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Original Research Article

Functional hearing and speech progress after cochlear implantation in late-implanted children: a prospective North Indian study

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ABSTRACT

Background: Evaluating 12-month auditory and speech outcomes in late-implanted pediatric cochlear implant recipients facing resource-variable and socioeconomic barriers in North India.
Methods: A prospective observational study was conducted at the Department of ENT of a tertiary care hospital in North India over a 12 months period. The subjects who had undergone a Cochlear implantation (CI) surgery and provided informed consent for inclusion in the study were considered. Preoperative evaluation included clinical evaluation and audiological assessment. Postoperative follow-up was performed at 1, 3, 6 and 12 months using Infant-Toddler Meaningful Auditory Integration Scale /Meaningful Auditory Integration Scale (IT-MAIS/MAIS) for auditory function, Free Field Audiometry (FFA) for hearing thresholds and Meaningful Use of Speech Scale (MUSS) for speech production.
Results: The study included 12 males (52.2%) and 11 females (47.8%). The mean age was 5.39±3.46 years. IT-MAIS/MAIS score increased from 7.48±6.01 at 1 month to 31.57±6.46 at 12 months ($p < 0.001$). Mean FFA threshold improved from preoperative values of 88.70±3.59 dB to 35.00±4.36 dB at 12 months ($p < 0.001$). Mean MUSS score increased from 5.74±5.09 at 1 month to 26.87±7.55 at 12 months ($p< 0.001$). Significant improvements were seen in all measures after device activation.
Conclusions: CI leads to significant improvements in auditory and speech abilities in the implanted individuals. The study results demonstrate an improvement in auditory and speech abilities over a period of 12 months. These findings support existing medical literature on the effectiveness of cochlear implantation for individuals with profound hearing loss.

Keywords: Auditory perception correction, Cochlear implants, Hearing loss, Speech perception

INTRODUCTION

Hearing is essential for understanding and producing speech, because auditory input is necessary for normal language development. Auditory feedback of one's own speech allows individuals to hear what they say and make adjustments in the clarity, intelligibility and rhythm of their speech production. A disruption in auditory input can affect normal speech and language development of an individual. Hearing loss is one of the sensory deficits that may develop during an individual's lifespan. The loss may be congenital or acquired later in life and can occur due to a variety of causes, viz., genetic factors, infections, ototoxicity, exposure to noise, trauma and/or the ageing process. Hearing loss is generally described in terms of

where the dysfunction is in the ear (conductive, sensorineural or mixed) and by the severity of the hearing loss (mild, moderate, severe and profound). Children, who have experienced a significant amount of time without adequate auditory input, will have long-term deficits in their linguistic, cognitive and literacy skills. Adults with post-lingual hearing loss experience communication difficulties, emotional turmoil and decreased involvement in social and occupational activities.[1]

The global burden of hearing loss is a significant public health challenge. According to World Health Organization (WHO) estimates, there are over 1.5 billion people worldwide with some degree of hearing impairment, of which 430 million have a disabling hearing loss that requires rehabilitation.[2] In individuals with severe to profound sensorineural hearing loss (SNHL), conventional amplification from hearing aids may not be enough to restore functional hearing. Cochlear implantation (CI) is an intervention offered to subjects with severe to profound SNHL, which provides them the option to gain access to sound. These are surgically implanted electronic devices that bypass the damaged hair cells of cochlea and directly stimulate the auditory nerve. An implant converts auditory input into electrical impulses which are transmitted by the surviving auditory nerve fibers to higher auditory centers. These modern innovations, driven by increasingly refined signal-processing strategies and electrode designs, have resulted in substantial improvements in speech perception and overall patient outcomes.[3]

Assessment of the hearing and speech ability of an individual after a CI is important for understanding the effectiveness of the procedure. The success of a CI is influenced by numerous factors viz., age of implantation, duration and severity of hearing loss, consistency and quality of post-surgical rehabilitation and various other individual characteristics.

In certain regions within India, the prevalence of hearing impairment is significant. These areas face unique challenges in providing comprehensive healthcare to individuals with hearing loss. Though there have been advancements in technology and rehabilitation techniques, yet, the socioeconomic status of patients, cultural beliefs, geographical barriers and insufficiently trained healthcare professionals influence the rehabilitation process and consequently the CI outcomes in these populations. The current study was done to assess the outcomes of CI in one such geographical region of India.

The objective of this study was to evaluate 12-month auditory and speech outcomes in late-implanted CI recipients at a tertiary-care center in North India.

METHODS

A prospective observational study was conducted from July 2024 to June 2025 in the Department of ENT of a tertiary care teaching Hospital in North India. Approval from the Institutional Ethics Committee was obtained prior to the initiation of the study. The study subjects were cochlear implant recipients attending the ENT Outpatient Department (OPD) for follow-up visits. Inclusion criteria comprised subjects aged 9 months or older who had undergone cochlear implant surgery. Written informed consent was obtained from all subjects or their legal guardians prior to enrolment in the study. Any subject or legal guardian who declined to provide written informed consent was excluded from the study.

The sample size calculation was based on a previous study by Liu S et al.[4] and utilized a standard formula for comparing means in a single group over time. The formula employed was,

$$X= (Z1\text{-}a/2 + Z1\text{-}\beta) \times 2\ \sigma^2/d^2$$

Z1-a/2 – critical value of the normal distribution at a/2 (for a confidence level of 95%, a=0.05 and the critical value is 1.96).

Z1-β - critical value of the normal distribution at β (for a power of 80%, β =0.2 and the critical value is 0.84).

σ2- Pooled variants using the standard deviation of mean MAIS at baseline and 12 months after cochlear implantation (value is 15.7).

d- Hypothesized difference we would like to detect in the MAIS score from the baseline (value is 3.5).

Based on these parameters, the minimum required sample size was calculated to be 21 participants. To account for a potential attrition or loss to follow-up during the study period, a 10% dropout rate was factored in, resulting in a final target sample size of 23 subjects.

Assessment protocols and outcome measures

A standardized battery of assessments was administered to each participant at predetermined intervals to evaluate the primary domains of interest, viz., hearing acuity, auditory integration and speech production.

Pre-implantation baseline assessment

Before CI surgery, all candidates underwent a thorough audiological evaluation to determine the severity of their hearing loss and establish a baseline for post-operative comparison. The assessments included objective tests such as Otoacoustic Emissions (OAE), Brainstem Evoked Response Audiometry (BERA) and behavioral evaluations. The main baseline measure for this study

was the pre-operative free field audiometry (FFA) threshold, which assesses functional hearing ability in a sound field environment.

Post-implantation auditory and speech assessments

Following the surgical procedure and subsequent device activation, subjects were evaluated at four follow-up intervals: 1 month, 3 months, 6 months and 12 months. This structured schedule was designed to track the development of auditory and speech skills. The auditory assessment was done by FFA, performed by an audiologist, while the Meaningful Auditory Integration Scale (MAIS) / Infant-Toddler MAIS (IT-MAIS) questionnaires and the Meaningful Use of Speech Scale (MUSS) were administered to the caregivers by the doctor.

FFA

FFA is a behavioral hearing test used to determine the softest sound level (hearing threshold) at which an individual responds with sound presented through calibrated loudspeakers in a sound-treated room. [5] This method provides a measure of functional hearing ability in a natural listening environment and is particularly valuable for pediatric populations where headphone use may be challenging. The outcome is measured in decibels Hearing Level (dB HL), where a lower numerical value indicates better hearing acuity.

MAIS / IT-MAIS

The MAIS and its version for younger children, the IT-MAIS, are validated 10-item parent-reported questionnaires designed to assess the meaningful use of sound in a child's everyday environment.[6] Rather than testing auditory skills in a structured clinical setting, this tool captures real-world behaviors as observed by primary caregivers. The scale evaluates three fundamental domains of auditory development: Firstly, Device Bonding/Use: Confidence and consistency in wearing the cochlear implant (Questions 1-2). Secondly Auditory Alerting: Spontaneous detection of and alerting to environmental/ speech sounds (Questions 3-6) and thirdly deriving meaning from sound: The ability to associate sounds with their sources and comprehend auditory information (Questions 7-10).

For each of the 10 questions, responses are scored on a 5-point Likert scale based on the frequency of the observed behavior: 0 (Never), 1 (Rarely), 2 (Occasionally), 3 (Frequently) and 4 (Always). The total score ranges from 0 to 40, with higher scores indicating a greater degree of meaningful auditory integration. IT-MAIS was utilized for children up to the age of 3 years, while the MAIS was used for elder children.

Meaningful use of speech scale (MUSS)

A more holistic evaluation for addressing the "speech abilities" component of the study title, the MUSS was incorporated into the assessmentprotocol.[7] While the MAIS effectively measures the development of auditory perception, the MUSS is a complementary tool that specifically evaluates the functional application of this perception in the form of expressive oral communication. Its inclusion allows for a distinct and critical analysis of speech production outcomes, which is the primary goal of cochlear implantation.

The MUSS is a 10-item parent-reported questionnaire that assesses a child's use of speech in natural everyday situations. It is structured to evaluate three core components of functional speech development: Firstly, the volitional control of speech**:** The child's control over vocalizations and speech production mechanisms (Questions 1-3). Secondly spontaneous use of speech**:** The use of speech as a primary mode of communication in various social contexts (Questions 4-8) and thirdly communication strategy: The child's ability to modify their speech to enhance clarity and ensure the listener understands the message (Questions 9-10).

The scoring methodology for the MUSS is identical to that of the IT-MAIS/MAIS, with each question rated on a 0-4 scale, yielding a total possible score of 40. Higher scores on the MUSS reflect a more consistent and effective use of meaningful speech in daily life.

RESULTS

The collected data was entered in a spreadsheet. Confidentiality of each study participant was maintained throughout the study. The data was analyzed using SPSS version 23.0. Descriptive summary using frequencies, percentages, graphs, mean and standard deviation was used to present study results. Probability (*P*) was calculated to test statistical significance at the 5% level of significance. Categorical variables were analyzed using the chi-square test. Continuous variables were calculated using an independent t-test. Regression analysis was done to establish an association between independent and dependent variables.

Demographic characteristics

The study enrolled 23 subjects who underwent unilateral cochlear implantation and completed 12 months of follow-up. The demographic distribution showed nearly equal gender distribution, with 12 males (52.2%) and 11 females (47.8%). The mean age at implantation was 5.39 ±3.46 years, ranging from 2 to 14 years.

Preoperative hearing evaluation

Preoperative free-field audiometry showed severe or profound sensorineural hearing loss in all subjects. Most (91.3%, n=21) had a hearing threshold of 90 dB HL, suggesting profound hearing loss with some residual hearing. One subject had a threshold of 75 dB and another had a threshold of 80 dB. The average preoperative free-field audiometry threshold was 88.70 ±3.59 dB HL.

Post-operative auditory performance (IT-MAIS/MAIS)

The IT-MAIS/MAIS for hearing assessment showed a progressive and significant improvement at all intervals of follow-up. The mean scores rose from 7.48±6.01 at 1 month to 15.43±5.83 at 3 months, 23.70±5.77 at 6 months and 31.57±6.46 at 12 months post-activation (*P* - 0.001). In Figure 1 demonstrate how mean MAIS/ IT-MAIS score over progresses over 12 months. The pattern suggested the maximum improvement in the first 6 months, followed by a slower progression from 6 to 12 months. At 1 month, most subjects–(65.2%, n=15) had scores ranging from 0-10, indicating little functional auditory integration ability. However, at 12 months there was a significant change in the pattern, with 60.9% (=14) of individuals scoring between 31 and 40 which indicated a well-established meaningful auditory integration ability in practical everyday tasks.

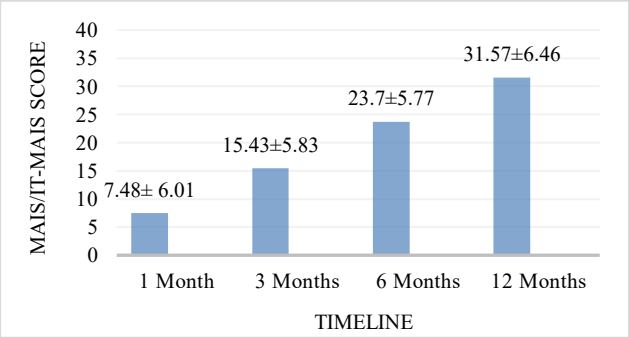

Figure 1: Mean MAIS/IT-MAIS scores over 12 months Bar graph showing progressive improvement in auditory integration scores from 1 month (7.48 ±6.01) to 12 months (31.57 ±6.46) post-activation (P < 0.001).

Postoperative hearing thresholds

Free field audiometry showed improvement in the hearing thresholds post implantation as compared to the preoperative levels. The mean FFA thresholds progressively improved from 44.13±4.79 dB HL at 1 month to 38.26±3.96 dB HL at 3 months, 36.09±4.00 dB HL at 6 months and finally to 35.00±4.36 dB HL at 12 months (*P*-0.001 for all comparisons with baseline).

The difference in threshold values from preoperative baseline (88.70±3.59 dB HL) to 12 months postoperatively (35.00±4.36 dB HL) was 53.70 dB, which changed the hearing status from profound/severe to mild hearing loss. Improvement from severe hearing loss to functional hearing can be seen in Figure 2.

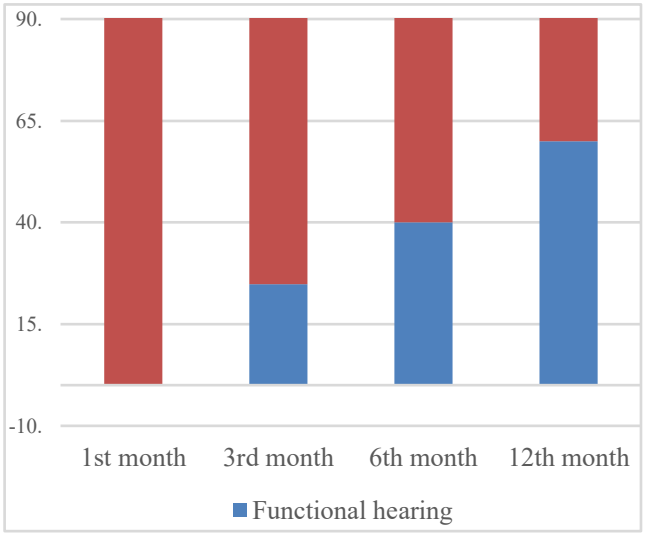

Figure 2: Progression of FFA improvement over 1 year.

Comparison of hearing thresholds showing a shift from preoperative profound loss (88.70±3.59 dB HL) to mild hearing loss (35.00±4.36 dB HL) at 12 months

Post-operative speech production (MUSS)

The speech production ability, as measured by MUSS scores, showed significant improvement over the 12-month follow-up**.** The mean scores increased from 5.74±5.09 at 1 month to 13.61±6.27 at 3 months, 20.26±6.79 at 6 months and 26.87±7.55 at 12 months (*P*-0.001). The rate of speech development also followed the pattern of auditory improvement, showing the steepest increase in the first 6 months post-activation, with a gradual but steady improvement afterwards. At 1 month, 69.6% (n=16) of subjects scored between 0 and 10, indicating little use of spontaneous speech. However, at 12 months, the scores were significantly different: 56.5% (n=13) scored between 21 and 30 and 30.4% (n=7) scored between 31 and 40, indicating extensive use of meaningful speech as the predominant form of communication.

Gender-based comparison

Table 1 shows that there is no statistically significant gender difference for any of the outcome measures at any point of time. The male and female subjects showed similar preoperative values and a similar pattern of improvement in IT-MAIS/MAIS, FFA and MUSS scores over the 12-month period (all p>0.05). This suggests that gender is not a predictor of cochlear implant outcomes.

Table 1: Gender-wise comparison of outcomes at 12 months.

Variable at 12 Months	Males (n=12)	Females (n=11)	P value
IT-MAIS/MAIS*	31.08 ±6.87	32.09 ±6.18	0.697
FFA (dB HL) †	35.42 ±4.68	34.55 ±4.08	0.618
MUSS‡	26.25 ±7.98	27.55 ±7.24	0.677

* IT-MAIS/MAIS: Infant-Toddler Meaningful Auditory Integration Scale / Meaningful Auditory Integration Scale
† FFA: Free Field Audiometry
‡ MUSS: Meaningful Use of Speech Scale

DISCUSSION

The rehabilitation of auditory abilities through CI is a complex process that goes beyond the surgical procedure. The study involved 23 subjects at a tertiary care center in North India and demonstrated notable improvements over 12 months in auditory thresholds, auditory integration and speech production. These outcomes should be considered in relation to age at implantation, duration of auditory deprivation, underlying causes and socioeconomic factors.

The average age at the time of implantation was 5.39±3.46 years, placing the majority of the subjects in the "late-implantation" group compared to the generally accepted benchmark of implantation, which is 12 months of age. [8] Gaurav et al have shown that children implanted at or before 5 years of age have significantly better MAIS scores than those implanted after 5 years, although both groups show a remarkable improvement.[9] These results are consistent with the hypothesis that early implantation results in superior potential outcomes, while older children also show significant benefit, although to a lesser extent, due to the persistence of cortical plasticity. A study by May Mederake has shown that implantation prior to 12 months of age allows for language development comparable to that of normal-hearing children.[8] However, the average 12-month MUSS score of 26.87±7.55 in the current study, though showing a dramatic improvement from baseline, is still significantly lower than the maximum possible score of 40, indicating that late-implanted children are unlikely to reach native-like levels of proficiency despite their ability to communicate effectively functionally.

Longitudinal study conducted by Niparko et al show that the course of language development is more accelerated in children implanted at younger ages.[10] In particular, children implanted after the age of 3-4 years showed slower progress in expressive language and needed prolonged auditory stimulation to reach age-normative milestones. This finding is consistent with the results of the present study, where progress in auditory perception (IT MAIS/MAIS) was more accelerated than progress in speech production (MUSS), suggesting that the 12-month follow-up reflects only an initial phase of a longer habilitation process.

The length of auditory deprivation is closely linked to the integrity of the nervous system. A meta-analysis carried out by Bernhard et al has shown that longer durations of hearing loss is associated with worse speech perception, most likely due to the loss of spiral ganglion cells and cortical reorganization.[11] In the present study, most children had more than five years of hearing loss, which could contribute to the 12-month mean FFA threshold of 35.0±4.36 dB HL and mid-range MUSS scores. In an Indian study, Patni et al, found age at implantation and deprivation duration to be major predictors of outcome, but they also showed consistent gains in MAIS even in children with more than five years of deprivation, thus confirming the feasibility of late implantation in countries where delays in diagnosis are frequent.[12]

Research on residual low-frequency hearing has indicated that although it may initially provide a benefit, electrical stimulation normalizes long-term performance for children with and without residual hearing.[13] In this study, 2 subjects had some residual hearing, but by the end of 1 year their scores were at par with the subjects of similar age.

Gender did not prove to be a limiting factor in our study. This was in agreement with the study of Sundaresan et al.[14] There were no significant gender differences in FFA, MAIS and MUSS scores ($p>0.05$), indicating equal biological and rehabilitative potential for both genders post-implantation.

Socioeconomic factors likely contributed to the wide variability in scores (MAIS±6.40, MUSS±4.52). Sharma et al showed that although income does not directly alter biological outcomes, it strongly influences access to auditory-verbal therapy, device maintenance and the richness of the linguistic environment.[15] Children from lower-resource families may rely mainly on home-based training, leading to slower progress despite successful implantation.

Finally, the psychosocial effects of cochlear implantation are significant. Shukla et al. explained how untreated hearing loss encourages social withdrawal and psychological distress, while hearing restoration decreases isolation and promotes re-engagement.[16] In this study, the improvement in FFA thresholds to around 35.00±4.36 dB and rising MUSS scores can be seen as not only functional gains but also signs of social integration, as children move from passive observers to active communicators in their environments.

Overall, these findings show that paediatric cochlear implantation in a late-implanted, resource-variable Indian group achieves notable auditory improvements and

steady speech development across genders, while emphasizing the importance of early diagnosis, reducing deprivation duration and ongoing intensive rehabilitation to enhance long-term language and academic success.

Strengths and limitations

The prospective longitudinal design follows a cohort of 23 participants over 12 months, eliminating recall bias and allowing an accurate view of the development of hearing and speech skills.

Use of standardized, validated tools (MAIS/IT-MAIS and MUSS) offers strong, measurable data that is comparable to international standards for objective functional results.

The study provides relevant context by offering realistic prognostic data for "late-implanted" children in a developing country, a group often underrepresented in global research.

Methodological limitations include a small sample size (n=23) and a short time follow-up.

Longer-term speech, language and educational outcomes need longer follow up with larger cohorts to be determined.

CONCLUSION

Cochlear implantation in this cohort of late-implanted children led to progressive improvement in functional auditory performance, hearing thresholds and meaningful speech production during the first 12 months after implantation. Although implantation was delayed, participants showed measurable gains in auditory integration and functional speech, indicating that cochlear implantation may be beneficial even if it occurs after the early childhood period. The findings add prospective data from a tertiary-care setting of North India and highlight the significance of timely diagnosis, appropriate candidate selection and sustained auditory-verbal rehabilitation in optimizing outcomes in late-implanted children.

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