



# Cochlear Model for the Evaluation of MRI Sequences and Cochlear Implant Electrode Pattern at 3T

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## Abstract

**Introduction** Cochlear implant (CI) magnets and surgical techniques (e.g., positioning) have made an impact on the relationship between CI and magnetic resonance imaging (MRI) by solving the problem of pain and artifact. Recent investigations displayed the possibility to evaluate the CI electrode position by MRI *in vivo*. However, further improved perceptual quality is needed to allow an improved evaluation of the electrode.

**Aims** The aim of this study was to assess a cochlear model for the examination of CI electrode pattern and MRI sequences *in vitro*.

**Materials and Methods** We investigated CI electrodes in a fluid-filled three-dimensional artificial scala tympani model combined with a fluid package in a 3T MRI scanner. Different high-resolution T2 sequences (0.6–0.2 mm voxel size) were used for the visual electrode pattern evaluation for finding an optimized sequence.

**Results** Artificial models can be used to evaluate MRI characteristics of CI electrodes. In our scanner configuration, a 0.3 mm voxel and 0.9 mm slice thickness sequence showed the best compromise between resolution and scanning time.

**Conclusion and Significance** MRI model-based testing can be performed *in vitro* to evaluate CI electrodes' pattern and to optimize sequences. An MRI model is a tool for *in vitro* testing of MRI sequences and might help for future *in vivo* applications.

## Keywords

- MRI
- cochlear implant
- cochlear model
- electrode position
- MRI sequences

## Introduction

Second generation of cochlear implant (CI) magnets and improved surgical techniques (e.g., implant positioning) have made a significant impact on the relationship between a CI and magnetic resonance imaging (MRI) scanning by solving the problem of pain inside the scanner<sup>1</sup> and cochlear/internal auditory canal obscuring artifacts. MRI has changed from a contraindication to a diagnostic tool.<sup>2</sup> Recent publications showed the opportunity to evaluate the CI electrode position

by MRI *in vivo* and underline that the magnet artifact is a solved problem by specific implant positioning, head positioning, and choice of sequence.<sup>2–4</sup>

*In vitro* testing allows the transfer of specific information to improve the *in vivo* situation. Models or *in vitro* observation in temporal bones has been used for the computed tomography (CT) evaluation of electrode position,<sup>5</sup> the estimation of force behavior during insertion,<sup>6</sup> and evaluation of intracochlear pressure during insertion in temporal bones<sup>7</sup> and different models.<sup>8</sup>

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The use of a model can be assumed to be beneficial as a tool to visually understand the electrode pattern in MRI scanning. It has multiple advantages in comparison to a direct evaluation and comparison of different MRI sequences in humans.<sup>9,10</sup> Initial *in vivo* observations of the MRI patterns of CI electrodes showed general differences and characteristics in terms of resolution and quality of scans, requiring further improvement of MRI sequences.<sup>11</sup>

The major advantage of a model is the application of multiple scans with different sequence parameters without any patient burden. The purpose of MRI sequences evaluation is to optimize its resolution, voxel size, and duration. This process can be extremely time consuming. The introduction of MRI scans as postoperative tool for the evaluation of CI patients requires a balanced sequence showing a good compromise between resolution, scanning time, and slice thickness. An independent model seems necessary as various MRI scanner suppliers differ substantially in terms of their parameters.

The visual pattern of CI electrode is different from a CT pattern in terms of the fluid diminishing effect in contrast to an artifact visualization in a deep vein thrombosis/computed tomographic scan. This visual change needs to be studied to get familiarized. This can be easily accomplished by a model simulating different positional situations and electrodes.

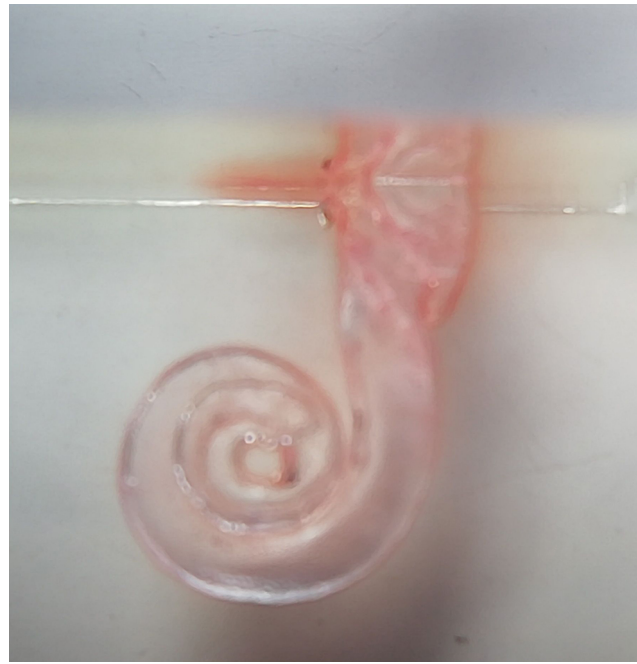
Focusing on the cochlea, an electrode position (scala position) in the axial plane can be evaluated even in the MRI.<sup>3</sup> The visual pattern in the coronal plane is more difficult to recognize as small changes may lead to torsional visual changes.

MRI scanning of models or temporal bones—different to CTs—requires a proper fluid signal. The attempt to scan an area with a low fluid signal results in an interruption of the MRI scanner procedure.<sup>12</sup> As an electrode evaluation is only possible in a T2 sequence detecting fluid areas, this problem needs to be solved.

The goal of this study was to establish a technique for the *in vitro* MRI evaluation of CI electrodes and determine optimized sequences.

## Materials and Methods

A three-dimensional (3D)-printed plastic scala tympani model of the cochlea (►Figs. 1 and 2) was filled with distilled water and inserted with different CI electrodes (Advanced Bionics, Stäfa, Swiss: HFMS; Cochlear, Melbourne, Australia: Contour, x32, Slim straight, Medel, Innsbruck, Austria Flex 28; Oticon, Vallauris, France: EVO). The design of each electrode can be classified into two groups (perimodiolar vs. lateral). The information for each electrode is additionally added to the legends. The model was provided by a CI manufacturer. This model was sealed to prevent evaporation. Afterward, the model was placed in a regular available gel-filled cool pack. This gel-filled cool pack was wrapped around a 5 l MRI scanning normation bottle (►Figs. 3 and 4). Normation bottles are used in every radiologic department to perform normation tasks. The bottle was placed in the 3T MRI scanner (Philips Acura) and different T2 2D drive multishot sequences were performed (►Table 1). In all cases, a coronal plane was performed for the scanning.



**Fig. 1** Three-dimensional-printed scala tympani model of the cochlea.

## Results

The 3D print of a cochlea enables the wrapping of a gel-filled cool pack around the model. This high grade of fluid in the cool pack and the contrasted fluid of the artificial 3D model offered an excellent contrast for the evaluation. The block configuration of the model allowed an easy angulation during the scanning survey.

The different electrodes were distinguishable and exhibited characteristic patterns. Lateral wall electrodes showed a T2 signal medially to the implant body and differentiated from each other by their number of contacts. This led to an identification of EVO (►Fig. 5), Flex 28 (►Fig. 6A–C), and slim straight array (►Fig. 7A, B). The pattern of modiolar

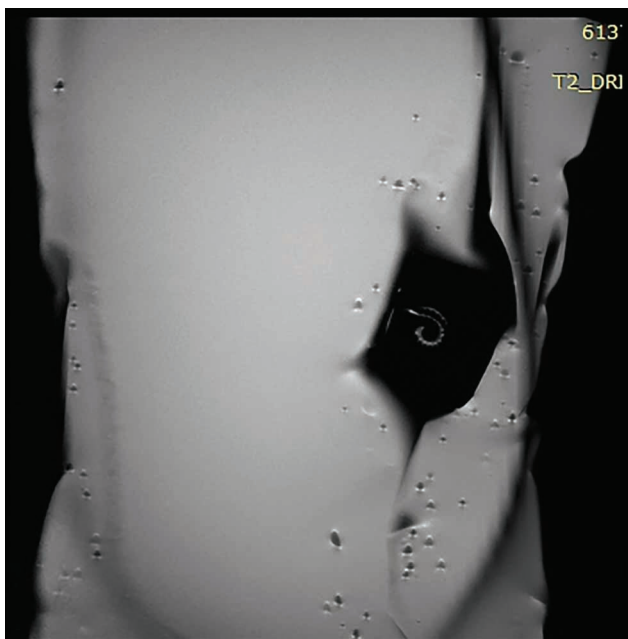


**Fig. 2** Three-dimensional-printed scala tympani model of the cochlea.

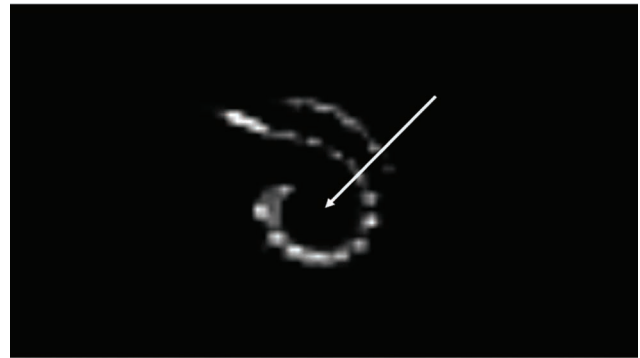
electrodes showed a fluid signal both medially and laterally from the electrode for the contour (►Fig. 8A, B) and the HFMS electrode (►Fig. 9A, B). Interestingly, the x32 device displayed only a fluid signal laterally, due to the tight wrapping of its electrode (►Fig. 10).



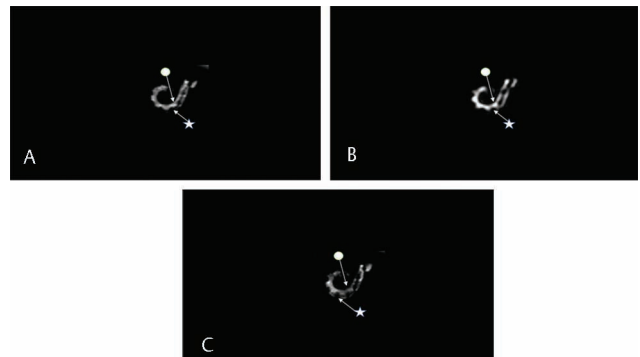
**Fig. 3** Model attached wrapped with a cool pack around a Normation bottle.



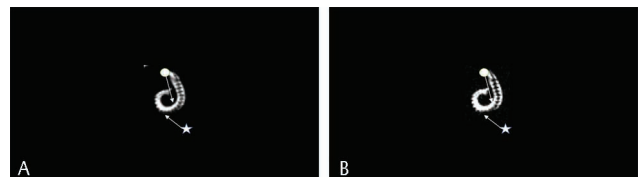
**Fig. 4** Model attached wrapped with a cool pack around a Normation bottle.



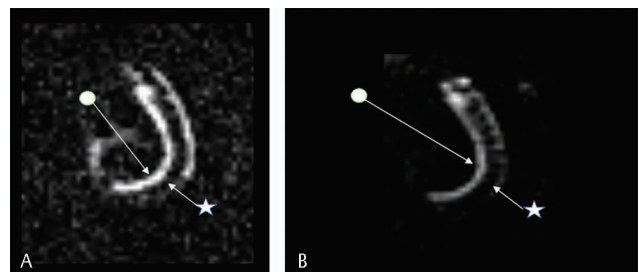
**Fig. 5** Oticon EVO electrode (lateral) magnetic resonance imaging scan with Sequence 2. An arrow indicates the modiolus position.



**Fig. 6 (A–C)** MED-EL Flex 28 electrode (lateral) at magnetic resonance imaging scan with Sequences 1, 4, and 3. Star indicates electrode, and ball indicates fluid signal.

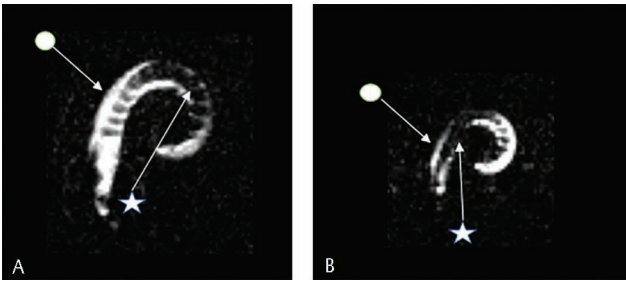


**Fig. 7 (A, B)** Cochlear slim straight electrode (lateral) at magnetic resonance imaging scan with Sequences 2 and 1. Star indicates electrode, and ball indicates fluid signal.

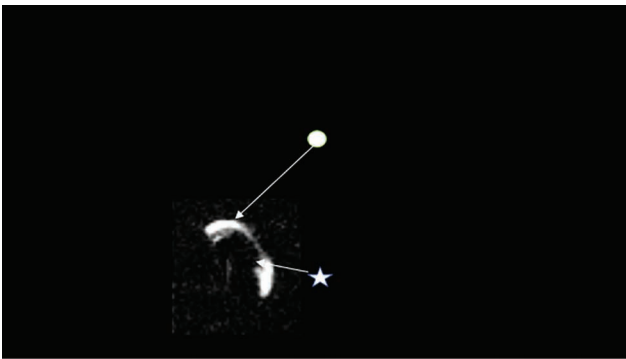


**Fig. 8 (A, B)** Cochlear contour electrode (perimodiolar) at magnetic resonance imaging scan with Sequences 1 and 2. Star indicates electrode, and ball indicates fluid signal.

Additionally, visible contacts allowed a differentiation between contour and HFMS electrodes. The evaluation of the different applied sequences highlighted the importance of adjusting following parameters: slice thickness, resolution,



**Fig. 9 (A, B)** Advanced Bionics HFMS electrode (modiolar) at magnetic resonance imaging scan with Sequences 3 and 1. Star indicates electrode, and ball indicates fluid signal.



**Fig. 10** Cochlear X32 electrode (perimodiolar) at magnetic resonance imaging scan with Sequence 1. Star indicates electrode, and ball indicates fluid signal.

and scanning time. The choice of the different sequences followed the aim of finding a good compromise between these three parameters. These parameters are interdependent and determined by the scanner. Comparing Sequence 1 with 4 for the Flex 28 electrode indicated that contrasting is more important for the differentiation of electrode structures than slice thickness. The same comparison for the HFMS and Flex 28 electrodes revealed that an increase in resolution from  $0.3 \times 0.3$  mm to  $0.2 \times 0.2$  mm. However, the improved resolution prolonged the scanning time from 16 minutes to 38 minutes.

**Discussion**

MRI scanning of CI electrodes in a model is a complex method. The presented model allowed in vitro testing of sequences prior to the introduction a clinical tool. It prevented significant discomfort for the patients avoiding repetitive testing and long scanning periods. The addition of the application of a cool pack to the 3D artificial model solved the general problem of a fluid contrast, which is needed for the MRI scanner not to interrupt the procedure.<sup>12</sup>

Using a model for the evaluation of electrodes makes the testing of MRI sequences independent from patients. This technique provides an easy way to evaluate and optimize sequences and electrodes for the MRI. A comparison of two different sequences indicated the value of a model for the

**Table 1** MRI description of the different MRI sequence parameter with evaluated electrodes (The different sequences are used as numbered).

Electrodes	Contour	Contour	Hi Focus	Flex 28	Straight	Straight	Hi Focus	Oticon evo	Flex 28	Flex 28	X32
<b>Fig.</b>	8a	8b	10a	6b	7b	7a	10b	5	6c	6a	9
<b>Sequence</b>	1	2	3	4	1	2	1	2	3	1	1
<b>Slice thickness (mm)</b>	0.9	2	1.4	0.5							
<b>Resolution (mm)</b>	$0.3 \times 0.3$	$0.3 \times 0.3$	$0.2 \times 0.2$	$0.6 \times 0.6$							
<b>FOV</b>	$150 \times 150$	$150 \times 150$	$150 \times 150$	$150 \times 150$							
<b>Time (min)</b>	16	17	38	13							
<b>TE (ms)</b>	100	87	87	87							
<b>TR</b>	3000	3000	3000	3000							
<b>TSE Tact</b>	17	16	11	16							
<b>Flip angle</b>	90°	90°	90°	90°							
<b>Refocus control</b>	120	120	120	120							
<b>Metric</b>	512	512	512	512							
<b>NSA</b>	5	5	5	8							
<b>Foldover direct</b>	AP	AP	AP	AP							

refinement of a high-resolution MRI sequence. The comparison illustrates that the voxel size is highly important for the quality of visualization (► Fig. 6B, C). Investigating the same electrode (► Fig. 6B; slice thickness/resolution 0.5 mm, voxel size  $0.6 \times 0.6$  mm [Sequence 4]) shows less contoured edges than (► Fig. 6A; slice thickness/resolution 0.9 mm, voxel size  $0.3 \times 0.3$  mm [Sequence 1]). The lower resolution is a disadvantage of Sequence 4 in comparison to Sequence 3. A combination of both preferred parameters is not possible as a physical conflict of the MRI scanner would occur. Finally Sequence 1 was preferred since it was the best compromise between the three parameters slice thickness, resolution (voxel size), and scanning time (► Table 1).

Additionally, the scan of different electrodes can be performed to gain an improved understanding of the complex visual MRI pattern changes, which are associated with changes of the model position in the coronal plain.

Evaluation of electrode position in the axial plain with an adequate resolution is applicable even with a 1.5 T MRI scanner.<sup>3</sup> Understanding the coronal visual pattern is an important step for the evaluation of insertional depth by MRI. Comparison of the electrodes shows a general difference between lateral wall electrodes and perimodiolar/modiolar electrodes. The fluid signal of lateral wall electrodes is medially positioned. Contrary, we detected a laterally positioned fluid signal in perimodiolar/modiolar electrodes. It enables easy differentiation between the lateral wall electrode types by counting the number of contacts (► Figs. 6 and 7). A differentiation of perimodiolar/modiolar electrode types was possible. The x2 electrodes revealed no medial fluid signal, while the contour and HFMS electrodes were characterized by medial and lateral fluid signals.

The evaluation of CI electrodes in temporal bones by MRI is challenging. Related to the complex aeration, limitations due to the requirement of an air bubble-free cochlea and a fluid contrast for the MRI scanning persist. The limitations of this study are related to the model. The employed model is only a scala tympani print. Ideally, a scala vestibuli integration into the model is required for a complete evaluation of the electrode MRI pattern. The possible translocation of electrodes cannot be simulated in this model. Alternatively, specific temporal bone models might be generated, which solve the problem of a so far missing fluid contrast. A further evaluation of the elaborated sequences in vivo is necessary.

## Conclusion

MRI testing can be performed in vitro for the evaluation of CI electrode patterns and optimization of sequences. The application of this model allowed the evaluation of MRI sequences and scanner characteristics.

### Statement of Ethics

The data used to support this study's findings are available from the corresponding author upon request.

### Data Availability Statement

All data are implemented in the manuscript.

### Authors' Contributions

Todt has conceptualized and written the manuscript, while H. Sudhoff, C. Riemann, and H.B. Gehl have cowritten the manuscript.

### Conflict of Interest

None.

### Acknowledgment

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