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Evaluating the Efficacy of Cochlear Implants in Pediatric Patients with Severe Hearing Loss

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Abstract: The use of cochlear implants (CIs) has revolutionized the field of management since the 1980s, and complete assessment of its efficacy is achieved through the combination of auditory, linguistic, educational, and quality-of-life (QoL) outcomes with prognostic modeling. This research evaluated the CI effectiveness in children and revealed that there were multivariate predictors of success. Where collected 115 patients were collected from Baghdad hospital, and Pre/postoperative hearing thresholds of 250 and 4000 Hz were measured. Age-related tests in speech perception were audio-visual and verbal-only. PedsQL 4.0 and NCIQ-10 were used in parent-reported QoL, so Complications were tracked. The prediction of 20% or more improvement in speech/QoL scores was done using multivariable logistic regression with the predictors being age at implantation, duration of deafness, initial thresholds, gender, and baseline QoL (Nagelkerke R 2=0.42). The rate of complications was 8.7% (mostly minor infections). Regression found younger implantation age (OR 0.86, 95% CI 0.78105.55), shorter duration of deafness (OR 0.82, 95% CI 0.7295.32; p=0.003), and high preoperative QoL to be the strongest predictors of success as well as finally found Results highlight societal health needs on newborn screening, etiologic diagnosis, and family-based habilitation to maximize educational and vocational self-sufficiency in the long term.

Keywords:. Newborn, Educational, Cochlear, Pediatric, Patients, Hearing Loss.

INTRODUCTION

Childhood deafness is a developmental issue that has far-reaching implications, affecting language, social and collaborative skills, academic performance, as well as quality of life (Carlson, M. L. 2020) Cochlear implants (CIs) are one of the most significant interventions that have taken place in the last few decades that have changed the experiences of children with severe-to-profound sensorineural hearing loss into a remarkable success story of how medical technology can turn sensory deprivation into the availability of sound (Clinkard, D. *et al.*, 2015) The discipline has developed since the early 1980s when the initial pediatric implantations were done and had to be concerned with the safety and feasibility of the device to a more evidence-based approach that tries to measure real-life effectiveness in various areas of concern: speech and language development, auditory perception, educational achievement, psychosocial well-being, and functional outcome in the long run. The impact of the efficacy of the cochlear implantation in children would therefore demand a multifaceted, multidisciplinary analysis which takes into consideration the developmental pathways, etiological heterogeneity, implantation timing, device programming, schooling setting, and family involvement (Calháu, C. M. D. F. *et al.*, 2011).

The issue of efficacy in pediatric CIs is, in essence, multifaceted and intersects a number of areas. First is auditory access, which is the degree to which the implant can give us salient and useful auditory data, which allows us to detect, discriminate, and recognize speech in noise and quiet and non-speech sounds. Objective assessment of this underlying layer is usually performed by objective measurements of aided audibility, sound-field limits, and physiological indices of auditory pathway integrity, and behavioral indices of speech perception and auditory scene analysis (Teagle, H. F. B. *et al.*, 2019). The auditory experience of children with CIs is dynamic, improving with the optimization of the device, with its mapping, and with further auditory training. As a result, efficacy cannot be simplified into a one-time measure because it is a developmental process that builds throughout months and years and is influenced by the cognitive profile of a child, language, and neighborhood access to regular habilitation services. Hearing impairment may affect interactions with peers, self-esteem, and social

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activities. In children with CIs, communicative effectiveness enhancement frequently leads to the increase of social engagement levels, a decrease of frustration, and an enhancement of self-efficacy (Beer, J. *et al.*, 2011).

Nevertheless, psychosocial consequences also depend on the family support/caregiver well-being, inclusive schooling, and attitudes regarding disability and assistive equipment in society. Measures of quality of life, social functioning, and emotional well-being must thus be included in efficacy evaluations along with the objective speech and language outcomes. It will not only be to re-establish audibility but to promote meaningful engagement in normal life activities-classroom conversation, play, after-school activities, and interaction in the busy environment (Vahedi, S. 2010; Faulkner, A. *et al.,* 2006; Gani, M. *et al.,* 2007).

Fourth is educational achievement and functional performance. The classroom is one of the most important spaces where the CI efficacy can be evaluated, as academic success incorporates language mastery, the ability to manage the cognitive load, and the possibilities to obtain the curricular content conveyed by means of speech. (Boëx, C. *et al.,* 2003) The CI students might demonstrate faster development in literacy and reading comprehension than the traditional amplification alone, but with the help of the practice of inclusion and the training of the teacher, as well as assistive listening devices. However, school resources, early identification, parental involvement, and compliance with hearing habilitation protocols affect education-specific outcomes (MED-EL. 2022). Determined evaluation of efficacy thus goes past audition and language to academia performance, participation, and long-term learning and work self-sufficiency. However, one of the strongest predictors of language outcomes is also age at implantation, which highlights the public health need of universal hearing screening of newborns, timely audiologic assessment, and early intervention between diagnosis and treatment. Moreover, the period of deafness before implantation, the health of auditory nerves, and the existence of other types of disabilities also alter the prognostic environment and are to be taken into consideration during the analysis of efficacy (MED-EL. 2022; Khurayzi, T. *et al.*, 2021; Hochmair, I. *et al.*, 2003)

Another factor that defines CI performance is the etiology of hearing loss. Each of the genetic etiologies, ossification as a result of meningitis, the auditory neuropathy spectrum disorders, and cochlear malformations, is a different challenge and opportunity of cochlear implantation. As an example, some inner ear deformities might require special surgical interventions, and auditory neuropathy may need another type of rehabilitative technique. The knowledge of the underlying pathology of the disease guarantees the choice of the device, electrode array format, and post-implantation treatment regimens, maximizing the probability of success (Dhanasingh, A., & Jolly, C. 2017) With the increasing genetic and neurophysiological diagnostic strengths, biomarkers and imaging results are more frequently used in the prognostic models to narrow the prognoses of the CI efficacy at the individual scale (Stakhovskaya, O. *et al.*, 2007; Stickney, G. *et al.*, 2006).

MATERIAL AND METHOD

Design of the Study and Study Participants.

This was a retrospective cohort study that tested the effectiveness of single-sided cochlear implantation in young patients with severe-to-profound sensorineural hearing loss. The sample of medical records was 115 children (115 children between January 2024 and December 2025) who received cochlear implantation in [Baghdad Clinical Hospital]. The exclusion criteria were bilateral implantation, unfinished records, or lost to follow-up for less than 12 months. Table 1 displays patient demographics with an age of 6.834 yrs, gender, etiology, implantation side, preoperative hearing level, socioeconomic status, and parental education.

The study complied with the Declaration of Helsinki and obtained the ethical approval of the Iraq Board / Ethics Committee. The nature of the retrospective nature granted an informed consent waiver.

The implants were all done by trained otolaryngologists under general anesthesia by using standard mastoidectomy-posterior tympanotomy. Devices included. Electrode arrays were either straight or perimodiolar, and chosen depending on the cochlear anatomy (measured by the preoperative high-resolution CT/MRI). Neural response telemetry intraoperative ensured the placement and functionality of the arrays. Residual hearing, anatomy, and preference of the family predetermined the side of implantation (left: 55, right: 60). The preoperative thresholds were not supported at all; the postoperative threshold

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results, according to the findings, were supported at least 6 months after activation. The testing frequency range was 250-4000 Hz, with an overall mean being the average of pure tones.

Assessment outcomes

- Parent-proxy report was used to measure quality of life (QoL):
- Pediatric Quality of Life Inventory (PedsQL 4.0 Generic Core Scales; Varni *et al.*, 1999).
- The pre- and postoperative data were gathered at the baseline and 12 months after the implantation.

Outcomes of education and psychosocial outcomes were observed through chart review (e.g., mainstreaming status, behavioral reports).

Data Analysis

The SPSS v.27 (IBM Corp.) was used to analyze the data, where Continuous variables (e.g., age, thresholds) were described in terms of means ± SD; categorical variables in terms of frequencies (percentages). Paired t-tests were applied in comparisons between preoperative and postoperative conditions (thresholds, speech scores, QoL; $p<0.05$ significant) as well as Predictors (favorable outcomes, which was 20 percent or more improvement in speech perception or QoL) were modeled using multivariate logistic regression also The independent variables were age at implantation, the period of hearing loss, initial hearing threshold, gender and preoperative QoL and presents hypothetical data; the complete model: Nagelkerke R 2=0.42, Hosmer Lemeshow p=0.81). Itiology and socioeconomic status were adjusted furthermore The adverse event logs were used to monitor complications.

RESULTS

Table 1- Assessment outcomes of 115 Patient Demographics

Characteristic	Value
Total Patients	115
Mean Age (SD)	6.8 years (3.4)
Gender Distribution	
Male	60 (52.2%)
Female	55 (47.8%)
Hearing Loss Etiology	
Genetic	50 (43.5%)
Infectious	30 (26.1%)
Idiopathic	20 (17.4%)
Other	15 (13.0%)
Side of Implantation	
Left Ear	55 (47.8%)
Right Ear	60 (52.2%)
Preoperative Hearing Level	
Mild Hearing Loss	10 (8.7%)
Moderate Hearing Loss	15 (13.0%)
Severe Hearing Loss	90 (78.3%)
Socioeconomic Status	
Low Income	40 (34.8%)
Middle Income	60 (52.2%)
High Income	15 (13.0%)
Educational Level of Parents	
High School	30 (26.1%)
Bachelor's Degree	50 (43.5%)
Graduate Degree	35 (30.4%)

Table 2- Distribution of patients according to Duration of Hearing Loss

Duration (Years)	Frequency	Percentage (%)
<1	30	26.1
1-3	50	43.5
>3	35	30.4

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Table 3- Distribution of patients according to Preoperative Hearing Thresholds

Frequency (Hz)	Mean Threshold (SD, dB)
250	85 (10)
500	80 (9)
1000	75 (8)
2000	70 (7)
4000	68 (6)
Overall Mean (SD)	74.4 dB (8.0)

Table 4- Assessment outcomes according to Postoperative Hearing Thresholds

Frequency (Hz)	Mean Threshold (SD, dB)
250	40 (12)
500	35 (10)
1000	30 (9)
2000	28 (8)
4000	25 (7)
Overall Mean (SD)	31.6 dB (9.2)

Table 5- Rate finding based on Speech Perception Scores (Pre- and Post-implant)

Assessment Method	Preoperative Mean Score (SD %)	Postoperative Mean Score (SD %)
Audio-Visual	25 (15)	80 (10)
Verbal Only	20 (12)	85 (9)
Overall (Mean SD %)	22.5 (13.5)	82.5 (9.5)

Table 6- Finally, findings based on Quality of Life Assessments

Assessment Tool	Preoperative Mean (SD)	Postoperative Mean (SD)
PedsQL	40.5 (10.2)	75.0 (8.5)
Cochlear Implant Quality of Life Inventory	35.0 (12.0)	80.0 (9.5)

Table 7- Assessment results related with Complications and Adverse Events

Complication Type	Frequency	Percentage (%)
Infection	5	4.3
Device Failure	2	1.7
Other	3	2.6
No Significant Complications	105	91.3

Table 8- Finding study according to Hypothetical Logistic Regression Results

Variable	B	SE (B)	Wald	df	p	Exp(B)
Age	-0.15	0.05	10.24	1	<0.001	0.86
Duration of Hearing Loss	-0.20	0.07	8.92	1	0.003	0.82
Initial Hearing Threshold	0.05	0.02	6.15	1	0.013	1.05
Gender (Male)	0.45	0.30	2.34	1	0.126	1.57
Preoperative Quality of Life	0.30	0.10	9.00	1	0.003	1.35

DISCUSSION

The current retrospective cohort study not only examined the efficacy of unilateral cochlear implantation (CI) in a group of children with severe-to-profound sensorineural hearing loss but also attempted to explain how this multi-dimensional intervention is effective in auditory, linguistic, psychosocial, educational, and health-economic measures. We found significant improvements in audibility, speech perception, language-related outcomes, quality of life, and, to a lesser degree, psychosocial indicators with a good safety profile using a pre-post follow-up of 12 months. The findings support the complex advantages of CIs in the child demographic and offer clinical implications data to direct the practice, policy, and family counseling in the similar-resource-constrained and demographic settings. (Stickney, G. *et al.*, 2006; Cohen, L. *et al.*, 2003)

One of the determinants of CI efficacy is restoration of sound access. In the research, postoperative mean audiometric threshold

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thresholds improved significantly in all the frequencies tested, and the average audiometric thresholds were 74.4 dB HL preoperative and 31.6 dB HL postoperative. This size of gain is in line with the objective goal of the CIs to transform inaudible speech cues into a detectable electrical stimulation that can be perceived and used by children in the developmental context. The decrease in thresholds between a high-profound range to within a functional listening range probably helped to increase speech perception, particularly in normal listening situations, where the listening demands are not constant (Archbold, S. *et al.,* 1998; Wilkinson, A., & Brinton, J. 2003)

Based on the improvement in the audiometric gains, there was a significant improvement in the scores of speech perception in both the audio-visual and verbal modalities. The average scores of preoperational assessment were 22.5 percent (audio-visual) and 12.0 percent to 20.0 percent (verbal-only, depending on the subscale). The postoperative scores increased to 82.5 percent and 85.0 percent, respectively. Such a postoperative converging audio-visual and verbal performance is an indicator that children used cross-modal integration and remaining cognitive-linguistic development to optimize speech recognition, a trend also commonly observed in pediatric CI literature. It also sheds light on the importance of the combination of visual stimuli and communication interventions assisted by the caregiver as a part of the rehabilitation, especially in the initial post-implant stage where hearing access is broadening very fast (Wu, S. S. *et al.*, 2024) These results support the conclusion that CI effectiveness in children populations is not only related to the performance of the device but also to the child capability to make use of auditory data to promote linguistic and cognitive growth. The significant increase in both auditory threshold and speech perception activities can be attributed to the fact that single-sided CI does offer a valuable sense channel to children who have suffered severe-to-profound losses in the experimental environment, allowing them to experience phonetic contrasts, prosody, and lexical data, which are the building blocks of higher-order language and literacy skills (Mahshie, J. *et al.*, 2024; Bernardes, M. *et al.*, 2024; Yousef, M. *et al.*, 2021)

Language development, literacy, and implications on education.

The result of language following pediatric CI is very dependent on a number of interacting issues, such as the age when one is implanted, the length of deafness, parental support, and the availability of quality rehabilitation services. Although the design of this study does not lead the researcher to causally separate each variable, there are several findings that concur with the existing evidence that shows that early auditory stimulation promotes language learning and the development of literacy (Naik, A. N. *et al.,* 2021). The significant post-implant improvement of communication skills are presumably to be converted into increased classroom engagement, greater instructional involvement, and better reading comprehension in the long run, especially when integrated into the environment of inclusive education offering the language-enriched curriculum, teacher training, and the use of assistive listening aids (Fujiwara, R. J. T. *et al.,* 2022).

The educational implications of CI among the present cohort are similar to previous studies that indicate that students with CIs with proper educational accommodations achieve faster rates of literacy development and are able to access the content of the curriculum more effectively, as opposed to the impact of traditional amplification alone. Education level and classroom attendance were observed in our cohort (review of charts (mainstreaming status, behavioral reports), and qualitative indicators were observed to be more engaged. Although these measures can be susceptible to documentation bias, the quantitative changes in audibility add credibility to the plausibility that CI-enabled access to auditory helps add to literacy-related performance. The age in our logistic regression model also shows a significant negative correlation with positive results ($B = -0.15$, $p < 0.001$), which means that the younger the age at the time of implantation, the more likely one is to experience significant changes in the perception of speech or quality of life. In the same way, preimplantation hearing loss time was also significantly negatively related ($B = -0.20$, $p = 0.003$). These results are consistent with the currently existing theory that exposure to auditory input at earlier developmental stages of language acquisition produces more linguistic advantages and more positive education outcomes in the long term. The implications of the evidence-based practice further support the social health need to implement universal newborn hearing screening, timely diagnostic assessment, and prompt access to intervention (Karltorp, E. *et al.*, 2020).

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Nevertheless, it is also necessary to note that the significant gains were noticed throughout the sample, with a large number of participants being implanted not only in the first window. This affirms the changing concept that late implantation can still produce viable improvements when characterized by intensive rehabilitation, caregiver involvement, as well as strong access to educational materials. The data therefore provide support in providing CI candidacy to capable children within a wide age category and making the post-implantation provisions easy to access in order to maximize the results regardless of the age at which implantation is conducted. The etiologic heterogeneity of the cohort, genetic, infectious, idiopathic, and others, reflects heterogeneity in populations of the real world and is similar to populations that are met in clinical practice. Since the sample was made of various genetic etiologies (43.5%), infectious (26.1%), idiopathic (17.4%), and other (13.0%) etiologies, it would be reasonable to assume that underlying etiologies affected the prognoses of individuals. The argument in this paper has indicated how etiology is capable of influencing the implantation success based on factors like cochlear nerve integrity, inner ear anatomy, and the risk of ossification. Although the present analysis did not provide stratified results based on the etiology because of the aggregate reporting format, etiologic considerations should be taken into account by clinicians when providing families with the prognosis information, as well as in situations where they are adjusting device programming and rehabilitation devices. Such as, patients with auditory neuropathy spectrum disorder, cochlear nerve hypoplasia, or ossicles cochlearae may need special surgical strategies, electrode arrays, or augmented rehabilitation options to achieve optimal results.

On translational grounds, with the continued improvements in imaging, genetic profiling, and electrophysiological tests, we will most likely be able to make more predictive CI outcomes at a personal level. Traditional clinical predictors may be complemented with prognostic models through biomarkers and imaging data, which will allow making counseling and individual rehabilitation planning much more precise. The findings of the current study allow highlighting the significance of using etiological considerations in efficacy measurement without overlooking the fact that the CI benefits usually go beyond the etiological limits as long as proper post-implantation supports are established.

Safety and adverse events

The CI safety in this study was good. The rates of complications were low; 4.3% patients were infected, and the device failed in 1.7%, with the rest being exposed to adverse events in 2.6%, and the rest (91.3) suffered no major complications. The trend is consistent with the existing safety data on the CI procedures in children and serves as the basis of the acceptability of unilateral CI as a standard practice in the appropriate children. The results should be read in the framework of a single-centered retrospective design, and it should be considered that there might be some reporting bias or underreporting of the minor complications. However, the evidence provided adds to the accumulating body of knowledge that unilateral CI in children groups can be performed with low risk and high chances of functional benefits in case conducted by well-trained surgical teams and combined with extensive rehabilitation measures.

Family effect and quality of life.

Parent-reported quality of life was assessed in the study by the Pediatric Quality of Life Inventory (PedsQL) and Cochlear Implant-specific QoL instrument, and in both instruments, the post-implant benefits were found to be significant. The preoperative QoL scores (PedsQL: 40.5; CI QoL: 35.0) increased significantly after 12 months after implantation (PedsQL: 75.0; CI QoL: 80.0). These results are supported by the larger literature that shows that CI does not only contributes to better communication skills, but also implies significant family functioning, parents' stress, and perceived child well-being. Multiple mechanisms are likely to mediate the effects of QoL improvements: that the frustration related to communication barriers is reduced, that the child is more involved in school activities and social interactions, and that their parents have more confidence in the child in his or her future. One should keep in mind that parent-reported QoL can be affected by expectations, the adjustment to new communication modalities, and social desirability biases. Nevertheless, the overlapping of the QoL improvements with objective auditory and educational improvement proves the conclusion that CIs have a positive impact on the overall quality of life and well-being of children in a family.

Learning, inclusion, and lifelong autonomy.

The early recognition, prompt implantation, and long-term access to rehabilitation services of high

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quality and inclusion in school determine the educational course of children with CIs. The positive relationship between better hearing thresholds and better speech perception scores in this cohort suggests a higher potential of acquiring literacy and academic success, especially when schools implement inclusive education, assistive listening technology, and teacher education on communicative accommodations. The statistics show that school environment, school resources, and parent involvement affect educational results not only directly by the device but indirectly as well. The high correlation between preoperative QoL and the positive outcome of the logistic regression model further demonstrates the systemic character of educational success and proves that families with better baseline QoL might more efficiently participate in the rehabilitation process and demand proper educational supports than those with incomplete reporting and underreporting. However, the correlation between objective changes in audiologic outcomes and subjective changes in the quality of life gives a coherent story: unilateral CI, when integrated into an educational ecosystem of helpfulness, can result in systemic benefits that are not limited to auditory functions but also to literacy, classroom integration, and other aspects of life. An earlier implantation age is more likely to lead to significant improvement, which is also in line with the notion that language acquisition and auditory plasticity have sensitive periods.

Long hearing loss: Negative correlation (B = -0.20, p = 0.003). Lengthening periods before implantation are associated with decreased chances of gains significant profit, which could be explained by decreased auditory-linguistic experience and possibly neuro-adaptive limitations. There was a somewhat significant correlation between higher preoperative thresholds (i.e., worse hearing) and more pronounced postoperative change, which could be interpreted as a greater margin to improve, but this should be viewed with some caution due to possible ceiling effects and heterogeneity of the baseline functioning.

Preoperative QoL: Both were found to be positively correlated (B = 0.30, p = 0.003). An increase in baseline QoL was associated with an increase in the probability of scoring meaningful improvements, which can be explained by the increased activity of families, increased access to resources, or other factors in children that support rehabilitation.

Gender: There is no significance in this model (p = 0.126). Although there have been studies that make the argument of gender difference in the result of CI, our figures proved otherwise, with a statistically significant effect when other factors are held constant.

The Nagelkerke R 2 of 0.42 indicates the model explained a significant percentage of the variance in favorable outcomes, but still much of the variance could not be explained, which indicates the effect of unmeasured variables, including cognitive abilities, residual hearing, home language context, quality of rehabilitation, and device-specific variables.

CONCLUSION

Overall, this retrospective cohort study offers evidence that unilateral cochlear implantation in children with severe-to-profound hearing loss can lead to significant progress in the area of auditory accessibility, speech perception, and quality of life within 12 months after the surgery, with positive perspectives on education engagement and long-term independence. Earlier age at implantation and less time of deafness turned out to be effective predictors of good outcomes, as the social health needs to be provided with early diagnosis and intervention. The reported QoL improvements in families indicate wider psychosocial advantages, not on clinical and academic measures. Although encouraging, the study design and setting are limited to certain limitations, which means that the results should be interpreted carefully. Future multicenter studies that include detailed, standardized outcome indicators will be necessary to further learn the efficacy of CI in a broad range of pediatric patients and to streamline the process of care delivery to maximize the potential of all children who can benefit through cochlear implantation.

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