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Effects of middle ear suspensory ligaments on acoustic-mechanical transmission in human ear

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The middle ear including tympanic membrane (or eardrum) and three ossicular bones (i.e., malleus, incus and stapes) constitutes a mechanical system for sound transmission from the external ear canal to cochlea. Three ossicles are suspended in an air-filled middle ear cavity by suspensory ligaments/muscle tendons and coupled to the eardrum by manubrium of the malleus. To describe middle ear biomechanics, it is necessary to understand mechanical properties of the suspensory ligaments and the effects of those tissues on acoustic-mechanical transmission through the ear. In this paper, we report bioengineering systems approach on ligaments function measurement and mechanical testing of human cadaver ears. Two laser Doppler vibrometers were used to measure simultaneously the movements of stapes footplate and eardrum in temporal bones across the auditory frequency range. After control study with intact ossicles, middle ear suspensory ligaments and tendons, such as superior malleolar ligament, posterior incudal ligament, stapedial tendon, and tensor tympani muscle tendon, were sectioned sequentially and displacements of the stapes footplate and eardrum were measured repeatedly for every section. In the meantime, the mechanical properties of stapedial and tensor tympani muscle tendons were measured in micro-tensile material testing system. A 3-D finite element (FE) model of human ear with accurate anatomic structure was then used for acoustic-mechanical analysis. The model-derived eardrum (umbo) and stapes footplate vibrations as the input sound was applied at the canal were compared with the results obtained from laser measurements in temporal bones. Our results show that the effects of ligaments on transfer function of the ear are frequency sensitive and vary with individual ligaments. The FE model demonstrates that a bioengineering systems approach provides a better understanding of ear biomechanics.