

Audiological Outcomes of Different Cochlear Implant Electrodes in Congenitally Deaf Children: A Prospective Observational Study

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Abstract

Objective: To evaluate short-term audiological outcomes in congenitally deaf pediatric patients implanted with lateral wall or perimodiolar cochlear implant electrode arrays. **Study design:** Prospective observational study. **Methods:** The study included children with bilateral congenital profound sensorineural hearing loss who underwent unilateral cochlear implantation between January 2022 and January 2023 at two tertiary referral centers. Audiological outcomes, including free field pure tone average (PTA) and word discrimination threshold (WDT), were assessed 6 months after initial device activation. Comparisons were performed according to electrode manufacturer and design. **Results:** A total of 259 patients (mean age 33.4 months) were analyzed. One hundred ninety-two patients received lateral wall electrodes and 67 received perimodiolar electrodes. The mean PTA was 33.01 dB HL for lateral wall arrays and 32.03 dB HL for perimodiolar arrays ($p = 0.18$). Mean WDT values were 64.22 dB HL and 62.72 dB HL, respectively ($p = 0.25$). No statistically significant differences were identified between electrode designs or among manufacturers. **Conclusion:** In the short term, lateral wall and perimodiolar cochlear implant electrode arrays provided comparable audiological outcomes in congenitally deaf pediatric patients.

Keywords

Cochlear Implants, Electrodes, Profound Hearing Loss, Hearing Outcomes

1. Introduction

Cochlear implant electrode arrays are engineered to optimize auditory outcomes

while minimizing intracochlear trauma. This includes proximity to neural structures, atraumatic insertion and explantation, and minimal cochlear damage with preservation of residual hearing. Three widely accepted goals for the development of CI electrode arrays are deep insertion into the scala tympani (ST) to access lower frequency cochlear neurons; greater operating efficiency by reducing the stimulus charge required to produce a comfortable loudness level; and reduced intracochlear damage during insertion [1]-[4]. Adequate cochlear coverage is believed to be crucial in the final auditory outcomes. Straight lateral wall (LW) electrodes are believed to stimulate the nerve fiber endings at the organ of Corti, whereas pre-curved perimodiolar (PM) electrode arrays are believed to stimulate the spiral ganglion cells [2]. Straight electrodes are claimed to cause less damage, less scalar translocation, and allow for deeper cochlear penetration, and may provide more adequate coverage. They are also easier to explain [5] [6]. PM electrodes are designed to be closer to their hypothetical target, the spiral ganglion cells, and thus provide adequate coverage. Being closer to their target means less energy consumption and increased efficiency. However, they are sometimes difficult to insert due to anatomical restraints [7] [8].

Whether these technical differences significantly affect the functional outcome is still unclear.

The aim of this study is to study a series of pediatric patients implanted with different electrodes and report on their short-term outcomes.

2. Patients and Methods

This was a prospective observational cohort study, conducted at two tertiary referral centers between January 2022 and January 2023. Children with bilateral congenital profound sensorineural hearing loss who underwent unilateral cochlear implantation were included. Patients with inner ear malformations, post-meningitic deafness, or revision surgeries were excluded. A variety of electrodes were used [Medel Flex series; Cochlear CI 512, CI 522; AB Slim J, MS, and Oticon Evo]. The choice of electrode depended on the availability, the surgeon's or patient's choice, or on specific anatomical considerations (mastoid pneumatization, cochlear size, cochlear orientation). Patients were operated through a standard mastoidectomy-posterior tympanotomy approach and a round window or extended round window electrode insertion. Intraoperative impedance and measurements were routinely performed in all patients. All patients were evaluated by pure tone audiometry (PTA) and word discrimination threshold (WDT) 6 months after first fitting.

2.1. Audiological Testing

Audiological assessments were conducted 6 months after initial device activation in a sound-treated booth using a free-field setup with a parent present inside the booth. Prior to testing, parents were instructed not to speak to or guide the child during the procedure. Loudspeakers were positioned at 0° azimuth at ear level, and consistent positioning was maintained across participants to ensure stand-

ardized testing conditions. Cochlear implant mapping was performed by using age-appropriate objective and behavioral measures. For younger children who were unable to reliably report loudness comfort levels, mapping was primarily based on objective measures, including electrically evoked compound action potentials (ECAPs), in combination with behavioral observations. Behavioral indicators such as changes in facial expression, eye widening, startle responses, cessation of activity, or discomfort were carefully monitored during stimulation. For older children who were able to cooperate, subjective loudness scaling and verbal feedback were incorporated. Final maps were refined over follow-up sessions to ensure comfortable loudness, appropriate dynamic range, and stable auditory responses.

Behavioral Observation Audiometry (BOA) and Visual Reinforcement Audiometry (VRA) were used for children under 3 years, while VRA and Conditioned Play Audiometry (CPA) were used for older children. Pure tone testing was conducted in the free field at octave frequencies of 500, 1000, 2000, and 4000 Hz using warble-tone stimuli. In children assessed using Behavioral Observation Audiometry (BOA), valid responses included consistent and repeatable behavioral reactions such as head turning, eye widening, or body movement, or alerting responses temporally associated with stimulus presentation. We acknowledge that free-field PTA primarily reflects audibility, programming parameters, and auditory adaptation rather than direct sensitivity to intracochlear electrode positioning; accordingly, PTA results were interpreted as functional auditory outcomes rather than direct measures of electrode location. Final maps were refined over follow-up sessions to ensure comfortable loudness, appropriate dynamic range, and stable auditory responses.

Word Discrimination Testing (WDT) was obtained in both age groups using the Arabic version of the Auditory Perception of Alphabet Letters (APAL) test [9]. Alphabet letter perception is a core component of the auditory rehabilitation program for these children and was therefore familiar to all participants prior to testing. Testing was conducted in the free field in a quiet environment, with stimuli presented at a calibrated conversational level (approximately 65 dB SPL). The test consisted of a fixed set of Arabic alphabet letters presented auditorily. For younger children, a closed-set response format was used, requiring the child to identify or point to the perceived letter, while older children provided verbal responses. Scoring was based on the number of correctly identified letters, and results were calculated as a percentage of correct responses relative to the total number of stimuli presented. We acknowledge that WDT performance, particularly in very young children, may be influenced by cognitive, linguistic, and maturational factors. Accordingly, WDT outcomes were interpreted as functional measures of auditory perception within the context of rehabilitation rather than as isolated indicators of intracochlear electrode positioning.

2.2. Data Analysis

Simple descriptive statistics such as mean, standard deviation, minimum, and max-

imum were calculated for all outcome variables. Normality of data was tested by the Kolmogorov-Smirnov test. Postoperative differences in PTA and WDT scores were assessed using paired t-tests. Comparison between different groups was performed by the ANOVA test. Significance was set at $p < 0.05$.

3. Results

The study included 259 patients, 120 females, and 139 males. The mean age was 33.4 months (11 - 48, ± 8.719). There were 116 MED-EL™ Flex series, 86 of the Cochlear™ corporation (38 Slim straight CI 522™ and 48 Contour advance CI512™), 44 of the Advanced Bionics™ corporation (25 Slim J™ and 19 Midscale MS™), and 13 for the Oticon company (Neuro 2, Evo™ electrode). The age and sex distribution were proportionally equal between both LW and PM electrodes (LW: 98 males, 84 females; PM: 41 males, 26 females).

Surgical problems and completeness of insertion were comparable. Incomplete insertion was more frequent with Medel Flex 28 electrodes (2 cases with one extracochlear contact point), one Cochlear Contour Advance was misplaced and had to be replaced, and one MS of Advanced Bionics had to be repositioned.

Audiological Results:

The mean PT threshold for all electrodes was 32.521 (20 - 45 ± 6.894), and the mean WDT was 63.766 (40 - 85 ± 15.053). At that stage, APAL scores were not reported due to the wide disparity of results.

We then calculated the results for each brand and compared them to the general mean. The second step was to compare different types of electrodes within each brand. The third step consisted of comparing the results between all LW and PM electrodes. Finally, all electrodes were compared.

3.1. Medel

There were 116 Flex implants. The mean PTA was 32.387 (20 - 45 ± 7.048) dB, and the mean WDT was 63.362 (45 - 85 ± 14.603) dB. Comparing these results with the combined data of all electrodes did not show any statistical significance for both PTA ($t = -0.501$, $p = 0.308$) and WDT ($t = -0.236$, $p = 0.813$).

3.2. Advanced Bionics

There were 25 Slim J implants and 19 MS implants. For the Slim J implants, the mean PTA was 34.64 (25 - 45 ± 7.042) dB, and the mean WDT was 68.6 (45 - 85 ± 15.717) dB. For the MS implants, the mean PTA was 31.25 (20 - 45 ± 6.751) dB, and the mean WDT was 63.75 (40 - 85 ± 14.73) dB. Comparing the results between the two types of electrodes, there was no statistically significant difference for PTA ($t = -1.5975$, $p = 0.0587$) and for WDT ($t = 1.033$, $p = 0.153$) (**Table 1**).

3.3. Cochlear Corporation

There were 38 CI 522 and 48 CI512 implants. For the CI522, the mean PTA was 32.447 (20 - 45 ± 7.055) dB, and the mean WDT was 64.15 (45 - 85 ± 15.73) dB.

For the CI512 implants, the mean PTA was 31.08 (20 - 40 ± 6.068) dB, and the mean WDT was 62.29 (40 - 80 ± 15.136) dB. Comparing the results between the two types of electrodes, there was no statistically significant difference for PTA ($t = 0.9518$, $p = 0.1719$) and for WDT ($t = 1.033$, $p = 0.121$) (**Table 2**).

Table 1. Comparison between Slim J and Midscale electrodes (Advanced Bionics™).

Electrode	Slim J	Midscale	<i>p</i>
PTA [mean (range ± SD)]	34.64 (25 - 45 ± 7.042) CI 31.67, 37.61	31.25 (20 - 45 ± 6.751) CI 28.01, 34.49	0.058*
WDT [mean (range ± SD)]	68.6 (45 - 85 ± 15.717) CI 28.01, 34.49	63.75 (40 - 85 ± 14.73) CI 56.67, 70.83	0.153*

*Not statistically significant at $p < 0.05$.

Table 2. Comparison between CI522 and CI512 electrode (Cochlear™ corporation).

Electrode	CI 522	CI 512	<i>p</i>
PTA [mean (range ± SD)]	32.447 (20 - 45 ± 7.05) CI 30.1, 34.8	31.08 (20 - 40 ± 6.06) CI 29.35, 32.86	0.171*
WDT [mean (range ± SD)]	64.15 (45 - 85 ± 15.73) CI 58.92, 69.4	62.29 (40 - 80 ± 15.13) CI 57.85, 66.73	0.121*

*Not statistically significant at $p < 0.05$.

3.4. Oticon

There were 13 EVO implants. The mean PTA was 36.785 (30 - 45 ± 4.857) dB, and the mean WDT was 63.571 (45 - 85 ± 15.717) dB.

3.5. Comparing LW vs. PM

There were 192 patients implanted with LW electrodes and 67 with PM electrodes. For LW electrodes, the mean PTA was 33.01 (20 - 45 ± 7.033) dB, and for the PM electrodes, it was 32.03 (20 - 45 ± 6.975) dB. This result was not statistically significant ($t = 0.92463$, $p = 0.178026$). Regarding the WDT, the mean value for the LW electrodes was 64.22 (40 - 85 ± 15.039) dB whereas it was 62.72 (40 - 85 ± 15.035) dB for the PM electrodes. These values were not statistically significant ($t = -0.68505$, $p = 0.247$) (**Table 3**).

There were no statistical differences between the mean PTA of LW electrodes and the general mean ($t = 0.3341$, $p = 0.3692$), or for the WDT ($t = 0$, $p = 0.5$). Similarly, there were no statistical differences between the mean PTA of PM electrodes and the general mean ($t = -0.664$, $p = 0.253$) or the mean WDT and the general mean ($t = -0.5$, $p = 0.308$).

3.6. Comparing All Electrodes

Comparing the results of PTA across all electrodes did not reveal any statistically

significant differences (F -ratio = 1.210, p = 0.3068). Similarly, the results for WDT did not reveal any statistically significant differences (F -ratio = 0.773, p = 0.543) (Table 4).

Table 3. Comparison between all electrodes.

Electrode Type	No.	PTA	WDT
		Mean (Range $\pm$ SD) dB	Mean (Range $\pm$ SD) dB
Slim J™	25	34.64 (25 - 45 $\pm$ 7.042)	68.60(45 - 85 $\pm$ 15.717)
Midscale™	19	31.25 (20 - 45 $\pm$ 6.75)	63.75 (40 - 85 $\pm$ 14.73)
CI 512™	48	31.08 (20 - 40 $\pm$ 6.06)	62.29 (40 - 80 $\pm$ 15.13)
CI 522™	38	32.44 (20 - 45 $\pm$ 7.05)	64.15 (45 - 85 $\pm$ 15.73)
EVO™	13	36.785 (30 - 45 $\pm$ 4.8576)	63.57 (45 - 85 $\pm$ 15.717)
Flex Series™	116	32.38 (20 - 45 $\pm$ 7.048)	63.36 (45 - 85 $\pm$ 14.603)
ANOVA	p	0.306*	0.543*

*Not statistically significant at $p < 0.05$.

Table 4. Comparing different electrodes with the general means of all electrodes.

Electrode Type	No.	Overall Results		P
		PTA 32.521 (20 - 45 $\pm$ 6.894)	WDT 63.766 (40 - 85 $\pm$ 15.053)	
Slim J™	25	34.64 (25 - 45 $\pm$ 7.042)	68.60 (45 - 85 $\pm$ 15.717)	0.211219*
Midscale™	19	31.25 (20 - 45 $\pm$ 6.75)	63.75 (40 - 85 $\pm$ 14.73)	0.348765*
CI 512™	48	31.08 (20 - 40 $\pm$ 6.06)	62.29 (40 - 80 $\pm$ 15.13)	0.119083*
CI 522™	38	32.44 (20 - 45 $\pm$ 7.05)	64.15 (45 - 85 $\pm$ 15.73)	0.783793*
EVO™	13	36.785 (30 - 45 $\pm$ 4.8576)	63.57 (45 - 85 $\pm$ 15.717)	1*
Flex Series™	116	32.38 (20 - 45 $\pm$ 7.048)	63.36 (45 - 85 $\pm$ 14.603)	0.616668*

*Not statistically significant at $p < 0.05$.

4. Discussion

The ultimate goal of a cochlear implant is to achieve adequate auditory function with structural preservation of all intracochlear structures. Many variables are at play, electrode array insertion depth, cochlear coverage, tonotopicity matching, spread of excitation, electrode modiolus distance, scalar dislocation, atraumatic array insertion, and the proper choice of the array that matches the particular anatomy of each individual [2] [10] [11]. Various electrode designs were devised and are either flexible following the lateral wall of the cochlea [LW electrodes] or preformed hugging the modiolus [PM]. Each design has its advantages and dis-

advantages regarding frequency matching, hearing results, energy consumption, and intracochlear trauma [7] [12]-[14]. Electrical stimulation is best provided by perimodiolar electrodes, while straight electrodes are less traumatic and may be better in residual hearing preservation [7].

In spite of theoretical and technical differences, there doesn't seem to be any functional difference between the two designs [15] [16]. A number of studies were conducted to compare the functional outcomes between the two. Speech perception outcomes for patients who received a lateral wall or perimodiolar electrode array (Slim Straight and Contour) were found to be similar at 3 or 9 months after implant activation. Similarly, in a study comparing the Hifocus 1 and the 1 J electrodes (AB corporation), the authors did not find any demonstrable influence on performance [17]-[19].

A negative correlation was observed between electrode-modiolus distance (EMD) at the cochlear base and monosyllabic word discrimination 6 months after implantation. However, this difference disappeared after 12 months [11]. PM arrays appear to offer superior and faster speech perception and superior melody perception during the first 6 months after implantation, but the differences do not persist in the long term, with performance equalizing between groups by 24 months [20]-[24].

A mismatch was observed between the predicted frequency and the default frequency provided by every electrode for all electrode arrays. The pitch mismatch was smaller for the perimodiolar electrode array than for the lateral wall electrode array [25] [26].

Superior audiologic outcomes are observed for electrode arrays inserted entirely within the scala tympani [27] [28]. Scalar translocation and tip fold-overs occurred more frequently with perimodiolar arrays than with lateral wall arrays [29]. Perforation of the SL, in contrast, predominantly occurred with straight electrodes and was not associated with localized ossification [30]. However, a meta-analysis suggested that there is no significant correlation between hearing preservation and either insertion depth or scala position [31]-[33]. Similar results were found in patients with inner ear malformations and in hearing preservation surgeries [34]-[39].

Most studies report adult outcomes. Our study was carried out exclusively in pediatric patients. A wide variety of electrodes from different manufacturers were used. This allows greater versatility in the comparison between suggested performances and programming strategies. The choice of electrode depended on availability, surgeon choice, patient choice, or anatomical restraints. This may be a minor limitation in the true intergroup comparisons. We included 259 congenitally deaf patients with a mean age of 33.4 months. There were 192 LW electrodes and 67 PM electrodes. For LW electrodes, the mean PTA was 33.01 dB and 32.02 dB for PM electrodes. Regarding the WDT, the mean value for LW electrodes was 64.02 dB whereas it was 62.72 dB for the preformed ones. These values were not statistically significant. Electrode-wide comparison did not reveal any statistically

significant difference in PTA or WDT. A study on pediatric patients with malformations did not reveal any significant difference between both types of electrodes [40], whereas another study suggested that PM electrodes may have offered a more predictable and consistent programming [41].

These findings in congenitally profoundly deaf children are comparable to results reported in adults [11] [20]-[23]. We chose the 6-month benchmark as some studies have shown that the most significant gains occur from 3 to 6 months with more gradual progress over the next 2 years [42] [43]. Long-term follow-up in the same cohort is ongoing to determine if there will be a difference in long-term outcomes or not. Additionally, an age-stratified outcome analysis will be performed to complement the results at the end of the intended extended evaluation period.

5. Conclusion

In our cohort of pediatric congenitally deaf patients, different electrode designs did not show any short-term difference in PTA thresholds or speech discrimination scores. Each of the electrode designs has its pros and cons, but for the time being, none seems to offer a significant functional advantage. The future designs should aim at taking advantage of each to achieve more optimal results, both on the anatomical and functional levels [2] [15] [44].

Statement of Ethics

This study protocol was reviewed and approved by the Ain-Shams University IRB [ASUMed-4932-24]. Written informed consent for the study was not required as it did not involve any change in the preplanned surgical intervention. Written informed consent was obtained from participants (or their parent/legal guardian/next of kin) for the surgery, including the type of device, which was predetermined during counselling.

Authors' Contributions

Badr Eldin Mostafa: Inception, surgeries, data collection, writing.

Lobna El Fiky: Inception, surgery, data collection.

Naglaa Nasser: Audiological evaluation.

Ahmed Mostafa: Surgery, data collection.

Abir Omara: Audiological evaluation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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