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Outcomes of Cochlear Implantation in Auditory Neuropathy Spectrum Disorder and the Role of Cortical Auditory Evoked Potentials in Benefit Evaluation

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Original Investigation

Abstract

Objective: To compare the outcomes of cochlear implantation (CI) in children with auditory neuropathy spectrum disorder (ANSD) and age-matched controls with profound sensorineural hearing loss, using categories of auditory performance (CAP), speech intelligibility rate (SIR), meaningful auditory integration scale (MAIS), and meaningful use of speech scale (MUSS), and to determine the role of Cortical Auditory Evoked Potentials (CAEP) in benefit evaluation after CI.

Methods: Ten patients (8 males and two females) with ANSD who underwent CI were included in the study. Auditory and speech scores were compared between baseline and after 12 months of habilitation in children with ANSD. Post CI speech scores in children with ANSD were compared with the control group (age-matched children with profound sensorineural hearing loss) at 12 months of habilitation. P1 latency of CAEP has a good correlation with auditory and speech scores in children with ANSD in the study group.

Results: Significant benefits were seen in children with ANSD who underwent CI compared to the baseline CAP and SIR scores and one year after habilitation. There is no statistically significant difference in outcomes between the two groups with CI (ANSD and profound sensorineural hearing loss) (p-value: CAP=1.00, SIR=0.84, MAIS=0.33, MUSS=0.08). Speech perception in noise test (SPIN) scores in children with ANSD were 63% and 80% with 0 dB signal noise ratio (SNR) and +10dB SNR, respectively. P1 wave of CAEP has a good correlation with the subjective outcomes.

Conclusion: CI in children with ANSD has showed benefits comparable to children with profound sensorineural hearing loss. CAEP is a useful tool in objectively assessing cortical maturity in children with ANSD following CI.

Keywords: Cochlear implantation; auditory neuropathy spectrum disorder; cortical maturity; speech scores; habilitation

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Introduction

Auditory neuropathy spectrum disorder (ANSD) or auditory dys-synchrony is a condition where otoacoustic emissions (OAE) and/or cochlear microphonics are present, and auditory brainstem responses (ABR) and acoustic reflexes are absent or abnormal (1-4). The pure tone audiogram of patients with ANSD may range from normal to profound hearing loss (1). Patients with normal pure tone thresholds may have poor speech discrimination scores. Speech recognition in patients with ANSD is poor than expected for the pure tone thresholds, and speech recognition in noise scores is also poor compared with the patients with sensorineural hearing loss (1, 2, 5). It can occur at any age, from childhood to advanced age. Neonatal hyperbilirubinemia and birth asphyxia have been suggested as the main risk factors in these children (6).

Fernandes et al. (6) showed that cochlear implantation (CI) in people with ANSD helps in improving the detection of speech sounds and the recognition of words and sentences, but still many people with ANSD have difficulty in speech perception in noisy conditions. A cochlear implant directly stimulates the auditory spiral ganglion cells and partially replaces the functions of the auditory air cells, thereby helping in neural synchrony and improved hearing outcomes (7-12). Approximately 20% of patients with ANSD have metabolic disturbances like anoxia, hyperbilirubinemia, and infections. Multiple handicaps are possible with these etiologies.

Habilitation after CI and behavioral assessments are difficult in these patients. Objective evaluation like cortical auditory evoked potentials (CAEP) would be of benefit in assessing the outcome after CI in these children. Previously, CAEP have been used in estimating the hearing threshold of patients with sensorineural hearing loss and of those with ANSD (13).

The aim of our study is to analyze the outcomes of CI in patients diagnosed with ANSD and to compare the outcomes with age-matched control group (children with profound sensorineural hearing loss who underwent CI), and to determine the role of CAEP in evaluating the benefits of CI in patients with ANSD.

Methods

Our study is a retrospective one conducted in patients who received a CI between 2012 and 2014. The patients were selected from the cochlear implantation database maintained at our institution. The ethical committee of our institution has reviewed and approved the study (Reference number-MERF/EC-JUL.15/03). Informed consent was obtained from all the patients or their legal guardians included in the study group. Patients with ANSD who underwent CI between 2012 and 2014 were included. Patients with severe inner ear malformations on imaging and incomplete habilitation after CI were excluded.

All patients who underwent CI were enrolled in the one year habilitation training (2 classes per week) in our institution training center. Fourteen patients who were diagnosed with ANSD underwent CI from 2012 to 2014. One child with severe inner ear malformation i.e., Michel's deformity with hypoplastic cochlear nerve on the left side, and Mondini deformity on right side, was excluded. Three patients did not complete the habilitation training citing personal reasons and were excluded from the study. The remaining 10 patients were included in the study group. The demographic and clinical details of 10 patients are described in Table 1.

The control group was selected from the CI database from our institute. Ten age-matched children with profound sensorineural hearing loss who underwent CI between 2012 and 2014 with normal inner ear anatomy were randomly selected as controls.

Categories of auditory performance (CAP)

Categories of auditory performance (CAP) is used to measure the auditory performance of a child after CI (14). The scores range from 0 to 7; they represent the hierarchical scale of auditory perceptive ability and are described in Table 2.

Speech intelligibility rate (SIR)

Speech intelligibility rate (SIR) is used to measure the speech intelligibility of a child with implantation by quantifying their everyday spontaneous speech in real-life situations (15). SIR has five categories and is described in Table 3.

The parents were interviewed with questions based on different real-life situations involving the child. The child's auditory and speech production behavioral information was obtained, and meaningful auditory integration scale (MAIS) and meaningful use of speech scale (MUSS) scores were recorded.

Baseline CAP and SIR scores recorded immediately after implantation were compared with scores recorded after one year of habilitation. After completing one year of habilitation, CAP, SIR, MAIS, and MUSS scores were recorded and compared with those of age-matched children with profound sensorineural hearing loss who underwent CI (control group).

Speech perception in noise (SPIN) test

The SPIN test was performed by measuring speech discrimination scores using phonetically balanced bisyllabic words with fixed signal noise levels [0 dB signal noise ratio (SNR), +10dB SNR] in children above three years of age. Speech stimuli were set at 40dB above the speech reception threshold. Live monitored speech stimuli and speech noise were delivered via headset through same speakers. The SPIN test

Table 1. Demographic details for children with auditory neuropathy spectrum disorder who underwent cochlear implantation

Sr.No.	Age (Years)	Sex	Risk factor for hearing loss	Imaging	OAE	ABR	Side	Implant model
1	1.5	M	Nil	Normal	Present	Absent	Right	Medel pulsar
2	2	M	Neonatal kernicterus	Normal	Present	Absent	Right	Medel sonata
3	2	M	Family history	Bulbous internal auditory canal	Present	Absent	Right	Medel pulsar
4	3	M	Neonatal jaundice	Normal	Present	Absent	Right	Medel pulsar
5	3	M	Neonatal jaundice	Normal	Present	Absent	Right	Medel sonata
6	4	F	Nil	Normal	Present	Absent	Right	AB HiRes 90K
7	5	F	Nil	Normal	Present	Absent	Right	Medel sonata
8	6	M	Nil	Normal	Present	Absent	Right	AB HiRes 90K
9	6	M	Nil	Normal	Present	Absent	Right	Medel pulsar
10	6	M	Nil	Normal	Present	Absent	Right	Medel sonata

OAE: otoacoustic emission; ABR: auditory brainstem response; IAC: internal auditory canal was applied to all the children after completing one year of habilitation after CI.

Cortical auditory evoked potentials (CAEP)

The P1 component of CAEP has been established as a marker for assessing cortical maturity. The latency of P1 wave decreases with age from birth due to persistent auditory stimulation, and it reaches 60 ms for a middle-aged adult. The clinical implication of CAEP lies in the fact that it does not require behavioral cooperation from the child. CAEP complements other audiological tests in patients who are difficult to behaviorally analyze (16). CAEP has been in use for different purposes, such as objectively estimating hearing thresholds, hearing aid fitting in children, determining cortical maturation, and predicting behavioral outcomes in children with ANSD (17).

The procedure was conducted in a sound-treated room using standardized equipment (HEARlab H1000-ACA, 2010, USA). The electrical responses were recorded from the electrodes placed over the head. The test stimulus was a recorded speech sound /g/ which has spectral emphasis in mid-frequency (18). The presentation level is at 65 dBHL. Aided CAEPs (with CI) were recorded for all the patients in the study group after completion of one year habilitation. The different parameters inferred from CAEP are latency and amplitude of P1 and morphology of the waveform. The latency of the wave P1, which is elicited using mid-frequency speech stimulus /g/, was considered for our analysis.

Statistical analysis

Statistical analysis was performed for quantitative variables in the study using Statistical Package for Social Sciences (SPSS) for Windows (version 17.0; Chicago, IL, USA). The Wilcoxon signed-rank test and Mann-Whitney U-test were used to compare the data between same group and two different groups after intervention. The Spearman's correlation test was used to correlate the subjective and objective (P1, CAEP) outcome parameters.

Results

Ten patients (8 males, 2 females) were included in the study group. The mean age of the children was 3.8 years (1.5 years to 6 years). Five patients had idiopathic etiology, four patients had history of neonatal jaundice, and one patient had birth asphyxia. Ten age-matched children (8 males, 2 females) who underwent CI for profound sensorineural hearing loss were included in the control group.

High-resolution computed tomography and magnetic resonance imaging of temporal bone, internal auditory canal, and brain were done for all the children. Out of them, nine patients showed normal inner ear and vestibulo-cochlear nerves on imaging, and one child had bulbous internal auditory canal. All 10 children in the control group showed normal inner ear and vestibulo-cochlear nerves on imaging.

Table 4 shows the CAP and SIR scores of each patient in the ANSD group at baseline and after 12 months of habilitation.

Table 2. Categories of auditory performance score

0	No awareness of environmental sound
1	Awareness of environmental sounds
2	Responds to speech sounds
3	Identifies environmental sounds
4	Discriminates speech sounds
5	Understands phrases without lip reading
6	Understands conversation without lip reading
7	Uses the telephone

Table 3. Speech intelligibility rate

Category 1	Pre-recognizable words in spoken language
Category 2	Connected speech is unintelligible but is developing for single words
Category 3	Connected speech is intelligible to a listener who concentrates and lip reads within a known context
Category 4	Connected speech is intelligible to a listener who has little experience of a deaf person's speech. The listener does not need to concentrate unduly
Category 5	Connected speech is intelligible to all listeners. The child is easily understood in everyday contexts

Baseline CAP and SIR scores were compared with CAP and SIR scores after 12 months of habilitation using the Wilcoxon signed-rank test. There is a statistically significant difference in CAP and SIR scores recorded immediately after the implantation and after 12 months of habilitation (p-value for CAP=0.005, SIR=0.007). Hence CI in children with ANSD provides significant audiological and speech outcomes (p-value <0.05 is significant) if habilitation training is given at least for one year.

Table 5 shows CAP, SIR, MAIS, and MUSS scores of each patient in the ANSD group and control group. CAP, SIR, MAIS, and MUSS scores after 12 months of habilitation in 10 ANSD patients were compared with age-matched controls using the Mann-Whitney U-test. There is no statistically significant difference in outcomes between these two groups (p-value: CAP=1.00, SIR=0.84, MAIS=0.33, MUSS=0.08). Outcomes of CI in children with ANSD are comparable with children with profound cochlear loss, and therefore CI has a definite role in regaining hearing and development of speech in children with ANSD.

Mean SPIN test scores after 12 months of habilitation at 0 dB and +10 dB SNR were 63% and 80%, respectively. Table 6 shows SPIN scores of all children in ANSD group at 0 dB and +10 dB SNR. SPIN test scores were correlated with latency of P1 component of CAEP using Spearman's correlation test. The correlation coefficient (R) ranges from −1 (strong negative correla-

Table 4. CAP and SIR scores in the ANSD group at baseline and at 12 months

No.	Baseline CAP	Baseline SIR	CAP 12M	SIR 12M
1.	0	1	5	2
2.	0	1	5	5
3.	2	1	5	4
4.	0	1	5	4
5.	1	1	5	3
6.	1	1	5	4
7.	1	1	5	4
8.	2	1	6	4
9.	2	1	4	2
10.	0	1	5	1

ANSD: auditory neuropathy spectrum disorder; CAP: categories of auditory performance; SIR: speech intelligibility rate; 12M: after 12 months of habilitation

Table 5. CAP, SIR, MAIS, and MUSS scores at 12 months in the ANSD group and control group

	ANSD Group				Control Group			
No.	CAP 12M	SIR 12M	MAIS 12M	MUSS 12M	CAP 12M	SIR 12M	MAIS 12M	MUSS 12M
1.	5	2	36	21	5	3	38	32
2.	5	5	34	29	5	4	40	30
3.	5	4	36	24	5	3	35	24
4.	5	4	34	26	5	2	32	24
5.	5	3	36	24	5	4	36	26
6.	5	4	39	22	5	3	36	24
7.	5	4	32	24	6	5	36	24
8.	6	4	38	32	4	2	32	25
9.	4	2	31	12	5	3	38	33
10.	5	1	30	20	5	4	36	28

ANSD: auditory neuropathy spectrum disorder; CAP: categories of auditory performance; SIR: speech intelligibility rate; MAIS: meaningful auditory integration scale; MUSS: meaningful use of speech score; 12M: after 12 months of habilitation

tion) to +1 (strong positive correlation). There is no statistically significant correlation between P1 latency and SPIN scores at 0dB (R value −0.13) and +10dB (R value −0.09) SNR. Figure 1, 2 shows the correlation pattern for P1 latency and SPIN scores at 0dB SNR and +10dB SNR, respectively.

The latency of P1 wave of aided CAEP done at 12 months post habilitation using mid-frequency speech stimulus /g/ was analyzed. The mean P1 latency was 60.1 ms. The correlation between the P1 latency and CAP, SIR, MAIS, and MUSS scores of each child was calculated using Spearman's correlation. The R value for CAP, SIR, MAIS, and MUSS with P1 latency were-0.78, −0.29, −0.84, and −0.53, respectively. There is a strong negative correlation between P1 wave latency and outcomes scores. Auditory scores (CAP, MAIS) have a better correlation than the speech scores (SIR, MUSS) with latency of P1 wave. The latency of P1 wave of CAEP for each patient in the ANSD group is showed in Table 6.

Table 6. SPIN scores in children with ANSD at 12 months after CI with 0 dB and +10 dB SNR and latency of P1 wave in children with ANSD at 12 months after CI

No.	SPIN Scores 0 dB SNR (in %)	SPIN Scores +10 dB SNR (in %)	P1 LATENCY (ms)
1.	65	80	46
2.	70	85	58
3.	65	80	42
4.	70	90	52
5.	60	75	45
6.	65	85	48
7.	70	85	62
8.	65	80	38
9.	50	65	132
10.	55	75	78

SPIN: speech perception in noise; ANSD: auditory neuropathy spectrum disorder; CI: cochlear implantation; dB: decibel; SNR: signal noise ratio; Ms: milliseconds

Discussion

Cochlear implantation has revolutionized the treatment of children with profound sensorineural hearing loss. There are enough scientific data to show the benefits of hearing perception skills and speech language development in children with CI. However, there is no consensus yet on how and when children with ANSD achieve hearing and speech development and the factors affecting it. One study showed patients diagnosed as ANSD having progressive deterioration in speech identification scores (SIS) despite of good pure tone thresholds, which may be due to progressive neural degeneration or neural dys-synchrony (19). Our study shows that CI in ANSD children provides significant benefit in hearing perception and speech outcomes at one year. Also, the benefits in hearing and speech outcomes after CI in children with ANSD are comparable with children having profound cochlear loss. However, long-term benefit assessment in these children is needed to determine the progressive and sustained benefit of CI in children with ANSD.

In our study, one child who was performing well for six months had deteriorated at the end of first year. On evaluation, the child had significantly increased P1 latency when compared to others. Hence, long-term outcomes and performance in background noise have become a concern for cochlear implantation in children with ANSD. Stringent parameters, such as open-set word

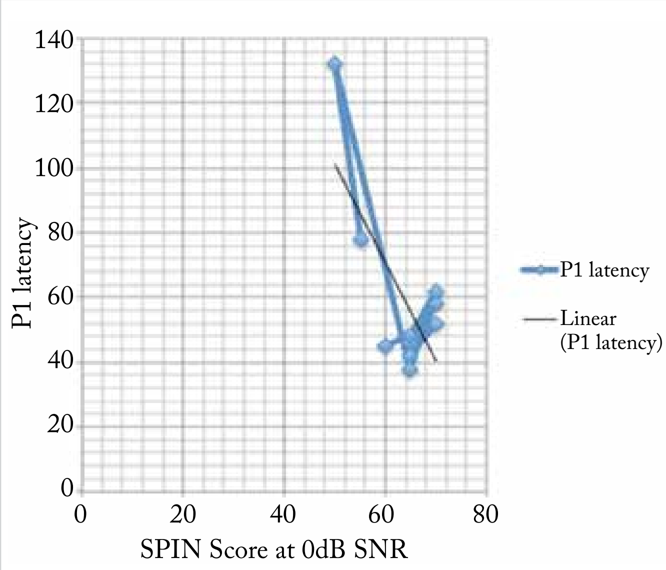

Figure 1. Correlation between latency of P1 of CAEP and Speech In Noise (SPIN) scores at 0 dB SNR

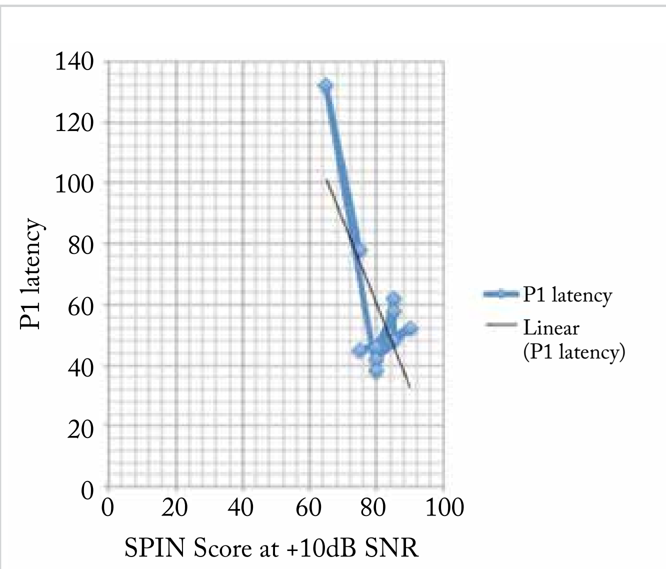

Figure 2. Correlation between latency of P1 of CAEP and Speech In Noise (SPIN) scores at +10 dB SNR

and sentence recognition tests, and the SPIN test, can identify the deficient areas to be focused in ANSD children undergoing cochlear implantation. Dorman et al. (20) showed that scores for hearing in noise test (HINT) in patients with profound sensorineural hearing loss who underwent CI were within +/– 1 standard deviation of mean scores of those with normal hearing. In our study, the SPIN test in 10 ANSD patients showed mean scores of 63% and 80% at 0 dB and +10 dB SNR, respectively.

The P1 component of CAEP reflects the auditory cortical maturity. The latency of P1 component of CAEP has a good negative correlation with hearing and speech scores (CAP, SIR, MAIS, and MUSS). CAEP can be used to complement these scores in after CI assessment in children with ANSD and will be very useful in situations where subjective evaluation is difficult. However, to know the true benefit of CI in ANSD, SPIN scores are to be compared between children with CI for profound cochlear loss and ANSD.

Auditory cortical maturity assessment is developing as a useful parameter after CI assessment. Guo et al. (21) showed a good correlation between Mandarin early speech perception scores and CAEP scores. Our study established a strong correlation between P1 latency and outcome assessment scores (CAP, SIR, MAIS, and MUSS). Subjective evaluations like different speech perception tests reflect the cortical maturity of an individual, whereas more objective evaluation like CAEP evades the inter-observer variability. Also assessing speech perception abilities in a very young child and children with autism, mental retardation, and other handicaps is very difficult. In these situations, CAEP can be used as a tool to assess cortical maturity for speech perception. Alvarenga et al. (22) also proved in his study that latency of P1 component correlated to the period of auditory deprivation, and it also served as the predictor of speech perception performance of children with CI. A comprehensive analysis of P1 wave of CAEP for speech stimulus covering all frequencies and correlating it with SPIN word and sentence tests would give us a clear picture in analyzing the benefit of CI in patients with ANSD. Such detailed analysis would be practically applicable in daily life.

The limitations of our study are a small sample size and short duration of follow-up. SPIN was not conducted for children with profound sensorineural hearing loss (control group) who underwent CI.

Conclusion

Cochlear implantation in children with ANSD, in spite of showing variable outcomes, has benefited the patients, and the results were comparable to those in children with profound sensorineural hearing loss. Our study also emphasized the statistically significant benefit for CI in children with ANSD. The gray areas to focus in outcomes evaluation after CI in ANSD are assessing the long-term benefits and SPIN with a large sample size. CAEP is a useful tool in objectively assessing cortical maturity in children with ANSD after CI. The need for extended habilitation training in ANSD and its benefits should be focused on in future studies.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Madras Otorhinolaryngology Research Foundation (Ref No: MERF/EC-JUL.15/03).

Informed Consent: Written informed consent was obtained from patients' parents who participated in this study.

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