COCHLEAR IMPLANT OUTCOMES IN CHILDREN: A FIVE-YEAR RETROSPECTIVE PROFILING STUDY

SEJAL MAHAJAN

Registration No: P01II24SO2023028

A Dissertation Submitted in Part of the Fulfillment of the

Degree of Master of Science

(Audiology)

University of Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MANASAGANGOTHRI,

MYSURU -570006

JUNE, 2026

CERTIFICATE

This is to certify that this dissertation entitled **" Cochlear Implant Outcomes in Children: A Five-Year Retrospective Profiling Study"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science **(Audiology)** of the student with Registration Number P01II24S023028. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

M. Pushpavathi

Mysuru
8th June, 2026

Dr. M. Pushpavathi

Director
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570 006

CERTIFICATE

This is to certify that this dissertation entitled **"Cochlear Implant Outcomes in Children: A Five-Year Retrospective Profiling Study"** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration number P01II23S023004. This has been carried out under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree

Mysuru

June, 2026

Dr. Geetha C
Guide
Associate Professor in Audiology
Department of Audiology
All India Institute of Speech and Hearing,
Manasagangothri, Mysuru- 570006

डॉ. गीता सी / Dr. Geetha C
सह-प्राध्यापक ऑडियोलॉजी
Associate Professor in Audiology
आर.सी.आई. सं. / RCI Regn. No. [illegible]
अखिल भारतीय वाक् श्रवण संस्थान
All India Institute of Speech and Hearing
मैसूरु / MYSURU-570 006

DECLARATION

This is to certify that this dissertation entitled **“Cochlear Implant Outcomes in Children: A Five-Year Retrospective Profiling Study”** is the result of my own study under the guidance of Dr. Sujeet Kumar Sinha, Associate Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for award of any other diploma or degree.

Mysore,

June, 2026

Registration Number:
P01II24S023028

ACKNOWLEDGEMENT

First and foremost, my deepest gratitude to my **Mumma and Papa**. You both are everything to me. From the very beginning none of this would have been possible without you both. I also extend my heartfelt love and appreciation to my incredible family on both my mother's and father's side. I love you all dearly.

I would like to express my sincere gratitude to our Director, **Dr Pushpavathi**, for providing me with the opportunity to be a part of AIISH and for her kind consideration in granting an extension for my dissertation.

Dr Jijo P. M., JSS Dharwad, sir, without your help, none of this would have been possible. Thank you for all your efforts in helping me get into AIISH and for your support in laying the foundation of my speech and hearing journey.

My sincere gratitude to **Dr Geetha C**, Associate Professor of Audiology at AIISH, for making this process possible and for giving me the opportunity to learn, unlearn, and grow throughout this dissertation. Your guidance, support, and encouragement brought about meaningful change in my experience, and I am truly thankful.

Thank you so much, **Nethra ma'am**, soon to be graduated as Dr. Nethra, for your patience and for helping me with everything without any hesitation. I am truly grateful for your support and will remember this for a long time. Wishing you all the very best. I am sure your future students will be lucky to have you as a mentor.

My best friend, **Shreya Shetty**, this would not have been possible without you. You know we are in this for the long run, and you have always had my back. I love you and thank you so much. I do not even need to say much, you already know it all.

They say quality over quantity, and that is **Preksha Agarwal**, who became my best friend in AIISH. Preks, thank you for always being there for me through all my ups and downs, and for all the fun banter over NFC coffee and open masala dosa. I will truly miss all of it. From our endless inside jokes to the small missions we set to get through this master's, you made everything easier. I love you.

My lovely girls**, Dibyamani, Lavina , and Nidhi B**, you all were always there to check on me emotionally and kept me going even when I had almost given up. I am so grateful for you all and love you all so much.

Abhishek Naik, thank you so much. It was really unexpected, and I never thought I would need your help this much, but you stood by me and were one of the reasons my data collection was completed. Wishing you the best.

Lastly, thank you to all my **classmates, clinical batchmates, staff, clinical supervisors, and faculty** for being a part of my master's journey**. Thank you, AIISH family**

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ABSTRACT

Cochlear implants (CIs) are an effective intervention for children with hearing impairment; however, variability in long-term auditory, speech, and language outcomes remains. The present study aimed to profile the demographic, audiological, speech-language, and psychological characteristics of pediatric CI recipients and examine the relationship between pre-implant factors and long-term outcomes. The retrospective profiling study was conducted using the clinical records of 70 children with congenital severe-to-profound hearing loss who had used CIs for at least five years. Demographic, audiological, speech-language, and psychological data were analysed using descriptive and inferential statistics. Age at diagnosis was predominantly 24–36 months, while age at implantation was predominantly 36–47 months. Significant improvements were observed in aided hearing thresholds, Ling six sound awareness and identification, speech perception, RLA, and ELA following CI use. Auditory and speech outcomes showed the greatest gains during the early years after implantation and subsequently stabilised, whereas language abilities continued to improve, with receptive language outcomes consistently exceeding expressive language outcomes. Psychological assessment findings indicated average cognitive functioning. Correlation analysis revealed significant but weak relationships between age at diagnosis, age at implantation, pre-implant auditory measures, language abilities, IQ, and long-term auditory, speech, and language outcomes at 60 months of CI use. The findings highlight the long-term benefits of CIs and underscore the importance of early identification, timely implantation, and favourable pre-implant auditory and language abilities in achieving optimal outcomes.

Keywords: cochlear implant, pediatric hearing loss, auditory outcomes, speech perception, language development, long-term outcomes, pre-implant factors.

CHAPTER I

INTRODUCTION

Cochlear implants (CIs) have been developed as an effective intervention for individuals with severe-to-profound sensorineural hearing loss (SNHL). Unlike hearing aids, CIs bypass damaged hair cells and directly stimulate the auditory nerve through electrical signals. CIs are considered one of the most successful neural prostheses developed in modern medicine and have provided partial hearing restoration to thousands of individuals worldwide (Yawn et al., 2015; Zeng et al., 2008).

It is widely acknowledged that auditory input plays an integral role in the normal development of central auditory nervous system in early childhood. According to Kral (2013), proper auditory stimulation in early stages facilitates normal development of auditory pathways. Alternatively, deprivation from auditory stimuli might result in aberrant neural organization that adversely affects future hearing and language development. In addition, it should be noted that adequate exposure to sounds does not ensure optimal outcomes since higher-level processes associated with hearing and language rely on many other components.

Based on these studies, early implantation is usually viewed favorably because it allows for normal development due to auditory stimulation provided during the critical period. As was proved by Sharma et al. (2002), early implantation results in more matured brain structures responsible for auditory processing. Nevertheless, early intervention cannot guarantee good results since outcomes significantly vary in different individuals, indicating that other factors than the timing of implantation play their role.

Hearing is fundamental to the development of speech, language, cognition, and social communication. Although CIs provide access to auditory input, outcomes among pediatric users remain variable. Geers (2003) observed improvements in speech perception among many children but also noted variability in higher-level skills, such as language processing and reading. Similarly, Nicholas and Geers (2007) reported that not all children with early implantation achieve age-appropriate language levels, suggesting limitations in the uniformity of outcome expectations. After cochlear implantation, children receive auditory-verbal therapy and speech-language therapy to learn listening and speaking skills; but there is still a lot of variability in outcomes among CI recipients who are children (Ching et al., 2013).

Such variability of outcome may be attributed to various factors, working simultaneously. Age of implantation and period of deprivation of hearing are some biological factors involved. As shown by Svirsky et al. (2000), earlier age of implantation correlates with better outcomes of speech and language acquisition. However, there are also audiological factors contributing to this, and they are related to residual hearing as well as regularity of using the implant.

Furthermore, parental interaction along with the level of language input in the domestic environment has been observed to significantly influence the communication development in children. Socioeconomic variations and availability of rehabilitation facilities can possibly add to the variations observed in children.

Specifically, in India, these issues might occur on a higher scale. In a study conducted by Daya et al. (1999), the effect of graded profile analysis scores on the improvement of speech perception was investigated among CI pediatric candidates. The study found that Children's Implant Profile (ChIP) analysis scores are related to improved speech perception scores. Likewise, Raza et al. (2020) studied pre-implant clinical profiles and family history of children with severe-to-profound deafness and found that consanguinity and positive family history were common associated factors.

Profiling among pediatric CI recipients have also been carried out in Indian research. Gupta (2012) showed that the age of CI implantation, the duration of auditory deprivation, and the degree of residual hearing affected post-implant performance in children. In a similar way, Rayamajhi et al. (2021), too, studied the sociodemographic factors related to revision CI surgery and stressed the importance of clinical follow-up, considering the differences in the availability of early hearing screening and rehabilitation programs. Even though CI surgery is increasingly becoming accessible, the differences in access to follow-up care and therapy programs are still impacting the long-term outcomes of children.

In general, CI's have greatly enhanced auditory access. According to Geetha and Antony (2025), in their retrospective study of the effects of CIs among pediatric CI recipients within two years of surgery, there were considerable improvements in auditory skills and language abilities. From the results obtained, age at implantation was one factor that contributed to the improvement in auditory skills while the socioeconomic status and pre-implant language skills influenced language acquisition in children with severe-profound hearing loss. Nonetheless, outcomes varied among individual children, indicating that access to technology does not guarantee success always.

1.1 Need for the study

CI outcomes are influenced by complex interactions among biological, audiological, rehabilitative, and environmental factors. Despite the fact that several studies have sought to establish predictors for post-implant success, the existing literature, especially in the Indian scenario, has tended to explore mainly the effects of factors such as age of implantation, surgery-related factors, and elements related to rehabilitation, with a major focus on audiological outcomes through standardized rating scales (Kulkarni et al., 2018). Although this information provides a basis for understanding auditory performance, studies carried out in India have investigated factors such as age of implantation, perinatal risks, pre-implant hearing aid usage, surgery-related factors, and rehabilitation factors regarding CI (Gaurav et al., 2020; Gaurav et al., 2022; Kulkarni et al., 2018).

However, most investigations tend to focus more on audiological outcomes and have given little consideration to speech and language outcomes. They provide only a restricted view of functional outcomes, particularly speech and language development. These outcomes provide limited insight into overall functional outcomes in areas like speech and language development. Past research shows that although gains in auditory perception after cochlear implantation are evident, they do not always match gains in communicative development. For example, there can be development of speech perception skills in some children but their expressive and receptive communication skills may not progress similarly (Nicholas & Geers, 2007). This reveals that traditional outcome assessments may not accurately represent real-life communicative performance in difficult listening environments like school or social situations.

One other weakness in the current literature base is the fact that there is a strong concentration on short-term outcomes, mostly within one to two years after implants are inserted. Short-term gains are good indicators of auditory development, but they may not adequately reflect long-term progress. The limited studies on longitudinal research has demonstrated that CI users continue to develop their speech-language skills over a number of years and in response to a variety of interacting factors (Niparko et al., 2010). Moreover, the process of development may be nonlinear; different developmental trajectories, such as rapid improvement, delayed acquisition, or even a period of stagnation, can be observed in young individuals. Nevertheless, developmental trajectories have been poorly studied in numerous empirical studies.

The retrospective profiling study carried out by Geetha and Antony (2025) has brought important insights related to auditory and language abilities in two-year post-implantation period. While the research revealed substantial benefits of CI's in developing auditory and language abilities within two years after implantation, there remains a lack of information about developmental outcomes at later stages.

Moreover, many researchers tend to identify predictors of outcomes without considering interactions among the predictors. Age at implantation, duration of deafness, residual hearing, rehabilitation efforts, and environmental conditions all interact to affect developmental outcomes of CI users (Niparko et al., 2010). As a result, examining predictors of outcome individually can negatively impact the understanding of outcome variability and also the current literature also reveals a discrepancy between standard clinic assessment.

Contextual issues could compound these problems in India, where discrepancies in the availability of early detection and rehabilitation, socio-economic inequalities, and other issues are expected to impact the findings (Kulkarni et al., 2018; Singh & Barman, 2017). Other factors, such as multilingual exposure, inconsistent attendance at speech-language therapy sessions, and device use, may contribute to variability in the development of speech and language skills. Besides, environmental factors such as parental education and socio-economic status are likely to affect the performance of children with hearing impairments in language-related tasks (Ching et al., 2013). Nevertheless, real-world factors are relatively poorly understood in the context of longitudinal outcome studies among the Indian population.

Another critical limitation is the lack of standardised protocols for long-term monitoring of patients with hearing impairments. Issues with test instruments, the duration of follow-ups, and other factors may hinder the comparison of results across multiple studies. In addition, there appears to be a lack of attention to translating scientific results into practical guidelines for rehabilitation practice.

Thus, there is an urgent need to adopt a more holistic, child-centred approach. Follow-up for up to a minimum of five years after implantation is significant from a clinical standpoint, as hearing, speaking, linguistic, and cognitive skills continue to develop through preschool and school age. Follow-up of up to five years post-implantation can assist in revealing any improvement, stabilization, delays or plateau effect which cannot be detected at the beginning stage of implantation taking into account overall development including speech, language, cognition and socialization aspects. Analyses of real-life data in a retrospective design could prove useful in gaining a deeper understanding of patients' differences and their device use.

Accordingly, the current research aimed to fill these gaps by conducting an extensive five-year retrospective analysis of children who received CIs. The study was based on the assumption that the interaction of several factors would have an associated with audiological and language skills outcomes.

1.2 Aim of the study

To profile the demographic, audiological, speech, and language outcomes of pediatric CI users of a tertiary centre, and to determine the relationship between pre-implant factors and long-term outcomes at five years post-implantation.

1.3 The objectives of the study were-

1) To profile the demographic, audiological, speech, and language variables in pediatric CI users,
2) To compare auditory speech and language outcomes between one year and five years post-implantation, and
3) To determine the relationship between the pre-implant variables and post-implant audiological, speech, and language outcomes at five years of implantation in children using CI.

CHAPTER II

REVIEW OF LITERATURE

CIs are widely recognized as an effective intervention for children with severe-to-profound sensorineural hearing loss, as they provide auditory access through direct electrical stimulation of the auditory nerve. Previous research has consistently demonstrated significant improvements in auditory perception and communication abilities following implantation (Niparko et al., 2010). However, outcomes among pediatric CI users are not uniform, and considerable variability has been reported across individuals.

This variability has led to an increasing research focus on identifying factors that may influence post-implant outcomes. Studies have suggested that variables such as age at implantation, duration of deafness, and rehabilitation significantly contribute to differences in auditory and language development (Nicholas & Geers, 2007; Niparko et al., 2010). Despite these findings, outcomes cannot be attributed to a single factor, indicating the involvement of multiple interacting influences. This review of literature discusses the various outcomes associated with cochlear implantation, including auditory, speech, and language outcomes, as well as the different factors that may influence post-implant performance among pediatric CI users. The review further highlights the variability in outcomes reported across studies and emphasizes the importance of understanding the combined contribution of audiological, rehabilitative, cognitive, environmental, and demographic factors in shaping long-term CI outcomes.

2.1 Indian Context and Research Gap

There is insufficient research available regarding CI outcomes in India, especially from a multivariate and longitudinal perspective. Gupta (2012) performed a study that was a prospective analysis to study various factors affecting the CI outcomes among children less than five years old. This study analyzed the impact of multiple child and parental factors on auditory perception, speech comprehension, and auditory integration outcomes among the participants during a one-year follow-up period. Age at implantation, time of auditory deprivation, and level of pre-operative hearing ability emerged as significant factors affecting CI outcomes, while other factors like maternal education, family support, language used at home, intelligence quotient (IQ), and etiology did not emerge as significant determinants of CI outcomes.

The study by Gaurav et al. (2020), who specifically concentrated on the impact of implantation age, evaluated the auditory performance of 50 Indian children with CIs. According to the researchers, the auditory performance outcome for children who had received implants before or at five years of age was significantly superior to that of those who had their devices implanted after five years, as demonstrated by higher CAP and MAIS scores after one year from the implantation. On the other hand, considerable improvement was seen among children whose devices were implanted after the age of five.

Notably, a recent study by Geetha and Antony (2025) focused on demographic, audiological, and environmental factors influencing CI outcomes and found significant improvements in both auditory and language performance after two years from implantation. Age at implantation, socioeconomic status, and language ability prior to surgery proved to be significant determinants of post-implant performance.

Even though such research has provided important findings about the possible factors affecting the CI outcome in Indian children, they all have mostly concentrated their attention on the short follow-up period lasting from one to two years. As a result, the long-term developmental pattern of auditory, speech, and language skills has not been well studied yet. Besides, there is a lack of research addressing the combined effect of numerous factors affecting the CI outcome in Indian children.

2.2 Cochlear Implant Outcomes

CI outcomes generally refer to the improvements seen in hearing, speech, language, communication, and overall quality of life after cochlear implantation in individuals with severe-to-profound hearing loss. These outcomes are usually assessed by examining abilities such as speech perception, auditory performance, spoken language development, listening skills, and everyday communication following implantation (Boisvert et al., 2020; Deep et al., 2021).

2.2.1 Auditory Outcomes

Auditory outcomes are often considered among the earliest indicators of benefit following cochlear implantation and commonly include abilities such as speech-sound detection, discrimination, and speech perception. A recent scoping review, Corbett and Van Zalk (2025) reported that children with bilateral CIs generally demonstrate better speech perception and hearing abilities following implantation. At the same time, the review pointed out that auditory outcomes are not always consistent across children, suggesting that post-implant auditory development may be influenced by multiple developmental and contextual factors.

Wu et al. (2023) conducted a systematic review on the effects of CI in toddlers receiving CIs under 12 months of age, revealing considerable improvement in auditory function among toddlers following CI surgery. Children receiving CI before reaching the age of 12 months tended to show better performance than those implanted later on auditory tests such as IT-

MAIS, LEAQ, CAP, GASP, and CNC.

2.2.2 Speech Outcomes

Speech production and intelligibility are important indicators of spoken language development in children with CIs because they reflect how effectively auditory information is used for speech output. Research has consistently shown that cochlear implantation leads to gradual improvements in speech abilities; however, the extent of improvement varies considerably across children.

Studies have also highlighted that speech outcomes improve progressively with increased CI use. Earlier longitudinal findings by Tobey et al. (2003) demonstrated significant gains in speech intelligibility over time, with improvement closely related to duration of device use. Supporting this, Peng et al. (2004) reported continued development in speech production abilities, including improvements in consonant production and overall intelligibility, although many children still performed below age-matched peers with normal hearing. The authors studied pediatric patients who had undergone CI surgery and found an improvement in their auditory and speech skills through follow-up assessment during a one-year period after surgery. An improvement was seen in various parameters such as the Speech Intelligibility Rating (SIR) and the Meaningful Use of Speech Scale (MUSS) that are used to assess the child's progress in speech production.

In addition to surgical factors affecting speech outcomes, various child-specific and environmental factors have been identified to play roles in speech outcomes. For instance, Corbett et al. (2025) found through a review study on pediatric bilateral cochlear implantation that speech and communication skills of children were affected not only by individual factors but also by their environment.

However, despite notable improvements that were reported in all studies, inconsistency in speech outcome was a common observation. Tobey et al. (2003) and Peng et al. (2004) found that a number of participants had difficulty maintaining good articulation, low phonological precision, and inconsistent speech production even with extended use of the devices. Moreover, according to Nittrouer et al. (2018), speech problems experienced by CI recipients might be associated with auditory and phonological processing limitations.

Currently, it can be noted that the existing research demonstrates the potential for cochlear implantation to lead to substantial improvements in terms of speech production and clarity; nevertheless, speech outcomes show considerable variation between patients. While speech production improvement is considered typical after CI surgery, successful communication depends not only on speech but also on the development of language components such as vocabulary and grammar.

2.2.3 Language Outcomes

Language outcomes in children with CIs include different parameters such as vocabulary, grammar, sentence formation, discourse, and pragmatic communication skills. Although cochlear implantation improves access to sound and spoken language, development across these language domains does not always occur at the same rate. Geers (2004) reported that while many children show noticeable improvement in spoken language after implantation, long-term language performance continues to vary considerably among children.

Many studies have shown that vocabulary development improves steadily following cochlear implantation. Connor et al. (2006) observed that children exposed to rich communicative environments and consistent rehabilitation demonstrated better vocabulary growth over time. However, the study also found that stronger vocabulary skills did not always mean equally strong grammatical and syntactic development. Similar findings were reported by Geers et al. (2003), who noted that although many children developed functional spoken communication, difficulties with grammatical accuracy and the formation of complex sentences often persisted even after implantation.

The timing of implantation has also been identified as an important factor influencing language development. Nicholas and Geers (2006) found that children implanted at younger ages generally developed better receptive and expressive language skills than those implanted later. Despite this advantage, many early-implanted children still showed delays in morphosyntactic skills compared with normal-hearing peers, suggesting that higher-level language development may continue for a longer period. Similarly, Lund (2016) suggested that vocabulary and language integration limitations may have a general effect on language structure and academic communication.

2.3 Factors Influencing Cochlear Implant Outcomes

Recent scoping reviews have further shown that rehabilitation and environmental variables strongly contribute to variability in CI outcomes. Corbett and Van Zalk (2025) reported that factors such as parental interaction, consistency of CI use, educational placement, auditory-verbal therapy, cognitive abilities, and social environment significantly affect speech perception and communication outcomes in pediatric CI users. Their review emphasized that CI outcomes develop within a broader developmental and environmental context.

2.3.1 Biological Factors

Factors relating to the biology of the child have great importance for CI results as they affect children's development of auditory, speech, and language abilities following their implantation. Such biological determinants include the age at which the implantation occurs, the degree of auditory deprivation, the level of cognitive ability of the child, as well as the cause of hearing loss. According to Deep et al. (2021), biological determinants are still significant.

2.3.1.1 Age at Implantation. Age at implantation is one of the most widely discussed biological factors influencing CI outcomes in children. Recent evidence continues to show that children implanted at younger ages generally demonstrate better auditory, speech, and language development, mainly because they receive auditory stimulation during a period of greater neural plasticity and rapid brain development.

Follow-up studies examining long-term outcomes have reported similar trends. Elhakeem et al. (2023) found that children implanted before age 2 demonstrated better postoperative hearing thresholds and stronger language test performance than those implanted later. These findings support the view that earlier auditory access contributes positively to both auditory pathway development and spoken language acquisition.

2.3.1.2 Duration of Auditory Deprivation. The length of auditory deprivation before CI is one of the key predictors of auditory and neural development of children. The current evidence continues to demonstrate that children who had shorter auditory deprivation were able to have better auditory, speech, and language development due to the fact that their auditory pathways got stimulation during a sensitive period.

The current studies were corroborated by previous neurophysiological evidence. According to Sharma et al., (2005), prolonged auditory deprivation can result in a delay of the process of auditory cortical maturation as well as poor auditory responses of the neurons. As far as the current research results go, auditory deprivation for a longer period of time has a negative effect on the process of auditory development. Nevertheless, duration of auditory deprivation cannot be the only determinant of successful rehabilitation; other important factors include age of a child at the time of implantation and many others.

2.3.1.3 Speech Perception Abilities. One of the key areas of functional ability following cochlear implantation in children is their perception of speech, which is essentially dependent on how well they can hear, recognize, and comprehend speech sounds. While it is established that CI leads to improved auditory performance, recent researches have found considerable differences in terms of speech perception abilities amongst children.

Such findings have been validated by other previous studies as well. For instance, Firszt et al. (2004) observed that despite having similar audiological profile, there was large variation in speech perception abilities in children. Similarly, Blamey et al. (2001) observed considerable variations in speech recognition performance amongst children, independent of any confounding variables such as time period of deafness and age of implantation.

Longitudinal studies have also shown that speech perception abilities improve gradually over time following cochlear implantation. Kirk et al. (2002) reported improvement in open-set speech recognition abilities among many children after implantation, although the speed and extent of progress varied considerably across individuals. Similarly, Geers et al. (2003) observed that while speech perception improves over time, not all children achieve age-appropriate performance, particularly in difficult listening situations.

The influence of both auditory and broader developmental factors on speech perception has also been emphasized in earlier research. Overall, current evidence suggests that speech perception outcomes following cochlear implantation are highly variable and influenced by multiple interacting biological, audiological, cognitive, rehabilitation-related, and environmental factors. These findings highlight the importance of evaluating speech perception through a comprehensive, functional assessment rather than relying solely on audiological measures.

2.3.2 Audiological Factors

Audiological factors play an important role in CI outcomes as they influence auditory access and speech perception abilities in children. Variables such as residual hearing, aided auditory performance, and pre-implant speech perception skills have been linked to post-implant auditory and language development. Li et al. (2022) reported that children with better residual hearing showed improved early auditory perception and speech intelligibility after cochlear implantation. Likewise, Deep et al. (2021) emphasized that preoperative auditory abilities and aided hearing performance continue to affect rehabilitation outcomes among pediatric CI users.

2.3.2.1 Pre-Implant Hearing Levels. The pre-implant pure-tone average is an important audiological measure used to assess the severity of hearing loss before cochlear implantation. It provides a baseline picture of the child’s hearing status and helps clinicians gauge the extent of the child's auditory access before receiving the implant. Recent literature shows that pre-implant hearing thresholds continue to play an important role in CI candidacy and outcome planning. Pignac et al. (2024), in a review of pediatric CI candidacy, reported that the pure-tone average is commonly used to determine candidacy, with many studies considering thresholds of 65–80 dB HL as an important lower boundary for implantation. This suggests that PTA helps identify children whose hearing loss is severe enough that hearing aids may not provide sufficient speech access.

Similarly, Firszt et al. (2004) reported that children with similar audiological profiles may still exhibit different speech-perception outcomes, indicating that PTA alone cannot explain post-implant variability.

Overall, pre-implant PTA is useful because it provides a baseline measure of hearing severity, supports CI candidacy decisions, and helps document the degree of auditory access before intervention. However, recent evidence suggests that PTA should be interpreted along with aided benefit, speech perception, residual hearing, duration of deafness, rehabilitation history, and child-related factors, as CI outcomes are multidimensional.

2.3.2.2 Aided Audiogram. Aided audiograms provide important information about how much benefit a child receives from hearing aids before cochlear implantation. Unlike unaided hearing thresholds, aided audiograms reflect how effectively amplified sounds are accessed in everyday listening situations and therefore give a better understanding of the child's functional hearing abilities. Recent studies have also highlighted the importance of aided performance during CI candidacy evaluation. Pignac et al. (2024) reported that aided hearing abilities and speech access are often more clinically meaningful than unaided hearing thresholds alone when determining whether hearing aids are providing sufficient benefit for spoken language development.

Similarly, McCreery et al. (2015) reported that improved aided audibility supports speech and language development by providing better access to speech sounds. Walker et al. (2015) also found that children with more consistent auditory access through amplification tended to demonstrate stronger early language development, although outcomes varied across individuals.

Despite their importance, aided audiograms should still be interpreted carefully. Factors such as hearing aid fitting, consistency of hearing aid use, auditory processing abilities, and rehabilitation exposure may influence aided performance. Children receiving limited benefit from amplification may depend more on cochlear implantation for auditory access, whereas children with better aided audibility may already have some early auditory experience before implantation.

Overall, aided audiograms provide valuable information about functional auditory access before cochlear implantation. However, recent literature suggests that aided performance should be considered alongside speech perception abilities, duration of deafness, rehabilitation, and child-related factors when evaluating and predicting post-implant outcomes.

2.3.3 Device-Related Factors

Device-related factors play an important role in CI outcomes, as they influence the quality and consistency of auditory input after implantation. Variables such as type of speech processor, mapping and programming, consistency of device use, datalogging, and duration of CI use have been linked to auditory, speech, and language development in pediatric CI users. Likewise, Wiseman and Warner-Czyz (2018) found that children who used their devices more consistently generally demonstrated better speech and language outcomes following cochlear implantation.

2.3.3.1 Consistency of Device Use. CI consistency has been noted as one of the factors that affect hearing, speech, and language development in children. Due to advances in datalogging, researchers have recently been able to investigate how device use influences rehabilitation outcomes. Daily auditory exposure is supposed to enhance both auditory and communication skills development. The results of such investigations can be corroborated by earlier studies on daily CI use. For instance, Likewise, according to Wiseman and Warner-Czyz (2018), daily CI use was associated with improved speech and language development; however, the degree of progress may differ from patient to patient.

Furthermore, the significance of cumulative auditory exposure has been stressed.

According to Gagnon et al. (2021), long-term auditory exposure positively influenced spoken language skills.

Despite these findings, consistency of device use should not be considered independently of other contributing factors. Family involvement, rehabilitation exposure, cognitive abilities, and individual differences in auditory processing may also influence outcomes. While regular CI use supports continuous auditory stimulation and auditory learning, rehabilitation outcomes continue to vary across children.

2.3.3.2 Duration of Cochlear Implant Use. Length of time spent with the CI device has been identified as one of the crucial factors that affect auditory perception, speech comprehension, and language development in children. As a result, with increasing duration of the use of the CI, the constant exposure to auditory information helps children develop listening skills, speech understanding, and communication.

These conclusions have been confirmed by previous longitudinal studies. Specifically, according to Wiseman and Warner-Czyz (2018), children who used CI for a more extended period tended to exhibit better auditory and language skills. In turn, Nicholas and Geers (2007) have noticed that more experienced children achieved higher levels of linguistic competency.

Long-term studies have also shown that improvement following cochlear implantation occurs gradually rather than immediately. Connor et al. (2006) reported continued growth in vocabulary and language abilities with sustained CI use over time. Likewise, Geers et al. (2003) observed gradual improvement in speech perception and language development with increasing years of implant experience, although variability across children remained evident.

According to the results of the research, auditory speech perception abilities increased progressively as the children utilized the device longer since it was found that better performances were achieved with closed-set and open-set speech perception tests. Moreover, children, whose usage of the device was constant, had better outcomes than children whose usage of the device was sporadic.

2.3.4 Rehabilitation Factors

Rehabilitation factors are critical to ensuring successful CI use because they facilitate the development of auditory, speech, and language abilities in CI recipients. Auditory-verbal therapy, early intervention, parental participation, communication environment, and follow-up are among the rehabilitation factors identified as determinants of successful CI use in children. According to Binos et al. (2021), auditory-verbal therapy is effective in promoting speech and language development in children using CIs. Similar findings have been made by Noel et al. (2022), who observed enhanced auditory development in children with CIs undergoing auditory-verbal rehabilitation.

2.3.4.1 Therapy Duration and Intensity. Rehabilitation is considered an important part of CI management, as regular therapy helps children develop auditory, speech, and language skills after implantation. Recent evidence continues to emphasize that both the duration and intensity of therapy can influence post-implant outcomes by providing consistent auditory and linguistic stimulation.

Sud et al. (2023) identified the influence of family factors and rehabilitation issues on communication outcomes in cochlear-implanted children. The authors found that high levels of parental stress, financial issues, and caregiver-related issues affected the receptive and expressive language development of affected children. It is evident from the findings of the paper that continuous counselling and professional assistance can contribute towards achieving good communication outcomes in such patients.

The findings mentioned are supported by prior literature on therapy intensity. According to Geers et al. (2003), children who received intensive auditory-verbal therapy showed better language outcomes than those who did not. Similarly, Dettman et al. (2016) argued that early and continuous involvement in therapy can enhance the speech and language development in such patients.

Literature has also recognized the significance of continuing intervention in the early years of life. For example, Moeller (2000) observed that children receiving intervention in their early life were likely to have better language outcomes. Additionally, Nittrouer et al (2016) believed that linguistic input during therapy can positively impact speech perception and language development.

2.3.4.2 Early Intervention. Early intervention is widely considered an important factor in shaping outcomes for children with CIs because it provides timely auditory stimulation and rehabilitation during critical periods of speech and language development. Early access to intervention may support the development of auditory skills, spoken language, and communication abilities by providing children with consistent auditory input at a younger age.

Several Indian studies have emphasized the importance of early intervention in achieving favorable outcomes following cochlear implantation.

As noted by Ching (2015), children who underwent cochlear implant surgery at a younger age achieved better language results than children who underwent the surgery at an older age. According to the results, early detection of hearing loss along with immediate amplification and surgical interventions positively affect language development.

Similarly, Sanju et al. (2022) observed that early identification of hearing loss and timely cochlear implantation contribute significantly to the development of auditory, speech, and language skills. These findings highlight the value of providing intervention at the earliest possible stage to support optimal developmental outcomes.

These recent findings are supported by earlier foundational studies. Dettman et al. (2016) suggested that early and continuous rehabilitation following implantation contributes positively to long-term auditory and language outcomes. Similarly, Yoshinaga-Itano et al. (1998) reported that children who received early identification and intervention generally demonstrated better language development than those who entered intervention later.

Moreover, according to Kennedy et al., early identification and management were associated with enhanced language performance, regardless of other contributing factors. All these results indicate that early intervention could confer developmental benefits for children.

However, despite the positive effects on the developmental progress, early intervention alone cannot ensure successful outcomes. In particular, individual differences in the therapy, rehabilitation, family participation, cognitive capacities, and characteristics of each individual play their role. Thus, early intervention is just one of the many factors contributing to children's postoperative progress.

Summing up all the above-presented information, one can claim that contemporary research indicates that early intervention plays an essential role in ensuring positive auditory, speech, and language outcomes after the cochlear implantation surgery. However, at the same time, rehabilitation outcomes are still multifactorial.

CHAPTER III

METHODS

The present study employed a retrospective register-based profiling study design to analyse the audiological, speech, and language outcomes in pediatric CI users. The study aims to determine the pattern of pre-implant audiological, speech, and language findings and to correlate these findings with post-implant outcomes at five years post-implantation. Case files of children who underwent cochlear implantation and were followed up at the All India Institute of Speech and Hearing (AIISH), Mysuru, were reviewed for profiling and outcome analysis.

3.1 Participants

The study includes pediatric CI users who have been implanted and followed up at the center. Case records of children meeting the selection criteria are reviewed, and details are extracted systematically for profiling and analysis. The study include 70 pediatric CI users.

Table 3.1: *Descriptive statistics of demographic variables of 70 children with Cochlear implants*

Participants	Mean	SD	Range
Chronological age (in months)	124.92	2.46	73.2-200.4
Gender	1.500	14.52	1-73
Age at implantation	43.7143	13.90	5-72

Note: SD= Standard deviation, IQR= Interquartile range

Device-related information was obtained from the clinical records of all participants. Data regarding the cochlear implant manufacturer and speech processor model were collected and documented. The implant systems used by the participants included devices from Cochlear, MED-EL, Oticon Medical, and Advanced Bionics. A range of speech processor models, including Freedom, CP802, CP810, CP910, CP1000, CP1110, Kanso, Kanso 2, Sprint, OPUS 1, OPUS 2, Sonnet, Sonnet 2, Rondo, Saphyr SP, Neptune, and Naída Q30, were identified. These variables were included to provide a comprehensive profile of the implant devices used by the study participants. The distribution of speech processor models used by the study participants is presented in Table 3.2.

Table3.2

Frequency Distribution of Speech Processor Models Documented Among the Study

Speech Processor Model	Number of Participants (n)	Percentage (%)
CP802	55	78.6
OPUS 2	7	10.0
Saphyr SP	6	8.6
Freedom	2	2.9
Total	**70**	**100.0**

3.1.1 Inclusion Criteria

- Children with bilateral severe-to-profound sensorineural hearing loss.
- Children implanted at the centre and using CI for at least 5 years.
- Consistent device use confirmed through therapy and follow-up records.
- Completion of post-implant assessments at 36-, 48-, and 60-months post-CI.

3.1.2 Exclusion Criteria

- Children with additional developmental, neurological, or cognitive disorders that could confound outcomes.

- Cases with cochlear malformations or cochlear nerve anomalies documented in radiological assessments.
- Children with irregular or discontinued device use.
- Incomplete case files with insufficient documentation of pre-implant or post-implant outcomes.

3.2 Materials

Registers, case files, therapy records, audiological reports, speech and language assessment reports, radiological reports, psychological evaluation reports, and Statistical Package for the Social Sciences (SPSS) version 25 databases of children with CIs are used for profiling and analysis.

3.3 Procedure

The children's case files were reviewed, and relevant information is systematically documented under specific headings. These include demographic details, audiological assessment findings, hearing device fitting details, therapy history, speech and language assessment findings, psychological assessment findings, and outcome measures.

- Demographic details, including date of birth, gender, age at first visit, parental education, parental income, place, referral details, and previous consultation history.
- Case history and audiological assessment details, including mode of communication before device fitting, aetiology of hearing loss, relevant medical history, additional disabilities, age at diagnosis of hearing loss, age at first consultation for CI assessment, tests used for audiological evaluation, audiological test results, and candidacy evaluation findings.
- Medical and radiological assessment findings, including medical reports and radiological findings related to cochlear and auditory nerve status.

- Hearing device fitting and therapy details, including age at hearing aid fitting, duration of hearing aid use, duration of therapy with hearing aids, duration of CI use, number of speech processor upgrades, and duration of use of each processor.
- Speech and language assessment findings, including RLA and ELA , were assessed using standard assessment tools.
- Psychological assessment findings including developmental quotient/intelligence quotient test results.
- Outcome measures including aided thresholds with hearing aids and CI, Ling's sound test results, speech identification scores (SIS), RLA and ELA findings.

Table 3.3

Parameters analysed from this retrospective profiling study

Domains	Parameters to be Analysed
Demographic Details	Date of birth, gender, age at first visit, parental education, parental income, place, referral details, previous consultation
Case History and Audiological Assessment	Mode of communication, etiology of hearing loss, medical history, additional disabilities, age at diagnosis, age at CI consultation, audiological evaluation findings, candidacy evaluation
Hearing Device Fitting and Therapy	Age at hearing aid fitting, duration of hearing aid use, duration of hearing aid therapy, duration of CI use, speech processor upgrades, duration of processor use
Speech & Language Assessment	RLA and ELA
Psychological Assessment	Developmental quotient/intelligence quotient findings

Outcome Measures	Aided thresholds, Ling's sound test results, SIS, electrophysiological findings, RLA and ELA age.

3.4 Outcome Measures

- Audiological outcomes, including aided thresholds and Ling's sound detection.
- Speech perception outcomes, including SIS.
- Language outcomes, including RLA and ELA.

3.5 Statistical Analysis

All data obtained were entered and analysed using Statistical Package for the Social Sciences (SPSS), version 25. Descriptive statistics, including means, standard deviations, frequencies, and percentage distributions, were used to analyse demographic, audiological, speech, and language variables. Appropriate statistical tests were performed to compare outcomes till five years post-implantation and to determine the relationships between pre-implant variables and post-implant audiological, speech, and language outcomes at five years post-implantation. Correlation analysis and suitable inferential statistical tests are used wherever applicable.

CHAPTER IV

RESULTS

This retrospective profiling study was conducted to analyse the demographic details and pre- and post-operative findings of children with CIs. Different aspects, such as audiological findings, speech-language details, and psychological assessment findings available in the clinical case records, were reviewed and analysed as part of the study. The study also documented several baseline pre-implant factors that may be related to long-term post-implant auditory, speech, and language outcomes in children with CIs.

All the available information obtained from the retrospective clinical records were systematically collected and analysed using descriptive statistical methods. Categorical variables were analysed using frequency and percentage analysis, whereas continuous variables were analysed using mean or median values. The obtained results helped in understanding the overall profile of children with CIs included in the study sample. The findings of the present study are organised and presented in the following sections.

4.1 Profiling the demographic details of children with CIs

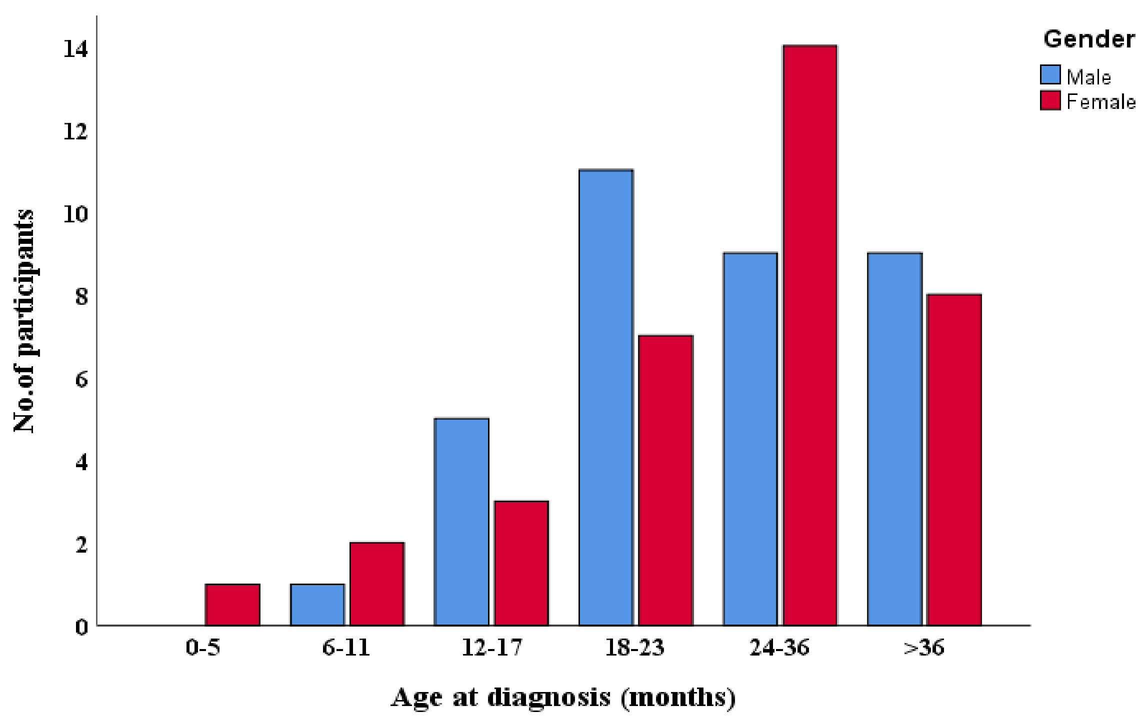
A total of 70 children with CIs were included in the present study. All participants selected for the study had used CI for at least 60 months at the time of data collection. The study consisted of an equal number of male and female children, with 35 participants in each group. Clinical case records revealed that all the children included in the study had congenital hearing loss.

4.1.1 Age at diagnosis of hearing loss and gender

Figure 4.1.1 shows the distribution of age at hearing loss diagnosis among male and female children with CIs included in the present study. Most of the children (n = 23) were diagnosed between 24–36 months of age, followed by the 18–23 months age group (n = 18). Only a few children were diagnosed during the early months of life, particularly between 0–5 months (n = 1) and 6–11 months (n = 3). Among male children, the highest number were diagnosed between 18–23 months (n = 11), whereas among female children, the highest number were diagnosed between 24–36 months (n = 14). Overall, a similar distribution pattern was observed among male and female children across age categories.

Figure 4.1.1.

Distribution of age at diagnosis of hearing loss among male and female children with Cochlear implants.

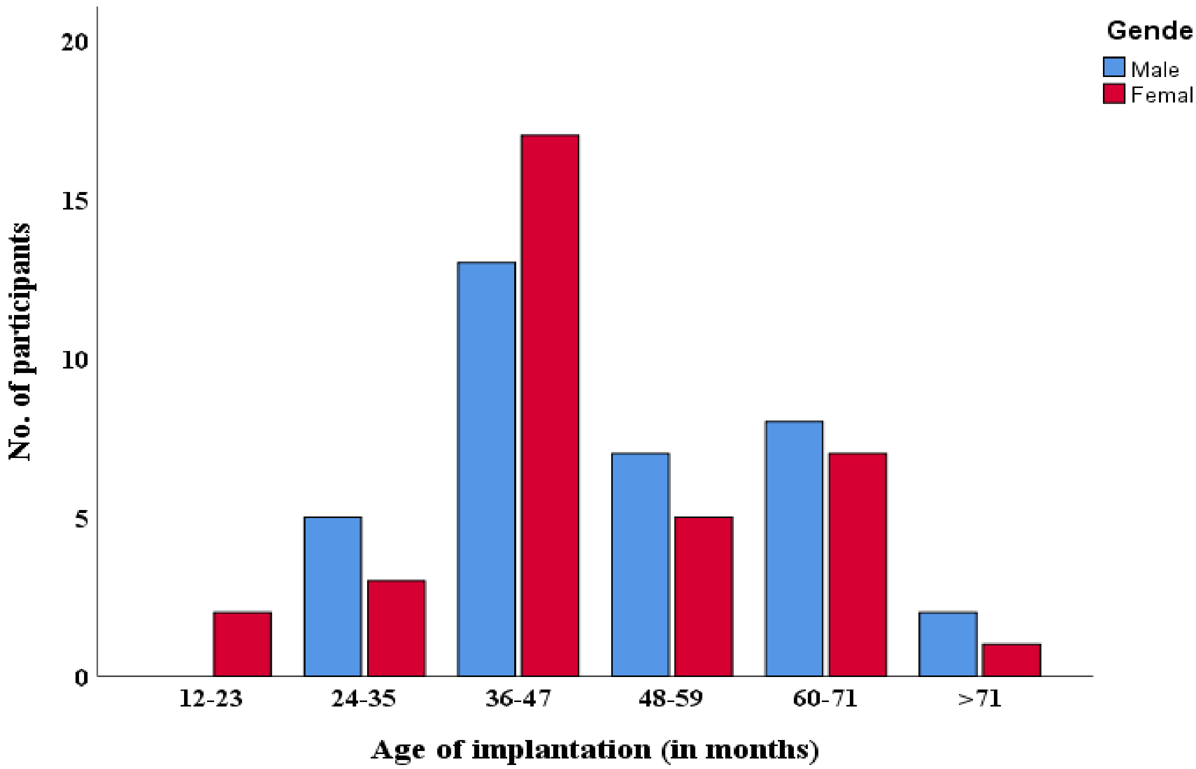


4.1.2 Age at implantation

Figure 4.1.2 shows the age at implantation among male and female children with CIs included in the study. Most of the children (n = 38) underwent implantation between 36–47 months of age. This was followed by the 60–71 months (n = 17) and 48–59 months (n = 8) age groups. Only a few children underwent implantation between 12–23 months (n = 4) and after 71 months of age (n = 3). A similar distribution pattern was observed among both male and female children across the implant age groups, except in the 12-23 months group.

Figure 4.1 2.

Distribution of age at implantation among male and female children with Cochlear implants

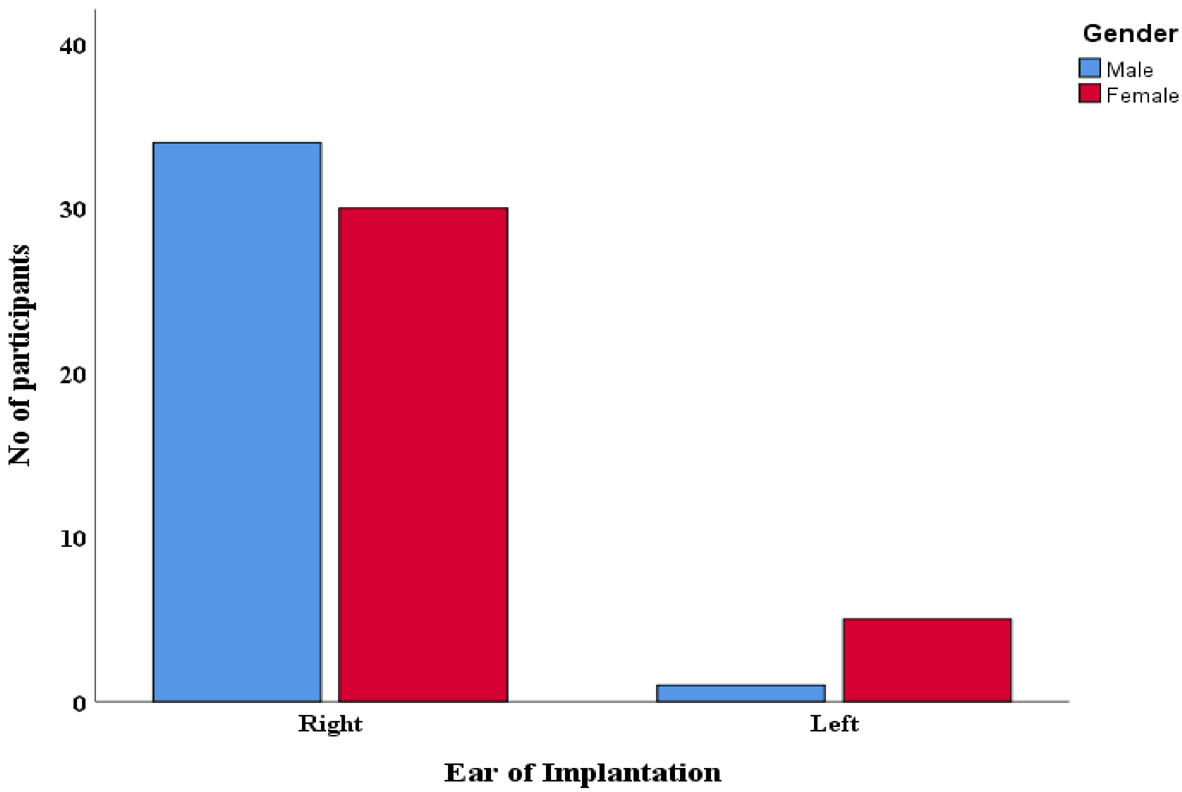


4.1.3 Ear of implantation

Figure 4.1.3 shows the distribution of the ear of implantation among male and female children with CIs. The majority of children underwent implantation in the right ear (64 participants), whereas only six of them received implantation in the left ear. Among male children, 34 underwent implantation in the right ear, and 1 in the left. Among female children, 30 underwent implantation in the right ear, and five of them underwent implantation in the left ear. Overall, right-ear implantation was more common among both male and female participants in the study.

Figure 4.1.3.

Distribution of ear of implantation among male and female children with Cochlear implants

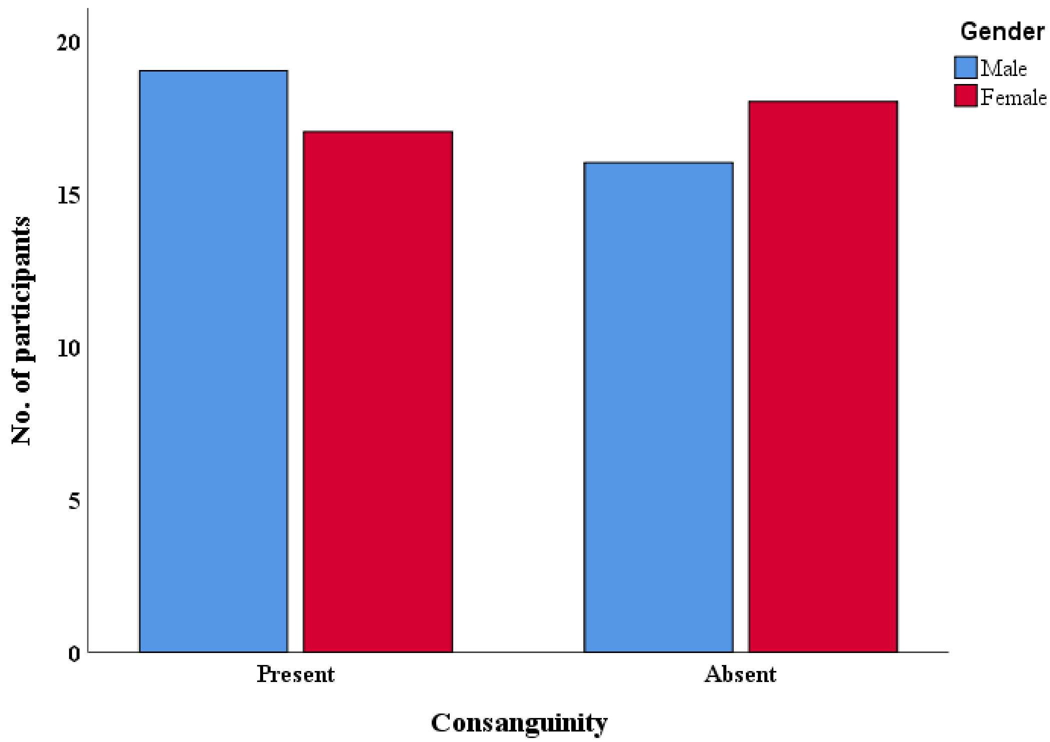


4.1.4 Etiology and consanguinity

The etiology of hearing loss among the children in the present study was congenital. Consanguineous marriage was also found to be one of the possible risk factors associated with hearing loss among the participants. Figure 4.1.4 shows the distribution of consanguinity among male and female children with CIs included in the study. Consanguinity was present in 36 children, including 19 males and 17 females, whereas consanguinity was absent in 34 children, which included 16 males and 18 females. A similar distribution pattern was observed among both male and female children.

Figure 4.1.4

Distribution of children with cochlear implants based on parental consanguinity status.

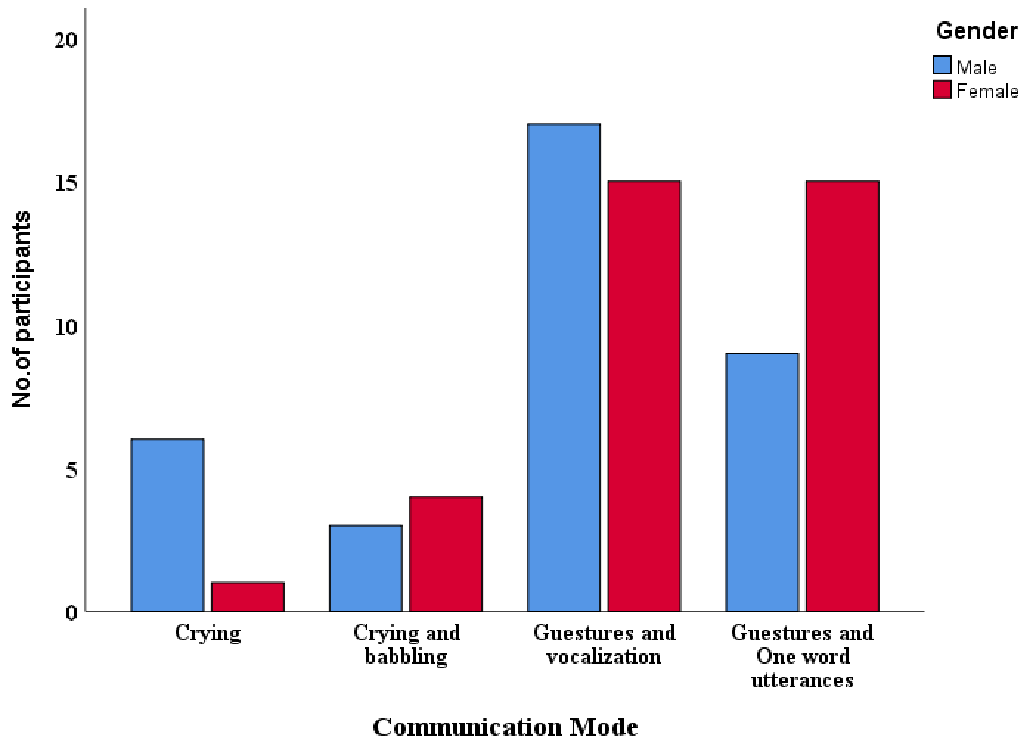


4.1.5 Pre-implant communication mode

Figure 4.1.5 shows the distribution of pre-implant communication mode among male and female children with CIs included in the study. Different modes of communication observed among the participants included crying, crying and babbling, gestures and vocalization, and gestures with one-word utterances. The highest number of children used gestures and vocalization as their primary mode of communication, including 17 males and 15 females. This was followed by gestures and one-word utterances, which were observed in 9 male and 15 female children. Very few children communicated only through crying, or cried along with babbling pre-implant. A similar communication pattern was seen among both male and female children included in the study.

Figure 4.1.5

Distribution of communication mode among male and female children with Cochlear implants

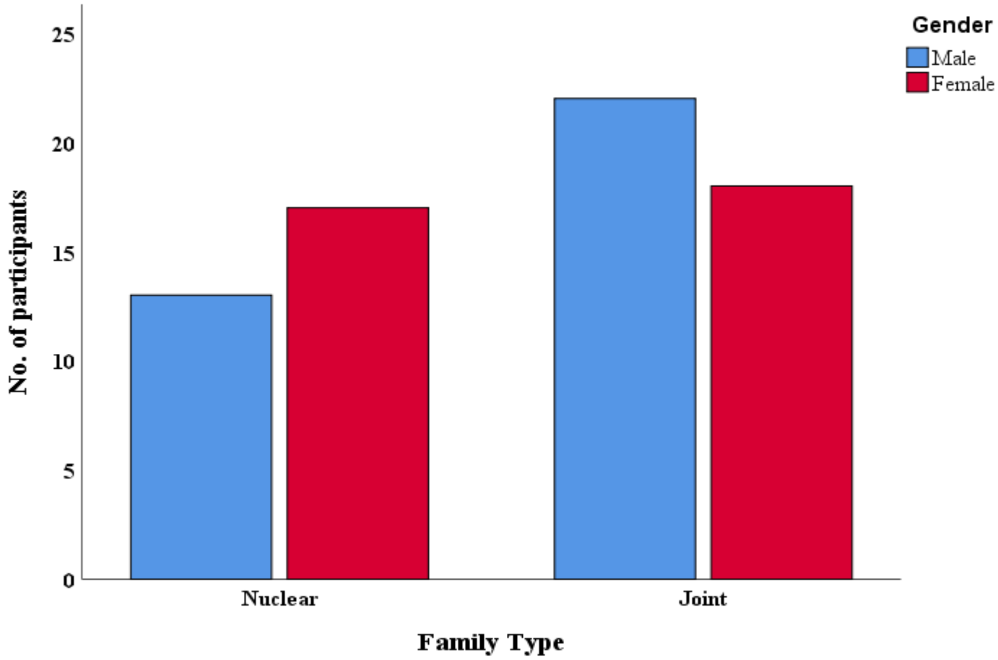


4.1.6 Family type

Figure 4.1.6 shows the distribution of participants by family type among children with CIs included in the study. The findings revealed that more children lived in joint families than in nuclear families. Of the 70 participants, 30 were from nuclear families, and 40 were from joint families. This indicates that most of the children in the present study were raised in joint-family environments.

Figure 4.1.6

Distribution of family type (nuclear vs joint) among male and female children with Cochlear implants.



4.1.7

Education and socioeconomic status of parents

The educational status of parents of children with CIs was categorized into no education, primary, secondary, and undergraduate (UG) and above levels. Among fathers, the majority had completed secondary education (n = 23), followed closely by those with UG and above education (n = 21). A considerable number of fathers (n = 18) had no formal education, while only a small proportion had primary education (n = 8). When analyzed by the child's gender, fathers of male children were more commonly in the UG and above category. In contrast, fathers of female children were predominantly educated up to the secondary level. Regarding mothers' education, most had completed secondary education (n = 34). This was followed by mothers with no education and those with primary education, while only a small number had attained UG or higher education. This distribution pattern was consistent across both male and female children, with secondary education being the most common level among mothers.

The socioeconomic status of the families was analyzed based on income categories. The majority of the participants belonged to the Income Slab I category. Of the 70 participants, 69 families were in Slab I, and only 1 family was in Slab II. This shows that most of the families in the study were from lower socioeconomic backgrounds.

4.2 Profiling of Audiological and Language Outcomes of Children with CIs

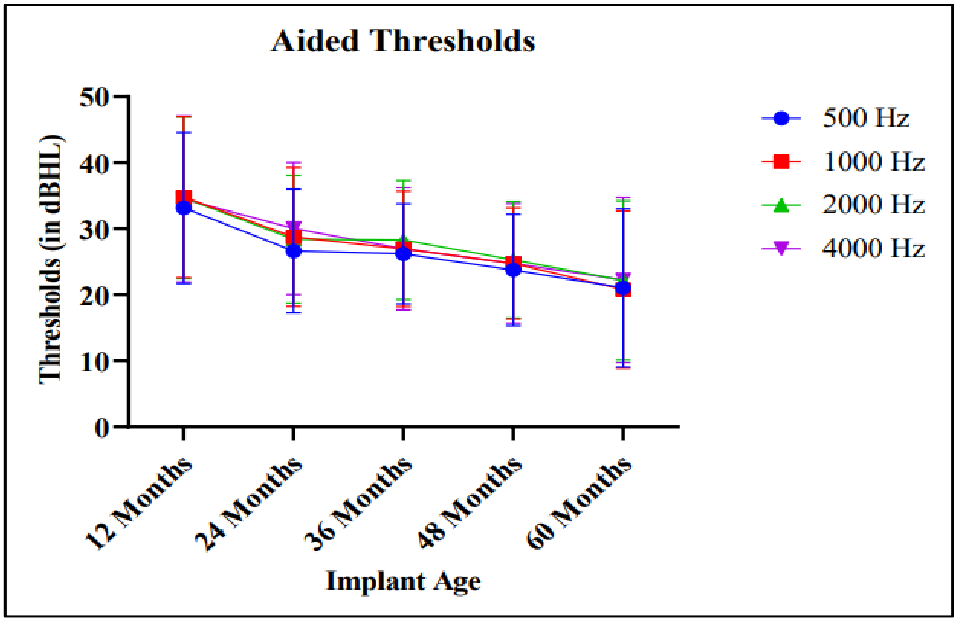
The present section describes the pre-operative audiological and speech-language details of children with CIs who had completed five years of implant use. The audiological findings included aided hearing thresholds at different frequencies, whereas the speech-language findings included communication mode and other baseline speech-language characteristics obtained from the clinical records. The findings were analyzed to understand the children's hearing and speech-language profiles before implantation and during long-term CI use.

4.2.1 Aided Thresholds of children with CIs

Figure 4.2.1 shows the aided hearing thresholds of children with CIs at 500 Hz, 1 kHz, 2 kHz, and 4 kHz, with increasing implant age. Before conducting the statistical analysis, the data were checked for normality using the Shapiro–Wilk test. The obtained p-value was greater than 0.05, indicating that the data followed a normal distribution. Hence, a parametric statistical analysis was performed to further compare the variables.

Figure 4.2.1

Distribution of aided hearing thresholds across 500 Hz, 1 kHz, 2 kHz, and 4 kHz frequencies among children with cochlear implants with increasing implant age



To compare aided thresholds across five implant age groups (12, 24, 36, 48, and 60 months) and four tested frequencies (500, 1000, 2000, and 4000 Hz), a two-way ANOVA was performed. The result showed a statistically significant main effect of implant age on aided thresholds with CI, [$F (4, 152) = 15.977$, $p < 0.001$, partial $\eta^2 = 0.296$], indicating a significant difference in aided thresholds across all five implant age groups. These findings suggest that aided thresholds improved significantly with increasing implant age in children with CIs. The main effect of frequency also showed a significant difference in aided thresholds across the four frequencies tested [$F (3, 114) = 6.968$, $p < 0.001$, partial $\eta^2 = 0.155$]. This indicates that aided thresholds varied significantly across 500, 1000, 2000, and 4000 Hz frequencies among children with CIs. There was no interaction effect between implant age and frequency on aided thresholds, [$F (12, 456) = 0.777$, $p = 0.470$, partial $\eta^2 = 0.025$]. Hence, no significant difference in the pattern of aided thresholds was observed across the different implant age groups and the frequencies tested.

Post hoc pairwise comparisons using the Bonferroni correction were conducted to identify differences between implant age groups and the tested frequencies. The findings revealed significant differences between the 12- and 24-month implant age groups ($p<0.001$) However, the 36-, 48-, and 60-month implant age groups ($p>0.005$) showed a similar pattern with no major differences observed between them.

4.2.2 Ling's Six Sound Awareness and Identification

Figure 4.2.2 illustrates the mean awareness thresholds and identification performance for Ling's six sounds (/a/, /i/, /u/, /s/, /ʃ/, and /m/) across different implant age groups among children with CIs. A progressive reduction in awareness thresholds was observed with increasing implant age, indicating improved detection of speech sounds following longer CI use. Among the six sounds, /a/ consistently demonstrated lower awareness thresholds across implant age groups, whereas the remaining sounds showed comparable patterns of performance. Similarly, identification scores increased with implant age, with the greatest improvements observed in the earlier years of CI use and a relatively stable pattern in the later years.

The effect of implant age on Ling's six-sound awareness thresholds was analysed using a two-way repeated-measures ANOVA. The analysis revealed a significant main effect of implant age on awareness thresholds [$F (4, 152) = 17.746$, $p < 0.001$, partial $\eta^2 = 0.378$], indicating improved awareness performance across implant age groups. A significant main effect of Ling's 6 sound awareness was also observed [$F (5,190) =37.8$, $p< 0.01$, partial $\eta^2 = 0.499$]. However, no significant interaction effect was observed between implant age and Ling's six sounds [$F (20, 760) = 0.534$, $p = 0.953$, partial $\eta^2 = 0.014$], suggesting that the pattern of improvement was comparable across the six speech sounds.

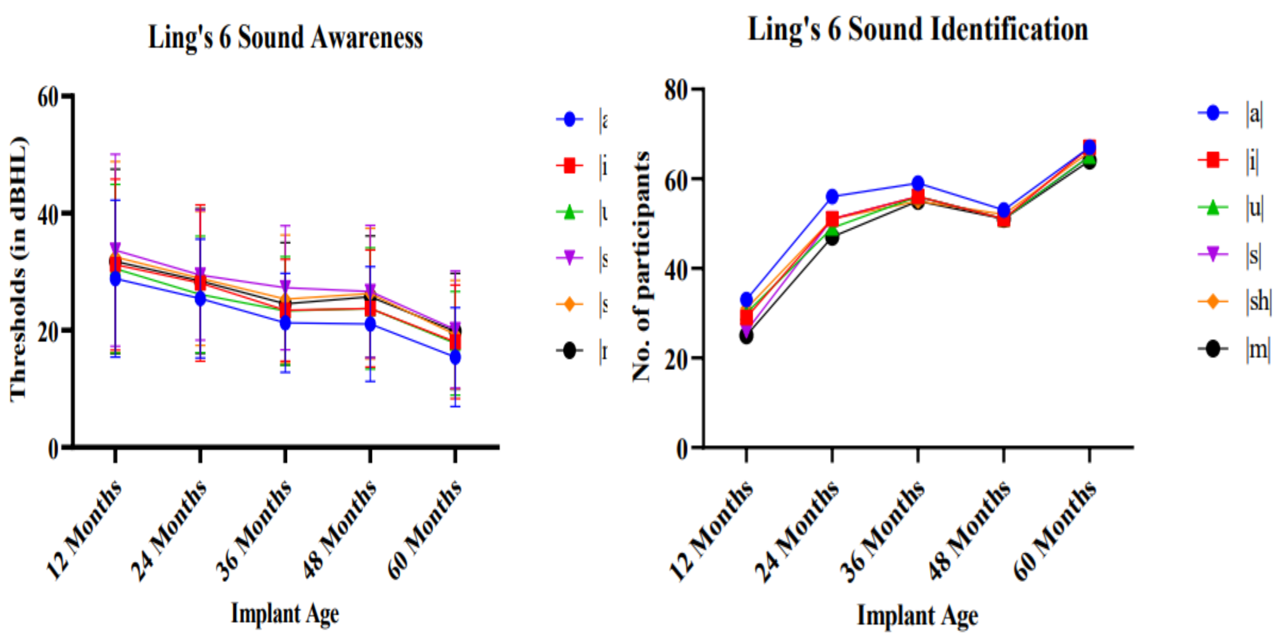
For Ling's six-sound identification, analysis using the General Linear Mixed Model demonstrated a significant main effect of implant age [$F(4,156) = 259.42$, $p<0.01$, partial $\eta^2 = 0.869$], indicating improved identification performance with increasing CI experience. A significant main effect of Ling's 6 sound was also observed [$F(5,195) = 7.095$, $p< 0.01$, partial $\eta^2 = 0.154$] reflecting differences in identification performance across the six Ling sounds. Furthermore, a significant interaction effect between implant age and Ling's six sounds [$F(20,780) = 6.49$, $p<0.01$, partial $\eta^2 = 0.143$] indicated that the pattern of identification performance varied across implant age intervals.

Post hoc pairwise comparisons using the Bonferroni correction were conducted to identify differences between implant age groups and the Ling six sounds awareness, The findings revealed significant differences between the 12- and 24-month implant age groups ($p=0.04$) However, the 24-, 36-, and 48-month implant age groups [$p>0.005$] showed a similar pattern with no major differences observed between them. 48- and 60-months showed significant difference ($p=0.15$). Similarly, Ling's six sound identification across implant age groups was also analyzed; 12- and 24-month, and 24- and 36-month implant age groups had a significant difference ($p<0.001$). However, the 36-, 48-, and 60-month implant age groups showed a similar pattern, with no major differences among them ($p >0.05$).

Figure 4.2.2

Mean awareness thresholds and identification performance for Ling's six sounds (/a/, /i/, /u/, /s/, /ʃ/, and /m/) across implant age groups among children with cochlear implants.

4.2.3 Speech identification scores (SIS) across Implant age

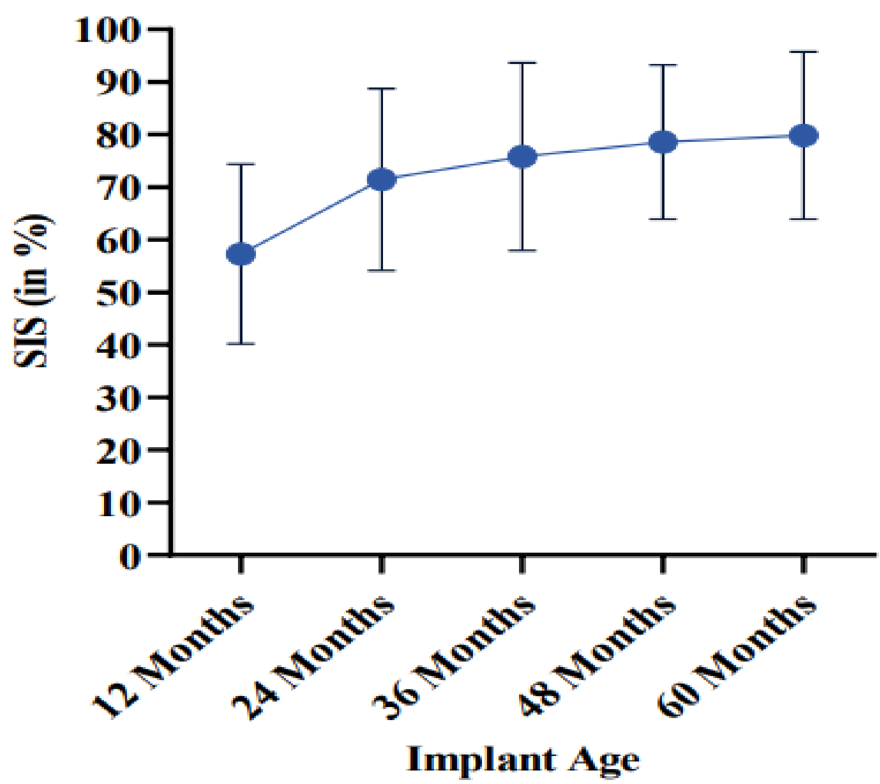


SIS were analysed across five implant age intervals to examine changes in speech perception performance among children with CIs. As the data were not normally distributed, the Wilcoxon signed-rank test was used to compare SIS scores between consecutive implant age intervals (12–24 months, 24–36 months, 36–48 months, and 48–60 months).

The analysis demonstrated a significant improvement in SIS between 12 and 24 months of implant age [$Z = -2.619$, $p = 0.009$], and between 24 and 36 months of implant age [$Z = -2.684$, $p = 0.007$]. In contrast, no significant differences were observed between 36 and 48 months [$Z = -1.821$, $p > 0.05$] or between 48 and 60 months of implant age [$Z = -1.350$, $p > 0.05$]. As illustrated in Figure 4.2.3, mean SIS scores increased progressively from approximately 58% at 12 months to 72% at 24 months, followed by further improvements to 76%, 79%, and 80% at 36, 48, and 60 months, respectively. Although the mean scores continued to show an upward trend with increasing implant age, the rate of improvement reduced after 36 months, indicating a plateau in speech identification performance during the later years of CI use. A similar trend was observed for aided hearing thresholds, where substantial gains were evident during the initial years following implantation, followed by stabilization with longer CI experience.

Figure 4.2.3

Mean Speech Identification Scores (SIS) across implant age intervals among children with cochlear implants. Error bars represent standard deviations.



4.2.4 Language outcomes with CIs across the 60 months of CI implant age.

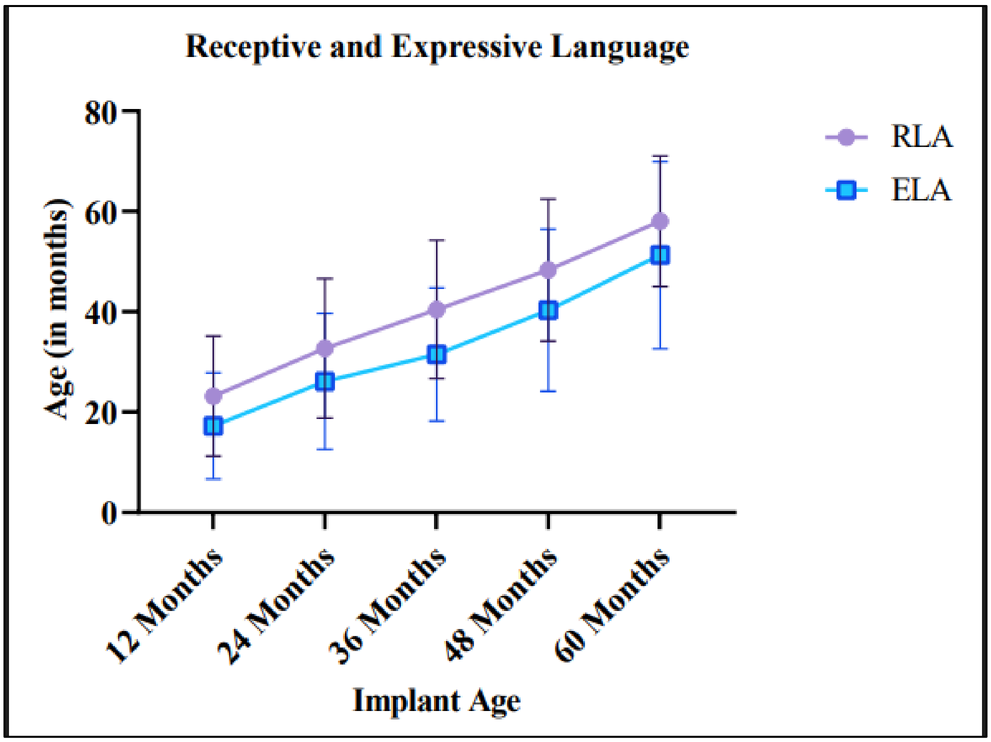
RLA and ELA outcomes of children with CIs were analysed across implant age up to 60 months of CI use. Before conducting the statistical analysis, the data were checked for normality using the Shapiro-Wilk test. The findings revealed that the data for both RLA and ELA did not follow a normal distribution across the implant age groups. Hence, a nonparametric statistical analysis was performed using the Friedman test.

The analysis revealed a significant difference in RLA scores across the different time points post-implantation [$\chi^2(4) = 73.99$, $p < 0.001$]. Similarly, ELA scores showed a significant difference across the reported timelines [$\chi^2(4) = 77.14$, $p < 0.001$]. The findings indicate that both receptive and expressive language abilities improved significantly with increasing implant age among children with CIs.

The Wilcoxon signed-rank test was used to compare RLA between consecutive implant age intervals (12–24 months, 24–36 months, 36–48 months, and 48–60 months). The analysis demonstrated significant improvements in RLA scores at 12-24 months [$Z = -5.29$ $p < 0.001$] and 24-36 months [$Z = -5.19$, $p < 0.001$] of implant age. In contrast, no significant differences were observed between 36 and 48 months [$Z = -4.79$, $p < 0.001$] or between 48 and 60 months of implant age [$Z = -3.72$, $p < 0.001$], and similarly was done for ELA between consecutive implant age intervals (12–24 months, 24–36 months, 36–48 months, and 48–60 months). The analysis demonstrated significant improvements in ELA scores at 12-24 months [$Z = -4.89$, $p < 0.001$], 24-36 months [$Z = -4.63$, $p < 0.001$], 36 and 48 months [$Z = -4.79$, $p < 0.001$], and 48 and 60 months of implant age [$Z = -4.21$, $p < 0.001$].

Figure 4.2.4

Mean receptive language age (RLA) and expressive language age (ELA) scores across different implant age groups (12, 24, 36, 48, and 60 months) in children with CIs. Both receptive and expressive language abilities demonstrated progressive improvement with increasing implant age, with receptive language scores remaining consistently higher than expressive language scores across all implant age groups. Error bars represent standard deviations.



4.2.5 Psychological assessment

The psychological assessment findings revealed that the children included in the present study showed average cognitive functioning. The mean IQ/DQ score among participants was 100.44 (SD = 4.31), with a median of 100. The scores ranged from 92 to 109, with an interquartile range of 7. The findings indicate that most of the children in the study demonstrated average intellectual functioning, with no major cognitive delays observed.

4.3 Relationship Between Pre-implant Factors and Post-implant Outcomes at 60 months

of CI

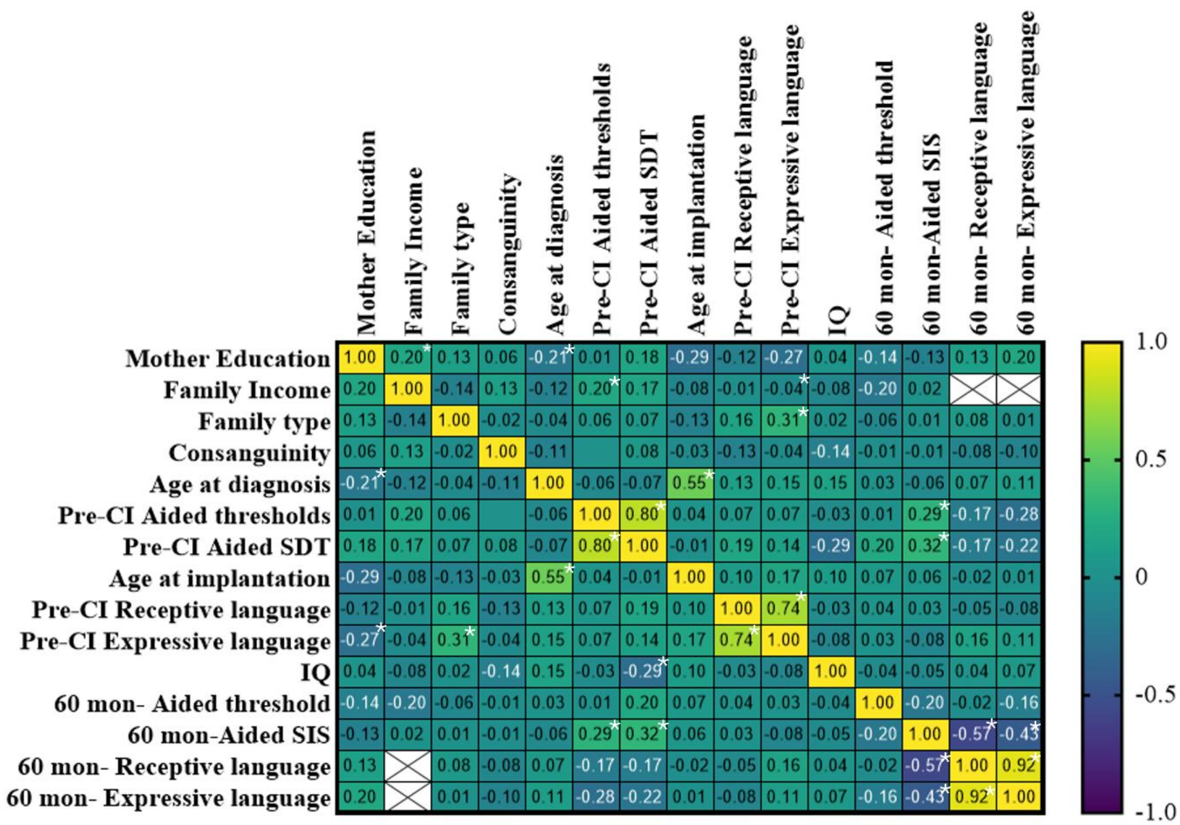
To examine the relationship between pre-implant variables and post-implant outcomes, the data were assessed for normality using the Shapiro–Wilk test. The results indicated that the variables were not normally distributed ($p < 0.05$). Therefore, non-parametric statistical analyses were performed. Although data from 70 participants were available, two participants had missing outcome measures and were excluded from the correlation analysis. Consequently, the final sample comprised 68 participants.

Spearman's rank correlation analysis was conducted to evaluate the relationship between pre-implant variables, including age at diagnosis, age at implantation, pre-implant aided thresholds, pre-implant aided SDT, pre-implant RLA, pre-implant ELA, and IQ, and post-implant outcomes measured at 60 months of CI use. The post-implant outcome measures included aided thresholds, SIS, RLA, and ELA.

The correlation matrix presented in Figure 4.3.1 along with the correlation coefficient values (r values), it demonstrates strong positive associations between pre-CI aided thresholds and pre-CI aided SDT, as well as between receptive and expressive language abilities measured both before implantation and at 60 months of CI use. Pre-implant language measures also exhibited positive relationships with post-implant speech and language outcomes. In addition, age at diagnosis showed a positive correlation with age at implantation. Conversely, demographic variables, including mother's education, family income, family type, and consanguinity, demonstrated weak or negligible associations with the outcome measures. Overall, stronger correlations were observed among the auditory, speech, and language variables than among the demographic factors.

Figure 4.3.1

Spearman's correlation matrix showing the relationship between demographic, audiological, language, cognitive, and post-implant outcome variables at 60 months of cochlear implants use among children with CIs. The values in each cell represent Spearman's rank correlation coefficients (r_s), ranging from −1 to +1, where positive values indicate a positive association and negative values indicate an inverse association. Color intensity reflects the strength of the correlation.



*Note**:** Values represent Spearman's rank correlation coefficients (r_s). Positive values indicate positive correlations, whereas negative values indicate negative correlations. * indicates statistically significant correlations at $p < .05$.*

The correlation matrix demonstrates weak positive correlation between pre-CI aided thresholds and pre-CI aided SDT (r = 0.80), as well as between pre-CI receptive and expressive language abilities (r = 0.74). A strong positive relationship was also observed between receptive and expressive language outcomes at 60 months post-CI ($r = 0.92$). In contrast, aided SIS at 60 months showed moderate negative correlations with receptive language ($r = -0.57$) and expressive language outcomes ($r = -0.43$), while most demographic variables exhibited weak or negligible associations with post-implant outcomes.

CHAPTER V

DISCUSSION

The present retrospective study explored the long-term auditory, speech, and language outcomes among 70 children with CIs who had completed a minimum of five years of implant use. The study's findings highlight existing delays and gaps in the timelines for identification, intervention, and implantation among children with hearing loss. The study also reflects the possible influence of socio-demographic and clinical factors on post-implant auditory, speech, and language outcomes. Further, the findings provide a better understanding of how auditory performance, speech intelligibility, and language development progress over prolonged CI use in children with CI.

5.1.1 Age at diagnosis of hearing loss

The findings of the present study revealed that 23 of 70 children with CI were diagnosed between 24 and 36 months of age, followed by 18 children diagnosed between 18 and 23 months of age. In contrast, only 1 child was diagnosed between 0–5 months and 3 children were diagnosed between 6–11 months of age. In the present study, 23 children were diagnosed between 24 and 36 months of age, and only four children were identified before 12 months of age, indicating substantial delays in diagnosis. According to the JCIH (2019) Position Statement, hearing loss should ideally be identified and confirmed within the first 3 months of life, with intervention initiated by 6 months of age. Delays beyond these recommended timelines may reduce opportunities for optimal auditory stimulation during critical periods of speech and language development. Ravi et al. (2022) reported that newborn hearing screening services in India are often restricted to isolated initiatives rather than being implemented as a comprehensive nationwide program. The authors further highlighted challenges such as inadequate infrastructure, shortage of trained professionals, poor parental awareness, and difficulties in follow-up services, which may contribute to delayed identification of hearing loss among children.

5.1.2 Age at implantation

The present study found that 38 children with CI underwent implantation between 36 and 47 months of age. This was followed by 17 children who underwent implantation between 60–71 months and 8 children between 48–59 months of age. Only 4 children underwent implantation before 24 months of age, whereas 3 children underwent implantation after 71 months of age**.** Dahlby-Skoog et al. (2025) observed that children who underwent implantation at an earlier age demonstrated better long-term language outcomes during adolescence and young adulthood. The authors suggested that early implantation minimises auditory deprivation and provides auditory input during the critical stages of language development, thereby improving spoken language skills in children with CIs. Sharma et al. (2002) highlighted the importance of early neural plasticity in facilitating auditory cortical development following implantation. Similarly, Shakrawal et al. (2020) reported better auditory and language outcomes among children implanted before four years of age compared to those implanted later, emphasizing the possible benefits of timely implantation for speech and language development.

5.1.3 Implanted ear

The present study found that right-ear implantation was more commonly performed among children with CIs. Of the 70 children included in the study, 64 underwent implantation in the right ear, whereas only 6 received implantation in the left ear. The predominance of right-ear implantation observed in the present study may be associated with the left hemisphere's dominant role in speech and language processing. Previous studies have suggested that auditory input from the right ear is predominantly transmitted to the left hemisphere, which is primarily involved in language functions. Supporting this, Chilosi et al. (2014) reported greater left-hemispheric activation and relatively better language outcomes among children with right-ear implantation. However, Wang et al. (2022) noted that the evidence regarding the superiority of implantation side remains inconclusive, as several studies have reported no significant differences in speech and language outcomes between right- and left-ear implantation.

5.1.4 Etiology and Consanguinity

Consanguinity was present among 36 children included in the study, comprising 19 males and 17 females, whereas 34 children belonged to non-consanguineous families, including 16 males and 18 females. All the participants included in the present study were reported to have congenital hearing loss. Previous studies have similarly reported a higher prevalence of congenital and hereditary hearing loss among children born to consanguineous parents, particularly among first-cousin marriages. Zakzouk (2002), Almazroua et al. (2020), and Batool et al. (2022) highlighted consanguinity as a possible contributing factor associated with congenital sensorineural hearing loss and hereditary hearing impairment. These findings collectively suggest that consanguinity may play an important role in the occurrence of congenital hearing loss among children with CI's.

5.1.5 Communication mode

A total of 32 children primarily communicated through gestures and vocalization, whereas 24 children demonstrated gestures along with one-word utterances. Only a few children relied mainly on crying, or on crying associated with babbling, as their mode of communication. These findings indicate that most children exhibited restricted verbal communication abilities prior to implantation. The restricted verbal communication abilities observed among children in the present study may be associated with limited auditory access prior to implantation due to congenital severe-to-profound hearing loss. Yoshinaga-Itano et al. (2020) further reported that children with congenital severe-to-profound hearing loss commonly demonstrate delays in pragmatic and conversational communication skills. These findings may account for the predominant use of gestures, vocalization, and one-word utterances observed among the participants in the present study.

5.1.6 Family type and referral

The findings of the present study revealed that a greater number of children with CI’s belonged to joint families when compared to nuclear families. Out of the total 70 participants, 40 children belonged to joint families, whereas 30 children were from nuclear families. Holt et al. (2020) emphasized that supportive parent–child interactions and enriched home environments contribute positively to spoken language and psychosocial development among children with hearing loss. Similarly, Necula et al. (2018) highlighted that cohesive and organized family environments, irrespective of family type, may support better auditory-verbal development in children with CI’s.

The referral pattern observed in the present study showed that doctor referral was the most common source of referral among the participants. A total of 30 children were referred by doctors, followed by 22 children referred through other referral sources and 18 children through self-referral. These findings suggest that healthcare professionals may play an important role in identifying hearing loss and facilitating referral for further audiological evaluation and intervention among children with hearing loss. Limited awareness regarding normal speech-language developmental milestones may reduce parents’ ability to recognize early communication delays in children with hearing impairment. Pallavi and Waknis (2021) observed that many parents demonstrated only moderate awareness regarding speech and language developmental milestones, whereas Alharbi et al. (2025) reported that inadequate parental knowledge regarding childhood hearing loss and delayed communication development could negatively influence timely diagnosis and intervention. In addition, Misron et al. (2025) emphasized that primary care professionals often serve as the first point of contact for children with suspected hearing loss and play an important role in facilitating early detection, referral, and intervention for better speech and language outcomes.

5.1.7 Education and socioeconomic status of parents

The findings of the present study showed that most fathers and mothers had completed secondary level education, while the majority of families belonged to lower socioeconomic backgrounds. Among fathers, secondary education was the most commonly observed educational level, followed by UG and above education, whereas a considerable number of fathers had no formal education. Similarly, most mothers had completed secondary education, while only a few had higher education qualifications. In addition, almost all families included in the study belonged to Income Slab I category, indicating a predominantly lower socioeconomic background among the participants.

Previous studies have suggested that parental education, family involvement, and socioeconomic status may influence communication development and rehabilitation outcomes among children with CI’s. Sharma et al. (2017) reported that parents with better educational background often demonstrate greater participation in therapy and auditory-verbal rehabilitation. Similarly, Kumar and Chinnaraj (2023) highlighted that parental support, early rehabilitation, and supportive educational environments may positively influence long-term auditory, speech, language, and academic outcomes in children with CI’s. Supporting these findings, Mueller et al. (2025) observed that higher parental education and increased parental involvement were associated with better speech perception, language, and academic performance, whereas lower socioeconomic status was linked to poorer language outcomes among children with CI's.

5.2 Profiling of Audiological, Speech Perception and Language Outcomes of Children with CI's

5.2.1 Aided Thresholds of children with CI's

Among the tested frequencies, higher aided thresholds were observed at 500 Hz during the earlier implant years when compared to 1000 Hz, 2000 Hz, and 4000 Hz. With increasing implant age, the thresholds at 500 Hz gradually improved, although the improvement appeared slower than that seen at 4000 Hz, where the thresholds reached stabilization earlier. In contrast, the mid frequencies showed relatively consistent thresholds with lesser variation across implant years. Overall, the findings indicate progressive improvement in aided hearing thresholds during the earlier years of CI use, followed by a plateau or stabilization of auditory performance during the later implant years across all tested frequencies. The findings revealed that significant differences were observed between the first and second year implant age groups. However, the third, fourth, and fifth implant year age groups showed a similar pattern with no major differences observed between them.

Peixoto et al. (2013) reported that long-term CI users demonstrated stable aided hearing thresholds over a follow-up period of more than 10 years. The authors observed no statistically significant differences between the early and late audiological assessments across most tested frequencies, suggesting stabilization of auditory performance over time.

However, a significant improvement was observed specifically at 2 kHz frequency, where aided thresholds were found to be better during the later assessment period. Waltzman et al. (2002) reported significant improvement in auditory and speech perception abilities among children with long-term CI use. Better outcomes were observed among children implanted at younger ages. The study further noted progressive improvement during the earlier years following implantation, followed by a plateau or stabilization of auditory performance over time without deterioration in outcomes.

5.2.2 Ling's Six Sound Awareness and Identification

Ling six sound awareness improved considerably during the first year following implantation and remained consistently high in the subsequent years. From the second year onwards, mean identification scores exceeded 90%, indicating a stable pattern of auditory performance. Among the six Ling sounds, only /a/ showed a significant improvement over time, increasing from 78% during the first implant year to 95% in the later years. The remaining sounds (/m/, /u/, /i/, /ʃ/, and /s/) demonstrated consistently high identification scores ranging from 90% to 98% across implant age groups, suggesting that these speech sounds were acquired relatively early and maintained over time. Similar observations were reported by Van Eeckhoutte et al. (2026), who found that children with bilateral CIs achieved detection thresholds within normal limits for the Ling 6(HL) sounds under quiet listening conditions. The authors further noted that children with CIs were able to detect and identify a broad range of speech sounds effectively, with only minor differences observed for certain low-frequency phonemes. Together, these findings suggest that access to the speech spectrum represented by the Ling sounds can be achieved early following implantation and remains stable with continued CI use.

5.2.3 Speech Identification scores across implant age

The SIS scores demonstrated gradual improvement during the first and second years following CI use. However, after approximately three years of implant age, the scores showed a relatively stable pattern with no major improvement observed thereafter. A similar trend was also noted for aided hearing thresholds, suggesting either stabilization or plateau of auditory and speech perception outcomes following prolonged CI use among children with CI's. Geers et al. (2003) reported that children with 4–7 years of CI experience demonstrated good speech perception abilities, with better performance for vowel perception than consonant perception. The authors suggested that simpler listening tasks are often acquired earlier than more complex speech perception skills. Similarly, Calmels et al. (2004) observed that speech perception improved steadily following implantation, with rapid gains during the initial years of CI use. Their findings showed that children generally achieved higher scores on closed-set speech perception tasks than on open-set tasks, reflecting the greater difficulty of open-set recognition. The authors further noted that speech perception performance gradually stabilized over time, while speech intelligibility continued to improve with prolonged CI experience.

5.2.4 Language Outcomes with CIs

Both receptive and expressive language abilities showed significant improvement with increasing implant age among children with CI's, indicating progressive language development following prolonged CI use. Geers et al. (2011) reported favorable long-term language outcomes among children with CI's, with more than half demonstrating language abilities comparable to their hearing peers in areas such as verbal reasoning, narrative skills, utterance length, and vocabulary use. Better language outcomes were associated with earlier implantation, longer duration of CI use, higher parental education and socioeconomic status, and oral communication environments. Similarly, Ganek et al. (2012) reported significant improvements in both receptive and expressive language abilities following implantation and highlighted that earlier implantation and prolonged CI use contribute to more favorable language development trajectories. The authors further noted that language outcomes are influenced by factors such as parent-child interaction, socioeconomic status, and communication environment. Despite overall improvements, Geers et al. (2011) noted considerable variability in language outcomes, with not all children achieving age-appropriate language abilities despite prolonged CI use.

5.2.5 Psychological assessment

The results showed that most children included in the present study demonstrated average intellectual functioning, with no significant cognitive delays observed among the participants. Similar findings were reported by Almomani et al. (2021), who observed improvements in cognitive abilities such as memory, reasoning, visualization, and attention following cochlear implantation. The authors highlighted that earlier auditory intervention was associated with better cognitive development, suggesting that adequate auditory access may support age-appropriate cognitive functioning in children with CI's and In contrast Kronenberger et al. (2019) and Beer et al. (2014) reported that some children with CI's continue to experience difficulties in executive functioning domains such as working memory, attention, and cognitive control despite demonstrating satisfactory auditory outcomes. These findings suggest that cognitive development following cochlear implantation may vary across children and may be influenced by factors beyond auditory rehabilitation alone.

5.3 Relationship Between Pre-implant Factors and Post-implant Outcomes at 60 months of CI

The findings show that stronger relationships are seen among auditory and language variables, while in contrast, demographic factors show weak association with outcomes. Pre-CI auditory measures and language abilities are positively related to post-CI outcomes, and age at diagnosis is also related to age at implantation.

Similar findings are reported in previous studies. Tait et al. (2000) found that children who had better communication skills and independence before implantation showed better speech perception after using CI's. Pre-implant autonomy had a significant positive relationship with Continuous Discourse Tracking scores ($r = 0.52$, $p < 0.01$) and Iowa Closed-Set Speech Perception Test scores ($r = 0.40$, $p < 0.05$), showing the importance of early communication skills. In the same way, Peterson et al. (2010) reported that children with better pre-implant speech perception, communication, and language abilities showed better language development after implantation. They also highlighted that age at implantation, communication mode, and pre-implant language skills play an important role.

Sharma et al. (2017) also reported that younger age at implantation is linked with better auditory and speech outcomes, while parental education and socioeconomic status had limited effect on short-term auditory outcomes. However, children from higher-income families showed better speech intelligibility and were more likely to get implanted earlier. Similarly, Leigh et al. (2016) found that age at implantation, additional disabilities, and communication mode are important factors affecting outcomes, while demographic factors showed inconsistent results. Killan et al. (2022) also reported a lot of variation in outcomes and suggested that multiple factors together influence performance after implantation.

Supporting the role of auditory access, Nickerson et al. (2019) found that pre-implant aided audibility, measured using SII, had a significant positive relationship with post-implant speech perception in noise ($r = 0.35$, $p < 0.05$). Children with better audibility before implantation showed better speech recognition after implantation, highlighting the importance of good auditory access before surgery. Similarly, Ching et al. (2018) reported that early fitting of hearing devices leads to better receptive and expressive language skills, and better speech perception is linked with better language and cognitive abilities. They also suggested that speech and language skills influence each other.

Taken together, these observations suggest that auditory, speech, and language development progress in an interconnected manner following cochlear implantation. Factors such as early diagnosis, timely implantation, stronger pre-implant language abilities, and adequate auditory access appear to support more favourable outcomes, while the variability across children indicates the combined influence of biological, clinical, and environmental factors.

CHAPTER VI

SUMMARY AND CONCLUSION

This retrospective register-based profiling study was carried out to assess the long-term auditory, speech, and language development in children with CI's after a period of at least 60 months of using their CIs and follow-up in the centre. The sample of the current study consisted of 70 children with bilateral severe-profound sensorineural deafness, all of whom had been born deaf and had at least five years of using CI. In terms of sex distribution, half of the children participating in the study were boys, and the other half were girls. All information from clinical records was collected retrospectively, covering various categories, including demographics, audiology, speech-language, psychology, hearing device use, therapy, and outcomes. In particular, some of the primary outcome variables used in the study included aided thresholds, Ling six sound awareness/identification, SIS, RLA and ELA.

Three main objectives motivated the conduct of this study. The first one was to profile the demographics, audiologic, speech, and language characteristics of the CI subjects. The second one was to determine differences in auditory, speech, and language achievements over the 1- to 5-year period after implant surgery, which would reveal performance trends regarding improvement or stability after the procedure. Finally, the third objective involved assessing the relationship between the pre-implant characteristics and post-implant audiological, speech, and language outcomes attained after five years of CI usage. In combination, the above objectives were aimed at understanding the long-term effects on CI subjects in terms of their auditory, speech, and language developments.

This current study reviewed the demographic characteristics, audiologic results, speech and language results, and variables related to CI outcomes among pediatric CI recipients. The main findings from this study are provided as follows:

- Right ear implants were more common than left ear implants (64 vs 6).
- Consanguinity was evident in almost half of the total participants (n=36).
- None of the subjects had any other disability apart from deafness.
- Most children used signs and gestures before getting CI implants, pointing towards their verbal deficiencies.
- The majority of children came from joint families and most families were poor.
- Doctors were the primary source of referral for CI.
- Significant improvements in aided thresholds were seen post-implantation, especially in first two years after CI intervention.
- Performance after implantation was much better compared to pre-implant hearing aid performance.
- Identification of Ling six sounds was greatly enhanced after implantation and maintained at a relatively consistent level throughout the years since implantation.
- Language ability as measured by SIS score showed improvement during the first few years of CI use and subsequently stabilized after about three years since implantation.
- RLA and ELA improved significantly after implantation; however, receptive language ability was greater than expressive language ability.
- Children tended to have average levels of cognitive function (Mean IQ/DQ = 100.44).
- The findings revealed stronger relationships among auditory, speech, and language variables than among demographic factors. Positive correlations, albeit weak, were

observed between pre-implant auditory and language abilities and long-term post-implant auditory, speech, and language outcomes. Age at diagnosis was positively correlated with age at implantation, and higher pre-implant language abilities were positively correlated with better speech and language outcomes following CI use

6.1 Conclusion

The children who experienced severe to profound hearing loss exhibited significant improvement in their auditory skills, speech and language skills following the usage of CI over a prolonged period of time. However, the best progress was noted during the initial years following the usage of CI, especially in relation to their auditory and speech skills, whereas thereafter there appeared to be stability in regard to both of these skills. Language skills, however, developed over a prolonged period of time, though the development of receptive language was superior compared to expressive language development among the children using CI. Those children who possessed better language skills prior to the usage of CI demonstrated better results.

6.2 Clinical Implications

- Early identification of hearing loss and timely cochlear implantation should be encouraged, as earlier access to sound may support better auditory, speech, and language development.
- Pre-implant language and auditory abilities can provide useful information about a child's likely progress after implantation and may help during parent counselling and rehabilitation planning.
- Regular follow-up of audiological, speech, and language outcomes is important to identify children who may need additional support or intensive intervention.

- Since auditory, speech, and language skills are closely related, rehabilitation should involve a multidisciplinary approach with active participation from professionals and family members.
- Family involvement, parental awareness, and socioeconomic factors may also influence outcomes and should be considered during rehabilitation planning.
- The findings adds to the limited Indian literature on long-term pediatric CI outcomes and may help guide clinical practice, rehabilitation services, and future research.

6.3 Limitations of the Study

- The study was retrospective and depended on information available in clinical records, the researcher had limited control over the completeness of data.
- The study was conducted at a single centre and included a specific group of children, which may limit the generalizability of the findings.
- Only children with a minimum of five years of CI use were included, so the findings may not represent outcomes during the earlier post-implant period.
- Factors such as therapy intensity, consistency of device use, parental involvement, communication environment, and educational placement were not examined in detail and may have influenced the outcomes observed in some children**.**

6.4 Future Directions

- Further research is needed to examine the influence of rehabilitation, family involvement, communication environment, and educational settings on auditory, speech, and language development.
- Future investigations may also explore psychosocial well-being, academic achievement, social participation, and quality of life in children with CIs.

- Identifying early predictors of outcomes may help clinicians recognize children who require additional support and facilitate more individualized rehabilitation planning.

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ಮಾನಸಗಂಗೋತ್ರಿ, ಮೈಸೂರು–570006

अखिल भारतीय वाक् श्रवण संस्थान
मानसगंगोत्री, मैसूरु - 570 006

INSTITUTE REVIEW BOARD (IRB) APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROPOSAL INVOLVING HUMAN SUBJECTS AT AIISH

AIISH Institute Review Board (IRB)

Ref: SH/IRB/M.4/AUD.17/2025-26 **Date: 06.01.2026**

Title Of The Dissertation	: Cochlear Implant Outcomes In Children: A Five-Year Retrospective Profiling Study.
Name of the Student	: Ms. Sejal Mahajan
Guide	: Dr Geetha C
Proposed Duration of the Project	: 08 months
Source of funding	: Non-funded Master's dissertation
Estimated budget	: Nil
Reference Number of the Project	: Nil
Date on which the IRB meeting was held	: 02.01.2026

A clear statement of the decision reached IRB meeting (In the event of the proposal is not approved, a statement of reasons for the same must be indicated) : **APPROVED**

Advice & suggestions (if any) : Ascent should be taken from the participant

Signature & Name of the Member Secretary-IRB
Dr. Animesh Barman
Professor of Audiology
All India Institute of Speech and Hearing, Mysore-570006

सदस्य सचिव / Member Secretary
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