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Speech development and auditory performance in children after cochlear implantation

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Abstract

Background: The aim of this study was to determine the auditory performance of congenitally deaf children and the effect of cochlear implantation (CI) on speech intelligibility.

Methods: A prospective study was undertaken on 47 children in a pediatric tertiary referral center for CI. All children were deaf prelingually and were younger than 8 years of age. They were followed up until 5 years after implantation. Auditory performance was assessed by using the categories of auditory performance (CAP) scale and speech intelligibility rating which evaluated the spontaneous speech of each child before and at frequent intervals for five years after implantation.

Results: Pre-lingually deaf children showed significant improvement in auditory performance after implantation. Six months after implantation 91% of children had the ability to respond to speech sounds. At the end of year one, 96% of children could discriminate speech sounds and 84% of children who reached the three year interval could understand common phrases without lip-reading. After cochlear implantation, the difference between the speech intelligibility rating increased significantly each year for 3 years ($p<0.05$) and did not plateau up to 5 years after implantation. The changes in auditory performance and speech development were parallel.

Conclusion: The results indicated the ability of cochlear implantations to significantly improve auditory receptive skills and subsequently speech development in young congenitally deaf children.

Keywords: Auditory performance, Speech intelligibility, Cochlear implantation, Outcome.

Introduction

Cochlear implantation can improve verbal skills and provide better communication in deaf children. Case to case differences in speech learning, prolonged follow up and poor evaluating methods made it difficult to assess speech perception after cochlear

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implantation in deaf children. The available diagnostic tests are mostly planned for adults; therefore, these tests may not evaluate the actual auditory skills in children. Archbold planned a category of auditory performance (CAP) scaling in 1995 which is used for all children and even for infants. This scaling is the best criterion for the assessment of auditory performance after cochlear implantation in children [1,2]. CAP consists of eight different scores which range from complete deafness (no reaction to sounds) to good verbal communication (answer to phone call)[2]. These tests evaluate the actual daily verbal and auditory skills in children so they can be used for showing the child's hearing improvement during follow up. These tests are repeatable with test to test validity and with a very simple interpretation even for inexperienced persons.

From another aspect, implantation has been reported to be associated with improvements in speech perception [4] and speech production. The speech intelligibility rating (SIR) was developed in 1989 and used as a framework to rank the child's spontaneous speech into one of five hierarchic categories [6,7]. SIR is not a performance test and was designed as a time-effective global outcome measure of speech production in real-life situations. Although studies have shown that speech perception improves after cochlear implantation [8]; the rate at which intelligible spoken language develops is less well documented and its acquisition has been seriously challenged by critics of implantation. However, intelligible speech remains a hope of many parents who submit their children to cochlear implantation [9]. To reply to critics and counsel parents, there is a compelling need to study a clearly defined large group of children after cochlear implantation. Results then could be generalized to other young deaf children with a multichannel cochlear implantation and used to monitor the development of speech intelligibility as well as to establish appropriate parental expectations.

The aim of this study is to compare auditory performance before and after cochlear implantation and monitor the improvement of auditory-verbal function in deaf children and at the same time document the development of intelligible speech in a group of young implanted children up to 5 years after their implantation.

Methods

We studied 47 deaf children who underwent cochlear implantation in the cochlear implantation center of Khorasan in an exclusive pediatric cochlear implantation program. A comprehensive audiologic assessment was undertaken identifying each child's best-aided thresholds, thus providing firm evidence of lack of hearing aid benefit.

All patients were congenitally deaf and before surgery a 3-6 month course of auditory rehabilitation by hearing aid gave no result. The rehabilitation team made a detailed evaluation of the child's communication, social and educational needs. Six cases who had additional disorders (including cerebral palsy, learning disorder and attention deficit hyperactivity disorder) and one patient with Nucleus implantation that was not possible to activate all electrodes (because of mechanical obstruction) were excluded from the study. From the forty seven consecutive children who met the inclusion criteria, 36 and 11 children received the Nucleus multichannel cochlear and MED-EL implant, respectively; and all electrodes of implants were active after surgery.

Etiology				
Congenital	28 children (59.6%)			
Meningitis	1 child (2.1%)			
Other causes	18 children (38.3%)			
	Minimum	**Maximum**	**Mean**	**STD**
Age at onset of deafness (months)	0	24	2.05	6.17
Age at implantation (months)	13	68	41.79	12.96
Duration of deafness (months)	13	68	39.74	11.32

Table 1. Demographic details of all the subjects included in the study.

CAP scaling was used to assess auditory performance before and after surgery. They were also programmed with the speech processing strategy recommended at the time and were upgraded with new encoding strategies as they became available. Pre-implant assessments were undertaken on 47 children; who were all present in our program during the first two years but this number was 32, 14 and 9 in the following years (3, 4, and 5-year intervals). A summary of the children's demographic details is listed in Table1.

The criteria used for SIR are described in Table 2. Each assessment was undertaken by the child's own implantation team in the familiar environment of the child's own home or school. To maintain consistency in scoring, the evaluations for each child were done by the same speech and language therapist in each interval. Preliminary studies of the inter-observer reliability have given a high correlation coefficient of 0.9 and further validation of the SIR score in progress.

The SIR is a noncontiguous scale and therefore, a nonparametric statistical analysis (Mann-Whitney U-test) was used to compare the results at each interval. Statistical significance was accepted at the $p<0.05$ level.

Results

The mean age was approximately 42 months at the time of implantation (min 13 and max 68 months). CAP scoring was done 6 months after surgery. The results of auditory performance assessment are shown in Table 3.

Only ten patients of our 47 cases were aware of environmental sounds before surgery (stage 1 according to CAP). 91% of children were able to respond to speech voices six months after surgery (stage 2). After 1, 2, 3, 4 and 5 years following the

Category	*Speech Intelligibility Rating criteria*
5	Connected speech is intelligible to all listeners. Child is understood easily in everyday contexts.
4	Connected speech in intelligible to a listener who has a 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. Prerecognizable words in spoken language. Primary mode of communication may be manual

Table 2. Criteria used to categorize children using the Speech Intelligibility Rating (SIR).

Stage/CAP scale		Before implantation	6 months	1 years	2 years	3 years	4 years	5 years
7	Ability to call a familiar person	0	0	4	13	9	6	5
6	Speech perception without lip reading	0	0	17	20	14	4	2
5	Word and term perception without lip reading	0	4	20	8	4	3	1
4	Speech vocal discrimination without lip reading	0	22	4	5	4	1	1
3	Vocal perception	0	7	1	0	1	0	0
2	Response to speech voice	0	10	1	1	0	0	0
1	Awareness of voices	10	4	0	0	0	0	0
0	Not aware of voices	37	0	0	0	0	0	0
Sum	Total number of cases	47	47	47	47	32	14	9

Interval after implantation (columns Before implantation to 5 years)

Table 3. 5 - Years follow up of auditory performance after cochlear implantation.

implantation, approximately 1%, 27%, 30%, 43% and 55% had the ability to call a familiar person, respectively.

The results of SIR before and for each of the 5 years after implantation are summarized in Table 4. Before cochlear implantation, the median and mode rating was category 1 (preverbal, gestural, or sign based communication). Six months later, this had become category 2 (unintelligible connected speech with some single words identifiable) and at the end of year one, intelligible connected speech to a listener who concentrated and read lips (category 3) was the average rating. By the 2 and 3-year interval, category 4 (intelligible speech to a listener with a little experience of deaf speech) was the median and mode of SIR. Five years after cochlear implantation, the improvement continued with the median and mode being the highest rating of category 5 (intelligible speech to all listeners) (Fig.1). The increase in ratings each year until the third year was statistically significant (from pre-implantation to year 1, p=0.000; from year 1 to year 2, p=0.000; and from year 2 to year 3, p=0.000).The difference between years 3 to 4 and 4 to 5 were not statistically significant (p> 0.05).

The children's auditory performance and speech development under the age of 4 was significantly better than those over 4 at the time of implantation (p<0.05).

Three children did not meet the expected intelligible speech development. One child had a family history of hearing loss and low parental motivation and cooperation and two had central auditory processing disorder (CAPD). Interestingly, the auditory performance was lower than expected in the same three cases.

It's also important to note that the changes of CAP scale and SIR were significantly correlated (p<0.05) (Fig. 2).

Authors have shown better outcome from the point of auditory performance and

Category **(SIR)**	*Before*	*6 months*	*1 year*	*2 years*	*3 years*	*4 years*	*5 years*
5	0	0	0	5	13	10	7
4	0	0	17	29	17	4	2
3	0	12	26	10	0	0	0
2	35	25	4	3	2	0	0
1	12	10	0	0	0	0	0
Total	47	47	47	47	32	14	9

SIR: Speech Intelligibility Rating

Table 4. Numbers of children in each SIR category at each of the yearly intervals.

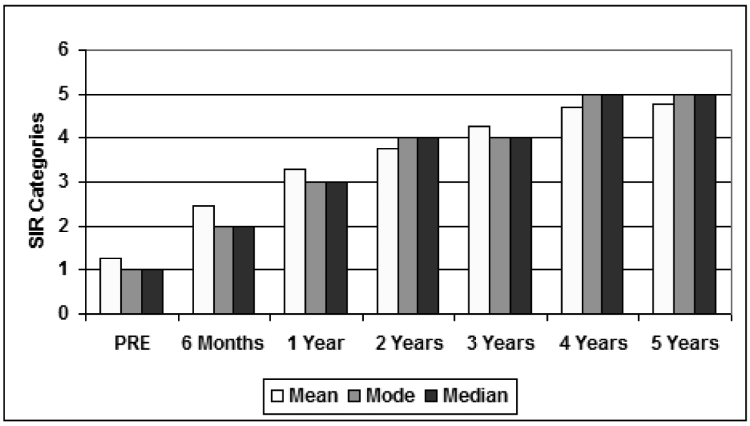

Fig.1. The median, mode and mean speech intelligibility ratings (SIR) at each of the yearly intervals.

speech intelligibility in congenitally deaf children who had cochlear implantation in early childhood comparing to those operated in adulthood.

Many authorities doubted that congenitally deaf children would have the central processing mechanisms to enable them to hear speech through an implantation device and to then produce intelligible spoken language. However, several studies have testified to the ability of these devices to enhance speech perception and speech production of profoundly deaf children, with benefits extending to congenital as well as to post-lingually deaf children [10,12].

Age at the implantation time has a significant effect on auditory and subsequent speech development. Govaertis et al. planned a trial in 2002 to evaluate the results of cochlear implantation according to the patient's age. 20-30% of cochlear implantations that were performed after 4 years, 66% of those between 2-4 years and 90% of those before 2 years of age became almost normal in auditory performance according to CAP scale after 3 years of follow

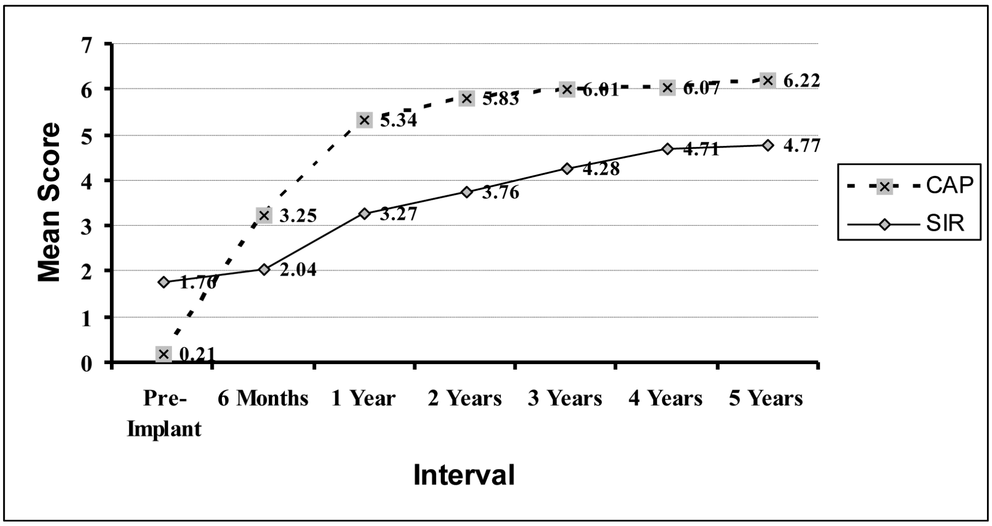

Fig. 2. Mean CAP and SIR score of patients during follow up.

up [13]. Nikolopoulos et al. studied 133 deaf children before school age and showed acceptable results in those who were operated before eight years of age [3].

Our study also indicated that age is a major factor in the development of auditory skills after surgery and better results were seen in those children who underwent surgery before the age of four while poor results were reported in those who were operated after that. So, screening tests for auditory disorders and early auditory rehabilitation in deaf children is essential to get an optimal result after implantation.

Children with other disorders had poor improvement even in early cochlear implantation; therefore we excluded them from the study (the mean CAP score in this group was lower than the rest). Yang et al. studied 26 children in 2004 to compare results of cochlear implantation between normal deaf children and those with other disorders such as cerebral palsy. The mean CAP score 1 and 2 years after surgery were 3.93 and 5.86 in the normal group and 2.5 and 4.17 in those with cerebral palsy or other mental anomalies, respectively [14]. All the patients who used cochlear device continuously were more successful in learning communicational skills. Lack of mental disorders has an important role in auditory development and IQ, speech perception and verbal improvement; therefore this item should be considered as a major criterion beside age, in selecting patients [15].

Archbold also reported that 80% of children were able to perceive daily speech without lip reading (stage 5) 3 years after surgery (like us) and 40% were able to perceive normal daily speech without lip reading (stage 6) [5].Our results have also been close to this study.

According to all results and in comparison to other studies, a significant auditory improvement was seen in the implanted children. The mean CAP in deaf children was 3.25, at 6 months, 5.34 after one year and 6.01 three years after cochlear implantation in our study. Donoghue also reported a mean CAP of 4, one year and 5, three years after surgery in his patients, which is lower when compared to our trial [11].

The results indicated that cochlear implantation and later auditory rehabilitation might lead to improvement of auditory performance and better perception of speech in deaf children.

Speech intelligibility studies have been constrained by small study groups, short follow-up periods, varying ages (mixing children and adolescents or adults), and incomplete data collection of each child's progress at every interval.

The children studied by Tobey et al, [16] varied in age from 2.4 to 17.8 years. Dawson et al [17] studied 11 children whose ages at implantation ranged from 8 to 20 years. Osberger et al [18] studied 29 cases over a 4-years period, but the children entered the study not from the time of implantation but at different intervals, resulting in varying numbers of children at each interval. Because of these limitations in data collection, it has been difficult to compare results over time and to interpret and generalize any trends that may be emerging.

The assessment of speech intelligibility relies on the listener's perception of what has been said by the speaker. To ensure objectivity, some studies have used predetermined language samples that must be elicited from the child. This has inherent difficulties.

First, the judgments must be made by a person with equal familiarity with the speech of deaf children and the number of presentations of each case to the listener must be limited to avoid recognition. Second, the child must have the necessary language skills to be able to produce the required speech sample. In the current study, it was decided to use a “real life” descriptive rating scale because it was a practical clinical measure that could be readily applied to a large group of young deaf children over time.

In addition, this approach circumvented the many difficulties presented by obtaining measures of intelligibility rating in more laboratory – type settings [19]. One other study [20] successfully used a 10-point speech intelligibility rating scale, but the individual gradings were not defined precisely.

The current study systematically followed the development of speech intelligibility in a group of prelingually deaf children over a 5-year period. Uniformity of rating was promoted by having the same speech and language therapist assessing a child throughout his time in the program. Given the strict entry criteria and full data collection, it is highly probable that the results can be generalized and reproduced with other prelingually deaf children receiving a cochlear implantation before the age of 6 years.

The result of this study show that the children’s speech intelligibility continued to develop over the 5-year period. The difference in ratings improved significantly each year for 3 years after implantation.

Although this was not statistically significant between the 3, 4 and 5-year interval (probably an affect of sample size), there was a clear underlying trend toward improved speech intelligibility.

The need for a long period of cochlear implantation use before the emergence of intelligible speech was identified. To date, no studies have been reported on children beyond 5 years of age. Such studies are clearly needed because the development of speech intelligibility does not plateau 5 years after implantation with many children having not yet reached their full speech intelligibility by this stage.

Conclusion

The results show that auditory performance would be improved significantly in most children who undergo cochlear implantation surgery especially before the age of four. We predict that 90% of these cases will be able to perceive daily speech without lip reading five years after surgery. On the other hand, the current study clearly shows the development of speech intelligibility parallel to improvement of auditory perception, even in children who were congenitally deaf, and rebuffs those critics who doubted that prelingually deaf implanted children could ever develop these invaluable communication skills.

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