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Changes in response characteristics of cortical auditory evoked potentials in bilateral cochlear implantees

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ABSTRACT

Background: Cochlear implants (CIs) represents the most successful intervention to restore hearing in profoundly hearing impaired children and adults. An objective measures such as cortical auditory evoked potentials (CAEPs) would provide more insights to the auditory process involved in post implantation. Aim of the study was to profile the change in response characteristics of CAEPs in simultaneous binaural cochlear implantees. Objective was to measure change in latency and amplitude in monoaural and binaural condition for speech stimulus with change in intensities.
Methods: Ours study is an observational retrospective study done at a tertiary ENT referral centre in south India, between Jan 2014 to Dec 2015. Out of total 15 patients with bilateral cochlear implantation, 7 consecutive bilateral simultaneous cochlear implantees with chronological age between 2-6 years were included in the study. Only pre-lingual congenital hearing loss children with no syndromic associations and normal cochlear anatomy were included while, peri-lingual, post-lingual children and children with sequential bilateral implantation were excluded from the study.
Results: Amplitude of P1 was higher for binaural stimulation compared to monoaural stimulation. Latency of P1 was smaller for binaural compared to monoaural stimulus. In monaural stimulation the latency of P1 was smaller in right ear compared to left ear. However the difference between the right ear, left ear and binaural conditions were not statistically significant. Ours is a preliminary study and more bilateral implantees will be included in future studies to give more power to the study.
Conclusions: We suggest that CAEPs can be used as a useful objective tool for assessment of post CI outcome.

Keywords: Cochlear implantation, Cortical auditory evoked potentials, P1 latency, P1 amplitude, Prelingual deafness, Congenital hearing loss, Objective test

INTRODUCTION

Cochlear implantation (CI) is accepted modality and standard of care to restore hearing in severe to profound cochlear hearing loss. Bilateral simultaneous or sequential CI is becoming common especially in pediatric clinical practice. 'Binaural benefits' include improved identification/localization of sound source in space, increased perception of loudness (binaural summation), improved hearing in quiet and noisy environment and binaural squelch.[1-7] Hence, it is reasonable to speculate that bilateral CI in young children may ameliorate the effects of auditory deprivation earlier than unilateral CI.

Auditory evoked potentials (AEPs) is an electrical response providing information about the neuronal activity and functional integrity of the auditory system in response to an auditory stimulus (clicks, pure tones, speech sounds). They are classified into short, middle and long latency evoked potentials depending upon the time delay between the onset of stimulus and the observed electrical response.

Cortical auditory evoked potentials (CAEPs) are long latency AEPs evoked by speech sound and processed in or near the auditory cortex. It is a non-invasive and objective measure of the central auditory nervous system. They occur at least after 50 milli seconds (ms) of presentation of acoustic stimuli and referred to as long latency AEPs (LLAEPs) or auditory late responses (ALRs).[8,9] The morphology of waveform in LLAEPs comprises of P1N1. N1 is a well-defined negative peak with a latency between 90 and 150 ms. N1 is preceded by a smaller positive peak, P1, with a latency of approximately 50 ms. The documentation of CAEPs in individuals with CI plays a significant role to determine the maturation of auditory cortex and presence of processing of auditory stimuli at higher centers.[10] It has been suggested that the peaks in CAEP waveform originates from multiple neural generators.[11]

The CAEP peak latency represents the entire synaptic transmission time along the auditory pathway. Hence it is believed that the presence of CAEP waveform reflects that the acoustic stimulus has been perceived by the listener.[11] The threshold for CAEPs has been found to correlates with a subject's psychophysical threshold. Since the main generators are likely to be originating from within the auditory cortex bilaterally. CAEPs can be used to program bilateral cochlear implantees and also to monitor the binaural advantages and maturation of the auditory cortex. It is expected that an objective measures such as CAEPs would provide more insights to the auditory process involved in post implantation. Therefore the current study is aimed at measuring the responses objectively utilizing CAEPs in bilateral cochlear implantees.

Aims and objectives

Aim of this study was to profile the changes in response characteristic of CAEPs in bilateral simultaneous CI done at our centre. Objective was to measure the changes in latency and amplitude of CAEPs both in mono-aural condition (right or left) and in binaural condition for different speech sounds at different intensities post cochlear implantation.

METHODS

Our study is an observational retrospective study done at tertiary care ENT hospital in South India from January 2014 to Dec 2015. There were a total of 15 patients with bilateral cochlear implantation at our centre during the study period. The inclusion criteria were age between 2-6 years, pre-lingual congenital bilateral profound hearing loss children, normal cochlear anatomy and bilateral simultaneous cochlear implantation were included in the study. Peri-lingual and post-lingual deafness, syndromic deafness and multiple disabilities and sequential bilateral implantation were excluded from the study. 7 bilateral simultaneous cochlear implantees with chronological age range from 2-6 years were included for the present study. The P1 responses are obscured by presence of a stimulus artifact in first 100 ms of recording seen in cochlear implant devices with all manufactures. These subjects were excluded from study.

All children underwent thorough pre-operative evaluation including blood investigations, ECG, audiological evaluation, speech and language evaluation, imaging studies including opinion of opthalmologist, cardiologist, pediatrician and clinical psychologist.

The participants underwent CI by same senior surgeon and similar oto-neurological team following standard protocols. The implant used was of the same model from the same manufacturer. All the participants had an uneventful surgery. Switch on of device was done 3 weeks after surgery. The implantees received habilitation at the same centre using same protocol. The participants did not exhibit any electrode malfunction. All the participants had a minimum of 3 months of experience with the device. As per out institutional protocol, CAEPs were measured at end of 3 month post switch.

Preparation for recording CAEPs

Participants were instructed to refrain from using hair products on the morning of recording session to avoid heightened impedance. Scalp preparation was done by cleaning it with alcohol wipes and mild abrasive gel (Nu-prep) prior to electrode placement. Midline electrodes were aligned in international 10-20 channel configuration.

Scalp electrodes were placed at Cz (active), ipsilateral mastoid (reference) and Fpz (ground). Electrode impedance was checked. If necessary, preparation was repeated to achieve an impedance less than 5 Kilo-ohms (K-ohms) between electrodes (active and ground; reference and ground). If impedances of less than five kohms could not be achieved, the electrode channel was deactivated prior to recording.

CAEP recording

Recording of CAEP responses was done using NAL HEAR Lab system (Frye Electronics). Cortical responses were obtained using sound field speech stimulus /m/ (low frequency), /g/ (mid frequency) and /t/ (high frequency) presented at 55 dBSPL, 65 dBSPL and 75 dBSPL.

All subjects received an optimal map based on the regular programming procedure and protocol by our experienced implant audiologist team. During programming all electrodes which evoke auditory sensation were marked as auditory and ones which did not evoke auditory sensation were marked as non-auditory electrodes. Optimized maps were loaded in the subject's sound processor.

The subject was encouraged to sit quietly in the test position using distractions such as age-appropriate toys and silent movies. The audiologist providing the distraction also observed the child's state, as the test progressed, to ensure he or she remained awake and alert and that electrodes remained in place. Speech stimuli were presented with a fixed stimulus interval of 1125 ms. Two randomly assigned stimuli were interleaved automatically in blocks of 25 presentations per stimulus. Each session lasted for the duration of 45-60 minutes including a ten minutes interval period. CAEP responses were recorded both in mono-aural condition (right or left) and in binaural condition.

Statistical method

All the continuous data were represented by mean with standard deviation (SD) and analysed by Mann-Whitney U test. The analysis was done by using SPSS 17.Version. A p value less than 0.05 was considered as significant.

RESULTS

Comparison of change in amplitude

Comparison of change in amplitude of right, left and binaural conditions for the three speech stimuli /m/, /g/ and /t/ at 55 dBSPL, 65 dBSPL and 75 dBSPL were recorded and is depicted in Table 1-3.

It was observed that amplitude of P1 in binaural condition (both ears) was higher compared to amplitude of P1 in mono-aural condition (right or left) for speech stimulus /m/, /g/ and /t/ at all 3 intensity levels (55 dBSPL, 65 dBSPL and 75 dBSPL). However, the difference between the right ear, left ear and both ears were not statically significant (p value for /m/=0.70, 0.84 and 0.61; p value for /g/=0.70, 0.70 and 0.59; p value for /t/=0.88, 0.73 and 0.66 respectively).

It was also observed that, there was increase in amplitude with increase in intensity both in mono-aural and binaural condition. It was noted that there was right ear advantage for the speech stimuli tested (/m/, /g/ and /t/) at all 3 intensity level (55 dBSPL, 65 dBSPL and 75 dBSPL). However, the difference between right and left ear was not statistically significant.

Table 1: Amplitude response for stimulus /m/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and both ears.

Intensity (dBSPL)	Right ear response (µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	0.99	0.41	0.94	0.31	1.14	0.42
65	1.08	0.34	0.99	0.25	1.19	0.33
75	1.16	0.34	1.03	0.24	1.18	0.33

Table 2: Amplitude response for stimulus /g/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and both ears.

Intensity (dBSPL)	Right ear response (µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	0.80	0.53	0.73	0.46	0.90	0.50
65	0.88	0.48	0.87	0.40	1.02	0.45
75	1.02	0.43	0.91	0.37	1.15	0.51

Table 3: Amplitude response for stimulus /t/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and both ears.

Intensity (dBSPL)	Right ear response (µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	0.74	0.51	0.68	0.42	0.84	0.48
65	0.82	0.46	0.79	0.43	0.99	0.45
75	0.87	0.47	0.85	0.38	1.07	0.47

Another interesting finding observed across participants is that the amplitude of P1 for /m/ is higher than /g/ and /t/ in both monoaural and binaural conditions at all stimulus levels. However, it was not statistically significant.

Comparison of change in latency

Comparison of change in latency of right ear, left ear and both ears (binaural conditions) for three speech stimuli tested (/m/, /g/ and /t/) at 55 dBSPL, 65 dBSPL and 75 dBSPL were recorded and is depicted in Table 4-6.

It was observed that P1 latency response for speech stimulus tested (/m/, /g/ and /t/) at different intensity levels (55 dBSPL, 65 dBSPL and 75 dBSPL) decreases as stimulation level was increased for both monoaural and binaural conditions. However, difference between the right ear, left ear and both ears was not statistically significant (p value for /m/=0.87, 0.80 and 0.85; p value for /g/=0.73, 0.87 and 0.85; p value for /t/=0.88, 0.87 and 0.86) at 55 dBSPL, 65 dBSPL and 75 dBSPL respectively.

It was also noted that latency of P1 was shorter for binaural compared to monoaural stimulation. While in monoaural stimulation the latency of P1 was smaller for right ear. However, the difference between right and left ear was not statistically significant.

There was no statistically significant difference in latency of P1 across all stimulus levels. The lack of non-significant statistics could be because of small sample size and it could be because the CAEPs were measured only after 3 months post implantation.

Out data and its outcome are preliminary results and we plan to include more patients and also have a control group in future studies.

Table 4: Latency response for stimulus /m/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and binaural conditions.

Intensity (dBSPL)	Right ear response(µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	159.86	22.02	160.14	23.5	155.43	22.1
65	155.29	22.9	156.00	20.3	151.14	20.1
75	152.43	21.3	154.00	21.0	149.29	20.8

Table 5: Latency response for stimulus /g/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and binaural conditions.

Intensity (dBSPL)	Right ear response(µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	150.57	27.5	154.43	26.1	147.43	20.5
65	147.14	22.7	150.00	22.1	144.13	20.5
75	142.43	20.5	143.86	21.3	141.29	19.7

Table 6: Latency response for stimulus /t/ at 55 dBSPL, 65 dBSPL and 75 dBSPL in right ear, left ear and binaural conditions.

Intensity (dBSPL)	Right ear response(µV)		Left ear response (µV)		Both ear response (µV)	
	Mean	SD	Mean	SD	Mean	SD
55	150.33	22.3	150.33	22.1	150.33	18.4
65	150.43	19.4	151.71	20.0	150.43	19.1
75	149.14	23.3	149.71	20.4	149.14	19.1

DISCUSSION

Bilateral CIs are gradually becoming as the accepted modality of treatment for bilateral severe to profound cochlear hearing loss in the developed world. This is because of the superior outcomes and advantage of binaural hearing over monaural hearing. The assessment of bilateral implantees has been done by various authors on the basis of speech understanding by Consonant Nucleus Consonant (CNC) and Hearing in noise test (HINT), Bambford Kowal Bench Sentence in noise test (BKB-SIN Test), Speech intelligibility in noise test etc.[7,12] However very limited studies on binaural hearing in subjects with bilateral CI using CAEP waveform morphology (an objective test) have been published especially from developing countries like India mainly because of cost constraints.[13]

The Litovsky study highlighted that bilaterally implanted children can hear speech in noise better, sometimes as early as three months after activation of their second implant.[14] The study also mentioned that bilaterally implanted children can use information about the locations of sounds to separate speech from noise much better with two implants compared with one and many of the bilaterally implanted children can by 12 months (after the second implant is received) correctly identify sounds coming from their right or their left that are 30 degrees apart. At the end, the result showed that subjects using bilateral cochlear implants had significantly improved abilities to identify source locations compared with unilateral CI users. In a study by Bauer et al, patients who received simultaneous early bilateral cochlear implants, the P1 latency was near normal limits by 1 month after implantation.[13]

In our studied we measured CAEPs only at 3 months of bilateral simultaneous cochlear implantation. Ours is a preliminary study with a small sample size of 7 patients with bilateral simultaneous CI with CAEP measurements done at 3 months post switch on.

It was observed in our study that amplitude of P1 was higher for binaural stimulation compared to mono-aural stimulation for all 3 speech frequency tested at 3 different intensity levels as shown in Table 1-3. However, the difference between the right ear, left ear and both ears were not statically significant. It was also observed that, there was increase in amplitude with increase in intensity both for mono-aural and binaural stimulation. It was also observed that there was right ear advantage seen for stimuli /m/, /g/ and /t/ at all 3 intensity level tested. However, the difference between right and left ear was not statistically significant.

It was also observed that the amplitude of P1 for /m/ was higher than /g/ and /t/ for both monoaural and binaural conditions at all stimulus levels tested. However, it was not statistically significant. The higher amplitude of P1 for /m/ could be because of spectral energy and gain levels in sound processor and group of neurons stimulated for /m/ (stimulus /m/ has a peak energy around 250 Hz delivered at apical electrodes). Secondly, amplitude of evoked potentials are higher in apical electrodes compared to basal electrodes. Brill et al. studied site of cochlear stimulation and its effect on electrically evoked compound action potentials (ECAP) using Med-EI standard electrode array.[15] They observed amplitude of ECAP was significantly higher in apical electrodes stimulating the apical region compared to basal region. They also reasoned the higher amplitude in apical region is due to narrowed distance between recording electrode and stimulated neural tissues at apex of cochlea or due to increased neural survival rate of neural tissue at apex.[15]

Regarding P1 latency responses for different speech stimulus tested at different intensity levels, in present study, it was observed that P1 latency decreased with increase in intensity level both for mono-aural and binaural stimulation as seen in Table 4-6. Also, the latency of P1 was shorter for binaural compared to monaural stimulation. Also for monaural stimulation the latency of P1 was smaller in right ear compared to left ear. However, the difference between the right ear, left ear and both ears was not statistically significant.

Based on our observation of P1 amplitude response and P1 latency response of the 7 bilateral simultaneous CI, the results indicate towards a right ear advantage when we tested the ears in mono-aural condition and secondly binaural stimulation advantage over mono-aural stimulation advantage.

Also it was observed that P1 latency and intensity function of CAEP is similar to latency –intensity function of Auditory Brainstem Response (ABR). Latency of P1 decreased as intensity of stimulus increased and amplitude of P1 increased as the stimulus level were increased.

The characteristics of waveform of CAEP (i.e. amplitude and latency) depends on stimulus level (intensity) and stimulus type (/m/, /g/ and /t/). The characteristics of CAEPs waveform (latency and amplitude) with respect to stimulus level and type of stimulus were not statistically significant in the present study (probably because of small sample size) but may be large enough to be important. Future studies needs to be carried out with larger number of patients.

Limitations

One of the main limitations of the study was limited data, due to less number of bilateral cochlear implantees. The main reason for lesser number of bilateral cochlear implantees in India is its prohibitive cost in developing country like us. Another limitation of the study is the unavailability of digitized software to calculate the binaural interaction component in CAEPs. Lastly we did not have CAEPs data in the above group at 1 month, 6 months and 12 months post implantation because it was a retrospective study. These are preliminary results of our study and we plan to include more patients with bilateral cochlear implantation in future with a control group and give more power to the study.

CONCLUSION

Bilateral simultaneous cochlear implantation has synergistic (ipsilateral and contralateral) stimulation which facilitates rapid development of central auditory pathways. We also conclude that CAEPs can be used as an objective tool for assessment of post CI outcome thus providing clinically useful biomarker of central auditory maturation and development in young children who undergo cochlear implantation.

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