Mansoura University habilitation outcome of prelingual cochlear-implanted children: 5 years of experience

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Introduction
The aim of this study was to explore the effects of different preimplantation and postimplantation factors on the postimplant outcome of prelingual cochlear-implanted (CI) children as regards their auditory and language development.
Patients and methods
This retrospective study included a sample of 33 prelingual CI children who were presented to the Phoniatric Unit, Mansoura University Hospitals, Mansoura, Egypt, and were implanted during the last 5 years starting from August 2009 to August 2014. All children received structured auditory and language therapy sessions after CI twice weekly. They were subjected to the protocol of assessment of a delayed language development (before and after language therapy sessions) using subjective and quasiobjective measures of evaluation including improvement quotient assessment, language assessment, and assessment of auditory abilities including detection, discrimination, identification, and comprehension.
Results
The results of the study proved that the better habilitation outcomes after CI children are correlated with young age at CI surgery, preoperative improvement quotient, language therapy before and after implantation, and regularity of hearing aids usage before surgery.
Conclusion
Early CI of the prelingual children is recommended to minimize initial language delays and to promote the development of age-appropriate communication skills.

Keywords:
auditory skills, children disability, cochlear implant, hearing impairment, language therapy

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Introduction

Hearing loss affects about 5.3% of the world's population that amounts to ~360 million people, of which 9% are children [1]. Young children who experience severe-to-profound sensorineural hearing loss (SNHL) face challenges in developing spoken language because of an inability to detect acoustic-phonetic cues that are essential for speech recognition, even when fitted with traditional amplification devices [hearing aids (HAs)] [2]. Cochlear implantation (CI) is currently the only Food and Drug Association-approved medical treatment available to partially restore hearing in patients with severe-to-profound SNHL [3].

Since the approval by the Food and Drug Association in 1984, thousands of prelingually deaf children have received CIs, and many have shown excellent outcome on a wide range of measures of hearing, speech, and language. Unfortunately, the same level of benefits has not been observed in all children, and some pediatric patients derive only minimal benefits from their CIs [4]. Some of the researchers believe that the success of a CI program is directly dependent on its ability to address the issue of patient expectation and balance it with the outcome [5].

Variables affecting the outcome of CI in children are the duration and etiology of deafness, age at onset of deafness, preimplant amplification history, communication mode, age at implantation, type of speech processor used, and duration of implant usage [5]. However, the final outcome in pediatric implantation is still not entirely predictable, as there are a large number of factors, alone or in combination, that will decide the outcome of CI [6]. Categorizing these determinants increases the ability of clinicians to offer educated preoperative prognosis and might potentially allow for manipulation of variables in an attempt to achieve the best possible outcome [7].

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Aim of the work

The aim of this retrospective study was to explore the effects of different preimplantation and postimplantation factors on the postimplant outcome of prelingual CI Arabic-speaking Egyptian children as regards their auditory and language development, to highlight both predictive and prognostic values of these factors on the progress of such children.

Patients and methods

Patients

his retrospective study included a sample of 33 prelingual CI children who were presented to the Phoniatric Unit, Mansoura University Hospitals, and implanted during the last 5 years starting from August 2009 to August 2014. All children received structured auditory and language therapy sessions after CI twice weekly (20 min each) at the Phoniatric Unit, Mansoura University Hospitals, Mansoura, Egypt, for a period ranging between 6 and 48 months.

The inclusion criteria were as follows.

(1) Bilateral severe-to-profound SNHL.
(2) Six months of minimum trial period with HA(s) before CI.
(3) No developmental or medical conditions other than their hearing loss that would be expected to interfere with speech and language development, including moderate or severe mental retardation and syndrome cases.
(4) Six months of minimum duration of language therapy received after CI.
(5) Regular attendance of language therapy sessions after CI.
(6) All children came from families in which Arabic was the only language spoken to the child.

Methods

Prehabilitation assessment

The following protocol of assessment was administered before CI (for children presented to the Mansoura Cochlear Implantation Team) or initially after CI (for children referred after CI from other centers).

Elementary diagnostic procedures: these included complete history taking, general examination, ENT examination, neurological examination, and subjective evaluation of language, speech, and voice. Auditory abilities including detection, discrimination, identification, and comprehension were assessed. For the purpose of scoring of the child's auditory abilities, each ability was graded along a three-point scale from 0 to 2, giving rise to a total score of 0–8 (Table 1).

Clinical diagnostic aids: improvement quotient (IQ) was determined using either the Stanford Binet Intelligence Scale '4th Arabic version' [8] for children below 5 years of age, or the Snijder and Oomen [9] nonverbal intelligence scale for children above 5 years of age. Children with moderate or severe degrees of mental retardation were excluded from the study.

Language assessment was conducted using the Preschool Language Scale-4 'Arabic Version' (Abu-Hasseba A., unpublished data) for determination of language age.

Preoperative auditory brain stem response, play audiometry, tympanometry, otoacoustic emission, and aided audiometry were carried out to determine the type and degree of hearing loss and HA satisfaction.

Additional instrumental measures: genetic evaluation was carried out to exclude cases with syndrome, when suspected.

Electroencephalography: normal electroencephalography record was one of the criteria used in candidacy selection.

Radiological evaluation: noncontrast computed tomography and MRI of the petrous bones were carried out preoperatively to visualize the cochlea, cochlear nerve, and inner ear structures as well as cochlear distance. This aimed at excluding children with radiological contraindications to surgery.

Habilitation program

The postimplantation habilitation program included two major components.

Table 1 The three- point scale of the child's auditory abilities:

	0	1	2
Sound detection	No response	Inconsistent response	Consistent response
Auditory discrimination	No response	For either speech or non-speech sounds	For both speech and non-speech sounds
Auditory identification	No response	For words varying in length	For words versus phrases/ sentences
Auditory comprehension	No response	For words, phrases and sentences	For stories
Total score			

(1) Auditory training, including training of sound detection, discrimination, identification, comprehension, auditory sequential memory, auditory closure, and listening in background noise.
(2) Language therapy program: this was tailored according to each child's communicative abilities.

Posthabilitation assessment

At least 6 months after CI habilitation program, all children were subjected to assessment of auditory abilities using the three-point scale and language assessment using the Preschool Language Scale-4 'Arabic Version' (Abu-Hasseba A., unpublished data). Aided audiometry was carried out 6 months after implantation to objectify the results and to ensure satisfactory response.

Statistical analysis

Data were collected, tabulated, and analyzed using SPSS statistical package, version 15 (SPSS Inc., Chicago, Illinois, USA). Qualitative data were presented as numbers and corresponding percentages. The Pearson correlation test and the analysis of variance test were used to measure the relationship between variables. A *P* value was considered statistically significant if less than 0.05.

Table 2 Description of some of the demographic data of the studied children (N=33)

Variables		Number of children	% of children
Sex	Males	17	51.5
	Females	16	48.5
Regularity of HAs usage		21	63.6
Pre-implant language therapy		25	75.8
Site of CI surgery	MUH	17	51.5
	Other hospitals	16	48.5
Type of CI	Cochlear	17	51.5
	Med-El	13	39.4
	Neurelec	2	6.1
	Advanced Bionics [Harmony]	1	3
Side of CI	Rt	21	63.6
	Lt	12	36.4

Table 3 Description of the results of the assessment protocol of the studied children (N=33)

Variables	Min	Max	Mean	SD
IQ	53	119	84.42	14.56
Pre-implant auditory abilities	0	0	0	0
Post-implant auditory abilities	2	10	6.30	2.36
Pre-implant language age (months)	8	25	14.58	5.21
Post-implant language age (months)	17	75	38.21	17.54
Degree of language improvement (months)	4	54	23.64	15.21
Language lag (months)	14	82	46.70	19.07

Results

Descriptive analysis

Demographic data

The study sample included 17 male (51.5%) and 16 female (48.5%) patients in the age range 60–119 months (mean 84.91±14.89) who were implanted between the age of 36 and 101 months (mean 63.76±15.07).

A total of 21 children from the study sample (63.6%) used HAs regularly, and 25 children (75.8%) received language therapy before implantation. The duration of preimplantation language therapy ranged from 2 to 48 months (mean 17.20±13.59). Only 17 cases (51.5%) underwent the CI surgery at the Otolaryngology Department, Mansoura University Hospital, and all of these children were implanted with Nucleus Freedom device (Cochlear Corporation, Sydney, Australia). Children who were implanted at other hospitals (16 cases, 48.5%) used either the Med-El (Med-El, Innsbruck, Austria) (13 cases, 39.4%), Neurelec (Oticon Medical, Vallauris, France) (two cases, 6.1%), or Harmony (Advanced Bionics AG, Stäfa, Switzerland) (one case, 3%) devices. All cases were unilaterally implanted (Table 2). The duration of postimplantation language therapy ranged from 6 to 48 months (mean 17.79±11.65).

Results of the assessment protocol

Children's IQ ranged from 53 (mild mental retardation) to 119 (above average mentality) (mean 84.42±14.56). Preimplantation auditory abilities were 0 in all studied children. However, postimplantation auditory abilities ranged from 2 to 8 (mean 5.30±2.36). Language age improved from 8 to 25 months (mean 14.58±5.21) before implantation to 17–75 months (mean 38.21±17.54) after implantation. We used the language improvement quotient (LIQ) to measure the degree of language improvement. We calculated LIQ by subtracting preimplantation language age from postimplantation language age divided by the total duration of language therapy. Language age deficit (LAD) was also used as indicative of the degree of discrepancy between chronological and language ages after implantation. LAD was calculated by subtracting postimplant language age from postimplant chronological age. The lesser the LAD, the better the language of the child (Table 3).

Correlative/comparative statistics

Variables were classified into dependent and independent variables as follows.

(1) Dependent variables included degree of language improvement, LIQ, LAD, and postimplant auditory abilities.
(2) Independent variables included age at CI surgery, IQ, regularity of HA usage, whether the child received preimplant language therapy, duration of preimplant language therapy, preimplant language age, and duration of postimplant language therapy.

Correlative analysis

A number of correlations were made between each of the dependent variables and age at CI surgery, IQ, duration of preimplant language therapy, preimplant language age, and duration of postimplant language therapy (Table 4).

Apart from LAD, the other correlations revealed the following results.

(1) There were negative correlations between age at CI surgery and each of the other dependent variables. The younger the age, the better the outcome.
(2) There were positive correlations between IQ and each of the other dependent variables. A significant correlation was found between IQ and postimplant language age.
(3) There were positive correlations between duration of preimplant language therapy and each of the other dependent variables. The longer the duration, the higher the scores. However, it negatively correlated with the LIQ, as it is one of the denominators of the quotient.
(4) There were positive correlations between preimplant language age and each of the other dependent variables. A significant correlation was found between preimplant language age and postimplant language age.
(5) Significant positive correlations were found between duration of postimplant language therapy and all other dependent variables. The longer the duration of postimplant language therapy, the better the outcome. However, it negatively correlated with the LIQ as well, as it is one of the denominators of the quotient.

As regards LAD, it negatively correlated with IQ, preimplant language age, and duration of postimplant language therapy. In contrast, LAD showed a positive correlation with duration of preimplant language therapy and a significant positive correlation with age at CI surgery (Table 4).

In addition, intercorrelations were made among the dependent variables. Apart from LAD, there were significant positive correlations between all other variables. Significant negative correlations were observed between LAD and postimplant auditory abilities, degree of language improvement, and LIQ (Table 5).

Comparative analysis

Children of the studied sample were further divided into two groups based on the regularity of HA usage and whether or not the child received preimplant language therapy. The scores of both groups in all of the dependent variables were compared to determine the group having the higher scores.

The results showed that children who experienced regular use of their HAs before CI obtained higher scores in all dependent variables (except LAD)

Table 4 Relationship between regularity of hearing aid usage and dependent variables

Dependent variable		No (n=12)	Yes (n=21)	t	P
Post-implant auditory abilities	Mean	5.75	2.42	1.016	0.317
	SD	6.62	2.33		
Post-implant language age (months)	Mean	31.08	11.94	2.069	0.047*
	SD	42.29	19.13		
Degree of language improvement (months)	Mean	16.33	10.37	2.482	0.019*
	SD	27.81	16.15		
Language lag (months)	Mean	59.00	39.67	3.174	0.003*
	SD	16.51	17.01		

Using ANOVA test, No= irregular use of HA, Yes= regular use of HA.
*P value $<$ 0.05= significant

Table 5 Relationship between pre-implant receipt of language therapy and dependent variables

Dependent variable		No (n=8)	Yes (n=25)	t	P
Post-implant auditory abilities	Mean	4.5	2.33	2.713	0.011*
	SD	6.88	2.11		
Post-implant language age (months)	Mean	30.5	13.15	1.722	0.104
	SD	40.68	18.27		
Degree of language improvement (months)	Mean	18.25	12.61	1.157	0.256
	SD	25.36	15.79		
Language lag (months)	Mean	55.25	43.96	1.485	0.148
	SD	17.67	19.02		

Using ANOVA test, No= Did not receive pre-implant language therapy, Yes= received pre-implant language therapy,
*P value $<$ 0.05= significant

compared with children having irregular HA use. A statistically significant difference was observed in postimplant language age, degree of language improvement, and LAD. In contrast, LAD was lower in children having regular HA use (Table 6).

Similarly, children who received preimplant language therapy obtained higher scores in all dependent variables (except LAD) compared with children who did not, with a statistically significant difference in postimplant auditory abilities. In contrast, LAD was lower in children who received preimplant language therapy (Table 7).

Discussion

CI is a powerful tool for helping children with severe-to-profound SNHL to gain the ability to hear and achieve age-appropriate communication skills. However, patient selection is of utmost importance to achieve optimum results. There is universal agreement among speech and hearing scientists that variability in speech and language outcomes is the most important and most challenging unresolved problem in the field today [10].

It is unlikely that any one factor can successfully predict speech and language outcomes in all CI patients, because the observed variance reflects complex multiparametric interactions distributed across many domains. Strong predictors (or 'risk factors') are historically tied to the following: (a) the patient (e.g. demographics: age, age at implantation, degree of deafness, duration of deafness, HA use, and residual hearing); (b) the environment (e.g. access to early intervention, socioeconomic standard, and communication mode); and (c) the device (e.g. generation of implant, surgical technique, and active channels dynamic range) [11].

This retrospective study was carried out on children who regularly attended habilitation program in our unit aiming at exploring the effects of different factors on the postimplant outcome of prelingual CI children as regards their auditory and language development, to highlight both predictive and prognostic values of these factors on the progress of such children.

The age at implantation was negatively correlated with the postimplant auditory abilities, the postimplant language age, the degree of language improvement, and LIQ of the studied children. However, it did not reach statistically significant levels. In contrast, it was statistically positively correlated with LAD. Previous studies by Kirk and colleagues [12,13] demonstrated that children implanted before 5 years of age achieve significantly better communication outcomes compared with children implanted after that age. Svirsky *et al.* [14] also suggested that early implantation will reduce or prevent the language delays typically seen in young children with profound deafness. Children with early implants (before 3 years of age) quickly catch up, as they are exposed to what is called the sensitive period for language auditory development. Sensitive period for language and auditory development is a period of time during which the development of a particular brain function is very sensitive to external input. Deprivation of external input during the sensitive

Table 6 Correlation between dependent and independent variables

Independent variable		Post-implant auditory abilities	Post-implant language age	Degree of language improvement	Language lag
Age at CI surgery	R	−0.292	−0.157	−0.259	0.625
	P	0.100	0.382	0.146	<0.001*
IQ	R	0.098	0.385	0.264	−0.304
	P	0.588	0.027*	0.138	0.085
Duration of pre-implant language therapy	R	0.228	0.326	0.188	0.171
	P	0.273	0.112	0.369	0.414
Pre-implant language age	R	0.320	0.566	0.310	−0.284
	P	0.069	<0.001*	0.079	0.109
Duration of post-implant language therapy	R	0.600	0.649	0.671	−0.224
	P	<0.001*	<0.001*	<0.001*	0.211

Using Pearson correlation
**P value < 0.05= significant

Table 7 Correlation between dependent variables

		Post-implant auditory abilities	Post-implant language age	Degree of language improvement	Language lag
Post-implant auditory abilities	R	–	0.667	0.660	−0.473
	P	–	<0.001*	<0.001*	0.005*
Post-implant language age	R	0.667	–	0.959	–
	P	<0.001*	–	<0.001*	–
Degree of language improvement	R	0.660	0.959	–	−0.677
	P	<0.001*	<0.001*	–	<0.001*
Language lag	R	−0.473	–	−0.677	–
	P	0.005*	–	<0.001*	–

Using Pearson correlation
**P value < 0.05= significant

period will prevent typical development of neural circuit for the particular function. When environmental input is restored after deprivation during the sensitive period, this alone will not normalize the affected brain circuit [15].

Our study revealed the importance of language therapy after CI, as a significant correlation was found between postoperative language therapy duration and postimplant auditory abilities, postimplant language age, and degree of language improvement. This is in agreement with the findings of Spival *et al.* [16], who conducted a prospective longitudinal study to assess the habilitation outcome in a group of implanted children over 10 years after implantation. After intervention, it was found that all children with age-appropriate auditory, speech and language, and academic skills had been implanted and received regular speech and language therapy. Moreover, Tobey *et al.* [17] reported that pediatric CI recipients' speech intelligibility, although widely ranging, increased as the length of device experience accumulated over time. Similarly, Ching *et al.* [18] found that speech intelligibility in pediatric CI recipients with 6 years of device experience did not reach a plateau.

A statistically significant correlation was found between the receipt of preoperative language therapy and the postimplant auditory abilities of the studied children. However, the duration of preoperative language therapy did not reach statistically significant levels. This could be as attributed to the fact that the preimplant speech reading (which was provided in preoperative habilitation) in prelingually deaf child is a good predictor of postimplant auditory speech processing abilities. Lynessa *et al.* [15] concluded that CI is successful when there is intramodal plasticity in which the visual signal is used to support the degraded auditory signal (e.g. lip reading in audiovisual speech); however, cross-modal plasticity in which the auditory cortex comes to process visual stimuli, such as sign language, is maladaptive plasticity.

Verbal IQ reflects crystallized intelligence or knowledge coming from prior learning and past experiences. As we grow older and accumulate new knowledge and understanding, crystallized intelligence becomes stronger. As deaf patients do not go through these processes during the period of auditory deprivation before CI, their verbal IQ is lower. Conversely, performance IQ reflects fluid intelligence, which is the ability to perceive relationships independent of previous specific practices or instructions concerning those relationships. Therefore, the performance IQ of the CI patients was comparable to that of their normal-hearing peers [19]. A significant correlation was found between postimplant language age of CI children and preoperative IQ. This is in agreement with the findings of Shrestha and Mahajan [20], who postulated that the total habilitation outcome score is comparable to the total initial evaluation score. Children with high initial scores performed better than children with low scores who had a poor outcome.

The other two important preimplant factors that influence communication development in children with CIs are means of communication mode and residual hearing before CI. Children with prelingual deafness who use oral communication (speech reading) generally achieve significantly higher levels of speech perception, speech production, and/or language skills compared with their deaf peers who use total communication (sign language) – that is, the combined use of sign and spoken English [21–23]. Very early use of HAs in children with residual hearing may act as a bridge to provide auditory access to language until the child receives an implant. Therefore, their experience with HAs before implantation may provide them with more advantages of early auditory stimulation than more profoundly deaf HA users with similar age at implantation [24]. In addition the auditory information delivered by CIs, although not the same as that provided by a normal human cochlea, appears to provide children with access to much of the critical and complex information necessary for learning spoken language [25]. Geers [26] postulated that, better spoken language skills, on average, for children with CIs were expected in those who were implanted at earlier ages and who, therefore, experienced longer periods using auditory stimuli for communicative purposes and shorter periods of auditory deprivation. This is in agreement with our study that revealed a significant correlation between the regularity in using HAs before CI and postimplant language age, degree of language improvement, and LAD.

Limitation of the study

Our study evaluated the factors affecting the habilitation outcome of children with bilateral severe-to-profound hearing loss and their individual role. However, the individual role of each factor could not be statistically proven due to small sample size, short follow-up period, and presence of confounding factors such as maternal education, nature of HA and its adjustments, and difference in speech and language therapists. The study, however, indicated that they definitely have a significant role to play.

Conclusion

Better habilitation outcomes after CI children are correlated with young age at CI surgery, preoperative IQ, preoperative language therapy, language age at the time of CI surgery, regularity of HAs usage, and language therapy duration after CI.

Recommendations

Our study recommends early CI of the prelingual children to minimize initial language delays and LAD and to promote the development of age-appropriate communication skills.

Conflicts of interest

There are no conflicts of interest.

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