The relationship between the electrical stapedial muscle reflex threshold and electrical and behavioral measures in cochlear implant patients

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Programming of multichannel cochlear implants (CIs) requires subjective responses to a series of sophisticated psychophysical percepts. It is often difficult for young prelinguistically deaf children to provide adequate responses for device fitting. This is especially true in setting levels of maximum comfortable loudness, whereby failure to indicate growth of loudness may result in elevation of stimulus levels to the threshold of pain. The acoustic or stapedial muscle reflex has been used previously to provide objective confirmation of acoustic stimulation, and there have been attempts to use the reflex in hearing-aid fitting. It has also been suggested that electrically elicited middle-ear muscle reflexes [electrically evoked stapedial reflex threshold (ESRT)] may have applicability in confirming and quantifying electrical stimulation through a CI. To assess the relationship between ESRT characteristics and levels of loudness perception with CIs, determine the reliability of the response, and investigate the potential use of ESRT in CI programming, 26 prelinguistically deafened CI users were evaluated. Reflexes have also been attempted on 312 electrodes, with responses present in 213 (68.3%). Comfort levels predicted by subjective judgments were highly correlated with the ESRT in individuals with CI. ESRT provides an objective, accurate, and rapid method of estimating maximum comfortable loudness levels, which may be useful in the initial programming of young implant recipients.

Keywords:
cochlear implants, electrical and behavioral measures, stapedial muscle reflex threshold

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Introduction

Over the past quarter of a century, cochlear implants (CIs) have become recognized as highly successful auditory rehabilitation devices for individuals with severe to profound hearing impairment who derived limited benefit from conventional hearing aids [1,2].

One of the main factors affecting the ability to maximize the full potential of a CI is an accurate map [3]. The goal of mapping is to enable CI recipients to perceive a desired range of acoustic signals. The process includes programming of the minimum and the maximum stimulation levels that are based on subjective measurements of thresholds (T levels) and the most comfortable level (C levels). These psychoelectric parameters are obtained to make normal conversational speech comfortably loud and as clear as possible, soft sounds distinguishable, and loud sound not too loud [4].

In adult CI users, programming is a relatively straightforward task as psychophysical measurements can be explained, and patients quickly understand the link between the mapping process and the output of their system [5]. In young children or infants, the mapping process is more complex, especially C levels. Setting the T level requires the child to respond to the presence or the absence of a sound. Although the same techniques are used in setting the C level, the child is now required to make a judgment about the sound beyond its simple presence or absence. Young children often lack the attention span, patience, and cognitive and language skills necessary to perform these tasks with good reliability and repeatability [6,7].

Various objective electrophysiological techniques have been used to supplement the behavioral measurements for CI patients. These measures include electrical stapedius reflex and auditory-evoked potentials. These objective measures can be used for several purposes, which include the prediction of neural survival, ear selection for a CI and prediction of potential benefit preoperatively, verification of device integrity, measurement of the specific electrode output intraoperatively or postoperatively, and to supplement various behavioral measures postoperatively [8].

The electrically evoked stapedial reflex threshold (ESRT) has been shown by researchers to correlate with C levels in the adult population. The ability to elicit the acoustic reflex by means of electrical stimulation in CI recipients has been established since 1986 [9]. One main cause for concern among some clinicians about using ESRT-generated program is that the generated program may be above the child's comfortable loudness level or that the child may be overstimulated. ESRT is reported to occur below behaviorally perceived levels of uncomfortable loudness [10]. Similar results were reported by others using the Vienna device [11–13]. Meanwhile, other researchers reported that CI users prefer program where ESRT levels are used as most comfortable level (MCLs) at least as much or better than program where MCLs have been set behaviorally [14]. Clinicians using ESRT routinely report that ESRTs are found before the user feels any discomfort.

Our study was designed to explore the role of the ESRT in the prediction of subjective behavioral measures (T and C levels) in CI users.

Participants and methods

Participants

ESRTs were measured in 26 prelingual users of Med-el multichannel CIs (Med-el Manufactures, Innsbruck, Austria). Six patients were excluded from the study because no ESRT was measured across all electrodes. Sixteen participants were female and four were male. Participants' ages ranged from 14 to 51 years. Experience with the CI ranged from 5 to 9 years. Causes of deafness included familial progressive, head trauma, progressive deafness of unknown cause, and meningitis. Informed consent was taken from all patients/their guardians prior to examination.

Methods

Psychophysical measures

Each participant used his or her device coupled to the Diagnostic Programming System through the dual-processor interface. The participant's own headset was used. Adults and cooperative children were able to provide psychophysical levels. The lowest level at which the participant responded reliably indicated T levels. Levels were increased gradually until the patient determined that the sound was loud, but not uncomfortable (C level).

Method of recording electrically evoked stapedial reflex threshold

Measurements of ESRT were made in the reflex decay mode of the interacoustic (AT-235). A 226-Hz probe tone was used. The signal was generated through the Diagnostic Programming System and presented through the CI. The sound transducer (ear phone or probe) was placed to the side of the head, out of the way, or not used. The biphasic electric pulses normally used in implant-programming procedures were presented through the speech processor at levels beginning at the behavioral threshold. Stimuli were presented in pairs to assist in the identification of the response. The keyboard was used to generate paired pulses. Stimulus levels were raised systematically from the keyboard, recording the response if present, until the uncomfortable level (UCL) was reached.

The ESRT was taken as the lowest stimulus level that produces a definite, repeatable deflection in the baseline recording of at least 0.05 ml synchronous with the stimulus presentation. The ESRT is considered to be 'absent' when current levels exceeding the participant's tolerance failed to produce changes in admittance that were time locked with the stimulus.

Results

A total of 312 electrodes were tested. ESRT measurement could be performed in 213 electrodes (68%). In the remaining 99 electrodes, ESRT could not be performed (31%) as shown in Table 1.

ESRT were recorded in a group of experienced Med-El implant users. The resulting data were correlated with the behavioral percepts of the threshold level and the C level volunteered by the implant users as shown in Table 2. There was a very high positive correlation between ESRT and C levels across all electrodes. In contrast, no significant correlations were found between ESRT and T levels as shown in Table 3.

As a result of the existence of correlations between ESRT measurements and C level measurements, we decided to derive prediction models for the C level value from ESRT measurements for each electrode as shown in Table 4.

Discussion

There is a substantial potential for speech understanding with multichannel CIs. Increased information about the speech signal has been derived with increased complexity of both the internal and the external components of the implant system. Consequently, greater demands have been made on the implant user in the type and the amount of information that has to be provided for 'setting' the device output [15]. Multichannel implants require extensive and sustained interaction and cooperation between the tester and the patient to determine both the minimum and the upper limits of all electrodes. Ideally, the patient should have the language and concepts necessary to make judgments about both the intensity level and the quality of stimulation on each electrode. In reality, very few young prelingually deafened children are able to set C levels reliably [16].

As it is often difficult to obtain reliable behavioral responses in very young children, ESRT may be used

Table 1 The percentage of electrodes in which electrically evoked stapedial reflex threshold could be measured

ESRT	Number of electrodes [*n* (%)]
Measured	213 (68.3)
Nonmeasured	99 (31.7)

ESRT, electrically evoked stapedial reflex threshold.

Table 2 Mean and SD of electrically evoked stapedial reflex threshold and behavioral measures (levels T and C)

Electrode number	Number of patients	T	C	ESRT
1	20	2.92 ± 0.62	31.24 ± 6.32	30.32 ± 6.51
2	20	2.95 ± 0.65	31.50 ± 6.35	31.69 ± 6.95
3	20	2.96 ± 0.67	31.75 ± 7.05	31.02 ± 6.72
4	20	3.01 ± 0.83	32.21 ± 8.12	31.57 ± 7.98
5	20	2.93 ± 0.72	31.51 ± 7.35	30.68 ± 7.49
6	17	2.97 ± 0.72	29.69 ± 7.27	29.25 ± 7.63
7	19	2.92 ± 0.81	32.16 ± 8.90	31.58 ± 8.55
8	17	3.11 ± 0.64	31.13 ± 6.36	30.28 ± 6.64
9	16	3.07 ± 0.66	30.87 ± 6.68	30.40 ± 6.46
10	16	3.06 ± 0.70	30.55 ± 6.96	29.82 ± 6.39
11	14	3.28 ± 0.68	32.73 ± 6.82	27.19 ± 11.86
12	14	3.27 ± 0.69	32.69 ± 6.85	31.94 ± 6.50

ESRT, electrically evoked stapedial reflex threshold.

Table 3 Correlation between electrically evoked stapedial reflex threshold with C and T

ESRT	C		T	
	r	*P*	*r*	*P*
1	0.899*	<0.001	0.001	0.997
2	0.904*	<0.001	0.343	0.139
3	0.871*	<0.001	-0.079	0.742
4	0.885*	<0.001	-0.107	0.654
5	0.960*	<0.001	-0.122	0.609
6	0.977*	<0.001	-0.066	0.816
7	0.873*	<0.001	-0.142	0.562
8	0.881*	<0.001	0.102	0.697
9	0.885*	<0.001	-0.295	0.267
10	0.862*	<0.001	0.609*	0.009
11	0.795*	<0.001	0.193	0.594
12	0.815*	<0.001	-0.344	0.331

ESRT, electrically evoked stapedial reflex threshold. *significant correlation between ESRT and T-Level in the 10th electrode.

Table 4 Prediction equations for C levels based on electrically evoked stapedial reflex threshold (data were approximated to two decimal points, levels in 'qu')

Electrode number	C
1	0.87 × ESRT + 4.76
2	0.80 × ESRT + 6.10
3	0.91 × ESRT + 3.43
4	0.90 × ESRT + 3.77
5	0.86 × ESRT + 5.07
6	0.83 × ESRT + 5.47
7	0.91 × ESRT + 3.47
8	0.84 × ESRT + 5.58
9	0.92 × ESRT + 3.04
10	0.94 × ESRT + 2.55
11	0.48 × ESRT + 19.63
12	0.86 × ESRT + 5.22

ESRT, electrically evoked stapedial reflex threshold; qu is the unit used by Med-EL to measure loudness. It is equal to (Current units x pulse width) divided by 1000.

to define the maps on the ESRT rather than arbitrarily setting the T or the C levels.

ESRT has been utilized in thousands of clinical cases worldwide to confirm the responsiveness to electrical stimulation, to guide initial programming, to monitor recipients over time, and to create maps. ESRT is useful in programming multiple-handicapped child, difficult to condition children, and adults with a long duration of deafness [5,10].

In our study, the applicability of ESRT-set C levels for programming children is also being evaluated currently. With the increased incidence of middle-ear disorders in children, it is possible that the reflex will be measurable in a smaller percentage of children than adults. Spivak and Chute [14] have reported that reflexes were absent in ~30% of the pediatric patients they studied, consistent with the 31% with no measurable responses in the current series. One main reason for not finding reflexes was nonresolvable middle-ear problems; in a few instances, the reason for not eliciting a reflex was an inability to generate sufficient charge in the presence of ossification and nonauditory stimulation. This is confirmed by the child having poorer than normal implant sound-field thresholds. For many children, there is no obvious reason for not being able to record a reflex. One reason may be that the reflex is difficult to separate from artifacts. Spontaneous movement of the tympanic membrane in children with flaccid membranes can make it difficult to isolate the reflex from background noise.

The main aim of this study was to find an objective, effective, reliable procedure to facilitate the identification of the appropriate C level in children or in patients unable to cooperate.

On analyzing data from the induction of the stapedial reflex at each electrode separately, we found a very high correlation between ESRT and behavioral C levels. These findings are in agreement with those obtained by Kosaner [5] and Walkowiak *et al.* [10]. Accordingly, we formulated the prediction equation to calculate the C level from ESRT as shown in Table 4.

There was no statistically significant correlation between ESRT and T level as seen in Table 3, which indicates that ESRT can be used to predict C levels only.

Conclusion

ESRT measures predict C levels in CI patients accurately. The use of ESRT measures may be helpful in setting C levels for certain implant recipients, both adult and pediatric. Further research will be necessary to determine variations in the prediction equation to improve the ability to use ESRT data to predict the C level accurately.

Acknowledgements

Conflicts of interest

None declared.

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