Invited Paper

Optical coherence tomography as a guide for cochlear implant surgery?

T. Just[a], E. Lankenau[b], G. Hüttmann[b], H.W. Pau*[a]

[a]Department of Otorhinolaryngology, University of Rostock, Doberaner Strasse 137-139, Rostock, Germany
[b]Institute for Biomedical Optics, University of Lübeck, Peter-Monnik-Weg 4, Lübeck, Germany

ABSTRACT

Optical coherence tomography as a guide for cochlear implant surgery?

To assess the potential use of optical coherence tomography (OCT) in cochlear implant surgery, OCT was applied in human temporal bones before cochleostomy. The question was whether OCT might provide information about the cochlear topography, especially about the site of the scala tympani. OCT was carried out on human temporal bone preparations, in which the cochleostomy was performed leaving the membranous labyrinth and the fluid-filled inner ear intact. A specially equipped operating microscope with integrated OCT prototype was used. Spectral-domain (SD)-OCT was used for all investigations. On all scans, OCT supplied information about inner ear structures, such as scala tympani, scala vestibuli while the membranous labyrinth was still intact. In the fresh temporal bone the scala media, basilar membrane and the Reissner's membrane were identified. This OCT study clearly documents the possibility to identify inner ear structures, especially the scala tympani without opening its enveloping membranes. These findings may have an impact on cochlear implant surgery, especially as an orientation guide to localize the scala tympani precisely before opening the fluid filled inner ear.

Keywords: Optical coherence tomography, scala tympani, cochlear implant, inner ear topography, residual hearing

1. METHODOLOGY

OCT system, imaging and image analysis

Two different systems can be used for experiments: time-domain (TD)-OCT with a central wavelength of 1310 nm (Sirius, 4Optigs AG, Lübeck, Germany) and spectral-domain (SD)-OCT with a central wavelength of 930 nm (Thorlabs Inc., USA) [1-3].

To begin with, OCT-systems were designed with a moving reference mirror. The system measures reflections, one after the other, from different depth in the tissue. The disadvantage of this TD-OCT was the complex set-up and limited scanning speed due to the moving mirror. By coupling a spectrometer to the interferometer a whole A-scan can be sampled at once with increased signal to noise ratio. Up to 5000 A-scans/second can be acquired by SD-OCT.

The optical imaging technique can be applied in contact as well as in a non-contact mode. At the Institute for Biomedical Optics in Lübeck, a variety of applicators have recently been developed. For the use in otolaryngology, besides the use of a small handpiece (the OCT measurement resolution: about 6 µm) two applicators are suitable: either a rod-lens endoscope modified for OCT with a measurement resolution of about 15 µm (TD-OCT endoscope, 0°, 3 mm diameter, length 300 mm, Richard Wolf GmbH, Knittlingen, Germany) or a specially adapted operating microscope with a measurement resolution of about 24 µm (Hi Res 1000, Möller Wedel GmbH, Wedel, Germany), which allows OCT scanning on any object in the centre of the field of vision, the microscope is focussed on. Devices for all three options: handpiece, endoscope and microscope are prototypes, not yet commercially available. As for the problem addressed, the operating microscope originally developed for OCT-guided brain tumor surgery fulfils the requirements best, we consequently focused on that method (Fig. 1). However, similar findings can be obtained with the other applicators too.

*hans-wilhelm.pau@med.uni-rostock.de; phone ++49-381-4948301; fax ++49-381-4948302; hno.med.uni-rostock.de

Photonic Therapeutics and Diagnostics IV, edited by Nikiforos Kollias, Bernard Choi, Haishan Zeng, Reza S. Malek, Brian Jet-Fei Wong, Justus F. R. Ilgner, Kenton W. Gregory, Guillermo J. Tearney, Henry Hirschberg, Steen J. Madsen, Proc. of SPIE Vol. 6842, 68421F, (2008) · 1605-7422/08/$18 · doi: 10.1117/12.771446

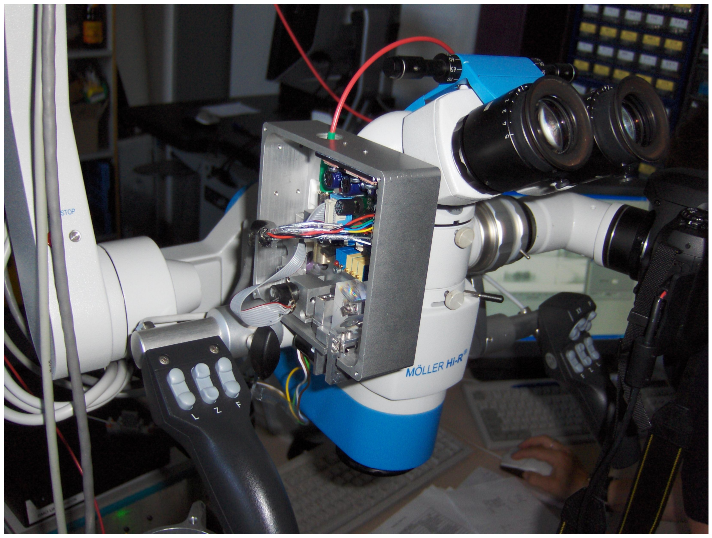

Fig. 1. A special OCT-adapted microscope, developed for OCT-guided tumor surgery of the brain (Hi Res 1000, Möller Wedel GmbH, Wedel, Germany).

Preparations on temporal bones

The objective of this paper was to demonstrate the feasibility of using OCT for visualization of intracochlear structures when applied from the outside of the intact membranous labyrinth.
For this purpose special preparations were performed on three fresh or formalin-fixed human temporal bones from body donators from the Anatomical Institute of Rostock University.
To answer the basic question of feasibility, the first experiments were performed on temporal bone preparations, in which the outer and middle ear was removed in order to have the easiest possible access to the cochlea.
The medial wall of the tympanon was exposed by removing the outer ear canal with the tympanic membrane and the ossicular chain except the stapes, as described by our group in previous papers, for better accessibility in two temporal bone specimens (P1: formalin-fixed and P2: fresh – taken from the body 24 h after death, kept deep-frozen till 3 hours prior to the preparation) [4, 5].
In both specimens the bone of the promontory was gradually removed by grinding with a 2 mm diamond bur, exposing the endosteum covering the lateral aspect of the basal cochlear turn in an area of approximately 1.5 x 1.5 mm. The membrane was left intact (Fig. 2).

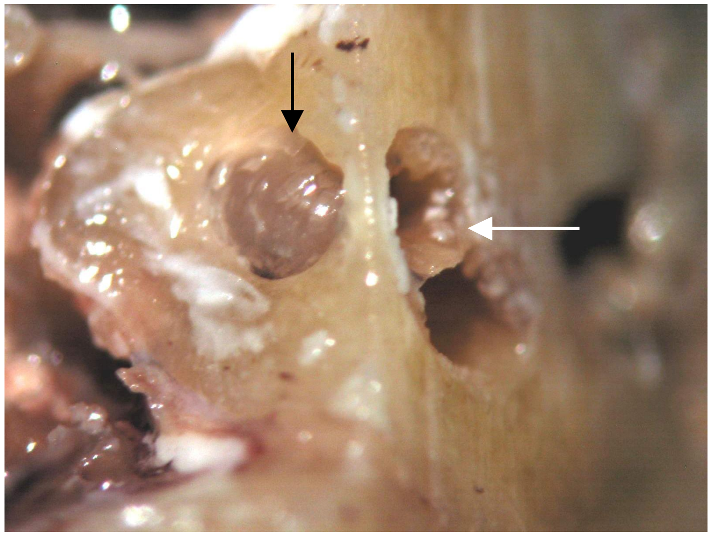

Fig. 2. Temporal bone preparation (formalin fixed temporal bone specimen, P1) with the cochlear endosteum exposed to the extent of approximately 1.5 x 1.5 mm (black arrow). Slightly anterior to this “fenestration” a cross-section through the temporal bone reveals the cochlear anatomy (white arrow).

For direct correlation between the cochlear anatomy and the structures shown on the OCT-scan in one temporal bone specimen (P1) additional preparations were carried out. A vertical section at right angles divided the whole piece of bone with the basal cochlear turn anterior to the “cochleostomy”. This was achieved by a diamond thread saw. From this intersecting plane a cross-section of the basal cochlear turn became visible, and OCT images taken in the area of the fenestration could be compared and related to the cochlear anatomy.
In the third temporal bone (P3), preparations were performed like in real cochlear implant surgery, with a rather large posterior tympanotomy through which a fenestration of the cochlea was performed at the typical cochleostomy site (inferior and anterior to the round window).
In each experiment, the scanning axis for OCT via the operating microscope was perpendicular to the axis of the cochlear turn and, thus, transverse to the lateral aspect of the basilar membrane.
The images obtained during OCT recordings were stored digitally.

2 RESULTS

The bone window (fenestration) can be demonstrated easily in each of the specimens on the OCT images. Between the ‘echoes’ of the two sections of bone the membranous labyrinth (mainly spiral ligament) is visible in the form of a very dense structure convex to the outside. The medial aspect of this structure has a characteristic pattern: the borderline towards the inside has two concavities. The structure between these concavities has the shape of a ridge, the top of which cannot be seen as the signals vanish in the depth. This ‘ridge’ represents the complex of the basilar membrane and the structures enclosing the scala media (Fig 3). The two concavities stand for the lateral aspects of the scala tympani (ST) and scala vestibuli (SV).

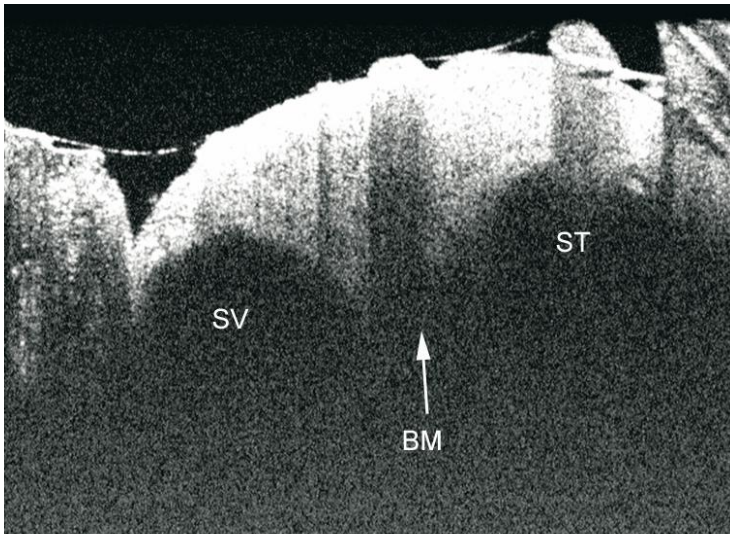

Fig. 3. OCT scan represents a vertical cross section through the lateral part of the cochlear in the formalin fixed temporal bone (P1): The lateral borders of the scalae (SV = scala vestibuli, ST = scala tympani) can be detected with the 'ridge' of the basilar membrane in between (arrow).

On some scans even the continuation of the membrane underneath the bone at the very edge of the fenestration can be presented. Figure 4 shows the comparison of the SD-OCT-B-scan and the aspect of the cochlear cross-section laid open on the perpendicular intersecting plane, demonstrating the usefulness of this new imaging technique.

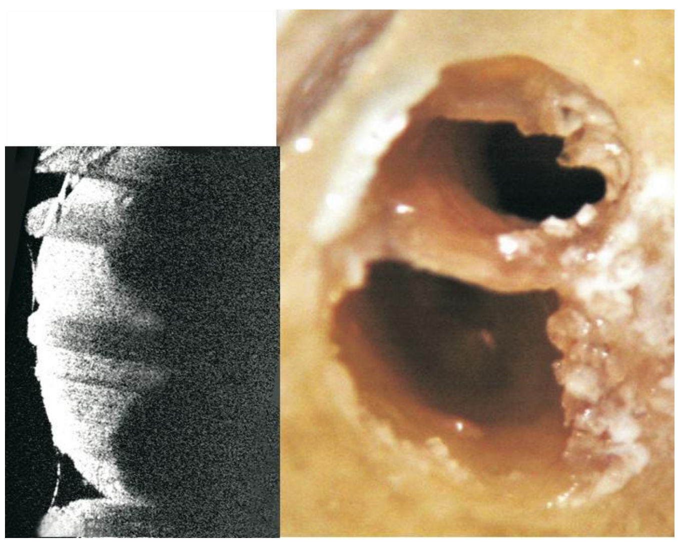

Fig. 4. Comparison of the OCT-"echoes" and the underlying anatomical structures (cross-section of the basal cochlear turn (P1).

On the fresh temporal bone preparation (P2), even more cochlear structures can be seen. While the enveloping membranes seem less compact than those of the formalin-fixed specimen, even such delicate structures like the boundaries of the scala media (Reissner´s membrane) can be detected (Fig. 5). Unfortunately, however, it was not possible to provide a comparison of the OCT-scan and the anatomical situs in this case, because in this fresh temporal bone specimen the scala media collapsed, when the bone was dissected. So far we were not able to preserve the Reissner´s membrane while cutting fresh cadaver cochleae.

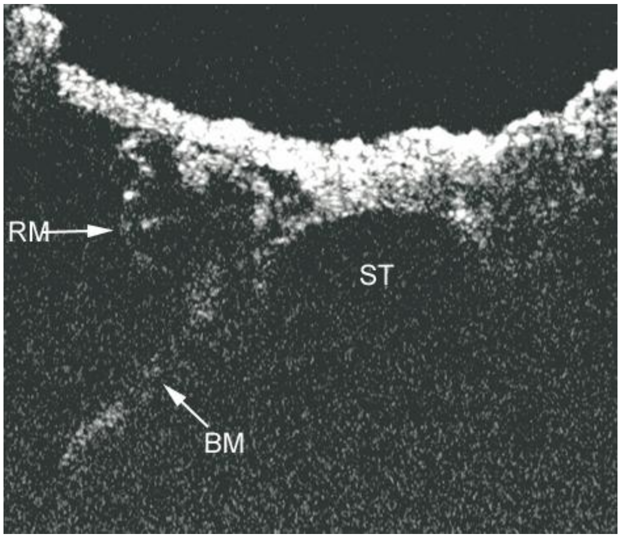

Fig. 5. OCT scan of the lateral part of the exposed cochlea in a fresh temporal bone (P2): besides the projections of the scalaes some fine structures within the cochlear can be identified: the triangular cross section of the scala media with the Reissner´s membrane (ST = scala tympani, RM = Reissner´s membrane, BM = basilar membrane).

The third fresh temporal bone (P3) the access was comparable to real cochlear implant surgery. The intact endosteum was watched and scanned through the posterior tympanotomy (Fig. 6).

Fig. 6. Aspect of the exposed cochlear endosteum through the posterior tympanotomy and the corresponding OCT scan (P3).

Figure 6 shows that basically it is possible to visualize the lateral view of the cochlea even in this more difficult condition with regard to the narrower access. However, further developments of the prototype seem necessary to improve the quality of the scans.
Intracochlear structures could be visualized in each preparation examined. The number of temporal bones was limited to three as the problem addressed was the very basic question whether the new technique may help to visualize structures

beyond the membranous surface for better orientation or not. The results reveal that the answer to this question is definitely yes.

REFERENCES

1. E. Lankenau, *Dispersive Einflüsse und Anwendungen in der medizinischen Diagnostik*, University of Lübeck, Lübeck, 2003.
2. D. Daniltchenko, F. Konig, E. Lankenau, M. Sachs, G. Kristiansen, G. Hüttmann and D. Schnorr, "Utilizing optical coherence tomography (OCT) for visualization of urothelial diseases of the urinary bladder," *Radiologe* 46(7), 584-589 (2006).
3. J. F. de Boer, B. Cense, B. H. Park, M. C. Pierce, G. J. Tearney and B. E. Bouma, "Improved signal-to-noise ratio in spectral-domain compared with time-domain optical coherence tomography," Opt. Lett. 28(21), 2067-2069 (2003).
4. H. W. Pau, T. Just, E. Lehnhardt, H. Hessel and D. Behrend, "An "endosteal electrode" for cochlear implantation in cases with residual hearing? Feasibility study: preliminary temporal bone experiments," Otol. Neurotol. 26(3), 448-454 (2005).
5. H. W. Pau, T. Just, S. Dommerich, E. Lehnhardt and D. Behrend, "Concept and anatomical feasibility study of an "endosteal electrode" for bimodal stimulation in severely deaf ears," Laryngorhinootologie 84(6), 402-407 (2005).