ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

Asia Pacific Journal of Research
A peer reviewed international Journal
IMPACT FACTOR : 6.58
Print -ISSN -2320 - 5504
Online-E-ISSN - 2347 - 4793
University Grants Commission
Approved Journal S.N.45797

ELECTRICALLY EVOKED AUDITORY BRAINSTEM RESPONSE IN COMPLETE COCHLEAR COVERAGE

Narendra Kumar Mariappan*, Ranjith Rajeswaran**, Jayakumar Praveena***

**Assistant Professor, MERF-Institute of Speech and Hearing, Chennai 600 028*

***Principal, MERF-Institute of Speech and Hearing, Chennai 600 028*

****Assistant Professor, Department of Speech and Hearing, SRM University, Kattankolathur, Kanchipuram, 603 203*

ABSTRACT

The present study is focused to profile the Electrically Evoked Auditory Brainstem Response (EABR) along the length of the cochlea. Twenty children, implanted with Med-El Pulsar cochlear implants were randomly selected for the study. Electrically evoked auditory brainstem responses were recorded in all children at three different regions in the cochlea using 300CU, 500CU and 700CU with 30 micro second duration biphasic pulses through the cochlear implant. The stimulation rate used were, 34.1/s. Response profiling were done based on morphology of the waveform, amplitude of EABR peaks, Intensity-latency function and rate latency function with respect to the site of stimulation along the length of cochlea. EABR morphology and amplitude were better at apical region of cochlea. Latency changes with respect to site of stimulation in EABR are minimal. Good EABR amplitude represents better synchronous firing of nerve fibers. Appropriate stimulation through apical electrodes in cochlear implant will improve speech perception especially in the presence of noise.

Key Words: EABR, Complete cochlear coverage, Apical stimulation

Introduction

Cochlear Implant (CI) is a bionic device, surgically implanted to restore hearing sensation in people with severe to profound hearing loss, who has minimal or no benefit with the hearing aids. Since the invention of clinically implantable CI by William F. House (1961), a single channel implant, most of the changes are focused on improving the quality of signal which in turn improves the quality of sound perception. At present there are multichannel implants that effectively stimulates throughout the length of cochlea thereby using the tonotopicity in the cochlea. For children, electrical stimulation of the cochlea can more effectively activate the central auditory pathway, providing auditory perception and enabling development of speech perception skills (R.T. Miyamoto, K.I. Kirk, S.L. Todd, A.M. Robbins, M.J. Osberger, 1995).

Electrically Evoked Auditory Brainstem Response (EABR) is the first electrical response to be recorded in human subjects (Starr & Brackmann., 1979). It is a test of neural synchrony, which records the synchronous firing of auditory nerve to an electrical stimulation. Recording is usually taken between the vertex and the mastoid contralateral to the implanted ear. A lower high pass filter of 10-20 Hz than conventional 100 Hz as of in A-ABR is used to avoid temporal spread of artifact. Rest of the parameters is similar to that of the A-ABR (Mason., 2003).

ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

Clinical use of EABR can be followed throughout the process of implantation. Pre-operatively it can be recorded using extra cochlear electrode for determining candidacy for CI, intra-operatively it can be incorporated to check the neural integrity and post-operatively for initial device programming and future fine tuning. Post operative recording of EABR can also provide valuable assistance with the management of patients with who present with the problem of device malfunction and difficulties in tuning. The common pediatric application of EABR is the estimation of physiologic threshold for electrical stimulation which is the basic step in the process of programming a cochlear implant (Brown et al., 1994; Shallop, Van Dyke, Goin, & Mischke, 1991). As behavioral test techniques are not feasible with infants and young children, EABR is a reliable alternative to behavioral techniques for estimating threshold and comfortable levels for electrical stimulation.

Characteristics and origins of EABR waveforms were similar to those of ABR, where the absolute latencies were 1-2 ms shorter than ABR latencies but III-V intervals remained the same as that of conventional ABR (Wang., 2009). Firszt et al. (2002) studied the effect of stimulus current level and the electrode site on EABR in 11 adult Clarion CI users and concluded that apical electrode had the best responses with respect to latency, amplitude and morphology and the basal electrode had the least responses. The results of threshold estimation with EABR in patients with CI are not as accurate as the estimation of behavioral thresholds with conventional ABR in children with HI. One factor affecting the accuracy of threshold estimation is electrode site within the cochlea (Suk and Reyul., 2000). The present study is focused to record EABR with a constant level of stimuli (CU) across the subjects and the stimulation site (apical, middle and basal turn) in the cochlea by comparing the morphology, amplitude and latency of EABR waveforms at different turns of cochlea.

Method

Participants

Twenty children (12 male and 8 female) implanted with Med-El Cochlear implant Sonata with complete cochlear coverage were recruited. All twelve intra cochlear electrodes were active, with normal impedance range and stabilized MAP. The implant age ranged from 5 months to 1 year. Children with abnormal cochlear development, auditory nerve anomalies, history of implant failure, disabled electrodes, incomplete insertion and associated problems were excluded from the study.

Procedure

Informed consent was taken from the parents of the children before EABR procedure. The subjects were instructed that they will be hearing series of sounds in their implanted side within the comfortable level. The subjects were asked to lie down in supine position on a couch in the sound treated room. The electrode sites vertex (Cz) for active electrode, forehead (Fpz) – common and contralateral mastoid (M1/M2) – reference were cleaned with nuprep and the electrodes were secured to their respective sites using T20 conductive gel and micropore surgical tape.

Biphasic pulses of 30 µs were used for eliciting EABR. Stimulus parameters were controlled using Maestro (version 4.0.1) software installed in a DELL laptop, through DIB II (Diagnostic Interface Box II, MEDEL) which is used to connect the external processor to the software which in turn stimulates the electrode sites (apical – El 2; middle – El 7 and basal – El 11) of implant via Dib coil transcutaneously. The stimuli were presented at 34.1/s stimulation rate at each stimulation level 300 CU (Current Units), 500 CU and 700 CU in alternating polarity. DIB II is linked with IHS Smart EP V 5.00 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 10– 3000 Hz and recorded between 0 – 10 ms time window. A total of 2000 sweeps of recording were done for all the subjects.

Analysis

Morphology, amplitude and latency of EABR waves were analyzed. For morphology the presence of major peaks eII, eIII, and eV of the EABR was analyzed. The peak to trough amplitude, measured in µV of each recorded EABR peak was analyzed. The latency of each EABR peak was measured from the onset of the stimuli to the peak measured in ms.

Statistical Analysis

The data were analyzed for statistical significance using appropriate tests performed through Scientific Package for Social Services (SPSS) version 20.0. Percentage of presence of EABR peak was used to describe morphology. Independent ‘t’ test was used to compare the amplitude and latency difference within a stimulation site. One way ANOVA was used to compare the amplitude and latency difference between the stimulation sites.

ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

Results

Twenty children with MedEl Sonata implant were included in the present study. Table 1 show the age at testing and implant age of the subjects. All subjects had unilateral cochlear implants. EABR waves could be recorded for all the subjects at 500 CU and 700 CU at all stimulation sites.

Table 1.

Demographic detail of the subjects

	Range	Mean ± SD
Age of children at time of testing	1.6 years – 11.4 years	5.8 years ± 2.9 years
Implant age	5 months – 1 year	9.1 months ± 2.7 months

Morphology

The number of EABR peaks recorded at different sites for 500 and 700 CU is tabulated in the Table 2. At apical electrode El 2, for the stimulation level of 500 CU, 50% of the subjects had all three major peaks eII, eIII, eV of EABR, 20% had only two peaks eIII and eV, 10% had only one peak eV and 20% had no EABR peaks. When the stimulation level was increased to 700 CU, 60% had all three peaks, 20% had two peaks and 10% in one peak and absent peak category. At medial electrode El 7, with 500 CU, 20% had all three peaks and one peak respectively, 50% had two peaks and 10% with absent peaks. But using 700 CU 60% had all EABR peaks, 30% with two peaks, 10% with one peak. For basal electrode El 11 using 500 CU none of the subjects had all three EABR peaks, 20% had two peaks, 50% had only one peak and 30% had absence EABR. As the stimulation level increased to 700 CU, 20% had three peaks, 30% with two peaks, 40% with one peak and 10% of the subjects had no responses. Figure 1 shows the morphology of EABR waveforms.

Table 2

Number of peaks recorded using 500 CU and 700 CU at three stimulation sites

Peaks	**El 2**		**El 7**		**El 11**	
	500 CU	**700 CU**	**500 CU**	**700 CU**	**500 CU**	**700 CU**
eII, eIII & eV	10	12	4	12	0	4
eIII & eV	4	4	10	6	4	6
Only eV	2	2	4	2	10	8
Absent peaks	4	2	2	0	6	2

ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

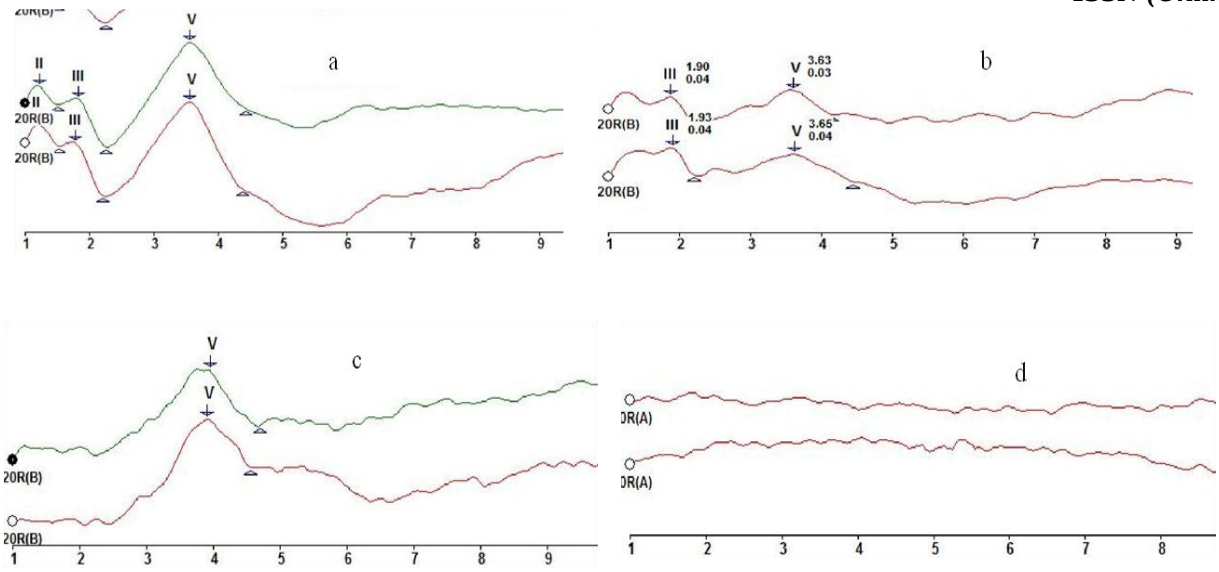

Figure 1: Morphology of EABR a) eII, eIII and eV; b) only with eIII and eV; c) waveform with only eV and d) no recordable EABR peaks

Amplitude of EABR peaks

Amplitude of the major EABR peaks (III and V) at both 500 CU and 700 CU are summarized in Table 3. It is evident that, as the stimulation level increased from 500 CU to 700 CU the EABR amplitude increases. It is also noted that as the stimulation site becomes more apical the mean amplitude increases. This amplitude changes across stimulation site and stimulation level were subjected to statistical analysis to find the level of significance.

Independent 't' test was used to find the significance of amplitude change with respect to stimulation level. At apical electrode EL 2, both eIII and eV amplitudes showed significant difference (p=0.019 and p=0.012 respectively) as the stimulation level was increased from 500 to 700 CU. At middle electrode El 7 only eV amplitude reached significance (p=0.047) with change in stimulation level. At basal electrode El 11 both eIII and eV did not reach significance (p>0.05).

Table 3

Mean amplitude of EABR peaks measured using 500 and 700 CU at three stimulation sites

Peaks	**El 2**		**El 7**		**El 11**	
	500 CU	**700 CU**	**500 CU**	**700 CU**	**500 CU**	**700 CU**
eIII	0.030	0.047	0.018	0.031	0.015	0.018
eV	0.038	0.062	0.028	0.043	0.018	0.027

Note: The amplitude values are in µV (Micro-Volt).

Amplitude change with respect to stimulation site for constant CU was analyzed using one way ANOVA. For 500 CU, only eV amplitude change reached statistical significance when the stimulation site was changed (p=0.02). Post Hoc analysis revealed that significant change in eV amplitude was seen between El 11 and El 2 (basal versus apical; p=0.013), but not between El 2-El 7 (p=0.256) and El 7-El 11 (p=0.250). At 700 CU, the amplitude change was significant for both eIII (p=0.001) and eV (p=0.000) with change in site of stimulation. Post Hoc analysis was done to find between which two stimulation sites, there was significant change in amplitude of EABR for constant stimulation level 700 CU. There was no statistical difference (p=0.160) in amplitude change between basal (El 11) and middle (El 7) electrodes. Amplitude change was significant between apical and basal electrode (P=0.001) and apical and middle electrode (p=0.042).

ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

Latency of EABR peaks

Absolute latencies of the major EABR peaks (III and V) at both 500 CU and 700 CU are summarized in Table 4. As the stimulation level increased from 500 CU to 700 CU, the latencies became better, but it was not appreciable. The mean difference in latencies ranged from 0.01 to 0.04ms for eIII and from 0.07 to 0.19ms for eV.

Independent 't' test was used to find the significance of change in latency with respect to stimulation level. At all three electrodes, the change in latency did not reach statistical significance ($p>0.05$) for change in stimulation level. One way ANOVA was used to find the change in latency across stimulation sites for constant stimulation level. At 500 CU, the latency change as a function of site of stimulation was not significant for both eIII ($p=0.486$) and eV ($p=0.186$) peak of EABR. At 700 CU, only eV latency change reached significance ($p=0.012$). Post Hoc comparison for 700 CU stimulation level revealed that the latency change was significant between El 2 and El 11 ($p=0.013$); approached significance ($p=0.048$) between electrodes El 2 and El 7, latency change was not significant between El 7 and El 11.

Table 4

Mean absolute latencies of EABR peaks measured using 500 and 700 CU at three stimulation sites

Peaks	**El 2**		**El 7**		**El 11**	
	500 CU	**700 CU**	**500 CU**	**700 CU**	**500 CU**	**700 CU**
eIII	1.91	1.87	1.95	1.92	2.03	2.02
eV	3.95	3.76	3.92	3.83	4.16	4.09

Note: The latency values are in ms (millisecond)

Discussion

All children had recordable EABR waveforms. EABR waveform patterns were similar to that of acoustic ABR waveforms, but without peak I, which is masked by the stimulus artifact. The morphology of EABR was best at the apical electrode and the poorest at the basal electrode. The amplitude of EABR was greatest at the apical electrode followed by the middle electrode and least at the basal electrode.

Gordon et al. (2002) suggests that greater neural synchrony can be achieved through electrical stimulation than the acoustic stimulation. In the present study we can see steep EABR peaks with steeper slope at apical electrode. This indicates that the neural synchrony is greatest at the apical region of cochlea. A greater density or survival rate of neuronal tissue adjacent to the electrode in the apical region could also explain the better morphology and amplitude at apical electrode than the basal and middle electrode. For synchronous activity, all the spiral ganglion cells should provide a time locked response, called as phase locking. Phase locking is a phenomenon present in auditory nerves especially for the frequencies up to 1000 Hz, and is fairly represented up to 5000 Hz. It is poorly represented for frequencies beyond 5000 Hz (Johnson, 1980; Trevino et al, 2009). The better morphology and amplitude at apical electrodes can be due to better phase locking at low frequencies (apical). The degeneration of the peripheral neurons and the spiral ganglion cells occur more rapid after the loss of hair cells in the basal end of the cochlea than the apical end (Zimmermann et al. 1995) which could be the reason for poor morphology at the basal electrode.

The latencies of EABR waveforms were 1 to 1.5 ms earlier than acoustic ABR waves (Table 4). This is in acceptance with various authors in the literature (Shallop et al. 1990; Brown et al. 1994; Wang et al. 2009; Brown et al, 2000; Firszt et al. 2002; Gordon et al. 2006; Gordon et al. 2007). This earlier latency can be due to the direct stimulation of spiral ganglion cells which reduces conduction time that takes place in acoustic ABR. The latency of the EABR peaks did not show significant change with respect to the site of stimulation, which can be attributed to the absence of travelling wave in CI stimulation. Hence at all stimulation sites, the latency is similar. One exception was that, eV at 700 CU stimulation reached significance and this was seen only between the electrodes El 2 and El 11. Thus the latency of the information reaching the nerve remains almost similar across the intra-cochlear electrodes, with significant difference seen only between the apical most and basal most electrodes. The latency changes in EABR are greatest at the level of threshold. Once the stimulation level is several times above the threshold, there is no or negligible change in the latencies of EABR.

In the current study, the apical electrode tends to elicit steeper (amplitude) and earlier (latency) EABR waveforms (Table 3 and 4), than the middle and basal electrode. The same trend has been reported by various authors (Gallego et al. 1997; Thai-van et al. 2007

ISSN (Print): 2320-5504
ISSN (Online): 2347-4793

Gordon et al. 2007; Abbas et al. 1999; Miller et al. 1993). These differences between the apical and other electrodes reflect the relative difference in the density of surviving spiral ganglions and the possible difference in the neurophysiology of the nerves at different regions of the cochlea.

Conclusion

EABRs can be reliably recorded from children using cochlear implants. It could shed light upon the survival of spiral ganglion cells and their effective functioning. Spiral ganglion cells are well preserved at the apical end of cochlea than the basal end. Apical neural elements have better phase locking ability - synchronous firing than the neural elements at the other region of cochlea. Stimulation of this apical region with appropriate speech coding strategy could improve the temporal coding in children with cochlear implants which in turn improves speech perception, especially in the presence of noise.

Reference

1. Abbas, P.J., Brown, C.J., Shallop, J.K., Firszt, J.B., Hughes, M.L., Hong, S.H. (1999). Summary of results using the nucleus CI24M implant to record the electrically evoked compound action potential. Ear Hear, 20 (1), pp. 45-59
2. Brown, C., Hughes, L., Luk, B., Abbas, P., Wolaver, A., Gervais, J. (2000). The relationship between EAP and EABR thresholds and level used to program the nucleus 24 speech processor: data from adults. Ear Hear, 21 (2), pp. 151-163.
3. Brown, C.J., Abbas, P.J., Fryauf-Bertschy, H., Kelsay, D., & Gantz, B.J. (1994). Intraoperative and postoperative electrically evoked auditory brain stem responses in nucleus cochlear implant users: implications for the fitting process. *Ear and Hearing*, *15* (2), 168-176.
4. Firszt, J.B., Wackym, P.A., Gaggl, W., Burg, L.S., & Reeder, R.M. (2002). Neurophysiology of cochlear implant users I: effects of stimulus current level and electrode site on the electrical ABR, MLR, and N1–P2 response. Ear Hear, 23, pp. 502-515
5. Gallego, S., Truy, K., Morgon, A., Collet, L. (1997). EABRS and surface potentials with a transcutaneous multielectrode cochlear implant. Acta Otolaryngol (Stockh), 117, pp. 164-168
6. Gordan, K. A., Papsin, B. C., Harrison, R. V. (2002). Auditory brainstem and midbrain development after cochlear implantation in children. Ann Otol Rhinol Laryngol, 111 (2002), pp. 32-37
7. Gordon, K.A., Papsin, B.C., Harrison, R.V. (2006). An evoked potential study of the developmental time course of the auditory nerve and brainstem in children using cochlear implants. Audiol Neurotol, 11, pp. 7-23
8. Gordon, K.A., Papsin, B.C., Harrison, R.V. (2007). Auditory brainstem activity and development evoked by apical versus basal cochlear implant electrode stimulation in children. Clin Neurophysiol, 118, pp. 1671-1684
9. Johnson, D. H. (1980). "The relationship between spike rate and synchrony in responses of auditory-nerve fibers to single tones". *The Journal of the Acoustical Society of America*. 68 (4), pp. 1115
10. Mason, S.M. (2003a). Electrophysiological and objective tests. *In:* B. McCormick & S. Archbold (eds.) *Cochlear Implants: Objective Measures.* London: Whurr, pp. 130-159.
11. Miller, C.A., Abbas, P.J., Brown, C.J. (1993). Electrically evoked auditory brainstem response to stimulation of different sites in the cochlea. Hear Res, 66 (2), pp. 130-172
12. Miyamoto, R. T., Kirk, K. I., Todd, S. L., Robbins, A. M., & Osberger, M. J. (1995). Speech perception skills of children with multichannel cochlear implants or hearing aids. *The Annals of otology, rhinology & laryngology. Supplement*, *166*, pp. 334-337.
13. Shallop, J. K., Beiter, A. L., Goin, D.W., Mischke, R. E. (1990). Electrically evoked auditory brain stem responses (EABR) and middle latency responses (EMLR) obtained from patients with the nucleus multichannel cochlear implant. Ear Hear, 11, pp. 5-15.
14. Shallop, J.K., VanDyke, L., Goin, D.W., Mischke, R.E. (1991). Prediction of behavioral threshold and comfort values for Nucleus 22-channel implant patients from electrical auditory brain stem response test results. *Ann Otol Rhinol Laryngol. 100,* pp. 896-8.
15. Starr, A., and Brackmann, D.E. (1979). Brainstem potentials evoked by electrical stimulation of the cochlea in human subjects. *Ann. Oto. Rhinol. Lar, 88,* pp. 550-56.
16. Suk, L.K., Reyul, S.K. (2000). Relationship of the Implant Electrical Auditory Brainstem Response Threshold to the Postoperative T Level in Children with Cochlear Implants. *Adv Otorhinolaryngol. Basel, Karger, 57,* pp. 270-72.
17. Thai-Van, H., Cozma, S., Boutitie, F. (2007). The pattern of auditory brainstem response wave V maturation in cochlear-implanted children. Clin Neurophysiol, 118, pp. 676-689
18. Trevino, A., Coleman, T. P., Allen, J. (8 April 2009). A dynamical point process model of auditory nerve spiking in response to complex sounds. *Journal of Computational Neuroscience*. 29 (1-2), pp. 193–201.
19. Wang, L., Zhangb, Q. Wangc, Q., Donga, M., Zengb, Y. (2009). Functional evaluation of auditory system in patients with cochlear implant using electrically evoked auditory brainstem responses. Acoust Phys, 55, pp. 857-865
20. Zimmermann, C.E., Burgess, B.J., & Nadol, J.B. (1995). Patterns of degeneration in the human cochlear nerve. *Hearing Research, 90* (1-2), pp. 192-201.