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Objective Measures in Cochlear Implant in Children and its Correlation to Outcome

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Abstract

Cochlear implantation (CI) has been established as a successful time-tested technology for restoration of hearing in individuals with bilateral severe to profound hearing loss. The study aimed to use of objective measures including electrically evoked stapedius reflex threshold (ESRT), brainstem auditory evoked potential (BAEP) and electric compound action potential (ECAP) in children with CI. In the current study, a total of 30 children underwent cochlear implant. Mean age of those children was 4.79. All patients were subjected to full clinical evaluation and history taking. The following tests were evaluated in all children; electrically evoked stapedius reflex threshold (ESRT), brainstem auditory evoked potential (BAEP) and electric compound action potential (ECAP). The main findings of the current study were; EABR-wave-V appeared at earlier latencies at apical electrode in comparison to middle and basal electrodes. Also, significant shorter III-V inter-wave interval and lower EABR thresholds were noticed at apical electrode in comparison to middle and basal electrodes, while wave-III latencies showed insignificant differences at different electrodes. A significantly younger age at implantation among good performers, also, good performers had longer duration of speech therapy. ESRT at apical, middle and basal electrodes were significantly higher among good performers in comparison to those with poor performance. Combination of objective and behavioral tests during the programming of speech processor of CI should be used to avoid setting very high intensity maximum level of sensation. From this study we found that ESRT is very helpful in setting C-level specially in children who cannot give subjective response.

Keywords: electrically evoked stapedius reflex threshold, brainstem auditory evoked potential and electric compound action potential

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1. 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]. One of the main factors affecting the ability to maximize the full potential of a CI is an accurate map. 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) [2]. The use of objective measures in the CI process has greatly contributed to the definition of the dynamic field, as they provide specific values that serve as the basis for the start of the mapping process, especially in cases of infants and young children. Some examples of these measures are electrically evoked stapedius reflex threshold (ESRT), neural response telemetry (NRT), brainstem auditory evoked potential (BAEP), and P300, among others [3, 4].

The current study aimed to use of objective measures including electric compound action potential (ECAP), ESRT and EABR in children with cochlear implant and its correlation to outcome in the form of speech and language development.

2. Patients and Methods

2.1. Study design

This study was a descriptive cross-sectional study that was conducted on 30 children male and female were included. There age ranged from 2-6 years old they were implanted with MED-EL multichannel CIs.

2.2. Ethical considerations

The proposal was reviewed by the IRB of faculty of medicine, Assiut university and approval was obtained number (17200120). All data were confidential and not used except for research purpose.

2.3. Exclusion criteria

- Any middle ear problem
- Any technical problems with the CI device
- Any child with congenital inner ear anomalies or eighth nerve hypoplasia as confirmed by CT and MRI

2.4. Equipment

- Immitancemeter (Interacoustics, model AT 235) with probe tone 226 Hz performing both tympanogram and acoustic reflex tests.
- Pure tone and speech audiometer Madesn model Orbiter 922
- Double walled sound treated booth I.A.C, model 1602-A-CT equipped with two loud speakers for sound field testing
- Lap top with MED- EL MAESTRO System Software version 9.0.
- Auditory evoked potential, interacoustics Eclipse EP25 for EABR testing.

All subjects in this study were submitted to the following

2.4.1. Complete history taking

- Personal history, prenatal history, natal history, postnatal history, family history to detect onset and possible causes of hearing loss.
- History of regular or irregular hearing aid use for at least 6 month and enrollment in speech therapy before cochlear implant surgery.
- Age of cochlear implant surgery and rehabilitation after surgery.

2.4.2. Test battery included

- General examination to exclude any syndromic hearing loss or other system affection
- ENT examination with emphasis on otoscopic examination
- Audiological evaluation:
  - Immittancemetry to exclude any middle ear problems:
    Immittancemetry comprising tympanometry at varying pressure from +200 to -400 mmH2O and acoustic reflex testing.
  - Sound field examination:
    Warble tones were used to detect the aided threshold at 500Hz, 1000Hz, 2000Hz and 4000Hz.
  - Aided speech reception threshold testing (SRT) using Arabic spondee words for children
  - Play audiometry for cooperative children
  - Aided word discrimination score (WDS) at 65 dB using the half list of Arabic phonetically balanced lists for children.
- Programming of CI using behavioral and objective measures

2.4.2.1. Behavioural C and T level measurement

Behavioural C- level was measured during programming session by asking the older children to indicate the perceptual loudness level of the stimulus in terms of a) Too Soft, b) Alright, c) Too Loud. The concept of soft and loud was clearly explained to the children with the help of pictures, facial expressions, etc. as necessary as in figure 1, in the younger children we depended on non-verbal (gestural, picture pointing, facial expression, body language) responses to stimulation, while the T level was locked 10% of the C level.

2.4.2.2. Objective measures recording

In this study we used three main objective measures they were ECAP, ESRT and EABR.

❖ ***Recording of ECAP***

Before ECAP testing, the integrity of the implant was verified and impedances on electrodes were determined using the telemetry function of the CI. ECAP responses were captured using MAESTRO System Software version 9.0 using the ‘AutoART’ task. Compound action potentials were recorded in three different electrodes of the implanted array, in the apical region electrode (1), middle region electrode (6) and in the basal region electrode (10).

❖ ***Recording of electric stapedial reflex threshold (ESRT)***

All children underwent tympanometry before ESR testing, the recording system of the middle ear analyzer is very sensitive to movement. To minimize artifacts caused by movement, passive cooperation was obtained from older children to stay quite while younger children were sedated using chloral hydrate, MED-EL speech processors CI were connected to the MAESTRO System Software version 9.0 programming system via MAX, the recording of ESR was attempted in the ear contralateral to that implanted. An appropriate probe tip was inserted in the ear once a normal tympanogram was obtained, the middle ear analyzer was set to the "special (reflex decay)" mode.

Stimulation was derived via the appropriate interface by means of standard biphasic pulses and presented through the child's own speech processor in case of SONNET 2 device and via telemetry coil in case of SONNET devices, Stimulation began at 20 programming units and the change in acoustic admittance for the 226-Hz probe's tone resulting from the stapedial reflex contraction was presented as a upward elevation of the prestimulus baseline The stimuli were presented in pairs to assess the identification of the response and repeatable upward elevation was positive, we start testing electrode (1) at the apical region, electrode (6) at the basal region and finally electrode (10) at basal region.

❖ **Recording of EABR**

EABRs were tested for three stimulation electrodes: we started with apical electrode (1), other one at the middle of electrode array (electrode 6) and finally one at the basal end (electrode 10).

2.5. Analysis of the response

Waves III and V latencies were measured for each waveform recorded within the range of stimulus levels. EABR threshold was defined as the lowest stimulus level at which EABR wave V could be detected in two replications of the stimulus condition.

2.6. Statistical analysis

Data was collected and analyzed by using SPSS (Statistical Package for the Social Science, version 20, IBM, and Armonk, New York). Quantitative data with normal distribution are expressed as mean ± standard deviation (SD) and compared with Student t test (between two means) and ANOVA test followed by post analysis (more than two means). Nominal data are given as number (n) and percentage (%). Speech discrimination before and after cochlear reprogramming was tested by paired t test. Correlations between different continuous variables in the current study were determined by Pearson correlation. Level of confidence was kept at 95% and hence, *P* value was considered significant if < 0.05.

3. Results

3.1. Demographic data of the studied hearing-impaired children

Mean age of enrolled children was 4.79 ± 0.95 years with range between 2.5 and 6 years old. Majority of children were males 19 (63.3%) and 11 (36.7%) were females. Majority (86.7%) of children had binaural hearing aid and only four patients had monaural hearing aid.

3.2. EABR response latencies and thresholds in apical, middle and basal electrodes (Table 2)

It was found that wave-V appeared at earlier latencies at apical electrode in comparison to middle and basal electrodes. With post-hoc analysis; latencies at basal electrodes were significantly higher in comparison to middle and apical electrode. Meanwhile, both middle and apical electrodes had insignificant differences.

3.3. ECAP threshold at different studied electrodes (table 3)

There was significant difference between different electrodes as regard ECAP-T and ECAP-C level where highest threshold was found with basal electrode and least threshold with apical electrode.

3.4. Comparison between word discrimination score before and after reprogramming using ESRT (table 4)

There was significant improvement in the word discrimination score after cochlear reprogramming using ESRT in comparison to before cochlear reprogramming.

3.5. Characteristics of studied patients based on word discrimination (table 5-6)

In our study we considered the poor performers have word discrimination score less than (52%) and good performers have score more than (52%). It was noticed that a significantly younger age at implantation among good performers, also, good performers had longer duration of speech therapy.

3.6. Correlations in the current study

It was found that there were significant correlations between basal ECAP-T with basal EABR threshold (r= 0.42, p= 0.02), middle ECAP-T (r= 0.44, p= 0.03) with middle EABR threshold and apical ECAP-T with apical EABR threshold (r= 0.45, p= 0.01). Also, there were significant correlations between both basal ECAP-C with ESRT (r= 0.72, p< 0.001), both middle ECAP-C with ESRT (r= 0.32, p= 0.03) and both apical ECAP-C with ESRT (r= 0.83, p< 0.001). There was significant correlation between both basal subjective-C with basal ESRT threshold (r= 0.38, p= 0.03), both middle subjective-C with middle ESRT threshold (r= 0.43, p= 0.01), and both apical subjective-C with apical ESRT threshold (r= 0.58, p< 0.001).

4. Discussion

This study aimed to use the objective measures in children with cochlear implant including ECAP, ESRT and EABR and its correlation to outcome in the form of improvement in word discrimination and language development. Mean age of those children was 4.79 years with range between 2.50 and 6 years, their mean age of implantation was 3.03 years with range between 2 and 4.50 years. Irregular use of CI was reported in only five children. One of the main findings in this study was that EABR-wave-V appeared at earlier latencies at apical electrode in comparison to middle and basal electrodes this could be explained by previous findings reported that EABR waveform pattern is similar to that of acoustic ABRs – but without wave I, which is masked by the electrical stimulus artifact – although the EABR usually appears 1.5–2 ms earlier due to the direct stimulation of spiral ganglion cells by the implant electrodes

Previous study suggested that the earlier latency is due to neural synchrony for electric evoked potential recordings in CI patients is likely greater than for acoustic stimulation in normal hearing individuals, because the auditory nerve is directly stimulated with a rapid-onset electrical pulse [5]. There was significant shorter III-V inter-wave interval and lower EABR thresholds were noticed at apical electrode in comparison to middle and basal electrodes, while wave-III latencies showed insignificant differences at different electrodes these findings agreed with previous authors [6-8]. In current study wave V was the most robust EABR component, obtained on more implant electrodes and for more stimulus intensities than the others and the latencies of EABR waves observed in this study were in agreement with the values reported by others [4, 9-11]. As regard the correlation between EABR response latencies at wave III, V and III-V interpeak latency with age at implantation and duration of implant use at different electrodes we found that there was positive correlation between latency of wave-III with age at implantation at middle electrode, positive correlation between III-V interpeak latency with age at implantation at basal electrode. Regarding correlations between EABR threshold with age at implantation and duration of implant use at different electrodes there were positive correlation between EABR threshold with age at implantation at apical electrode and negative correlation between EABR threshold with duration of implant use at apical electrode. In similar with the current study, it was found that the correlation studies revealed prolongation of wave V latency and III–V interpeak interval (at E5) with increase of age at implantation, also there was a significant decrease in EABR threshold (at E20) with longer duration of implant use and increase in EABR thresholds (at E20) with increase of age at implantation [12].

Table 1. Demographic data of the studied hearing-impaired children

	N= 30
Age (years)	4.79 ± 0.95
Range	2.50-6
Sex	
Male	19 (63.3%)
Female	11 (36.7%)
Family history	16 (53.3%)
Consanguinity	21 (70%)
History of fever	3 (10%)
Age of suspicion of onset of hearing loss	
Since birth	27 (90%)
Since age of 1 month	1 (3.3%)
Since age of 6 month	1 (3.3%)
Since age of 1.5 year	1(3.3%)
Hearing aid age of fitting	1.38 ± 0.83
Range	3 months-4
Hearing aid use duration	1.06 ± 0.61
Range	6 months-3
Side of hearing aid	
Monaural	4 (13.3%)
Binaural	26 (86.7%)
Age at implantation	3.03 ± 0.82
Range	2-4.50
Duration of implantation	1.73 ± 0.80
Range	3 months-3.50
Irregular use of CI	5 (16.7%)
Duration of speech therapy	1.27 ± 0.81
Range	3 months-3

Table 2. Comparison between EABR response for wave III, V and III-V interpeak latencies and thresholds in apical, middle and basal electrodes

Latencies (ms)	Apical	Middle	Basal	*P* value	*P*1 value	*P*2 value	*P*3 value
Wave III	**1.77 ± 0.26**	**1.78 ± 0.27**	**1.83 ± 0.61**	**0.87**	**0.45**	**0.09**	**0.11**
Wave V	**3.36 ± 0.99**	**3.90 ± 0.54**	**4.18 ± 0.55**	**0.01**	**0.19**	**< 0.001**	**0.03**
III-V interpeak	**1.21 ± 0.32**	**1.64 ± 0.27**	**2.35 ± 0.64**	**0.03**	**0.34**	**<0.001**	**0.01**
Threshold (qu)	**16.46 ± 4.26**	**17.23 ± 5.17**	**20.94 ± 3.69**	**<0.001**	**0.19**	**< 0.001**	**<0.001**

Table 3. Comparison between ECAP threshold and ECAP-C at different studied electrodes

	Apical electrode	Middle electrode	Basal electrode	*P*	*P1*	*P2*	*P3*
ECAP- T	15.11 ± 4.19	18.98 ± 3.90	19.15 ± 4.78	0.01	0.45	<0.001	0.06
ECAP-C	14.98 ± 3.19	15.55 ± 2.20	18.65 ± 3.54	0.03	0.02	<0.001	0.07

Table 4. Comparison between word discrimination score before and after reprogramming using ESRT

	Word discrimination (%)
Before reprogramming	20.14 ± 2.67
After reprogramming	26.37 ± 3.51
***P* value**	**< 0.001**

Table 5. Characteristics of studied patients based on word discrimination

	Word discrimination		***P* value**
	Good performers (n= 10)	**Poor performers (n= 20)**	
Age (years)	2.01± 0.42	5.33 ± 1.34	< 0.001
Sex			**0.03**
Male	5 (50%)	14 (70%)	
Female	5 (50%)	6 (30%)	
Family history	5 (50%)	11 (55%)	0.11
Consanguinity	7 (70%)	14 (70%)	---
History of fever	0	3 (1.5%)	0.11
Age of suspicion of onset of hearing loss			0.98
Since birth	10 (100%)	18 (90%)	
Since age of 1 month	0	1 (5%)	
Since age of 6 month	0	1 (5%)	
Hearing aid age of fitting	1.36 ± 0.80	1.39 ± 0.45	0.45
Hearing aid use duration	1.06 ± 0.22	1.07 ± 0.34	0.11
Side of hearing aid			0.10
Monaural	1 (10%)	2 (10%)	
Binaural	9 (90%)	17 (85%)	
None	0	1 (5%)	
Age of implantation	2.01 ± 0.42	5.33 ± 1.34	**< 0.001**
Duration of implantation	1.90 ± 0.99	1.65 ± 1.11	0.19
Duration of speech therapy	1.58 ± 0.22	1.01 ± 0.23	**0.02**
Types of devices			0.22
MEDEL- SONNET	8 (80%)	18 (90%)	
MEDEL- SONNET-2	2 (20%)	2 (10%)	
Type of strategy			0.18
FS4	10 (100%)	20 (100%)	

Data expressed as frequency (percentage), mean (SD). *P* value was significant if < 0.05

Table 6. ECAP, ESRT and EABR of patients based on word discrimination.

	Word discrimination		***P* value**
	Good performers (n= 10)	**Poor performers (n= 20)**	
ECAP-T			
Apical electrode	15.09 ± 4.98	15.22 ± 5.56	0.39
Middle electrode	19.01 ± 5.50	18.90 ± 2.87	0.06
Basal electrode	19.19 ± 2.34	18.99 ± 3.45	0.11
ECAP-C			
Apical electrode	15.01 ± 5.29	14.87 ± 3.45	0.08
Middle electrode	15.56 ± 3.11	15.35 ± 1.98	0.20
Basal electrode	18.65 ± 4.11	18.66 ± 2.89	0.32
ESRT			
Apical electrode	25.56 ± 6.27	21.12 ± 3.33	**< 0.001**
Middle electrode	31.23 ± 5.98	24.45 ± 3.98	**< 0.001**
Basal electrode	35.45 ± 4.44	28.45 ± 2.34	**< 0.001**
EABR threshold			
Apical electrode	16.45 ± 4.26	16.50 ± 3.89	0.22
Middle electrode	17.23 ± 2.22	17.20 ± 1.90	0.09
Basal electrode	20.91 ± 6.26	20.92 ± 5.54	0.34

Data expressed as frequency (percentage), mean (SD). *P* value was significant if < 0.05

In contrast, previous studies reported that EABR latencies in children using cochlear implants are not dependent upon the duration of hearing loss/age of the children at the time of implant [13]. Another study concluded that EABR thresholds obtained were always within the subject's behavioral dynamic range and showed correlation to both psychophysical T & C levels and behavioral 'T' levels approximate most to threshold EABR rather than 'C' levels. The results in this study related to that subjective- T level was taken as 10% of the C- level [14]. In this work there was difference between different electrodes as regard ECAP-T and ECAP-C level where highest threshold was found with basal electrode and least threshold with apical electrode. Post-hoc analysis revealed apical electrode had the least threshold in comparison to basal electrode with no significant differences was found between apical and middle electrode and between middle and basal electrodes.

Also there were significant correlations between ECAP-C with ESRT at apical, middle and basal electrodes, similarly previous study noticed that correlation between ECAP-C and ESRT varies from moderate to very strong i.e. 0.68 to 0.93 [15]. In the current study, there were significant correlations between EABR threshold and ECAP-T at basal, middle and apical electrodes and this was in agreement with a previous study that showed a significant correlation ($r = 0.71$, $P < 0.001$) exists between ECAP-T and EABR [16]. Also, another study shown strong correlation between ECAP and EABR [17]. Also, significant correlation was identified between the EABR and the ECAP thresholds in each of the stimulation regions. Correlation was found moderate for the basal region, and high in the middle and apical regions [18]. There was no statistically significant correlation between ESRT and subjective T level, which indicates that ESRT can be used to predict C levels only. In line with this finding, previous study of 6 experienced COMBI 40 implant system users and found that the overall correlation between ESRT and MCL was high i.e. r= 0.92 and concluded that the ESRT findings can be used successfully for the programming of speech processor [19]. Results from the present study showed that there was significant improvement in all tested frequencies in sound field examination after reprogramming using ESRT in comparison to baseline data at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. In the current study ESRT at apical, middle and basal electrodes were significantly higher among good performers in comparison to those with poor performance.

In agreement with the current study, previous study [20] studied the relationship between ESRT and behavioral comfort levels in experienced CI users and reported high correlation. Other studies done by [21, 22] showed that the estimation of comfort level using ESRT is reliable and useful in CI users. They confirmed the concept that ESRT could be the most useful objective tool to establish the comfort level in CI users. So, ESRT can be very efficiently help in mapping the CI especially when the goal is safely defined c-level as overestimation or under estimation of c-level lead to poor adaptation to CI and consequently lack of progress in auditory performance and speech and language development. In conclusion, the study explores the trends and correlations between electrophysiological thresholds and behavioral comfort levels recorded over time, among a cohort of comparable cochlear implant. The EABR, ECAP and ESRT test prove to be an effective method to evaluate the functions of the auditory pathway in children after cochlear implantation.

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