Delivery of Therapeutics into the Inner Ear via Perforation of the Round Window Membrane

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The cochlea, or inner ear, is the organ of hearing and balance. It is located within a space fully enclosed within the temporal bone of the skull, except for two membrane-covered portals connecting it to the middle ear space. One of these portals is the round window, which is covered by the Round Window Membrane (RWM). A longstanding clinical goal is to deliver therapeutics into the cochlea to treat a plethora of auditory and vestibular disorders. Standard of care for several difficult-to-treat diseases calls for injection of a therapeutic substance through the tympanic membrane into the middle ear space, after which a portion of the substance diffuses across the RWM into the cochlea. The efficacy of this technique is limited by an inconsistent rate of molecular transport across the RWM. A potential solution to this problem involves the introduction of one or more holes with diameters of tens of micrometers through the RWM to enhance the rate and reliability of diffusive transport. In addition, cochlear implants are now routinely inserted into the cochlea to enable people with profound deafness to develop a sense of hearing. Traditionally the cochlear implant is inserted through the bone separating the middle and inner ear spaces via a surgical cochleostomy. In the past few years there has been much clinical interest in inserting the cochlear implant through the RWM. This development motivates the need to create holes of diameter several hundred micrometers in the RWM. In this talk we will discuss the placement and geometry of the RWM within the context of the ear and skull. The RWM consists of two epithelial layers surrounding a stroma containing collagen and elastic fibers. We relate experimentally the orientations of the fibers to the RWM geometry in the context of the development of constitutive modeling. We fabricate needles for perforating the RWM based upon two-photon photolithographic methods and demonstrate that perforations can be introduced without adversely affecting the sense of hearing. We also demonstrate that the rate of diffusion of a therapeutic proxy across the RWM is greatly enhanced following the perforation of the RWM. Overall, our results demonstrate that concepts related to experimental mechanics, mechanical properties, and mechanical failure can be used in the development of medical treatments for auditory and vestibular disorders.