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AUDITORY PERFORMANCES AND SPEECH PRODUCTION OUTCOMES IN COCHLEAR IMPLANTED CHILDREN

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ABSTRACT. Auditory Performances and Speech Production Outcomes in Cochlear Implanted Children

Introduction: Cochlear implantation is a well established treatment option in bilateral severe to profound hearing impaired children who received limited or no benefits from hearing aids. For parents, clinicians and speech therapist(s) the main goal after cochlear implantation is to develop the children's auditory perception and all the skills needed to communicate through spoken language.

Material, Methods: We assessed 50 cochlear implanted children using pure tone audiogram for hearing level and global assessment scores like Revised Categories of Auditory Performance and Speech Intelligibility Scale for speech perception and production. We have included in our study only the pre/perilingual patients with minimum 6 months of cochlear implant use. All patients were implanted unilaterally with MedEl devices. The group was split into two groups according to the implantation age, G1, group of children implanted under the age of 5 years, and G2, group of children implanted over the age of 5.

Results: After one and a half year of implant use and fitting sessions, most of the patients have had good hearing levels, they reached the 20-25 dB pure tone threshold. The auditory performance was improving permanently after the implant activation. The younger patients had small scores at the beginning but they progressed faster than the older ones. According to estimates, children implanted under the age of 5 years could have an intelligible conversation with a familiar person, about 2 years after implantation and around three years began to speak in order to be understood, perhaps with some difficulty, by people less familiar with their speech. Children implanted after the age of 5 had a slower evolution, they could understand a simple conversation with a familiar person after 2 ½ years of implant use and only after 4-5 years some of them could have a phone conversation.

Discussions: Pure tone audiometry is a valuable indicator of cochlear implant functionality and helps adjust the speech processor parameters for a satisfactory threshold on each frequency. Speech and language development is a slow process, both for toddlers and older children. The speech production is a slower process and needs a lot of training with professional speech therapists. The younger children will perform better than the older children who needs more time to reach the maximum level.

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Conclusions: Speech development, the most important but the most difficult stage, involves an intensive auditory-verbal training, conducted by qualified persons, training which has to be continued at home, by the family, continuously stimulating the child, motivating him, with a strong effort from all of those who are around the child in order to achieve the best results.

Key words: *cochlear implant, children, outcomes, threshold, scores*

ZUSAMMENFASSUNG. Auditory Performances und Sprachproduktion Ergebnisse in Cochlea implantierten Kindern

Einleitung: Die Cochlear- implantation ist eine gute feststellende Option für Kinder mit strenger bis tiefer bilateralen Schallempfindungsschwerhörigkeit, die begrenzenden oder keine Vorteil durch Hörgeräte. Für Eltern, HNO-Ärzte und Reden das Hauptzeil nach der Cochlear-Implantation Schallempfindungsschwerhörigkeit ist es, um die Kinder mit der Schallempfindungsschwerhörigkeit und alle Bedürfnisses zu sprochende Sprache zu mitteilen.

Material, Method: Wir haben Tonaudiometrische Untersuchung für Horniveau und Global Assistment Scores like Revised Categories of Audiology Performance und Verständnissprachskala für Schallempfindungsschwerhörigkeit für 50 Kindre mit der Cochlear-Implantation untersucht. Wir haben in unserem Studie nur die prä/perisprochenden Patienten, die minimum 6 Monaten Cochlear-Implantation verwenden, eingeschossen.

Alle Patienten haben Einsetige Cochlear-Implantation Med-El bekommen. Die Gruppe hat in zweiten Gruppen nach dem Alter geteilt, G1, die Gruppen mit den Patienten unter 5 Jahren, und G2, die Gruppen Patienten über 5 Jahren.

Ergebnisse: Seit einem ein und halb Jahr von Implantverwenden und mehrere Anspassungen, die meisten Patienten hatten guten Horniveau vorgestellt, die zu 20-25 dB Pure Tone erreicht haben. Die Horfahikeit wurde, nach der Cochlear-Implantation Aktivierung, ständing verbessert. Am Anfang hatten die jungeren Patienten kleine Noten, aber sie hatte viele Progress als die alterer gemacht. In Übereinstimmung mit Wertschätzung, die Kindern, unter dem Alter 5 jahren Cochlear-Implantation bekommen hatten, konnte eine verständliche Gespräche mit einer vertrauten Person nach dem 2 Jahren uber der Implantation haben und rund drei Jahren begann zu sprechen oder um verstanden zu sein, vielleicht mit einigen Schwierigkeiten, die Menschen mit ihrer Rede weniger vertraut. Die Kindern, die nach dem 5 Jahren eiem CI bekommen hatten, hatten eine langsamere Entwicklung, konnten sie eine einfache Gesprach mit vertrauten Personen verstehen, nach dem 2 Jahren sie der C.I verwerdert hatten, und erst nach 4-5 Jahren einigen von Ihnen konnten eine Telephongesprach haben.

Diskussionen: Tonaudiometrische Untersuchung ist ein wertvoller Indikator für die Cochlea-Implantat-Funktionalität und hilft uns der Sprachprozessor Parameter für eine zufriedenstellende Schwelle auf jeder Frequenz zu einstellen. Die Sprech-und Sprachentwicklung ist einen langsameren Prozess, sowohl für kleine Kindern als auch für ältere Kindern. Die Spracherhaltung ist einen langsameren

Prozess und es braucht viel Ausbildung mit einen professionist Reden. Die jüngeren Kinder werden bessere als die älteren Kinder entwickeln, die mehr Zeit brauchen, um die maximale Stufe zu erreichen.

Schlussfolgerungen: Die Sprachentwicklung, die wichtigste, aber die schwierigste Phase, beinhaltet eine intensive auditiv-verbale Schulung von qualifizierten Personen,die Ausbildung, die zu Hause standig fortgesetzt werden, von der Familien standig das Kind stimuliert und motiviert, mit einem starke Anstrengungen aller derer, die rund um das Kind sind, um die besten Ergebnisse zu erzielen.

Stichworte: *Cochlear implantation, Kinder, Ergebnisse, Schwelle, Partituren*

INTRODUCTION

Sensorineural hearing loss is the most common congenital condition, 1 to 3 in 1,000 newborns are diagnosed with this sensorial deficit. Profound sensorineural hearing loss, more difficult to correct with conventional hearing aids, has led to the search for suitable solutions, culminating in the cochlear implant, a semi implantable auditory device, which is surgically inserted in the inner ear and directly stimulates the cochlear nerve, currently the most effective solution for severe and profound hearing loss.

Cochlear implant creates the conditions for receiving sounds, but doesn't provide speech understanding without an intensive auditory-verbal rehabilitation, the most important stage, when the implanted patient is learning step by step to interpret the incoming sound, to imitate these sounds in an more and more elaborate way, developing the speech, more or less close to normal.

Cochlear implant was introduced in our country 11 years ago. In the ENT Clinic of Cluj County Clinical Emergency Hospital the first three cochlear implants were performed in November 2003. From 2003 to 2009 56 cochlear implants were performed, both on children and adults. Most children had prelingual hearing loss, while adults had postlingual hearing loss. Auditory-verbal rehabilitation was done in most cases by speech therapists from Cluj-Napoca's Hearing Impaired Special High School.

This paper is intended to be the assessment of the results obtained by our cochlear implanted children during this period.

MATERIAL, METHODS

1. Study group

The study group consisted of 50 patients diagnosed with pre/perilingual severe to profound bilateral sensorineural hearing loss, unilaterally cochlear implanted in ENT Clinic Cluj-Napoca, from 2003 to 2009.

The inclusion criteria in the study group were:
- Severe to profound bilateral sensorineural hearing loss;
- Pre/perilingual hearing loss ;
- Unilateral cochlear implant;
- Experience with a cochlear implant for at least 6 months;
- Age under 18 years at the implantation moment.

Exclusion Criteria:
- Other hearing loss than severe or profound sensorineural;
- - Postlingual onset of hearing loss;
- - Experience with cochlear implant under 6 months;
- - Age over 18 years at the moment of implantation

2. Auditory-verbal assessment of pre-and postoperative cochlear implant patients

2.1. Evaluation of hearing threshold

All patients were evaluated preoperatively in the audiological department of Cluj-Napoca's ENT Clinic, by pure tone audiometry, auditory evoked potentials (Maico device MB21 and IHS), immittance tests (Hortmann tympanometer), Transient Evoked Otoacoustic Emisions and ASSR (auditory steady state response) (device IHS). Pure tone audiogram was also done preoperatively with hearing aids, in free field conditions.

Postoperatively, after the cochlear implantation, we performed free-field audiometry before every fitting session. Depending on the audiogram profile we've adjusted the speech processor's MCL (most comfortable level) and THR (auditory threshold minimum) values for each electrode in order to improve the speech perception. We took into account or considered the 250, 500, 1000, 2000 and 4000 Hz frequencies, both preoperative and postoperative values from every fitting session.

2.2. The global assessment of speech perception and production

1). CAP_R (Revised Categories of auditory performance) is a score evaluation developed by S. Archbold et al (1995) (1,2) and revised (3) quantifying the patient's auditory skills in the natural context. CAP_R is a global scale of auditory perception, used especially in cochlear implanted children, which evaluates the auditory performance in a 9-point scale, with increasing difficulty, from no perception of environmental sounds to the ability to speak on the telephone with an unknown person. It is a simple, easy way to evaluate auditory perception in both older and young children. At preoperative evaluation the child was assigned a certain score, depending on the skills, the second evaluation was performed at 6 months after the cochlear implant activation, then at 12, 18, 24 and 36 months. CAP_R

Table 1.

Revised Capacities of Auditory Performance Scores

Revised Capacities of Auditory Performance Scores
1. is unaware of environmental sounds
2. is aware of environmental sounds
3. can identify some environmental sounds
4. can understand a few simple spoken words
5. can understand some common phrases
6. can understand a spoken conversation with a familiar person
7. can understand a spoken conversation with an unfamiliar person
8. can use the telephone with a familiar person
9. can use the telephone with an unfamiliar person

2). SIR (Speech Intelligibility Rating) is an evaluation score developed by Allen et al. (1998) (4), assessing the individual's capacity to use natural speech in context. It is a five point's scale which assesses the global progress of the child's verbal skills, the absence of spoken language, and the ability to have an intelligible conversation. (Table 2) The child's spontaneous language is assessed observing him while playing or engaging in various activities, while communicating with other children, when looking up a book, etc.

Table 2.

Speech Intelligibility Rates

	Speech Intelligibility Rates
1	No spoken language
2	Unintelligible speech
3	Speech which is intelligible to a familiar listener in context
4	Speech which is intelligible to a listener with little experience of deaf children
5	Speech which is intelligible to all.

The evaluation was done on a scale from 1 to 5 points depending on the child's abilities, both by direct observation of the child in different situations and based on parental reports. The assessments were made preoperatively then postoperatively at 6 months after that at 12, 18, 24 and 36 months after cochlear implant activation.

The collected data were processed using SPSS 17.0 for Windows and Excel.

RESULTS

1. Demographics data

The study group consisted of 50 patients younger than 18 years at the time of implantation. Age at last evaluation was between 19 months and 219 months, all patients with pre/perilingual sensorineural hearing loss.

The group was split into two groups, G1 (N = 27), patients operated before the age of 5 years (60 months) and G2 (N = 23), group of patients over the age of 5 at the moment of surgery.

In group G1 chronological age ranged between 19 and 75 months with an average of 52.30 ± 19.95 (months) and median of 53.0 months. Age of implantation ranged between 12 and 60 months, with an average of 35.44 ± 12.31 months and median of 35.33 months. Hearing loss onset was before the acquisition of language, between 0 and 9 months, with an average of 0.59 ± 1.92 months and median of 0.36. The average duration of implant use was 15.26 ± 12.78, ranging between 6 and 60 months and median of 11.0 months.

In group G2 chronological age ranged between 97 and 219 months with an average of 133.78 ± 44.95 (months) and median of 135.67 months. Age of implantation ranged between 68 and 191 months with an average of 110.87 ± 37.73 months and median of 103.33 months. Hearing loss has been occurred between 0 and 4 months, the average being 0.35 ± 0.98 months and median of 0.27. Duration of implant use was 21.43 ± 19.75, ranging between 6 and 62 months and median of 13.0 months.

In both groups the etiology of hearing loss was unknown in most of the cases, 48.1% in group G1 and 30.4% in group G2. The second as frequency was the genetic etiology (18.5% to 26.1% in G1 and G2) and then the ototoxic etiology (14.8% to 21.7% in G1 and G2).

2. Evaluation of hearing threshold in patients with cochlear implant

The preoperative thresholds were established in our audiology department using the pure tone audiometry with headphones before the surgery, or using auditory evoked potentials and ASSR (Auditory Steady State Response). After the first fitting the thresholds were measured using free-field audiometry.

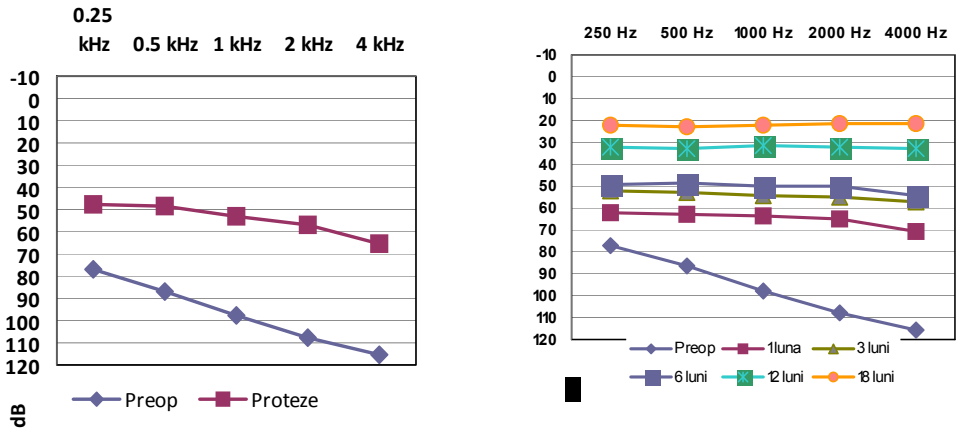

Figure 1. 1A. Audiograms before surgery with and without hearing aids;
1B Audiograms before and after surgery

Hearing aided thresholds measured before the surgery have had average values ranging from 47.56 ± 6.53 at 250 Hz to 65.61 ± 5.49 at 4000 Hz. (Fig. 1A) These low thresholds impeded proper perception of environmental sounds and speech. Using the cochlear implant, thresholds improved after each fitting session coming after a year and a half for a 20-25 dB HL on every measured frequency. (Table 3) The differences between measurements were statistically significant ($p < 0.001$), with two exceptions, from 3 to 6 months, for frequencies of 250 Hz (2.90±1.333, $p=0.641$) and 4000 Hz (2.70±1.349, $p=0.974$) when the level improvement was not statistically significant. (Figure 1B).

3. The overall assessment of speech perception and production CAP_R Score

Table 3.

Table shows the scores of pre-and postoperative assessments. Preoperative assessment scores had mostly low values (1 and 2), but as the patients were gaining auditory experience these scores increased gradually to maximum values.

CAP	preoperator		6 luni		12 luni		18 luni		24 luni		36 luni	
	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
1	19	5										
2	8	10	4	2								
3		7	11	9	3							
4		1	10	8	7	7	3	2				
5				3	3	3	1	5	2	4		1
6			2	1		2	1	2	1		1	3
7							1	1	1	2	1	
8									1	1		1
9											1	2
Total	27	23	27	23	13	12	6	10	5	7	1	7

In both groups we calculated the differences in scores from one assessment to another, using Wilkoxon ranks test for ordinal values. Coefficients z and statistically significant p values ($p < 0.05$) showed improvements in both groups, with one exception, in G1 group of small children, where between 2 and 3 years the improvements were not considered statistically significant ($z = -1.633$ $p = 0.102$). (Table 3)

To compare the groups, at every evaluation, we used ANCOVA test which showed us that there were statistically significant differences between the two groups only before surgery 0.878 ± 0.187, $p < 0.001$, CI 95% =0.501-1.254, while in the other assessments the differences were small with no statistical significance. Before surgery and during the first 18 months the difference was in favor of G2 group. At two years assessment the difference was in favor of the G1, although these differences were not statistically significant (Figure 2).

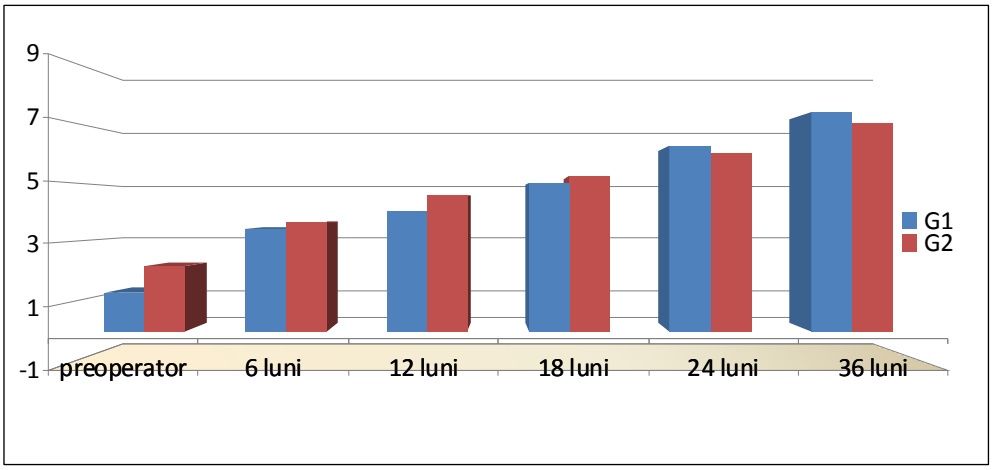

Figure 2. CAP_R score before and after surgery in the two groups, comparatively; beginning to 2 years assessment the results started to be better in G1 group

Spearman correlation coefficient used for ordinal variables indicated a positive and significant correlation between the CAP_R score and duration of implant use, moderate for G1 group (ρ=0.60, p=0.001) and strong for the group G2 (ρ=0.866, p<0.001)

We estimated the duration of use required to achieve different scores. Thus, on average about seven months after cochlear implant use, children operated before the age of 5 years started identifying environmental sounds; about one year after implant activation they achieved the performance to identify some simple words; 2 years after implantation they understood simple conversations with someone familiar. At 3 ½ years, four years, these children could or were able to speak on the phone reach the performance to talk on the phone with strangers, they understood a conversation with a stranger, without lipreading.

Children in group G2 needed more time to achieve high scores compared with children in group G1.In the group of children operated over the age of 5 years at the beginning the performances were better, after a year they understood simple words, after a year and a half they understood simple phrases and after 2 ½ years they could understand a conversation with a familiar person. Between four and five years some of these children could speak on the phone with a familiar person, they could understand a conversation with a familiar voice without lip reading (Table 4).

Table 4.

Estimated period of implant use to reach different CAP_R levels

CAP_R	G1		G2	
	Media	**Eroarea std.**	**Media**	**Eroarea std.**
2	6.000	10.643	6.000	9.030
3	7.250	5.322	6.000	7.373
4	10.923	2.952	6.333	7.373
5	20.333	6.145	16.857	4.827
6	24.000	6.145	32.600	5.711
7	39.000	10.643	-	-
8	24.000	10.643	62.000	12.770
9	39.000	10.643	50.500	9.030

SIR Score

Table 5.

Table shows the frequency and percentage of speech intelligibility scores obtained by the patients at each evaluation.

	Preoperator n (%)		**6 luni n (%)**		**12 luni n (%)**		**18 luni n (%)**		**24 luni n (%)**		**36 luni n (%)**	
SIR	**G1**	**G2**	**G1**	**G2**	**G1**	**G2**	**G1**	**G2**	**G1**	**G2**	**G1**	**G2**
1	21	8	2									
	77,8	34,8	7,4									
2	6	10	24	14	7	5	2	1				
	22,2	43,5	88,9	60,9	53,8	41,7	33,3	10,0				
3		5	1	9	6	7	4	9	3	5	1	4
		21,7	3,7	39,1	46,2	58,3	66,7	90,0	60,0	71,4	33,3	57,1
4									1	2	2	3
									40,0	28,6	22,7	42,9
5	-	-	-	-	-	-	-	-	-	-	-	-
Total	27	23	27	23	13	12	6	10	5	7	3	7

Speech intelligibility score increased from one evaluation to another in each group, as shown in table 5.

For each group we analyzed the statistical relationship between scores obtained from one assessment to another, using Wilkoxon ranks test, for ordinal variables. SIR score values increased statistically significant between preoperative and 6 month postoperative evaluations, both in group G1 ($z = -4.472$, $p = 0.000$)

and group G2 (z =- 2.972, p = 0.003), then between the 6 months to 1 year assessment, for G1 z =- 2.828, p = 0.005 and for G2 z =- 2.236, p = 0.025. From one year to 18 months evaluations only G2 group had a statistically significant increase (z =- 2.000, p = 0.046) of SIR score. In G1 group there was a statistically significant increase between 18 months and 2 years evaluation (z =- 2.000, p = 0.046). From 2 years to 3 years assessments the mean score increased in both groups but it was not statistically significant (p = 0.317).

To compare the scores between the two groups at each evaluation, we have used the ANCOVA test. The differences were statistically significant only preoperatively (0.647±0.170, p<0.001, IC95%=0.305-0.990) and at 6 months postoperatively (0.428±0.119, p=0.001, IC95%=0.189, 0.668). The differences at 2 years and 3 years assessments were in favor of the G1, but without statistical significance (Figure 3).

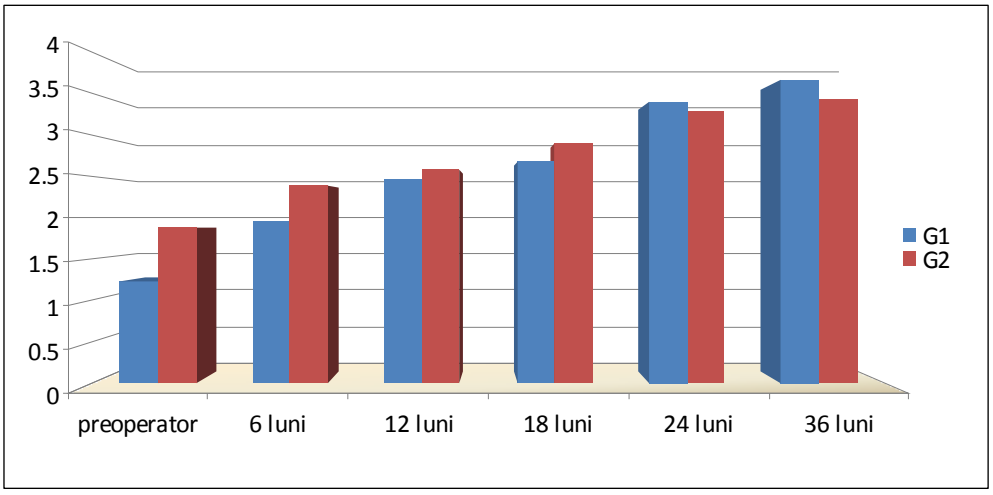

Figure 3. SIR scores before and after surgery, comparing the 2 groups

The Spearman correlation test for SIR score and duration of implant use, showed a statistically significant, positive and moderate correlation of SIR with duration of cochlear implant use for both groups (ρ = 0.736, p = 0.000, to G1 and ρ = 0.609, p = 0.002 for G2).

Children operated in the first five years of life progressed rapidly, reaching an average speech intelligibility score of 4 in 34 months, while older children needed about 4 ½ years to reach the same score.

DISCUSSION

Pure tone audiometry is a valuable indicator of cochlear implant functionality. Pure tone audiometry performed before each fitting session helped adjust the speech processor parameters, the most comfortable level and the threshold (THR) adjusting them in order to achieve a satisfactory level of threshold on each frequency. These parameters were increased progressively within 12-18 months to give auditory pathway time to develop under the influence of sound stimulus.

Preoperative auditory performance score was lower in the group implanted before the age of 5 years, compared with the group of older children, who had more preoperative auditory training than younger children. Postoperative sound stimulation and the auditory-verbal training improved the auditory performance, the scores were better from one assessment to another; the progress was visible every six months in both groups. Between children implanted before the age of 5 and children implanted at older ages there were statistically significant differences only in preoperative evaluation after that the results became comparable, improving with increasing duration of cochlear implant use, that is proportional to the experience of hearing.

Because of selection criteria older children started with a slight advantage in hearing experience by wearing hearing aids, but this advantage disappeared over time, small children showing faster progression than older children.

Children implanted under the age of 5 years could have a conversation with a familiar person after two years of using the implant and about three years and a half they could use or speak on the phone with unknown persons. Children implanted over the age of 5 years had a slower evolution, they could understand a simple conversation with a familiar person after 2 ½ years of implant use and only after 4-5 years some of them could have a phone conversation.

Speech and language development is a slow process, both for toddlers and older children. Between the two groups there were differences only in the first two years, then the younger children started to have better performance than the older. By using a cochlear implant, because of auditory stimulation, the performance was improving from one assessment to another in both groups.

Development of speech involves not only the auditory stimulation, but an intensive auditory-verbal training, conducted by qualified persons, training which has to be continued at home, by the family, continuously stimulating the child, motivating him, with a strong effort from all of those who are around the child.

According to estimates, children implanted under the age of 5 years could have an intelligible conversation with a familiar person about 2 years after implantation and around three years could begin to speak in order to be understood, perhaps with some difficulty, by people less familiar with their speech. Children implanted at a young age have a chance to learn to speak more properly, clearly, and may reach the performance to be understood by everyone, including people less or not at all familiar with hearing impaired speech.

Children who were operated at an older age and had learned to articulate before implantation need to correct their speech, the manner of articulation, and in many cases, despite a huge effort they don't reach the performances of early implanted children. Sometimes they fail to articulate in a way that can be generally understood and speech quality could be affected.

Children's speech development creates prerequisites to integrate them into mainstream schools, with close-age children. Success of integration depends besides on the auditory perception and spoken language development, on child's cognitive abilities, educational and intellectual level, and family and teachers involvement. Teachers from mainstream schools should know more about these problems, about hearing impaired and cochlear implanted children and they should support these children's integration.

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