ORIGINAL ARTICLE

Estimation of traveling wave delay of the basilar membrane using frequency-specific electrocochleography: Methodology and normative data

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OBJECTIVE: The aim of the study was to estimate traveling wave delay of the basilar membrane using transtympanic electrocochleography in healthy subjects without hearing loss or vestibular disorders.

SUBJECTS AND METHODS: Sixteen ears in 10 healthy volunteers were tested with transtympanic electrocochleography, using a monopolar needle electrode. They had no vertigo or dizziness and had pure tone thresholds of ≤20 dB nHL at the frequency range of 0.250 to 6 kHz. A series of 2-8-2 tonal stimuli (19.7/sec) at 0.5, 1, 2, and 4 kHz, each at 90 dB nHL, were delivered. Latency of the action potential was measured across the frequency range. Latency difference was then calculated by subtracting action potential latency measured for 1 specific frequency from another. The latency difference was used as a measure of traveling wave delay.

RESULTS: Action potential latency was 4.03, 3.5, 3.05, and 2.8 msec at 0.5, 1, 2, and 4 kHz, respectively. We noted that traveling wave delay showed a tendency to decrease toward the basal turn of the cochlea, which means that traveling wave velocity is higher at the basal turn of the cochlea compared with the apical turn. The traveling wave delay estimate obtained in this study is consistent with data extracted from the literature.

CONCLUSION: The study indicated that traveling wave delay could be estimated using transtympanic electrocochleography. With this technique, the wave resolution is very good, thereby making identification of the response peak easier. No additional hardware is required for signal processing unlike with the derived band technique. Further study with patient groups is warranted.

Traveling wave velocity (TWV) has been proposed as a noninvasive and objective test in the diagnosis of endolymphatic hydrops (ELH).[1] Several additional studies have been published.[2-6] However, TWV still seems to be in the experimental stage rather than in clinical use due to time-consuming procedures and some contradictory results.[7]

TWV estimation can be accomplished using several techniques. One is the derived band auditory brainstem response (ABR): measuring the latency difference of ABR to high-intensity click stimuli with 2 sets of ipsilateral, high-pass masking noise.[4,8,9] Tone-burst ABR and tone-burst–evoked otoacoustic emissions may also be used.[6,7,10]

The compound action potential (CAP) of the eighth nerve is the earliest synchronized electrical activity originating from the spiral ganglion neurons in response to a stimulus. Wave resolution of CAP is extremely good in the electrocochleography (ECoG) recording technique. CAP may also be obtained in response to tone-burst stimuli with good recording quality. Therefore, we thought that it would be possible to estimate TWV by means of CAP in response to frequency-specific stimuli. We preferred measuring traveling wave delay (TWD) rather than velocity, disregarding distance between frequencies in the cochlea. Taking advantage of aforementioned features of CAP, we aimed to establish normative data on TWD estimates by means of CAP in response to tone-burst stimuli recorded using transtympanic ECoG (TT-ECoG).

SUBJECTS AND METHODS

The study was performed on 16 ears in 10 subjects who were fully informed about the TT-ECoG procedure and who gave their consent.

Subject inclusion: All subjects had air and bone conduction thresholds of ≤20 dB nHL across the frequencies of 0.125 to 6 kHz. There were no complaints of dizziness or vertigo. Pure tone thresholds were obtained with the use of calibrated audiometers (AC-5 and AC-30, Interacoustics, Assens, Denmark) in soundproof booths (Interacoustics, Assens, Denmark). Tympanogram and stapedius reflex were normal (Amplaid model 775, Milano, Italy). Before the TT-ECoG, the outer ear canal was cleaned and disinfected under otomicroscopic view. For topical anesthesia of the tympanic membrane, a combination of lidocaine 2.5% and prilocaine 2.5% (Emla cream™, AstraZeneca Medical and Chemical Products Co, İstanbul, Turkey) was applied for a few minutes with a cotton ball to the tympanic membrane.

ECoG recording: An active, stainless steel monopolar needle electrode, 6 cm in length, was passed through the tympanic membrane at the junction of posterior-inferior and posterior-superior parts. For insulation, a thin silicon tube was used to cover the part resting outside the tympanic membrane. Upon reaching the bony stiffness of the promontory, the electrode was fixed in place. A 12-mm–long platinum needle electrode placed on the ipsilateral mastoid surface served as a reference point. Another electrode placed on the forehead served as ground.

A TT-ECoG test was performed when the subjects were supine in a quiet room designed for testing auditory-evoked potentials. For delivering sound stimuli, an earphone (ER-3A™, Etymotic Research Co, Elk Grove Village, Ill, USA) was inserted into the outer ear canal. Better fixation of the recording electrode was achieved by placing a foam tip the earphone into the ear canal. A series of 2-8-2 tone stimuli (at the rate of 19.7/sec) were delivered with a Blackman window at 0.5, 1, 2, and 4 kHz at 90 dB nHL. Low- and high-pass filters were set at 10 to 1500 Hz. A total of 128 or 256 stimuli were used depending on response quality. Sweep time was set at 20 msec. Potentials were amplified for 50,000 times.

Measuring TWD: Action potential (AP) latency was measured for each frequency of interest. Latency difference was calculated by subtracting AP latency measured for 1 specific frequency from another AP latency measured for another frequency. Frequency pairs for which the latency difference was calculated were 4-2, 4-1, 4-0.5, 2-1, 2-0.5, and 1-0.5 kHz. The latency difference was used as a measure of TWD.

RESULTS

All the volunteers were male, and the mean age was 21.3±0.5 years. Mean AP latency for each 0.5, 1, 2, and 4 kHz are given in Table 1. TWD tended to decrease toward the basal turn of the cochlea, implying that TWV is higher at the basal turn compared with the apical turn. AP traces at 0.5,1, 2, and 4 kHz in response to 90 dB nHL tone-burst stimuli are presented in Figure 1. Mean ± standard deviation of TWD for each frequency pair is shown in Figure 2.

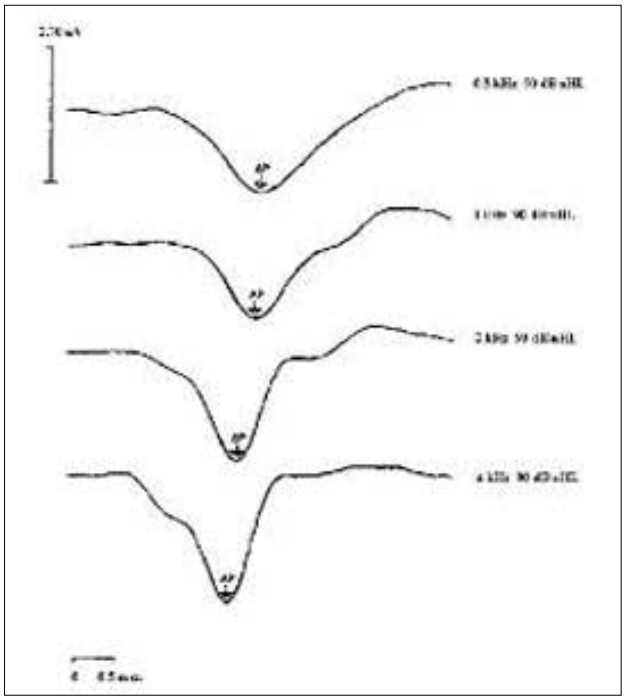

Figure 1: AP traces at 0.5,1, 2, and 4 kHz in response to 90 dB nHL tone-burst stimuli. Note the AP latency delay from 4 kHz to 0.5 kHz. AP latency at 4, 2, 1, and 0.5 kHz is 2. 15, 2.28, 2.50, and 2.58 msec, respectively. (AP, action potentials.)

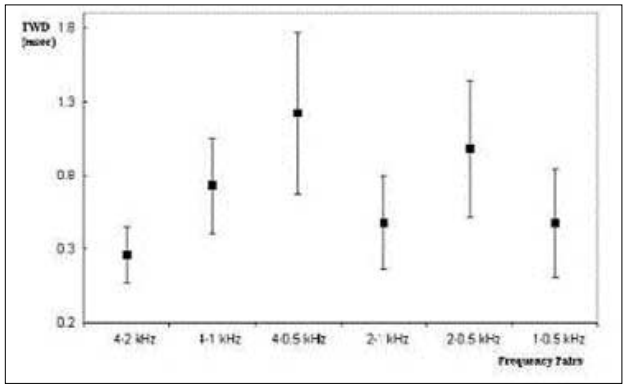

Figure 2: Graphic representation of traveling wave delay between frequency pairs.

DISCUSSION

The reason for using TWV or TWD in diagnosing ELH is that the high pressure inside the endolymphatic circulation is expected to increase the stiffness of the basilar membrane, thereby increasing the amplitude of the traveling wave movement along the basilar membrane.

This is one of the few studies in which ECoG has been used in estimating traveling wave delay. The peak of the response in ECoG, ie the AP, is easy to identify because of better wave resolution. Traveling wave delay was calculated in this study instead of traveling wave velocity, for which exact distances among the points corresponding to a particular frequency inside the cochlea should have been known. Latency difference between the frequencies of interest gives time delay with which the traveling wave propagates from one particular frequency to another throughout the basilar membrane.

Table 1. Mean ± standard deviation, minimum and maximum AP latency across the frequency range. (AP, action potentials)

Frequency	Mean AP Latency (msec)±SD	Minimum (msec)	Maximum (msec)
0.5 kHz	4.03±0.50	3.30	4.70
1 kHz	3.50±0.42	2.90	4.20
2 kHz	3.05±0.23	2.60	3.30
4 kHz	2.8±0.28	2.40	3.20

Except for the otoacoustic emissions, other "early-auditory–evoked potentials" seem to not be completely free of error due to a inherited problem: their relatively long distance of origins to the cochlea (not earlier than 5 to 7 msec). From an anatomical perspective, the spiral ganglion from which the CAP originates is very close to the basilar membrane. This proximity may provide accuracy in TWD estimates. Another problem with the derived band ABR technique is the difficulty in marking the real peak of the response resulting from signal-to-noise ratio of certain quality. In addition, the subtraction process may lead to response degradation. If derived band ABR or auditory-evoked responses to tone-burst stimuli recorded by means of classic ABR montage is being used, most of the time response quality or signal-to-noise ratio may allow correct threshold determination, but identifying the real peak may not be possible because of the few artifactual peaks along the trace. However, this is not the case in CAP because of better response quality and wave resolution in frequency-specific ECoG. Moreover, for the derived band technique, commercially available evoked-potential equipment necessitates additional hardware for click stimulus to be mixed with high-pass filtered white noise.

In earlier studies, it was shown that TWD decreased with increasing frequency, and a decrease in TWD was linked to recruitment.[11] A decent comparison between our TWD results and values obtained from the literature could not be made because TWD/TWV difference, and different frequency pairs selected. In a study in which TWV was compared among normal-hearing subjects and Meniere's and noise-induced hearing-loss patients, Thornton and Farrell used stimuli at 4 different sensation levels.[2] They presented a wave V-latency difference of 0.6 msec between 1.42 kHz and 5.68 kHz as the lower 95% confidence limit. Our closest frequency pair corresponding to the frequency interval in that study was 1 to 4 kHz. At this frequency interval, TWD estimate was 0.73± 0.37 msec (Table 1). Mean traveling time from 4 to 1 kHz, shown in the study by Gould and Sobhy was 0.69 msec (0.97 minus 0.28 msec). which is also comparable with what we found.[8] The TWV that Gould and Sobhy estimated was higher than TWV obtained by other authors, but the TWV plotted against the frequency range followed the same curvilinear pattern.[8,12-14] Donaldson and Ruth investigated TWV in 24 normal-hearing subjects and found the TWV estimate higher than the TWV reported by other investigators. Latency values at 5721, 3100, 1500, and 787 Hz were 6.17, 6.85, 8,36, and 10.02 msec, respectively. They noticed a larger intersubject variability at the most basal region of the cochlea.[9] Kim and colleagues reported concerns and difficulties in implementing the TWV technique with commercially available evoked-potential equipment.[4] Murray and colleagues used tone-burst ABR and measured latency difference instead of TWV.7 However, exact numeric data could not be extracted for comparison purposes from the graph provided in their study. Serbetcioglu and Parker compared latency delay and TWV obtained using derived ABR, tone-burst otoacoustic emission, and derived frequency following responses and found the same curvilinear pattern across the frequency range. Latency difference between 866 Hz and 3,464 Hz for ABR and derived frequency following responses were about 0.6 and 0.5 msec, respectively. They also came to the conclusion that latency delay is preferable over TWV because of the uncertainty of distance measures.[6]

This study indicated that TWD could be estimated using TT-ECoG. The large range of TWD could have resulted from either the small size of the subject population and/or large intersubject variability. This seems to be a factor limiting its use for clinical purposes. Considering the advantages, we find the CAP recorded by means of ECoG-electrode montage preferable in estimating TWD. With this technique, the wave resolution is very good and identification of the response peak easy. No additional hardware is required for signal processing, unlike the derived-band technique. Further study consisting of patients diagnosed with Meniere's disease and other types of cochlear hearing loss is warranted in order to verify the utility of the test.

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