Simultaneous extratympanic electrocochleography and auditory brainstem responses revisited

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Abstract

The purpose of this study was to revisit the two-channel, simultaneous click-evoked extratympanic electrocochleography and auditory brainstem response (ECoG/ABR) recording technique for clinical use in normal hearing participants. Recording the compound action potential (AP) of the ECoG simultaneously with ABR may be useful when Wave I of the ABR is small or diminished in patients with sensorineural or retrocochlear disorder and minimizes overall test time. In contrast to some previous studies that used the extratympanic electrode both as non-inverting electrode for the ECoG and inverting electrode for ABR, this study maintained separate recording channel montages unique to conventional click-evoked ECoG and ABR recordings. That is, the ABR was recorded using a vertical channel (Cz to ipsilateral ear-lobe), while the ECoG with custom extratympanic electrode was recorded using a horizontal channel (tympanic membrane to contralateral ear-lobe). The extratympanic electrode is easy to fabricate in-house, or can be purchased commercially. Maintaining the conventional ABR montage permits continued use of traditional normative data.

Introduction

Electrocochleography (ECoG or ECochG) and auditory brainstem responses (ABR or BAER) are well-established auditory evoked potential tests used for the assessment of a variety of auditory conditions. A typical ECoG could be characterized by: cochlear microphonic, summates potential (SP), and compound action potential (AP), and they appear within the first 5 ms following stimulus onset. These ECoG components convey some information about the status of the inner ear and the auditory nerve. The typical ABR has up to seven components within the first 10 ms following stimulus onset, and Waves I, III, and V are often used to evaluate neural conduction time from the auditory nerve through the auditory brainstem. Except for some differences in stimulus and recording parameters, the AP of the ECoG is the same component as Wave I of the auditory brainstem response (ABR) with identical latency.1,2

A prolonged ABR Wave I-V interpeak latency is one useful clinical index of a neurological lesion.3-6 Wave I of the ABR is often smaller compared to Wave V, and any lack of a Wave I for any reason will make interpretation difficult or impossible. If Wave I is not visible in the ABR, it can be attributed to poor signal-to-noise ratio, location and placement of electrodes on the head and ears, or peripheral hearing loss.4,5,6,7 Wave I is also reduced in amplitude whenever stimulus intensity is decreased.7 Placing an electrode on or near the tympanic membrane (TM) as opposed to the ear canal or ear lobe has the effect of increasing amplitude of the ECoG AP and ABR Wave I, as expected, and no significant difference across stimulation rate and no interaction effect. Extratympanic electrode placement takes little additional clinic time and may improve the neurodiagnostic utility of the ABR.

Comparatively, the ABR test is used far more often than ECoG. However, several investigators in the last 40 years have reported on the clinical utility of combining both the ECoG and ABR in a simultaneous fashion. Continued clinical interest in using the simultaneous ECoG-ABR method has been reported for intraoperative monitoring.11,12 However, this technique does not appear to be in routine use within outpatient otology or audiology clinics. Nevertheless, this technique can be performed using modern-day technology and well-trained clinicians are capable of safe placement with minimum patient discomfort. This study is an effort, in part, to increase clinician awareness. ECoGs in outpatient clinics are routinely performed using non-
traumatic extratympanic (ET) electrodes. The other type is a cotton or foam-tipped electrode that is placed gently into the ear canal until the electrode makes physical contact with the tympanic membrane. These electrodes are referred to as tymptrodes or TM electrodes based on a design initially developed by Stypulkowski and Staller. The TM electrode has been reported to improve the average ECoG AP amplitude over other laterally-placed extratympanic electrode alternatives, and it has also been reported to be useful for ABR Wave I detection when used in the same recording channel with a vertex electrode.

The purpose of this study was to revisit the simultaneous ECoG/ABR technique for moderately-high intensity neurodiagnostic testing using three different stimulation rates. This study differs from previous TM electrode studies by our use of a 2-channel setup with a dedicated vertical channel for conventional ABR (Cz to ipsilateral earlobe) and a horizontal montage for conventional ECoG with TM electrode (TM to contralateral earlobe). This study is in contrast to the Cz to TM and Cz to ipsilateral earlobe setup employed by Ferraro and Ferguson and Attias et al., which are both vertical channel montages. This study also differs from other studies that investigated simultaneous ECoG/ABR recordings with more laterally-placed ear canal electrodes or more medially-placed transtympanic electrodes. Generally, the ECoG is recorded using slower stimulation rates than for ABR due to differences in overall amplitude and minimum number of stimulus repetitions needed. A slower stimulation rate typically yields improved waveform morphologies with more defined peak components and higher peak amplitudes over a longer test time, whereas a faster stimulation rate reduces test time with lower peak amplitudes and possibly some latency prolongation. Therefore, we also evaluated the simultaneous ECoG/ABR technique at three different stimulation rates to determine the most efficient stimulation rate that maximizes test time and waveform quality.

Materials and Methods

Participants

Ten females between the ages of 18 to 35 with normal hearing sensitivity and no known history of high noise exposure or otologic/neurologic problems were recruited for this study. All participants were screened with otoscopy, pure tone audiometry (125 to 8000 Hz), and tympanometry. Otoscopy was performed to ensure clear ear canals. Pure tone audiometry revealed hearing thresholds at or better than 25 dB HL at all audiometric test frequencies. Tympanograms were considered normal if they had a static admittance between 0.30 and 1.60 ml and tympanometric peak pressure between -100 and +25 daPa, using a 226 Hz probe tone. Although both ears were screened, only the left ear was used in the study.

Ethics

All participants gave verbal and written informed consent for their participation in this research as approved by the human subject institutional review board at the University of Arkansas at Little Rock (Protocol #13-062).

Construction of extratympanic electrode

Custom foam sponge ET electrodes were handmade using a flexible
silastic (silicone/elastic) tube approximately 10 centimeters (cm) in length and 1 millimeter (mm) in diameter, a small soft foam sponge at the tip, and a 32 gauge silver wire. Cotton can also be used instead of foam. The silver wire is fed through the silastic tube and a small hook is formed at one end. The silver wire is then hooked through a small portion the foam and then tucked back into the silastic tube. Finally, the other end of the silver wire is pulled until the hook and foam are firmly set inside the silastic tubing so that this end of the silver wire is well insulated and is not exposed directly to the ear canal and tympanic membrane. Only the foam is to make contact with the tympanic membrane. Our preference is to use Teflon-coated silver wire, the ends of which are stripped of Teflon just prior to the construction of the TM electrode so that the silver is tarnish free.

Procedure

In addition to the TM electrode, four silver-silver chloride (Ag-AgCl) disc electrodes were used for the recordings (Natus Medical Inc., San Carlos, CA, USA). Disc electrodes were placed at Cz (non-inverting), Fpz (ground), and A1 (Left Earlobe) and A2 (Right Earlobe) both used as the reference or inverting electrode. Except for TM electrode, all other electrode impedances were kept below 5 kΩ for each electrode and below 2 kΩ between electrodes. Prior to electrode placement, all electrode sites were treated with an alcohol wipe and a lightly abrasive skin prep gel using a cotton swab or gauze pads to ensure maximum adhesion and conductivity. All disc electrodes were filled with Ten-20 conduction paste. Prior to placing the TM electrode into the ear canal, the foam tip was filled and saturated with ultrasonic gel with the use of a needle syringe until the gel made sufficient contact with the silver wire in the silastic tube.

Auditory stimulation protocol set-up

Participants were instructed to relax in a reclining chair for the simultaneous ECoG/ABR recordings. For all recordings, a two-channel Bio-Logic Navigator Pro (Version 6.2.0) evoked potential system was used. The left tubal ER-3A insert earphone transducer was used to deliver broadband clicks (0.1 ms duration) separately at stimulus rates of 9.3, 11.3, and 15.3/s. A minimum of 2048 stimuli were delivered using an alternating polarity with a fixed intensity level of 85 dB nHL. Broadband click stimuli are calibrated annually through a service contract, but they were also verified independently by the second author to conform with ISO 389-6:2007. All waveforms were collected using a time window of 10.66 ms and a sampling rate of 24,015 Hz (256 samples). Two recordings per stimulation rate were collected for repeatability and reliability purposes.

To implement the two-channel recording, the first channel was reserved for the ABR with the second channel reserved for the ECoG. Channel 1 was set with Cz as non-inverting (+) and A1 as inverting (-) electrodes sites, while Channel 2 was set with TM as non-inverting (+) and A2 as inverting (-) electrode sites. Ground at Fpz was common to both channels. Channel 1 was differentially-amplified with a gain of 100,000, a bandpass filter of 100 to 3000 Hz, and an artifact rejection level of ±50 µV. Channel 2 was differentially-amplified with a gain of 50,000, a bandpass filter of 10 to 3000 Hz, and an artifact rejection level of ±50 µV. This montage produced ECoG and ABR waveforms of opposite polarity with ABR Wave I oriented positive up and ECoG AP oriented negative down (Figure 1).

Data and statistical analyses

Prior to data analysis, the two repeated waveforms were averaged together into one grand average. For each grand averaged waveform, two examiners independently marked Waves I (peak) and I’ (following through) for the ABR, and SP, AP, and Baseline for ECoG. Waves III and V were not specifically examined for this study. Any disagreements between examiners were resolved jointly prior to data analysis. Amplitude and latency descriptive statistics were computed for ECoG AP and ABR Wave I for each of the three stimulation rates. Also, a two-factor analysis of variance (ANOVA) with repeated measures was performed. Factor 1 was set as test type (ABR and ECoG), with factor 2 set as stimulation rate (9.3, 11.3, and 15.3/sec). Finally, a one-way ANOVA was conducted of the stimulation rate for the SP/AP ratio. An α level of <0.05 was used as the level of rejection for all tests.

Table 1. Descriptive statistics (n=10) for extratympanic electrocochleography (ECoG) action potential (AP) and auditory brainstem response (ABR) Wave I latency and amplitude across the three stimulation rates.

| Stimulation rate | 9.3/s | 11.3/s | 15.3/s |
|------------------|-------|--------|--------|
| Amplitude        |       |        |        |
| ECoG AP          | 1.10  | 1.13   | 1.12   |
| ABR Wave I       | 0.48  | 0.46   | 0.46   |
| Latency          |       |        |        |
| ECoG AP          | 1.48  | 1.48   | 1.51   |
| ABR Wave I       | 1.47  | 1.47   | 1.48   |

Figure 2. Amplitude comparison (n=10) between and auditory brainstem response (ABR) Wave I and extratympanic electrocochleography (ECoG) action potential (AP) for each of the three stimulation rates.

Figure 3. Summating potential/action potential ratio (n=10) comparison across the three stimulation rates.
Results

Means and standard deviations for ECoG AP and ABR Wave I are shown in Table 1 for each of the three stimulation rates. The two-factor ANOVA revealed a significant amplitude difference between Wave I and AP ($F(1.9) = 31.280$, $P = 0.000$), but no significant difference across stimulation rate ($F(2.18) = 0.364$, $P = 0.964$) and no interaction effect ($F(2.18) = 0.721$, $P = 0.500$). Thus, while AP was expected to be larger than Wave I, not a single stimulation rate proved to be statistically advantageous (Figure 2). Furthermore, the one-way ANOVA revealed no significant difference across stimulation rate for SP/AP ratio ($F(2.18) = 0.030$, $P = 0.970$). Again, not a single stimulation rate proved to be statistically advantageous for the SP/AP ratio (Figure 3).

Discussion

The purpose of this study was to revisit the two-channel, simultaneous ECoG/ABR recording technique for renewed interest in clinical use. In contrast to previous studies conducted by others, this study implemented the conventional vertical ABR montage with ipsilateral earlobe reference and the conventional horizontal ECoG montage with contralateral earlobe reference both with left ear only stimulation. As expected, the results show that ECoG AP is substantially larger than ABR Wave I; however, the three different stimulation rates were not statistically different from one another.

The relevance of the study findings is that clinicians can be encouraged to set up both the ECoG and ABR to maximize clinical information in an outpatient setting with the anticipation of a small or absent ABR Wave I. This set up works well using a typical two-channel auditory evoked potential system. This setup may also be useful for cases of auditory neuropathy spectrum disorder (ANSD), especially when evoked potential system. This setup may also be useful for cases of Wave I. This set up works well using a typical two-channel auditory evoked potential system. This setup may also be useful for cases of auditory neuropathy spectrum disorder (ANSD), especially when expected, the results show that ECoG AP is substantially larger than ABR Wave I; however, the three different stimulation rates were not statistically different from one another.

A limitation of this study is the low number of participants. Recruitment can be challenging because of the perceived invasiveness of the TM electrode. It is interesting to note that there is greater amplitude variability among participants between ECoG and ABR. Amplitude variability for ECoG may be reduced by increasing the number of participants, but physical placement of the TM electrode (and its impedance) is far more difficult to standardize.

Future research to optimize the simultaneous ECoG/ABR recording technique should include: i) use on patients with sensorineural hearing loss, retrocochlear disease (including ANSD), and Meniere’s disease; and ii) use of stimulation rates beyond 15.3/s, and potentially evaluating difference between click and newer chirp stimuli. Additionally, there could be gender and age effects. Finally, as with any clinical measurement, adoption of this technique should result in the collection of normative data for routine clinical use.

Our next step is to study this technique in patients with sensorineural hearing loss. As this study was conducted in a University teaching clinic not associated with a hospital or otolaryngology clinic, our studies would be limited to normal hearing participants and patients with sensorineural hearing loss. Fortunately, we have begun a collaboration with a local otolaryngology clinic to conduct follow-up studies with patients who have confirmed tumors and other auditory disorders.

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