CLINICAL RESEARCH

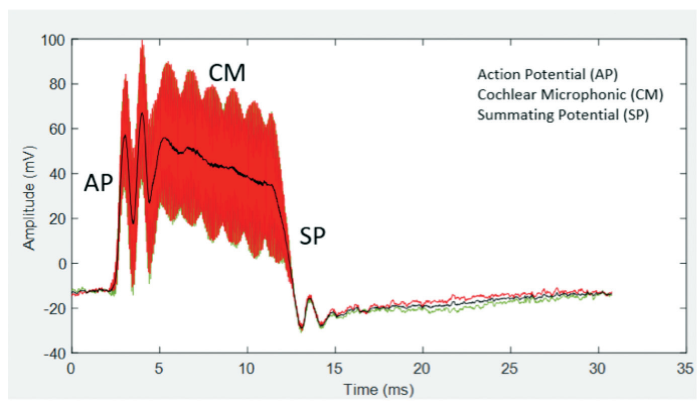
On the Convergence of Electrocochleography and Cochlear Implants

Human sensory perception is an output of complex electrical networks in the body with audition being the result of the auditory networks operating as billions of connected batteries working in harmony. Similar to a battery, cells tuned for sensory reception have potential to release energy under specific conditions. In the case of acoustic hearing, the mechanical vibration of sound traveling through fluid in the cochlea mechanically triggers the transfer of ions through hair cells resulting in a measurable electrical charge and the propagation of this energy through the auditory system.

Measurement of peripheral auditory electrical potentials has almost a century of history that includes systematic research and the development of clinical tools used in observational and diagnostic interpretation of the physiologic response. Measurement of these auditory potentials within the first 10 msec of stimulus is referred to as electrocochleography (ECochG); Eggermont (2017) expertly reviews the history of ECochG and its applications in the diagnosis of Meniere's disease, auditory neuropathy, and cochlear implants. This article will focus on the emergence of ECochG as a measurement recorded through a cochlear implant electrode both during and following surgical implantation.

Electrocochleography measured from a normal hearing auditory system results in the prototypical morphology shown in Figure 1. Contained within this response are three constituent components each regarded as reflecting healthy function of this system: (1) the cochlear microphonic (CM), (2) summating potential (SP), and (3) action potential (AP) also called the compound action potential (CAP). The CM reflects characteristics of the stimulus waveform and is generally regarded as predominately reflecting activity of the outer hair cells with limited contribution of later receptor potentials. The SP is also regarded as originating from the outer hair cells and is calculated as a direct current (DC) shift from the CM baseline. The SP will change in morphology with changing stimulus frequency and level, the characteristics of this interaction are affected by cochlear non-linearities and contribute to its utility in the diagnosis of Meniere's disease. Finally, the AP reflects recruitment of fast acting fibers that respond to signal onsets, the averaged response peaks are negative and notated as N1 or N2, each aligning respectively with waves I and II in the auditory brainstem response.

Figure 1. Total electrocochleography amplitude (mV) in response to a tone pip is shown as a function of time (msec).



Clinically, measurement of the ECochG has most often been completed using extratympanic or transtypmpanic electrode placements. Extratympanic measurements are recorded from electrodes placed in the ear canal or on the tympanic membrane. Transtympanic placements involve insertion of a needle electrode through the tympanic membrane or placement of the electrode while the tympanic membrane is not present. When procedurally feasible, round window measurement of the ECochG has been completed using ball or "golf club" electrodes. Extra-tympanic measures are convenient and avoid the discomfort associated with penetration of the tympanic membrane or measurement during a surgical procedure. As with measurement of any receptor cell potential, a comparatively nearfield measurement will improve the signal to noise ratio. In this regard, extratympanic measures are more prone to contamination from environmental and stimulus interference, possibly requiring a longer duration of recording and signal averaging when compared to the transtympanic methodologies.

As an intracochlear stimulation and recording platform, the cochlear implant electrode is uniquely situated to measure the human ECochG from a location adjacent to the signal generators. Dalbert, Pfiffner, Röösli, et al. (2015) report a comparison of extra- and intracochlear measurements in which extracochlear electrode placement used needle electrodes placed on the promontory and intracochlear measures used the first or apical contact of a HiRes™ 90k Advanced Bionics cochlear implant system. Across nine participants, all had low-frequency acoustic stimulus evoked ECochG present at both measurement sites. Direct comparison of ECochG amplitudes across measurement sites was complicated by the use of two different measurement systems; however, the intracochlear measures were larger on average than the extracochlear measures, 33.5 dB and 18.1 dB relative to 0.1 µV, respectively. Further, the successful measurement of ECochG responses from an implanted electrode suggests preservation of the cochlear structures necessary to acoustically generate the ECochG (Adunka, Mlot, Suberman, et al., 2010).

Modern cochlear implants and electrode arrays are designed to evoke, record, and transmit data from the implanted internal components to the sound processor outside of the head, a process routinely used to measure electrode impedances and electrically evoked auditory potentials. The use of these systems for the measurement of acoustically evoked auditory potentials is an emerging application that reflects the cochlea's structural function and integrity. When considering the cochlear implant as a platform for ECochG measurement, the complexity of measurement and hardware requirements are reduced as compared to traditional systems that require purpose-built electrodes, conditioning amplifiers, and a computer for data processing and storage. Figure 2 shows an intra-operative setup for measurement of the ECochG during electrode insertion. In this example, the implant body has been placed under the skin flap with the headpiece placed in the wearing position with the internal and external coils aligned, allowing for data transmission to the external sound processor, which in turn transmits measured data to a receiving computer or tablet. For presentation of the acoustic stimulus, an ear-tip is placed in the patient's external ear canal during surgery.

An ECochG generated by low-frequency stimuli physiologically originates from the apical region of the cochlea. Based on this physiology, it's reasonable to theorize that amplitudes might systematically increase as the measurement electrode is placed in the cochlea and inserted basally. Harris et al. (2017) measured CM amplitudes during electrode insertion across 14 participants. From these measures, three model responses were observed: (1) the type A response that showed a progressive increase in amplitude as the electrode approached lower frequency cochlear regions, (2) the type B response that peaked soon after insertion and steadily decreased as the electrode advanced, and (3) the type C response reached maximum amplitude at mid-insertion and decreased as the electrode was fully inserted. The authors suggest that additional research to understand intraoperative ECochG response characteristics might support the development of template patterns that are indicative of cochlear function during electrode insertion.

Figure 2. An intra-operative setup for the measurement of ECochG is shown. Visible are the recording tablet, the sound tube for acoustic signal presentation, and the cochlear implant system used for recording and transmission of data.

O'Connell et al. (2018) report on the measurement of ECochG, specifically CM amplitudes, during cochlear implantation with 18 participants. Among their observations, the authors found that electrode location in the cochlea was related to the magnitude of post-operative threshold shift. Electrode placement in the scala tympani resulted in a smaller threshold shift than when the electrode translocated into the scala vestibuli (16 dB for ST versus 38 dB when translocated to the SV). Although intra-operative ECochG thresholds were not predictive of post-operative behavioral thresholds, post-operative ECochG thresholds were significantly related to post-operative behavioral thresholds, suggesting this objective measure may hold a relationship to the behavioral measure. Koka et al. (2016) also found a significant correlation between post-operative ECochG and behavioral thresholds. In their study, frequency-specific 50 msec tone bursts were used to measure ECochG thresholds that were compared to traditionally measured audiograms with thresholds between 125 and 4000 Hz. For measurable thresholds, the closest agreement was among 125, 250, and 500 Hz. The association was attributed to the tonotopic organization of the cochlea and proximity of the apical electrode used for measurement.

While ECochG has established clinical applications outside of cochlear implants, their convergence has renewed interest among research and clinical communities. The process of electrode insertion no longer needs to be in absence of insight into the physical interaction between the electrode and cochlear structures. The benefit of objective threshold measurements extend to post-operative clinical applications in which audiologists can cross-check these measures with the behavioral audiogram and reliably obtain thresholds from challenging patients. These two applications are first indications of what will develop on these measurement platforms. Future research should investigate the use of these tools in the prescription of combined electric and acoustic hearing as well as diagnostic utilities that can extend beyond the ECochG to a variety of other objective measurements.

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027-N166-02 RevB