
ORIGINAL ARTICLE

Electrically Evoked Auditory Brainstem Responses in Cochlear Implant Patients

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OBJECTIVE: The purpose of this study was to clarify the relationship between electrically evoked auditory brainstem responses, the MAP threshold, and the maximum comfort level in patients who had received a Nucleus 24 cochlear implant(Cochlear Corporation, Australia).

PATIENTS AND METHODS: The study consisted of 7 adults and 7 children who had received a Nucleus 24 cochlear implant. Electrically Evoked Auditory Brainstem Responses were obtained postoperatively. Electrically evoked auditory brainstem responses were correlated with the MAP threshold and the comfort level in each patient.

RESULTS: Electrically evoked auditory brainstem responses were evaluated in all cochlear implant patients who participated in the study. The electrically evoked auditory brainstem response threshold was found to fall between the threshold and comfort level of the MAP (in approximately the lower third of the MAP dynamic range) in all patients tested.

CONCLUSION: The electrically evoked auditory brainstem response threshold can be used to predict the MAP threshold and comfort level, especially in difficult-to-test patients and young children.

Electrical auditory brainstem responses (EABRs) have been studied in patients with a cochlear implant for several purposes, including the preoperative assessment of the results of auditory nerve stimulation and the evaluation of cochlear implant function, neural integrity, and perioperative and postoperative neural survival⁽¹⁻⁷⁾. EABR measurements have been also used to predict the behavioral MAP threshold and comfort level^(2,7-11).

Because the age at which patients can undergo cochlear implantation is decreasing, the need for objective tools for programming young children is increasing. As an objective measurement, the EABR may be helpful in determining the threshold (T) and comfort level (C) used to program young children or difficult-to-test patients who have little auditory experience and may not cooperate during programming.

The purpose of this study was to clarify the relationship between the EABR threshold, the MAP threshold, and the maximum comfort level in patients who had received a Nucleus 24 cochlear implant.

PATIENTS AND METHODS

Subjects

The study consisted of 14 patients (age range, 4-44 years; mean age, 19.71 years) who had received a Nucleus 24 cochlear implant. Full insertion of all electrodes was achieved in all patients. All subjects were fitted with either an ESprit or a SPrint speech processor. They all used a SPEAK map in monopolar 1+2 mode with a pulse width of 25 μ s. The demographic characteristics of the study subjects are presented in the Table.

Equipment and procedure

Electrically evoked potential responses were recorded with an Amplaid MK 15 evoked potential system externally triggered by the stimulus output of the Cochlear Corporation PCI. The stimuli used to evoke the EABR were generated with WinDPS software (version R116.02) and the PCI. A series of 25 μ s/phase biphasic current pulses was administered to the patient at a rate of 30 Hz via the SPrint speech processor. The

Table: Demographic information of the cochlear implant patients studied

Subjects Evaluated (No.)	Sex	Test age (y)	Duration of Hearing Loss (y)	Cause of Hearing Loss
1	M	14	8	Meningitis
2	M	27	18	Meningitis
3	F	18	8	Chronic otitis media
4	F	15	Unknown	Hereditary; progressive
5	F	22	22	Congenital; unknown
6	F	15	14.5	High fever
7	F	4	1/2	Measles
8	F	30	30	Hereditary; congenital
9	F	36	36	Hereditary; congenital
10	F	12	Unknown	Progressive
11	F	20	11	Meningitis
12	F	44	23	Unknown
13	F	11	11	Hereditary
14	M	8	8	Unknown

M, Male; F, female.

stimulation mode was set to monopolar 1. The EABR was recorded with gold cup scalp electrodes placed as follows: on the nape of the neck (C4) (the negative electrode), on the vertex (Cz) (the positive electrode), and on the contralateral earlobe/mastoid (the ground electrode). Responses were recorded with a 10-ms analysis window and a filter bandwidth of 100 Hz to 2500 Hz.

Each EABR recording was replicated twice with 1000 sweeps, and EABR threshold testing was conducted when the subjects were relaxed or asleep in a reclining chair. In the pediatric patients, 50 mg/kg of chloral hydrate was used for sedation, if necessary.

The current levels used in WinDPS programming software are represented in arbitrary units that range from 1 to 255 (from 10 μ A to 1.75 mA in a nominal range). The current levels used in the study to measure the EABR were the current levels used for mapping. The EABR threshold in each patient was measured postoperatively 6 to 24 months after the first tune-up. The EABR testing of all patients was performed by the second author, who had not been informed of the patients' behavioral T and C levels. The stimulation level for the EABR was initially set at the level of 100 and was increased by 20 current levels until an EABR was obtained. The EABR threshold was defined as the replicable wave V obtained at the lowest level of stimulation. The patients were instructed to alert the clinician to stop the procedure if the stimulus level was too high to disturb.

All EABR thresholds were collected on a set of 4 electrodes (electrodes 20, 15, 10, and 5) that were spaced across the cochlea. The results were then compared with the behavioral measures of the threshold (the T level) and the maximum comfort level (the C level) used to program the speech processor. The T and C levels obtained 1 month after the surgery (T1 and C1) and the latest T and C levels (T2 and C2, which were obtained 6 to 24 months after the first programming) were used in this study.

The T level is defined as the lowest current level that elicits a very soft but consistent hearing threshold. The C level is defined as the maximum current level that

does not produce an uncomfortably loud sensation for the individual. Behavioral measurement of all thresholds and maximum comfort levels was obtained by the first author, who is experienced in working with the Cochlear Corporation programming software. Typical clinical procedures were used for measuring T and C levels in all but 1 patient. The mapping of that patient, who was 4 years old, was performed with play audiometric techniques.

RESULTS

The EABR of each subject was recorded. At the higher current levels, the EABR waveform morphology demonstrated the presence of waves II through V. As the stimulus level decreased, the amplitude of wave V also decreased, and the latency increased slightly. Wave I was absent in all patients on any recordings because of common artifacts. Waveform morphology was judged to be better for recordings on more apical channels. The mean (\pm SD) wave V latency at the thresholds was as follows: electrode twenty, 4.44 (\pm 0.75) milliseconds; electrode fifteen, 4.45 (\pm 0.45) milliseconds; electrode ten, 4.45 (\pm 0.32) milliseconds; and electrode five, 4.43 (\pm 0.52) milliseconds.

The EABR is characterized by a series of vertex-positive peaks. The most robust portion of this response, wave V, was typically recorded with a latency of approximately 4.0 ms. Figure 1 displays a series of typical EABR responses from 1 adult cochlear implant patient.

The goal of this study was to investigate the extent to which the EABR threshold could be used to predict the threshold and comfort level for the stimulus used to program the speech processor. The EABR threshold was shown to fall between the T and C levels of the MAP in all subjects tested. The EABR threshold was in 33% to 42% of the lower half of the MAP 1 dynamic range (T1 and C1) and in 26% to 42% of the lower half of the MAP 2 dynamic range (T2 and C2). Figure 2 shows all patients in whom the EABR threshold was within the MAP range, as well as trends exhibited across subjects in both the MAP level and the EABR threshold.

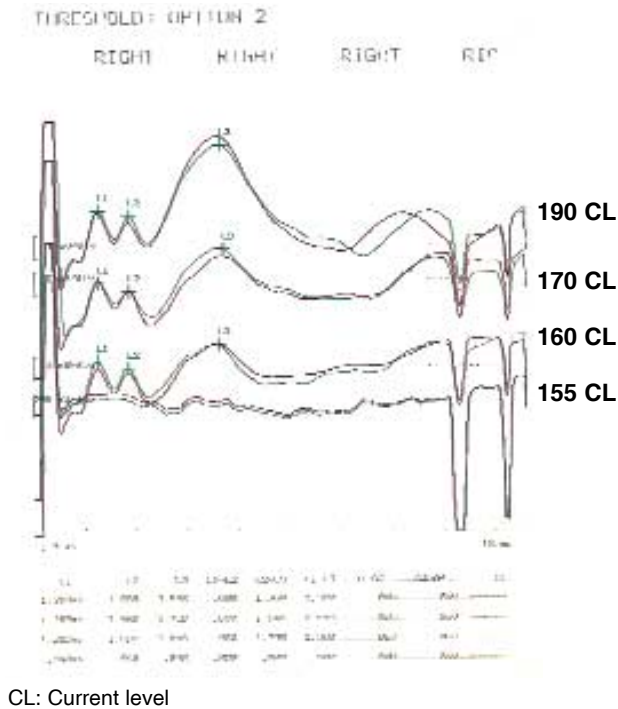
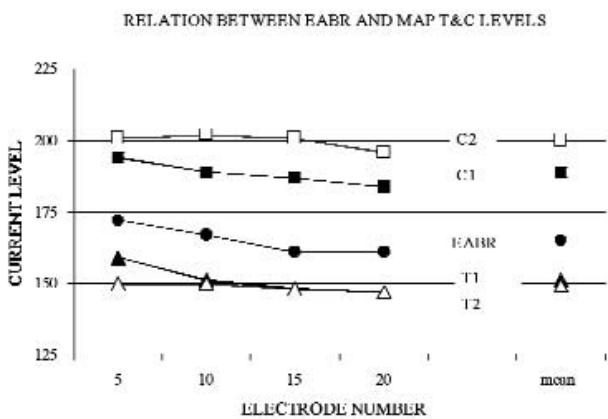


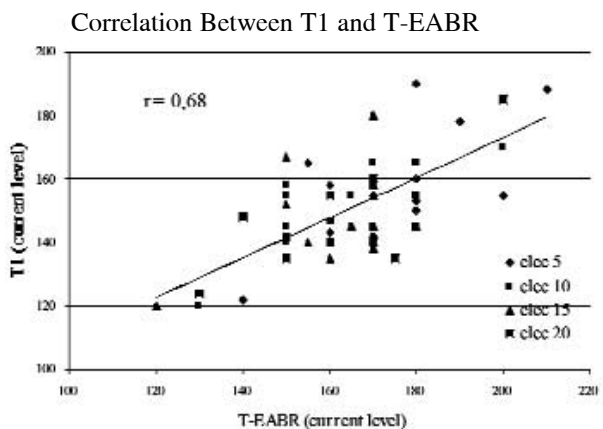
Figure 1: Typical EABR waveforms for four stimulation levels (190 CL, 170 CL, 160 CL and 155 CL respectively) obtained from the patient OS for the electrode 20.



C1: comfort level obtained 1 month after the surgery
 C2: comfort level obtained at the latest MAP
 EABR: Electrical auditory brainstem response
 T1: threshold obtained 1 month after the surgery
 T2: threshold obtained at the latest MAP

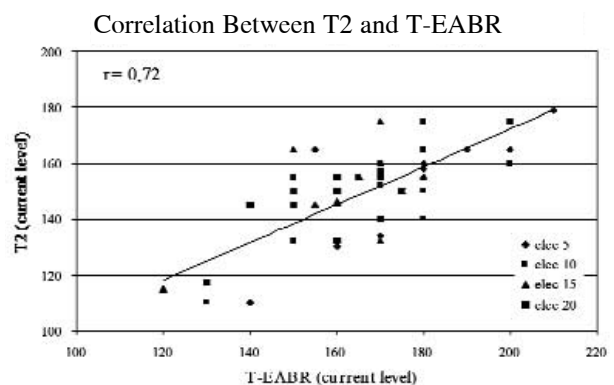
Figure 2: Mean electrical auditory brainstem response threshold for each electrode tested, MAP thresholds (T), and comfort levels (C).

In some subjects, the EABR threshold was found to fall approximately midway between the T and C levels; in others, the threshold approximated or slightly exceeded the MAP T levels. The relationship between the EABR threshold and the T1 (Figure 3) and T2 levels (Figure 4) in all subjects was evaluated, and in all cases, the EABR threshold equaled or exceeded the respective T1 or T2 level. The correlation coefficient between the MAP T level was $r = 0.68$ for T1 and $r = 0.72$ for T2 across all electrodes ($P < .001$).



T1: threshold obtained 1 month after the surgery
 T-EABR: Electrical auditory brainstem response threshold
 Elec: electrode

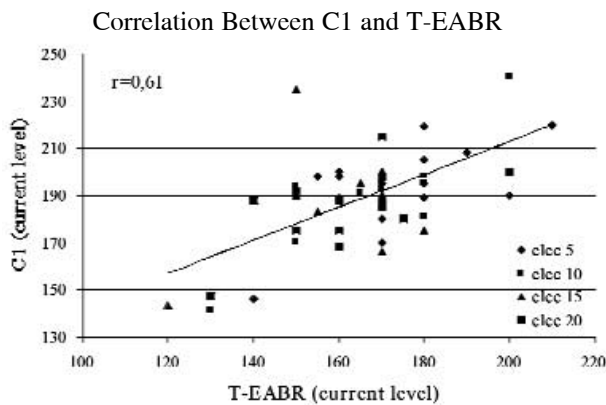
Figure 3: Correlation between the electrical auditory brainstem response threshold and the T1 (current level) obtained 1 month after surgery.



T2: MAP threshold
 T-EABR: Electrical auditory brainstem response threshold
 Elec: electrode

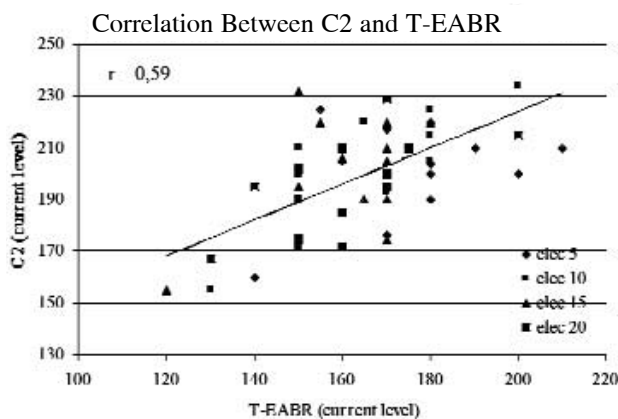
Figure 4: Correlation between the electrical auditory brainstem response threshold and the T2 (current level) obtained at the most recent MAP.

The correlation between the EABR and the C levels was found to be $r = 0.61$ (C1 level) and $r = 0.59$ (C2 level) ($P < .001$). Figures 5 and 6 show the relationship between the MAP C levels and the EABR thresholds. The results indicated that there was a variability across the study subjects. The EABR threshold was recorded in each subject at a level higher than the T level used to program the speech processor.



C1 :comfort level obtained 1 month after the surgery
T-EABR: Electrical auditory brainstem response threshold
Elec: electrode

Figure 5: Correlation between the electrical auditory brainstem response threshold and the C1 (comfort level) obtained 1 month after surgery.



C2: comfort level obtained at the latest MAP
T- EABR: Electrical auditory brainstem response threshold
Elec: electrode

Figure 6: Correlation between the electrical auditory brainstem response threshold and the C2 (comfort level) obtained at the most recent MAP

DISCUSSION

During the last several years, there has been an increase in the acceptance of cochlear implants as the treatment of choice for children with severe or profound hearing impairment. The number of pediatric patients with a cochlear implant has led to an increase in the clinical use of electrically evoked auditory potentials.

The primary purpose of this study was to investigate the relationship between the EABR threshold and MAP T and C levels. The data obtained from this study showed that EABR thresholds recorded from cochlear implant patients fall within dynamic range of the MAP. Those EABR thresholds were found to be closer to the MAP T levels than to the C levels used to program the speech processor. The results correlating the EABR threshold with the MAP T and C levels are similar to those reported previously^(11,12).

The results obtained by Brown and colleagues showed that the mean EABR threshold corresponded to approximately two-thirds of the MAP dynamic range in patients who had received a Nucleus 22 Cochlear implant⁽¹¹⁾. The results of the group data demonstrated that the EABR thresholds were between 30% and 80% of the MAP dynamic range. However, a closer look at the individual data revealed a variability across subjects⁽¹¹⁾. In another study, EABR thresholds for the Clarion cochlear implant approximated the most comfortable level than the behavioral thresholds⁽¹²⁾. Similar findings were also cited by Shalloo and colleagues, who found that the EABR threshold current level was near the behavioral comfort level rather than the behavioral threshold⁽²⁾. The EABR threshold was found to fall within the behavioral dynamic range of most of the adult and pediatric subjects who used a Clarion cochlear implant⁽¹⁰⁾.

We did not find the EABR threshold to be highly correlated with either the behavioral threshold level or the comfort level used to fit the speech processor in this study, a finding similar to those in the literature⁽¹⁰⁻¹²⁾. That result was attributed by Brown and colleagues to the temporal integration that occurred when the higher stimulation rates were used to obtain behavioral threshold and comfort levels^(11,12).

The results of our study suggest that the EABR threshold may be elicited by stimulus levels that are audible to the patient. This finding may be useful in young children who are not able provide reliable behavioral information, because the EABR threshold can be used at a level at which the subject can hear the stimulus but does not find the stimulation uncomfortable. This level can be used to begin conditioning a young child to respond to electrical stimulation. The use of the EABR threshold can facilitate the initial hook-up in very young children. Because the ABR is an indicator of good neural synchrony in the brainstem, the information obtained from the EABR will also pertain to a part of the central auditory system in addition to the level at which mapping should be initiated.

Although the EABR threshold cannot precisely predict MAP T and C levels, it can be useful in the estimation of the behavioral levels in cochlear implant fitting. The EABR threshold can also be used as a level from which to begin conditioning for behavioral MAP levels and can facilitate cochlear implant programming, especially in difficult-to-test patients and young children.

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