Shape Modelling of the Inner Ear From Micro-CT Data

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The HEAR-EU project is a collaborative project between Alma IT Systems, MED-EL, SCANCO Medical, the University of Bern, the University Hospital of Bern, the University of Pompeu Fabra (UPF) and the Technical University of Denmark (DTU).

Introduction

The Cochlear Implant (CI) is an established technology that recovers lost auditory sensation in patients suffering from a range of severe hearing disabilities (Figure 1).
Improvements to the technology and the surgical procedure could potentially be achieved by providing further and more detailed information about the anatomy and physiology (Figure 2) of the specific patient and the variation in the population.

This kind of information can be represented in a Statistical Shape Model (SSM) of the inner ear from µCT data. The extensive research and established tools in the field of shape modelling can readily find applications relating to the CI technology. Knowledge of the anatomical variability could for instance influence how CI manufacturers design their implants.

The spiral shaped cochlea presents an anatomy with small important features that can only be properly perceived in high resolution µCT scans. From a research point of view, the complex anatomy and the large data sizes makes it a challenging dataset to handle and to construct a shape model from.

AIM: To build a statistical shape model of the inner ear from µCT data.

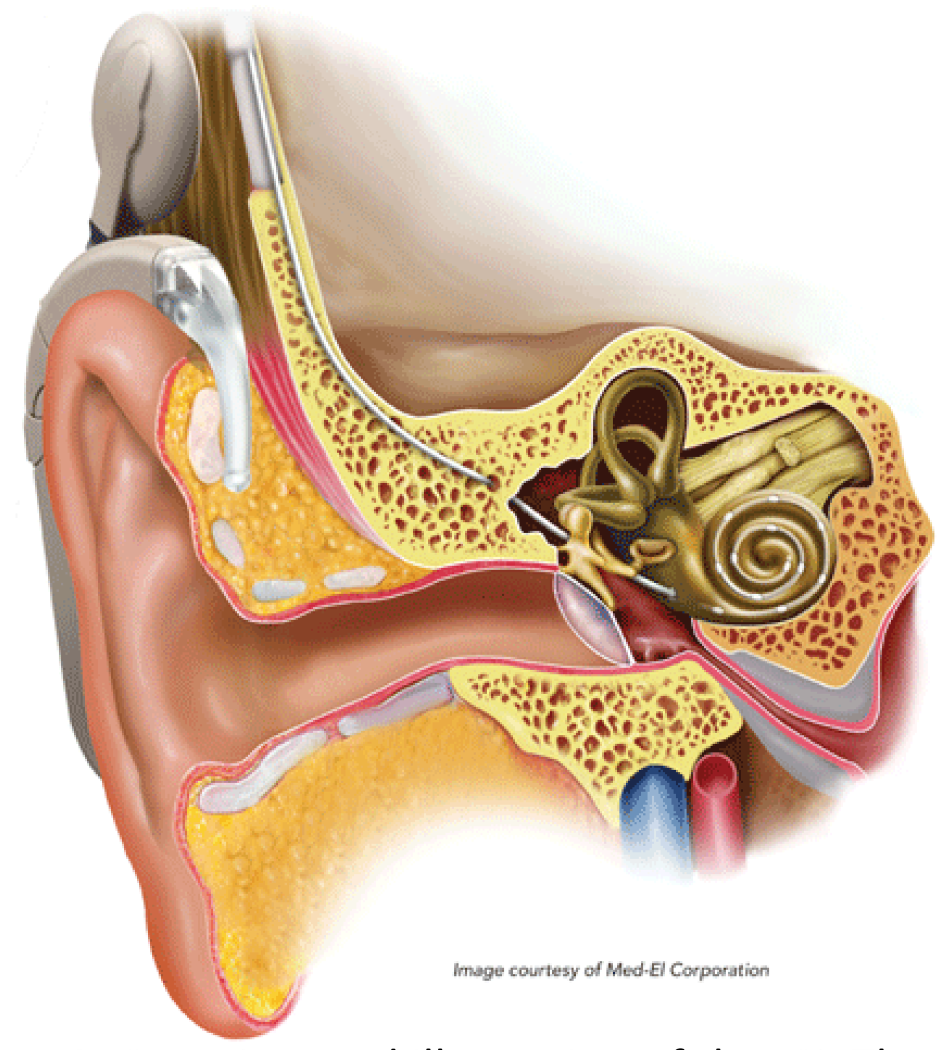

Figure 1: Overview and illustration of the CI. The external part is similar to a classic hearing aid. The internal part is an array of electrodes placed in the spiral-shaped cochlea.

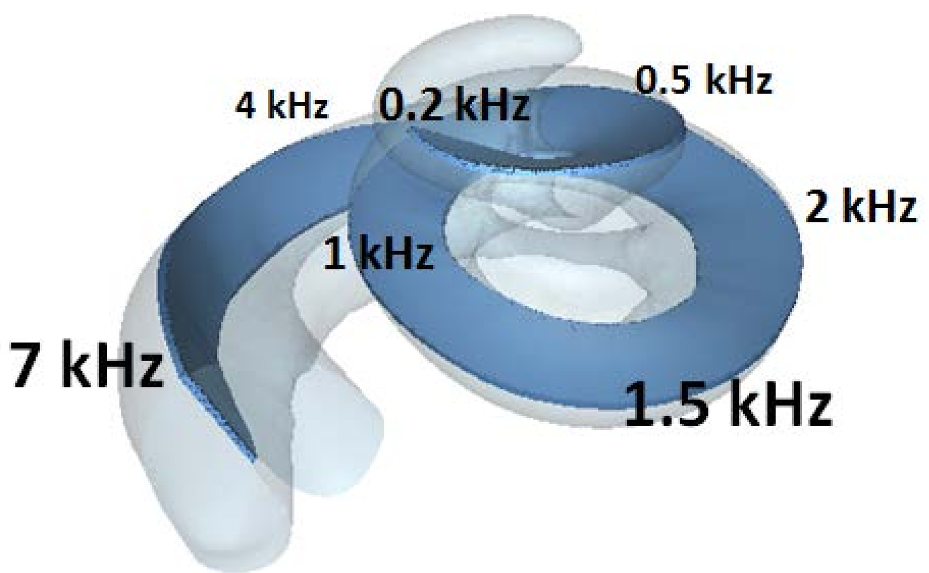

Figure 2: Illustration of the tonotopic map of the cochlear.

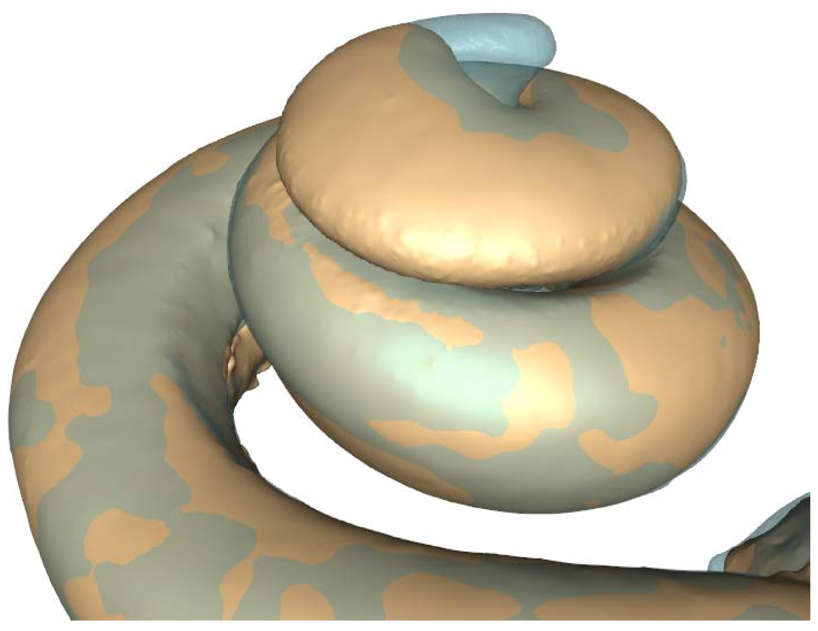

Figure 5: Illustration of a registration result, and the difficulty in capturing the cochlear turning.

Material & Methods

DATA: 17 temporal bones excised from human cadavers were dried (University Hospital of Bern) and then scanned with a micro-CT system (Scanco Medical). The region of interest in the data was reconstructed in 24 micron isotropic voxels (resulting in approx. 6GB of data per scan).

SEGMENTATION: The inner ear (i.e. cochlea and vestibular system) was segmented manually using *ITK-SNAP*. The surfaces of the segmentations were extracted using Marching Cubes and post-processed using MRF surface reconstruction to provide smooth and well-formed surface meshes (Figure 3 and 4).

IMAGE REGISTRATION: A single dataset was chosen as a reference to which all other datasets were registered to.
Initial: Rigidly aligning center of mass and principal directions, which is robust due to the asymmetric shape.
Deformable: Multi-scale B-Spline grid using the *elastix* library. This part poses an interesting challenge. On one hand, large deformations are desired to capture the turning of the cochlea. However, it is paramount that the separation of the cochlea turns remains intact, which limits the allowable deformation freedom (Figure 5).

MODEL BUILDING: The transformations from the registrations were applied to the reference surface model to create surfaces representing the anatomy in the individual datasets with point correspondences.
A classic point distribution shape model was built using *Statismo*.

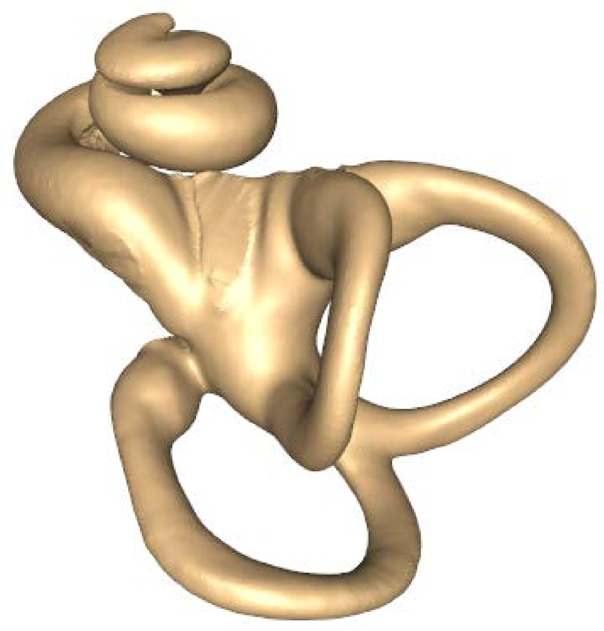

Figure 3: Example inner ear surface model extracted from µCT.

Figure 4: Close-up of the cochlea of the surface model (Figure 3).

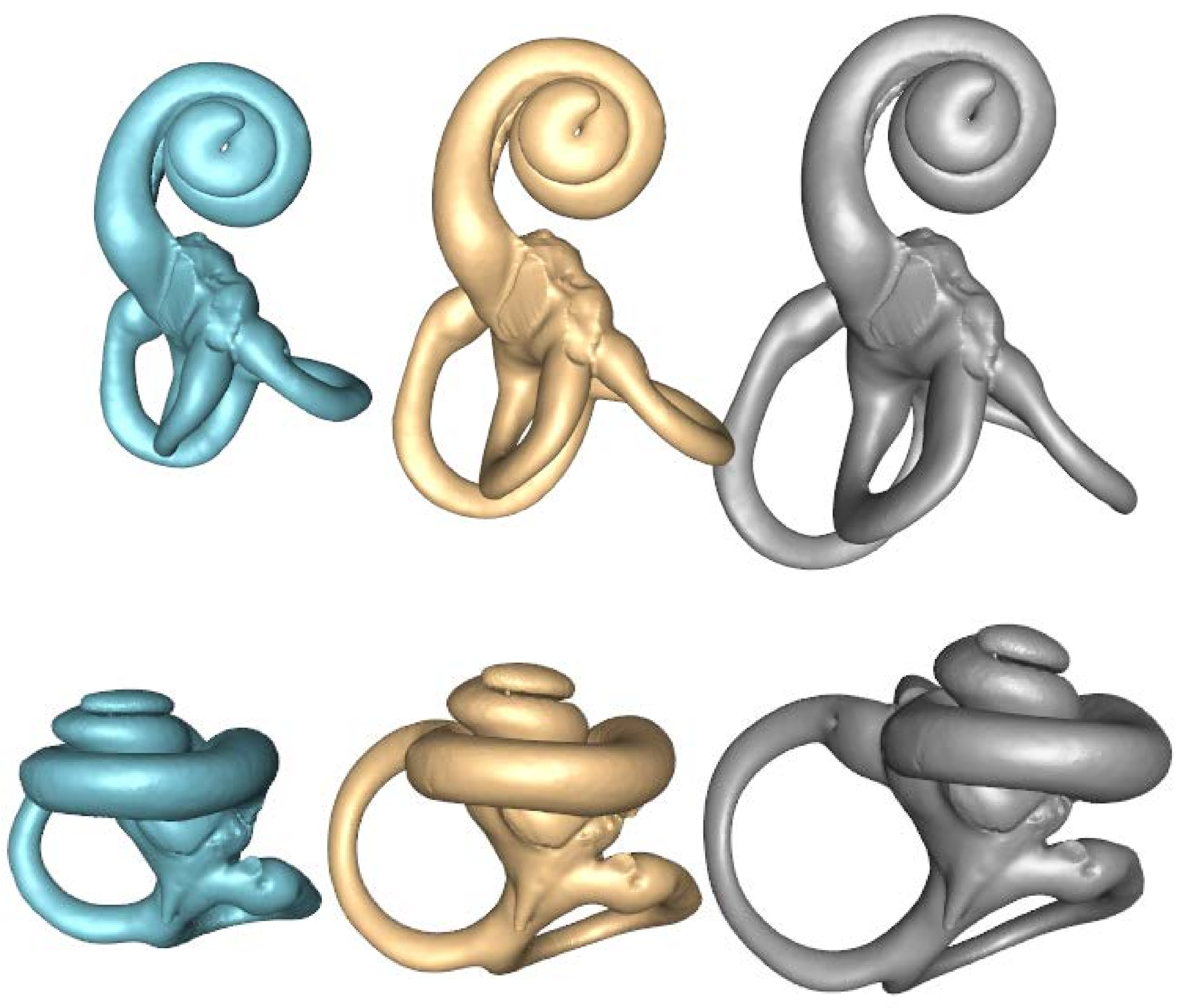

Figure 6: Illustration of the 1st mode of the shape model (mean +/- 3 stds.)
The overall change of size is captured is this mode.

Results

The model contains 466k vertices , 933k triangle faces and captures the variability in 16 modes of variation (Figure 6).

EVALUTION: The quality of the model is limited by the accuracy of the registration, which is evaluated against the ground truth segmentation or surface model using Dice Score and Hausdorff Distance:

- Average Dice Score: 0.96 +/- 0.01
- Average Hausdorff distance: 0.69 +/- 0.24 mm

Discussion & Conclusion

Previous studies of anatomical variability has focused mostly on simple 1-D statistics such as average cochlea height and length. The shape model representation allow a much more nuanced shape variability description – for instance the correlation between the radii of the *semi-circular canals.*
Other attempts of shape modelling of the cochlea have been made previously. Our model is based on more data, and on data with a higher resolution. This allow us to explore the variability of new anatomical details – for instance the length of the *lamina spiralis*, which is highly relevant for understanding the physiology of cochlea.

In conclusion , a shape model of the inner ear has been constructed using publicly available software. The model is based on 17 µCT data sets, capturing more detail and variation than previous studies.

Acknowledgement: The research leading to HEAR-EU results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement № 304857.