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Cochlear Duct Length: Rethinking Its Role in Auditory Outcomes

Original Investigation

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Abstract

Objective: To assess the relation between cochlear duct length (CDL) and audiological outcome after cochlear implant surgery in prelingually deafened children.

Methods: In a prospective cohort study, 36 prelingually deaf children underwent cochlear implantation at All India Institute of Medical Sciences, Jodhpur. Preoperative high-resolution computed tomography (HRCT) and high-resolution T2 weighted sequences magnetic resonance imaging (MRI) of temporal bones were used to calculate CDL. Patients were followed up for 12 months postoperatively with visits every three months for audiological scoring (infant-toddler meaningful auditory integration scale and revised central auditory processing scores).

Results: Thirty-six candidates were included in the study. The mean CDL, as measured on temporal bone HRCT, was 32.72+/-1.278 mm, and, with MRI, was 33.4689+/-1.31. This study is suggestive of widely dispersed data (coefficient of variance <0.5), and hence, the hypothesis of "implantation in CDL close to 31.5 mm will give the best improvement in functional outcome scores" cannot be generalized. The improvement in functional outcome scores is likely attributable to other causes/multifactorial causation.

Conclusion: We found no relationship between CDL and audiological outcomes post-cochlear implantation in prelingually deaf children. Further research with larger sample sizes, prospective multicenter designs and extended follow-up periods is warranted to strengthen evidence in this area.

Keywords: Hearing loss, cochlear implantation, cochlear duct, radiology, audiology, patient outcome assessment, pediatric otorhinolaryngology

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Introduction

The anatomy of the cochlea is the most significant factor for successful cochlear implantation. Cochlear anatomy varies among humans, so measuring the cochlear duct length (CDL) forms the basis for achieving better cochlear implant results. CDL is defined as the length of the scale media, measured from the middle of the round window to the helicotrema (1). Precise knowledge of CDL is crucial if accurate placement of the intracochlear electrode array is required while preserving residual hearing. Additionally, with the advancements in cochlear implants, variable lengths of electrodes are now available in the market for implantation. Reports of incomplete insertion of longer electrodes highlight the variability in the length of the cochlear duct as a significant factor in the depth of insertion (2). Therefore, preoperative estimation of CDL and precise insertion of the electrode array can significantly contribute to the success of cochlear implantation. The measurement of CDL has been conducted radiographically (3). At our center, it is routine for all patients with congenital hearing loss to undergo high-resolution computed tomography (HRCT) of the temporal bone as part of the cochlear implantation workup. Using software and mathematical formulas, we can calculate the CDL. Our study focuses on the Asian race, specifically the North Indian race, characterized by smaller skulls.

There are two main perspectives on cochlear implantation. One believes the best outcomes occur when residual hearing is preserved, even in patients with profound hearing loss (4). Some surgeons prefer inserting an electrode up to 80% of the cochlear duct to avoid disturbing apical hair cells (electroacoustic stimulation) (5), thus preserving residual hearing. For this reason, some institutions use a two-turn length measurement of the cochlea to err on the side of caution. The other perspective argues for deeper insertion to stimulate frequencies along the cochlea's spiral ganglion. Newer, more flexible electrodes taper towards the apex (direct apical hair cell stimulation), allowing full insertion and better stimulation of lower speech frequencies (6).

Few studies correlate auditory outcomes with CDL. We use Medel's 31.5 mm electrode, which claims atraumatic insertion and optimal positioning in the apical turn. We hypothesize that electrodes around 31.5 mm, inserted atraumatically, will stimulate a more comprehensive frequency range, leading to better speech outcomes.

Methods

Study Design

Prospective cohort study.

Study Setting

The department of otorhinolaryngology and the department of intervention and diagnostic radiology collaborated at the All India Institute of Medical Sciences, Jodhpur, and Rajasthan (India).

Study Duration

Two years and three months (17th Nov 2020-28th Feb 2023). Patients aged less than 36 months were enrolled in the study. Approval All India Institue of Medical Sciences, Jodhpur Institutional Ethics Committe (IEC), AIIMS (IEC reg. no.: AIIMS/IEC/2020/3163, date: 23/09/2020), and registration was done with Clinical Trial Registry-India (CTRI Registration No.: CTRI/2020/11/029149 obtained on: 17/11/2020). Informed and written consent in a language the parents could understand was obtained from them before they participated in the study.

Preoperative Evaluation

All candidates underwent preoperative evaluation, including audiological evaluation [brainstem evoked response audiometry (BERA), auditory steady state response (ASSR), oto-acoustic emission, tympanometry, aided audiogram], radiology (temporal bone HRCT, inner ear MRI), TORCH profile, and assessments by various departments like pediatrics for ruling out the syndromic association, cardiology for ruling out structural heart abnormality and Long QTc syndrome, ophthalmology, and psychological evaluation for intelligence quotient and behavioral assessment, developmental quotient and social quotient.

Measurement of CDL on temporal bone HRCT and MRI

To get the full basal turn, the cochlea was organized in the double oblique coronal plane (Figure 1, green line). Heavily T2 weighted cumulative uncertainty-based evaluation sequences were used for calculating CDL in MRI.

CDL=4.16A-3.98 (1,7,8)

CDL refers to CDL, and A is the largest measured length from the round window to the cochlea's lateral wall going through the modiolus.

In the study, individuals with profound hearing loss, as indicated by ASSR and the absence of waves up to 90 dB in BERA, were considered. Two independent radiologists calculated the CDL in both computed tomography (CT) and MRI, and the average value was taken.

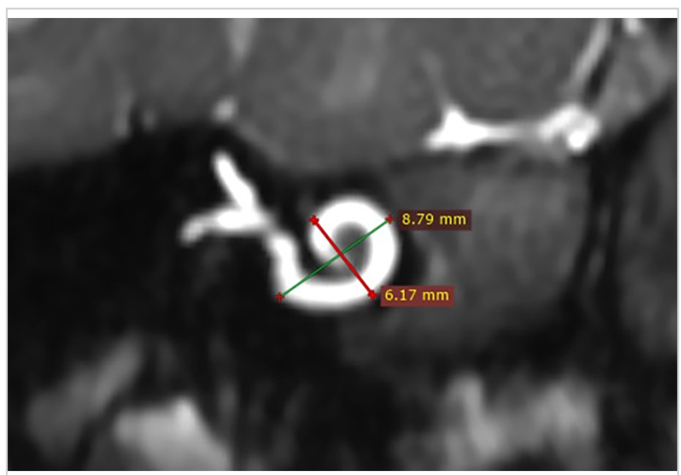

Figure 1. Double oblique coronal reformatted image of cochlea in MRI (heavily T2-weighted CUBE sequence)
MRI: Magnetic resonance imaging, CUBE: Conventional unilateral brain exploration

Exclusion Criteria

Children with a CDL of less than 31.5 mm and an age of more than three years were excluded from the study. Additionally, individuals with anomalous cochlea, low IQ, syndromic association, or genetic disorders were also excluded.

All patients had both ears stimulated with hearing aids for three months preoperatively. Subsequently, all patients underwent unilateral right-side implantation.

Patients with residual hearing or those who demonstrated improved aided audiometry after a minimum use of external hearing aids for three months were identified during preoperative evaluations.

Refined Study Approach and Ethical Considerations

Unlike the studies in literature that have adopted the predominant linear relationship focus between CDL and speech outcomes, our study has adopted a nuanced approach. We incorporated the theory of complete tonotopic stimulation by selecting an electrode array closely aligned with CDL.

The following assumptions guide our methodology:

Ethical Exclusion Criteria

Using an electrode array in a relatively smaller CDL is hypothesized to result in complications like kinking, bending, trauma, or displacement.

Recognizing the ethical implications, patients with CDL smaller than the electrode length were ethically excluded from the study.

Inserting a 31.5 mm electrode into a smaller CDL is considered ethically inappropriate and contradicts the concept of residual hearing preservation.

Surgical Technique

All surgeries were performed by a senior neuro-otologist with extensive experience in cochlear implantation surgery using the veria technique (9,10) (Figure 2). Our study used Med-El Sonata ti100 standard (Electrode volume-13 μL) in all 36 candidates.

Smooth Insertion Process

Meticulous exclusion of ineligible patients facilitated a smooth insertion of the electrode array in all subjects (11). Intraoperatively, resistance-free insertion was achieved until the level of marking (blue indicator) on the electrode. Patients experiencing resistance or not undergoing full-length insertion (not reaching the mark) were excluded from the study for further radiological evaluation to assess the position, over-insertion, kinking, and bending at the apex.

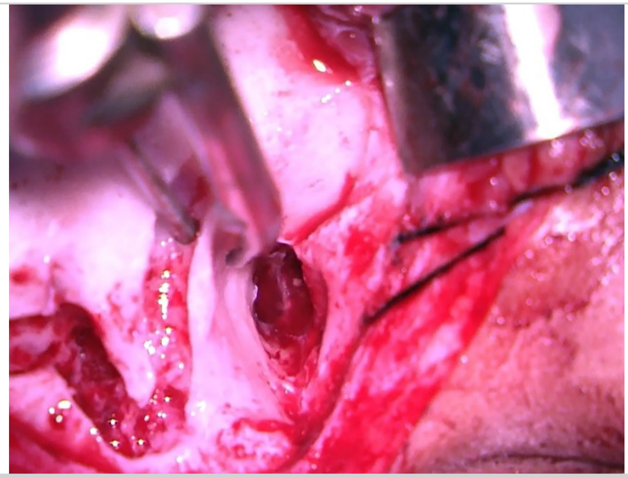

Figure 2. Veria technique: drilling of a tunnel parallel (1.4 mm) to posterior canal wall using Trifon's perforator with guard for electrode insertion (11 o'clock) on right ear

Intraoperative neural response telemetry (NRT) assessments were done in patients, and those experiencing difficulties or complications were also excluded from the study. Amplitude in the electrodes' apical, middle, and basal turns on electrically evoked compound action potential (ECAP) stimulation was recorded. To avoid unnecessary radiation exposure, especially considering our pediatric age group, the position of the electrodes were confirmed using postoperative X-ray instead of routine postoperative CT scanning. The use of radiation was approached cautiously in pediatric cases.

Follow-up

Candidates who underwent cochlear implantation participated in a preoperative assessment using the revised categories of auditory performance score (Revised CAP) and infant toddler meaningful auditory integration scale (IT-MAIS) one week before surgery (12-14). Subsequently, candidates were contacted every three months post-switch-on, with all patients completing a one-year follow-up post-switch-on (15).

Statistical Analysis

All data collected was tabulated in an Excel spreadsheet and was analyzed using the Statistical Package for Social Sciences (SPSS). International Business Machines (IBM) Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp. The results of the categorical measurements were presented in numbers or ratios. Results of quantitative variables were presented as median (95% confidence interval) or mean±SD, Pearson's correlation coefficient, One-Way Analysis of Variance test. The level of significance was taken as 5% with a p-value <0.05 being considered significant.

Results

The final assessment included 36 implanted children after applying all exclusion criteria, forming the basis for calculating the results. The study population includes children who are less than three years of age, of whom 90.78% were aged between 28 and 36 months (Figure 3).

The mean CDL measured on temporal bone HRCT was 32.72+/-1.278 mm and on MRI was 33.4689+/-1.31 mm.

The graph shows a plot between CDL and improvement in CAP score from preoperative period to postoperative 12th month (Figure 4). The downward slope of regression equation is suggestive of relatively more improvement in the CAP score in the length of the lower cochlear duct compared to the length of the higher cochlear duct. This is a widely dispersed scatter plot (R^2-0.005) which signifies that the improvement in the CAP score was not strongly correlative with CDL change, and multifactorial cause can be attributed.

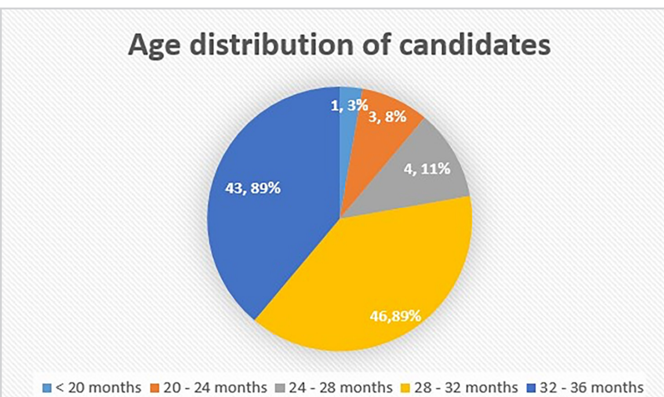

Figure 3. Pie diagram showing age distribution of the cochlear implanted population

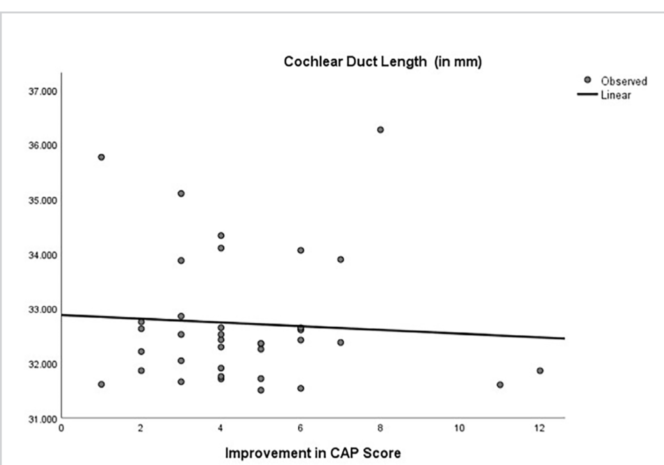

Figure 4. The graph shows a plot between cochlear duct length and improvement in categories of auditory performance score from preoperative period to 12 months postoperatively

The graph shows a plot between and improvement in IT-MAIS score from preoperative period to postoperative 12th month (Figure 5). The downward slope of regression equation is suggestive of relatively more improvement in the IT-MAIS score in the length of the lower cochlear duct compared to the length of the higher cochlear duct (r=-0.122). The highest improvement in the IT-MAIS score was found with CDL of 32.281 (average).

The graph shows good homoscedasticity for the least square method regression equation.

The scatter plot in the above analysis is suggestive of widely dispersed data (coefficient of variance <0.5) (Figure 6) and hence the hypothesis of "implantation in CDL close to 31.5 mm will give best improvement in functional outcome scores" cannot be generalized. The improvement in functional outcome scores is likely attributable to other causes/multifactorial causation.

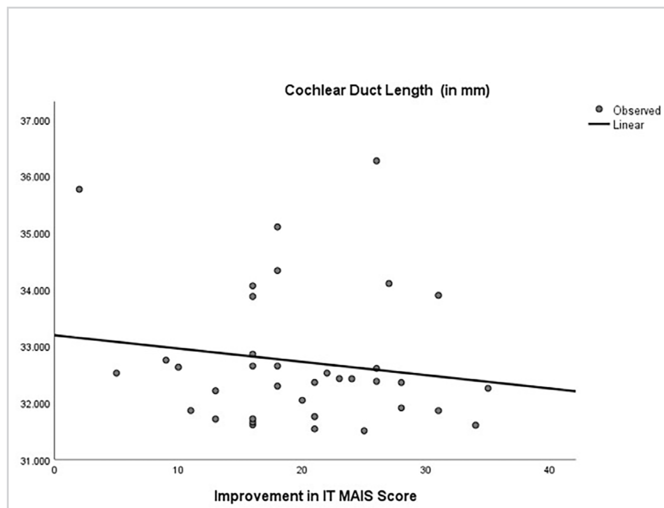

Figure 5. The graph shows a plot between cochlear duct length and Improvement in infant toddler meaningful auditory integration scale (IT-MAIS) score from preoperative period to 12 months postoperatively

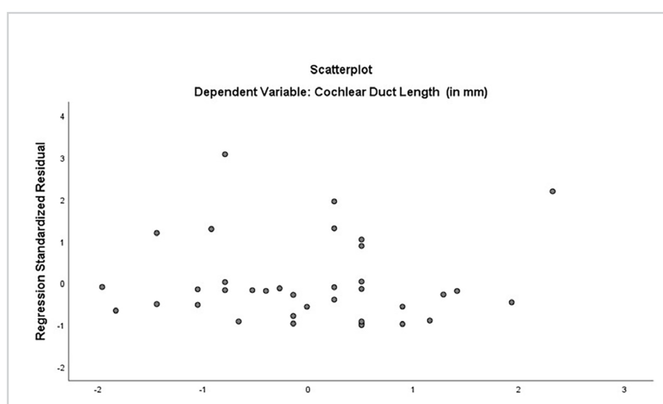

Figure 6. Scatter plot in above analysis is suggestive of widely dispersed data (coefficient of variance <0.5)

Discussion

Cochlear implants have existed for over 40 years, with nearly 20 years of presence in India. As we reflect on this established technology, it is imperative to explore futuristic aspects tailored to individual patients based on the unique anatomy of the cochlea. This involves incorporating current theories of residual hearing preservation and leveraging the maximum benefit of tonotropicity (16).

In the current market, various cochlear implant models claim effectiveness in cases with anomalies and lesser CDLs. These models differ in electrode arrays and thickness and employ multiple engineering techniques to provide maximum acoustic stimulation, including targeting apical low-frequency hair cells and achieving improved insertional depth. While the cochlear duct has been widely discussed as a parameter, there still needs to be clear evidence of the tonotopic distribution within a cochlea, which may vary among individuals based on factors such as ethnicity and race.

In light of existing evidence, we hypothesize that an electrode array inserted atraumatically, with a length similar to the CDL, can cover the entire tonotopic region. Although there are limited studies linking CDL to long-term postoperative auditory outcomes, there is a notable absence of research utilizing the same electrode in prelingual age-stratified data.

A study by Jain et al. (17) in 2020 examined the relationship between postoperative audiological results and cochlear nerve cross-section as determined by MRI, finding no association.

Kuthubutheen et al. (18) suggested no correlation between CDL and audiological outcomes in post-lingual patients using Med-El Flexsoft™ (Flex 31) and Flex28™ (Flex 28) implants.

Johnston et al. (19) study indicated that preoperative CDL measurement could predict full electrode insertion but found no correlation with audiological outcomes.

Our study hypothesized that smaller CDL could result in incomplete implant electrode insertion, while longer lengths could leave unstimulated areas near the helicotrema, particularly affecting lower frequencies. Given the tonotopic division of the cochlea based on frequency, it is expected that complete stimulation across all cochlear areas would yield better audiological outcomes. In scenarios with incomplete cochlear coverage, poorer auditory results are anticipated (20).

Despite existing studies, there is still a gap in understanding the relationship between cochlear parameters and audiological outcomes, especially in prelingually deaf children. This study aims to contribute valuable insights by investigating the impact of CDL on cochlear implantation outcomes in this specific population, thereby aiming for the need for a patient-specific customized electrode array for better speech outcome.

In contrast to the predominant focus on establishing a linear relationship between CDL and speech outcomes in existing studies, our approach seeks to address this gap by embracing the theory of complete tonotopic stimulation. We emphasize selecting an electrode array that closely aligns with the CDL.

In our study, all 36 cochlear implant recipients received a unilateral Med-El Sonata Ti100 STANDARD cochlear implant. The mean CDL, as measured on temporal bone HRCT, was 32.72+/-1.278 mm, and on MRI was 33.4689+/-1.31 mm. We used the same formula, and the two mean values are comparable; however, we used the HRCT values for correlation for statistical purposes because we found existing studies that were calculated using HRCT with the same demographic data (Western Rajasthan, India) for better reliability.

Based on prior studies, it has been determined that there is an inverse relationship between the age of cochlear implantation and the improvement observed in IT-MAIS and CAP scores. This implies that an infant undergoing cochlear implantation at one year could achieve the desired IT-MAIS and CAP scores within three months. Conversely, achieving similar results could take up to twelve months for those who receive implants at the age of three years.

We conducted analyses of CAP and IT-MAIS scores at three months, six months, and 12 months post-implantation, focusing exclusively on children aged under 36 months. Thus, the selection criterion aimed to minimize variation in CAP and IT-MAIS scores among implant recipients under 36 months. Notably, our findings revealed that children implanted between three to five years of age required additional years of auditory-verbal therapy (AVT) to attain CAP and IT-MAIS scores comparable to those achieved by younger recipients within one-year post-implantation, hence excluding the age group of more than three years. Postoperative AVT was administered to all patients, with cochlear measurements and outcome evaluations conducted by impartial observers to minimize bias.

We used lateral wall-hugging electrodes. Perimodiolar hugging electrodes can have an increased risk of scalar shift. Liebscher et al. (21) did not find measurable differences in the word recognition score (WRS). In contrast, Aschendorff et al. (22) reported a detrimental effect of dislocation of up to 10 percentage points (pp) for the WRS of patients with scalar dislocations as well as perimodiolar electrodes are shorter and cannot stimulate lesser frequency hair cells located at the apical turn.

Interestingly, bilaterally implanted infants demonstrated the potential to achieve near-normal CAP scores shortly after surgery, underscoring the efficacy of early intervention. Consequently, we adopted a one-year time frame for assessing children under three years of age, presuming minimal impact of neuroplasticity during this period.

Our study standardized the electrode choice to the 31.5 mm Med-El standard electrode for all patients, excluding those with CDL less than 31.5 mm. We emphasized gentle, smooth insertion techniques to minimize complications regardless of electrode choice. Tactile feedback during insertion was crucial, with any perception of resistance prompting reassessment to prevent electrode malposition. Complete insertion up to the marker without resistance was ensured, with each cochleostomy packed to enhance scar tissue formation and minimize complications.

Intraoperative NRT assessments were normal for all patients. All the patients showed desirable amplitude in the apical turn, middle and basal turn of the electrodes on ECAP stimulation, indirectly reflecting stimulation of active hair cells of all the regions of the cochlea after the insertion of electrodes (23). In one study (24), different electrodes were used to assess the effect of speech outcome and the results were different with different electrodes. Hence, we used the same electrode in all patients to reduce the confounder.

Postoperative radiology was conducted selectively, with MRI preferred over CT to avoid unnecessary radiation exposure. Due to resource constraints and logistical challenges, intraoperative assessment was deemed sufficient, supported by literature demonstrating its reliability.

As per the literature, the choice between cochleostomy and round window insertion did not yield significant differences in speech outcomes at the 12-month postoperative mark (25). Although findings suggesting improved outcomes with shorter CDL indirectly imply comprehensive stimulation across tonotopic areas in patients lacking residual hearing or experiencing hearing enhancement after three months of acoustic stimulation, this raises questions regarding preserving residual hearing by avoiding full insertion. However, the robustness of our study in substantiating this hypothesis is limited due to the absence of a linear relationship observed in the study. Hence, reliance solely on CDL may not always hold, given the multifactorial nature influencing speech outcomes despite extensive exclusion criteria. Our study poses a significant query regarding CDL, which is particularly noteworthy as many implant companies prioritize this metric. Our study revealed no statistically significant correlation between CDL and audiological outcomes, even at 12 months postoperatively, as confirmed by scatter plot analysis. Consequently, including additional results at three and six months is deemed unnecessary.

Conclusion

In conclusion, our study found no significant relationship between CDL and audiological outcomes following cochlear implantation in prelingually deaf children, even after applying multiple exclusion criteria at various levels (demographic, clinical assessment, radiological, surgical technique, and NRT to minimize the potential confounders. Future research with larger sample sizes, matching, prospective multicenter designs, and longer follow-up periods is needed to provide more substantial evidence in this area.

Ethics

Ethics Committee Approval: Approval to conduct this study was taken from the Institution Ethics Committee (IEC), AIIMS (IEC Reg. No.: AIIMS/IEC/2020/3163, date: 23/09/2020).

Informed Consent: Informed and written consent in a language the parents could understand was obtained from them before they participated in the study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: P.A., P.S.K., A.G., Concept: S.T., A.G., Design: V.S., D.K., K.S., A.G., Data Collection and/or Processing: P.A., Analysis and/or Interpretation: V.M., S.T., Literature Search: V.S., P.S.K., Writing: P.A., V.M.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The author(s) declare that no financial interests or relationships that could be perceived as influencing the research presented in this article.

Main Points

- Theoretically, cochlear duct length (CDL) is an important tool for predicting the accuracy of electrode placement.
- Limited clinical outcomes of CDL measurements are present in the existing literature.
- The IT-MAIS and modified compound action potential (CAP) score are easy and parent-friendly tools to assess performance in post-implant children.
- While preoperative CDL measurement is helpful for precise selection of an electrode with a matching length, there is no substantial improvement in speech outcomes directly correlated with CDL.
- Speech outcome shows no correlation even after matching the age, race, intelligence quotient, device selection, operating surgeon, and operating conditions. Therefore, overemphasizing CDL should be minimized.

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