

Testing a Cochlear Implant Electrode Insertion Training System for Optimal Electrode Array Placement in Different Inner Ear Anatomies

Sarah Draut^{*1}, Clemens Stihl^{*1}, Andrea Schreier¹, Anandhan Dhanasingh², Justus Müller-Goebel³, Joachim Müller¹

¹Department of Otorhinolaryngology, LMU University Hospital, LMU Munich ²Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital Zurich ³Department of Research and Development, MED-EL GmbH

✉ Corresponding Author : Clemens Stihl <clemens.stihl@med.uni-muenchen.de>

* These authors contributed equally

Citation

Draut, S., Stihl, C., Schreier, A., Dhanasingh, A., Müller-Goebel, J., Müller, J. Testing a Cochlear Implant Electrode Insertion Training System for Optimal Electrode Array Placement in Different Inner Ear Anatomies. *J. Vis. Exp.* (228), e69129, doi:10.3791/69129. (2026).

Abstract

Successful intracochlear placement of the cochlear implant (CI) electrode array is a key surgical step in cochlear implantation. Without it, rehabilitation cannot proceed, and all pre- and postoperative efforts are futile. Therefore, electrode insertion requires a high level of precision and devotion from the surgeon. Since clinical and anatomical conditions vary, intensive training to optimally and safely place the electrode array inside the cochlea is essential. During residency, every trainee surgeon should undergo a defined amount of lab training. Drilling cadaveric temporal bones to safely reach the cochlea and optimally insert CI electrodes, as in reconstructive middle ear surgery, is crucial. According to the literature, around 10-20% of individuals with congenital hearing loss are reported to have various degrees of inner ear malformation. Cadaveric temporal bones used for drilling training are typically obtained from elderly donors and rarely show inner ear malformations. In contrast, patients receiving cochlear implants represent a highly selected group in whom anatomical variations of the inner ear are significantly more common than in the general population. Lack of training in placing electrodes in malformed inner ears is seen as one of the key reasons for encountering complications during electrode insertion. The present work is a demonstration study to evaluate an advanced electrode insertion training system featuring interchangeable transparent inner ear models that represent both normal and anatomically variant cochleae. Included anatomical types are incomplete partition (IP) types I, II, and III, as well as cochlear hypoplasia, common cavity, enlarged vestibular aqueduct (EVA), and normal inner ear anatomy, represented in three different sizes. The aim of this study is to demonstrate the use of the presented electrode insertion training system and to provide experiential recommendations on optimal electrode placement inside the cochlear portion across different types of inner ear anatomy, derived from four resident surgeons supervised and guided by an experienced surgeon.

Introduction

Cochlear implantation (CI) is the state-of-the-art treatment option for severe to profound sensorineural hearing loss¹. The procedure involves surgical placement of the implant's electronic device on

the surface of the skull as well as insertion of the electrode array into the cochlea. This enables direct electrical stimulation of the auditory nerve. Optimal placement of the electrode within the cochlea is crucial for establishing an effective electrode-

neural interface, which is essential to maximize the benefit of the device for the recipient². It requires extensive training for the surgeon to position the electrode precisely. During residency, the trainee surgeon should complete an appropriate amount of lab training using cadaveric temporal bones. Training should include drilling to safely access the cochlea, as well as inserting CI electrodes³. In addition, CI manufacturers offer specialised trainings to ensure that every surgeon can handle their specific electrode arrays safely without complications. Nonetheless, the reported rates of electrode misplacement in clinical practice, especially in some array types, emphasize the importance of further training solutions.

According to the literature, around 10-20% of individuals with congenital hearing loss have some form of inner ear malformation, as described in detail by Jackler et al.⁴ and Sennaroglu et al.⁵. Each type of inner ear malformation is associated with specific challenges during surgery and electrode insertion. Commonly reported complications are electrode buckling outside the cochlea, electrode floating in the cystic cochlear portion, and the electrode entering the internal auditory canal⁶. Cadaveric temporal bones used for surgical training are typically obtained from elderly adults who donate their bodies for research and education. As a result, inner ear malformations are extremely rare in these specimens⁷. A lack of specific training in electrode placement and cochlear access in malformed inner ears is regarded as a key contributor to electrode insertion complications during CI surgery.

Based on our clinical experience since 1990, inner ear malformations often require electrode arrays with varying lengths and designs to achieve optimal placement. MED-EL is one of the Food and Drug Administration (FDA) approved CI manufacturers that offers a wide range of electrode options, making it possible to better accommodate diverse and complex inner ear anatomies⁸. In a recent collaboration, MED-EL (Innsbruck, Austria) and COSA Ltd. (Cambridge, UK) developed an advanced training system for CI electrode insertion. The system features a realistic head model with a predrilled mastoidectomy. It further offers the possibility to insert different transparent inner ear models, representing various types of inner ear malformations. Using a microscope, the basal turn of the cochlea is visualised in the coronal view, enabling precise observation of the electrode entering the cochlea. The design of the electrode insertion training system makes it well-suited for educating trainee surgeons on the following aspects: (i) How should the electrode be held according to the recommendation of the CI manufacturer? (ii) What is the best insertion angle? How can the electrode be supported to follow the lateral wall of the cochlea, and how can a misplacement of the electrode inside the internal auditory canal be prevented? (iii) How to insert the electrode fully inside the cochlea when facing insertion resistance? (iv) What is the maximum electrode insertion angle in different degrees of cystic malformation, and how can an

overlap of electrode channels be prevented? (v) What is the optimal electrode placement technique in a common cavity malformation?

In this article, we share our experience with electrode insertion in various inner ear malformations, offering practical tips and strategies to support a successful placement of the electrode and minimize complications during CI surgery.

Protocol

This study was performed entirely in a laboratory setting and did not involve patients. Therefore, ethics committee approval was not required for this study.

1. Description and setup of the electrode insertion training system.

1. Set up the electrode insertion training system.

NOTE: The electrode insertion training system contains a right-sided headpiece including a transparent inner ear model in the anatomically correct position. The mastoidectomy and the posterior tympanotomy are predrilled, providing access to the cochlea. A digital microscope is positioned above at a focal distance of 6 cm with a 4K (2000x) magnification to focus on the coronal view of the inner ear model, allowing visualization of the electrode as it enters the cochlea during insertion. This view is displayed on a monitor (1280 x 800) mounted directly above the microscope. Additionally, a magnifying lens that gives 175% magnification with an integrated light source is placed above the mastoidectomy site to enhance visibility of the posterior tympanotomy. The cochlear entrance is outlined in red to aid identification through the posterior tympanotomy. The training system includes ten different inner ear models for the right ear. Normal anatomy (NA) comes in three different sizes as represented by the A-value (diameter of cochlear basal turn), namely NA-M with an A-value of 8.4 mm, NA-L with an A-value of 9.6 mm, and NA-XL with an A-value of 10.4 mm. Further models represent various inner ear malformation types like enlarged vestibular aqueduct syndrome (EVAS), incomplete partition (IP) types I, II, and III, cochlear hypoplasia (CH) in two different variants, and a common cavity malformation (CC). **Figure 1** shows the assembly of the training system along with the transparent inner ear models.

To ensure a smooth insertion, fill the transparent models with a lubricant, such as glycerine with a concentration of 99.5% and a viscosity of 870 Pa·s, in this case.

2. Electrode handling (**Figure 2**)

1. Prepare the electrode and instruments before insertion.
2. Use the soft-grip forceps provided by the manufacturer.

3. Hold the electrode only with the angled soft-grip forceps.
4. Position the electrode lead within the straight segment of the angled tip.
5. Lock the electrode directly behind the array stopper.
6. Avoid grasping the electrode array in the area of the electrode contacts.
7. Do not compress or twist the electrode.
8. Confirm stable fixation before approaching the cochleostomy or round window.

3. Angling the electrode during insertion (**Figure 3**)

1. Align the forceps before advancing the electrode.
2. Maintain a superior-inferior insertion angle.
3. Guide the electrode towards the lateral wall of the cochlea.
4. Avoid an inferior-superior angle.
5. Do not lead the electrode towards the medial wall.
6. Continuously observe the electrode trajectory during advancement.
7. Try to maintain a steady, slow speed.

4. Recommendations when facing electrode insertion resistance

1. Stop advancing the electrode array immediately when resistance occurs.
2. Do not apply force.
3. Withdraw the electrode by a few millimetres.
4. Re-advance the electrode slowly.
5. Maintain the lateral wall trajectory during reinsertion.
6. Prevent extracochlear buckling at all times.

5. Inserting electrodes in different inner ear anatomies

NOTE: The following sections demonstrate electrode insertion using transparent inner ear models representing various anatomical types, including incomplete partition (IP) types I, II, III, cochlear hypoplasia, common cavity, enlarged vestibular aqueduct (EVA), and normal anatomy cochlea in two different sizes. The objective is to share insights into safe electrode insertion techniques to minimize complications.

1. Incomplete partition type I (**Figure 4**)

1. Identify a complete cystic cochlear portion on imaging.

2. Select an electrode length appropriate for limited angular insertion.
3. Insert the electrode at a superior-inferior angle.
4. Guide the electrode strictly along the lateral wall.
5. Limit insertion depth to a maximum of 360°.
6. Prevent overlap of apical electrode contacts.

2. Incomplete partition type II (**Figure 5**)

1. Identify a normal basal turn with a cystic apex on imaging.
2. Insert the electrode through the regularly formed basal scala.
3. Maintain a lateral wall trajectory.
4. Advance the electrode up to 450°.
5. Stop insertion before entering the cystic apical portion.
6. Avoid electrode overlap beyond 450°.

3. Incomplete partition type III (**Figure 6**)

1. Identify a widened internal auditory canal (IAC) on imaging.
2. Anticipate a high risk of electrode misdirection into the IAC.
3. Avoid central or straight insertion paths.
4. Insert the electrode at a superior-inferior angle.
5. Continuously guide the electrode along the lateral wall.
6. Confirm that the electrode remains within the cochlear portion.

4. Common cavity (CC) (**Figure 7**)

1. Identify a single undivided cavity in preoperative imaging.
2. Avoid straight advancement of the electrode.
3. Pre-bend the electrode array gently.
4. Introduce the curved segment first.
5. Allow the electrode array to form a loop within the cavity.
6. Stabilize the looped configuration.
7. Prevent entry of the electrode into the IAC.

5. Cochlear hypoplasia (**Figure 8**)

1. Measure cochlear length precisely before insertion.
2. Select an electrode matching the reduced cochlear length.
3. Advance only until the cochlea lumen is fully covered.
4. Avoid over-insertion beyond the developed basal turn.

6. Enlarged vestibular aqueduct (EVA) (Figure 9)

1. Identify normal basal turns with a mildly cystic apex on preoperative imaging.
2. Insert the electrode along the lateral wall at a superior-inferior angle.
3. Advance the electrode up to 540°.
4. Stop insertion before entering the cystic apical region.
5. Avoid overlap of the electrode contacts within the apex.

7. Normal anatomy in different sizes (Figure 10)

1. Measure the A-Value of the cochlea preoperatively.
2. Select electrode length according to cochlear size.
3. Insert the electrode fully along the lateral wall.
4. Expect deeper angular insertion in smaller cochleae (Figure 10, A-value of 8.1 mm leading to approx. 600°).
5. Expect reduced angular insertion in larger cochleae (Figure 10, A-value of 10.4 mm leading to approx. 450°).

Results

The presented models demonstrate how electrode handling, insertion angle, and anatomical variation influence intracochlear electrode positioning.

Electrode handling

Different grasping techniques using soft-grip forceps resulted in variable control of the electrode lead. Suboptimal grips reduced stability, whereas correct engagement of the straight portion of the angled tip at the array stopper ensured reliable control during insertion (Figure 2).

Angling the electrode during insertion (Figure 3)

Electrode trajectory was shown to be strongly dependent on the orientation of the forceps. A superior-inferior alignment consistently guided the electrode along the lateral cochlear wall (Figure 3B), while an inferior-superior orientation increased the likelihood of medial wall deviation (Figure 3A). This finding highlights the importance of forceps orientation in achieving controlled lateral wall placement.

Incomplete partition type I

In incomplete partition type I, selection of an electrode length that matches the cystic cochlea enables appropriate angular coverage, whereas deeper insertions increase the risk of electrode overlap (Figure 4A,B). IP type I is characterized by the cochlear portion being completely cystic along with the absence of a central modiolus trunk. The cystic cochlea is separated from the dilated vestibule. Careful planning, based on preoperative imaging,

enables the selection of an electrode with a suitable length to cover the recommended angular depth as shown in Figure 4C. Insertion beyond 360° of angular depth may lead to electrode overlap (Figure 4D, white arrow).

Incomplete partition type II

In incomplete partition type II, stable positioning was achieved when insertion was limited to the formed cochlear turns (Figure 5); advancement into the cystic apex was associated with electrode overlap and potential channel interaction.

Incomplete partition type III

In incomplete partition type III, the absence of the modiolus and the widened internal auditory canal created a high risk of electrode misdirection. A lateral wall-directed insertion approach reduced the likelihood of unintended entry into the internal auditory canal and supported retention within the cochlear lumen (Figure 6).

Common cavity (CC) (Figure 7)

In common cavity malformations, direct advancement of the electrode tip increased the risk of misplacement. Electrode reshaping and introducing the curved segment first as described in the protocol (Figure 7D), promoted a looped configuration within the cavity, facilitating stable positioning and reducing the risk of extrusion into adjacent structures.

Cochlear hypoplasia

Insertions in cases with cochlear hypoplasia underscore the importance of precise preoperative measurements. Reduced cochlear dimensions limited the achievable insertion depth and necessitated careful selection of electrode length to avoid overinsertion (Figure 8).

Enlarged vestibular aqueduct (EVA) (Figure 9)

In enlarged vestibular aqueduct anatomy, nearly normal cochlear development allowed standard insertion to a predefined angular depth. Beyond this point, entry into the cystic apex became more likely. Limiting insertion depth reduced the risk of electrode overlap and potential interchannel interference.

Normal anatomy with different sizes

In normally developed cochleae, cochlear size significantly influenced angular insertion depth for electrodes of identical length. Smaller cochlear dimensions resulted in greater angular coverage compared with larger cochleae, emphasizing the importance of cochlear size assessment during surgical planning (Figure 10).

Electrode insertion was performed manually under continuous visual control using the training system employed in this study. Accordingly, the protocol was designed to standardize electrode handling, angulation, and trajectory within this model rather than to assess procedural performance metrics. The primary outcome

was a qualitative evaluation of electrode trajectory and final placement in the training model, with all resident surgeons

reproducibly achieving optimal positioning across all anatomical variations represented, under senior supervision.

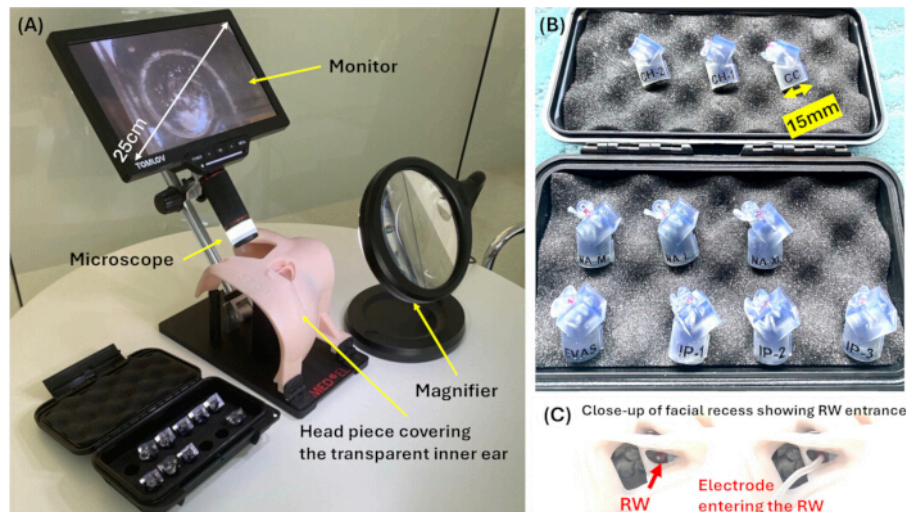


Figure 1: Advanced training system for cochlear implant electrode insertion along with transparent inner ear models of different anatomies. (A) Left panel shows the assembly of the electrode insertion training system. (B) Cochlear models of all different inner ear anatomies tested in this study. (C) Close-up of the facial recess. [Please click here to view a larger version of this figure.](#)

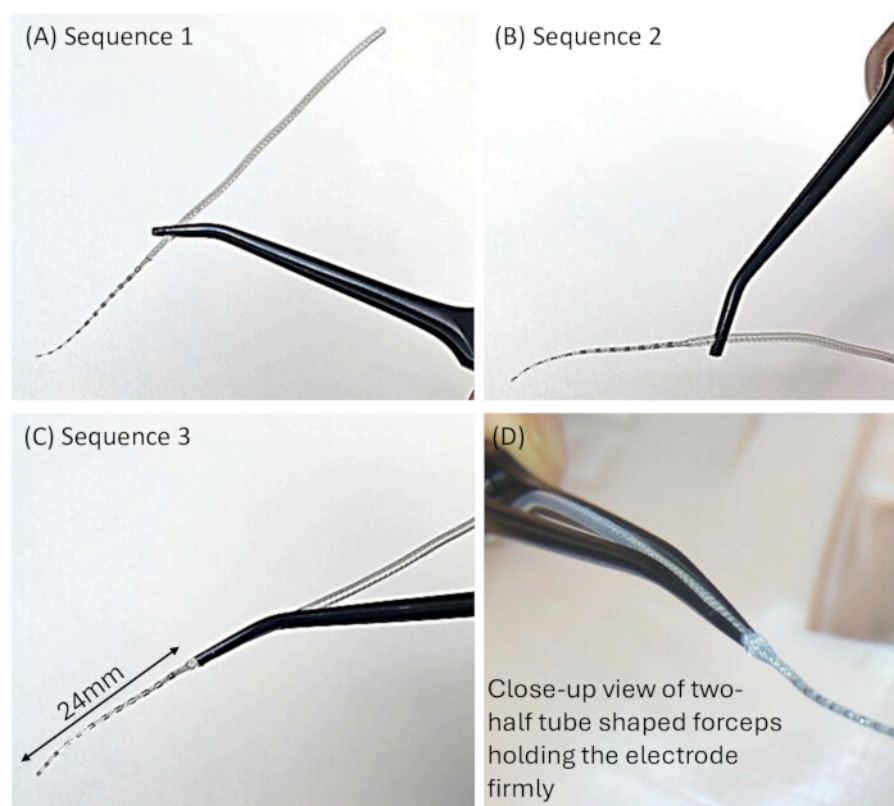


Figure 2: Soft-grip forceps holding the electrode in three different sequences. (A,B) Sequences 1 and 2 showing sub-optimal ways of holding the electrode. (C) Sequence 3 showing the optimal way of holding the electrode, enclosed by the angled tip of the soft-grip forceps. (D) Close-up view of forceps with a tip consisting of two half tube shaped ends, holding the electrode firmly right behind the array stopper. [Please click here to view a larger version of this figure.](#)

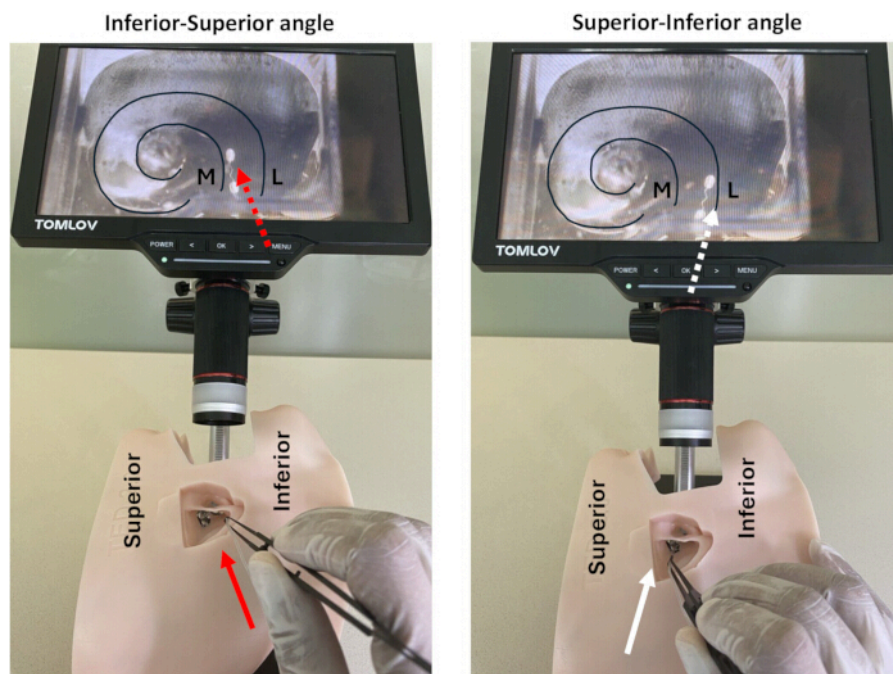


Figure 3: Positioning of the electrode. (A) Positioning the electrode in an inferior-superior angle leads the tip of the electrode array closer to the medial wall (M) of the cochlea. (B) Positioning the electrode at a superior-inferior angle leads the electrode towards the lateral wall (L) of the cochlea. [Please click here to view a larger version of this figure.](#)

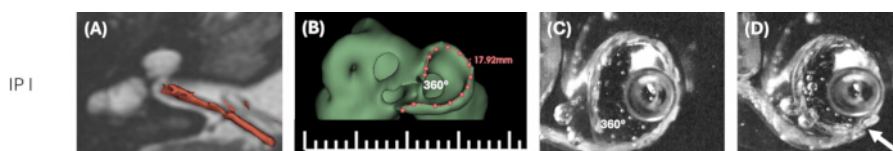


Figure 4: Incomplete partition type I. (A) Axial view of IP type I. (B) Three-dimensional (3D) shell model of an IP type I showing the cystic cochlear portion. (C) Electrode optimally covering an angular depth of 360° in a cystic cochlear portion avoiding overlapping of electrodes. (D) Insertion beyond 360° of angular depth may lead to electrode overlap, as shown by the white arrow. [Please click here to view a larger version of this figure.](#)

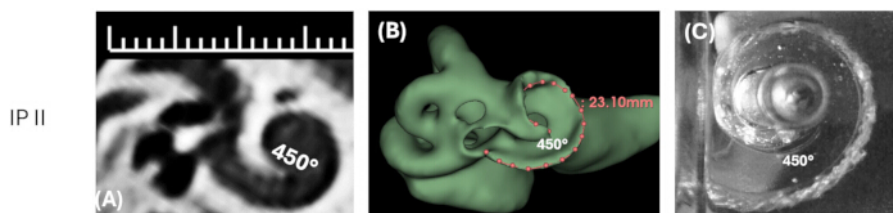


Figure 5: Incomplete partition type II. (A) Coronal view of IP type II. (B) 3D shell model of IP Type II illustrating the normal development of the basal turn of the cochlea until 450°. (C) Electrode optimally covering an angular depth of 450° in IP type II. [Please click here to view a larger version of this figure.](#)

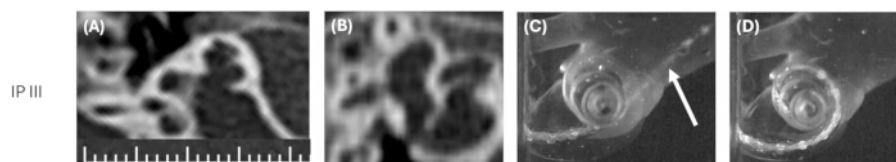


Figure 6: Incomplete partition type III. (A) Axial and (B) coronal view of IP type III. (C) Electrode inside the internal auditory canal. (D) Electrode optimally placed inside the cochlear portion. [Please click here to view a larger version of this figure.](#)

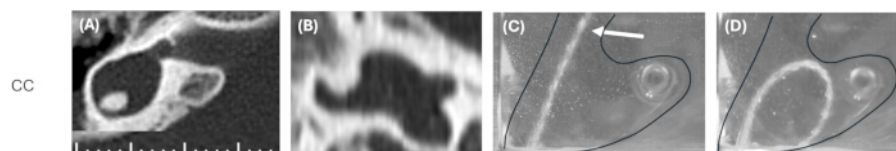


Figure 7: Common cavity (CC). (A) Axial and (B) coronal view of a common cavity. (C) Insertion of a straight electrode into a common cavity. The white arrow indicates dislocation of the electrode array inside the IAC. (D) Correctly placed electrode in the recommended optimal looped configuration inside the cavity. [Please click here to view a larger version of this figure.](#)

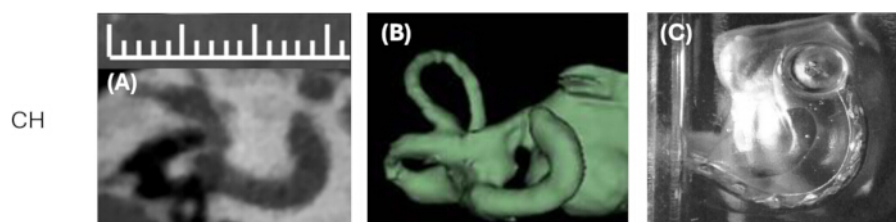


Figure 8: Cochlear hypoplasia. (A) Coronal view of a hypoplastic cochlea with the first half of the basal turn developed. (B) 3D model of the hypoplastic cochlea taken for electrode insertion. (C) Placement of a 12 mm long electrode covering the entire hypoplastic cochlea. [Please click here to view a larger version of this figure.](#)

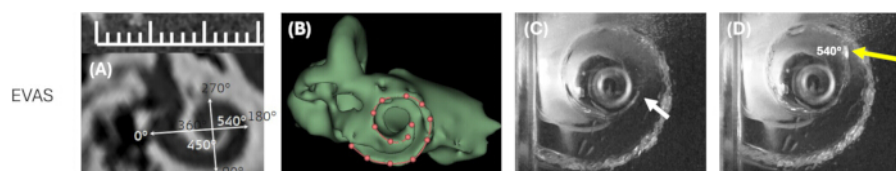


Figure 9: Enlarged vestibular aqueduct (EVA). (A) Coronal view of an EVA showing the lateral wall of the cochlea clearly up to 540°. (B) 3D shell model of an EVA case, illustrating the cochlear length measurement for an angular insertion depth of 540°. (C) Optimal insertion of the electrode covering 540° of angular depth, as indicated by the white arrow. (D) Over-inserted electrode pushed beyond 540°, leading to an overlap of apical and mid channels, indicated by the yellow arrow. [Please click here to view a larger version of this figure.](#)

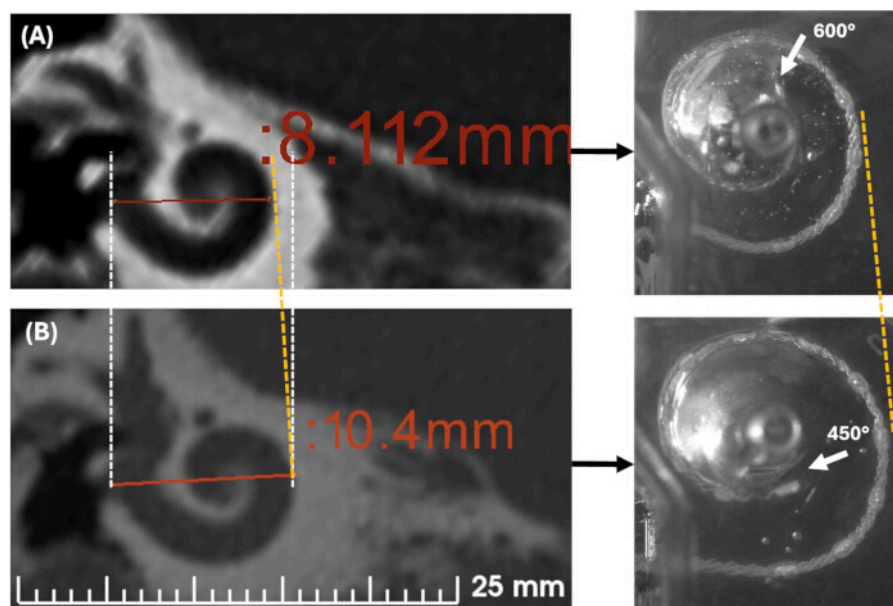


Figure 10: Normal anatomy in different sizes. (A,B) Effect of different cochlear sizes on electrode insertion depth. Coronal view of anatomically normal inner ears of two different sizes (A-value of (A) 8.1 mm and (B) 10.4 mm). In a smaller-sized cochlea, a full insertion of a 28 mm long electrode covers about 600° of angular depth, whereas in a bigger-sized cochlea, it covers only 450°, as indicated by white arrows. [Please click here to view a larger version of this figure.](#)

Discussion

This study provides a structured overview of optimal electrode insertion techniques across seven distinct inner ear anatomies. Key aspects for achieving optimal electrode insertion include accurately identifying the anatomical type from preoperative imaging, understanding possible insertion-related complications, and learning how to securely and comfortably handle the electrode using appropriate surgical tools.

Accurate identification of the inner ear anatomy on preoperative imaging highly depends on the clinician's experience. Among the various types, IP type II and EVA can appear similar to each other. However, the extent of the lateral wall visible in the coronal view differs. In IP type II, it is up to 450°, whereas in cases with an EVA it is about 540° and therefore can serve as a distinguishing feature^{9,10,11}. Alsughayer et al. in 2022 reported electrode tip fold-over when inserting a long length electrode in an IP type I malformation type when the electrode was pushed beyond 360° of angular insertion depth¹². Among other reasons, this was one of the factors that led us to design the study to cover 360° in IP type I, 450° in IP type II, and 540° in EVA, thereby avoiding placing the electrode in the cystic apical region.

One of the key insights gained from this study is that, regardless of the anatomical variation, guiding straight electrodes along the lateral wall of the cochlea is advantageous. This approach not only facilitates full insertion but also helps prevent the electrode

from entering the IAC, a particular concern in IP type III and common cavity malformations. Electrode insertion resistance is a well-documented complication in the literature, arising from various factors, such as anatomical variations, electrode design characteristics, surgical technique, or the electrode tip encountering intracochlear structures¹³. Forcing the electrode further when resistance occurs increases the risk of significant electrode buckling, which can result in an incomplete or partial insertion. To avoid the risk of buckling, we recommend slightly retracting the electrode array and then carefully reinserting it. This technique proved effective, as confirmed through real-time visualization on the monitor of the electrode insertion training system used in this study.

Aschendorff et al. previously reported the use of radiologically assisted navigation for precise electrode placement in IP type III, a method that requires specialized intraoperative imaging systems¹⁴. However, this approach is technically demanding, requires the availability of appropriate technical infrastructure, and involves a considerable increase in intraoperative time. In contrast, systematic electrode insertion training offers a simpler and more cost-effective approach to reducing the risk of electrode misplacement.

In addition to correctly identifying the inner ear anatomy and understanding the insertion-related challenges specific to each anatomical type, it is essential to know how to properly and comfortably hold the electrode to achieve full insertion of the chosen electrode. The soft-grip forceps provided with MED-EL

straight electrodes feature a specially designed tip with two half tubes, intended to securely lock the electrode and provide precise control during insertion. Adhering to the manufacturer's instructions is essential for learning to handle the instruments safely and effectively. Choosing electrode length matching the size of the cochlea as measured by the A-value is another recommendation, especially for resident surgeons to follow¹⁵.

Training on cadaveric temporal bones is both expensive and time-consuming, and specimens with congenital inner ear malformations are exceedingly rare. The advanced electrode insertion training system evaluated in this study addresses these limitations: it allows unlimited practice attempts, provides real-time visualisation of electrode movement within the transparent cochlear model, and enables the user to adjust the insertion trajectory for optimal placement within the cochlea.

This study used electrode variants from a single CI manufacturer. Consequently, the procedural recommendations provided are specific to MED-EL electrodes and may not be directly applicable to electrode arrays from other CI manufacturers. Another limitation arises from the use of a resin polymer in the fabrication of transparent cochlea models, which differs from biological tissue in terms of frictional properties, tactile feedback during electrode insertion, and the absence of physiological factors, such as bleeding or tissue elasticity. Therefore, these findings and observations obtained from this training system should be interpreted with caution and carefully translated to *in vivo* conditions.

For all four resident surgeons, this was the first experience of inserting an electrode in inner ear anatomies other than the normal anatomy. The ability to visually observe the electrode entering the cochlea proved to be highly instructive, underscoring the educational value of this training system. For example, by adjusting the trajectory from an inferior-superior to a superior-inferior angle, it was possible to visualize how the electrode tip reoriented towards the lateral wall, thereby facilitating optimal insertion into the cochlear portion and preventing misdirection. The senior surgeon regarded this training system as a valuable educational tool for resident surgeons, offering learning opportunities that are difficult to achieve using cadaveric temporal bones.

The advanced training system presented in this study enables young CI surgeons to practise electrode insertion across a broad range of inner ear anatomies. During insertion, maintaining a superior-inferior trajectory and guiding the electrode along the lateral wall of the cochlea helps achieve a full insertion and reduces the risk of electrode misplacement. Careful preoperative planning and especially selecting an electrode array matched to the specific inner ear morphology further minimizes insertion-related complications.

Disclosures

One of the co-authors (AD) is a full-time employee within the research and development department of MED-EL GmbH.

Acknowledgments

Dr Filip Hrnčirik and Dr Iwan Vaughan Roberts from COSA Ltd, Cambridge UK, are acknowledged for their efforts in co-developing the electrode insertion training system presented in this study.

References

- Hochmair, I. et al. MED-EL Cochlear implants: state of the art and a glimpse into the future. *Trends Amplif.* **10** (4), 201-219 (2006).
- Dhanasingh, A. et al. Cochlear implant electrode design for safe and effective treatment. *Front Neurol.* **15**, 1348439 (2024).
- Freund, M., Frithioff, A., Konge, L., Sørensen, M. S., Andersen, S. A. W. Cochlear implant surgery: Learning curve in virtual reality simulation training and transfer of skills to a 3D-printed temporal bone - A prospective trial. *Cochlear Implants Int.* **22** (6), 330-337 (2021).
- Jackler, R. K., Luxford, W. M., House, W. F. Congenital malformations of the inner ear: a classification based on embryogenesis. *Laryngoscope.* **97** (3 Pt 2 Suppl 40), 2-4 (1987).
- Sennaroğlu, L., Bajin, M. D. Classification and current management of inner ear malformations. *Balkan Med J.* **34** (5), 397-411 (2017).
- Johnson, B. R. et al. Management of cochlear implant electrode arrays misplaced in the internal auditory canal: A systematic review. *Otol Neurotol.* **45** (6), e460-e467 (2024).
- Naik, S. M., Naik, M. S., Bains, N. K. Cadaveric temporal bone dissection: is it obsolete today? *Int Arch Otorhinolaryngol.* **18** (1), 63-67 (2014).
- Dhanasingh, A., Hochmair, I. Special electrodes for demanding cochlear conditions. *Acta Otolaryngol.* **141** (sup1), 157-177 (2021).
- Dhanasingh, A. E. et al. A novel three-step process for the identification of inner ear malformation types. *Laryngoscope Investig Otolaryngol.* **7** (6), 2020-2028 (2022).
- Wang, F., Anaghan, D., Dhanasingh, A., Hui, L. Clinical validation of manual measurement of cochlea length with post-operative electrode insertion depth: A pilot study. *Laryngoscope Investig Otolaryngol.* **10** (4), e70237 (2025).
- Alshalan, A. et al. Estimation of outer-wall length in optimizing cochlear implantation in malformed inner ears. *Sci Rep.* **14** (1), 27308 (2024).
- Alsughayer, L., Al-Shawi, Y., Yousef, M., Hagr, A. Cochlear electrode array tip fold-over in incomplete partition-I - A case report. *Int J Pediatr Otorhinolaryngol.* **139**, 110438 (2020).
- Cheung, L. L., Kong, J., Chu, P. Y., Sanli, H., Walton, J., Birman, C. S. misplaced cochlear implant electrodes outside the cochlea: A literature review and presentation of radiological and electrophysiological findings. *Otol Neurotol.* **43** (5), 567-579 (2022).
- Aschendorff, A. et al. Radiologically assisted navigation in cochlear implantation for X-linked deafness malformation. *Cochlear Implants Int.* **10** (Suppl 1), 14-18 (2009).

15. Dhanasingh, A. The rationale for FLEX (cochlear implant) electrode with varying array lengths. *World J Otorhinolaryngol Head Neck Surg.* **7** (1), 45-53 (2020).