The other part of the ear – a ‘balanced’ view

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The inner ear has two important functions, hearing and balance, and yet we know much less about how the balance or vestibular system works compared to its auditory counterpart. In recent years, however, the field of vestibular research has made significant advances to redress this ’imbalance’ in our understanding.

Common to all vestibular organs (there are five organs in each inner ear: two otolith and three semicircular canals) is the specialized neuroepithelium that converts mechanical energy (head motion) into electrical signals (action potentials). The actual conversion or transduction process is carried out by specialized receptor hair cells embedded in the neuroepithelium. Like the auditory system, there are two morphologically distinct hair cells types in the vestibular periphery but they are very different from those found in the cochlea. Known as type I and type II hair cells, they are morphologically and physiologically distinct. Information, specifically electrophysiological, has been obtained mostly from acutely isolated preparations where individual hair cells have been enzymatically and/or mechanically removed from the neuroepithelium prior to recording. While this approach has proved informative, nevertheless, a major drawback with acute isolation studies is the unavoidable destruction of the intimate relationships between individual components of the vestibular neuroepithelium. For example, a unique feature of this neuroepithelium is the presence of cup-like or calyx afferent terminals that envelop type I hair cells. The precise reason for this exuberant post-synaptic specialization has remained a mystery and could not be realistically studied in acutely isolated preparations.

Recently however, this major biological impediment has been overcome by the development of more intact preparations where the specific cellular microarchitecture has been preserved. In these new, semi-intact preparations, it is now possible to record from the three major neuroepithelial components: the two hair cell types, and calyx afferent terminals. Results indicate there are significant differences in electrophysiological responses. For example, by maintaining the close apposition between the postsynaptic calyx terminal and the presynaptic type I hair cell an unusual form of non-quantal synaptic transmission has been identified. It appears the surrounding calyx acts as a barrier to diffusion, restricting normal spread of potassium (K^+) away from the basolateral surface of the hair cell during the transduction process. This, in turn, causes K^+ to accumulate in the cleft between the hair cell and the calyx terminal leading to dramatic depolarization of the type I hair cells and potentially the calyx afferent terminals as well. This unconventional form of transmission has major implications on hair cell/afferent function.

Semi-intact preparations not only allow the study hair cell/afferent interactions, but also provide a means of investigating efferent action on the neuroepithelial components. Very little is known about the predominantly cholinergic efferent vestibular system (EVS), which transmits information *from* the CNS and modulates activity in peripheral vestibular organs. Classical anatomical studies suggest the EVS makes widespread contacts throughout the neuroepithelium, and it is therefore assumed all vestibular hair cells are subject to similar EVS influence. Emerging evidence from semi-intact preparations indicate that the EVS may have more targeted effects than previously thought. For example, during acetylcholine (ACh) exposure, fewer than 25% of type II hair cells respond, while a majority of type I hair cells are activated. The latter result is puzzling, as efferents terminals cannot make direct contact with type I hair cells due to the intervening afferent calyx. Why only some type II hair cells respond, and why type I hair cells respond at all to cholinergic stimulation remains a mystery.

Combining semi-intact preparations with recordings from isolated whole labyrinthine preparations, we are building a more complete picture of how peripheral vestibular organs function. By minimizing effects of tissue preparation and preserving the critical cellular milieu we are redefining peripheral vestibular function in ways that were not possible even a few years ago. Adopting a similar minimalist approaches to the study of the central vestibular system we predict this will also yield significant new insights into overall vestibular function.