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Original Research Article

Factors affecting audiological performance and speech intelligibility in prelingually deaf children after cochlear implantation: a study

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ABSTRACT

Background: The primary aim is to understand the factors affecting the audiological, speech and language outcome in prelingually deaf children, with bilateral severe to profound sensorineural hearing loss, who have undergone cochlear implantation.
Methods: 40 prelingually deaf children, with bilateral severe to profound sensorineural hearing loss, who have undergone cochlear implantation were enrolled. Auditory performance and speech intelligibility was gauged by revised categories of auditory performance (CAP) score and speech intelligibility rating (SIR) respectively, preoperatively and at 3 months, 6 months and 1 year post cochlear implantation. These values were analysed using statistical package for social sciences with respect to duration of auditory deprivation, duration of use of hearing aid prior to cochlear implantation, duration of auditory verbal therapy prior to cochlear implantation and age of child at cochlear implantation.
Results: There is a negative relation between CAP and duration of auditory deprivation at 6 months and 1 year post cochlear implantation. Also, negative relation is seen between CAP and age of child at cochlear implantation at 6 months and 1 year post cochlear implantation. There is a negative relation between SIR and duration of auditory deprivation at 6 months and 1 year post cochlear implantation. Also, negative relation is seen between SIR score and age of child at cochlear implantation at 3 months, 6 months and 1 year post cochlear implantation.
Conclusions: Lesser the auditory deprivation and younger the child at cochlear implantation, better is the audiological performance and speech intelligibility post cochlear implantation.

Keywords: Audiological performance, Speech intelligibility, Prelingual children, Cochlear implantation

INTRODUCTION

In the last two decades, cochlear implant has proved itself to be a technological boom and boon for the management of severe to profound hearing loss patients especially those who relied on lip-reading, sign language, and amplification systems that were often unable to make speech sounds audible for the profoundly deaf user.[1,2] It is undoubtedly one of the most life changing inventions till date.

The food and drug administration (FDA) approved the use of cochlear implants in adults in 1984 and for children in 1990.[3] Over the past two decades the outcome of cochlear implantation has significantly improved. This has been credited primarily to improvement in technology and surgical techniques.

However the final outcome in pediatric implantation cannot be predicted completely as there are a variety of factors which alone or in combination will decide the outcome of cochlear implantation.

A lot of factors have been shown to influence outcome of cochlear implantation. Categorizing these determinants increases the ability of clinicians to offer educated

preoperative prognosis and might potentially allow for manipulation of variables in an attempt to achieve the best possible outcome.

The intent of this study was to evaluate the impact of multiple factors affecting the audiological performance and speech intelligibility in prelingually deaf children after cochlear implantation.

First of all, providers of health care could identify the patients who gain most or least from the treatment. Secondly, following implantation, the hospital team could recognize patients who were underperforming comparative to expectations and were, therefore, candidates for additional rehabilitative measures.

METHODS

The present study was an observational study with secondary data analysis. 40 prelingually deaf children with bilateral severe to profound sensorineural hearing loss who have undergone cochlear implantation from January 2010 to April 2014 at a tertiary care centre were enrolled in the study.

All the children were screened as per inclusion and exclusion criteria and selected without any gender bias. Inclusion criteria were children with bilateral severe to profound sensorineural hearing loss, prelingual deafness, unilateral cochlear implant, children receiving auditory verbal therapy regularly (at least 2 sessions per week) for a minimum period of one year post cochlear implantation and willingness to participate in the study. Exclusion criteria were other reasons for speech impairment like associated syndromes and central nervous system infections, explantation of cochlear implant, post operative infections like meningitis and those who were lost to follow up.

Due clearance was obtained from the institutional ethics committee. Written informed consent was taken from the parents of the children for the study.

Data in respect of selected subjects was collected from the case sheets and personal folders of the operated children (maintained in our centre) and also by detailed personal interviews of the parents of the children.

The auditory performance was gauged by the revised categories of auditory performance (CAP) score described by the shepherd centre based on nottingham cochlear implant program (Table 1).[4] The CAP comprises a hierarchical scale of auditory perceptive ability.[5] CAP assesses the extent of auditory perception utilised to pursue day to day tasks ranging from awareness of environmental sounds to making telephonic conversations. It reflects everyday auditory performance in a more realistic way.

For assessing speech intelligibility, speech intelligibility rating (SIR) described by O'Donoghue et al in 1999 was used (Table 1).[6] SIR measures the speech intelligibility which might be recognizable by the listener. It assesses the speech intelligibility of the candidate by quantifying his/her everyday spontaneous speech. It is a time-effective global outcome measure of speech intelligibility in real-life situations. SIR consists of five performance categories ranging from "prerecognizable words in spoken language" to "connected speech is intelligible to all listeners".[5]

CAP and SIR of all children were gauged preoperatively and at 3 months, 6 months and 1 year post cochlear implantation. This was meticulously done by registered speech therapists at our centre. The CAP and SIR observed were recorded in the personal folders of the children maintained in our centre.

Data collected was compiled and the CAP and SIR scores obtained preoperatively and at 3 months, 6 months and 1 year post cochlear implantation were analysed with respect to the following factors:

- Duration of auditory deprivation.
- Duration of use of hearing aid prior to cochlear implantation.
- Duration of auditory verbal therapy prior to cochlear implantation.
- Age of child at cochlear implantation.

Data analysis was performed using microsoft excel and the software SPSS (statistical package for social sciences) version 20.0.

Kruskal-Wallis test was used to find the association between CAP score and factors like duration of auditory deprivation, duration of use of hearing aid prior to cochlear implantation, duration of auditory verbal therapy prior to cochlear implantation and age at cochlear implantation.

Chi-square test and Fisher's Exact test was used to find the association between SIR and duration of auditory deprivation, duration of use of hearing aid prior to cochlear implantation, duration of auditory verbal therapy prior to cochlear implantation and age at cochlear implantation.

By considering the actual data, Spearman's correlation coefficient (rho) has been calculated to see correlation of CAP and SIR at 3 months, 6 months and 1 year post cochlear implantation with respect to duration of auditory deprivation, duration of use of hearing aid prior to cochlear implantation, duration of auditory verbal therapy prior to cochlear implantation and age of child at cochlear implantation.

For all tests, a p value of ≤0.05 was considered statistically significant.

RESULTS

There were 22 males (45%) and 18 females (55%) in the study. Sex ratio for males and females was 1:0.8.

Onset of hearing loss was congenital for all children. For all children; mother's antenatal history, child's birth history and immunization history was normal. All children in this study had prelingual sensorineural hearing loss. Otoacoustic emissions test for all children was – "Refer". All children had bilateral profound senserineural hearing loss.

There were no syndromic associations. Ophthalmological and psychological evaluation, high-resolution computed tomography temporal bone and magnetic resonance imaging brain scans were normal for all children.

All children were using bilateral hearing aids prior to cochlear implantation. All children received auditory verbal therapy prior to cochlear implantation.

Table 1: The revised categories of auditory performance (CAP) score and speech intelligibility rating (SIR).

The revised categories of auditory performance (CAP) score (described by the Shepherd centre based on Nottingham cochlear implant program)	
Category	**Criteria**
0	Unaware of environmental sounds
1	Detects some environmental sounds
2	Responds to some speech sounds
3	Can identify some environmental sounds
4	Understands some spoken words with additional performatives
5	Understands common phrases
6	Understands some spoken words without performatives
7	Responds appropriately to simple questions
8	Understands conversations with familiar speakers
9	Understands conversations with unfamiliar speakers
10	Follows recorded stories
11	Uses the telephone with familiar speakers
12	Uses the telephone with unfamiliar speakers
Speech intelligibility rating (O'Donoghue et al)	
Category	**Criteria**
5	Connected speech intelligible to all listeners. Child understood everyday contexts.
4	Connected speech is intelligible to a listener who has little experience of a deaf person's speech.
3	Connected speech is intelligible to a listener who concentrates and lip-reads.
2	Connected speech is unintelligible. Intelligible speech is developing in single words when context and lip reading cues are available.
1	Connected speech is unintelligible. Pre-recognizable words in spoken language; primary mode of communication may be manual.

Table 2: CAP score with respect to auditory deprivation prior to cochlear implantation (in months) (*-significant).

CAP		**Auditory deprivation prior to cochlear implantation (in months)**				**P value**
		≤ 12	13-24	25-36	>36	
3 months after cochlear implantation	Min	2	3	1	1	0.188
	Max	3	5	5	5	
	Median	3	3	3	1.5	
6 months after	Min	5	5	3	3	0.042*
	Max	7	7	6	7	
	Median	6	5	5	3	
1 year after	Min	8	8	5	4	0.006*
	Max	9	10	8	9	
	Median	8.5	8	7	5	

Table 3: SIR with respect to duration of auditory deprivation prior to cochlear implantation (in months) (*-significant).

	Duration of auditory deprivation prior to cochlear implantation (in months)	SIR				Total	P value
		1	2	3	4		
3 months after cochlear implantation	≤12	2	2	0	0	4	0.251
	13–24	12	3	0	0	15	
	25–36	12	1	0	0	13	
	>36	7	1	0	0	8	
6 months after	≤12	0	2	2	0	4	0.089
	13–24	1	12	2	0	15	
	25–36	2	10	1	0	13	
	>36	4	3	1	0	8	
1 year after	≤12	0	0	0	4	4	<0.001*
	13–24	0	4	10	1	15	
	25–36	0	6	7	0	13	
	>36	0	6	1	1	8	

Table 4: Median CAP score with respect to age at cochlear implantation (in months) (*-significant).

CAP		Age at cochlear implantation (in months)				P-value
		≤36	37–48	49–60	>60	
3 months after cochlear implantation	Min	2	1	1	1	0.245
	Max	5	5	5	3	
	Median	3	3	1	1	
6 months after	Min	5	3	3	3	0.018*
	Max	7	5	7	5	
	Median	6.5	7	3	3	
1 year after	Min	8	5	3	4	0.006*
	Max	10	9	5	7	
	Median	8.5	7	3	6	

Table 5: Correlation between CAP and various factors (*-significant).

		CAP at 3 months	CAP at 6 months	CAP at 1 year
Duration of auditory deprivation (in months)	Correlation coefficient	-0.162	-0.417	-0.545
	P value	0.318	0.007*	<0.001*
	N	40	40	40
Duration of use of hearing aid prior to cochlear implantation (in months)	Correlation coefficient	-0.287	-0.303	-0.296
	P value	0.072	0.058	0.063
	N	40	40	40
Duration of auditory verbal therapy prior to cochlear implantation (in months)	Correlation coefficient	-0.212	-0.244	-0.309
	P value	0.189	0.129	0.052
	N	40	40	40
Age of child at cochlear implantation (in months)	Correlation coefficient	-0.207	-0.443	-0.599
	P value	0.200	0.004*	<0.001*
	N	40	40	40

All children underwent unilateral cochlear implantation on right ear and there were no postoperative complications. Post cochlear implantation all the children received auditory verbal therapy for a minimum period of 12 months (ranging from 13 months to 36 months). All the children have taken admission in a normal school.

Age of child at detection of hearing loss (in months) was ranging from 3 months to 40 months with an average of 19.23 months, standard deviation (SD) of 9.54 months and median of 18 months.

Table 6: Correlation between SIR and various factors (*-significant).

		SIR at 3 months	SIR at 6 months	SIR at 1 year
Duration of auditory deprivation (in months)	Correlation coefficient	-0.252	-0.447	-0.531
	P value	0.117	0.004*	< 0.001*
	N	40	40	40
Duration of use of hearing aid prior to cochlear implantation (in months)	Correlation coefficient	-0.325	-0.316	-0.234
	P value	0.041	0.057	0.145
	N	40	40	40
Duration of auditory verbal therapy prior to cochlear implantation (in months)	Correlation coefficient	-0.272	-0.272	-0.316
	P value	0.090	0.090	0.057
	N	40	40	40
Age of child at cochlear implantation (in months)	Correlation coefficient	-0.408	-0.569	-0.547
	P value	0.009*	< 0.001*	< 0.001*
	N	40	40	40

Duration of auditory deprivation (in months) was ranging from 9 months to 45 months with an average of 26.70 months, SD of 10.49 months and median of 26.5 months.

Duration of use of hearing aid prior to cochlear implantation (in months) was ranging from 4 months to 67 months with an average of 23.70 months, SD of 13.80 months and median of 23.5 months.

Duration of auditory verbal therapy prior to cochlear implantation (in months) was ranging from 4 months to 65 months with an average of 22.25 months, SD of 13.19 months and median of 23.5 months.

Age of child at cochlear implantation (in months) was ranging from 19 months to 109 months with an average of 50.23 months, SD of 17.74 months and median of 48 months.

For data analysis regarding duration of use of hearing aid prior to cochlear implantation, the children were divided into 4 groups; that is, up to 20 months (16 children, 40%), 21- 30 months (16 children, 40%), 31 to 40 months (5 children, 12.5%) and >40 months (3 children, 12.5%).

For analysing duration of auditory verbal therapy prior to cochlear implantation, the children were divided into 3 groups; that is, up to 20 months (18 children, 45%), 21-30 months (15 children, 37.5%) and >30 months (7 children, 17.5%).

For analysis of duration of auditory deprivation, the children were divided into 4 groups; that is, upto 12 months (4 children, 10%), 13- 24 months (15 children, 37.5%), 25 to 36 months (13 children, 32.5%) and >36 months (8 children, 20%).

For data analysis regarding age at cochlear implantation, the children were divided into 4 groups; that is, upto 36 months (4 children, 10%), 37- 48 months (17 children, 42.5%), 49 to 60 months (12 children, 30%) and >60 months (7 children, 17.5%).

By using Wilcoxon signed-rank test, it was seen that there is a significant difference between CAP score and SIR prior to cochlear implantation and at 3 months, 6 months and 1 year post cochlear implantation. Median CAP was 3 at 3 months, 5 at 6 months and 7 at 1 year after cochlear implantation. In our study, median SIR was 1 at 3 months, 2 at 6 months and 3 at 1 year after cochlear implantation.

By using Kruskal Wallis test, it was seen that there is a significant difference between CAP score at 6 months and 1 year after cochlear implantation with respect to auditory deprivation prior to cochlear implantation (Table 2). Hence, lesser the auditory deprivation, better is the CAP score and audiological performance post cochlear implantation.

By using Fisher's exact test, it was seen that there is a significant association between duration of auditory deprivation prior to cochlear implantation with SIR at 1 year (Table 3). Hence, lesser the auditory deprivation, better is the SIR and speech intelligibility post cochlear implantation.

By using Kruskal Wallis test, it was seen that there is no significant difference between CAP score at 3 months, 6 months and 1 year after cochlear implantation with respect to duration of use of hearing aid and duration of auditory verbal therapy prior to cochlear implantation.

By using Fisher's exact, it was seen that there is a significant association between duration of use of hearing aid and duration of auditory verbal therapy prior to cochlear implantation with SIR at 6 months post cochlear implantation. Hence, use of hearing aid and auditory verbal therapy prior to cochlear implantation has a beneficial effect on speech intelligibility.

By using Kruskal Wallis test, it was seen that there is a significant difference between CAP score at 6 months and 1 year after cochlear implantation with respect to age at cochlear implantation (Table 4). Hence, younger the child at cochlear implantation, better is the CAP score and audiological performance post cochlear implantation.

By using Fisher's exact, it was seen that there is no significant association between age at cochlear implantation with SIR at 3 months, 6 months and 1 year after post cochlear implantation.

Spearman's correlation coefficient (rho) was calculated to see correlation of CAP and SIR at 3 months , 6 months and 1 year post cochlear implantation with respect to following factors:

Duration of auditory deprivation

There is a negative significant relation between CAP score and duration of auditory deprivation at 6 months and 1 year post cochlear implantation ($p<0.05$), correlation coefficients being -0.417 and -0.545 respectively (Table 5). Also, there is a negative significant relation between SIR and duration of auditory deprivation at 6 months and 1 year post cochlear implantation, correlation coefficients being -0.447 and -0.531 respectively (Table 6). Hence, lesser the auditory deprivation, better is the CAP and SIR score, that is, better audiological performance and speech intelligibility post cochlear implantation.

Duration of use of hearing aid prior to cochlear implantation

In our study there is no significant relation between CAP score, SIR and duration of use of hearing aid prior to cochlear implantation.

Duration of auditory verbal therapy prior to cochlear implantation

There is no significant relation between CAP score, SIR and duration of auditory verbal therapy prior to cochlear implantation.

Age of child at cochlear implantation

There is a negative significant relation between CAP score and age of child at cochlear implantation at 6 months and 1 year post cochlear implantation. Correlation coefficients are -0.443 and -0.599 respectively. Also, there is a negative significant relation between SIR score and age of child at cochlear implantation at 3 months, 6 months and 1 year post cochlear implantation. Correlation coefficients are -0.408, -0.569 and -0.547 respectively. Hence, younger the child at cochlear implantation, better is the CAP score and SIR, that is better audiological performance and speech intelligibility post cochlear implantation.

DISCUSSION

Speech and language development occurs significantly in the first decade of life and is a continuum rather than an isolated event. Neuroplasticity, that is, the ability of the brain to respond adaptively to behaviourally relevant stimuli is a feature of both motor and sensory functions. If a congenitally deaf child has hearing restored after the first few years of life then, although the child is able to hear, his speech intelligibility will be affected as he will be unable to acquire normal speech and language. The existence of a critical period for language development during the first five years of life is well established.[3,7] Hence provision of auditory stimulation during this phase is critical as deafness significantly reduces language development.[3]

Children with severe to profound sensorineural hearing loss face tremendous hurdles in developing spoken language.[8] This causes a ripple in their psychosocial atmosphere and also challenges their academic achievements. Cochlear implantation has been introduced as the treatment of severe to profound sensorineural hearing loss around the world.[9] Studies reported that children who underwent cochlear implantation had a significant gain in auditory perception, speech production and social development.[8]

About one in 1000 babies born in India is profoundly deaf. The number of such would be obviously huge given the nearly 40,000 births in India every day. The cochlear implant surgery is a fairly new technological advancement in our country, the first one being carried out in 1994.[10]

There are a lot of factors (child/parents/family/implant related etc.) which affect the auditory performance and speech intelligibility in a post cochlear implantation child.[3,11-13] Many prospective and retrospective studies have been conducted to evaluate these factors.[13-16]

The primary intent of our study was to evaluate the impact of duration of auditory deprivation, duration of use of hearing aid prior to cochlear implantation, duration of auditory verbal therapy prior to cochlear implantation and Age of child at cochlear implantation, on the audiological performance and speech intelligibility in prelingually deaf children after cochlear implantation.

In a study by Bakhshaee et al the mean CAP was 3.25 at 6 months, 5.34 after one year and 6.01 three years after cochlear implantation.[17] Donoghue also reported a mean CAP of 4 at one year and 5 at three years after cochlear implantation.[17,18] In a study by Zhou et al, median SIR was 2 at 6 months, 3 at 12 months, and 5 at 24 months.[5]

As per Green et al there was a significant negative correlation between duration of deafness and auditory cortical activation.[19] Cosseti et al commented that

duration of deafness affects postoperative outcomes following cochlear implantation.[20]

Chen et al performed a study to evaluate the auditory performance of infants of different age at cochlear implantation and emphasize the importance of the hearing aid trial and habilitation before implant. Infants undergoing hearing aid trial and habilitation demonstrated a significant positive effect on the development of auditory skills in comparison with infants without trial and habilitation.[21]

As per Ingvalson et al, Auditory-Verbal therapy could be effective for improving speech and language outcomes for cochlear implant recipients.[22]

Paul et al using CAP scores as outcome measures concluded that intervention before the age of 4 years seemed to be critical to avoid irreversible auditory performance losses and intervention before the age of 2 years seemed to be critical to achieve optimal results.[23]

Richard et al concluded that earlier implantation for children with a congenital profound hearing loss appeared to provide improved potential for developing speech perception.[24]

Robbins et al concluded that performing implantation in children with profound hearing loss at the youngest age possible allows the best opportunity for them to acquire communication skills that approximate those of their peers with normal hearing.[25]

If the auditory system does not receive adequate stimulation within 8 years after birth, it is likely that the higher order auditory cortex gets reorganized due to neural scavenging.[26] The auditory cortex is taken by other sensorial systems, especially by visual one and cochlear implantation is useless regarding speech and language acquisition. This is called cortical re-organisation.

Sharma et al studied 245 children with congenital deafness, and showed that the latency of the P1 cortical auditory evoked potential (CAEP) biomarker response decreases to within normal limits in children who receive a cochlear implant by 3.5 years, while children implanted after the age of 7 years demonstrate abnormal P1 CAEP responses.27

Waltzman et al found that speech production could substantially increase after 1 year post cochlear implantation. As the device itself is unaltered after initial implantation, this improved performance is believed to reflect a neuroplastic process within the central auditory system.[28]

Early intervention with appropriate auditory prostheses such as cochlear implants results in high likelihood of normal auditory cortical development in children with congenital deafness.[29]

CONCLUSION

In our study, overall, age at cochlear implantation and duration of auditory deprivation were two major factors which had a negative correlation with audiological performance and speech intelligibility in prelingually deaf children post cochlear implantation. These findings are similar to the conclusions drawn in various studies quoted earlier.

Recommendations

- Emphasis is given to timely detection of deafness in early years of life by meticulous screening programs. General awareness should be created in the environment.
- Children who have severe to profound sensorineural loss should be provided with hearing aid till the time the child undergoes cochlear implantation. This takes care of the essential auditory stimulus required. Also, the child gets used to wearing a hearing aid device and postoperative usage of cochlear implant device use is consistent.
- Auditory verbal therapy should be an important part of management protocol prior to cochlear implantation. It should be started as early as possible.
- Counselling and training of parents regarding use of hearing aid and auditory verbal therapy of the child is essential to help in early speech development.
- Age at cochlear implantation is one of the most important factors affecting outcome of cochlear implantation. Hence, the child should be implanted as early as possible to provide him with an audiological and speech outcome similar and comparable to a normal child.
- Parents should be sensitized on the advantages of auditory stimulus prior to cochlear implantation, the role of auditory verbal therapy at home, patience and participation of parents in management prior to cochlear implantation as well as religious auditory verbal therapy and follow up post cochlear implantation.
- Documentation and records of all candidates of cochlear implantation should be thoroughly maintained in detail both prior to and post cochlear implantation. This will give us an insight into the various factors and go a long way in predicting their potential effect on auditory and speech outcomes.

Similar studies should be conducted in future with larger sample sizes and longer follow up periods to widen our perspectives and knowledge on the factors affecting audiological and speech outcomes in prelingually deaf children post cochlear implantation.

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