Human Summating Potential to Tone Bursts: Observations on Tympanic Membrane Versus Promontory Recordings in the Same Patients

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Abstract

Electrocochleographic responses to tone bursts and clicks were recorded from the tympanic membranes (TMs) and promontories of six suspected Meniere's patients. Although the majority of ears had normal summating potentials (SPs), regardless of recording site and stimulus type, some displayed amplitude-enlarged SPs at both sites and to both types of stimuli. The following observations were made from these patients regarding the choice of recording approaches and stimuli for ECochG: (1) Although SP amplitudes at the promontory were approximately four times larger than corresponding TM values, response "patterns" leading to diagnostic interpretation were the same at both sites; (2) the majority of patients who displayed enlarged SP amplitudes to tone bursts also had enlarged SPs to clicks; and (3) with tone-burst stimuli, the amplitude of the SP alone was sufficient for diagnostic interpretation of the ECochG waveform.

Key Words: Action potential (AP), broad-band click (BBC), electrocochleography (ECochG), extratympanic (ET), Meniere's disease, summating potential (SP), tone burst, transtympanic (TT), tympanic membrane (TM)

I n this edition of the *JAAA*, we presented an article (Ferraro et al, 1993) hereafter referred to as article 1) describing the procedures for recording and measuring the cochlear summating potential (SP) to tone bursts from the tympanic membrane (TM) in humans. In addition, normal SP amplitudes as a function of tone-burst frequency were defined for 500-, 1000-, 2000-, 4000-, and 8000-Hz stimuli. In the process of developing our procedures for clinical application, we have compared TM and promontory recordings to tone bursts in a small sample of Meniere's patients. Our motivation was not only to apply the use of tone-burst stimuli for electrocochleography (ECochG) in a clinical population, but also to help resolve the continuing controversy regarding the applicability of transtympanic (TT) versus extratympanic (ET) ECochG. Although the observations to be shared are from a limited number of subjects, they nonetheless form the bases for several of our current studies.

METHOD

E lectrocochleographic recordings were obtained from both the TMs and promontories of six patients suspected of having Meniere's disease/endolymphatic hydrops. All patients were referred by an otologist for electrocochleographic evaluation to help substantiate a diagnosis of endolymphatic hydrops. Diagnostic criteria included the following clinical symptoms: recurrent vertigo; low frequency, fluctuating hearing loss; tinnitus; and aural pressure. Although unilateral disease was suspected in the majority of these cases, it was our policy to perform bilateral ECochG examina-

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tions when possible. Our rationale for this is that we have found the comparison of responses between ears in the same patient to be very useful because the nonaffected ear can be used as a control. It was our routine to also measure auditory brainstem responses, which were negative for retrocochlear disorder in all six patients.

A description of our TM electrode and approach, recording parameters, and method for defining and measuring the SP are provided in article 1. The only difference between TT and TM recording parameters was that the TT recordings were averaged from 500 samples, whereas 1000 samples were required for the TM condition.

The TT electrode was a Teflon-insulated, monopolar needle (0.45 mm diameter, 38.0 mm length) with cable. Prior to insertion of the electrode, the TM was anesthetized by injection of 1 percent Xylocaine with adrenalin in a standard stapes-canal block. The electrode was then placed using the technique described by Hickey et al (1990), which allowed for both TT and TM recordings to be made using the same sound generation and delivery systems. With this placement technique, the needle is inserted through the foam EAR tip of the insert transducer parallel to the central sound delivery tube. The foam is then compressed and the assembly inserted into the ear canal by hand so that the needle tip pierces the TM and is brought to rest on the promontory. The electrode is held in place by the foam tip, which expands after release to conform to the ear canal. Both electrodes and the foam tip were gas sterilized before application. Figure 1 is a diagram showi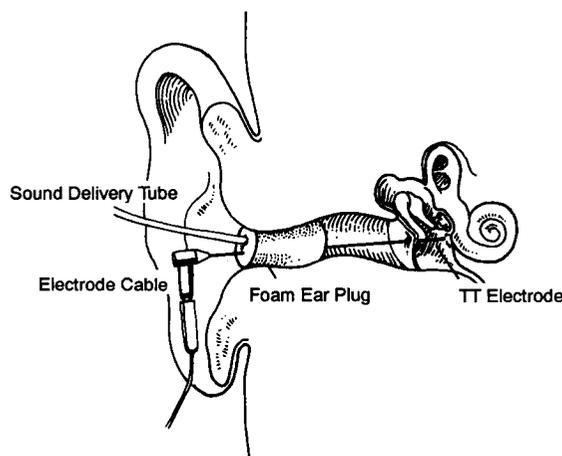ng the recording assembly in place. Electrode impedance was monitored to help indicate contact with the promontory. An impedance less than 50,000 ohms was deemed acceptable for recording. At times, the EAR plug alone was insufficient to stabilize the electrode. When this occurred, an elastic band attached to a Plexiglass ear cup was also used to hold the electrode in place.

Initially, our plans were to conduct simultaneous, two-channel recordings from the TM and promontory. We found it unfeasible, however, to have two electrodes in the ear canal, with one resting on the surface of the TM and the other perforating it. Thus, our procedure was to perform the TM recording first, and immediately after the Xylocaine injection. The amount of time taken to perform the TM recordings also allowed for sufficient anesthetization of the TM for the TT approach.

RESULTS AND DISCUSSION

Figure 2 displays TM- and TT-recorded electrocochleograms from the unaffected (and normally hearing) ear of one of our patients. These responses were judged as normal, given their small SP amplitudes. Of particular note in these tracings is that the magnitudes of the TT recordings were approximately four times
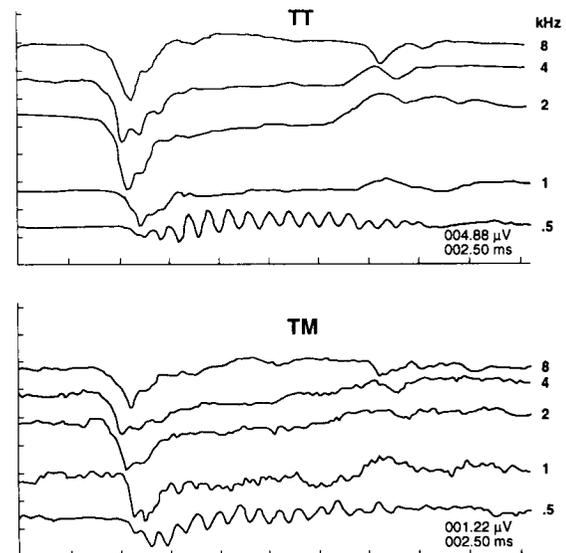

Figure 1 Illustration of the transtympanic (TT) recording assembly (adapted from Hickey et al, 1990, p. 327).

Figure 2 Normal responses to tone bursts recorded from the tympanic membrane (TM) and promontory (TT) of the unaffected and normally hearing left ear of subject 3. Tone-burst frequency (in kHz) indicated to the right of each waveform. Amplitude (μV)/time (msec) scale at lower right of each set of tracings.

larger than the TM magnitudes (see respective microvolt scales). The overall "pattern" of the TT recordings, however, was preserved in the TM waveforms.

The above finding is illustrated more dramatically in Figure 3, which displays ECochG tracings from the affected ear of this patient. The audiogram for this ear is shown in the upper right corner. A pronounced SP trough was present in the electrocochleogram at 1000, 2000, and 4000 Hz under both recording conditions. SP amplitudes at these frequencies were −1.0, −1.2, and −0.4 microvolts, respectively, for the TM recordings, and −3.7, −3.7, and −1.5 microvolts for the corresponding TT responses.

Some important observations can be noted from the tracings in Figure 3. First, the amplitudes of the TT-SPs once again were approximately four times larger than the TM amplitudes. In addition, the TM responses were "noisier," reflecting the less favorable signal-to-noise ratio inherent in extratypmanic/tympanic versus transtympanic conditions. TM-SP amplitudes at 1000 and 2000 Hz were, respectively, 4.6 and 5.1 standard deviations larger than the normal SP amplitudes we reported for

these frequencies in article 1. Even the comparatively smaller TM-SP amplitude at 4000 Hz was 1.4 standard deviations larger than the norm. Gibson (1991) reported that the normal TT-SP amplitude to a 90 dB HL 1000-Hz tone burst was −0.4 micro-volts, and amplitudes larger than −3.6 micro-volts were beyond the 95 percent range. Normal TT-SP amplitudes at other frequencies have not been published.

During the course of our various investigations, we have collected TT data from nine normally hearing ears. Table 1 summarizes our findings regarding SP amplitudes from this population. It is apparent from both Gibson's (1991) and our data that the amplitudes of the SPs in Figure 3 were enlarged. In addition, the response patterns present in the TT responses were once again preserved in the TM tracings.

Figure 4 displays ECochG responses from the above ear to broad-band clicks. Component amplitudes were measured from baseline (base) to the trough of the SP, and to the first negative peak (N_1) of the AP. Our normal SP/AP amplitude ratio for both TT and TM recordings is approximately 25 percent. The tracings shown in Figure 4 displayed enlarged ratios of 50 percent (TT) and 75 percent (TM).

Table 2 summarizes the ECochG findings at each tone-burst frequency and to clicks from 11 ears of our 6 Meniere's patients. We were only able to record from the left ear in subject 2, and testing was discontinued for subject 6 before click-evoked responses could be obtained from the right ear. "N" indicates a normal SP amplitude for both TT and TM recordings based on the normative values reported in article 1 (Table 1) and Table 1 of this report. "TT" and "TM" indicate an amplitude-enlarged SP (greater than ± 1 SD from the norm) from the promontory and TM, respectively.
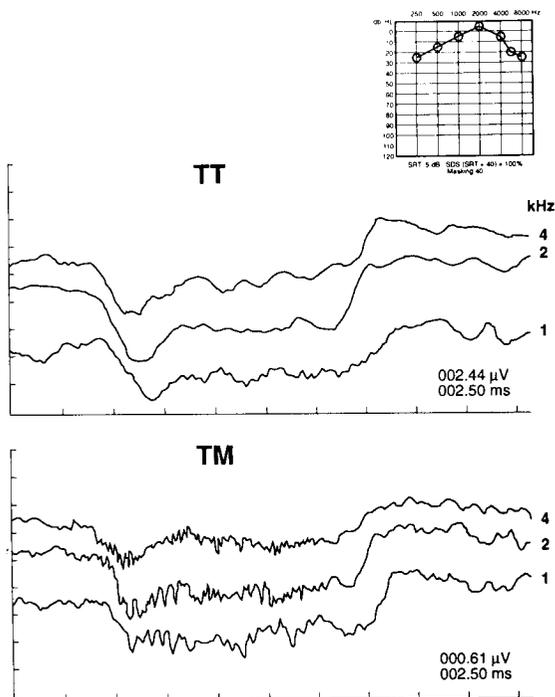

Figure 3 Abnormal responses to tone bursts recorded from the tympanic membrane (TM) and promontory (TT) of the affected right ear of subject 3. Tone-burst frequency (in kHz) indicated to the right of each waveform. Amplitude (μV)/time (msec) scale at lower right of each set of tracings. Pure-tone audiogram at upper right.

Table 1   Transtympanic SP Amplitudes by Frequency for Nine Normal Ears

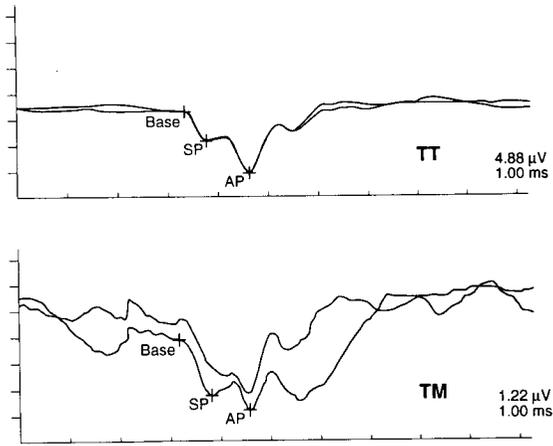|	Frequency (Hz)				
	500	1000	2000	4000	8000
Mean SP Amplitude (microvolts)	+0.91	+0.34	−0.16	−0.08	+1.39
Standard Deviation	0.91	0.47	0.51	0.48	1.25
Range	−0.09 +2.34	−0.39 +1.04	−1.17 −0.09	−0.04 +0.78	+0.29 +4.49

Figure 4 Abnormal responses to clicks recorded from the tympanic membrane (TM) and promontory (TT) of the affected right ear of subject 3. Summating potential (SP)/ action potential (AP) amplitude ratio is enlarged. "Base" indicates reference for SP and AP amplitude measurements. Amplitude (μV)/time (msec) scale at lower right.

Table 2 Summary of ECochG Findings at Each Tone-Burst Frequency and to Clicks for Six Subjects with Suspected Meniere's Disease

Subject	Ear	Frequency (Hz)					
		500	1000	2000	4000	8000	Click
1	Left	N	N	N	N	N	N
	Right	N	N	TT	N	N	N
2	Left	N	N	N	N	N	N
3	Left	N	N	N	N	N	N
	Right	N	TT,TM	TT,TM	TT,TM	N	TT,TM
4	Left	N	N	N	N	N	N
	Right	N	N	N	N	N	N
5	Left	N	N	N	N	N	N
	Right	N	N	N	N	N	N
6	Left	N	TT,TM	TT,TM	TT,TM	N	TT,TM
	Right	N	TT,TM	TT,TM	TT,TM	N	*

N = normal SP; TT = abnormal SP: promontory; * = could not test; TM = abnormal SP: tympanic membrane.

As indicated in Table 2, the majority of our electrocochleograms were normal, regardless of recording technique. A partial explanation for this is that no attempt was made to conduct examinations only when the patient was experiencing symptoms of Meniere's disease. Ferraro et al (1985) have shown that the incidence of positive ECochG findings is considerably higher if the patient has active symptoms, such as hearing loss and aural fullness, at the time of the exam. In addition, some of our patients may have been suffering from some form of vestibular/hearing disorder other than Meniere's disease. Of more importance to our purposes, however, were the results from subjects 3 and 6, who had positive electrocochleograms. When an enlarged SP was recorded from the promontory, the TM-SP was also enlarged. For subject 3, the SP was enlarged in the right ear at 1000, 2000, and 4000 Hz. Subject 6 displayed bilateral SP enlargement at these frequencies. The click-evoked SP (and SP/AP amplitude ratio) was also enlarged in these ears.

A lone exception to the agreement between TT and TM recordings was seen in subject 1, where an enlarged SP at 2000 Hz was noted at the promontory but not the TM. Figure 5 displays the TT recordings from this subject's right ear (audiogram at upper right). The amplitude of the trough at 2000 Hz was approximately −1.0 microvolts, which was only 1.6 standard deviations larger than the normal TT mean for this frequency reported in Table 1. Whether or not this was truly abnormal is arguable, given our limited normative database for TT recordings and liberal criterion for defining an abnormal response (i.e., only ± 1 SD from the mean). Gibson (1992) reported a mean TT-SP amplitude of −2.36 microvolts (SD = 3.44) at 2000 Hz for 26 normal ears. According to these values, an SP amplitude of −1.0 microvolts would be well within the normal range. Subject 1, however, did not have normal hearing in this ear. His best pure-tone threshold was 30 dB HL at 2000 Hz, and thresholds at 500, 1000, and 4000 Hz were 50 dB or greater. Hearing loss certainly may account for the poorly defined/immeasurable ECochG tracings at frequencies
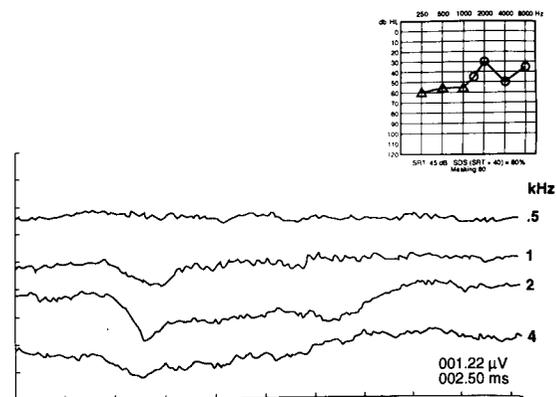

Figure 5 Responses to tone bursts recorded from the right promontory of subject 1, showing enlarged summating potential trough at 2 kHz. Tone-burst frequency (in kHz) indicated to the right of each waveform. Pure-tone audiogram at upper right.

other than 2000 Hz, and even the "normal" SP amplitude observed at 2000 Hz with the TM approach (i.e., TM amplitudes were approximately four times smaller than corresponding TT values). The need for further study regarding the effects of hearing loss and/or audiometric contour on SP amplitudes to tone bursts is clearly illustrated by this case.

CONCLUSIONS

TT versus TM ECochG

The choice of recording approaches for ECochG is often based on subjective as well as objective factors. Objectively, and from an electrophysiologic point of view, the TT approach offers distinct advantages over noninvasive methods. Because of the electrode's closer proximity to the cochlear and neural generators, TT responses are considerably larger in amplitude, more stable, repeatable, and sensitive, and involve less signal averaging. On the other hand, the TT approach may be unfeasible, impractical, and/or unacceptable in certain clinical situations (e.g., outside of a medical setting). Our data support the application of noninvasive methodology under these conditions when the TM is used as a recording site. The SP to tone bursts was indeed recordable from the TM, even though TM-SP amplitudes were approximately four times smaller than TT amplitudes. In the majority of our cases to date, however, the pattern of response leading to diagnostic interpretation was the same for both approaches. This is in agreement with Lambert and Ruth (1988), who reported similar findings for click-evoked ECochG.

We observed certain subjective aspects related to the choice of recording techniques that involved both the patient and physician. As expected, patients clearly preferred the noninvasive and comparatively painless TM approach over the TT method. In addition, our physician became somewhat disenchanted with TT ECochG because the examination lasted approximately 1 hour and his participation (i.e., anesthetizing the TM and inserting/removing the electrode) was needed only at the beginning and end of this period.

Use of Tone-Burst Stimuli

As was the case for our normal subjects from article 1, the application of tone bursts as evoking stimuli (as opposed to broad-band clicks)

in a clinical population extended the duration of the SP beyond that of the AP. This allowed us to examine the SP in an unabbreviated form at different frequencies. Our database, however, is still too limited for us to conclude that these aspects enhanced the electrophysiologic evaluation of patients. For example, both of our patients who had enlarged SP amplitudes to tone bursts at the promontory and TM also had enlarged SPs and SP/AP amplitude ratios to clicks at these sites. Further investigation is needed to assess whether the lengthier tone-burst evaluation provides more useful clinical information than using clicks alone. In addition, although enlarged SP amplitudes at 500 and 8000 Hz have been observed in Meniere's patients, they always were accompanied by enlarged SPs at 1000, 2000, or 4000 Hz (Orchik, 1990; Gibson, 1992). None of our patients had enlarged amplitudes at 500 and 8000 Hz. Given the additional time required, further study is needed to assess the benefits of recording responses to 500- and 8,000-Hz tone bursts as part of the ECochG examination.

In article 1, we questioned the relevance of measuring the SP/AP amplitude ratio when tone bursts are used as stimuli. Figure 6, which displays the TM response to a 1000-Hz tone burst from one of our Meniere's patients, illustrates part of our rationale for this statement. Although the SP is well defined (and clearly enlarged), the AP appears to be absent or totally overshadowed by the SP, making the SP/AP amplitude ratio immeasurable. On the other hand, the amplitude of the SP alone was sufficient to classify the response as abnormal.

Finally, and as mentioned earlier, further investigations are needed to determine the relationship between TM-SP amplitudes to tone bursts and hearing loss and/or audiometric configuration in both Meniere's and nonMen-
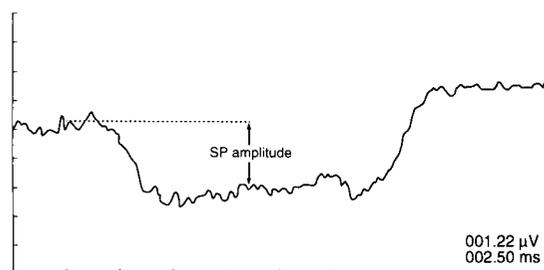

Figure 6 Abnormal response to a 1000-Hz tone burst recorded from the tympanic membrane of a Meniere's patient. Abnormal classification based solely on amplitude-enlarged summating potential (SP). Amplitude μV/time (msec) scale at lower right.

iere's populations. Gibson (1991) has presented data of this nature for TT recordings. Providing similar information using the TM technique should strengthen the clinical utility of this approach. Additional comparative data between TT and TM recordings should also be of assistance in selecting procedures when both options are available, or in justifying the use of one (i.e., the TM approach) when the other is unavailable.

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