Do the Age of Implantation, the Widths of Internal Acoustic Canal and Bony Cochlear Nerve Canal Affect the Auditory Performance of Primary School Children with Bilateral Cochlear Implants?

Original Investigation

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Abstract

Objective: To reveal the correlation between implantation age, the internal acoustic canal (IAC) width, bony cochlear nerve canal (BCNC) width, and auditory performance in primary school children with bilateral cochlear implantation (CI).

Methods: Preoperative IAC and BCNC widths of 57 pre-lingually deaf children aged 7–11 years who had previously undergone bilateral CI in our institution were reviewed and cut-off values were calculated. Twenty-four patients who had additional problems and could not attend school and those who refused to participate in the study were excluded. The remaining 33 were invited to the hospital, and their speech perception tests, and language development scores were analyzed (16 of 33 patients had been operated on before the age of 24 months).

Results: The cut-off values calculated from the 114 ears of 57 patients were 3.86 mm for IAC width and 1.56 mm for BCNC width. The auditory performances of the 33 patients after CI were not significantly different in the narrow and normal width groups. However, speech perception test results, and language development scores of patients implanted before the age of 24 months were significantly higher.

Conclusion: There are some studies showing that children with bilateral sensorineural hearing loss have narrower IAC and BCNC widths. However, we concluded that the widths of the IAC and the bone cochlear nerve canal did not affect auditory performance. We found that implantation age is the single most important determinant of speech-language development after CI.

Keywords: Cochlear implantation, age factor, bilateral hearing loss, temporal bone, surgery, cochlear nerve, pediatric, audiology, speech development

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Introduction

Cochlear implantation (CI) is an accepted treatment option for patients with severe to profound sensorineural hearing loss (SNHL) who do not benefit from hearing aids. Cochlear implants are useful in the perception of sound, speech understanding, and intellectual development in such patients (1, 2). Cochlear implants differ from hearing aids in that they convert sound into electrical impulses. Implants also stimulate the cochlear nerve directly, bypassing the hair cells in the organ of Corti (2).

Retrocochlear SNHL occurs when the lesion is localized between the cochlea and the central auditory nervous system. While many malformations of the inner ear structure (Michel's deformity, cochlear aplasia, and Mondini's deformity) are associated with SNHL in pediatric patients, CI is a well-defined surgical procedure allowing hearing rehabilitation in such cases (3).

High-resolution computed tomography (CT) and magnetic resonance (MR) imaging are used in the preoperative surgical planning and the evaluation of congenital anomalies (4). In radiological findings, internal acoustic canal (IAC) width of less than 3 mm is considered as stenosis, and this has been reported as one of the causes of SNHL (5, 6). Recently, it has also been suggested that bony cochlear nerve canal (BCNC) stenosis could be associated with cochlear nerve deficiency (7). Currently, however, the number of reported studies is insufficient to determine the effect of BCNC and IAC dimensions on auditory performance after bilateral CI.

The main aim of this study is to reveal the correlation between the age of implantation, the widths of IAC and BCNC, and post-implant auditory performance in primary school patients with bilateral CI.

Methods

Ethical Approval

The study was approved by the University of Health Sciences Turkey, İstanbul Training and Research Hospital Clinical Research Ethics Committee (decision no: 2575, date: 13/11/2020). All procedures were performed in accordance with the ethical standards set forth by the World Medical Association Declaration of Helsinki (Scotland 2000). Informed consent forms were obtained from all parents before their participation.

Patients and Study Design

The study included 57 pre-lingually deaf primary school-aged children who underwent bilateral CI in our clinic. Children with peri- or post-lingually deafness, except 7-11 years old or those who underwent unilateral CI were excluded from the study. Severe to profound hearing loss was confirmed by the auditory brainstem response test in all 57 prelingually deaf children. Preoperative high-resolution CT and inner ear MR images were examined to detect abnormalities in the cochlea and the vestibulocochlear nerve.

Clinical evaluation of the patients and the CI decisions were made by a council of otolaryngologist, radiologists, speech-language therapists, and psychologists. We followed our patients with free field audiometry at the 2nd and 6th months after implantation. Routine post-operative speech and language rehabilitation sessions were held for at least two hours per week. Some patients, however, needed sessions up to 10 hours per week.

Preoperative CT images of children were reviewed by a single head and neck radiologist to determine the dimensions of the IACs and the widths of the BCNCs in the 114 ears of the 57 patients, and the means were used to determine their cut-off points which were found as 1.56 mm for BCNC and 3.86 mm for IAC.

To evaluate auditory performance, parents were asked to bring in their children, and patients were evaluated with speech perception test and verbal language development scale by a single experienced speech-language therapist. Of the 57 patients, 24 who had additional problems and could not attend school and those who refused to participate in the study were excluded. In the evaluation of speech perception, the Monosyllabic Trochee Polysyllabic Word Test (MTP) was used as a closed-set test and the Glendonald Auditory Screening Procedure (GASP) was used as an open-set test. The Turkish version of the Test of Early Language Development (TELD-3) was used to assess verbal language development. The auditory performances of the groups with narrow and normal canal widths were compared.

Measurement of IAC and BCNC Width

On transverse temporal CT image, the width of IAC was measured as the distance between the anterior and posterior bony margins at the middle of the canal (Figure 1a, 2a), and the width of the BCNC was measured as the distance between bony margins at the midportion between the base of modiolus and the fundus (Figure 1b, 2b). On coronal temporal CT image, the length of the IAC was measured as the distance from the falciform crest to the midpoint between the inferior and superior lips of porus acusticus internus and the height of the IAC was measured as the distance between superior and inferior bony margins at the middle of the canal (Figure 1c, 2c). All measurements were taken by the same head and neck radiologist.

Figure 1. Temporal bone computerized tomography images showing the measurements of a) the width of internal auditory canal on transverse plane; b) the width of bony cochlear nerve canal on transvers plane; c) the length and height of internal auditory canal on coronal plane

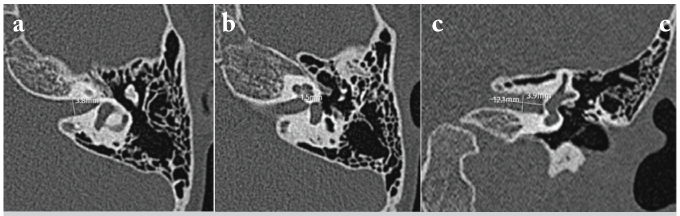

Figure 2. Temporal bone CT images showing the measurements of a) the width of internal auditory canal on transverse plane; b) the width of bony cochlear nerve canal on transvers plane; c) the length and height of internal auditory canal on coronal plane

CT: Computed tomography

Speech Perception Tests

Closed-Set Test: MTP, devised by Erber and Alencewicz (8), consists of monosyllabic, trochee, spondee, and polysyllabic words. The test can be applied to children aged two years and older. In the test, children are shown 12 images and asked to point to/repeat the word they heard. The correctly recognized words are scored. The test was administered only aurally, without the aid of lip reading. Each word was given twice in a 12-word test and the test was evaluated over 24 points.

Open-Set Test: Erber (9) developed the GASP. The test uses only question sentences. This is helpful as children can get confused when questions and commands are used together in the same test. Children can repeat or answer the question.

The Turkish Version of the Test of Early Language Development (TEDIL)

TEDIL is the Turkish adaptation of the TELD-3. The Turkish version, which was developed in 2005 and finalized in 2009, measures early verbal language development and covers three of the five basic components of language (semantics, morphology, and syntax). It measures the receptive and expressive verbal language skills of children. TEDIL consists of parallel forms, A and B and each form includes two subtests. There are a total of 76 items in each form. Some of these items address the skills to identify and describe images, and others address the ability to follow verbal instructions and verbally answering questions. TEDIL has five objectives: (a) to identify children who are significantly behind their peers in terms of early language development and to ensure that they receive early intervention; (b) to identify individual verbal strengths and weaknesses; (c) to set the program and process in language therapy; (d) to serve as a scale for examining language skills in early childhood; and (e) to support other assessment techniques (10). TEDIL is a useful tool for identifying children with language development problems.

Statistical Analysis

Statistical analysis was performed using the IBM SPSS Statistics 17.0 package program (SPSS Inc.; Chicago, IL, USA). The Kolmogorov–Smirnov test was used to determine whether or not the variables were normally distributed. Categorical variables of the data were presented with n (%). While presenting descriptive analyses, mean ± standard deviation (SD), median (minimum-maximum), Q1 and Q3 values were used. The Mann–Whitney U test was used for unpaired group comparisons and the Kruskal–Wallis test for comparisons between more than two groups. To determine the cut-off value for the 114 ears, a cut-off determination graph with normal distribution was used. Measurements were compared between the IAC AP and BCNC groups with the Kruskal–Wallis test. The Mann–Whitney U test was used for the comparison between groups separated by age of implantation. Spearman's correlation coefficient was used to examine the relationships between measurement data. The relationship between IAC and BCNC values and their relationship with the other measured parameters were analyzed using the Spearman's correlation coefficient. A p-value less than 0.05 was considered statistically significant.

Results

The mean age of the 57 primary school children participating in our study was 8.28 years (range 7 to11 years). The cut-off values calculated from 114 ears of 57 patients were 3.86 mm for IAC width and 1.56 mm for BCNC width.

The ears of 33 patients who could respond to language development tests were evaluated under two groups. The first group consisted of 17 patients (51.52%) who were implanted at the age of 24 months or older (mean age was 45 months), and the second group consisted of 16 patients (48.48%) who were implanted younger than 24 months (mean age was 17 months).

According to the cut-off values, there were three patients (9.09%) with unilateral stenosis in the width of IAC and three patients (9.09%) with bilateral stenosis. There were three patients (9.09%) with unilateral stenosis in BCNC width and five patients (15.15%) with bilateral stenosis (Table 1). In addition, when these 33 patients were examined, nine patients (27.27%) with radiological anomalies were detected. Of the nine patients, four had right high jugular bulb (12.12%), three had left high jugular bulb (9.09%), one patient (3.03%) had right chronic otitis media and one patient (3.03%) had incomplete partition type 2 (Table 2).

Auditory performance was tested in language development and speech perception. In the evaluation of speech perception, the MTP and the two-syllable test were used as closed-set test, and the GASP and the two-syllable test were used as open-set test. TEDIL was used to assess verbal language development.

Patients with and without IAC stenosis were compared, and no significant differences were found between the three groups

Table 1. Canal widths and test scores of patients with stenosis

	R IAC (mm)	R BCNC (mm)	L IAC (mm)	L BCNC (mm)	MTP	GASP	2 syllable Open-Set Test	TEDIL receptive language
1. R IAC stenosis	3.7	-	-	-	24	9	9	32
2. R IAC stenosis	3.7	-	-	-	24	10	9	37
3. b-BCNC stenosis	-	1.5	-	1.3	24	3	5	13
4. b-BCNC stenosis	-	1.3	-	1.5	24	10	8	32
5. b-BCNC stenosis	-	1.2	-	1.4	24	7	5	26
6. b-BCNC stenosis	-	1.3	-	1.4	24	8	7	28
7. b-BCNC + L IAC stenosis	-	1.3	3.7	1.3	24	10	10	33
8. R BCNC stenosis	-	1.4	-	-	24	10	7	29
9. L BCNC stenosis	-	-	-	1.5	24	10	8	34
10. b-IAC stenosis	3.7	-	3.7	-	24	10	9	28
11. R BCNC stenosis	-	1.5	-	-	24	10	8	36
12. b-IAC stenosis	3.5	-	3.4	-	24	8	7	22
13. b-IAC stenosis	3.4	-	3.4	-	23	7	5	12

R: Right, L: Left, b-: Bilateral, IAC: Internal acoustic canal, BCNC: Bony cochlear nerve canal, MTP: Monosyllabic Trochee Polysyllabic Word Test, GASP: Glendonald Auditory, Screening Procedure, TEDIL: Test of Early Language Development, (-): No stenosis

Table 2. Radiological characteristics of patients

	n	%
IAC width		
Normal (>3.86 mm)	27	(81.82)
Unilateral stenosis	3	(9.09)
Bilateral stenosis	3	(9.09)
BCNC width		
Normal (>1.56 mm)	25	(75.76)
Unilateral stenosis	3	(9.09)
Bilateral stenosis	5	(15.15)
Facial dehiscence		
Right	1	(3.03)
Left	2	(6.06)
Radiologic anomalies		
Normal	24	(72.73)
High jugular bulb	7	(21.21)
Chronic otitis media	1	(3.03)
IP type 2	1	(3.03)

IAC: Internal acoustic canal, BCNC: Bony cochlear nerve canal, IP: Incomplete partition

in terms of speech perception and language development (MTP: p=0.576, GASP: p=0.461, TEDIL: p=0.108) (Table 3). Similarly, no significant differences were found between the three groups (MTP: p=0.403, GASP: p=0.175, TEDIL: p=0.233) in terms of BCNC width (Table 4).

Thirty-three patients were divided into two groups according to implantation age. The open-set test and TEDIL language development test scores of the early implanted (<24 months of age) group were found to be significantly higher than late implanted (≥24 months of age) group (Table 5: early implanted open-set test score mean ± SD 8.06±1.88, late implanted mean ± SD 6.24±2.84; p=0.037; early implanted TEDIL score mean ± SD 28.75±7.57, late implanted mean ± SD 22.76±8.85; p=0.036). Neither were there any significant differences between the results of the closed-set tests (MTP scores: early implanted, mean ± SD 23.94±0.25; late implanted, mean ± SD 22.76±3.85; p=0.081).

The correlation between canal measurements and auditory performance tests were examined. Accordingly, positive correlations were observed between right IAC antero-posterior distance and the two-syllable open-set test, and between left AC height and GASP (Table 6).

Discussion

The most important goal of CI is to enable children born with severe hearing loss to attend mainstream education. Most children with cochlear implants attend mainstream schools and this is a measure of CI outcome success. The results of our study show that about 33 out of 57 implantees were enrolled in mainstream education.

CI is considered the best treatment option for severe to profound bilateral SNHL. Radiological dimensions of BCNC and IAC can be easily measured using temporal bone CT; however, the recommended cutting values for stenosis vary in different studies (11).

In our study, we compared the auditory performance of children who underwent bilateral cochlear implant surgery in terms of their implantation age, IAC and BCNC widths. Since

Table 3. IAC width and auditory performance

	IAC width					
	Normal		Unilateral stenosis		Bilateral stenosis	
	n=27		n=3		n=3	
	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
MTP	23.56±1.58	24.00	24.00±0.00	24.00	23.67±0.58	24.00
2 syllable closed-set test	23.22±3.08	24.00	24.00±0.00	24.00	23.67±0.58	24.00
GASP	7.63±2.87	9.00	9.67±0.58	10.00	8.33±1.53	8.00
2 syllable open-set test	6.89±2.67	8.00	9.33±0.58	9.00	7.00±2.00	7.00
TEDIL receptive language performance	25.30±8.72	28.00	34.00±2.65	33.00	20.67±8.08	22.00
TEDIL expressive language performance	28.07±7.50	30.00	35.67±4.04	38.00	18.33±16.26	24.00

SD: Standard deviation, IAC: Internal acoustic canal, MTP: Monosyllabic Trochee Polysyllabic Word Test, GASP: Glendonald Auditory Screening Procedure, TEDIL: Test of Early Language Development

Table 4. BCNC width and auditory performance

	BCNC width					
	Normal		Unilateral stenosis		Bilateral stenosis	
	n=25		n=3		n=5	
	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
MTP	23.48±1.64	24.00	24.00±0.00	24.00	24.00±0.00	24.00
2 syllable closed-set test	23.12±3.19	24.00	24.00±0.00	24.00	24.00±0.00	24.00
GASP	7.68±2.76	9.00	10.00±0.00	10.00	7.60±2.88	8.00
2 syllable open-set test	7.08±2.81	8.00	7.67±0.58	8.00	7.00±2.12	7.00
TEDIL receptive language performance	24.64±8.98	24.00	33.00±3.61	34.00	26.40±8.02	28.00
TEDIL expressive language performance	27.16±9.25	28.00	33.67±3.21	35.00	28.00±8.60	31.00

SD: Standard deviation, BCNC: Bony cochlear nerve canal, MTP: Monosyllabic Trochee Polysyllabic Word Test, GASP: Glendonald Auditory Screening Procedure, TEDIL: Test of Early Language Development

Table 5. Implantation age and auditory performance

	Implantation Age												p
	Early implanted (<24 months)						Late implanted (≥24 months)						
	n=16						n=17						
	Mean ± SD	min	Q1	median	Q3	max	Mean ± SD	min	Q1	median	Q3	max	
MTP	23.94±0.25	23.00	24.00	24.00	24.00	24.00	23.29±1.96	16.00	24.00	24.00	24.00	24.00	0.157
2 syllable closed-set test	23.94±0.25	23.00	24.00	24.00	24.00	24.00	22.76±3.85	8.00	23.00	24.00	24.00	24.00	0.081
GASP	8.88±1.67	4.00	4.00	9.50	10.00	10.00	6.94±3.15	0.00	4.00	7.00	10.00	10.00	0.080
2 syllable open-set test	8.06±1.88	3.00	3.00	8.50	9.00	10.00	6.24±2.84	0.00	5.00	7.00	8.00	10.00	0.037
TEDIL receptive LP	28.75±7.57	12.00	22.50	32.00	34.00	37.00	22.76±8.85	7.00	16.00	24.00	31.00	34.00	0.036
TEDIL expressive LP	29.94±9.41	0.00	27.00	31.00	36.50	39.00	25.94±7.99	11.00	21.00	26.00	31.00	38.00	0.079

MTP: Monosyllabic Trochee Polysyllabic Word Test, min: Minimum, max: Maximum, GASP: Glendonald Auditory Screening Procedure, TEDIL: Test of Early Language Development, LP: Language performance, Q1: First quartile, Q3: Third quartile

the development of the nervous system is completed at an early age, there is no age-related difference in IAC and BCNC dimensions. Our study included patients of similar ages.

Although BCNC and IAC widths are considered risk factors for severe SNHL, most patients in this study had normal BCNC and IAC width. According to our data, the cut-off values were 1.56 mm for BCNC and 3.86 mm for IAC. We found that BCNC or IAC stenosis did not significantly affect auditory performance after bilateral CI. Kim et al. (11) noted with a similar result that a narrow BCNC did not significantly affect auditory outcome after CI. However, there

Table 6. Correlation between canal measurements and auditory performance

		R IAC ap (mm)	R IAC length (mm)	R IAC height (mm)	R BCNC (mm)	L IAC ap (mm)	L IAC length (mm)	L IAC height (mm)	L BCNC (mm)
MTP	r	0.296	0.095	0.101	-0.110	0.151	0.074	0.196	-0.131
	p	0.094	0.598	0.575	0.543	0.402	0.680	0.276	0.467
2 syllable closed-set test	r	0.269	0.222	0.096	-0.198	0.125	0.202	0.227	-0.216
	p	0.130	0.214	0.595	0.270	0.489	0.260	0.203	0.227
GASP	r	0.225	0.144	0.294	-0.008	0.202	0.224	0.390	0.029
	p	0.207	0.423	0.097	0.964	0.259	0.211	0.025	0.871
2 syllable open-set test	r	0.371	-0.020	0.212	0.071	0.339	0.129	0.234	-0.140
	p	0.034	0.912	0.235	0.696	0.054	0.473	0.191	0.438
TEDIL receptive language performance	r	0.287	0.160	0.295	-0.023	0.231	0.277	0.317	-0.042
	p	0.105	0.374	0.095	0.899	0.195	0.118	0.072	0.818
TEDIL receptive language performance	r	0.314	0.103	0.316	0.071	0.299	0.226	0.312	0.006
	p	0.075	0.570	0.073	0.694	0.091	0.206	0.077	0.975

R: Right, L: Left, b-: Bilateral, IAC: Internal acoustic canal, BCNC: Bony cochlear nerve canal, ap: Anteroposterior distance, MTP: Monosyllabic Trochee Polysyllabic Word Test, GASP: Glendonald Auditory Screening Procedure, TEDIL: Test of Early Language Development

are some studies showing an association between BCNC or IAC width and auditory performance after bilateral CI (12, 13). The real reason for the low scores in these studies may not be IAC or BCNC stenosis, but concomitant inner ear anomalies.

In our study, the age of implantation was the single most important determinant of speech-language development after implantation. We found that children in the early implanted group had better performance, as also observed in the literature (14).

Speech perception may be impaired in patients with long-term hearing deprivation. Meister et al. (15) asserted that prolonged auditory deprivation adversely affected daily auditory performances. This situation is best avoided by early CI (16). Several studies have concluded that prelingually deaf children had improved speech perception following CI (17). In addition, Jain et al. (18) showed that early implant users developed more vocabulary than late implant users. Our findings were similar to the research findings mentioned above.

Our study has several limitations. First of all, a limited number of patient populations has been included in the study. Further studies with larger case numbers are needed. Secondly, auditory performance was tested in language development and speech perception in our study. The test battery can be expanded by applying daily communication skills and auditory reasoning performance tests. Thirdly, it would be useful to follow-up more closely on their routines, such as their postoperative speech and language rehabilitation schedules, whether or not they adhere to these schedules and how many hours per week they attend.

Conclusion

There are some studies showing that children with bilateral SNHL have narrower IAC and BCNC widths. However, we concluded that the width of the IAC and the bone cochlear nerve canal did not affect auditory performance. In our study, we found implantation age to be the single most important determinant of speech-language development after CI. Children with narrow BCNC are also candidates for early CI and rehabilitation.

Ethics Committee Approval: The study was approved by the University of Health Sciences Turkey, İstanbul Training and Research Hospital Clinical Research Ethics Committee (decision no: 2575, date: 13/11/2020).

Informed Consent: Informed consent forms were obtained from all parents before their participation.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: O.Ö., A.S.M., E.Y., M.Ç., Ö.Y., Concept: O.Ö., E.Y., Ö.Y., Design: O.Ö., E.Y., Ö.Y., Data Collection and/or Processing: O.Ö., A.S.M., M.Ç., Analysis and/or Interpretation: O.Ö., A.S.M., E.Y., Ö.Y., Literature Search: O.Ö., A.S.M., E.Y., Writing: O.Ö., E.Y.

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Main Points

- In our study, unlike other studies, we concluded that the width of the internal acoustic canal and bony cochlear nerve canal did not affect auditory performance.
- We found that implantation age is the single most important determinant of speech-language development after cochlear implantation (CI).
- Children with narrow internal acoustic canal and bony cochlear nerve canal are also candidates for early CI and hearing rehabilitation.

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