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Otoacoustic Emissions (OAEs): A 30-Year Perspective

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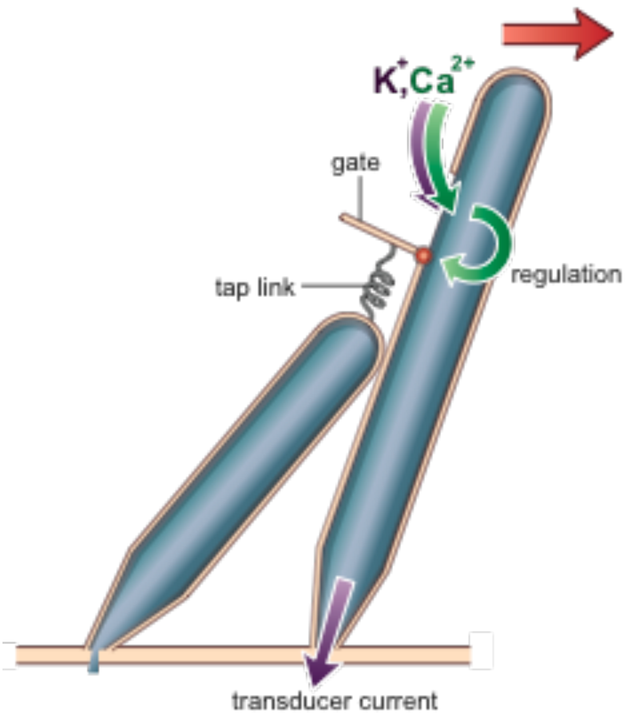
The First Decade: Discovery of OAEs and Outer Hair Cell Motility

Thirty years ago, beginning in 1980, several groups of hearing scientists demonstrated independently that outer hair cells can elongate and contract (Brownell, 1982; Flock, 1980; Mountain, 1980). The rather revolutionary discovery of outer hair cell motility suggested an anatomical and physiological explanation for the generation of otoacoustic emissions, first reported by David Kemp a few years earlier (Kemp, 1978). Although outer hair cell motility clearly plays an important role in the production of OAEs, ongoing investigations for the past 30 years have yielded varying theories, and even some controversy, as to the precise mechanisms underlying the origins of OAEs. For example, early on the assumption was that OAEs must escape the cochlea via a reverse traveling wave along the basilar membrane. However, so far formal experiments have failed to identify such a reverse traveling wave in the mechanics of the the basilar membrane. Although measurements made with a pressure sensor in the cochlear fluids have shown evidence of a reverse pressure wave which, in theory, could result in a traveling wave, the lack of direct evidence of a reverse traveling wave on the basilar membrane has led to an alternate theory suggesting that OAEs escape the cochlea via acoustic waves coupled to the cochlear fluids. Understanding the exact mode of reverse propagation of OAEs is likely to profoundly influence clinical applications.

Also, the rather simplistic early classification of OAEs as either spontaneous or evoked has given way to a more complex taxonomy. Importantly, there appear to be major differences in the way two clinically popular evoked OAEs ... transient evoked OAEs (TEOAEs) and distortion product OAEs (DPOAEs) ... are generated. With the more recently proposed classification system, OAEs are categorized based on their mechanism of generation and grouped into two categories ... OAEs arising from a nonlinear mechanism (e.g., DPOAEs) and OAEs arising from a linear reflection mechanism (e.g., TEOAEs). A central issue in accepting or rejecting this theoretical model of OAEs is in the phase behavior of OAEs and their clinical application.

A basic understanding of cochlear physiology is necessary to understand the distinction between these two modes of OAE generation. Unfortunately, the clinical audiologist is hard-pressed to find an up-to-date, straight forward ,and clinically focused source of information on the mechanisms of OAE generation. With this in mind, we include in our forthcoming textbook *Otoacoustic Emissions: Principles, Procedures and Protocols* a clinically oriented review of current explanations for the generation of OAEs. A unique feature in Chapter 2 (Anatomy, Physiology, Mechanisms, and Theory) and Chapter 3 (Taxonomy for OAEs: Conventional and Alternative Theories) is the inclusion of original color drawings depicting rather complex cochlear processes that are essential to an understanding of OAE generation. An example of such a drawing, illustrating critical anatomical and transduction processes associated with movement of the ciliary bundle at the apex (top) of the outer hair cell, is shown in Figure 1.



If the cochlear origins and mechanisms are fundamentally different for TEOAEs versus DPOAEs, then perhaps we should view the two types of OAEs as independent measures of cochlear function. Extending this idea to the clinical setting, there seems to be some scientific rationale for utilizing both TEOAE and DPOAE recordings in the assessment of cochlear function. Anecdotal reports from audiologists support the notion that selected patients yield divergent OAE findings, for example, apparently normal TEOAEs yet no detectable DPOAEs. Combining both types of OAEs in a clinical test protocol may provide information that contributes to more precise definition of cochlear function (or dysfunction) and, in turn, more effective intervention strategies.

The Second Decade: Emergence of Distortion Product OAEs and Exploration of Clinical Uses

Transient OAEs were applied almost exclusively in the clinical setting from their discovery in 1978 until the mid-1990s. During that period, an FDA-approved device ... the ILO88 ... that evolved from the equipment used by Dr. Kemp in his initial research was most often used by clinical audiologists around the world. The name of OAE device was derived from Dr. Kemp's affiliation at the Institute for Laryngology & Otology in 1988, the year the device was introduced. Early clinical studies of OAEs, ranging from newborn hearing screening to diagnostic auditory assessment of children and adults, were conducted almost entirely with the ILO88 device using default test parameters. Although accumulated clinical experience with TEOAEs certainly confirmed their value in varied patient populations, the new technique was routinely performed in a relatively small proportion of audiology facilities. And, the reliance on a single device with default settings probably slowed the pace of innovative clinical investigation that invariably leads to more varied and powerful applications of a new technique.

Three major developments in the mid-1990s contributed to a quantum increase in the clinical application of OAEs, especially in the U.S.A. One was the introduction to the market of a variety of FDA-approved OAE devices, especially instrumentation for recording DPOAEs. It's actually possible to specify the date and place of this mini-explosion in OAE application. Most major manufacturers of audiologic equipment unveiled their OAE devices at the 1994 American Academy of Audiology Convention in Richmond Virginia, the first generation of the OAE devices you now use in your clinic. Less than 2 years later, in 1996, two CPT (Current Procedural Terminology) codes were approved for OAEs. The combination of readily available FDA-approved devices and a way of billing for OAE services naturally fueled a steep increase in the clinical application of the procedure.

The third factor contributing to widespread use of OAEs, particularly in children, was a direct outgrowth of the increased availability of the technique. Those of us practicing pediatric audiology soon unexpectedly encountered a seemingly impossible combination of test findings in selected patients. Occasionally we recorded perfectly normal OAEs in children with no detectable ABR, and often no behavioral response to pure tone or speech signals. This pattern of findings, which was very perplexing and disconcerting at the time, was the first sign of what is now recognized world-wide as auditory neuropathy spectrum disorder, or ANSD (Hayes & Sininger, 2008). A review of the literature on auditory neuropathy will show a dramatic increase in the number of published papers beginning in 1996 that continues unabated even now. Of course, every day in clinics around the world untold hundreds of children with suspected auditory neuropathy are identified, evaluated, and managed by audiologists as part of routine clinical care, and the findings are not written up for publication. By the new millennium, OAEs were firmly entrenched in the audiology test battery, and have become a mandatory procedure for diagnostic assessment of infants and young children.

The Last 10 Years: Multiple Generators and Multiple Clinical Applications

As this Newsletter went to press, the literature contained no less than 3445 peer-reviewed articles on OAEs. An impressive volume of research evidence lends support to multiple clinical applications of OAEs in children, and also in an amazing array of adult patient populations. Accumulated experience with OAEs has led to some proven procedures and protocols for clinical measurement and analysis, as suggested by the title of our book ... *Otoacoustic Emissions: Principles, Procedures and Protocols*. The vast clinical literature pertaining to OAEs in cochlear pathophysiology in children and adults is also summarized in two chapters of the Book.

Developments in OAEs within the past decade go far beyond the simple addition of novel or expanded clinical applications. As noted at the outset of this Newsletter, recent basic science research interpreted in the context of clinical experiences has contributed to a clearer understanding of the mechanisms and cochlear processes underlying OAEs. One exciting area of discovery that connects basic research with clinical application involves the utilization of OAEs in measurement of efferent (descending) auditory pathways. Toward the end of our Book, we devote a chapter to a discussion of OAE suppression as a clinical tool. Advances in technology now permit the combined and integrated measurement of OAEs and other time-tested clinical techniques, such as aural immittance measures (e.g., tympanometry and acoustic reflexes) and the auditory brainstem response (ABR). New FDA-approved devices, often hand-held and very easy to operate, now permit sequential recording of either TEOAEs and/or DPOAEs before or after high frequency tympanometry or ABR measurement.

In conclusion, 30 years after their discovery we are still learning more about the multiple mechanisms responsible for generation of OAEs at the same time we are witnessing a consistent expansion and refinement of clinical applications. As clinical audiologists and clinical researchers, we look forward to the opportunity to convey some of this information and excitement about OAEs to our colleagues in the form of our book *Otoacoustic Emissions: Principles, Procedures and Protocols.*

References

Brownell WE. (1982). Cochlear transduction: An integrative model and review. *Hearing Research*, 6, 335-360

Brownell WE. (1983). Observations on a motile response in isolated outer hair cells. In WR Webster & LM Aitken (eds). *Mechanisms of Hearing.* Monash Australia: Monash University Press, pp. 5-10

Flock A. (1980). Contractile proteins in hair cells. *Hearing Research, 2,* 411-412

Hayes D & Sininger YS. (2008). Guidelines for Identification and Management of Infants and Young Children with Auditory Neuropathy Spectrum Disorder. Denver CO: The Children’s Hospital.

Kemp DT. (1978). Simulated acoustic emissions from within the human auditory system. *Journal of the Acoustical Society, 64,* 1386-1391

Kemp DT. (1980). Towards a model for the origin of cochlear echoes. *Hearing Research, 2,* 533-548

Mountain DC. (1980). Changes in the endolymphatic potential and crossed bundle stimulation alter cochlear mechanics. *Science, 210,* 71-72