

## Paper Selection

- Pau, H. W., Lankenau, E., Just, T., Behrend, D., & Hüttmann, G. (2007). Optical coherence tomography as an orientation guide in cochlear implant surgery? *Acta oto-laryngologica*, 127(9), 907-13. doi: 10.1080/00016480601089408.
- Klenzner, T., Ngan, C. C., Knapp, F. B., Knoop, H., Kromeier, J., Aschendorff, A., et al. (2009). New strategies for high precision surgery of the temporal bone using a robotic approach for cochlear implantation. *European Archives of OtoRhinoLaryngology*, 266(7), 955-960. Springer. doi: 10.1007/s00405-008-0825-3.

## Introduction

Cochlear implant surgery was usually performed on the patients who are completely deaf or suffer severe hearing loss. The implantation procedure is standardized and was considered safe. The accurate positioning of the electrode array into the scala tympani is less critical, as long as the auditory nerve could be stimulated. However, recent studies show that the electrode was placed in the wrong scala (scala vestibuli) in many cases, and the surgeons have not noticed the malposition [3].

The indication for cochlear surgery has been extended toward more substantial residual hearing. It requires more accurate electrode insertion to avoid the damage of cochlear structure and preserve the inner ear function. The integration of medical imaging technology and robotic assisted surgical system provides the capability of highly precise insertion, which would greatly increase the safety and quality of cochlear implant surgery. The two papers selected share this common motivation. The first paper [1] discussed the preliminary validation of using Optical Coherence Tomography (OCT) as the orientation guide in cochlear implant surgery. The second the paper [2] presented robotic assisted approach following the trajectory generated from pre-operative CT scan. A 1.9mm endoscope was used for the visualization and validation.

## Critical Review

- Pau, H. W., Lankenau, E., Just, T., Behrend, D., & Hüttmann, G. (2007). Optical coherence tomography as an orientation guide in cochlear implant surgery? *Acta oto-laryngologica*, 127(9), 907-13. doi: 10.1080/00016480601089408.

### Background:

As mentioned above in introduction, cochlear implant surgery still has a large room to be improved in terms of quality, safety and surgical outcome. A very challenging part of the cochlear implantation is to correctly position the electrode into the scala tympana, not the scala vestibule. OCT is considered as the imaging technique that could be used to visualize the cochlear structure, and further could serve as the orientation guide for cochlear implant surgery.

### Method

The authors discussed different OCT systems and explained the preparation of the temporal bones. They have three different OCT concepts: handheld probe (resolution 6  $\mu\text{m}$ ), OCT integrated endoscope (resolution 15  $\mu\text{m}$ ,  $\varnothing 3\text{mm}$ , L = 300 mm), and OCT integrated microscope (resolution 15  $\mu\text{m}$ ) which was originally designed for OCT-guided brain tumor surgery and was chosen as the OCT system to use in this paper. Three fresh or formalin-fixed human temporal bones from body donors were prepared for the experiment. The first bone (P1) was formalin-fixed and second (P2) was fresh and was kept deep frozen till three hours prior to the preparation. The outer and middle ear was removed in both bone specimen (P1 and P2), as well as the bone of the promontory to ensure the easy access to the cochlea. The first temporal bone was cut with a diamond saw to reveal the cross-section of the basal cochlear turn. This enables the comparison between the OCT image and the related cochlear anatomy. The third temporal bone (P3) was prepared as in real cochlear implant surgery, but with larger posterior tympanotomy through which a fenestration of the cochlea was made at the typical

cochleostomy site. The scanning axis of OCT was perpendicular to the axis of the cochlear turn and transverse to the lateral aspect of the basilar membrane,

### **Key results and Significance**

The key results presented in this paper are the OCT images of the cochlear structure. From the first and second temporal bone (P1 and P2), OCT images with fairly good quality were obtained. The scala tympani, scala vestibule, and basilar membrane could be easily identified in the OCT image. The comparison between the OCT image and the cochlear anatomical structure of P1 demonstrated the capability of OCT imaging. In P2, fresh temporal bone, more cochlear structures can be identified, such as Resissner's membrane. The access for OCT was more limited in temporal bone P3 compared to P1 and P2. Thus the quality of the OCT image was not as good as those from P1 and P2. However, the main cochlear features (scala tympani, scala vestibule, and basilar membrane) could still be identified despite of the narrow access. The capability of OCT to visualize cochlear structures beyond the membranous surface for better orientation was confirmed.

### **Analysis and assessment**

This paper explored the possibility of using OCT to assist cochlear implant surgery and validated the capability of OCT imaging for better guidance. Three temporal bones prepared with different methods gave the comparison between the OCT images under ideal condition and that under more realistic condition. Though the feasibility of OCT imaging as orientation guide could be validated, the authors mentioned further development of the OCT system is necessary to improve the quality of the OCT scan. The comparison of the OCT image and the picture of the cross section of the basal cochlear turn in P1 gave a good demonstration of the capability of OCT. At the end the paper, the author discussed the scenario in which the OCT could be extremely useful and could provide great advantage to improve the implantation procedure.

### **Relevance**

This paper was particularly interesting to us because we planned to use OCT to image the cochlea as well. This paper gave us a good reference of how the OCT image would look like. While our concept was to incorporate a side-view OCT system with steady hand robot to realize safe path planning, 3D OCT imaging of the cochlear canal, and robotically assisted electrode insertion, this paper studied the visualization the OCT integrated microscope could provide the surgeon a better orientation guide to make the correct opening to insert the electrode.

Then due to the major change of our imaging concept, micro-borescope has been decided to replace the OCT imaging system. The following paper studied the robotic approach to realize high precision cochlear implant surgery and used an endoscope for visualization.

- Klenzner, T., Ngan, C. C., Knapp, F. B., Knoop, H., Kromeier, J., Aschendorff, A., et al. (2009). New strategies for high precision surgery of the temporal bone using a robotic approach for cochlear implantation. *European Archives of OtoRhinoLaryngology*, 266(7), 955-960. Springer. doi: 10.1007/s00405-008-0825-3.

## Background:

Because cochlear implant surgery has been being extended to be performed on the patient with significant residual hearing, more accurate electrode insertion is necessary to preserve the inner ear function. Robotically assisted system has the advantages of high accuracy, missing fatigue, and rapidity, thus it could provide the capability of constant reproducible surgical procedure.

## Method

A human temporal bone was prepared for the experiment. It was drenched in a 2 M sodium hydroxide solution for 24 hours to remove the soft tissue. Four titanium screw markers with a recessed head were attached on the surface of the temporal bone for the registration of the navigation and the robotic system. CT scan of this temporal bone was taken (voxel dimension 0.18 mm x 0.18 mm x 0.60 mm). Manual segmentation and automatic reconstruction generated

the 3D surface model of the tympanic cavity. Based on the 3D model, a virtual tool trajectory was planned through the facial recess indirection to the basal turn of the cochlea.

In the experiment, the temporal bone was first fixed on the operating table and then registered to the robotic system. The registration was repeated four times. Fiducial and target registration error were computed. Then the endoscope ( $\varnothing 1.8\text{mm}$ ) was attached to the robot to imitate the actual drilling tool and served as visualization to verify the planned trajectory.

### **Key results and Significance**

The desired target registration error of this experiment was  $<0.5$  mm, which was determined from histological data. The average fiducial registration error and target registration error were 0.3 mm and 0.25 mm respectively. Four trials were repeated with the robot system. The endoscope advanced continuously and smoothly without collision and interference. The recorded endoscope view was compared with the model of the virtual endoscopy of the 3D data set. No major aberration was detected.

### **Analysis and assessment**

This paper presented a robotic approach to enable high precision cochlear implant surgical procedure. With the help of robotic assistance, a small error was achieved and fulfilled the error tolerance. Using the endoscope to imitate the drilling tool validated the trajectory following and provided an intuitive way to evaluate the system by comparison the actually endoscope view with the virtual endoscopy from the 3D data. The authors discussed the future work to improve the system: better CT imaging to reduce the registration error, CO<sub>2</sub>-laser to replace the drill to avoid occurring forces, better robot mechanism as well as noninvasive registration method. The feasibility of robotic approach for cochlear implant surgery was verified.

### **Relevance**

This paper had the common idea of robotically assisted system and endoscopic imaging as we have for our project. Though we are using the robot for electrode insertion, while they used the robot for drilling, the desired error range is comparable. We use the micro-borescope for the safe path finding. Pre-operative CT scan is not required in our concept. The safe path in this paper was generated from the CT scan and the endoscope in this paper served purely as validation function.

## **Bibliography**

[1] Pau, H. W., Lankenau, E., Just, T., Behrend, D., & Hüttmann, G. (2007). Optical coherence tomography as an orientation guide in cochlear implant surgery? *Acta oto-laryngologica*, 127(9), 907-13. doi: 10.1080/00016480601089408.

[2] Klenzner, T., Ngan, C. C., Knapp, F. B., Knoop, H., Kromeier, J., Aschendorff, A., et al. (2009). New strategies for high precision surgery of the temporal bone using a robotic approach for cochlear implantation. *European Archives of OtoRhinoLaryngology*, 266(7), 955-960. Springer. doi: 10.1007/s00405-008-0825-3.

[3] Aschendorff A, Kubalek R, Turowski B, Zanella F, Hochmuth A, Schumacher M, et al. Quality control after cochlear implant surgery by means of rotational tomography. *Otol Neurotol* 2005; 26: 34-7.