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Original Article

Quantifying Residual Hearing Loss from Electrode Insertion Trauma in Cochlear Implant Surgery: A Prospective Double-Blind Study

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BACKGROUND: The aim is to quantify the electrode insertion trauma-induced hearing loss (EITHL), its risk factors, and its impact on speech outcomes in prelingually deafened children undergoing cochlear implantation.

METHODS: This was a prospective, observational study conducted at a single center between 2021 and 2024. Forty children aged 1–5 years with severe-to-profound sensorineural hearing loss underwent cochlear implantation using either the cochleostomy or round-window (RW) techniques. Auditory steady-state response (ASSR) thresholds were utilized to assess hearing preservation levels. Speech outcomes were evaluated by measuring word recognition scores (WRS) at 6, 12, and 24 months. The correlation between electrode insertion depth, hearing preservation, and speech outcomes was analyzed.

RESULTS: All participants achieved Grade 1 hearing preservation (>75%). The mean hearing preservation rates at 3, 6, 9, and 12 months were 93.2%, 92.3%, 92.9%, and 92.1%, respectively. Although the RWT demonstrated better hearing preservation than the CS technique, the difference was not statistically significant. A significant increase in low-frequency hearing thresholds was observed over time, with 12-month values of 84.9 ± 3.5 dB (250 Hz), 90.2 ± 3.7 dB (500 Hz), and 92.4 ± 4.0 dB (1000 Hz). A negative correlation was found between the depth of electrode insertion and hearing preservation ($r = -0.45$, $P = .03$). Word recognition scores improved over time, with bilateral implant recipients showing significantly higher scores ($P < .00$).

CONCLUSION: Cochlear implantation via both CS and RW approaches preserves residual hearing in prelingually deafened children, with RW insertion demonstrating superior preservation. Deeper electrode insertion is associated with poorer hearing preservation, while better hearing preservation correlates with improved speech outcomes.

KEYWORDS: Cochlear implantation, residual hearing loss, electrode insertion trauma, intra-cochlear trauma, congenital deafness

INTRODUCTION

Cochlear implantation represents a revolutionary intervention for individuals grappling with severe-to-profound hearing loss, holding the potential for restored auditory function and enhanced quality of life.[1] However, despite its remarkable success, concerns persist regarding electrode insertion trauma causing loss of residual hearing during surgery, which could significantly impact auditory verbal outcomes.[2-4] In the recent studies, the depth of electrode insertion within the cochlea has emerged as a pivotal factor influencing the extent of trauma and subsequent auditory outcomes.[5]

Historically, histological studies have offered valuable insights into the consequences of electrode insertion trauma on cochlear structures.[6-8] Roland and Wright (2006)[9] demonstrated a correlation between deeper electrode insertion and increased trauma to delicate cochlear structures, laying the foundation for subsequent research in this area. While retrospective analyses have attempted to link the depth of electrode insertion with postoperative hearing thresholds, conflicting findings underscore the need for a

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comprehensive understanding of the factors influencing hearing outcomes in cochlear implant (CI) recipients.[10] Recent advancements in imaging techniques, notably cone-beam-computed tomography (CBCT), have facilitated precise measurement of electrode position within the cochlea, offering further insights into this correlation.[11] An understanding of the relationship between electrode insertion trauma, its risk factors, and its impact on functional outcome is crucial for refining surgical techniques and enhancing outcomes in cochlear implantation. Hence, we have conducted a prospective study to evaluate the evolution, risk factors, and impact on speech outcomes of residual hearing loss following insertion trauma.

Methods

This prospective, observational study, conducted between 2021 and 2024, was primarily aimed at quantifying electrode-insertion-trauma–induced residual hearing loss (EITHL) in prelingually deafened children who underwent cochlear implantation using the Veria technique. In addition to this primary objective, the study also sought to evaluate the correlation between the magnitude of EITHL and various technical factors, particularly the angular and linear depth of insertion (DOI). Other parameters analyzed included electrode-specific features such as array type, electrode-to-modiolus distance as well as cochlear anatomical characteristics like cochlear duct length (CDL) and cochlear volume. A further secondary objective was to compare EITHL between 2 different surgical approaches for electrode insertion: the cochleostomy (CS) technique and the round-window (RW) approach. Study was approved by the Ethical Committee of All India Institute of Medical Sciences (Approval no: AIIMS/IEC/2021/3375; Date: March 12, 2021) conducted in accordance with the Declaration of Helsinki and reported per STROBE guidelines. Patients were recruited after obtaining the written informed consent from their parents or legal guardians.

Inclusion and Exclusion Criteria

Inclusion criteria included prelingual onset of severe-to-profound sensorineural hearing loss, aged between 2 and 6 years at the time of cochlear implantation, absence of additional developmental or cognitive disorders, and informed consent obtained from parents or legal guardians. Children who had received prior auditory verbal therapy or were fitted with hearing aids for at least 6 months before implantation were included to ensure a comparable baseline for auditory stimulation. Exclusion criteria included children with anatomical cochlear malformations, auditory neuropathy, and a history of prior otologic surgeries.

MAIN POINTS

- The study aimed to evaluate EITHL, its risk factors, and the impact on speech outcomes in prelingually deafened children who underwent cochlear implantation.
- Forty children (ages 1–5) with severe-to-profound sensorineural hearing loss received cochlear implants through either cochleostomy or RW techniques.
- Hearing preservation (HP) was assessed using ASSR thresholds, and speech outcomes were evaluated with WRS at 6, 12, and 24 months.
- All children achieved Grade 1 hearing preservation (>75%), with mean HP rates of 93.2% at 3 months, 92.3% at 6 months, 92.9% at 9 months, and 92.1% at 12 months.
- The RW technique showed better HP compared to cochleostomy, although the difference was not statistically significant.
- Low-frequency hearing thresholds increased over time, with mean thresholds of 84.9 dB at 250 Hz, 90.2 dB at 500 Hz, and 92.4 dB at 1000 Hz by 12 months.
- A significant negative correlation was observed between electrode insertion depth and hearing preservation ($r = -0.45$, $P = .03$), indicating that deeper insertion leads to reduced HP.

Sample Size Calculation

Sample size calculation was based on effect sizes observed in previous studies and desired levels of significance, ensuring adequate statistical power to detect correlations between electrode insertion trauma, DOI, and speech outcomes. A total of 40 children were enrolled.

Audiological Evaluation

Given that children of this age can typically cooperate with hearing measurements, detailed audiological assessments were conducted preoperatively.

- Preoperative Hearing Assessment: Auditory steady-state response (ASSR) and auditory brainstem response (ABR) were conducted to determine hearing thresholds. Auditory brainstem response thresholds were included to address the limitations of ASSR in defining precise hearing thresholds due to the lack of standardized reference values.
- Hearing Aid Trial: All children had a minimum of 6 months of hearing aid use prior to implantation to document their auditory progression and establish pre-implantation auditory capabilities.
- Postoperative Hearing Assessment: Residual hearing was measured using ASSR thresholds at 3, 6, 9, 12, and 24 months. The contralateral ear was masked to prevent crossover hearing effects, ensuring accurate assessment of the implanted ear.

Surgical Procedure

All CI surgeries were performed by experienced pediatric CI surgeons using the Veria technique. Two subgroups were defined based on the method of electrode insertion:

Cochleostomy: The electrode array was inserted through a CS drilled into the cochlear wall antero-inferior to the RW.

Round-Window Insertion: The electrode array was inserted through the RW membrane into the cochlea.

To minimize insertion-related trauma, a standardized set of soft surgical principles was followed in all cases. These included slow and controlled electrode insertion, preservation of perilymph, minimal suction near the CS or RW site, and avoidance of mechanical force during array advancement.

Electrode Array

Both Standard and Flex Soft straight-type electrode arrays from MED-EL were used, each measuring 31.5 mm in length with an active stimulation range (ASR) of 26.4 mm. The Flex Soft array tapers from 1.3 mm at the base to 0.5 mm at the apex and contains 7 paired and 5 unpaired (apical) electrodes (total 19 contacts). The Standard array includes 12 paired electrodes (total 24 contacts). Electrodes were randomly assigned.

Imaging

Postoperative cone beam-computed tomography was performed using the Planmeca Promax 3D scanner (Planmeca, Finland). The DICOM files were analyzed using OTOPLAN® (Cascination AG, Bern, Switzerland) to confirm accurate intracochlear electrode insertion.

Outcome Measures

Residual Hearing Loss: Hearing preservation was calculated based on pre- and postoperative ASSR thresholds using the formula:

$$S = \left[1 - \frac{(PTApost - PTApre)}{(PTAmax - PTApre)}\right] \times 100 \quad (1)$$

Grade 1: >75% hearing preservation

Partial: 25–75% hearing preservation

Minimal: <25% hearing preservation

Speech Outcomes: WRS: Speech comprehension was assessed using a bisyllabic word recognition test, adapted for children. Images representing bisyllabic words were presented, and children were required to match the spoken word to the corresponding image. The contralateral ear was masked during speech testing to ensure results reflected the performance of the implanted ear.

Speech Progression: Evaluated at 12 and 24 months to assess auditory-verbal development.

Electrode and Cochlear Metrics

Electrode-Modiolar Distance (EMD): Computed on CT slices orthogonal to the modiolus axis.

Depth of Insertion (DOI): Measured in degrees and millimeters using OTOPLAN®.

Scalar Position of Electrode: Categorized into tympanic, media, vestibular, and tip fold.

Cochlear Duct Length and Cochlear Perimeter: Measured using OTOPLAN® software (Figure 1).

Process of Blinding

The study was single-blinded rather than double-blinded, as the nature of cochlear implantation and its postoperative evaluations do not allow for double-blinding. However, measures were taken to minimize bias: audiologists and speech-language pathologists assessing speech outcomes were blinded to the method of electrode insertion as well as degree of hearing preservation. Coded datasets were used during evaluations to ensure unbiased assessments. Masking of the non-implanted ear was performed during speech perception assessments to prevent contralateral hearing influence.

Statistical Analysis

Continuous variables were presented as means with SD and medians with interquartile ranges (IQR). Repeated-measures ANOVA was performed to compare the change in the mean of HP at successive intervals. Pearson's correlation analysis was utilized to examine the correlation between various cochlear–electrode parameters and HP levels. A 2-sample *t*-test was used for subgroup analysis (cochleostomy vs. round window). Cox proportional hazard model was used to quantify the relationship between HP and the speech outcome, and the subgroup analysis was performed using a log-rank test. Statistical significance was considered for *P*-values < .05. The statistical analysis was performed using SPSS (version 29.0.2.0) (IBM SPSS Corp.; Armonk, NY, USA).

RESULTS

Demography and Clinical Features

The study included 40 prelingually deafened children, with a median age of 4 years (range: 2-5 years) and a gender distribution of 55%

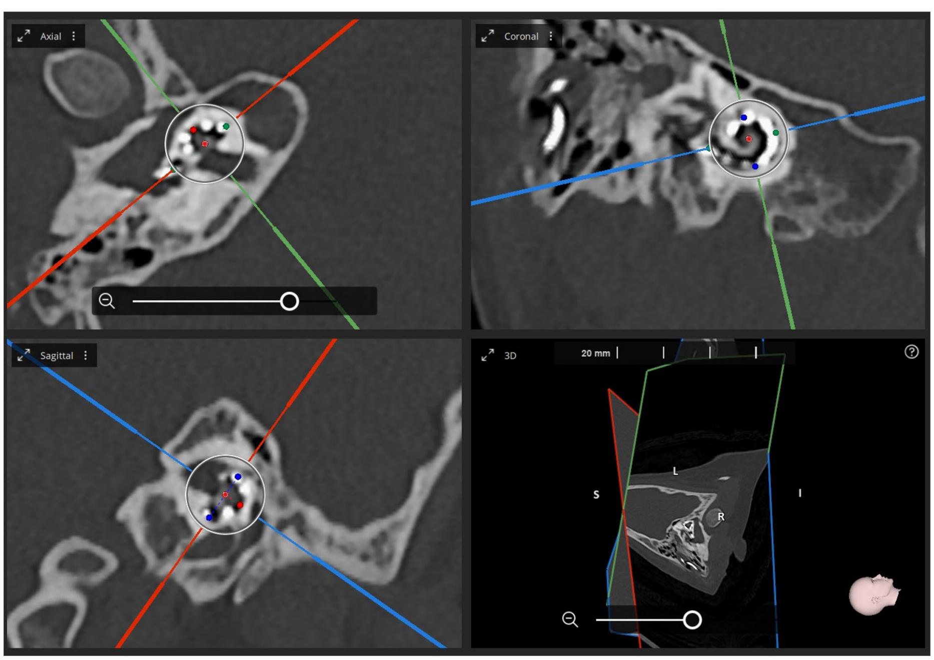

Figure 1. The OTOPLAN interface shows measurements of various parameters in various view.

male and 45% female. The median age of implantation was 37 months, ranging from 49 to 75 months. The preoperative median ABR was 90 dB (IQR: 80-90). Cognitive assessments revealed an IQ of 94 (range: 92-98) and a DQ of 96 (range: 92-100). Bilateral implants were more common, accounting for 65% of cases. The Veria technique was employed in all surgeries, with an equal distribution of RW and CS insertions (20 each). Standard electrodes were used in 70% of patients (28 cases), while the remaining 30% (12 cases) received Flex soft electrodes (Table 1).

Otoplan Parameters

Table 2 outlines several cochlear implantation parameters, including a cochlear volume of 68.16 mm^3, a duct length of 32.19 mm, and a perimeter of 24.4 mm. The scala tympani volume was measured at 30.83 mm^3. The angular DOI reached 651° for CS and 649° for the round window (RW). Electrode-modiolus distances in CS were 2.0 mm at E1 and 4.6 mm at E12, while RW measurements showed 1.9 mm at E1 and 4.8 mm at E12, highlighting subtle differences between the 2 methods.

Evaluation of Residual Hearing Loss

Based on Equation 1, all patients were calculated to have Grade 1 hearing preservation. The mean hearing preservation (HP) values at 3, 6, 9, and 12 months were 93.2 ± 2.4%, 92.3 ± 2.1%, 92.9 ± 3.1%, and 92.1 ± 1.9%, respectively. Repeated measures ANOVA revealed no statistically significant difference in HP across these time points (P = .078).

On comparison of HP between electrode insertions performed via cochleostomy and the RW approach, the RW consistently demonstrated better HP at 3, 6, and 12 months post-implantation compared to cochleostomy, but this difference was not statistically significant at any time point. The values are given in Table 3.

Table 1. Clinical and Demographical Features

Variables	Number	%
Age (Median with range)	4(2-5) years	
Gender		
Male	22	55
Female	18	45
Type of disability		
Prelingual deafness	40	
Post lingual	0	
Age of implantation	37(49-75) months	
Higher mental function		
IQ	94(92-98)	
DQ	96(92-100)	
Laterality		
Unilateral	26	35
Bilateral	14	65
Surgical technique		
Veria	40	
Type of insertion		
RW	20	50
Cochleostomy	20	50
Type of electrode		
Standard	28	70
Flex soft	12	30

Table 2. OTOPLAN Variables

Parameter	Values
Cochlear volume	68.16 ± 10.74 mm^3
Cochlear duct length	32.185+/−1.725 mm
Cochlear perimeter	24.4 ± 0.22 mm
Scala tympani volume	30.828+/−4.004 mm^3
Linear depth of insertion	
CS	18.9+/−2.5 mm
RW	18.2+/−3.1 mm
Angular depth of insertion	
CS	651+/−94.5^0
RW	649+/−93.6^0
Electrode-Modiolus distance	
CS	
E_1	2.0 ± 0.09 mm
E_{12}	4.6 ± 0.24 mm
RW	
E_1	1.9 ± 0.03 mm
E_{12}	4.8 ± 0.84 mm
Scalar positioning	
CS	ST
RW	ST

CS, Cochleostomy; E, Electrode; RW, round window; ST, Scala Tympani.

Upon analysis of low-frequency specific (250 Hz, 500 Hz, and 1000 Hz) hearing thresholds, at baseline, the mean thresholds were 83.5 ± 3.2 dB (250 Hz), 85.3 ± 3.4 dB (500 Hz), and 88.5 ± 3.7 dB (1000 Hz). Over time, thresholds generally increased at 3 months (84.1 ± 3.3 dB, 87.4 ± 3.5 dB, 90.1 ± 3.8 dB), 6 months (84.4 ± 3.4 dB, 88.1 ± 3.6 dB, 91.9 ± 3.9 dB), and 12 months (84.9 ± 3.5 dB, 90.2 ± 3.7 dB, 92.4 ± 4.0 dB). Significant differences were found at 500 Hz and 1000 Hz frequencies (P-values of .03 and .00, respectively), indicating changes in hearing thresholds over time at these frequencies (Figure 2). The mean threshold shift at 12 months post-implantation for 250 Hz was 1.1 ± 0.9 dB in the Flex Soft group and 1.9 ± 1.2 dB in the standard group (Mann–Whitney U test = 135, P = .08), indicating no statistically significant difference. At 500 Hz, the Flex Soft group showed a significantly lower mean threshold shift of 2.1 ± 1.1 dB compared to 4.2 ± 1.4 dB in the standard group (U = 91, P = .01). Similarly, at 1000 Hz, the mean threshold shift was significantly lower in the Flex Soft group (2.9 ± 1.3 dB) than in the standard group (5.1 ± 1.5 dB; U = 79, P = .004).

Correlation of Residual Hearing Loss

The study explored correlations between hearing preservation and various parameters. Angular depth of insertion (DOI) exhibited a moderate negative correlation with hearing preservation at (−0.45,

Table 3. Showing the Comparison of Hearing Preservation between 2 Insertion Technique

Timepoint (Months)	Round Window HP (%) (Mean ± SD)	Cochleostomy HP (%) (Mean ± SD)	*P*
3	95.2 ± 2.1	92.0 ± 2.5	.06
6	94.9 ± 2.0	91.5 ± 2.3	.08
12	94.6 ± 2.2	90.5 ± 2.7	.78

HP, hearing preservation.

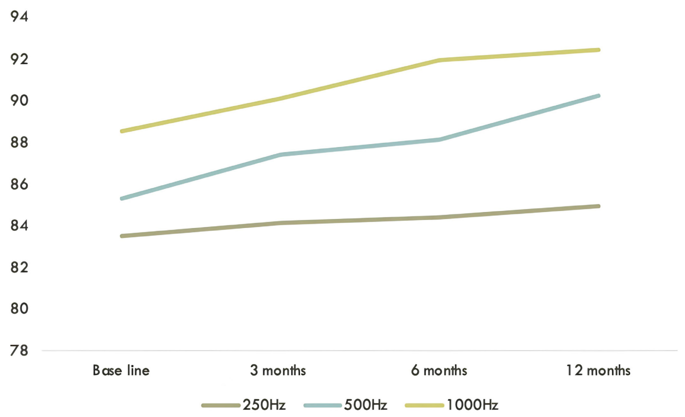

Figure 2. Line diagram representing the evolution of low frequency-specific hearing thresholds at 0, 3, 6, and 12 months.

$P = .03$), while electrode-modiolus distance showed a moderate positive correlation (0.37, $P = .01$). Cochlear duct length (CDL), scala tympani volume (STV), and cochlear volume (CV) displayed positive correlations, although not statistically significant as given in Table 4.

The mean impedance values were 1.72 (SD = 0.59), 4.96 (SD = 0.91), 6.66 (SD = 1.97), and 8.16 kΩ (SD = 2.11) at 0, 3, 6, and 12 months post-implantation, respectively. A repeated-measures ANOVA indicated a significant effect for test time points [F (3, 132) = 52.61; $P < .001$]. Pearson correlation analysis revealed no significant correlation between impedance values and hearing preservation levels, with no significant interaction observed [$r = 0.60$; $P = .515$]. Spearman's correlation analysis showed a moderate positive correlation between the use of standard electrodes and greater threshold shift at 500 Hz ($\rho = 0.39$, $P = .01$) and 1000 Hz ($\rho = 0.43$, $P = .004$). The correlation was weaker and non-significant at 250 Hz ($\rho = 0.22$, $P = .08$).

Impact on Speech Outcome

The mean closed-set WRS in quiet at 6 months, 12 months, and 24 months was 40.2% (SD = 3.9%), 80.1% (SD = 5.4%), and 88.4% (SD = 6.1%), respectively, in unilateral CI recipients. In contrast, bilateral CI recipients demonstrated significantly better performance, with mean scores of 45.6% (SD = 3.5%) at 6 months, 85.7% (SD = 4.9%) at 12 months, and 92.3% (SD = 5.2%) at 24 months, indicating superior speech recognition outcomes in bilateral cases (t(38) = −4.50, $P < .001$). Since all patients had Grade 1 hearing preservation (HP), we employed a Pearson's correlation analysis between WRS and HP levels and found a strong positive correlation with statistical significance ($r = 0.52$, $P = .003$).

Table 4. Correlation Analysis of Various Factors with Hearing Preservation

Variable	*r*	*P*
Angular DOI	−0.45	**.03**
Electrode-Modiolus distance	0.37	**.01**
CDL	0.45	.55
STV	0.32	.21
CV	0.56	.88

CDL, Cochlear duct length; CV, cochlear volume; DOI, depth of insertion; STV, scala tympani volume,

To further quantify this relationship, we performed a Cox proportional hazards regression analysis for hearing preservation (HP) grade, which revealed a significant effect of HP on the hazard of achieving a higher word recognition score (WRS) (Hazard Ratio = 2.10, 95% CI: 1.35-3.25, $P = .005$). This indicates that patients with better hearing preservation had more than twice the likelihood of achieving improved WRS over time, irrespective of the insertion technique used. The model's accuracy was assessed with the Hosmer-Lemeshow test, and 1000 bootstrap resamples were used for validation. Additionally, bilateral CI recipients had better WRS than unilateral CI recipients, as indicated by a statistically significant difference in their survival curves (log rank test, $P = .01$), further supporting the superior performance of bilateral implantation in achieving better speech outcomes (Figures 3 and 4).

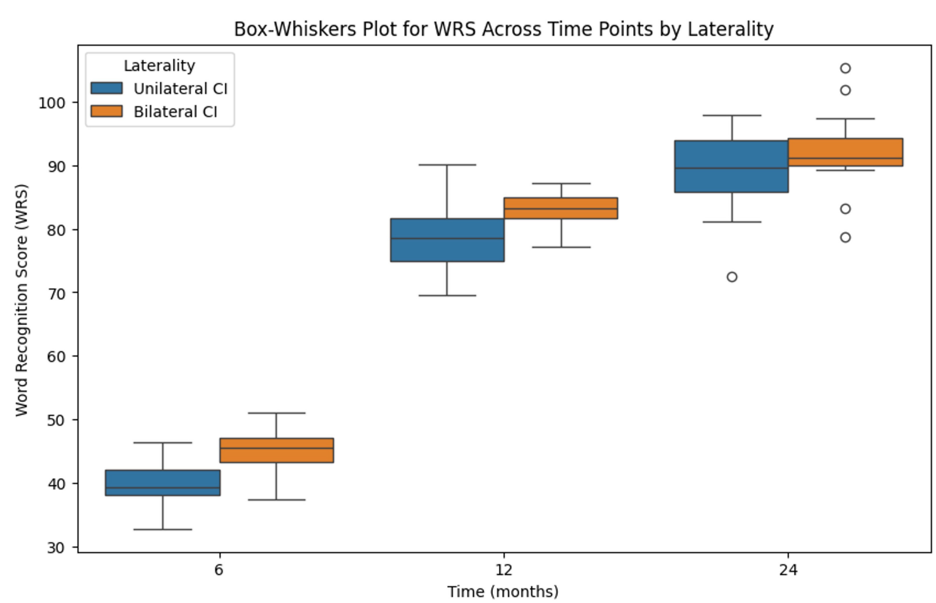

Figure 3. Box-Whisker plot showing the comparison of mean word recognition scores across different time points with age and grade of hearing preservation as covariates.

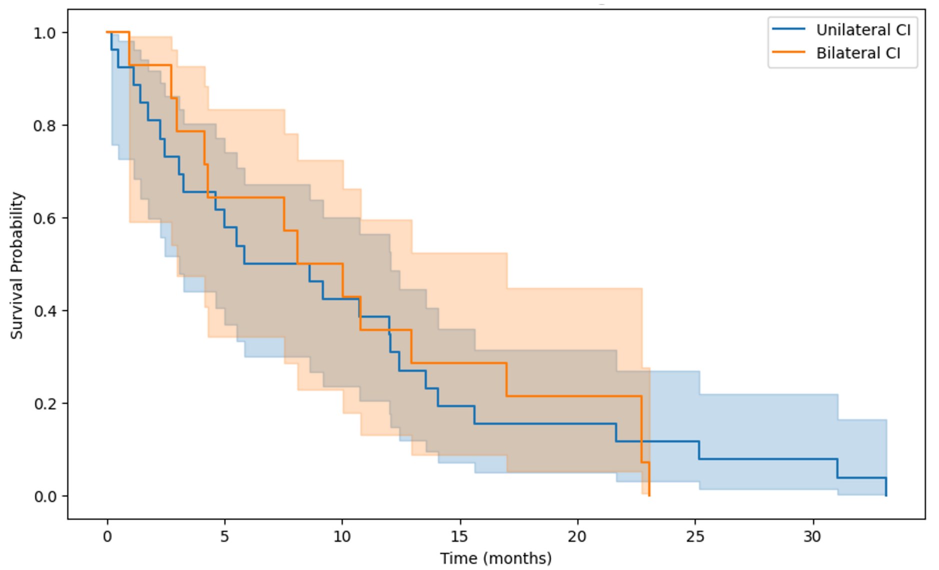

Figure 4. Kaplan–Meier plot illustrating the hazard function of hearing preservation for better speech outcomes. Subgroup analysis between bilateral and unilateral CI recipients, computed using the log-rank test with significance set at 0.05.

DISCUSSION

This prospective study aimed to investigate the degree, progression, risk factors, and impact of insertion trauma-induced residual hearing loss on speech outcomes. The results indicated grade 1 HP in all patients with a mean HP of 93.2 ± 2.4% at 3 months. Throughout the follow-up period, the progression of residual hearing loss was monitored, revealing initial stability in hearing preservation; however, low-frequency thresholds gradually increased over time, with mean thresholds rising by 10 dB at the 6-month follow-up and an additional 5 dB at both the 12- and 24-month assessments. Risk factors associated with poorer hearing preservation included deeper electrode insertion depths and greater electrode-modiolus distances, both statistically significant ($P < .05$). Notably, the RW approach demonstrated a higher rate of hearing preservation compared to the cochleostomy technique, with preservation rates of 85% and 65%, respectively. In terms of speech outcomes, WRS were analyzed at 6, 12, and 24 months post-implantation, revealing that patients with stable hearing preservation achieved mean WRS of 40.2%, 80.1%, and 88.4% at these time points. Importantly, these scores indicated consistent improvement over time, suggesting that better hearing preservation positively impacted speech recognition abilities, irrespective of the surgical technique employed.

Inserting electrode arrays into the cochlea carries the risk of damaging delicate cochlear internal structures. Histological examinations have revealed trauma caused by electrode insertion, including damage to the spiral ligament, basilar membrane, and osseous spiral lamina.[6,7] Damage to these structures can lead to localized loss of spiral ganglion cells, with the extent of neural damage correlating with the severity of tissue injury.[7,9] Therefore, atraumatic insertion techniques are crucial to prevent such damage and potential neural tissue degeneration. However, the impact of ganglion cell loss on rehabilitation outcomes remains uncertain.[12] In the authors' study, even though we didn't have any histopathological evidence for the aforementioned data, the electrophysiological findings in the form of electrode impedance suggest progressive intra-cochlear inflammation and fibrosis.

Residual hearing preservation rates exhibit considerable variation across different studies.[3-5,13-15] Determining the key factors underlying these differences poses a challenge. Notably, the authors' study differs in its inclusion criteria from others, encompassing all CI candidates with measurable preoperative residual hearing regardless of its level or frequency. Consequently, the authors' subjects had significantly lower preoperative low-frequency Pure-Tone Averages (PTAs) compared to similar studies, with a difference of 81.3 dB HL in the authors' study versus 51.5 dB HL in Carlson et al.[16] Applying Carlson et al.'s inclusion criteria to the authors' patients would yield a preservation rate nearing 50%, aligning more closely with rates reported in other studies, which typically hover around 55%.

Hassepass et al.[17]conducted a retrospective study aimed at assessing the impact of 2 distinct CI electrode insertion methods on insertion depth, angle, and hearing preservation in the scala tympani. The findings indicate that comparable insertion depth, angle, and low-frequency hearing preservation can be attained using a straight narrow electrode via either the cochleostomy or round window approach, particularly during initial activation. This flexibility provides surgeons with the opportunity to adjust access to the scala tympani as required.[17] Contrary to this, the authors' findings showed better hearing preservation in the round window insertion group with no statistically significant difference.

Apart from analyzing the connection between different patient factors and hearing preservation, we also investigated the authors' data for correlations with individual frequencies. The authors' findings reveal an inverse and somewhat linear relationship between preservation and frequency. Preservation rates were highest in the low frequencies and declined with increasing frequency. This observation aligns with cadaveric histopathology studies, which illustrate heightened intracochlear fibrosis and osteogenesis in the basal turn, while the cochlear apex, responsible for low-frequency hearing, tends to be relatively spared.[2,8]

Lee S.Y.[18] conducted a comparative analysis between a slim modiolar electrode (SME) and a slim straight electrode (SSE), both implanted by a single surgeon, to evaluate their impact on the progression of residual hearing using various parameters through cross-sectional and longitudinal audiologic analyses. Both the SME and SSE implantations demonstrated positive outcomes in residual hearing preservation. The study findings contribute to the authors' understanding of hearing preservation with the SME and highlight the potential influence of electrode physical characteristics and placement, particularly electrode-to-modiolus distance, on the loss of acoustic hearing. Additionally, in the authors' Pearson correlations analysis, electrode-modiolus distance (EMD) showed a strong positive correlation with HP. Although the authors' study primarily involved luminal type electrodes, further investigation involving various types of electrodes is warranted.

Additionally, in the authors' correlation analysis, we found a moderate negative correlation between depth of electrode insertion and HP. Nordfalk KF conducted a study to explore the relationship between insertion depth and the postoperative loss of residual hearing and vestibular function.[5] The findings indicate a very weak correlation between the final outcome in residual hearing and the angular insertion depth for depths exceeding 405°. Furthermore, there was no correlation found between postoperative loss of vestibular function and angular insertion depth or age at implantation.

The findings of the present study disagree with the conclusions drawn by Balkany et al. and D'Elia et al., indicating that preserved residual hearing does not offer a postoperative advantage for speech performance.[19,20] Across all three studies, no significant differences were observed in open-set speech perception in quiet between patients with and without preserved residual hearing following implantation with a conventional electrode. However, our findings allowed the authors to construct a Cox proportional hazard model for speech outcomes as a function of the degree of hearing preservation, demonstrating good discrimination.

As illustrated in the Kaplan–Meier plot, a subgroup analysis comparing unilateral and bilateral CI recipients revealed a statistically significant difference (log-rank test, $P < .05$). Nevertheless, this should be interpreted with caution, as the established binaural advantages in bilateral users—such as the squelch effect, summation, localization, and the head shadow effect—may confound the relationship. Thus, we regard the observed statistical difference as a potential fallacy rather than a direct causal link between hearing preservation and speech performance.

CONCLUSION

We observed stable preservation of residual hearing over time, although increases in low frequency thresholds were noted. Correlation analyses revealed associations between preservation and various parameters, emphasizing the impact of insertion depth and electrode-modiolus distance. Furthermore, our study supports that preserved residual hearing confer a postoperative advantage for speech performance. These findings collectively contribute to the optimization of cochlear implantation procedures and rehabilitation strategies, ultimately improving outcomes for pediatric patients with hearing loss.

Limitations of the Study

1. Study did not include objective intraoperative measures of insertion trauma, such as force monitoring or histopathological indicators.
2. The inclusion of children up to 75 months of age at implantation, which may introduce variability due to prolonged auditory deprivation. However, this reflects real-world challenges in a developing country, where delayed diagnosis and limited access to care are common barriers to early intervention.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author upon reasonable request .

Ethics Committee Approval: This study was approved by the Ethical Committee of All India Institute of Medical Sciences (Approval No: AIIMS/IEC/2021/3375, Date: March 12, 2021).

Informed Consent: Written informed consent was obtained from the parents or legal guardians of the patients who agreed to take part in the study.

Peer-review: Externally peer reviewed.

Author Contributions: Concept – N.D.K., V.S.; Design – N.D.K., V.S.; Supervision – V.S., A.G.; Resources – P.K., S.T.; Materials – S.T., P.K.; Data Collection and/or Processing – N.D.K., S.M.; Analysis and/or Interpretation – N.D.K., V.S., S.T.; Literature Search – N.D.K., S.M.; Writing – N.D.K., V.S.; Critical Review – V.S., A.G., P.K.

Declaration of Interests: The authors have no conflicts of interest to declare.

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