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Real-time opto-electronic holographic measurements of sound-induced tympanic-membrane displacements

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Purpose: The tympanic membrane (TM) is the initial structure involved in the middle-ear's acoustical-mechanical transformation of environmental sounds to sound pressure within the inner ear. While we know some basic facts about the workings of the healthy TM in a limited frequency range, many unknowns remain including how sound is coupled to the ossicles by the TM, especially at high frequencies, as well as the effects of pathology on TM function.

Materials & Methods: We use computer-assisted opto-electronic holography that employs fast, high-resolution digital cameras, highly sensitive piezo-controlled positioning stages and advanced signal processing techniques to generate holographic images of the motion of the entire TM at rates up to 500 frames per second. We use two techniques. (1) Time-averaging of the holographic images over several stimulus cycles generates iso-displacement contours of the magnitude of motion of the entire surface of the TM or (2) Stroboscopic holography determines the magnitude (with resolutions of 5-10 nanometers) and phase of the displacement of the surface of the TM. Preliminary measurements have been made in cadaveric cat and chinchilla ears with the middle-ears open.

Results: The TM displacement patterns observed are similar to those produced by others [Khanna & Tonndorf JASA 51:1904-20, 1972] at frequencies less than 4 kHz, however, the holograms determined with stimulus frequencies above 4 kHz show clear standing waves with inter-maximal distances consistent with surface wave velocities of about 10 m/s. The displacement patterns on the chinchilla TM indicate larger displacements and a downward shift in the frequencies needed to observe complex patterns of TM motion consistent with the mechanical hypersensitivity of the chinchilla middle ear. Conclusions Opto-electronic holography rapidly determines the motion of the entire TM surface. The preliminary data suggests surface waves of TM motion and clear interspecies differences in TM function. [Supported by NIDCD and WPI]