with recurrent disease after surgery (SP) as 80%.

This study aimed to develop a procedure for detecting cholesteatomas in patients with cochlear implants using magnetic resonance imaging (MRI).



**Figure 1.** Exemplaric cholesteatoma of a left mastoid cavity scan with HASTE at 1.5 T.

## 2. Method

We performed MRI scans on five volunteers with a cochlear implant (Synchrony 2, MED-EL, Innsbruck, Austria). The implants were fixed with a swimming cap at a 120° angle from the nasion to the external ear canal line, with a distance of 12 cm. Inside the scanner, the volunteers were advised to scan in a chin-to-chest (anteverision) position (Ay et al., 2021). A cushion supported the head.

1.5 T scanning was performed with a MAGNETOM Altea scanner (Siemens, Erlangen, Germany). The performed sequences included a non-EPI HASTE DWI (t2\_haste\_diff\_cor\_p2).

3T scanning was performed using a MAGNETOM Skyra scanner (Siemens, Erlangen, Germany). The performed sequences were a RESOLVE DWI (resolve\_4scan\_trace\_tra\_p2\_192) and an EPI Sequence (ep2d\_diff\_4scan\_trace\_p2). For both scanners, a 20-channel head coil was used.

SAR values were calculated for each sequence. Related to the sequence installed on the different scanners, sequences could not be performed in all scanners.

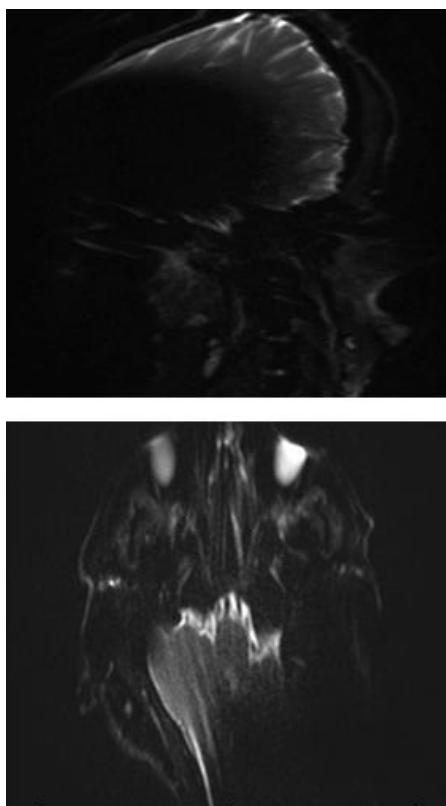
The ethical board of the Westfälische Wilhelms Universität (2019, 135 fS, 20.08.2019) gave their approval for the study.

### 3. Results:

#### 3.1. EP2D-Diff-Sequence

In all three subjects, the EP2D diffusion sequence shows a pronounced susceptibility artifact in both the axial and coronal planes with areal signal loss and, in some cases, considerable geometric distortions. Around the cochlear implant, central, hypointense signal losses with hyperintense fringes are impressive, whereby these fringe phenomena appear particularly pronounced in the coronal plane.

Due to the pronounced stretching and distortion effects, anatomically correct visualization of the mastoid cavities, the external auditory canal, and the internal auditory canal is considerably impaired on both sides. (Figure 2a,b).



**Figure 2.** a and b Exemplaric scan with an EPI2D sequence 3 T in a coronal and axial plane.

#### 3.2. RESOLVE Sequence

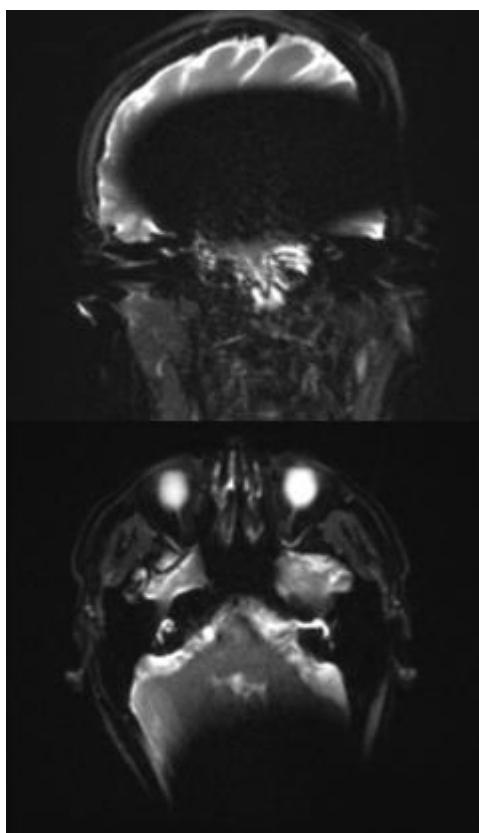
In the transverse as well as in the coronal image plane, a localized signal loss in the region of the cochlear implant can be seen, corresponding to a pronounced metal-induced susceptibility artifact. The average artifact extension in the axial orientation is 108 mm (subject 1: 103 mm; subject 2: 106 mm; subject 3: 116 mm), while in the coronal plane, it is 146 mm (subject 1: 156 mm; subject 2: 147 mm; subject 3: 134 mm). In the coronal image, a disproportionate craniocaudal and mediolateral

artifact extension is also impressive, which extends beyond the temporal lobe to the midline and projects into deeper contralateral brain sections.

In each case, the artifacts are accompanied by geometric distortions as well as grid- or band-like signal inhomogeneities in the peripheral area.

In all three cases examined, the ipsilateral mastoid air cell can be visualized mainly in both planes. In subjects 2 and 3, however, the distal section of the ipsilateral mastoid exhibits a partial artifact overlay, which limits assessment. The contralateral mastoid cavity can be assessed in its full extent in all subjects without restrictions.

In the axial plane, both the ipsilateral cochlea and the internal auditory canal remain unaffected by the artifact spread. The course of the internal auditory canal can be visualized artifact-free up to the cerebellopontine angle and assessed without any discernible geometric distortions. In the coronal view, however, complete traceability of these structures is not reliably possible due to superimposed artifacts. The same applies to the visualization of the external auditory canal, which can only be assessed to a limited extent in the coronal plane due to artifacts. (Figure 3a and b).



**Figure 3.** a and b. Exemplaric scan with a RESOLVE sequence 3 T in a coronal and axial plane.

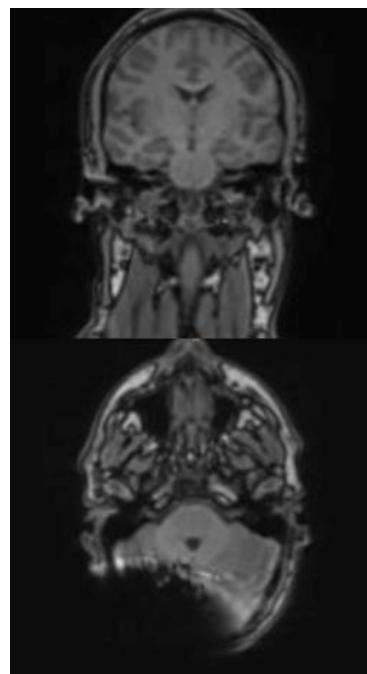
### 3.3. HASTE Sequence

In the HASTE sequence (1.5 Tesla), all three subjects exhibited a signal extinction localized around the cochlear implant, consistent with a metal-induced susceptibility artifact. This is localized ipsilaterally, temporoparietally, and occipitally, and manifests as a centrally hypointense area. The mean extent of the artifact in axial orientation is 60 mm (subject 3: 61 mm; subject 4: 48 mm; subject 5: 71 mm). In the coronal plane, the average extension is 102 mm (test subject 3: 128 mm; test subject 4: 125 mm; test subject 5: 54 mm). In cases 3 and 4, the artifact extension in the coronal plane extends beyond the midline. A relevant geometric distortion of the surrounding structures is not recognizable in any of the cases. Minor, unspecific signal inhomogeneities can be seen at the edges of the artifact zones. Due to the image quality, the anatomical detail recognizability is limited in all three subjects.

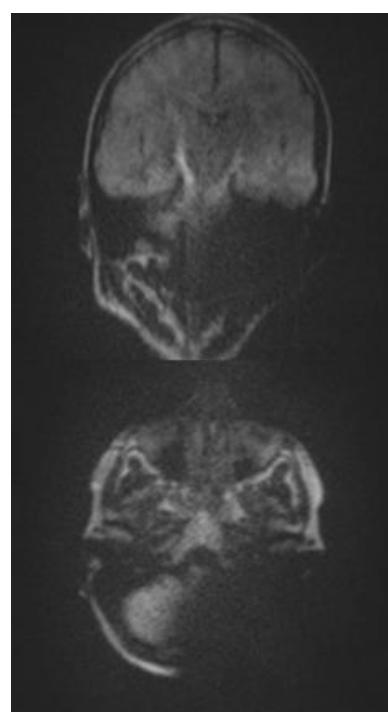
In subjects 3, 4 and 5 both the ipsilateral and the contralateral mastoid can be displayed completely and without artifact overlay. The same applies to the internal and external auditory canals, which are imaged artifact-free on both sides. (Figure 4a and b)

The effect of a closer position of the implant to the EAC and a non-anteverted head position inside the scanner is shown in Figure 5a and b. Here, the ipsilateral mastoid and internal auditory canal (IAC) are not assessable.

SAR values calculated for all used sequences and scanners were between 0.18 and 0.36 (W/kg)



**Figure 4.** a and b. Exemplaric scan with HASTE sequence 1.5 T in a coronal and axial plane.



**Figure 5.** a and b. Exemplaric scan with HASTE sequence 1.5 T in a coronal and axial plane with an EAC distance of 7 cm, without a chin-to-chest position of the head in the scanner.

### 3.4. Discussion

Cholesteatoma assessment by MRI scanning has become a routine procedure in many otologic departments, as it offers an option for a non-surgical second look after cholesteatoma surgery. A high rate of sensitivity and specificity made it a reliable tool (Bozer et al., 2024).

A significant disadvantage of the commonly used epi and non-epi sequences in DWI is susceptibility to magnetic fields and the generation of distortion artifacts (Nassiri et al., 2024). This has, so far, made radiological cholesteatoma follow-up in cochlear implant recipients impossible. Therefore, the follow-up in cases of subtotal petroectomy relied on clinical observation and CT scans (Morelli et al., 2025). Despite this limitation, the rate of cholesteatoma in this group is described to be between 9.3% and 20% (Yan et al., 2020; Aristigue et al., 2022; Gray et al., 1999).

Subtotal petroectomy is a reliable surgical technique in cases of COM, Cholesteatoma, temporal bone fractures, otosclerosis, vestibular schwannomas, and inner ear malformations, including a blind sac closure, which makes a visual microscopic observation impossible. Recent publications have reported high rates of recurrent cholesteatoma in patients without cochlear implants after 8 years (Macielak et al., 2023). The magnetic artifact of the cochlear implant currently makes radiological cholesteatoma follow-up by MRI impossible.

Our findings enable a radiologic assessment of the mastoid with a cochlear implant in place, thereby resolving this issue. The use of RESOLVE or HASTE sequences for cholesteatoma detection makes it possible to assess the mastoid region for the first time. However, it is worth noting that not only is the used sequence important. Additionally, the implant must be placed 12 cm behind the external auditory canal (EAC), and the patient's head must be positioned inside the MRI scanner in a chin-to-chest position (Ay et al., 2021). (Figures 3 and 4). The importance of not solely focusing on the used sequence becomes clear when examining Figure 5. In this case. However, a proper sequence was used, but a visualization of the mastoid region was not possible because the implant position and head position were not as advised.

This proposed guideline needs to be tested *in vivo* now. Although the HASTE sequence is available at 3 T, we were unable to test it since it was not installed at the time of observation.

Although it has been shown that hair cells' function (residual hearing) is not affected by MRI scanning in cochlear implant recipients (Eichler et al., 2023), specific SAR values are of high importance. The SAR values in our observations, ranging from 0.18 to 0.36 W/kg, were all within the manufacturer's given limitations: 3.2 W/kg for head MRI (1.5T) and 1.6 W/kg for head MRI at 3T (MEDEL, Innsbruck, Austria). Therefore, all scans could be performed even *in vivo* without any risk to the patient.

**Table 1.** Assessment of the ipsilateral and contralateral mastoid, IAC, and EAC with EPI sequence at 3T, RESOLVE at 3T, and HASTE at 1.5 T.

Structure	EPI	RESOLVE	HASTE
<b>Ipsilateral Mastoid</b>	Not assessible	assessible	assessible
<b>Contralateral Mastoid</b>	Not assessible	assessible	assessible
<b>Ipsilateral IAC</b>	Not assessible	mainly assessible	assessible
<b>Contralateral IAC</b>	Not assessible	assessible	assessible
<b>Ipsilateral EAC</b>	Not assessible	mainly assessible	assessible
<b>Contralateral EAC</b>	Not assessible	assessible	assessible

## 4. Conclusion

Postoperative cholesteatoma assessment after CI implantation and subtotal petroectomy appears to be possible under 1.5 T and 3 T, considering the MRI sequence, implant position, and head position.

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