Finite-element modelling based on optical coherence tomography and corresponding X-ray microCT data for two human middle ears

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INTRODUCTION

Optical coherence tomography (OCT) is an emerging imaging modality which is non-invasive, can be employed *in vivo* and can record both static anatomy and vibrations. An akinetic swept-source laser system makes imaging of the full depth of the human middle ear possible in real-time and it provides both brightness mode (B-mode) images and phase-resolved Doppler vibrography measurements. Wang performed finite-element modelling of the human middle ear for one human ear at a single frequency (500 Hz) using microCT and doppler OCT data of the same ear [1].

OBJECTIVE

The objective is to build multiple finite-element models based on X-ray microCT data and to validate them with OCT shape and vibrometry data from the same ears.

MATERIALS and METHODS

Specimens were right cadaver ears of a 66-year-old Caucasian male and a 76-year-old Caucasian male. We used OCT to record vibrations at 500 Hz for the first ear and vibrations at three different frequencies (500 Hz, 1 kHz and 2 kHz) for the second ear. X-ray microCT images were obtained from the same specimens and were used for the modelling. The models were generated using locally developed software: Fie, Tr3, Fad, Thrup'ny [2]. Identification and segmentation of structures was done using Fie, followed by triangulation in Tr3, finite-element preprocessing with Fad and the final display of the model in Thrup'ny.

We used SAP IV [3] and Code_Aster [4] to run finite-element simulations. The material properties and boundary conditions of the models were obtained from previously reported studies. Simulations were implemented using linear transient time analysis, harmonic analysis and modal analysis. Model verification was performed by using multiple finite-element solvers and comparing their simulation results.

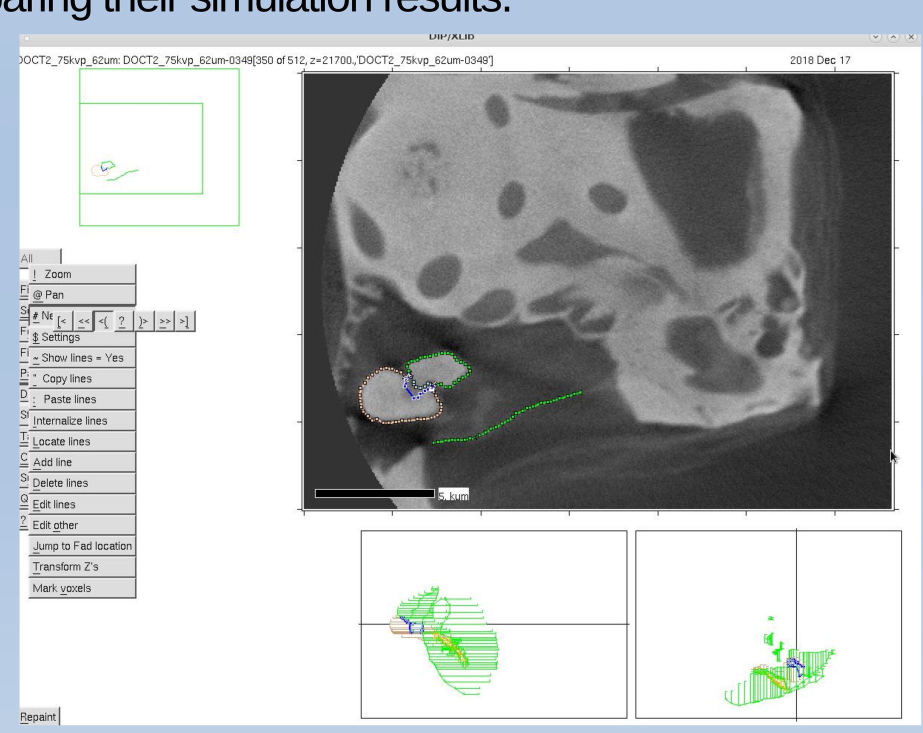

Fig. 1. Image segmentation using Fie

RESULTS

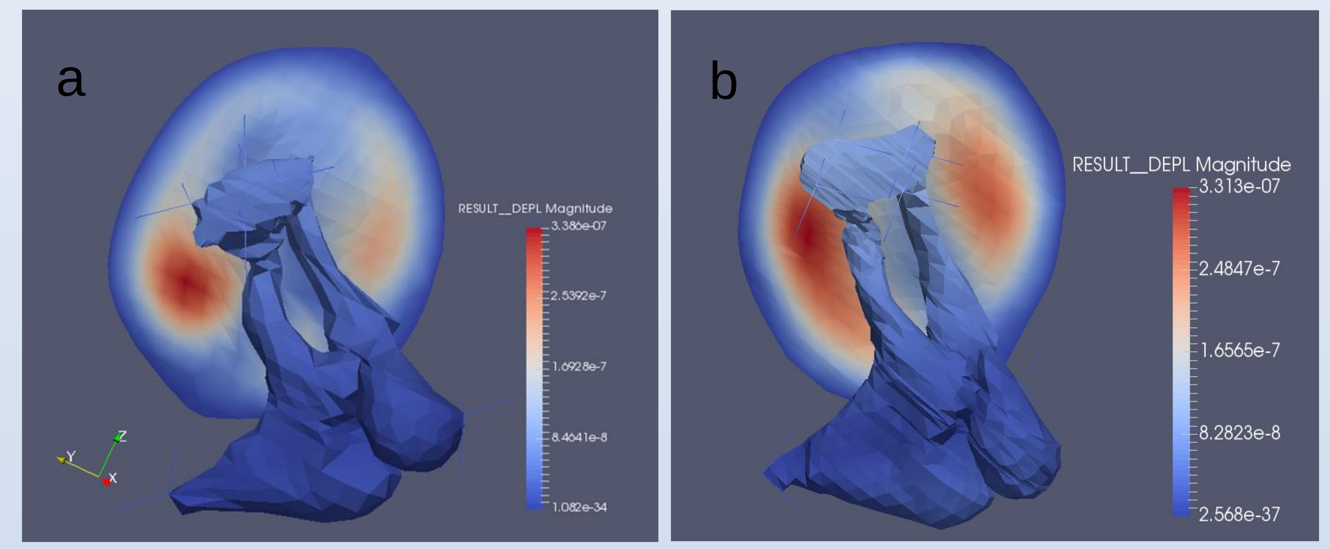

Fig. 2. Displacement pattern from a static simulation for two different ears. The displacement values given are the magnitudes of the displacement vectors.
(a) First ear (b) Second ear

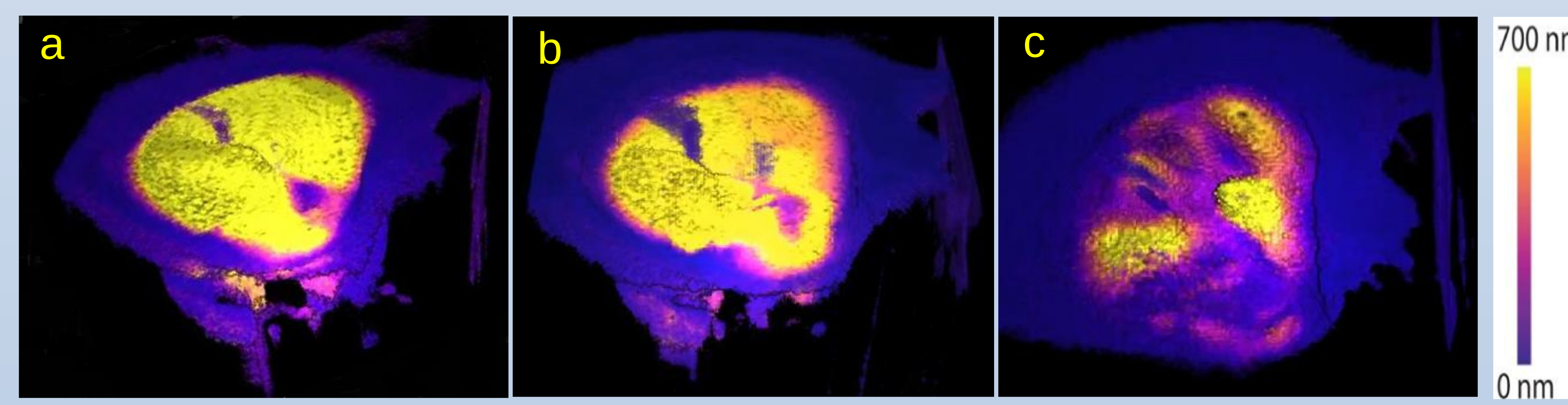

Fig. 3. View of 3D vibration map of OCT displacement measurements for second ear, plotted with a colour map of vibration-amplitude-weighted hue and B-mode-weighted alpha value [5]. (a) 500 Hz (b) 1 kHz (c) 2 kHz

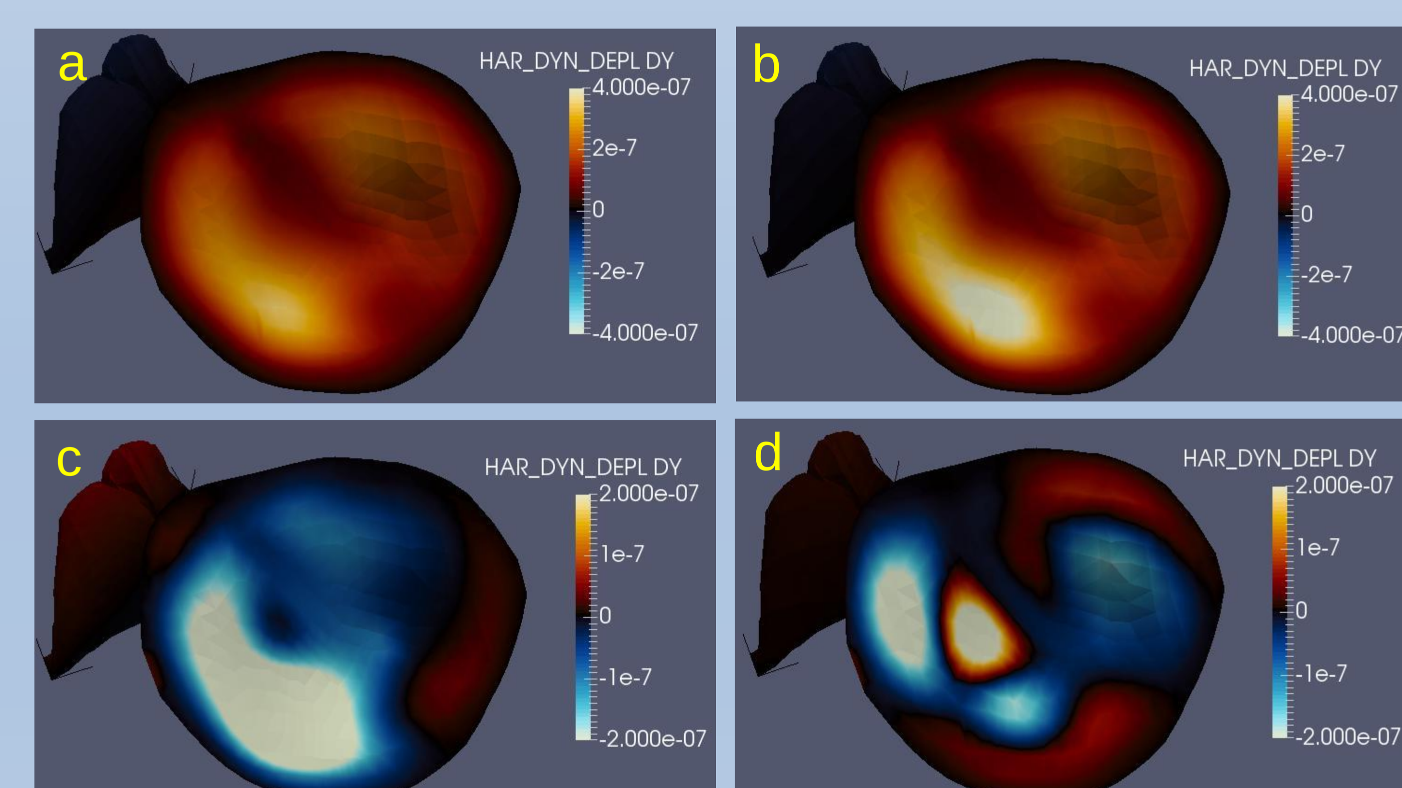

Fig. 4. Displacement pattern from a harmonic simulation for second ear. The diaplacement values shown are the real part of the y component of displacement.
(a) 500 Hz (b) 1 kHz (c) 2 kHz (d) 3 kHz

DISCUSSION

So far we have built finite-element models of two ears. For both ears, OCT measurements and static simulation results both showed the maximal displacement appearing in the posterior region of the tympanic membrane. There were smaller displacements on the malleus, incus and stapes (Fig. 2).

For the second ear, OCT data are available for multiple frequencies. We see a complex pattern of displacements at 2 kHz while there is a simple pattern for 500 Hz and 1 kHz which is similar to the static results (Fig. 3).

For the second ear we show harmonic simulation results for different frequencies (Fig. 4). The results are in qualitative agreement with the OCT vibration patterns of the same ear. As the frequency increases, the pattern becomes more complex.

Model creation and validation will be done for more ears and we will investigate how changes in geometry contribute to differences in the responses of the finite-element models. This will help us understand the relationships between geometry and function in the middle ear.

CONCLUSION

Individualized finite-element models can be validated using OCT vibrational data for the same ear. This will ultimately lead to patient-specific models based on *in vivo* OCT measurements and improve diagnosis of abnormalities in the middle ear.

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