



Original Article

Statistical Analysis of Various Factors Affecting the Results of Cochlear Implantation

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OBJECTIVE: Evaluation of several factors that affected the outcome in patients who underwent cochlear implant surgery.

MATERIALS and METHODS: Retrospective study on 8 postlingual adults and 52 prelingual children with severe to profound hearing loss who underwent cochlear implantation at the Otolaryngology-Head and Neck surgery department, Kasr-Al Aini Hospital, Cairo University. A statistical analysis of several factors was performed to reveal any significant effect of the outcome of the procedure.

RESULTS: The duration of deafness in adults showed a significant linear yet non-monotonic correlation with the postoperative average auditory thresholds as revealed by Pearson's correlation coefficient ($r=0.839$, $p=0.009$) and a linear regression model ($f=14.211$, $p=0.009$), which showed that the increase in the duration of deafness led to an increase in hearing thresholds and accounted for 70.3% of the variance in the outcome ($\beta=0.839$, $t=3.770$, and $p=0.009$). Age at implantation in children showed a positive linear, monotonic relation with the postoperative receptive ($r=0.725$, $p<0.001$, $r_s=0.354$, $p=0.010$) and was a significant predictor of outcome ($\beta=0.440$, $t=2.961$; $p=0.005$) according to multiple linear regression. Mann-Whitney U-test was performed to evaluate the difference in medians of outcomes in relation to the regularity of attendance to speech rehabilitation. We found a significant effect over the auditory hearing thresholds (the mean ranks of regulars and irregulars were 21.48 and 31.92, respectively; $u=202.00$, $z=2.48$, $p<0.05$).

CONCLUSION: An increase in the duration of deafness leads to less favorable results of postoperative auditory thresholds in postlingual adults. Additionally, an increase in age at implantation may be associated with increased expressive language age in the first year postimplantation, and regular attendance to a speech rehabilitation program is associated with better postoperative auditory thresholds and a higher receptive language age.

KEY WORDS: Cochlear implantation, factors, outcome, age, duration of deafness, speech rehabilitation

INTRODUCTION

Cochlear implantation has evolved to become an effective and widely performed procedure for the restoration of sound in severe and profound hearing-impaired individuals^[1].

Despite extensive research examining both adult and pediatric postimplantation outcomes, the considerable variability in postoperative performance remains incompletely understood. Predictions of postimplantation benefit should be individualized and based on comprehensive preoperative assessment, with attention to the complex interplay of the aforementioned patient^[2].

MATERIALS and METHODS

This retrospective study was conducted on 70 patients with severe to profound hearing loss; they were divided into 8 postlingual adults and 62 prelingual children. Both groups underwent cochlear implantation using device models (The Nucleus CI24K; Cochlear nucleus, Melbourne, Australia) and (The Med-El Sonata, Med-El, Innsbruck, Austria) at the Otolaryngology-Head and Neck surgery department, Kasr-Al Aini Hospital, Cairo University during the period from May 2009 to March 2012. A written consent was taken from all patients or from their legal guardians and this study has obtained the approval of the ethical committee of the Otolaryngology department of Cairo University. Several factors that are known in the literature to affect the outcome of cochlear implant procedures were analyzed for identification of any statistically significant relation between them and the outcomes in our cases. In adults, the primary outcome was postoperative word discrimination scores without visual cues, and the secondary outcome was word discrimination scores with visual cues and average auditory hearing thresholds. The primary outcome for children was postoperative expressive language age, and the secondary outcome was postoperative receptive language age and auditory hearing thresholds. All outcomes were evaluated 1 year after the implantation. Factors included the duration of deafness and preoperative word discrimination scores in adults. In children, they included the age at implantation, the preoperative language age, the causes of sensorineural hearing loss, the presence of intraoperative events (the presence of ossified basal turns of the cochlea

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Table 1. Descriptive statistics of the factors and the outcomes in adults

Factors in adults		Shapiro-Wilk test p-value*	Mean±S.D.	Median - IQR***	Range
Age at implantation in years		0.155	31.86±10.37	30.15-20.23	27.70
Duration of deafness in years		0.018	3.12±2.23	2.00-2.00	7.00
Preoperative W.D.S in Percents **	Without visual cues	<0.001	9.00±16.80	0.00-24.00	40.00
	With visual cues	0.012	26.00±31.27	10.00-62.00	68
Outcomes in adults		Shapiro-Wilk test p-value*	Mean±S.D.	Median-IQR***	Range
Postoperative W.D.S in Percents **	Without visual cues	0.547	66.87±20.64	73.50-34.00	60.00
	With visual cues	0.131	85.12±10.19	88.00-18.75	28.00
Post operative Average Auditory hearing thresholds in Decibels		0.050	31.87±8.63	30.62-6.88	28.75

* Factors with p-value >0.05 also appeared normally distributed by visual inspection of their histograms, normal Q-Q plots and plots and those with p-value <0.05 looked otherwise.

** W.D.S: World discrimination scores

*** IQR: interquartile range Factors were correlated with the primary and secondary outcomes using Pearson's correlation or Spearman rank correlation and the results are shown in the following tables .

Table 2. The correlations between the factors and the postoperative world discrimination scores without visual cues

Factors in adults	Pearson's correlation		Spearman rank correlation	
	r-value	p-value	r _s -value	p-value
Age at implantation in years	0.232	0.581	0.286	0.493
Duration of deafness in years	-0.452	0.261	-0.089	0.833
Preoperative W.D.S * without visual cues	-0.243	0.561	-0.109	0.797

*W.D.S: Word discrimination scores

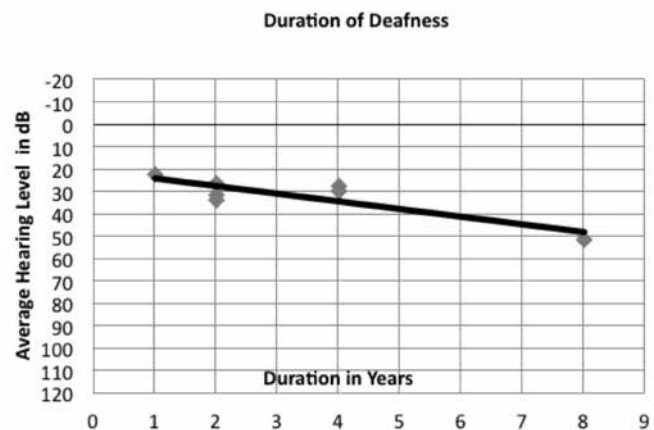
during drilling and perilymph gusher), and regularity of attendance to speech rehabilitation sessions in children. The aided free-field auditory thresholds for all subjects were assessed using warble tones.

Statistical Analysis

Statistical analysis for the factors included the Shapiro-Wilk test, normal Q-Q, and histogram plots for assessment of normal distribution of the factors. Descriptive statistics for quantitative data were presented as mean±standard deviation for normally distributed data and median with interquartile range for abnormally distributed data. Quantitative factors were correlated with the outcomes using Pearson's correlation and Spearman rank correlation coefficient, and further evaluation was done through linear regression models. The categorical factors were analyzed using Wilcoxon paired-sample test and Mann-Whitney U-test.

RESULTS

Descriptive statistics of factors and outcomes in adults are shown in Table 1. The previous tables revealed neither a linear nor a monotonic relationship between the factors and the outcomes, with the exception of the duration of deafness, which had a significant linear yet non-monotonic correlation with the average auditory hearing thresholds ($r=0.839$, $p=0.009$, $r_s=0.472$, $p=0.237$) (Table 4). It revealed that the increase in the duration of profound deafness was associated with increased auditory thresholds. Linear regression was performed to investigate this relation further. The linear regression model was significant for the correlation of the duration of deafness with the aided free-field thresholds ($f=14.211$, $p=0.009$, $r^2=0.703$; adjusted

**Figure 1.** Correlation between the duration of deafness in postlingual adults and average hearing thresholds

$r^2=0.654$). It showed that the increase in the duration of deafness led to an increase in the hearing thresholds and accounted for 70.3% of the variance in the outcome (unstandardized B coefficient=3.244, standard error=0.869, $\beta=0.839$, $t=3.770$, and $p=0.009$). The correlation between postoperative average aided thresholds and duration of deafness was visually assessed using a scatter plot in the following graph (Figure 1) and revealed a direct linear relationship. We can safely assume that a prolonged duration of deafness prior to implantation is associated with higher (i.e., worse) auditory hearing thresholds. Quantitative factors were correlated with the primary and

Table 3. The correlations between the factors and the postoperative world discrimination scores with visual cues

Factors in adults	Pearson's correlation		Spearman rank correlation	
	r-value	p-value	r _s -value	p-value
Age at implantation in years	0.496	0.212	0.589	0.124
Duration of deafness in years	-0.340	0.410	-0.053	0.901
Preoperative W.D.S * with visual cues	0.211	0.617	0.301	0.469

*W.D.S: Word discrimination scores

Table 4. The correlations between the factors and the postoperative average auditory thresholds

Factors in adults	Pearson's correlation		Spearman rank correlation	
	r-value	p-value	r _s -value	p-value
Age at implantation in years	-0.684	0.062	-0.643	0.086
Duration of deafness in years	0.839	0.009**	0.472	0.237
Preoperative W.D.S * without visual cues	0.586	0.127	0.218	0.604
Preoperative W.D.S * with visual cues	0.421	0.300	0.114	0.788

*W.D.S: Word discrimination scores. **a significant linear correlation descriptive statistics of factors and outcomes in children are shown in the following Table (5)

Table 5. Descriptive statistics of the factors and the outcomes in adults

Factors in children		Shapiro-Wilk test p-value*	No.	%	Mean±S.D.	Median-IQR**	Range
Age at implantation in years		<0.01			56.57±26.39	51.00-23.25	176.00
Preoperative language age in months	Receptive	<0.01			8.78±6.08	7.00-3.00	41.00
	Expressive	<0.01			9.61±6.93	7.00-6.00	47.00
Frequency of commonest causes of SNHL	<i>Heredofamilial</i>		36	58.1			
	<i>Unknown</i>		15	24.2			
	<i>Other causes*</i>		11	17.7			
Cases with intraoperative events			6	9.7			
Attendance for speech rehabilitation	Regular		33	53.2			
	Irregular		29	46.8			
Outcomes in children		Shapiro-Wilk test p-value*	No.	%	Mean±S.D.	Median-IQR***	Range
Postoperative language age in months	Receptive	<0.01			18.19±10.52	18.00-12.00	66.00
	Expressive	<0.01			18.67±9.42	18.00-12.00	54.00
Post operative Average Auditory hearing thresholds in Decibels		0.048			48.34±12.00	50.00-12.50	59.17

* Factors with p-value >0.05 also appeared normally distributed by visual inspection of their histograms, normal Q-Q plots and plots and those with p-value <0.05 looked otherwise.** IQR : interquartile range
SD: Standard deviation

secondary outcomes using Pearson's correlation or Spearman rank correlation in the following tables.

According to the previous tables, age at implantation showed a positive linear, monotonic relation with the postoperative receptive ($r=0.725$, $p<0.001$, $r_s=0.354$, $p=0.010$) (Table 6) and expressive language age ($r=0.682$, $p<0.001$, $r_s=0.381$, $p=0.005$) (Table 7), but it did not show any relation with postoperative average auditory thresholds (Table 8); the preoperative receptive language age showed a weak monotonic relation with postoperative receptive language age ($r_s=0.274$, $p=0.050$) (Table 6) and a weak linear relation with

postoperative expressive language age ($r=0.650$, $p<0.001$) (Table 7). Preoperative expressive language age showed a positive linear relation with postoperative expressive language age ($r=0.613$, $p<0.001$) (Table 7), but neither showed any relation with postoperative average auditory thresholds (Table 8). This reveals that an increase in age at implantation is associated with an increase in postoperative receptive and expressive language age. A multiple linear regression model was developed to further evaluate the relation between the three factors and postoperative expressive language age. The model was significant and accounted for 51.6% of variance in the expressive language age ($f=17.057$, $p<0.001$, $r^2=0.516$; adjusted $r^2=0.486$).

Table 6. The correlations between the factors and the postoperative receptive language age

Factors in children		Pearson's correlation		Spearman rank correlation	
		r-value	p-value	r _s -value	p-value
Age at implantation in years		0.725	<0.001	0.354	0.010
Preoperative language age in months	Receptive	0.715	0.274	0.274	0.050
	Expressive	0.687	0.236	0.236	0.093

Table 7. The correlations between the factors and the postoperative expressive language

Factors in children		Pearson's correlation		Spearman rank correlation	
		r-value	p-value	r _s -value	p-value
Age at implantation in years		0.682	<0.001	0.381	0.005
Preoperative language age in months	Receptive	0.650	<0.001	0.264	0.059
	Expressive	0.613	<0.001	0.221	0.116

Table 8. The correlations between the factors and the postoperative average auditory thresholds.

Factors in children		Pearson's correlation		Spearman rank correlation	
		r-value	p-value	r _s -value	p-value
Age at implantation in years		-0.203	0.148	-0.119	0.402
Preoperative language age in months	Receptive	-0.170	0.228	-0.037	0.795
	Expressive	-0.172	0.223	0.035	0.805

Table 9. Results of Kruskal-Wallis test for effect of causes over the outcomes

Outcomes in children		Kruskal-Wallis H test	
		Chi-square	p-value
Postoperative auditory thresholds		4.579	0.101
Postoperative language age	Receptive	0.960	0.619
	Expressive	1.206	0.547

Only age at implantation had a significant correlation with the outcome (unstandardized B coefficient=0.157, standard error=0.053, $\beta=0.440$, $t=2.961$; $p=0.005$). We can safely assume that an increase in age at implantation is associated with an increase in postoperative expressive language age. The causes of sensorineural hearing loss in children were considered a variable that was associated with better or worse post-implantation results. Therefore Kruskal-Wallis H-test was conducted to compare the outcomes according to the causes of sensorineural hearing loss, and the results are shown in Table 9. Table 9 showed that there was no statistically significant association between either of the causes and postoperative auditory thresholds or postoperative receptive and expressive language age. Thus, this study could not reveal if either of the causes had a better or worse prognosis over the outcome of implantation. We also investigated the effect of the presence of intraoperative events, including the presence of ossified basal turns of the cochlea during drilling or occurrence of a perilymph gusher, and regular attendance to speech rehabilitation sessions on the prognosis of the implantation. Table 10 displays the medians for the outcomes grouped according to the presence of intraoperative events and regularity of attendance to speech rehabilitation. We ran a Mann-Whitney U-test to evaluate the difference in medians of the outcomes in relation to the presence of intraoperative events; we found no significant effect

with the presence of intraoperative events on auditory thresholds or receptive and expressive language age [($u=185.00$, $p\text{-value}=0.240$), ($u=173.00$, $p=0.134$), and ($u=184.00$, $p=0.213$) respectively]. We also ran the Mann-Whitney U-test to evaluate the difference in medians of outcomes in relation to the regularity of attendance to speech rehabilitation. We found a significant effect on auditory hearing thresholds (the mean ranks of regulars and irregulars were 21.48 and 31.92, respectively; $u=202.00$, $z=2.48$, $p<0.05$) and receptive language age (the mean ranks of regulars and irregulars were 30.80 and 21.86, respectively; $u=221.50$, $z=2.18$, $p<0.05$); however, we found no significant effect over expressive language age ($u=245.50$, $p\text{-value}=0.085$). So, we can safely assume that patients who regularly attend speech rehabilitation are associated with lower (i.e., better) auditory thresholds and higher receptive language age.

DISCUSSION

Cochlear implantation is considered an elective choice for the treatment of severe and profound deafness [3]. Cochlear implantation also represents a valid option in post-lingually deafened adults, who manage to achieve high levels of speech perception not only in quiet but also in the presence of noise and when using the telephone [4].

In this study, we revealed that the duration of deafness prior to cochlear implantation in adults can be a valuable predictor of postoperative auditory thresholds, and prolonged delay of implantation may lead to less satisfying results of the thresholds of hearing following implantation. The average duration of deafness for postlingual adults was 3.12 ± 2.23 , with a median of 2.00 and an interquartile range of 2.00 in years and a significant direct linear relation with auditory threshold conduction thresholds. These results agree with the results of Moon et al. [5] and Holden et al. [6] on deaf adults, who also found

Table 10. Comparison of Medians of the outcomes grouped according to the presence of intraoperative events and regularity of attendance to speech rehabilitation.

Outcomes in children		Presence of intraoperative events		Regularity of speech rehabilitation attendance	
		Present	Absent	Regular	Irregular
Postoperative auditory thresholds in Decibels		53.75	49.37	45.00	45.00
Postoperative language age in months	Receptive	12.00	18.00	18.00	12.00
	Expressive	12.00	18.00	18.00	12.00

that shorter durations of deafness were associated with better performance postimplantation.

In the present study, the descriptive statistics revealed that the average age at implantation for the 62 prelingual subjects was 4.70 years, with a standard deviation of 2.19 years, a median of 4.25 years, and interquartile range of 1.93 years, which was much older than the age at implantation recommend by most of the literature and studies for achieving a favorable outcome in prelingual cases. Evidence for a sensitive period for language development within the first 2 years of life is accumulating. Miyamoto et al. [7] provided data for improved speech perception and oral linguistic skills in children implanted before their second birthday compared with children implanted when older than 2 years of age [7]. Such a relatively high age at implantation in our cases can be attributed to many factors, including lack of newborn hearing screening, failure of the parents/family to respond early to the condition, or low socioeconomic state and/or presence of financial barriers and decreased public awareness. A study done by Stern et al. [8] revealed that patients from lower-income families had lower rates of implantation compared with higher-income groups. We also revealed that children with higher age at implantation were associated with a higher expressive language age 1 year postimplantation. These results are rather contradicting with most of the literature, which state that a younger age at implantation is associated with better language age outcomes. Ganek et al. [9] stated that earlier age at cochlear implantation is associated with better communication development. A study by Niparko et al. [10] showed that children implanted prior to 18 months of age followed language development trajectories similar to hearing peers. Implantation after 18 months created less favorable trajectories [9, 10]. The contradicting results in our study may be explained by the rather short period (1 year) after which language evaluation was done post implantation.

Also, most of the previous studies had compared children implanted before the age of 2 and after that age, while all our subjects were over 2 years old.

In the present study, 58.1% of children's sensorineural hearing loss was of congenital/heredofamilial etiology, 24.2% was unknown, and the remaining 17.7% was due to other causes. Other studies had a similar incidence of causes of sensorineural hearing loss in children [5, 11]. Intraoperative events occurred in 9.7% of children of our study and had no statistical significant effect on the outcome. A study by Adunka et al. [12] concluded that occurrence of perilymph gusher had no influence over the outcome [12]. Robey et al. [13] stated that the incidence of perilymph gusher is about 1% [13].

We also revealed in our study that children who regularly attended speech rehabilitation were associated with better outcomes in the

form of lower auditory thresholds and a higher receptive language age. A statistically significant variation was found when comparing aided air conduction thresholds and postoperative receptive language age between subjects who attended speech rehabilitation regularly and those who did not ($p=0.013$ and $p=0.029$, respectively). A study by Tobey et al. [14] stated that speech rehabilitation services had a positive impact on speech perception, intelligibility, and language age and suggested that this is due to early emphasis on speech and auditory skill development, which may have a later impact on the child's ability to make use of the auditory information provided by the cochlear implant to produce intelligible speech [14]. This lack of attendance to speech rehabilitation may be attributed to the fact that most participants of cochlear implantation live in far destinations and can not comply with regular attendance for speech rehabilitation, which may require up to 2 visits a week.

Our outcome in postlingual adults regarding word discrimination and aided air conduction thresholds compare favorably with worldwide standards. Studies discussing the outcome of cochlear implantation in postlingual adults show similar results [15, 16]. Our outcomes for prelingual pediatric cases showed a median of 18 months and an interquartile range of 12 months for both expressive and receptive language age. These results were comparable with other studies on language development postimplantation [17, 18]. However, they lagged behind when compared to results of studies by Svirsky et al. [19] and Robbins [20].

In conclusion, this study revealed that the duration of deafness is a valuable predictor of the outcome in postlingual adults, where an increase in the duration of deafness leads to less favorable results of postoperative auditory thresholds. Additionally, the study revealed that an increase in age at implantation may be associated with increased expressive language age in the first year postimplantation, and finally, compliance with a strict speech rehabilitation program is essential to improve the postimplantation performance.

Candidates should receive the implant at a younger age than in our study; this may be achieved by increasing public awareness of the availability and cost-effectiveness of this procedure, improve infant hearing screening performance. Measures should be taken to increase attendance to speech rehabilitation sessions due to their importance in improving language development; a possible solution is to provide outreach centers to provide rehabilitation services for those who can not come to the center on a weekly basis.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of the Department of Otolaryngology, Cairo University, Egypt.

Informed Consent: Written informed consent was obtained from the patients who participated in this study.

Peer-review: Externally peer-reviewed.

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