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Outcome of Cochlear Implantation at Different Ages from 0 to 6 Years

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Objective: To evaluate the outcome of cochlear implantation in young children in relation to the age at implantation.
Study Design: A retrospective longitudinal and cross-sectional analysis of pediatric cochlear implant patients.
Patients: All children with congenital deafness who underwent implantation before the age of 6 years (n = 48 for the longitudinal analysis and n = 70 for the cross-sectional analysis)
Interventions: All children received a multichannel cochlear implant.
Main Outcome Measures: Categories of Auditory Performance (CAP) score and integration into the mainstream school system.
Results: For all children, the CAP score increased after implantation. Implantation beyond the age of 4 years hardly ever resulted in normal CAP scores or in integration into the mainstream primary school (20 to 30% of cases). Implantation between the age of 2 and 4 years always resulted in normal CAP scores after 3 years with a 66% probability of integration into the primary school. Implantation before the age of 2 years always resulted in immediate normalization of the CAP scores, with a 90% probability of integration into the mainstream kindergarten, well before entrance into the primary school.

Conclusion: All children with congenital deafness who underwent implantation before the age of 6 years appeared to benefit from the implant. However, these data add evidence to the importance of early implantation (before the age of 2 years). Intervention before the age of 4 years seemed to be critical to avoid irreversible auditory performance losses, and intervention before the age of 2 years seemed to be critical to achieve optimal results. **Key Words:** Pediatric cochlear implant—Children—Outcome—Integration—Hearling loss—Early intervention.

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Cochlear implants are widely used to treat profound perceptive hearing loss. Based on growing evidence of positive outcomes, the indications are steadily shifting in terms of both degree of hearing loss and age at implantation (1–3). Mainly as a result of the implementation of universal hearing screening programs, the age at detection of congenital hearing losses is substantially decreasing. Infants with congenital hearing loss are nowadays referred by the age of 1 to 3 months for diagnostic evaluation and therapeutic intervention (4). Whether or not cochlear implantation in these infants is relatively urgent is an important question.

Although it can be assumed that early implantation and, in consequence, early (partial) restoration of hearing may yield better results than late implantation, the evidence for this is only slowly being built up. One reason is that it is difficult to reliably assess the auditory performance of very young children. Pure tone audiometry is the only available measure that is widely acknowledged as reliable, but it is not really valid as an outcome measure of cochlear implantation. Therefore, indirect measures may have to be used, such as scores of speech and language development, the Categories of Auditory Performance (CAP) scores (5,6), and eventual integration into the mainstream school system.

The pediatric cochlear implant program of the St. Augustinus Hospital started in 1994. The authors began giving implants to children younger than 2 years of age in 1996 and younger than 1 year in 2000. This report gives the results in relation to the age at implantation.

PATIENTS AND METHODS

The patients were formed into two study groups—a longitudinal group and a cross-sectional group—and one control group.

Longitudinal study group

All congenitally deaf children who underwent implantation between January 1994 and August 1999 who were between 1 and 6 years old at the time of implantation were included in this group. All these children thus had a follow-up time of at least

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2 years. In addition, all children who underwent implantation before the age of 1 year were also included, regardless of the follow-up time. Children with severe mental retardation or with cochlear malformations were excluded.

All children received a multichannel bipolar LAURA cochlear implant (Philips Hearing Implants, Edegem, Belgium, now Cochlear Technology Center Europe) (7,8) with the phase-locked continuous interleaved speech coding strategy (9).

The CAP score (see below) was determined at regular intervals, namely before and 3, 6, 12, and 24 months after the intervention.

In addition, for each child the moment of the first hearing aid fitting was recorded, as well as whether and when the child was integrated into the mainstream kindergarten or primary school.

The children were grouped by age at implantation. Six age cohorts were defined: those who underwent implantation between 0 and 12 months of age, between 13 and 24 months, and so on until the last cohort of children, who underwent implantation between 61 and 72 months of age. Median values and ranges were used to describe the results.

Cross-sectional study group

All congenitally deaf children who underwent implantation between January 1994 and August 2001 who were between 9 months and 6 years old at the time of implantation were included in this group. Children with severe mental retardation or with cochlear malformations were excluded.

Children who underwent implantation before August 1999 received a multichannel bipolar LAURA cochlear implant (7,8) with the phase-locked continuous interleaved speech coding strategy (9). Children who underwent implantation after August 1999 received a multichannel monopolar Nucleus 24 cochlear implant (Cochlear Corp., Sydney, Australia) with the ACE coding strategy.

The CAP score was determined at regular intervals: before and 3, 6, 12, 24, 36, and 48 months after the intervention. At each interval, this CAP score was compared with the normal CAP scores at the given age (data from the control group), and the percentage of children falling within the normal range was calculated. Because no normative data were available for children over 36 months of age, the normal range was taken to be a CAP score 6 to 7.

Control group

Four control groups were evaluated with CAP scores. The control groups consisted of normally hearing children aged 12, 18, 24, and 30 months. For each group, the median CAP score and its range were calculated.

Categories of auditory performance score

The CAP is a global outcome measure of auditory receptive abilities (5,6). It comprises a nonlinear, hierarchical scale on which children's developing auditory abilities can be rated in eight categories of increasing difficulty. The categories are as follows:

0 = no awareness of environmental sound
1 = awareness of environmental sounds
2 = responds to speech sounds
3 = recognizes environmental sounds
4 = discriminates at least two speech sounds
5 = understands common phrases without lipreading
6 = understands conversation without lipreading with a familiar talker
7 = can use the telephone with a familiar talker

TABLE 1. *Control group*

Age group	N	Median age (mo)	Range (mo)	CAP mean	CAP range
12	26	12	11–14	2	1–5
18	28	18	17–19	5	1–7
24	36	24	22–26	6	3–7
30	23	30	29–32	7	5–7

Numbers, ages, and CAP scores for the different age groups (12, 18, 24, and 30 months) of the normal-hearing children.
CAP, categories of auditory performance.

The score was calculated on the basis of the responses to a questionnaire by the parents and the professional therapist who monitored the child.

RESULTS

Control group

The control group consisted of 113 children. Table 1 shows the numbers, age distribution, and CAP results for each group.

Longitudinal study

The longitudinal study group consisted of 48 children. Table 2 shows the numbers and age distribution of the children in each group. Each cohort consisted of at least 6 children. All children had a full 2-year follow-up after implantation, with the exception of the youngest cohort, as explained in Patients and Methods. Fig. 1 shows the consecutive CAP scores for each age group at different moments after implantation. Table 3 shows the age at which the first hearing aids were given to the child and the percentage of the children who were partially or fully integrated in the mainstream school at the moment of the study. At this writing, some children, who were not yet integrated at the moment of the analysis, are doing sufficiently well so that they can be expected to integrate within the near future. The number between brackets shows the sum of those already integrated and those who are likely to be integrated in the near future as judged by professional therapists.

Cross-sectional study

The cross-sectional study group consisted of 70 children, categorized according to the age at implantation into seven categories. Table 4 shows the numbers and age distribution of the children in each group.

TABLE 2. *Longitudinal study group*

Age group	N	Median age (mo)	Range (mo)
0	6	8	5–10
1	9	19	13–23
2	7	30	25–35
3	13	40	37–47
4	7	56	50–60
5	6	70	63–71

Numbers and ages for the different cohorts (0 to 5 years of age at the time of implantation).

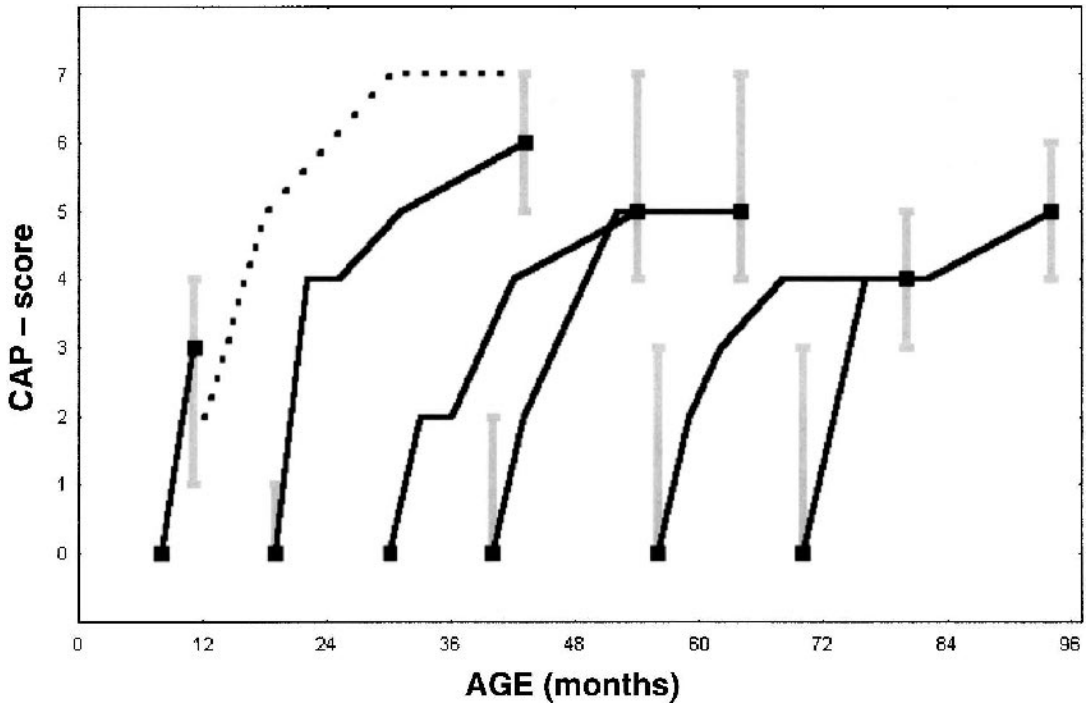

FIG. 1. Longitudinal group, showing the consecutive median Categories of Auditory Performance (CAP) scores for the six age cohorts. Five cohorts had a follow-up of 2 years. For each cohort, the range of the CAP score is given preoperatively and 2 years postoperatively. Dotted line, the median CAP score of the control group.

Fig. 2 shows the percentage of children from each age group that reaches normal CAP scores with respect to normally hearing children of the same age.

Table 5 shows the time it took for 50%, 75%, and 90% of children with implants to reach normal CAP scores.

DISCUSSION

This study shows that the auditory outcome of cochlear implantation in children with congenital deafness decreased with the age at implantation. Also, integration into the mainstream school systems tended to decrease with the age at implantation.

The CAP score was used as an outcome measure of auditory performance (5,6). This is a global measure, and the reduction of the auditory performance to only eight levels implies poor accuracy and little detail. On the other hand, and in contrast to pure tone audiometry, it measures supraliminal performance, and this reflects everyday auditory performance in a more realistic way. In addition, CAP is the only supraliminal auditory receptive outcome measure that is applicable to all children irrespective of their age. This is important for studies like this, wherein children of different ages from 0 to 6 years are followed up for 2 years and compared between different age groups. Speech audiometry would not be suitable, because this is not possible for the very young children, and even for the older group, different speech lists should be used at different ages, making the results incomparable. The interobserver reliability of the CAP has been formally confirmed (6), and normative data are provided in this study, for which a control group of 113 normally hearing children aged 11 to 32 months were

TABLE 3. *Longitudinal study group*

Age group	Age (with range) of first hearing aids (mo)	Mainstream integration (%)	Age of integration (mo)
0	2 (1–4)		
1	7 (3–12)	67 (89)	37
2	13 (9–21)	57 (63)	67
3	13 (3–32)	23 (54)	96
4	15 (10–37)	17 (33)	79
5	20 (10–44)	14 (14)	84

Figures in the third column refer to the percentage of children who have been integrated in the mainstream school system so far. Figures in parentheses represent the same children plus those who are anticipated to be able to integrate in the near future.

TABLE 4. *Cross-sectional study group*

Age group	N	Median age (mo)	Range (mo)
12	10	13	9–15
18	11	18	16–20
24	7	23	22–26
30	4	29	28–30
36	9	37	34–39
42	9	42	40–45
48+	20	58	47–71

Numbers and ages for the different age groups (12 to over 48 months at the time of implantation).

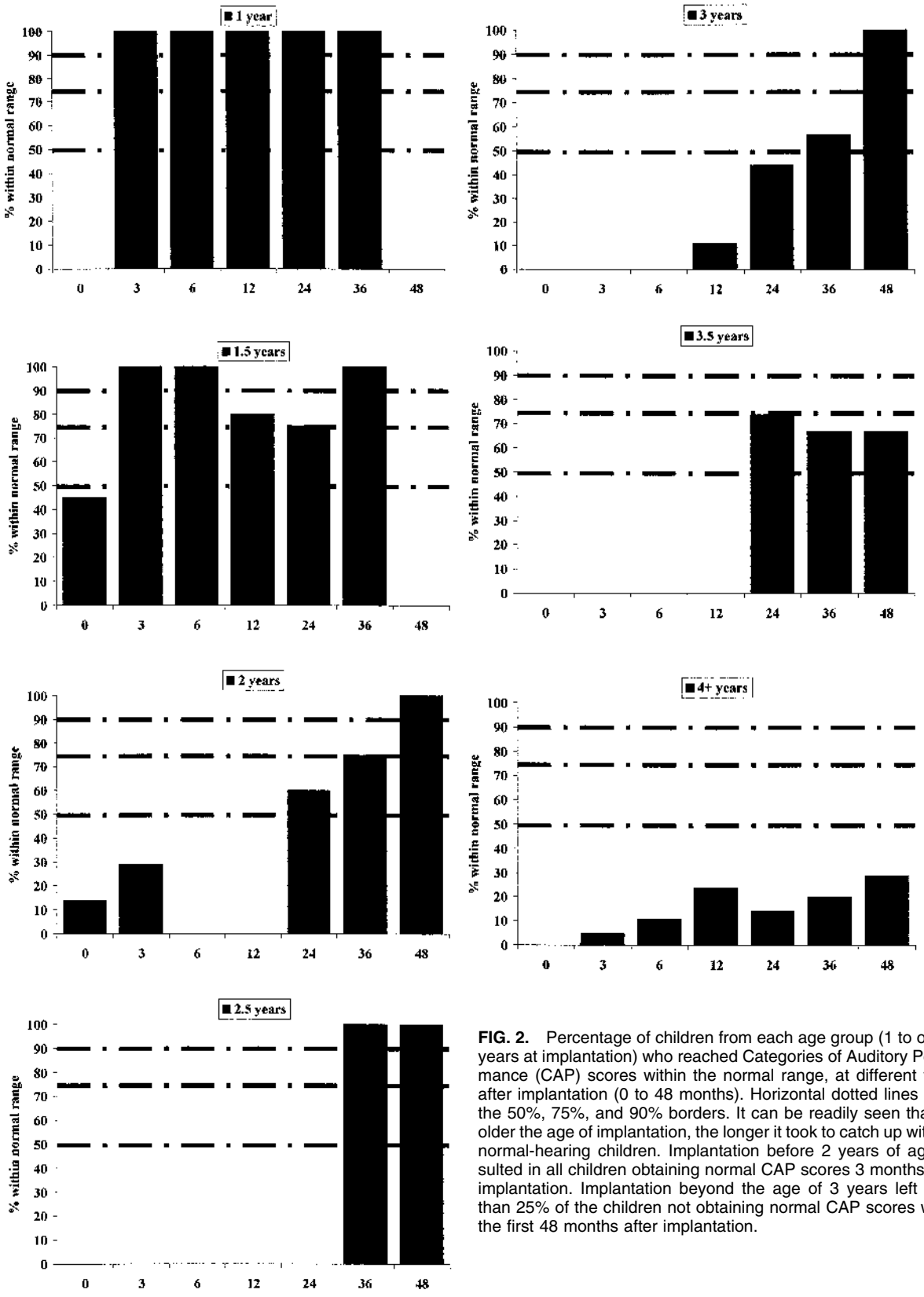

FIG. 2. Percentage of children from each age group (1 to over 4 years at implantation) who reached Categories of Auditory Performance (CAP) scores within the normal range, at different times after implantation (0 to 48 months). Horizontal dotted lines show the 50%, 75%, and 90% borders. It can be readily seen that the older the age of implantation, the longer it took to catch up with the normal-hearing children. Implantation before 2 years of age resulted in all children obtaining normal CAP scores 3 months after implantation. Implantation beyond the age of 3 years left more than 25% of the children not obtaining normal CAP scores within the first 48 months after implantation.

TABLE 5. *Cross-sectional group*

Months	T50	T75	T90
12 (n = 10)	3	3	3
18 (n = 11)	3	3	3
24 (n = 7)	24	36	48
30 (n = 4)	36	36	36
36 (n = 9)	36	48	48
42 (n = 9)	24	never ?	never ?
>48 (n = 20)	36	never ?	never ?

Time (months) to reach normal categories of auditory performance (CAP) scores for 50% (T50), 75% (T75), and 90% (T90) of the children implanted at different ages (12 to over 48 months of age at implantation). As an example, it takes a median time of 48 months before 75% of children implanted at the age of 36 months reach normal CAP scores.

assessed. All normally hearing children achieve a CAP-score of 6 or 7 (use of the telephone) by the age of 24 to 36 months.

An indirect measure of success is the integration in the mainstream school system. In Belgium, all children with severe to profound hearing impairment are referred to specialized rehabilitation centers. These centers provide hearing rehabilitation and scholar education throughout the educational career of the child. However, the centers are also stimulated and financially supported to promote the integration of a hearing-impaired child in the mainstream kindergarten or primary school.

This study shows that only children who received implants before the age of 4 years had a chance of reaching CAP level 7 within 2 years after implantation. This is the highest possible CAP level, but it does not imply normal hearing.

No children from the longitudinal group who underwent implantation after the age of 4 years reached this highest CAP level within the first 2 years after implantation (Fig. 1). In the cross-sectional study with a follow-up of more than 2 years for some of the children, only some 20% reached normal CAP scores (score 6 or 7) after a long postoperative interval (Fig. 2). Also, only 33% of these children are likely to ever be integrated in the mainstream school system, and this will only occur by the age of 6 to 7 years (median 79 months), which is approximately 2 to 3 years after surgery (Table 3). The parents of these children should therefore be counseled appropriately, and the realistic expectations should not be set too high.

Children who underwent implantation between the ages of 2 and 4 years seem to level off 2 years after surgery at a median CAP score of 5 (Fig. 1). This corresponds to understanding of common phrases without lip-reading. The cross-sectional data, however, show that the auditory performance of these children tended to further increase after 2 years. At least half of them had normal CAP scores after 3 years, and all had normal CAP scores after 4 years (Fig. 2). In addition, about 60% have integrated or will probably integrate in the mainstream school system at the age of about 7 years (median 67–96 months), which is approximately 3 years after surgery (Table 3). In consequence, implantation between the ages of 2 and 4 years may yield a good auditory outcome, but it may take 3 to 4 years for this to happen.

Implantation before the age of 2 years resulted in normal CAP scores as early as 3 months after implantation (Fig. 1 and Table 5). It seems that children who receive their implants at about 18 months of age lag a bit behind their normally hearing peers, whereas those receiving their implants in their first year of life follow the normal line. It is shown that 67% attend mainstream school at the age of 3 years (which is the first class in the kindergarten), and it is anticipated that about 90% will ultimately be able to integrate before entering primary school.

A possible sampling bias exists in the fact that the children who received their implants early appeared to be those who also received their hearing aids at a significantly earlier stage (Table 3) in their life than those who underwent implantation later. This probably reflects the impact of the universal neonatal hearing-screening program that started in 1998 in Flanders, Belgium (4). This, together with many sensitization campaigns over the past few years, has increased the awareness of the public and among professionals and has boosted the early intervention programs. Thus, one might speculate that the better results of early implantation are not due to the implant as such but to the early enrolment of these children in intervention programs. This would be in line with other reports claiming that early intervention of whatever kind is beneficial to the child (9–12). Although our numbers are insufficient to enable any firm conclusions to be drawn, this bias does not seem to be entirely true. Indeed, some children who received early intervention with hearing aids (started in the first year of life) nevertheless underwent implantation at an older age. Three such children received their implants between the ages of 2 and 3 years, and only two of them (66%) have integrated or will integrate. Of six such children who received their implants between 3 and 4 years, only one is anticipated to become integrated (17%). One such child received an implant between 4 and 5 years and will not integrate (0%), and another received an implant between 5 and 6 years and has just been integrated into a mainstream primary school (100%). This suggests that children who received their implants at a relatively late age, even if they had been enrolled at a very young age (first year of life) in an intervention program with hearing aids, did not perform any better with their implants than children who underwent implantation at the same age but did not receive hearing aids at such a young age. Thus, the relatively poor results of cochlear implants at later ages did not seem to be caused by a late detection effect. This finding is therefore very suggestive for a real beneficial effect of early cochlear implantation—before the age of 2 years—in comparison with cochlear implantation at a later age.

In conclusion, this study provides evidence in favor of early implantation, before 2 years of age. It provides data that may be helpful in counseling the parents of implant

candidates in a realistic way. All children in this age group (0–6 years) with congenital deafness seemed to benefit from cochlear implantation. A child older than 4 years of age has a small chance (roughly 20–30%) of reaching normal CAP scores and of being integrated into the mainstream school system; if this happens, it will only be at the age of 6 to 7 years. A child between 2 and 4 years of age will most probably reach a normal CAP score but this will take 3 years, and only two out of three may be able to integrate. A child below the age of 2 is very likely to immediately reach normal CAP levels after implantation, and almost all (90%) of these children will probably be able to integrate into the mainstream kindergarten.

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