Electric Auditory Brainstem Response (EABR) as A predictor of Speech Perception Outcome in Cochlear Implanted Children

Original Article

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ABSTRACT

Purpose: To study the Electric Auditory Brainstem Response (EABR) measures and their relation to speech perception outcomes-both in quiet and noise-and to the phonological tests.

Patients and Methods: Twenty-six unilaterally implanted children were subjected to EABR recording. EABR was recorded from one apical electrode E21 (A) and one basal electrode E2 (B). Word recognition scores (WRS), Bamford-Kowel Bench speech in noise (BKB-SIN test), and phonological assessment [auditory level, speech intelligibility index, and language test] were done.

Results: This research showed statistically significant better EABR responses recorded from the apical electrodes (A) compared to the basal ones (B) as regards amplitude growth function (AGF) slopes, maximum amplitudes, thresholds, and latencies. Significant positive correlations were reported between both EABR slopes and maximum amplitudes and the WRs; however, significant negative correlations were found between EABR slopes and maximum amplitude measurements and the dB SNR loss of BKB-SIN values. Furthermore, the AGF slopes had significant correlations with the auditory level and the speech intelligibility index.

Conclusion: EABR AGF slopes and maximum amplitudes were both correlated with speech recognition in quiet and in noise and were correlated with phonological assessment. These encouraging findings can be used for CI outcome prediction and can help clinicians provide optimal services to pediatric CI recipients and facilitate realistic expectations among caregivers.

Key Words: Amplitude growth gunction (AGF), Auditory level, bamford-kowel-bench speech in noise (BKB-SIN), cochlear implant (CI), electric auditory brainstem (EABR).

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INTRODUCTION

One of the most effective neural prostheses to date is the cochlear implant (CI). For those with severe sensorineural hearing loss who don't benefit enough from conventional hearing aids, it provides artificial hearing. The CI's electrode array is implanted into the scala tympani of the cochlea for electrical stimulation of the spiral ganglion neurons (SGN), which subsequently leads to sound perception[1].

Spiral ganglion neurons (SGNs) are the target stimulation of CI. The transmission of auditory stimuli and perceptual outcomes are thought to be impacted by the SGNs' integrity. The findings of various research indicate that the physiological status of the auditory nerve-specifically, the quantity and reactivity of its neurons-might be significant for the results of CI.[2,3]

SGN density can be estimated using Electrically Auditory Brainstem Response (EABR), a clinically relevant evoked potential estimate of the auditory nerve response to electrical stimulation. EABR had been studied in patients with 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, perioperative and postoperative neural survival[4-8].

EABR, threshold, latency, amplitude and AGF slope are all correlated with SGN survival in animal models 9. Specifically, animals with higher SGN densities tend to have larger amplitudes, steeper AGF slopes, shorter latencies and lower thresholds, than animals with fewer functional SGNs[3].

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In humans, EABR measurements and their correlation with speech perception were not consistent. Some studies reported that EABR waveform significantly correlate with the event CI outcome in terms of speech perception[10,11] While, others reported the contrary[12].

The present study aimed at studying EABR measurements and the relation between EABR measurements and speech recognition results in unilateral cochlear implanted children.

PATIENTS AND METHODS:

This study was done in the time-period between May 2021 to May 2022 at Audio-vestibular Unit, ORL Department. Our Institutional Review Board approved the study (Ethical approval code No. 34622/4/21). This study conforms to the Declaration of Helsinki. Informed consent was obtained from all individuals' parents included in our study.

The study included 26 children [16 females (61.5%) and 10 males (38.5%)] unilaterally implanted with a fully inserted electrode. The participants' ages ranged from 7 to less than 18 years old. The inclusion criteria were regular speech therapy after CI operation for a minimum of 2 years; aided responses less than 35 dB (satisfactory); auditory level with a score of 4-5; and speech intelligibility index from 3 to 5. Lastly, IQ was more than 80. All participants were diagnosed with bilateral profound sensorineural hearing loss before implantation based on behavioral measures, ABR, and auditory steady state response. None of the study participants were diagnosed with auditory neuropathy or cochlear nerve deficiency.

All subjects were submitted to:

A. Phoniatric evaluation including:

1- language assessment using the assessment protocol of language including assessment of inner language, passive, active, Syntax and phonology

2- speech assessment including segmental assessment of consonant and vowels, assessment of suprasegmental aspect of speech including rate, stresses, pauses and tonality

Clinical diagnostic aids including documentation of clinical assessment by

1- language test using psl4 and reel scale[13]

2- Capacity of Auditory Performance (CAP) test for auditory level

3- Speech Intelligibility index[14]

4- IQ test using Stanford-Binet Intelligence scale 5th edition[15]

B. Audiological assessment:

Full audiological history, including the onset, cause and duration of hearing loss, speech therapy details, the type of hearing aid used, the length of time the HA was used and how frequently. Details of CI were also involved regarding the age of the patient at the time of surgery, the duration of use of the CI, the side of implantation, and the type and number of programming cycles.

Initial audiological assessment included aided thresholds and aided speech recognition thresholds (SRT)[16]. Speech recognition tests included word recognition scores (WRS) using age-appropriate test[16,17] and speech recognition in noise using BKB-SIN[18,19]. The results of the latter were interpreted according to the SNR loss as normal (0–3 dB), mild (>3–7 dB), moderate (>7–15 dB), or severe (>15 dB) according to the BKB manual[18,19].

C. Electric Auditory Brainstem Response (EABR):

Before starting measuring EABR we start measuring impedance and checking the values for the most comfortable level (MCL). The electrodes positioning used were vertex or high forehead for the non-inverting (active (+)) electrode, contralateral mastoid for the inverting (reference (-)) electrode and lower forehead for the ground electrode[20]. Biphasic pulses were used for eliciting EABR. Stimulus parameters were controlled using Custom Sound Pro (version 5.3) software, through Cochlear Ltd Programming Pod. This is used to connect the external processor to the software which in turn stimulates the electrode sites (one apical (E21) and one basal (E2)) of implant via coil transcutaneously. Cochlear Ltd Programming Pod is linked with IHS Smart EP V 5.35 analyzer via trigger cable that triggers the smart EP for recording. EABR was recorded from scalp using EEG electrodes connected to the pre-amplifier manufactured by IHS (Intelligent Hearing Systems) which were averaged by the Universal Smart Box (IHS) and analyzed using Smart EP version 5.0 software installed in Lenovo PC.

The waveforms were amplified 100,000 times, band pass filtered in the range 50-1500 Hz, Gain 50 and recorded between 0 - 10 ms time window. A total of 1500 sweeps of recording were done for all the subjects. Pulse width 37µV.

EABRs were recorded from two electrodes: one located at the apical end of the array (A) (E-21), and the other at the basal end (B) (E-2). A biphasic pulse with interphase gap (IPG) of 50us was used to elicit EABR responses.

Stimulus levels started from a level near the comfortable level and stimulation level was increased until plateau or saturation was obtained, or compliance was reached and then decreased till the last identified and repeated response was obtained at increment steps of 10 current levels (CL). Step increment was decreased to 5 CL when approaching the threshold. Due to the electrical current, a significant stimulus artefact was often observed in the first 0.8 milliseconds of the trace. So, the first 1.2ms were digitally blocked to lessen the artefact. Digital filter was applied using band-pass filter with cutoff values of 50 Hz–1500 Hz[21].

For morphology, the presence of major peak eV of the EABR at the expected latency (around 3.5ms) was analyzed. The trough to peak amplitude was measured in µV of each recorded eV peak and was analyzed. Amplitude of wave V was measured in each trace obtained at each different current level (Fig. 1). EABR amplitude growth function (AGF) was obtained for both apical and basal electrodes (Fig. 2). Slope (µA/cl) was calculated through linear regression function fitting for the AGF. Maximum amplitude (µV): it was defined as the start of the plateau curve (saturation). Wave V latency was obtained at max amplitude for each AGF.

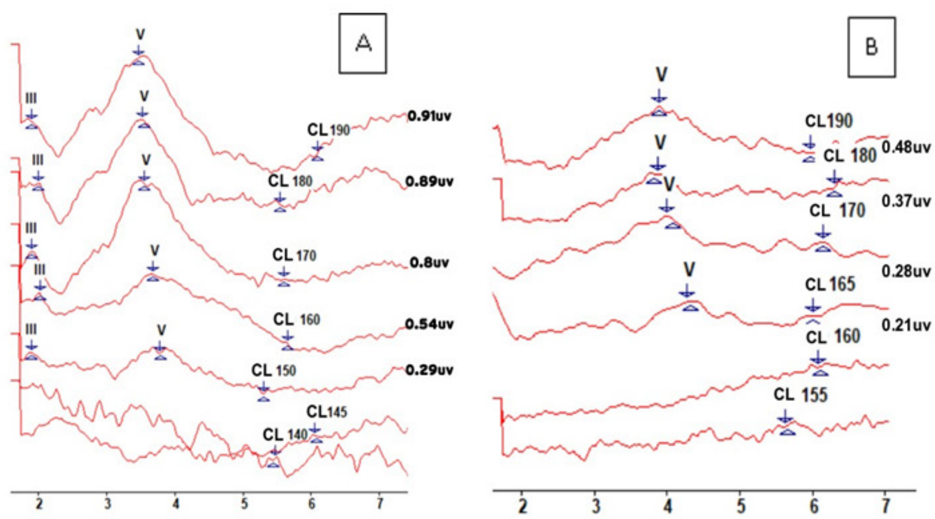

Fig. 1: EABR traces of one of our participants, (A) showing EABR response (wave V) down to threshold recoded from apical electrode E 21 (B) showing EABR response (wave V) down to threshold recoded from Basal electrode E 2. Notice that wave III is well detectable at the Apical EABR but not at the basal recordings

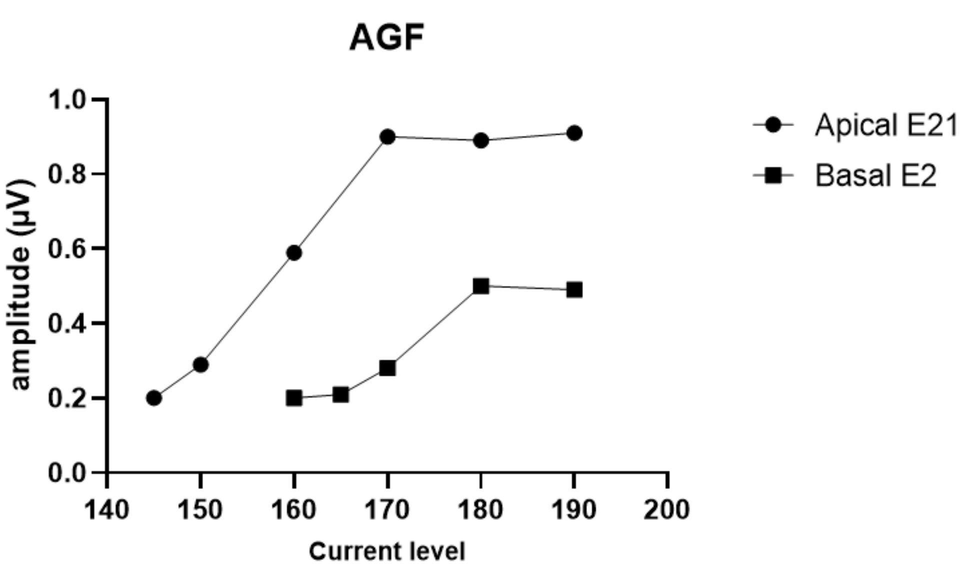

Fig. 2: EABR recording from one case. wave V amplitudes (µV) recorded at each stimulation level (cl) to generate the amplitude growth function (AGF)

EABR threshold (cl) was defined as the least current level which gave two repeatable wave V[22]. So, for each variable, two measurements were obtained, one derived from the apical (A) electrode and one from the basal electrode (B).

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guidelines on human experimentation (Research ethics committee, Approval code: (34622/4/21). All authors including declare that they have no conflict of interest (financial or non-financial). Informed consent was obtained from all individuals' parents included in our study.

Data were gathered, collated, and statistically analyzed by Graph-pad prism version 8. Two distinct kinds of statistical analysis were performed: a) Descriptive statistics, such as the number (No), percentage (%) mean ($\overline{x}$), standard deviation, Median and Interquartile range, and b) Analytical statistics Paired t-test was used to compare matched pairs of normally distributed data, and the Wilcoxon rank test was applied for non-parametric data. The Shapiro-Wilk test was used to determine whether the data were normal. For correlation between variables, Pearson test was applied for normally distributed data and spearman test for data not followed normal distribution. A two-sided *P-value of <0.05* was considered statistically significant.

RESULTS:

The age of the study group ranged from7 to <18 years with mean of 13.2±4.15 years. They were 16 females (61.5%) and 10 males (38.5%))

As regards EABR morphology, Wave V could be detected in 100% of patients in both apical and basal electrodes. Wave III could be recorded from the apical electrodes in twenty-three (88.46%) and could be recorded from twenty patients (76.9%). from basal electrodes. Wave I and II could not be detected in any of our patients in apical or basal electrode. Apical electrodes showed better configuration than basal ones (Fig. 1).

EABR measured parameters showed statistically significant differences between the apical and basal EABR recordings. Apical responses showed statistically significant lower thresholds, shorter latencies, higher amplitudes and steeper AGF slopes relative to the recordings derived from the basal electrode (Table 1, Figure 3).

Aided word recognition score was measured, and its values ranged from (68-92%) with mean and SD (82.15± 6.22), while BKB-SIN test showed SNR loss ranged from (13.20– 16.20 dB) with mean and SD 14.99 ± 0.99.

There were statistically significant positive correlations between WRS and both EABR max amplitudes and AGF slope measured at apical and basal electrodes, while there were statistically significant negative correlations between both EABR max amplitudes and AGF slopes, at apical and basal electrodes, and SNR loss in dB of BKB-SIN test (Table 2; Figure 4). However, no significant correlations were found between EABR thresholds and latencies and speech perception tests (WRS, SNR loss in dB of BKB-SIN).

There were statistically significant positive correlations between AGF slope at both apical and basal electrodes with both auditory level and intelligibility. However, there were no significant correlations between EABR threshold, latencies, amplitude of wave eV and phonological assessment (Table 3).

No statistically significant correlations between age, duration of hearing loss, duration of CI use and age of surgery and EABR measures at apical and basal electrodes could be found in the current work.

Table 1: Comparison between EABR-measurements recorded from apical electrodes (A) and basal electrodes (B).

Variable		Apical Electrode	Basal Electrode	Test of significance	*P*
Latency (ms)	Median (IQR)	3.57 (3.48-3.718)	3.86 (3.7-4)	Z = 4.4459	*<0.0001**
Maximum Amplitude (µV)	Median (IQR)	0.82 (0.70 - 1.00)	0.60 (0.47 - 0.83)	Z= -3.7338	*<0.0001**
Slope (µV/CL)	Median (IQR)	0.015 (0.011 -0.02)	0.013 (0.009 - 0.017)	Z= -2.2351	*0.023**
Threshold (CL)	Mean (SD)	156.54 (7.845)	171.35 (11.00)	t=10.00, df=25	*<0.0001**

CL (current level), df (degree of freedom), IQR (interquartile range), ms (millisecond), µV (microvolt), SD (standard deviation), t (paired t-test), Z (Wilcoxon Rank test), P is considered significant if *p <0.05*

Table 2: Correlation between EABR Max amplitudes (µV) and AGF slopes (µV/CL) recorded from the apical and basal electrode with word recognition score (WRS) and BKB SNR loss.

	Amplitude A		Amplitude B		Slope A	Slope B
	r	*p*	r	*P*	r	*p*
Word Recognition Score	0.452	*0.020**	0.636	*0.000**	0.684	*0.000**
SNR loss (in dB)	-0.463	*0.017**	-0.603	*0.001**	-0.743	*0.000**

A: Apical Electrode, B: Basal Electrode, r: Pearson correlation coefficient, P is considered significant if $p < 0.05$

Table 3: Correlation between EABR AGF slope (µV/CL) recorded from apical (A) and basal (B) electrodes and phonological assessment.

	Slope A		Slope B	
	rs	*p*	rs	*p*
Auditory Level	0.587	*0.002**	0.516	*0.007**
Speech Intelligibility Index	0.538	*0.005**	0.575	*0.002**

A: Apical Electrode, B: Basal Electrode, EABR: Electric Auditory Brainstem Response, AGF: amplitude Growth Function rs: spearman correlation coefficient, P is considered significant if $p < 0.05$

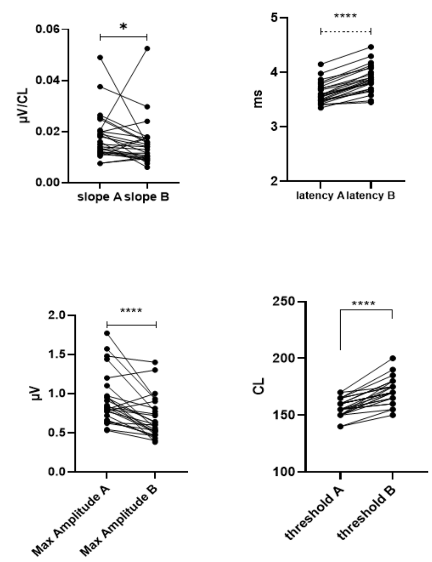

Fig. 3: Comparison of EABR different measurement (slope, maximum amplitude, latency and threshold) recorded from apical electrode (A) with that recorded from basal electrode (B). Data are expressed in median and IQR (Interquartile range). [* if $P < 0.05$; ** if $P \leq 0.01$; *** if $P \leq 0.001$; **** if $P \leq 0.0001$]

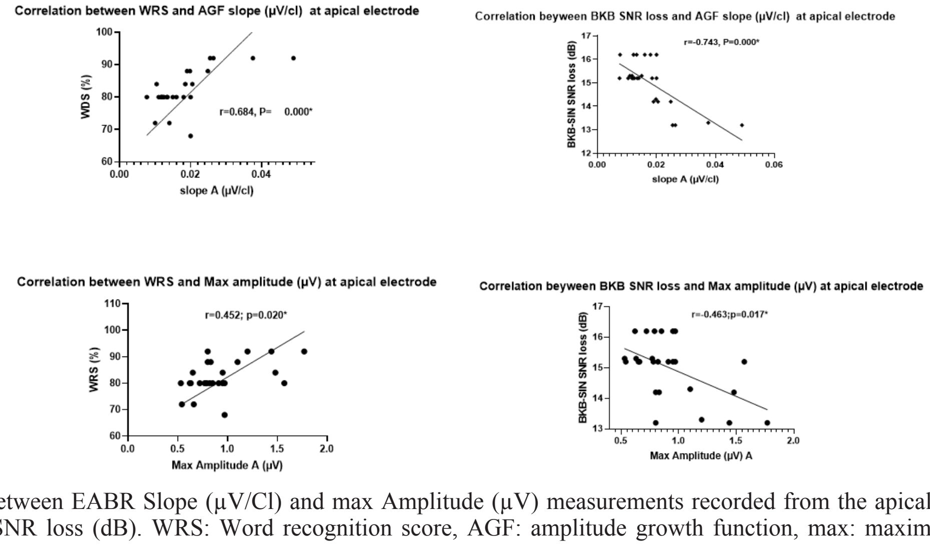

Fig. 4: Correlations between EABR Slope (µV/Cl) and max Amplitude (µV) measurements recorded from the apical electrode with both WRS (%) and BKB SNR loss (dB). WRS: Word recognition score, AGF: amplitude growth function, max: maximum. P is considered significant if $p < 0.05$

DISCUSSION

Cochlear implant (CI) is described as “the most successful neural prosthesis”[23]. Researchers are interested in investigating speech and language outcomes in pediatric CI recipients. The integrity of the spiral ganglion neurons (SGNs), the target of CI stimulation, is believed to affect the transmission of auditory inputs and perceptual outcomes. Electrically Auditory Brainstem Response (EABR), is a clinically relevant evoked potential estimate of the auditory nerve response to electrical stimulation[7].

The aim of this study was to study EABR measures at apical and basal electrode and its relation to speech perception outcomes.

This research results showed statistically significant differences between EABR wave morphology, detectability, and measures (*amplitudes, thresholds, latencies and AGF slopes*) recorded from the apical electrode compared to the basal one. The EABR wave morphology recordings from the apical electrodes were better recoded from the basal ones, also wave III detectability were higher in the apical region than basal ones. The apical electrodes showed lower thresholds, shorter latencies and larger amplitudes compared to the basal electrodes. Also, the slopes of the AGF recorded from the apical electrodes were steeper than the basal one.

According to several studies, EABR latencies decreased and EABR waveform amplitudes increased as the recording moved from the base to the apex of the array[12,24].

In agreement with the current research Hodges *et al*.[25], on their study done on ten post lingually deafened adult using Nucleus 22 channel cochlear implant with ages ranged from 37 to 67 years documented that the increase in current intensity was associated with increase in the amplitude of wave V, also latency generally decrease as stimulus intensity was increased. Also, Shallop *et al*.[8] on their study done on 25 patients that were tested either intraoperatively by EABR at the time of implantation or as an outpatient with EABR and/or EMLR after initial stimulation and programming, The patients ranged in age from 2.5 to 77 years at the time of surgery, their results showed that The apical EABR responses are larger and have the shortest wave V latency in comparison to responses from the basal electrodes and showed a slight latency intensity shift. Researchers examined the impact of stimulus current intensity and electrode position on EABR in patients utilizing CI and found that the apical electrode responded better in terms of latency, amplitude, and morphology than the basal one.[12,24]

Prado-Guitierrez *et al*.[9] in their study on guinea pigs reported that EABR responses (slope, threshold, Latencies, and amplitudes) are affected by the underlying SGCs, the higher the SGC survival, the better the measured parameters.

In their investigation on guinea pigs, Miller *et al*.[26] found a statistically significant relationship between the number of SGNs and the EABR threshold. Other investigations found a "strikingly good correlation" between the highest peak-to-peak amplitude and neuronal survival and the slope of the input/output function.[27-29] According to Radeloff *et al*.'s investigation on guinea pigs given stem cell injections, EABR recorded from the animals (with stem cells) that expressed more surviving SGCs had bigger amplitudes, lower thresholds, and steeper AGF slopes[30].

It has been proposed that the variations in the population and pattern of surviving (SGCs) within the apical region may be the cause of this variance in latency, amplitude, and shape[24]. Pronounced loss of SGCs usually occurs at the base of the cochlea, while the middle and apical regions showed fewer decline in the neuronal cells and more stable population of the nerve fibers[31].

Surviving SGCs is not the only responsible factor, but electrode position has been described to play a significant role that determine the morphology and the EABR measured parameter[7]. The EABR threshold is influenced by the electrode array position with respect to the SGCs. The threshold decreases as the array gets nearer to the SGCs (as seen at the array's apex)[32]. So, to summarize these results regarding this point, the better responses obtained from the apical electrodes may be due to the larger neuronal count at this region and the electrode's proximity to the activated SGCs.

As regards speech test scores, the mean value of WRS was 82.15 ± 6.2 and BKB SNR loss in dB was 14.99 ± 0.99. This illustrates that CI users have difficulty in noisy environments. This is related to limitation of the processing strategies in CIs being spectrally broad and so, phonemically related spectral structure is poorly represented with broadened filters. So, this explains the poor performance with background noise[33].

This study results showed significant positive correlations between both EABR slope, amplitude measurements and WRs at both apical and basal electrodes. Furthermore, statistically significant negative correlations were obtained between previous measurements, at both apical and basal electrodes, and dB SNR loss of BKB-SIN values. No significant correlations were found between EABR thresholds, latencies, and WRS or dB SNR loss of BKB-SIN test.

Neural health affects speech outcome, several studies investigated how patterns of neural reorganization resulting from auditory deprivation might result in differences in spoken-language perception ability after the hearing is restored following CI activation in young children[34]. It has been suggested that poor growth of the output with increasing input, indicates that there are very few neurons which are active, and hence global transmission of the information to the auditory cortex is affected[35]. The current study results agreed with Kubo *et al*. who reported that consonant recognition score (CRS) measured 1 month postoperatively was correlated with the amplitude growth curve of EABR. Gallelgo *et al*.[36] found that wave V was significantly correlated with speech perception (phoneme recognition). Walton *et al*. and Gibson *et al*.[10,11] reported in their studies that the EABR waveform morphology significantly correlates with the eventual outcome in terms of speech perception.

Firszt *et al*. and Lundin *et al*.[12,37] found no relationship between EABR latencies and speech perception which was in accordance with our results. Smith and Simmons reported in their study that EABR threshold is not a good indicator of surviving cell which is well correlated with speech discrimination[27]. On the contrary, Firszt *et al*.[12] and Makhdoum *et al*.[38] reported no correlation between EABR amplitude and Speech reception test.

Abbass *et al*., also reported poor or non-significant correlation between EABR measures (slope and threshold) and speech recognition score[39].

BKB-SIN test was found to be correlated with ECAP measures. Kim *et al*. and Basiony *et al*.[2,40] studied the relation between ECAP slope and BKB and a conclusion was reached that the slope values were substantially linked with BKB-SIN test results. The better performance related to steeper sloped ECAP growth functions. However, to the authors ' knowledge no EABR research was done in correlation with BKB-SIN or other speech in noise tests.

Intelligibility of speech depends mainly on integrity of auditory system. So, persons with healthier SGN can benefit more from their CI and hence will have more intelligible speech[35]. This research results showed a positive relation between speech intelligibility and AGF slope obtained from apical and basal electrodes denoting that person with better slopes had better speech intelligibility scores which agreed with Wang *et al*.[22] who reported in their study a positive relation between AGF slope and speech intelligibility. No correlations were found between speech intelligibility and any of the other parameters (threshold, latency, and amplitude) which disagreed with Wang *et al*. results[22].

A higher auditory level translates into greater ability to distinguish one sound from another (pattern perception), recognize the sounds or words heard, and eventually understand the stimulus through audition.[41] This research results showed significant positive correlation between auditory ability and both EABR AGF slope measurement at both apical and basal electrodes.

In cochlear implanted children with a narrow internal auditory canal and a deficit cochlear nerve, Song *et al*. and Yamazaki *et al*. investigated the association between intracochlear EABR and auditory performance using the CAP[42,43]. According to their findings, people with high CAP ratings produced better EABR recordings than people with low CAP scores.

This study demonstrated no clinically significant correlation between EABR measures and age of participants. This agreed with Abdelsalam and Afifi[24] and Gordon *et al*.[44]. No statistically significant differences were observed between children and adults regarding EABR wave latencies and observational thresholds in their reports. This indicates that regardless of the length of auditory deprivation throughout childhood, the electrically evoked auditory brainstem pathways can still respond to electrical stimulation in children who receive cochlear implants. No clinically significant correlation was found between EABR measures and age at implantation or duration of CI use which agreed with Gordon *et al*.[44] and disagreed with Abdelsalam and Afifi[24].

Duration of CI use affects the auditory plasticity. Gallego *et al*. and Gordon *et al*.[36,44] reported that after chronic stimulation, significant decrease of wave V latencies occurred. This is related to the enhanced central neuroplasticity the takes place after continuous CI use. Numerous factors are critical for these findings, that should be taken into consideration as the underlying etiology of the hearing loss, preoperative residual hearing, the duration of previous HAs use before implantation which insure the continuous auditory input.

CONCLUSION

In conclusion, apical electrode had better EABR recording [higher amplitudes, steeper slopes, lower thresholds, and shorter latencies] than basal electrode. There are strong correlations between EABR AGF slopes and amplitudes, and CI performance measured by phoniatric and audiological evaluation tests. These optimistic results can be used to predict CI outcomes, assist physicians in giving pediatric CI users the best care possible, and support caregivers in having reasonable expectations.

CONFLICT OF INTEREST

There are no conflicts of interest.

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