THE AMERICAN JOURNAL OF OTOLOGY/VOLUME 11, NUMBER 4 *July 1990*

A SIMPLIFIED TECHNIQUE FOR TRANSTYMPANIC ELECTROCOCHLEOGRAPHY

Mitchell K. Schwaber, M.D. and James W. Hall III, Ph.D.†*

ABSTRACT

Recently, electrocochleography (ECochG) has enjoyed a resurgence in clinical use, particularly in the preoperative and intraoperative evaluation of Meniere's disease patients. With a transtympanic electrode, large amplitude, repeatable waveforms can be easily recorded. Despite this fact, transtympanic ECochG has not been widely adopted in the United States, primarily because of the technical difficulties in securing the electrode and then delivering a stimulus. We have developed a simplified transtympanic electrode placement, using a standard subdermal needle held in place by a foam plug earphone. The foam plug earphone not only secures the electrode, but also delivers the stimulus. We have used this technique in a series of cases, both intraoperatively as well as in the outpatient clinic. The advantages of this approach are discussed and illustrated with individual and group data.

Among the first clinical reports of auditory evoked responses were descriptions of intraoperative recordings of cochlear and eighth nerve activity with electrodes located on the promontory of the cochlea.[1,2] However, because of the technical difficulties associated with electrical artifact and electrode placement, electrocochleography (ECochG) failed to gain widespread acceptance. The subsequent development of averaging computers and far-field evoked responses soon led to the adoption of scalp-recorded auditory brainstem response (ABR) into clinical practice; ECochG remained primarily a research tool. Recently, there has been a resurgence of interest in ECochG, due in part to studies that show an enlarged summating potential in ears with Meniere's disease.[3–7] Both preoperative and intraoperative ECochG has been used to evaluate these patients, and a variety of stimulus delivery and electrode configurations have been reported. Two major types of electrocochleography electrodes have been used, transtympanic and ear canal.[7–11]

Transtympanic ECochG was first developed by early investigators using a long needle electrode, placed through the tympanic membrane and held in place by a wire suspension system. A speaker or a headphone was then held near the subject to provide the acoustic stimulus. Recently, Prass, Kinney, and Luders[12] described a transtragal technique, passing the electrode through the tragus and the ear drum, and then securing the electrode with sutures. A small plastic tube was introduced into the ear canal to provide the stimulus. The technique reported by Gibson and colleagues[5,9] consisted of a myringotomy and insertion of a silver ball electrode through it and onto the promontory. A headphone was then held in place with a specially designed apparatus. Due in part to all of the equipment necessary to perform transtympanic ECochG, investigators began to explore the use of ear canal electrodes in their search for an easier method.

Coats,[8] an early leader in the development of ear canal electrodes, designed the Eartrode, a silver ball electrode glued to a mylar plastic clip. After insertion into the ear, the clip springs open to hold the silver ball in contact with the canal skin. Unfortunately, electrode impedance is often quite high with this system and patients occasionally complain of discomfort. This led to the development of ear canal foam plug systems, including the Enhancer I and the TIPtrode.[11,13]

The Enhancer I consists of an electrode-gel-impregnated foam plug through the center of which is a sound conducting plastic tube. Similarly, the TIPtrode consists of a foam plug with a thin gold foil wrap attached to the outside surface, and a sound conducting plastic tube through the cen-

*Department of Otolaryngology, Vanderbilt University Medical Center, Nashville, Tennessee
†Division of Hearing and Speech Sciences and Department of Otolaryngology, Vanderbilt University Medical Center, Nashville, Tennessee
Reprint requests: Mitchell K. Schwaber, M.D., Department of Otolaryngology, Room S–2119 MCN, Vanderbilt University Medical Center, Nashville, TN 37232-2559

ter. With both foam plug systems, the stimulus is delivered by a small plastic tube that connects the speaker to the foam plug. The electrodes are attached by a wire to standard pins that can then be connected to most evoked response units. Electrode impedance is usually very low, and patient comfort and ease of insertion are significantly improved over the Eartrode. However, as with all canal electrode configurations, the amplitude of the waveform depends largely upon the distance of the electrode from the cochlea itself.

This has led to the recent development of the tympanic membrane (TM) electrode, which consists of a silver ball attached to a small sponge which is placed onto the ear drum.[11,14] As expected, early reports indicate larger amplitude waveforms compared to the other canal electrode systems. A TM electrode type is not commercially available.

We have developed a simplified transtympanic electrode placement, using a standard subdermal needle held in place by a foam earphone. In developing our simplified technique, we have sought to combine the best features of the two major types of electrode systems. Clearly, transtympanic ECochG provides the largest most repeatable waveforms. Also, the foam plug sound delivery system seems to be one that patients tolerate quite well. By combining a transtympanic electrode with a foam plug sound system, electrode position and sound delivery have been greatly simplified, and reliability of the response enhanced, as the foam plug holds the electrode in place.

METHODOLOGY

Procedure

ECochG/ABR recordings were made with a commercially available evoked response system. Measurement parameters are summarized in Table 1. Combined ECochG/ABR assessment intraoperatively was carried out with an Fz-to-promontory (noninverting-to-inverting) electrode array. The Fz site, determined by the 10-20 International Electrode System, is on the midline approximately halfway between the bridge of the nose and the top (vertex) of the head. ECochG assessment for diagnosis of Meniere's disease was done with a contralateral ear canal-to-promontory (noninverting-to-inverting) electrode arrangement. The ECochG AP component (i.e., ABR wave I) was therefore always directed upwards.

The promontory electrode was a sterile stainless steel subdermal needle electrode (Nicolet Biomedical Instruments). This needle has a 12 mm shank and a 0.4 mm diameter, a 1 meter wire, and a standard pin (Fig. 1). In the operating room, all other recordings were also made with this subdermal needle electrode whereas in the clinic silver chloride disk-type electrodes were applied at sites other than the promontory. In the clinic, the tympanic membrane was anesthetized with a Phenol swab. A microscope was used for viewing the tympanic membrane. The patient typically reported a burning or tingling sensation. In the operating room, the patient was already under general anesthesia at this point in the procedure. The promontory electrode was placed by the otologist under an

Table 1. Electrocochleography (ECochG) and Auditory Brainstem Response (ABR) Measurement Parameters

Stimulus	
transducer	ER-3A insert tubephone
type	click
duration	0.1 msec
polarity	alternating
rate	7.1/sec
intensity	80 to 90 dB HL
presentation mode	monaural
masking	none
Acquisition	
	10 or 15 msec (ABR/ECochG)
	5 msec (ECochG alone)
prestimulus time	1 msec
sweeps	25 to 100 (promontory electrode)
	1000 to 2000 (earcanal electrode)
filter settings	1 or 3 to 1500 Hz
notch filter	none
electrode sites	
Channel 1 *	
noninverting (+)	Fz
inverting (−)	promontory (ipsilateral)
Channel 2	
noninverting (+)	Fz
inverting (−)	earcanal (ipsilateral)
Ground	Fpz
impedance	< 10 K ohms

*Contralateral earcanal noninverting electrode to ipsilateral promontory inverting electrode for ECochG alone

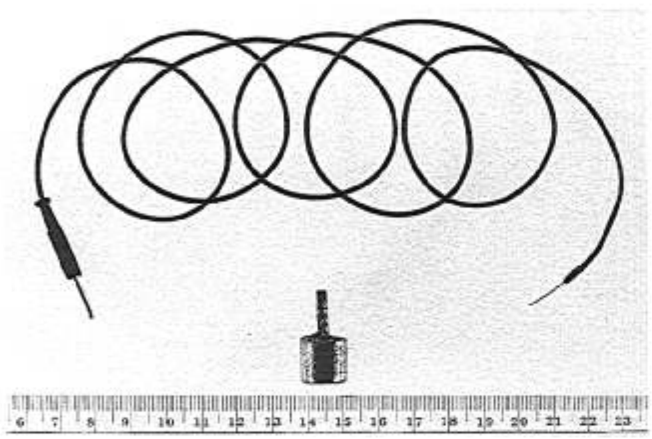

Figure 1. Subdermal stainless steel needle electrode and gold foam coated foam insert (TIPtrode) used in electrocochleography recordings.

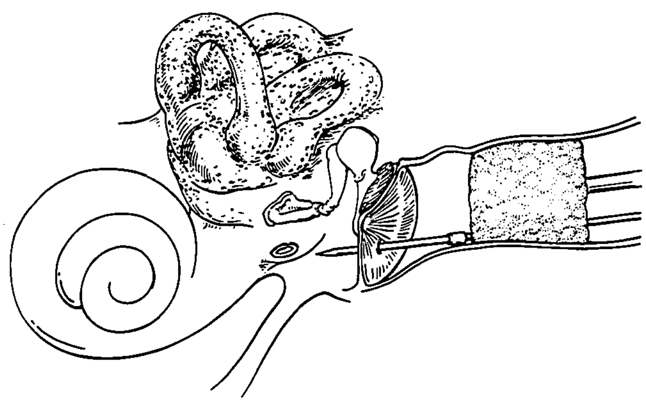

Figure 2. Illustration of simplified technique for transtympanic insertion of subdermal needle electrode onto promontory. Electrode lead is then secured within external auditory canal by foam insert from tubephone.

operating room microscope. The insulated portion of the sterile subdermal needle electrode (between the shank and the wire) was grasped with bayonette forceps and the electrode was directed down the external auditory canal. The needle was then inserted through the inferior-posterior portion of the tympanic membrane to rest on the promontory (Fig. 2). In the clinic, patients did not report pain, and rarely expressed discomfort during insertion of the transtympanic needle.

After transtympanic electrode placement, the electrode lead, which extended from just lateral to the tympanic membrane, was secured temporarily by hand against the wall of the ear canal. The otologist then took a compressed gold foil foam ear insert (TIPtrode) and placed it within the ear canal in the customary fashion (Fig. 2). The TIPtrode was sterile for intraoperative ECochG. Both the promontory electrode lead and transducer tube were then secured with surgical tape to the patient's neck or chest. After placement of the electrode, some patients undergoing ECochG recording in the clinic have fallen asleep. At the conclusion of ECochG assessment, ear phone and electrode system were removed by simply pulling them gently out of the canal. The TIPtrode was discarded and the needle electrode was sent for gas sterilization. The entire promontory electrode placement procedure requires less than one minute in the operating room and less than three minutes in the clinic. To date, no promontory electrode placed with this technique, has become dislodged during testing. There have been no known medical complications or tympanic membrane or middle ear damage arising from promontory needle placement.

ECochG data were analyzed for three replicated waveforms recorded simultaneously with the TIPtrode and with the simplified transtympanic needle electrode techniques. Analyses included calculation of the SP and AP amplitude (in μvolt) from a common baseline, the SP/AP amplitude ratio (in %), and a measure of AP variability and SP/AP variability (in %). The variability measures provided an index of the difference in amplitude among replicated waveforms. For the AP component, the variability measure was as follows:

Table 2. Summary of Electrocochleography Data for Three Patient Groups

Group				*Electrode Type*									
				Promontory					*TIPtrode*				
Subject # Age (yrs)	*Sex*	*PTA1 (dB)*	*PTA2 (dB)*	*SP (μv)*	*AP (μv)*	*AP var (%)*	*SP/AP (%)*	*SP/AP var (%)*	*SP (μv)*	*AP (μv)*	*AP var (%)*	*SP/AP %*	*SP/AP var (%)*
Clinic													
1. 37	M	33	22	1.71	7.14	6	24	1	NR	.31	28	NR	NR
2. 42	M	52	53	2.28	6.22	37	37	2	.14	.22	21	61	72
3. 54	F	13	22	.43	2.24	26	20	17	NR	NR	NR	NR	NR
4. 38	M	42	32	3.14	9.03	6	35	3	.12	.32	29	51	34
5. 60	F	8	7	2.14	6.11	6	35	2	.21	.28	138	61	34
Mean values				**1.94**	**6.15**	**16**	**30**	**5**	**.16**	**.28**	**54**	**54**	**49**
Operating Room: Sac decompression													
1. 24	M	17	5	1.29	3.53	19	38	13	.29	.60	44	62	22
2. 36	M	58	38	1.10	15.20	17	72	3	NR	.20	23	NR	NR
3. 71	M	40	63	.80	1.46	47	50	9	.10	.07	76	259	400
4. 57	M	55	55	.43	1.54	83	38	39	.09	.11	27	74	31
5. 40	M	35	47	1.83	8.75	4	20	1	NR	.09	22	NR	NR
Mean values				**3.09**	**6.10**	**34**	**45**	**13**	**.16**	**.21**	**38**	**132**	**151**
Operating Room: Tumor removal													
1. 35	F	12	2	.24	1.91	30	13	8	NR	1.98	NR	NR	NR
2. 66	F	23	15	.62	2.54	53	24	3	NR	.50	72	NR	NR
3. 65	M	27	53	NR	.72	6	NR	NR	NR	NR	NR	NR	NR
4. 30	M	18	60	NR	.28	14	NR	NR	NR	NR	NR	NR	NR
5. 37	M	15	25	.55	1.38	1	NR	NR	NR	NR	NR	NR	NR
Mean values				**.52**	**2.04**	**21**							

$$\frac{(AP1-AP2) + (AP2-AP3) + (AP1-AP3)/3}{\text{mean AP amplitude}} \times 100$$

An equivalent equation was also used for the SP/AP relation. This measure permitted a comparison of the reliability between the two ECochG techniques and among the three patient groups.

Subjects

Subject characteristics are summarized in Table 2. All subjects underwent ECochG recording simultaneously with ear canal (TIPtrode) and the simplified transtympanic needle technique. For five subjects, ECochG was carried out in a clinical setting in evaluation of suspected Meniere's disease. ECochG recordings for the other 10 subjects were carried out in the operating room during neurotologic surgery. For five of these patients, ECochG data were obtained prior to endolymphatic sac decompression. For the other five, ECochG was recorded at the start of surgical removal of posterior fossa tumors. The tumors (one per patient) included a facial nerve tumor, a brainstem epidermoid, and eighth nerve tumors (1 acoustic neurinoma, 1 hemangioma, 1 meningioma).

RESULTS

Selected ECochG data for transtympanic versus ear canal electrode placements are compared in Table 2 and illustrated in Figures 3, 4, and 5. Promontory electrode impedance ranged from 2 to 12 K ohms (average of 7 K ohms) for this series of 15 patients. Amplitude of the ECochG action potential (AP) component (also referred to as wave N1) recorded intraoperatively and in the clinic for a high intensity (80 to 90 dB HL) click stimulus is typically on the order of 1 to 9 μvolts, depending on the degree and etiology of hearing loss (Table 2 and Fig. 3–5). A clear and reliable AP was typically apparent with as few as 25 to 100 sweeps, or about 4 to 14 s of test time. In comparison, the TIPtrode electrode in this patient series produced AP amplitude values that were, on the average, 0.21 μvolt. Notably, only two of the five patients undergoing tumor removal showed a reliable AP (ABR wave I) with the TIPtrode, even after 1500 sweeps were averaged (about 4 minutes of test time).

Response reliability, defined as the degree of similarity among wave latency and amplitude measures from one test session to another or among successive averaged waveforms, is an important feature of ECochG recording. Assessment of test-retest reliability for promontory ECochG recordings is not clinically justifiable as the needed diagnostic information is obtained on the initial assessment. A second ECochG test is therefore not indicated. As demonstrated by the waveforms in

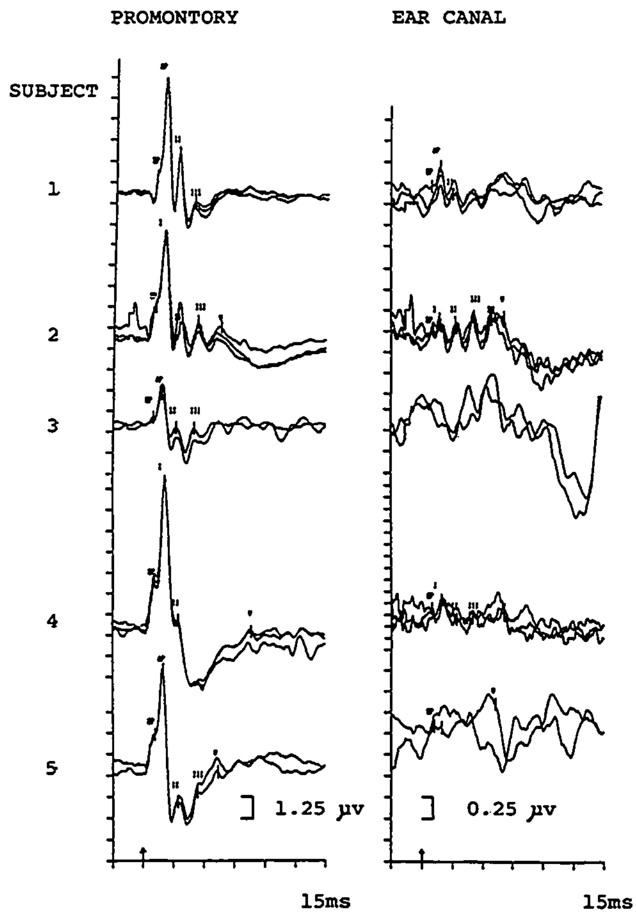

Figure 3. Electrocochleography (ECochG) waveforms recorded simultaneously in a clinic with ear canal (TIPtrode) versus simplified transtympanic needle electrode technique from patients with suspected Meniere's disease. Note five-fold increase in amplitude for promontory electrode site in most portions of figure. Audiometric and ECochG data for these patients are summarized in Table 2.

Figures 3 to 5, identifiability and reliability of ECochG components in successively averaged waveforms, however, is clearly greater for transtympanic than ear canal electrode recordings. This observation is confirmed by the variability measure reported in Table 2 for the AP component and the SP/AP relation. In this series of 15 consecutive patients undergoing the simultaneous transtympanic and ear canal electrode ECochG recording, all showed a reliable AP component with the transtympanic electrode (observed in all three replications) versus only one-third with the ear canal electrode site (Table 2). Detectability of the SP was also more likely with the transtympanic electrode than the ear canal electrode. With the ear canal electrode, no SP could be consistently detected among the three replicated waveforms in four of the 10 patients with suspected or diagnosed Meniere's disease (the first two groups). In contrast, all of these patients had a clear SP with the transtympanic electrode technique. Electrical interference with waveform analysis, although not quantifiable, appeared distinctly reduced for transtympanic ver-

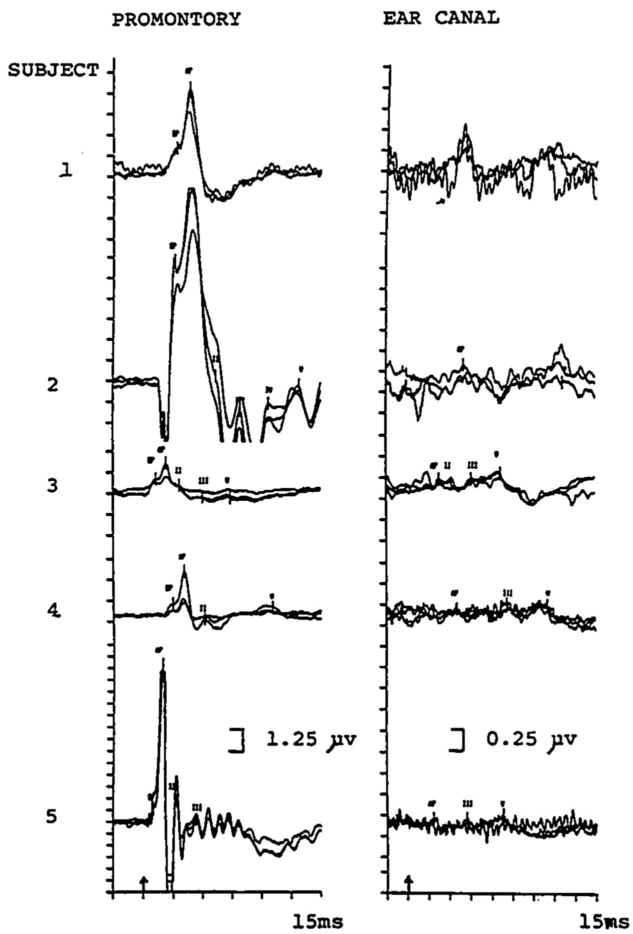

Figure 4. Electrocochleography (ECochG) waveforms recorded simultaneously in the operating room with ear canal (TIPtrode) versus simplified transtympanic needle electrode technique from patients immediately prior to endolymphatic sac decompression procedure. Note five-fold increase in amplitude for promontory electrode site in most portions of figure. Audiometric and ECochG data for these patients are summarized in Table 2.

sus ear canal recordings, particularly in the operating room test environment (Figs. 4 and 5). In addition, auditory brainstem response components (waves II, III, and V) were not diminished with the promontory electrode technique but, rather, were typically enhanced. These observations are partially illustrated by the waveforms in Figures 3 to 5, although the reduced sensitivity of these displays tends to obscure this observation.

COMMENT

The recent development of easily inserted ear canal electrodes has increased the use of ECochG as a clinical test in the evaluation of suspected Meniere's disease patients. Data obtained have often been used to make important clinical judgments, including presence or absence of increased endolymphatic pressure in the involved ear or in the supposedly normal contralateral ear. Also, changes in the electrocochleogram have been used to "document" the efficacy of treatments. Unfortunately, most of these studies have been performed with ear canal electrodes. Because of the low amplitude of the waveforms, ear canal electrode results are subject to a great deal of artifact and are often not repeatable. This problem is handled in a variety of ways, the most popular of which is to discard the worst response of several runs, and then to average the remaining responses together. Clearly, the significance of ear canal ECochG studies in such patients should be questioned.

Transtympanic ECochG, on the other hand, provides clear, large amplitude waveforms that can be reproduced in the same patient, as well as among different investigators. In order to achieve a real understanding of the electrocochleographic findings in Meniere's disease, reproducible waveforms must be easily obtainable by all investigators.

Our simplified approach places transtympanic ECochG well within the realm of practicing otologists. The electrode-foam plug and/or TIPtrode is easy to insert and readily maintains its position. By virtue of the robust nature of the transtympanic ECochG, a clear response is typically observed with few stimulus presentations and brief test time (less than 15 seconds), even in the relatively hostile op-

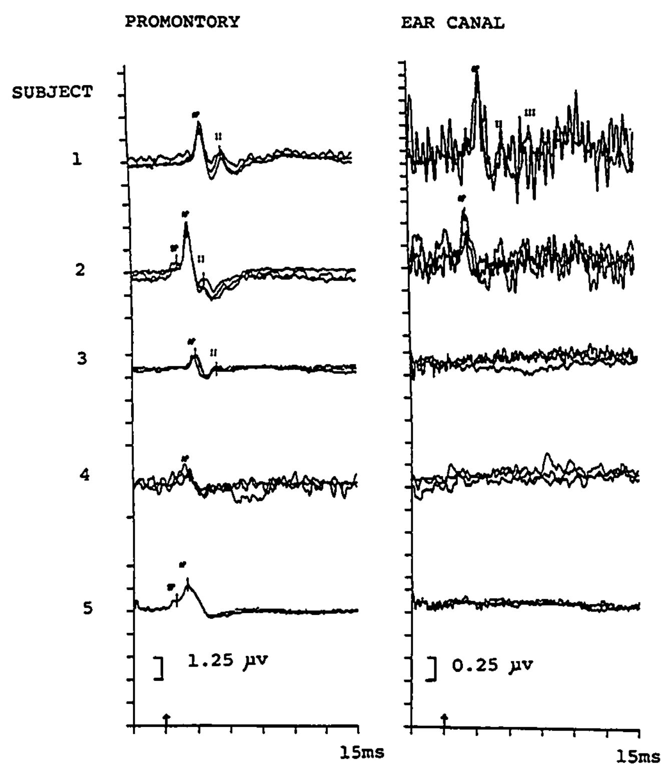

Figure 5. Electrocochleography (ECochG) waveforms recorded simultaneously in the operating room with ear canal (TIPtrode) versus simplified transtympanic needle electrode technique from patients prior to surgery for tumor removal. Note five-fold increase in amplitude for promontory electrode site in most portions of figure. Audiometric and ECochG data for these patients are summarized in Table 2.

erating room test environment. This is a distinct clinical advantage for intraoperative ECochG applications. This transtympanic needle electrode technique provides a standard, against which all other techniques can be judged for simplicity, response magnitude, and waveform repeatability.

REFERENCES

1. Lempert J, Wever EG, Lawrence M: The cochleogram and its clinical application: a preliminary report. Arch Otolaryngol 1947;45:61–67.
2. Ruben R, Sekula J, Bordley J: Human cochlear response to sound stimuli. Ann Otol Rhinol Laryngol 1960;69:459–476.
3. Coats AC: The summating potential and Meniere's disease: I. Summating potential amplitude in Meniere's and non-Meniere's ears. Arch Otolaryngol 1981; 107:199–208.
4. Dauman R, Aran J, Savage R, Portmann M: Clinical significance of the summating potential in Meniere's disease. Am J Otol 1988;9:31–38.
5. Gibson W, Moffat D, Ramsden R: Clinical electrocochleography in the diagnosis and management of Meniere's disorder. Audiology 1977;16:389–401.
6. Goin D, Staller S, Asher D, Mischke RE: Summating potential in Meniere's disease. Laryngoscope 1982; 92:1383–1389.
7. Mori N, Asai H, Sakagami M: Comparison of summating potential in Meniere's disease between trans- and extratympanic electrocochleography. Audiology 1987;26: 348–355.
8. Coats A: On electrocochleographic electrode design. J Acoust Soc Am 1974;56:708–711.
9. Gibson W, Prasher D, Kilkenny G: Diagnostic significance of transtympanic electrocochleography in Meniere's disease. Ann Otol Rhinol Laryngol 1983;92:155–159.
10. Kumagami H, Nishida H, Masaaki B: Electrocochleographic study of Meniere's disease. Arch Otolaryngol 1982;108:284–288.
11. Ruth RA, Lambert PR, Ferraro JA: Electrocochleography: methods and clinical applications. Am J Otol 1988;9:1–11.
12. Prass RL, Kinney SE, Luders H: Transtragal, transtympanic electrode placement for intraoperative electrocochleographic monitoring. Otolaryngol Head Neck Surg 1987;97:343–350.
13. Stypulkowski P, Staller S: Clinical evaluation of a new ECoG recording electrode. Ear Hear 1987;8:304–310.
14. Yanz J, Dodds H: An ear canal electrode for the measurement of the human auditory brainstem response. Ear Hear 1985;6:98–104.

This study was supported in part with funding from a Vanderbilt University Research Council (URC) grant awarded to Dr. Hall.