High-Resolution Imaging of the Human Cochlear Partition Using Optical Coherence Tomography (OCT)

Christopher I. McHugh[1,2], Paul Secchia[1], Nam Hyun Cho[1,2], Lukas Graf[2], Michael Ravicz[1,2], and Hideko Heidi Nakajima[1,2]

[1]Harvard Medical School and Speech and Hearing Bioscience Technology Program; [2]Massachusetts Eye and Ear; Boston, MA 02114 USA

Background

Sensorineural hearing loss ranks as one of the most prevalent disabilities globally. According to the World Health Organization, over 1.5 billion people are affected by some degree of hearing loss, of which 430 million experience a disabling level of impairment. For affected individuals, hearing loss can have significant interpersonal, psychosocial, and economic consequences.

Given the far-reaching implications of hearing loss, there has been a surge in the development of innovative therapies for cochlear regeneration, as well as a variety of implantable devices. However, these medical solutions often come at a high financial cost and may carry potential risks. At present, there are limited methods to assess the health of the inner ear, as conventional imaging modalities do not have adequate resolution to assess the cochlear microanatomy.

The ability to non-invasively assess the condition of the cochlea and gauge its potential to respond favorably is crucial. This is important not only for identifying those who are good candidates for such therapies but also for tracking the cochlea's response during treatment.

Analogous to ultrasonography, optical coherence tomography (OCT) is an imaging technique which utilizes low-coherence light to atraumatically capture high-resolution images of the internal structure of biologic systems, including the cochlea. Here we demonstrate that with OCT, we can obtain micrometer-scale intracochlear images in situ through the intact round window membrane (RWM) to delineate intracochlear structures in fresh human cadaveric specimens.

Methods

Human temporal bones were obtained from anonymous donors (13-40 h post-mortem) at the Massachusetts General Hospital and prepared using an expanded facial recess approach, consisting of the removal of the mastoid air cells and facial nerve, and thinning of the cochlear promontory near the RWM to maximize the number of possible viewing angles into the cochlea. Care was taken to not disrupt the stapes, RWM, or otic capsule in order to preserve the intracochlear structures. Specimens are cooled immediately on retrieval in order to prevent degradation but no preservative agents were utilized. The samples are fixed to a Noga micromanipulator coupled to a linear translation stage to optimize bone positioning for image acquisition.

OCT is used to visualized the cochlear partition through the RWM. Images are collected using ThorLabs Ganymede III high-resolution 905-nm-wavelength Spectral-Domain Optical Coherence Tomography (SD-OCT) hardware. The axial resolution is 2.23 µm (in water) and the lateral resolution is ~8 µm, using a 36 mm, 0.055NA, 2x objective lens, which allows for the visualization of cochlear structures.

To assist with identification of cochlear partition structures, OCT images were compared to histological correlates using slides obtained from the Mass Eye and Ear Otopathology library.

Results

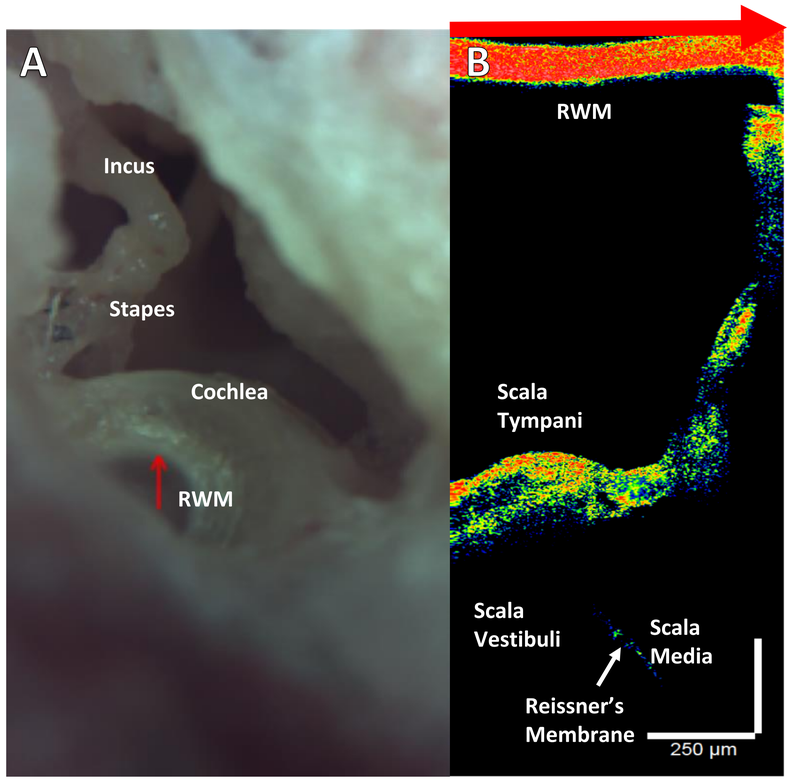

Figure 1. Representative images from a fresh specimen (~13 hours post mortem). (A) Microscopic image of the middle ear. The red arrow is over the round window and indicates the plane through which the OCT images are taken. (B) OCT image of the human cochlear partition demonstrating micro-meter level resolution of intracochlear structures. Red arrow corresponds to the arrow in panel A. RWM = Round window membrane.

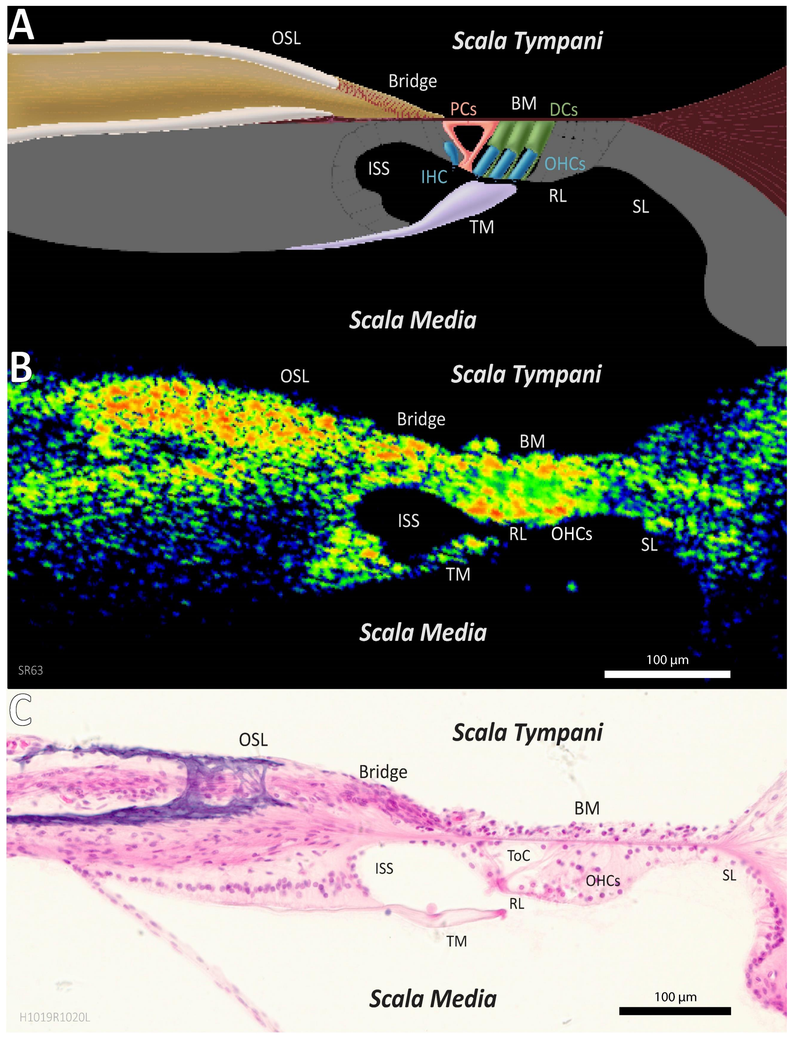

Figure 2. Trans-RWM OCT allows for the imaging of microstructures within the human cochlear partition. (A) Schematic representation of the cochlear partition including supporting cells found within the Organ of Corti. (B) High-resolution OCT image with identifiable structures labelled. (C) Histologic image of a similar appearing cochlea for reference. OSL = osseus spiral lamina; ISS = inner spiral sulcus; TM = tectorial membrane, PCs = pillar cells; BM = basilar membrane; IHC = inner hair cell; OHCs = outer hair cells; DCs = Deiter cells; SL = spiral ligament; ToC = tunnel of Corti.

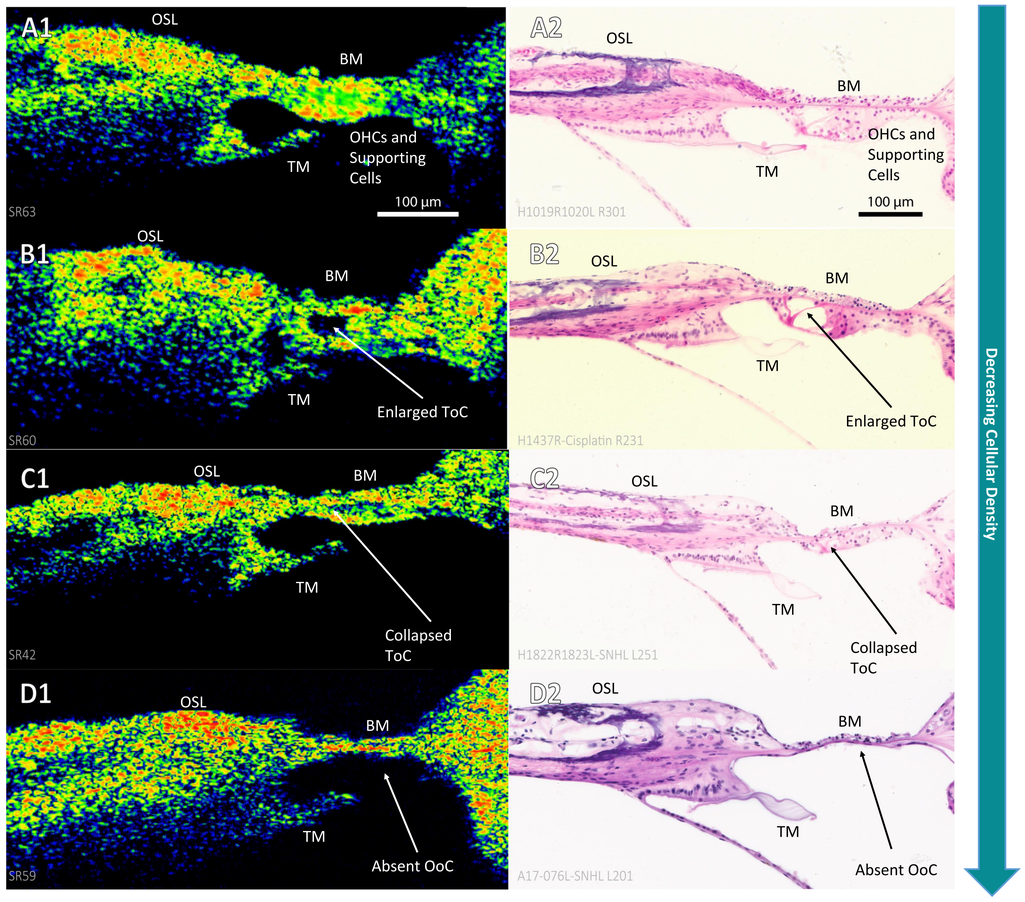

Figure 3. OCT imaging captures presence or absence of cochlear structures, which may be useful as a proxy for the health of the cochlear parenchyma. Panels represent OCT images paired with similar appearing histology with decreasing cochlear structures moving from panel A to D. (A) Cochlear partition with intact and recognizable cytoarchitecture. Outer hair cells and supporting cells are intact (same specimen as in Figure 2). (B) Recognizable cytoarchitecture but many supporting cells and outer hair cells are absent. This appears as an enlarged tunnel of Corti on OCT. (C) Tunnel of Corti is collapsed, tectorial membrane is further from the partition. (D) Bare basilar membrane without recognizable Organ of Corti. OSL = osseus spiral lamina; TM = tectorial membrane; BM = basilar membrane; OHCs = outer hair cells; ToC = tunnel of Corti; OoC = Organ of Corti.

Conclusions and Future Directions

OCT is capable of rapidly and non-invasively producing high resolution images of the cochlear microanatomy in fresh human temporal bones. Specifically, we were able to distinguish structures within the Organ of Corti, such as hair cells and supporting cells. The basilar membrane, reticular lamina, and the tectorial membrane and its positioning were recognizable. The bridge, osseous spiral lamina, spiral ligament, and Reissner's membrane were also visible. In some specimens, we have been able to estimate the presence of inner and outer hair cells, supporting cells, and pillar cells.

OCT imaging through the round window allows assessment of cochlear condition in an intact cochlea in a relatively non-invasive manner from the middle-ear cavity. It may therefore be a useful tool for selecting patients for novel otoregenerative therapies, and/or to assess their response to treatment.
One major limitation of this system is the degree to which the temporal bones must be dissected to obtain sufficient exposure to the RWM. However, this may be improved by the improvements in endoscopic OCT devices, which are currently commercially available. Further development of OCT endoscopic technology could allow for intra-cochlear imaging without disruption of as much of the temporal bone architecture as is required for our study.

This study demonstrates the potential of a diagnostic method of estimating cochlear health without disrupting the intracochlear space.

Acknowledgements

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References

Full reference list of studies can be found following the QR code.