An optical coherence tomography study for imaging the round window niche and the promontorium tympani

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ABSTRACT

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Tympanosclerosis may involve the tympanic membrane, the ossicles, and the oval and round window niche, respectively. The surgical treatment of the obliterated oval window niche is most challenging. Beside stapesplasty, vibroplasty coupling the floating mass transducer (FMT) onto the round window niche and into a new, so-called third window is indicated. In the latter situation, drilling a hole into the promontorium is necessary to couple the FMT close to the membranous endosteum. Damage of the membranous inner ear must be avoided. The question was whether OCT is useful to identify the endosteum and to provide microanatomical information of the round window niche. OCT was carried out on human temporal bone preparations, in which a third window was drilled leaving the membranous labyrinth and the fluid-filled inner ear intact and the overhang of the round window niche was removed. An especially equipped operating microscope with integrated OCT prototype (spectral-domain-OCT) was used. The OCT images and 3D reconstructions demonstrate the usefulness of OCT to measure the drilling cavity, to visualize the inner ear structures, and to obtain microanatomical information of the round and oval window niche. These findings may have an impact on stapes surgery, on cochlea implantation, and on vibroplasty coupling the FMT onto the round and third window. OCT-guided drilling allows for more precise identification of the intact inner ear.

Keywords: Optical coherence tomography, round window niche, promontorium, inner ear topography

1. INTRODUCTION

Vibromechanical stimulation of the inner ear with an implantable hearing aid (Vibrant Soundbridge, MedEl, Innsbruck, Austria) via the oval window niche is a reliable procedure to improve hearing. The floating mass transducer (FMT) can be attached on the long process of the incus[1], directly onto the stapes footplate[2] or by means of middle ear prostheses.[3,4]
In patients with a stapes footplate fixation or in surgically unfavourable situations, coupling of the FMT onto the round window niche seems to be a solution for such a problem. There are, however, intraoperative situations in which neither the access via the oval window nor via the round window niche offers an appropriate access, like e.g. in patients with obliterative tympanosclerosis and in malformations. In such cases, a so-called “third window” vibroplasty can be indicated[5]. In this surgery, the FMT is positioned either directly onto the exposed membranous inner ear or onto a thin bony shell covering the fluid-filled inner ear. From cochleostomy technique in cochlear surgery and in “third window” vibroplasty it is known that it is possible to expose the cochlear endosteum without opening the fluid-filled inner ear. To reduce acoustic trauma during drilling it would be helpful to have an operating guide for fenestration of the promontorium.
This paper demonstrates the ability of the SD-OCT to visualize the morphology of the round window niche and to monitor the fenestration procedure required for vibroplasty.

2. METHODOLOGY

Optical coherence tomography system, imaging and image analysis

A spectral-domain (SD)-OCT with a central wavelength of 840 nm (Thorlabs, Newton, New Jersey, USA) was incorporated into an operating microscope (Hi Res 1000, Möller Wedel GmbH, Wedel, Germany). This system allows

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OCT scans on any object in the centre of the field of vision of the microscope. Details of the microscope with integrated OCT technology have been published elsewhere[6,7] and are only briefly reviewed here.

The scan head of the OCT device was coupled to the camera port of the microscope. The acquisition of the OCT images was done during normal visualization of the tissue surface. The device, which is based on a commercial OCT device but has increased output power, delivers a light intensity of 3 mW to the tissue. The lateral and longitudinal resolution is about 24 µm and 12 µm, respectively. The OCT-system is able to automatically adjust to imaging distances between 230 and 290 mm by computer controlled adjustment of the reference arm length. Approximately 1 s is required to obtain an OCT B-scan, consisting of 1000 single A-scans. A depth range of up to 3.5 mm can be visualized. Due to light scattering of most biological tissues, real measurement depths vary with tissue type and reach 1-2 mm in soft tissue and about 0.75-1.5 mm in bony structures.

Preparations on temporal bones

The current experimental study aimed at finding out whether optical coherence tomography could be a helpful diagnostic tool for evaluation of the round window niche and for visualization of the promontory during cochleostomy for third window vibroplasty. For this purpose, special preparations were performed on five fresh or formalin-fixed human temporal bones from body donators from the Anatomical Institute of Rostock University. Additionally, intraoperative OCT scans of the promontory and the exposed round window niche were performed.

To answer the basic question of feasibility, the first experiments were performed on temporal bone preparations, in which the outer ear was removed in order to have the easiest possible access to the promontory and round window niche. The medial wall of the tympanon was exposed by removing the outer ear canal with the tympanic membrane. Modified descriptions were published elsewhere.[8,9] In the first part of the temporal study, the bony overhang of the round window niche was removed with a 2.0 mm cutting drill to expose the round window membrane (Fig. 1). In two additional temporal bones, preparations were performed like in real middle ear surgery via the transmastoidal approach, with a rather large posterior tympanotomy through which a fenestration of the cochlea was performed at the typical cochleostomy site anterior inferior to the round window.

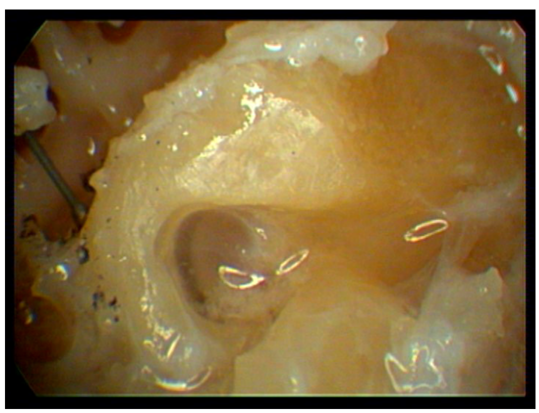

Fig. 1. Temporal bone preparation (formalin fixed temporal bone specimen) with the exposed round window niche. Slightly posterior superior to the round window a total ossicular replacement prosthesis positioned on the stapes footplate is visible.

In the second part of the temporal bone study, a third window cochleostomy without opening of the membranous inner ear was performed anterior inferior to the round window niche on the most prominent part of the promontory (Fig. 2)[5]. The drilling procedure was continued until the “blue line” of the cochlea, indicating that the burr was about to reach the endosteum and shortly thereafter a white spot became visible. The latter one indicates a punctual exposure of the membranous cochlea in the level of the spiral ligament. The thin bony shell still covering the endosteum was removed.

A B

Fig. 2. Temporal bone preparation (fresh temporal bone specimen) with a fenestration of the cochlea anterior inferior to the round window. A floating mass transducer was inserted (I = long process of the incus; S = stapes; RMN = round window niche)
B For better correlation of the OCT images and to show the thickness of the bony cochlea a separate hole was drilled superior to the round window.

To produce a precise cylindric cavity for insertion of the floating mass transducer of the Vibrant Soundbridge (Medel, Innsbruck, Austria), an especially designed 2.5 mm cutting drill with a conical shape was used (Fig. 3). 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.

Fig. 3. Photograph of the 2.5 mm especially designed cutting drill with a conical shape.

For direct correlation between the cochlear and middle ear anatomy and structures shown on the OCT-scans in one temporal bone additional preparations were carried out. A cross section through the cochlea was performed to visualize the round and oval window (stapes) niche and the vestibulum (Fig. 4). This was achieved by a diamond thread saw. For demonstration of the correlation between cavities of different depths and the corresponding OCT images holes were drilled in the temporal bone very close to each other.

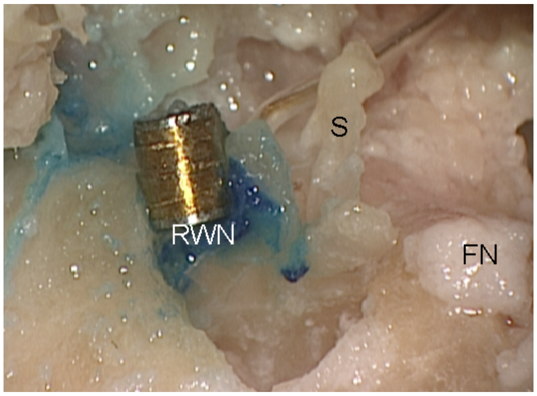

Fig. 4. Temporal bone preparation (fresh temporal bone specimen) with the round window niche (RWN) exposed to the extent of approximately 2.5 x 2.5 mm and inserted FMT. Slightly anterior to this region the stapes (S) and the facial nerve can be identified.

3. RESULTS

Round window niche

In each of the temporal bone specimens, the round window membrane could be demonstrated easily on the OCT images. The shape, thickness and curvature of the round window membrane are not constant. The vestibular surface of the round window membrane varied and in three temporal bone specimens was concave, in one specimen slightly flat and in the remaining specimen slightly convex. In the fresh temporal bone specimens with a convex surface of the membrane (vestibular surface of the membrane having a rounded, elevated surface toward the inner ear) the curvature of the membrane could be changed by stapes movement, indicating a still fluid filled inner ear. Figures 5 and 6 show an SD-OCT-B-scan of the "normal" round window membrane and a reconstruction of the round window niche, respectively.

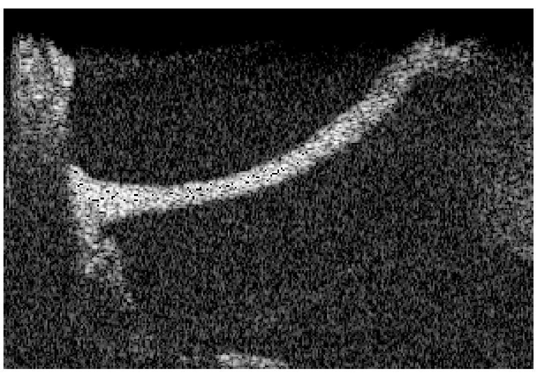

Fig. 5. Typical optical coherence tomography scan of a normal round window membrane with a slightly concave surface.

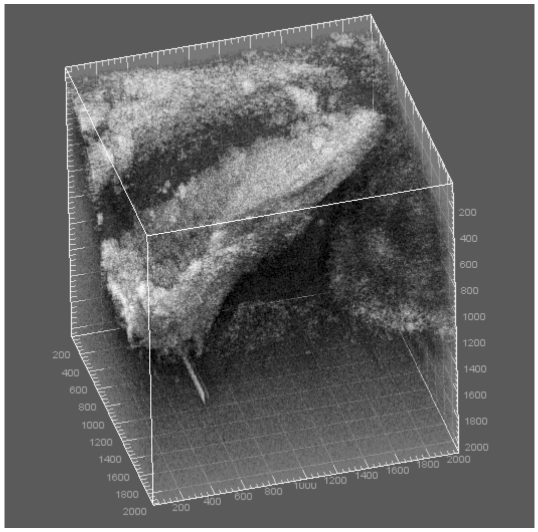

Fig. 6. Three-dimensional reconstruction of the round window membrane from optical coherence tomography scans.

Cochleostomy for vibroplasty

OCT-B scans (Fig. 7) and 3D reconstructions enable the surgeon to measure the depths of the cavity, but also the thickness of the bone layer covering the membranous endosteum up to values of 0.5 – 1 mm. OCT scan of the third window via the posterior tympanotomy hole is shown in Figure 8 (please compare to Fig. 2). A complete 3D reconstruction is given in Fig. 9 (please compare with the temporal bone preparation shown in Figure 4).

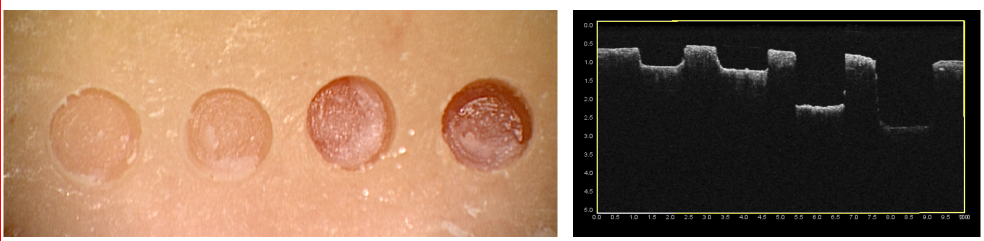

Fig. 7. Comparison of the OCT measures and the bone preparations.

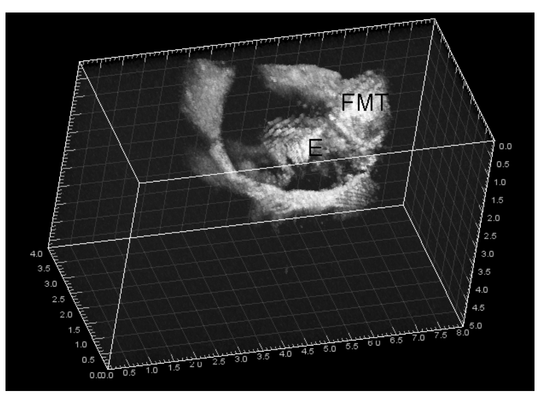

Fig. 8. OCT measurement through the posterior tympanotomy hole (about 3.5 mm). The OCT scan shows clearly the insertion depths of the FMT and membranous endosteum (E). Correlation to Figure 2.

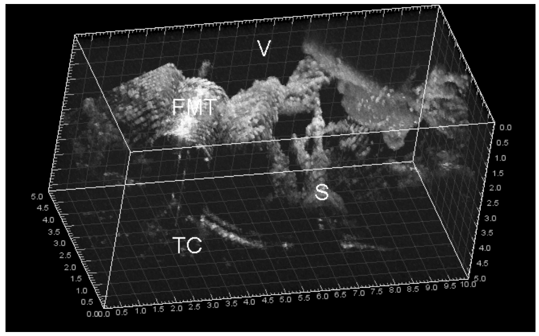

Fig. 9. 3D reconstruction of the complete preparation (comparison to Figure 4). FMT = floating mass transducer; S = stapes suprastructure; V = vestibulum; TC = tympanic cavity.

4. DISCUSSION

The success of reconstructive middle ear surgery for improvement of hearing depends on the morphology and movability of the stapes footplate. Previously, we could demonstrate that SD-OCT can visualize the morphology of the stapes footplate and several pathological changes of the oval window niche[10-12] associating with a conductive or combined hearing loss. In patients with a severe combined hearing loss a vibroplasty may be an alternative to solve this problem. In patients with a fixation of the stapes footplate or in surgically unfavourable situations a vibroplasty with coupling of the floating mass transducer onto the round window membrane may be indicated. The paper shows that SD-OCT can be used to visualize the morphology of the round window membrane. It is possible that SD-OCT may detect pathological changes of the round window membrane, like in intracochlear schwannoma. To reduce inner ear trauma due to drilling near the endosteum[13], we ought to measure the layer thickness and shape intraoperatively after exposure of the membrane in patients with sudden hearing loss who undergo exploratory tympanotomy. The OCT images and 3D reconstructions also demonstrate the usefulness of OCT to measure the drilling cavity and visualize the inner ear structures. These findings may have an impact on vibroplasty coupling the FMT onto a “third window”. OCT-guided drilling allows identification of the intact membranous inner ear more precisely.

5. CONCLUSION

SD-OCT applied via an operating microscope allows an accurate assessment of the morphology of the round window niche. The application of intraoperative OCT could be potentially useful to detect pathological changes or involvement of the round window membrane in inner ear diseases, such as intracochlear schwannoma. The preliminary results shown here also demonstrate that SD-OCT is capable of measuring the morphology of the promontory and inner ear structures during fenestration for vibroplasty. Visualizations of the oval and round window niche are useful in a wide range in middle ear surgery.

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