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Three-dimensional reconstruction and modeling of middle ear biomechanics using high resolution computed tomography and finite element analysis

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Purpose: To present a systematic and practical approach that uses high-resolution computed tomography (HRCT) to derive models of the middle ear for finite element analysis (FEA).

Materials and methods: This prospective study included 31 subjects with normal hearing and no previous otological disorders. Temporal bone images obtained from 15 right ears and 16 left ears were used for evaluation and reconstruction. High-resolution computed tomography of temporal bone was performed using simultaneous acquisition of 16 sections with a collimated slice thickness of 0.625 mm. All images were transferred to an Amira visualization system for 3D reconstruction. The created 3-D model was translated into two commercial modeling packages, Patran and ANSYS, for finite element analysis.

Results: The characteristic dimensions of the model were measured and compared with previous published histological section data. The result confirms that the geometric model created by the proposed method is accurate except the tympanic membrane is thicker than that of histological section method. No obvious difference in the geometrical dimension between right and left ossicles was found ($p > 0.05$). The 3D model created by finite element method and predicted umbo and stapes displacements are close to the bounds of the experimental curves of Nishihara's, Huber's, Gan's and Sun's data across the frequency range of 100-8000 Hz.

Conclusion: The model includes a description of the geometry of the middle ear components, and dynamic equations of vibration. The proposed method is quick, practical, low cost and most importantly, non-invasive as compared with histological section methods.