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

Authors and Affiliations:

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **Yes**

If **Yes**, can you record movies/images using your own microscope camera?

Yes

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

3. Filming location: Will the filming need to take place in multiple locations? **No**

4. Testimonials (optional): Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **No**

Current Protocol Length

Number of Steps: 15

Number of Shots: 34

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

INTRODUCTION:

~~REQUIRED: Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Joachim Müller:** This research focuses on improving cochlear implant electrode insertion training, addressing how to optimize placement across diverse inner ear anatomies and reduce complications.
 - 1.1.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.3.3* **NOTE: 1.1.1 is split into two parts because of its length and the introduction of the team.**

~~Describe the research gap or limitation in existing methods and how this protocol addresses them.~~

- 1.2. **Clemens Stihl:** Existing training lacks exposure to inner ear malformations. This protocol uses interchangeable transparent models enabling realistic, repeatable, anatomy-specific insertion training.
 - 1.2.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 3.2.1*

CONCLUSION:

~~Describe the most important consideration or challenge when performing this protocol.~~

- 1.3. **Justus Maximilian Müller-Goebel:** Accurate anatomical identification and proper electrode selection are critical to ensure reliable and reproducible results.
 - 1.3.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

~~Are there any additional methods or analyses that can be performed following this procedure?~~

- 1.4. **Clemens Stihl:** Post-procedure analyses include assessing insertion accuracy, trajectory, and angular depth, and comparing techniques across different anatomies to optimize outcomes

- 1.4.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Sarah Draut:** Future studies can test different electrode designs, include multi-manufacturer systems, and correlate training performance with real surgical outcomes.

- 1.5.1. INTERVIEW: Named Talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Protocol

2. Electrode Handling and Insertion Using the Electrode Insertion Training System

Demonstrators: Clemens Stihl, Sarah Draut, Andrea Schreier, Justus Maximilian Müller-Goebel

2.1. To begin, set up the electrode insertion training system [1]. Prepare the electrode and required instruments before insertion [2].

2.1.1. WIDE: Talent assembling and positioning the electrode insertion training system on a workbench.

2.1.2. Talent arranging the electrode and instruments neatly on the table.

2.2. Using the manufacturer's provided angled soft-grip forceps, hold the electrode [1] and position the electrode lead within the straight segment of the angled tip [2]. Then lock the electrode directly behind the array stopper [3-TXT]. Confirm stable fixation of the electrode before approaching the cochleostomy or round window [4].

2.2.1. Shot of the soft-grip forceps being used to hold the electrode.

2.2.2. Shot of the electrode lead positioned in the straight segment of the forceps tip.

2.2.3. Talent locking the electrode behind the array stopper.

2.2.4. Shot of the electrode securely held in the forceps before insertion.

2.3. Now align the forceps before advancing the electrode [1]. Maintain a superior-inferior insertion angle during advancement [2]. Guide the electrode toward the lateral wall of the cochlea while avoiding an inferior-superior angle and the medial wall [3].

Videographer: Please capture the screen of the instrument for all shots labeled SCREEN. Also, capture the hands of demonstrator holding the electrode and moving it around wherever applicable.

2.3.1. Talent aligning the forceps with the cochlear model.

2.3.2. SCREEN: Shot showing the superior-inferior insertion angle.

2.3.3. SCREEN: Shot of the electrode advancing along the lateral wall.

2.4. Stop advancing the electrode immediately if resistance occurs [1] and withdraw the electrode by a few millimeters [2]. Re-advance the electrode slowly while maintaining the lateral wall trajectory and preventing extracochlear buckling [3].

2.4.1. SCREEN: Shot showing halted advancement at resistance.

- 2.4.2. Talent slightly withdrawing the electrode. *Videographer: film the display as well here.*
- 2.4.3. SCREEN: Shot of careful electrode reinsertion along the lateral wall.

3. Electrode Insertion in Different Inner Ear Anatomies

NOTE: We added 3.1.0, 3.4.0, 3.7.0 and 3.9.0 to introduce a new author for every section they were performing.

- 3.1. For incomplete partition type I (*one*) anatomy, identify a complete cystic cochlear portion on the imaging software [1]. Select an electrode length appropriate for limited angular insertion [2].

Videographer: Please capture the screen of the instrument for all shots labeled SCREEN.

- 3.1.1. SCREEN: Display imaging showing a complete cystic cochlear portion.
- 3.1.2. Talent selecting appropriate electrode length. **NOTE:** There is an alteration for 3.1.2 to show the hand movement.
- 3.2. Insert the electrode at a superior-inferior angle strictly along the lateral wall [1]. Limit insertion depth to a maximum of 360 degrees and prevent overlap of apical contacts [2].
 - 3.2.1. SCREEN: Shot of superior-inferior lateral wall insertion in the model. **NOTE:** 3.2.1 has a wrong slate number (3.1.2)
 - 3.2.2. SCREEN: Shot showing insertion limited to 360 degrees without overlap.
- 3.3. For incomplete partition type II (*two*) anatomy, identify a normal basal turn with a cystic apex [1]. Insert the electrode through the normally formed basal scala and maintain the lateral wall trajectory [2]. Advance it up to 450 degrees and stop before entering the cystic apex to avoid overlap [3].
 - 3.3.1. SCREEN: Imaging showing normal basal turn with cystic apex.
 - 3.3.2. SCREEN: Shot of electrode insertion through basal scala along lateral wall.
 - 3.3.3. SCREEN: Shot of insertion is performed at 450 degrees and being stopped before cystic apex. **Authors: Please point out the cystic apex on the display if possible.**
- 3.4. For incomplete partition type III (*Three*) anatomy, identify a widened internal auditory canal [1]. Insert the electrode at a superior-inferior angle and continuously guide along the lateral wall [2], confirming the electrode remains within the cochlea [3].
 - 3.4.1. SCREEN: Imaging showing widened internal auditory canal.
 - 3.4.2. SCREEN: Electrode is being inserted at a superior-inferior angle and guided along the lateral wall.

- 3.4.3. Talent pointing out at the electrode within the cochlea.
- 3.5. For the common cavity, identify a single undivided cavity [1]. Pre-bend the electrode array gently [2] and introduce the curved segment first [3].
 - 3.5.1. SCREEN: Imaging showing single cavity.
 - 3.5.2. Talent pre-bending the electrode array.
 - 3.5.3. Shot of curved segment insertion.
- 3.6. Allow the electrode to form a loop within the cavity [1]. Stabilize the configuration while preventing the electrode's entry into the internal auditory canal [2].
 - 3.6.1. SCREEN: Shot of electrode loop formation.
 - 3.6.2. SCREEN: Shot of the electrode being stabilized within the cavity.
- 3.7. For cochlear hypoplasia, measure cochlear length before insertion [1]. Select a matching electrode length [2] and advance only until the lumen is fully covered without over-insertion beyond the basal turn [3].
 - 3.7.1. SCREEN: cochlear length is being measured.
 - 3.7.2. Talent selecting an electrode of appropriate measurement.
 - 3.7.3. SCREEN: The electrode is being advanced until lumen is fully covered.
- 3.8. For an enlarged vestibular aqueduct, identify normal basal turns with a mildly cystic apex [1]. Insert the electrode along the lateral wall at a superior-inferior angle and advance up to 540 degrees. Stop insertion before the cystic apex and avoid apical overlap [2].
 - 3.8.1. SCREEN: Imaging showing enlarged vestibular aqueduct anatomy.
 - 3.8.2. SCREEN: Shot of electrode being inserted into the lateral wall up to 540 degrees.
- 3.9. For normal anatomy of different sizes, measure the A-value preoperatively [1]. Select the electrode length based on cochlear size and insert it fully along the lateral wall. Expect deeper angular insertion in smaller cochleae and reduced angular insertion in larger cochleae. [2-TXT].
 - 3.9.1. SCREEN: Measurement of A-value on imaging software.
 - 3.9.2. SCREEN: Shot of full lateral wall insertion in model cochlea. NOTE: 3.9.2 was split into 3.9.2 and 3.9.3 because two different cochleae were used. 3.9.2 covers deeper angular insertion and 3.9.3 covers reduced angular insertion.

Results

4. Results

- 4.1. Different grasping techniques using soft-grip forceps resulted in variable control of the electrode lead [1], with correct engagement of the straight portion of the angled tip at the array stopper ensuring reliable control during insertion [2].
 - 4.1.1. LAB MEDIA: Figure 2A–D.
 - 4.1.2. LAB MEDIA: Figure 2A–D. *Video editor: Highlight C and D*
- 4.2. A superior-inferior alignment guided the electrode along the lateral cochlear wall [1], while an inferior-superior orientation increased the likelihood of medial wall deviation [2].
 - 4.2.1. LAB MEDIA: Figure 3B. *Video editor: Highlight the white arrow directed toward the lateral wall labeled “L”*
 - 4.2.2. LAB MEDIA: Figure 3A. *Video editor: Highlight the red arrow positioned closer to the medial wall labeled “M”.*
- 4.3. In incomplete partition type I, selecting an electrode length matching the cystic cochlea enabled appropriate angular coverage [1]. Insertion beyond 360 degrees of angular depth led to electrode overlap [2].
 - 4.3.1. LAB MEDIA: Figure 4A–C. *Video editor: Sequentially highlight images A to C.*
 - 4.3.2. LAB MEDIA: Figure 4D. *Video editor: Highlight the white arrow*
- 4.4. In incomplete partition type II, stable positioning was achieved when insertion was limited to the formed cochlear turns [1].
 - 4.4.1. LAB MEDIA: Figure 5. *Video editor: Sequentially highlight images A to C*
- 4.5. In incomplete partition type III, a lateral wall-directed insertion approach reduced unintended entry into the internal auditory canal and supported retention within the cochlear lumen [1].
 - 4.5.1. LAB MEDIA: Figure 6. *Video editor: Sequentially highlight images A to D*
- 4.6. In common cavity malformations, introducing the curved segment first promoted a looped configuration within the cavity and facilitated stable positioning [1].
 - 4.6.1. LAB MEDIA: Figure 7A–D. *Video editor: Highlight 7D*
- 4.7. In cochlear hypoplasia, reduced cochlear dimensions limited achievable insertion depth and required careful electrode length selection [1].
 - 4.7.1. LAB MEDIA: Figure 8. *Video editor: Sequentially highlight images A to C*

4.8. In enlarged vestibular aqueduct anatomy, limiting insertion depth reduced the risk of electrode overlap and potential interchannel interference [1].

4.8.1. LAB MEDIA: Figure 9. Video editor: Highlight the arrows in C

4.9. Smaller cochlear dimensions resulted in greater angular coverage for electrodes of identical length [1] compared with larger cochleae [2].

4.9.1. LAB MEDIA: Figure 10A,B. *Video editor: Highlight row A images*

4.9.2. LAB MEDIA: Figure 10A,B. *Video editor: Highlight row B images*

1. Electrode

Pronunciation link: <https://www.merriam-webster.com/dictionary/electrode>

IPA: /ɪˈlek.troʊd/

Phonetic Spelling: ih·lek·trohd

2. Cochleostomy

Pronunciation link: <https://www.merriam-webster.com/dictionary/cochleostomy>

IPA: /ˌkoʊ.kliˈɑː.stə.mi/

Phonetic Spelling: koh·klee·os·tuh·mee

3. Cochlea

Pronunciation link: <https://www.merriam-webster.com/dictionary/cochlea>

IPA: /ˈkɑː.kli.ə/

Phonetic Spelling: kok·lee·uh

4. Extracochlear

Pronunciation link: No confirmed link found

IPA: /ˌɛk.strəˈkɑː.kli.ə/

Phonetic Spelling: eks·truh·kok·lee·er

5. Anatomies

Pronunciation link: <https://www.merriam-webster.com/dictionary/anatomy>

IPA: /əˈnæt.ə.miz/

Phonetic Spelling: uh·nat·uh·meez

6. Cystic

Pronunciation link: <https://www.merriam-webster.com/dictionary/cystic>

- IPA: /'sɪs.tɪk/
Phonetic Spelling: sis·tik
7. Basal
Pronunciation link: <https://www.merriam-webster.com/dictionary/basal>
IPA: /'beɪ.səl/
Phonetic Spelling: bay·suhl
 8. Apex
Pronunciation link: <https://www.merriam-webster.com/dictionary/apex>
IPA: /'eɪ.peks/
Phonetic Spelling: ay·peks
 9. Scala
Pronunciation link: <https://www.merriam-webster.com/dictionary/scala>
IPA: /'skɑː.lə/
Phonetic Spelling: skaa·luh
 10. Auditory
Pronunciation link: <https://www.merriam-webster.com/dictionary/auditory>
IPA: /'ɔː.də.tɔːr.i/
Phonetic Spelling: aw·duh·tor·ee
 11. Vestibular
Pronunciation link: <https://www.merriam-webster.com/dictionary/vestibular>
IPA: /ve'stɪb.jə.lə/
Phonetic Spelling: veh·stib·yuh·ler
 12. Aqueduct
Pronunciation link: <https://www.merriam-webster.com/dictionary/aqueduct>
IPA: /'ɑː.kwə.dʌkt/
Phonetic Spelling: aa·kwuh·duhkt
 13. Hypoplasia
Pronunciation link: <https://www.merriam-webster.com/dictionary/hypoplasia>
IPA: /,haɪ.poo'pleɪ.ʒə/
Phonetic Spelling: hy·poh·play·zhuh
 14. Lumen
Pronunciation link: <https://www.merriam-webster.com/dictionary/lumen>
IPA: /'luː.mən/
Phonetic Spelling: loo·muhn
 15. Preoperatively
Pronunciation link: <https://www.merriam-webster.com/dictionary/preoperative>
IPA: /,pri:'ɑː.pə.ə.tɪv.li/
Phonetic Spelling: pree·op·uh·ruh·tiv·lee
 16. Cochleae
Pronunciation link: <https://www.merriam-webster.com/dictionary/cochlea>
IPA: /'kɑː.kli.ə/
Phonetic Spelling: kok·lee·eye

