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Acoustic-structural coupled finite element analysis for sound transmission in human ear – middle ear transfer function

RZ. Gan[1], T. Cheng[1], MW. Wood[2], Norman[1], Oklahoma City[2]; USA

A 3-dimensional finite element (FE) model of human ear with accurate structural geometry of the external ear canal and middle ear, including tympanic membrane, ossicles, suspensory ligaments, and middle ear cavity, has been recently published by our group. The model has been built with fluid (air) - structural interfaces among all the moving surfaces for coupled analysis from the ear canal through tympanic membrane (TM) to middle ear cavity. In this paper, the coupled FE analysis was employed to derive acoustic-mechanical transmission from the air-filled canal to the stapes footplate in normal and pathological ears. The structural alterations such as perforations of the TM caused by trauma or chronic otitis media were created in the model at different locations with various sizes for acoustic-structural coupled FE analysis. In the meantime, perforations of the TM were generated in human cadaver ears or temporal bones. Two laser Doppler interferometers were used to measure simultaneously the transfer function of the middle ear in terms of the relationship between vibrations at the TM and stapes footplate. The FE model-derived results on transfer functions of the middle ear under normal and TM perforation conditions are very similar to the data measured from temporal bones across frequency range of 200 to 8k Hz. The FE model provides precise predictions on the effect of perforation location and size on middle ear transfer function. This study indicates that our FE model can serve as an excellent analytic tool for investigating middle ear structure-function relationship in normal and pathological ears with visualization of structural variation and multi-field mechanics analysis