Finite-element modelling of the human eardrum based on X-ray micro computed tomography and Doppler optical coherence tomography in the same ear

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The eardrum plays a critical role in transferring sound into vibrations in the inner ear. The vibration patterns of the eardrum, particularly at high frequencies, have been investigated by many groups but are still not well understood. Computational modelling of the eardrum and middle ear offers a pathway toward better understanding of the mechanical function of these structures, but the tuning and validation of such models require accurate anatomical and mechanical experimental data. Such data usually come from populations of ears and little is known about how differences in individual middle-ear geometry and material properties affect eardrum function.

Recent advances in Doppler optical coherence tomography (OCT) of the middle ear have demonstrated its ability to simultaneously capture anatomical image data and Doppler-mode vibration data of the ear in response to sound. In the present study, we obtain brightness-mode (B-mode) anatomical OCT images of a human temporal bone for which simultaneous Doppler-mode vibration OCT images were collected. For the same ear we also collect 3D X-ray micro computed tomography (microCT) images. The microCT data provide a higher spatial uniformity of resolution than OCT and are free from shadowing and multiple scattering artifacts which are present in the OCT B-mode data. The microCT images are manually segmented to create a finite-element model for the eardrum. The Doppler OCT images, masked by the B-mode OCT images to reduce noise, are also segmented and the resulting 3-D model is transformed to Cartesian coordinates and aligned with the microCT-based model. The simulated vibration patterns are compared with the measured Doppler-mode OCT velocity data to validate the finite-element model.

This method of combining anatomical and vibration data from the same ear can be used to generate a set of finite-element models for a range of human ears, in order to advance our clinical understanding of the effects of natural variations in eardrum shapes, of eardrum pathologies, and of various surgical reconstruction techniques.

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