First complete anatomical analysis of the entire cochlea at a sub-millimeter resolution using synchrotron-radiation phase-contrast imaging

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I. Introduction

Hearing loss affects nearly half a billion individuals worldwide and is expected to increase drastically in prevalence by 2050 [1]. The cochlea is the spiral-shaped end organ of hearing within the inner ear that contains sensory hair cells responsible for transducing mechanical sound vibrations to the electrical impulses we perceive as sound. Cochlear implants are surgically implanted neural-prosthetic devices which bypass the sensory hair cells and directly stimulate auditory nerve fibers to restore sound perception in cases of sensorineural hearing loss. However, current cochlear implant electrodes are short and do not stimulate the entire cochlea due to the lack of anatomical knowledge on fine intracochlear structures [2]. The objective of current work is to present anatomical measurements of the entire cochlea with a focus on longer electrode implant insertions.

II. Methodology

Nineteen human cadaveric cochleae were scanned using synchrotron-radiation phase-contrast imaging (SR-PCI) at 9µm. SR-PCI uses synchrotron X-rays and combines phase contrast techniques with computed tomography to produce three-dimensional images with both cochlear bone and soft tissue detail [3].

For each three-dimensional image, the two main cochlear ducts, the scala tympani and scala vestibuli, were semi-automatically segmented and aligned along the cochlea's virtual spiral axis of rotation. The images were then radially sliced about the axis of rotation. Radial cross-sections at 5° increments were analyzed to obtain geometric measurements of the entire cochlea, from the cochlear base to the apex.

III. Results & Discussion

The maximum inscribed circle, as shown in Figure 1, and the cross-sectional area were measured in 19 cochleae at various degrees up to the cochlear apex.

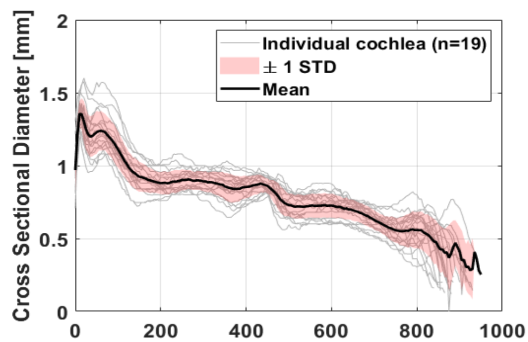

Fig. 1 The largest inscribed circle inside the scala tympani cross-sections.

These preliminary measurements show that the cross-sectional diameter and area generally decrease from the base (0°) to apex (900°) of the cochlea as expected. The angular depth of a typical electrode cross-sectional diameter can then be used to inform safe implantation of longer electrode arrays to restore low-frequency ranges.

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References

1. L. M. Haile *et al.*, "Hearing loss prevalence and years lived with disability, 1990-2019: Findings from the Global Burden of Disease Study 2019," *The Lancet*, (2021) 397(10278):996-1009.
2. E. Avci, T. Nauwelaers, T. Lenarz, V. Hamacher, and A. Kral, "Variations in microanatomy of the human cochlea," *Journal of Comparative Neurology*, (2014) 522(14):3245–61.
3. L. Helpard *et al.*, "An Approach for Individualized Cochlear Frequency Mapping Determined from 3D Synchrotron Radiation Phase-Contrast Imaging," *IEEE Trans Biomed Eng*, (2021) 68(12):3602–1.