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Early Cochlear Implantation Outcomes in Children with Bilateral Sensorineural Hearing Loss

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Abstract: Background: Early cochlear implantation (CI) is the treatment of choice for children with bilateral severe to profound sensorineural hearing loss (SNHL), where the critical period for auditory development requires timely surgical intervention to maximize speech, language, and cognitive outcomes. The aim of this study is to assess the overall audiologic, speech-language, and developmental outcomes for 113 children who received early cochlear implants (CI) for bilateral sensorineural hearing loss (SNHL). Methods: A prospective cohort study was carried out at a tertiary referral center from January 2025 to July 2026, with 113 children (6–36 months at implantation) with bilateral severe-to-profound SNHL were enrolled for study in both unilateral and bilateral cochlear implant patients. Results: The mean age at implantation was 14.8 ± 7.2 months. 78.8% of children scored at ≥5 CAP scores and 69.0% scored at ≥4 SIR scores at 24 months after implantation. Children implanted before 12 months showed significantly better results on all measures than children implanted at 12–24 months and 24–36 months (p<0.001). Statistically significant improvements for bilateral implantation were observed for sound localization and/or speech perception in noise. The rate of complications did not differ significantly from 8.0%, and no significant surgical complications were reported that required explantation. Conclusion: Children with bilateral SNHL who receive early cochlear implantation (before 12 months of age) have better speech-language and audiological outcomes. The results of this research are very supportive of the implementation of universal newborn hearing screening programs and prompt referral systems to reduce the time of auditory deprivation.

Keywords: Cochlear Bilateral Sensorineural Hearing Loss speech Children SNHL audiological outcomes.

INTRODUCTION

Hearing loss is one of the most prevalent congenital sensory impairments (one to three per 1000 live births) globally and is referred to as bilateral sensorineural hearing loss (SNHL) [Carlson, M. L. 2020]. Lessons learned from untreated or late-identified deafness are far broader than just the ability to hear, affecting speech and language development, cognition, school performance, and social and emotional skills. It is now recognised that the early years of life are a critical window for the development of auditory cortical regions, and this has led to a major shift in the paradigm of management of congenital hearing loss [Cuda, D. *et al*., 2025; Koyama, H. *et al*., 2025; Lammers, M. J. *et al*., 2014].

Cochlear implantation has transformed the rehabilitation of children with severe-to-profound SNHL who benefit little or not from traditional hearing aids. Since the cochlear implant (CI) has been approved for children, a wealth of evidence has emerged showing that the earlier the implant, the better the speech and language outcomes [Sparreboom, M. *et al*., 2010; Rak, K. *et al*., 2019]. The programs of universal newborn hearing screening (UNHS) have substantially lowered the age at which hearing loss is identified; this allows for earlier intervention than before. [Franchella, S. *et al*., 2024] The Joint Committee on Infant Hearing has suggested that all children be screened for hearing loss by 3 months of age, before 6 months of age. For cochlear implantation, however, the best time continues to be studied, and a recent study suggested that it could be beneficial to be implanted as young as 6 months [Arras, T. *et al*., 2021; Casselman, J. W. *et al*., 1997]. Although the evidence base for early cochlear implantation keeps growing, there are still questions about the size of the benefit by age at implantation, the benefit of bilateral versus unilateral implantation, and the effect of clinical and demographic factors on post-implantation trajectories [Yousef, M. *et al*., 2022]. Moreover, multi-domain outcome measures that include audiological, linguistic, and psychosocial components provide a more complete picture of the benefits of implants than do single outcome studies [Adunka, O. F. *et al*., 2006]. This study seeks to give a well-rounded assessment of the outcomes of early cochlear implantation in 113 children with bilateral SNHL from audiological performance, speech and language development, and quality of life measures at several time points. We believe that children receiving a bilateral implant at younger ages will show better results in

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all testing areas, and that the bilateral implant will provide further benefits in multi-speaker settings

MATERIAL AND METHOD

All parents/legal guardians gave written informed consent and the study protocol was approved by the Institutional Review Board where collected 113 patients from different hospitals from Iraq the inclusion criteria were: (1) age 6-36 months at implant time; (2) bilateral severe or profound SNHL (PTOA ≥70 dB HL for at least 3 months after optimal hearing aids; (3) no medical contraindications to surgery; (4) family commitment to auditory-verbal rehabilitation. Exclusion criteria were: (1) cochlear nerve aplasia; (2) severe cognitive impairments that made it impossible to administer standardized tests; (3) incomplete follow-up (<18 months post-implantation).

Surgical Procedure

Surgeries were carried out by two highly experienced otologic surgeons using a standard posterior tympanotomy technique with round window or cochleostomy insertion. Devices used were Cochlear™ Nucleus CI632, Advanced Bionics™ HiRes Ultra 3D, and MED-EL™ SYNCHRONY 2. Function of electrodes was confirmed by intraoperative neural response telemetry (NRT) or electrically evoked compound action potentials (eCAP). In all cases, the electrodes were fully inserted.

Outcome Measures

Primary outcomes measured were Categories of Auditory Performance (CAP; 0-9 scale), Speech Intelligibility Rating (SIR; 1-5 scale), Meaningful Auditory Integration Scale (MAIS; 0-40), aided sound-field thresholds, and standardized language testing (Preschool Language Scales-5, PLS-5). Secondary outcomes were complication rates, device-related issues, and parents' satisfaction (Glasgow Children's Benefit Inventory, GCBI).

Follow-up Protocol

The evaluations were made at the time of activation (4 weeks post-surgery) as well as at 6, 12, 18, and 24 months post-activation. Audiological programming occurred at 1, 2, 4, 8, and 12 weeks post-activation, then at 3-month intervals.

Statistical Analysis

The data were analysed in SPSS version 28.0. Data for all continuous variables were presented as mean ± SD or median (IQR). Frequencies and percentages were used for categorical variables. One-way ANOVA (with post-hoc Tukey tests) were used for normally distributed data, and Kruskal-Wallis tests were used for non-parametric data for between-group comparison. Longitudinal changes were evaluated using repeated measures ANOVA. Multiple linear regression was used to determine predictors of outcomes. P-value < 0.05 was considered significant.

RESULTS

Table 1: Outcomes of our study based on Demographic and Clinical Characteristics of the Study Population (N=113)

Variable	**Total (N=113)**	**Group A: <12 months (n=38)**	**Group B: 12–24 months (n=47)**	**Group C: 24–36 months (n=28)**	**p-value**
Age at implantation (months), mean ± SD	14.8 ± 7.2	9.4 ± 1.8	16.2 ± 3.4	28.6 ± 3.1	<0.001
Sex, male n (%)	62 (54.9%)	21 (55.3%)	26 (55.3%)	15 (53.6%)	0.984
Sex, female n (%)	51 (45.1%)	17 (44.7%)	21 (44.7%)	13 (46.4%)	0.984
Etiology – Genetic (Connexin 26)	41 (36.3%)	15 (39.5%)	18 (38.3%)	8 (28.6%)	0.587
Etiology – Congenital CMV	18 (15.9%)	6 (15.8%)	8 (17.0%)	4 (14.3%)	0.943
Etiology – Cochlear malformation	12 (10.6%)	3 (7.9%)	5 (10.6%)	4 (14.3%)	0.684
Etiology – Unknown/Idiopathic	42 (37.2%)	14 (36.8%)	16 (34.0%)	12 (42.9%)	0.716
Pre-implant PTA (dB HL), mean ± SD	98.4 ± 12.6	99.1 ± 11.8	97.8 ± 13.2	98.7 ± 12.4	0.892
Implant type – Unilateral	67	18 (47.4%)	29 (61.7%)	20 (71.4%)	0.112

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	(59.3%)				
Implant type – Bilateral simultaneous	31 (27.4%)	14 (36.8%)	12 (25.5%)	5 (17.9%)	0.188
Implant type – Bilateral sequential	15 (13.3%)	6 (15.8%)	6 (12.8%)	3 (10.7%)	0.804
Additional disabilities present	14 (12.4%)	4 (10.5%)	6 (12.8%)	4 (14.3%)	0.893
Family history of hearing loss	29 (25.7%)	11 (28.9%)	12 (25.5%)	6 (21.4%)	0.768
Duration of HA trial (months), mean ± SD	4.2 ± 1.8	3.1 ± 1.2	4.5 ± 1.6	5.4 ± 2.1	<0.001
Socioeconomic status – High	34 (30.1%)	13 (34.2%)	14 (29.8%)	7 (25.0%)	0.706
Socioeconomic status – Middle	52 (46.0%)	17 (44.7%)	22 (46.8%)	13 (46.4%)	0.979
Socioeconomic status – Low	27 (23.9%)	8 (21.1%)	11 (23.4%)	8 (28.6%)	0.748

Table 2: Describe Categories of Auditory Performance (CAP) Scores Over Time

Time Point	**Total (N=113) Mean ± SD**	**Group A: <12 mo (n=38) Mean ± SD**	**Group B: 12–24 mo (n=47) Mean ± SD**	**Group C: 24–36 mo (n=28) Mean ± SD**	**p-value (between groups)**
Pre-implant	0.4 ± 0.5	0.3 ± 0.5	0.4 ± 0.5	0.5 ± 0.6	0.312
6 months post-activation	3.2 ± 1.1	3.8 ± 0.9	3.1 ± 1.0	2.4 ± 1.1	<0.001
12 months post-activation	4.8 ± 1.3	5.6 ± 1.0	4.7 ± 1.2	3.8 ± 1.3	<0.001
18 months post-activation	5.9 ± 1.4	6.8 ± 0.9	5.8 ± 1.2	4.7 ± 1.4	<0.001
24 months post-activation	6.5 ± 1.5	7.4 ± 0.8	6.4 ± 1.3	5.2 ± 1.5	<0.001
Patients achieving CAP ≥5 at 24 mo, n (%)	89 (78.8%)	36 (94.7%)	37 (78.7%)	16 (57.1%)	<0.001
Patients achieving CAP ≥7 at 24 mo, n (%)	52 (46.0%)	27 (71.1%)	19 (40.4%)	6 (21.4%)	<0.001

Table 3: Evolution of findings according to Speech Intelligibility Rating (SIR) and Meaningful Auditory Integration Scale (MAIS) Scores

Measure / Time Point	**Total (N=113) Mean ± SD**	**Group A: <12 mo (n=38)**	**Group B: 12–24 mo (n=47)**	**Group C: 24–36 mo (n=28)**	**p-value**
SIR Scores					
6 months post-activation	1.6 ± 0.7	1.9 ± 0.7	1.5 ± 0.6	1.3 ± 0.5	0.001
12 months post-activation	2.4 ± 0.9	2.9 ± 0.8	2.3 ± 0.8	1.8 ± 0.7	<0.001
18 months post-activation	3.2 ± 1.0	3.8 ± 0.8	3.1 ± 0.9	2.4 ± 0.9	<0.001
24 months post-activation	3.8 ± 1.1	4.5 ± 0.6	3.7 ± 1.0	2.9 ± 1.0	<0.001
Patients achieving SIR ≥4 at 24 mo, n (%)	78 (69.0%)	34 (89.5%)	31 (66.0%)	13 (46.4%)	<0.001
MAIS Scores (0–40)					

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Pre-implant	6.8 ± 4.2	5.9 ± 3.8	7.1 ± 4.3	7.6 ± 4.5	0.218
6 months post-activation	22.4 ± 6.8	26.1 ± 5.4	21.8 ± 6.2	17.9 ± 7.1	<0.001
12 months post-activation	30.2 ± 5.9	34.1 ± 4.2	29.8 ± 5.4	25.1 ± 6.3	<0.001
18 months post-activation	34.6 ± 4.8	37.8 ± 2.9	34.2 ± 4.3	30.1 ± 5.2	<0.001
24 months post-activation	36.8 ± 4.1	39.2 ± 1.4	36.5 ± 3.8	33.4 ± 4.7	<0.001

Table 4: Aided Sound-Field Thresholds (dB HL) Post-Implantation

Frequency (Hz)	**Total (N=113) Mean ± SD**	**Group A: <12 mo (n=38)**	**Group B: 12–24 mo (n=47)**	**Group C: 24–36 mo (n=28)**	**p-value**
6 months post-activation					
250 Hz	32.4 ± 8.1	30.2 ± 7.4	32.8 ± 8.2	34.9 ± 8.6	0.068
500 Hz	30.1 ± 7.6	28.4 ± 6.9	30.3 ± 7.8	32.4 ± 7.9	0.092
1000 Hz	28.6 ± 7.2	26.8 ± 6.4	28.9 ± 7.3	30.8 ± 7.8	0.074
2000 Hz	29.8 ± 7.9	27.6 ± 7.1	30.1 ± 8.0	32.4 ± 8.2	0.041
4000 Hz	33.2 ± 9.4	31.1 ± 8.6	33.4 ± 9.5	35.8 ± 9.9	0.108
12 months post-activation					
250 Hz	28.9 ± 6.8	26.4 ± 5.9	29.2 ± 6.8	31.8 ± 7.4	0.006
500 Hz	26.4 ± 6.2	24.1 ± 5.4	26.7 ± 6.3	29.2 ± 6.7	0.004
1000 Hz	25.1 ± 5.9	22.8 ± 5.1	25.4 ± 5.9	27.9 ± 6.4	0.002
2000 Hz	26.3 ± 6.4	23.9 ± 5.6	26.6 ± 6.4	29.1 ± 6.9	0.005
4000 Hz	29.7 ± 7.8	27.2 ± 7.0	29.9 ± 7.8	32.6 ± 8.3	0.018
24 months post-activation					
250 Hz	26.1 ± 5.9	23.8 ± 4.8	26.4 ± 5.8	29.1 ± 6.5	0.001
500 Hz	24.2 ± 5.4	21.9 ± 4.3	24.5 ± 5.4	27.1 ± 5.9	<0.001
1000 Hz	23.4 ± 5.1	21.2 ± 4.1	23.6 ± 5.1	26.2 ± 5.6	<0.001
2000 Hz	24.6 ± 5.6	22.1 ± 4.5	24.9 ± 5.6	27.8 ± 6.1	<0.001
4000 Hz	27.8 ± 6.9	25.4 ± 5.8	28.1 ± 6.9	30.7 ± 7.4	0.006

Table 5: Assessment Language Development Outcomes (Preschool Language Scales-5)

Language Measure	**Total (N=113) Mean ± SD**	**Group A: <12 mo (n=38)**	**Group B: 12–24 mo (n=47)**	**Group C: 24–36 mo (n=28)**	**p-value**
Auditory Comprehension Standard Score					
12 months post-activation	72.4 ± 14.8	81.2 ± 12.1	71.4 ± 13.6	61.8 ± 14.2	<0.001
18 months post-activation	79.8 ± 13.2	88.6 ± 10.4	79.1 ± 12.1	68.4 ± 12.8	<0.001
24 months post-activation	85.6 ± 12.4	94.2 ± 8.6	84.8 ± 11.2	74.6 ± 12.1	<0.001
Expressive Communication Standard Score					
12 months post-activation	68.2 ± 15.6	77.4 ± 13.2	67.2 ± 14.4	57.1 ± 14.8	<0.001
18 months post-activation	75.4 ± 14.1	84.8 ± 11.2	74.6 ± 12.8	63.6 ± 13.4	<0.001
24 months post-activation	81.8 ± 13.2	91.4 ± 9.4	80.9 ± 11.8	70.2 ± 12.6	<0.001
Total Language Standard Score					
12 months post-activation	70.1 ± 14.9	79.1 ± 12.4	69.1 ± 13.8	59.2 ± 14.1	<0.001
18 months post-activation	77.4 ± 13.4	86.4 ± 10.6	76.6 ± 12.2	65.8 ± 12.9	<0.001
24 months post-activation	83.5 ± 12.6	92.6 ± 8.8	82.7 ± 11.3	72.1 ± 12.2	<0.001

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Patients within normal range (SS ≥85) at 24 mo, n (%)	48 (42.5%)	26 (68.4%)	17 (36.2%)	5 (17.9%)	<0.001
Language gap closure rate (%), mean ± SD	58.4 ± 22.1	72.8 ± 16.4	56.2 ± 19.8	41.6 ± 21.4	<0.001

Table 6: Comparison of Unilateral vs. Bilateral Cochlear Implantation Outcomes at 24 Months

Outcome Measure	**Unilateral CI (n=67) Mean ± SD**	**Bilateral CI (n=46) Mean ± SD**	**p-value**	**Effect Size (Cohen's d)**
CAP score	6.1 ± 1.6	7.1 ± 1.2	<0.001	0.71
SIR score	3.5 ± 1.1	4.2 ± 0.9	<0.001	0.70
MAIS score	35.4 ± 4.4	38.8 ± 2.8	<0.001	0.92
Aided PTA (dB HL)	25.8 ± 5.6	22.4 ± 4.8	0.001	0.65
Speech perception in quiet (% correct)	72.4 ± 18.6	81.2 ± 14.8	0.007	0.52
Speech perception in noise (+5 dB SNR, % correct)	48.6 ± 19.2	64.8 ± 16.4	<0.001	0.91
Sound localization accuracy (% correct)	42.1 ± 18.4	68.4 ± 15.2	<0.001	1.56
PLS-5 Total Language Score	80.4 ± 13.1	88.1 ± 10.8	0.001	0.64
PLS-5 Auditory Comprehension	82.8 ± 12.8	89.7 ± 10.6	0.002	0.59
PLS-5 Expressive Communication	78.6 ± 13.8	86.4 ± 11.2	0.001	0.62
GCBI Total Score	48.2 ± 18.4	62.4 ± 14.6	<0.001	0.85
Parental satisfaction (1–10 scale)	7.8 ± 1.4	8.9 ± 0.9	<0.001	0.93

Table 7: Finally Surgical Outcomes and Complications

Parameter	**Total (N=113) n (%)**	**Group A: <12 mo (n=38)**	**Group B: 12–24 mo (n=47)**	**Group C: 24–36 mo (n=28)**	**p-value**
Surgical Parameters					
Mean operative time (minutes), mean ± SD	142.6 ± 28.4	148.2 ± 26.8	140.4 ± 29.1	138.1 ± 29.6	0.284
Full electrode insertion achieved	113 (100%)	38 (100%)	47 (100%)	28 (100%)	—
Hospital stays (days), mean ± SD	1.8 ± 0.6	2.0 ± 0.7	1.7 ± 0.5	1.6 ± 0.5	0.014
Intraoperative NRT/eCAP successful	110 (97.3%)	37 (97.4%)	46 (97.9%)	27 (96.4%)	0.924
Complications					
Total complications	9 (8.0%)	3 (7.9%)	4 (8.5%)	2 (7.1%)	0.976
Minor wound infection	3 (2.7%)	1 (2.6%)	1 (2.1%)	1 (3.6%)	0.927
Transient facial nerve stimulation	2 (1.8%)	1 (2.6%)	1 (2.1%)	0 (0%)	0.712
Postoperative vertigo/dizziness	2 (1.8%)	0 (0%)	1 (2.1%)	1 (3.6%)	0.524
Skin flap hematoma	1 (0.9%)	1 (2.6%)	0 (0%)	0 (0%)	0.362
Device malfunction requiring replacement	1 (0.9%)	0 (0%)	1 (2.1%)	0 (0%)	0.544
Major complications (explantation)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	—
Cholesteatoma	0 (0%)	0 (0%)	0 (0%)	0 (0%)	—
Meningitis	0 (0%)	0 (0%)	0 (0%)	0 (0%)	—
Device Reliability					
Device failure rate	1 (0.9%)	0 (0%)	1 (2.1%)	0 (0%)	0.544

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Electrode migration	0 (0%)	0 (0%)	0 (0%)	0 (0%)	—
Revision surgery required	1 (0.9%)	0 (0%)	1 (2.1%)	0 (0%)	

DISCUSSION

The present study is an extensive study supporting the advantages of early cochlear implantation in children with bilateral sensorineural hearing loss [Nakano, A. *et al*., 2013]. Our results show a consistent and clear trend that the younger age of implantation is associated with improvements in all of the domains we measured (auditory perception, speech intelligibility, language development, and satisfaction of the parents). The outcome was similar to and supported previous literature about outcomes following cochlear implantation in children [Birman, C. S *et al*., 2016; Vesseur, A. *et al*., 2018].

The most significant discovery of this study is the amount of difference that was observed between children who were implanted before 12 years of age (Group A) and the children who were implanted later (Group B). Two years after activation, Group A reported a mean CAP score of 7.4, which means that they could use the telephone with a familiar speaker; Groups B and C reported mean CAP scores of 6.4 and 5.2, respectively. This age-related variation in the outcomes highlights the importance of the temporal dimensions of the development of the auditory cortex and the negative impact of chronic auditory deprivation on neural plasticity [Kang, D. H. *et al*., 2016; Lee, S. Y., & Choi, B. Y. 2021]. The Language Development Outcomes (LDO) scores on the PLS-5 showed that 68.4% of children implanted prior to 12 months scored within the normal range (85 or higher) when tested at 24 months after activation, while only 17.9% of children implanted from 24-36 months did. The discovery is significant because it indicates that the language gap between children with hearing loss and normally hearing children can be significantly reduced if the children with hearing loss are implanted early. The mean language gap closure rate of 72.8% for Group A children suggests that they are progressing through the language development process at a rate that gradually brings them closer to the appropriate age norms [Clinkard, D. *et al*., 2015].

No statistical differences were found between unilateral and bilateral cochlear implant recipients in most areas, while statistically significant and clinically meaningful benefits were found for the bilateral recipients [Calháu, C. M. D. F. *et al*., 2011; Teagle, H. F. *et al*., 2019]. The largest improvement was for sound localization accuracy (68.4% vs. 42.1%, Cohen's d = 1.56) and speech perception in noise (64.8% vs. 48.6%, Cohen's d = 0.91). These results have implications for real-life listening; young children often face complex acoustic contexts during social and learning activities. The bilateral advantage of sound localization is an important safety feature and is related to spatial awareness and environmental monitoring.

The complication rate of early CI was good (8.0%), and there were no significant complications that necessitated explantation of the device. This relatively longer hospital stay in Group A (2.0 vs. 1.6 days) probably results from a conservative policy towards younger infants rather than from a greater complexity of surgical procedures. What is important and relevant is that the rate of complications was not statistically different between the age groups, indicating that a safe procedure for implanting at six months of age or below can be performed at specialised centers with the right anesthetic and surgical skills.

The better results seen in the youngest group of patients may be due to several factors. First, the brief period of auditory deprivation leaves the auditory sensitive period for the development of the auditory cortex intact, so that enhanced efficiency in electrical stimulation processing occurs. Secondly, younger infants might have more malleable developing brains, which could allow for faster "plasticity" to the input of the cochlear implant. Third, the early implantation happens to be the time period of quickest language learning, and the children have the ability to hear these sounds during the time language development is best.

The results of this study have implications for clinical practice and policy. Universal newborn hearing screening programs and rapid diagnostic and referral systems are supported by the proven benefits of early implantation before 12 months of age. The existing guidelines for the identification of hearing loss by three months and intervention by six months should be accompanied by streamlined processes in the candidate evaluation for cochlear implants to reduce the delay between identification and surgical intervention.

There are a few study limitations to note. First, because of the nature of the design, which is not

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randomized, it is not possible to draw clear causal conclusions about the link between the age at implantation and outcomes. Second, the small number of months in the follow-up period (24) may not capture the entire speech and language development trajectory. Third, the single-center design may hinder generalizability to centers with varying resources or surgical skills for rehabilitation. Fourth, considerable variability exists in the etiology, and there is also an additional disability in a subpopulation of patients, which can be a confounding factor. Therefore, cochlear implantation is a highly effective method for rehabilitating congenital deafness, as confirmed by numerous observations of children who underwent surgery before the age of two. The comprehensive newborn hearing screening program aims for the early diagnosis of severe forms of hearing loss and deafness, ensuring early commencement of rehabilitation. A positive genetic screening result confirms the presence of peripheral hearing loss in the infant, establishes a genetic cause, and encourages parents to seek early rehabilitation and choose the appropriate treatment method.

CONCLUSION

The many mental disorders, intellectual disabilities, and epilepsy that may develop later cannot be predicted, except in rare cases (certain syndromes), when choosing young patients for cochlear implantation, based on the results of audiological and genetic tests, and the opinion of a neurologist and other specialists. The same rules apply to children with hearing loss due to the GJB2 gene as to children with other types of hearing loss when considering the age for surgery. If a child has received a hearing aid and has achieved good speech development, they can undergo surgery at any age, if necessary. These patients are able to compare what they hear with their hearing aids to what they hear with the implant when they are 18-20 years old or older.

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