All author names (first name) (last name): Fabian Müller*, Jan Hermann, Daniel Schneider, Gabriela O'Toole Bom Braga, Stefan Weber

Planning of tunnel-based robotic access to the inner ear

Abstract: A new planning strategy for tunnel-based robotic access to the inner ear is proposed based on the study of three-dimensional models of the middle and inner ear anatomy. With the goal of minimizing access- and insertion-related trauma to increase consistency, especially with respect to preservation of residual hearing during cochlear implantation, a trend for more promising trajectory placement can be identified.

Keywords: Robotic cochlear implantation, image guided surgery, inner ear access

1 Introduction

Robotic cochlear implantation is an emerging treatment option for patients with sensorineural hearing loss that uses a robotic system with an image-guided approach to access the middle and inner ear [1]. In this work, we report on improvements to the planning strategy made specifically for the purpose of enabling atraumatic robotic access to the cochlea. The facial recess as well as other structures at risk in the temporal bone limit the freedom on the middle and inner ear access planning in terms of trajectory angles and safety constraints. Access to the cochlea through the facial recess is established via a cochleostomy, a round window or even a so-called extended round window access. Experience has shown, that a tissue-sparing round window approach with preservation of the round window membrane is assumed as the best approach with regard to residual hearing preservation [2]. The aim of this work is to evaluate an optimal trajectory to the inner ear taking into account the complex anatomy of the round window including intracochlear structures.

***Corresponding author: (Fabian) (Müller):** ARTORG Center for Biomedical Engineering Research, Murtenstrasse 50 3008 Bern, Switzerland, e-mail: fabian.mueller@artorg.unibe.ch
Jan Hermann, Daniel Schneider, Gabriela O'Toole Bom Braga, Stefan Weber: ARTORG Center for Biomedical Engineering Research, Murtenstrasse 50, Bern, Switzerland.

2 Methods

The OpenEar library, consisting of three-dimensional models of eight human temporal bones based on computed tomography and micro-slicing, was manually adapted and extended to be used for robotic inner ear access planning [3]. This extension to the near periphery of the round window includes the generation of three-dimensional models of the round window membrane, the osseous spiral lamina, the cochlear aqueduct, the inferior cochlea vein and the corresponding adaption of adjacent structures like the scala tympani and scala vestibule. An approach was developed to automatically plan a trajectory to the inner ear that satisfies anatomical approximation constraints and optimizes access soft constraints such as angle of cochlear access, scala tympani divergence and avoidance of delicate and vital intracochlear structures such as the osseus spiral lamina and the organ of Corti. For all data sets a solution space with optimal access positions and corresponding trajectories is generated. A final trajectory with predefined soft constrain priorities is calculated.

3 Results

In seven out of eight cases, a solution space is found in which the trajectories pass safely through the facial recess. All safety-related anatomical distance requirements are met, while the solution space spanned by the soft constrain priorities is Pareto-optimal. For all cases, the optimal target position of the trajectory is between the antero-inferior rim and the centre of the round window membrane. The planned trajectories are compatible with the middle ear access, avoid damage of critical inner ear structures, and allow implantation with minimal insertion angle and scala tympani divergence.

4 Discussion

In conventional cochlear implantation, it is recommended to aim for an electrode insertion vector from postero-superior to antero-inferior to avoid electrode migration between the scalae and to protect the modiolus and basilar membrane [4]. In robotic cochlear implantation, it has previously been assumed that placing the target in the centre of the round window and planning a trajectory with minimal insertion angles results in an optimal scala tympani insertion trajectory with minimal cochlear trauma [2]. However, this assumption does not take into account the complex anatomy of the round window including intracochlear structures. This work shows that when considering the inner ear access constrains, there is a clear tendency for an optimal trajectory target position to be between the antero-inferior rim and the centre of the round window membrane. The analysis presented herein is not based on clinical imaging data, and clinical computed tomography does not provide the necessary image resolution to identify individual intracochlear structures. However, current otologic planning software is capable of segmenting and modelling the promontory bone and the round window membrane in a clinical workflow. Using these features and the results of this work, it is possible to select a more promising target position that may provide a less traumatic approach.

5 Conclusion

Considering the aforementioned inner ear access soft constraints with the aim of minimizing access and insertion-related trauma, a tendency can be identified that the position between the antero-inferior rim and the centre of the round window membrane may be an optimal position for cochlear tunnel-based access. The results of this analysis have implications for future planning strategies for robotic surgical procedures on the inner ear.

Author Statement

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References

1. Weber, S., K. Gavaghan, W. Wimmer, T. Williamson, N. Gerber, J. Anso, M. Caversaccio, *Instrument flight to the inner ear.* Sci Robot, 2017. **2**(4).
2. Topsakal, V., M. Matulic, M.Z. Assadi, G. Mertens, V.V. Rompaey, and P. Van de Heyning, *Comparison of the Surgical Techniques and Robotic Techniques for Cochlear Implantation in Terms of the Trajectories Toward the Inner Ear.* J Int Adv Otol, 2020. **16**(1): p. 3-7.
3. Sieber, D., P. Erfurt, S. John, G.R.D. Santos, D. Schurzig, M.S. Sorensen, and T. Lenarz, *The OpenEar library of 3D models of the human temporal bone based on computed tomography and micro-slicing.* Sci Data, 2019. **6**: p. 180297.
4. Luers, J.C., K.B. Huttenbrink, and D. Beutner, *Surgical anatomy of the round window-Implications for cochlear implantation.* Clin Otolaryngol, 2018. **43**(2): p. 417-424.