Imaging real-time nanometer cellular motions in the inner ear at acoustic frequencies

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The inner ear is a highly tuned frequency analyzer. This tuning depends on the coordinated motion of hundreds of receptor cells ("hair cells") within the sensory epithelium of the cochlea (the organ of Corti). To date the mechanism of cochlear tuning remains unknown mainly because the cochlear hair cells are not easily accessible, and their motions are small and occur at high frequencies. We report on a system designed to visualize and quantify nanometer motions of cells in the inner ear at frequencies relevant to the hearing of the species under study. The system utilized the optical architecture of a light microscope with a pulsed light source constructed from a high power, ultra-fast light emitting diode (LED). The LED was computer controlled via a current source and was synchronized to strobe at particular phases within the period of the stimuli delivered to the cells. Cellular motions were captured with a CCD camera and the resulting images were analyzed and quantified using cross-correlation techniques. We present results of hair-cell motion from two preparations: the gerbil cochlea, using an intact cochlear epithelium and electrical stimulation ranging from 20 Hz to 9 kHz; and the frog inner ear, using isolated hair cells and mechanical stimulation ranging from 20 Hz to 700 Hz. The challenge using the first preparation was imaging through a 200-μm-thick tissue; the final spatial resolution was 432 nm/pixel. The challenge using the second preparation was to improve the spatial resolution while maintaining enough light for high contrast imaging; here the final spatial resolution was 30 nm/pixel. From both preparations the motion of interest was usually less than our pixel size and thus images were interpolated resulting in a 16x improvement in the spatial resolution (27 nm/pixel and 1.9 nm/pixel respectively). We discuss the impact of our data on our understanding of cochlear tuning.