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Ten-Year Follow-Up of a Consecutive Series of Children With Multichannel Cochlear Implants

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Objectives: To assess a group of children who consecutively received implants more than 10 years after implantation with regard to speech perception, speech intelligibility, receptive language level, and academic/occupational status.
Study Design: A prospective longitudinal study.
Setting: Pediatric referral center for cochlear implantation.
Patients: Eighty-two prelingually deafened children received the Nucleus multichannel cochlear implant.
Interventions: Cochlear implantation with Cochlear Nucleus CI22 implant.
Main Outcome Measures: The main outcome measures were open-set Phonetically Balanced Kindergarten word test, discrimination of sentences in noise, connective discourse tracking (CDT) using voice and telephone, speech intelligibility rating (SIR), vocabulary knowledge measured using the Peabody Picture Vocabulary Test (Revised), academic performance on French language, foreign language, and mathematics, and academic/occupational status.
Results: After 10 years of implant experience, 79 children (96%) reported that they always wear the device; 79% (65 of 82 children) could use the telephone. The mean scores were 72% for the Phonetically Balanced Kindergarten word test, 44% for word recognition in noise, 55.3 words per minute for the CDT, and 33 words per minute for the CDT via telephone. Thirty-three children (40%) developed speech intelligible to the average listener (SIR 5), and 22 (27%) developed speech intelligible to a listener with little experience of deaf person's speech (SIR 4). The measures of vocabulary showed that most (76%) of children who received implants scored below the median value of their normally hearing peers. The age at implantation was the most important factor that may influence the postimplant outcomes. Regarding educational/vocational status, 6 subjects attend universities, 3 already have a professional activity, 14 are currently at high school level, 32 are at junior high school level, 6 additional children are enrolled in a special unit for children with disability, and 3 children are still attending elementary schools. Seventeen are in further noncompulsory education studying a range of subjects at vocational level.
Conclusion: This long-term report shows that many profoundly hearing-impaired children using cochlear implants can develop functional levels of speech perception and production, attain age-appropriate oral language, develop competency level in a language other than their primary language, and achieve satisfactory academic performance.
Key Words: Children—Cochlear implantation—Long-term results.
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Cochlear implantation is a technique commonly used for the treatment of profoundly deaf children. Since the first implantations in the late 1980s, numerous studies have assessed the deaf children's progress after implantation and have demonstrated that cochlear implantation may provide beneficial inputs for improving speech perception, speech production, and, finally, language and literacy skills (1–12).

However, very few articles have reported results covering a long period (13–16) and very few have reported results on everyday speech perception (in noise and via telephone), on language skills, or on academic performance.

The present study will examine the long-term outcomes of the first cohort of pediatric implant users who received cochlear implants (CIs) at the Montpellier Pediatric Cochlear Implant Center. It assesses prospectively and longitudinally the cases of 82 children who consecutively received implants and were followed up by the same team for a period of more than 10 years after implantation, without any exclusion, with regard to speech perception, production, telephone use, language level, and academic/occupational status.

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PATIENTS AND METHODS

This prospective, longitudinal study involved all prelingually profoundly deaf children who consecutively received implants between January 1989 and December 1995 through the Montpellier Pediatric Cochlear Implant Program. Eighty-two children with bilateral, profound sensorineural hearing loss received CIs during that period. All these children have been periodically followed up and monitored for more than 10 years by the CI center staff. One was lost at follow-up after 3 years because he went back to a foreign country to reside (Patient 59).

The individual children profiles are listed in Table 1. All children received a Nucleus 22 multichannel CI (CI 22M; Cochlear Corporation, Englewood, CO, USA).

All children are currently using the spectral peak (SPEAK) speech coding strategy (the only one permitted by the CI 22), except 3 children who have recently received reimplants of a CI 24 and could therefore benefit from a more recent speech strategy (Advanced Combination Encoders [ACE] Strategy). The mean age at implantation was 4.8 years (SD, ±2.3 years; range, 1.9–14 years; median, 3.9 years). The mean length of use was 11.7 years (SD, ±1.7 years; range, 10–15.8 years).

Open-set word scores were measured using Phonetically Balanced Kindergarten (PBK) word list adapted to the French language. Sentence recognition in noise was assessed by measuring the percentage of words correctly repeated from common phrases delivered via a tape recorder in background noise (signal-to-noise ratio, 10 dB). The connective discourse tracking (CDT) test is based on verbatim repetition of text presented by means of live voice to the listener. The task was scored according to the number of words correctly repeated by the listener per minute. The texts were chosen from stories adapted to the child's age. The test was delivered either via live voice or via telephone.

The Speech Intelligibility Rating (SIR) was used to measure the speech intelligibility of children who received implants (17–18). The SIR is a five-point hierarchical scale describing various degrees of speech intelligibility from unintelligible speech (rating, 1) to speech that is intelligible to all listeners (rating, 5).

Receptive language level was measured using the Peabody Picture Vocabulary Test-Revised (PPVT-R), adapted to the French language (19–20). The test was scored on the basis of a six-point hierarchical scale indicating the receptive language level relative to the normally hearing peers of equivalent age (1, minimal [<10th percentile]; 2, poor [10th–25th percentile]; 3, lower mean [25th–50th percentile]; 4, upper mean [50th–75th percentile]; 5, good [75th–90th percentile]; and 6, excellent [>90th percentile]).

Finally, academic performance assessment was achieved by sending the families a questionnaire regarding their child's educational placement and grade level, mode of communication at school and at home, and mean results at school. The academic performance for elementary, junior high school, and high school students was assessed using national standards (21–22). The students are rated by the teachers on basic skills in mathematics, written French language, and foreign language (English) on a scale from 0 to 20. The achievement of a score of 10 is required of a student to pass a grade level and to advance to the next. If the students were in a post–high school curriculum or in a vocational cursus, these data were considered nonrelevant and were not collected. Finally, the delay in academic placement was calculated by means of reference to the average academic status of their normally hearing peers of comparable age (in France, the mean age at entrance in junior high schools is 11 years, and the mean age at entrance in high schools is 15 years) (21–22).

A battery of statistical tests were performed to determine the impact of 5 categoric factors on 4 outcome measures at the follow-up after 10 years (PBK open-set word scores, CDT, SIR, and vocabulary). The statistical analyses included univariate analysis using Pearson χ^2 test, one-way analysis of variance (ANOVA), multivariate analysis using a stepwise logistic regression, and multifactor ANOVA. The independent variables were the age at implant (<4 years versus >4 years), associated disability (yes versus no), initial communication mode (oral versus total), initial educational placement (mainstream versus school for the deaf), and number of active electrodes after 10 years of implant use (<15 versus >15). Regarding the age at implantation, we divided the children between those who received implants early and those who received implants later in childhood on the basis of a median split (age, 4 years). The initial communication mode and the educational placement corresponded to the status during the first 2 years after implantation because no changes occurred during this early period. The level of significance was set at 0.05. A p value between 0.05 and 0.08 was considered as having a trend for significance.

RESULTS

Device Performance and Reimplantations

Of the 82 children who received implants, 11 (13.4%) experienced device failure or complications requiring reimplantation (Table 2). The causes of reimplantation were device failure or decrease in performance in 10 patients and infection in 1 patient. Of the 10 children with device failure, 2 experienced a total failure of sudden onset, 6 experienced partial failures, and 2 experienced pain over the implant side.

The causes of device failure were a defective factory device (inverted capacity) in 4 patients, internal device failure in 2 patients, leakage in 1 patient, and trauma to the electrode array in 1 patient.

All children who experienced device failure successfully received reimplants on the ipsilateral side.

One child presented a severe retroauricular infection that resisted surgical drainage and wide spectrum

TABLE 1. *Individual children profiles, mode of communication, educational placement, and academic/occupational status of the 82 children with implants[a]*

Patient	Age (yr)			Pathogenesis	Associated disability	Communication mode			Education placement			Delay (yr)	Academic/ occupational status
	At onset	At implant	Current			Initial	5 years	10 years	Initial	5 years	10 years		
1	2.0	4.0	19.9	Meningitis		O	O	O	M	M	M	0	University
2		3.3	19.2	Unknown		O	O	O	M	M	M	0	Vocational
3		2.8	18.3	Unknown		O	O	O	M	M	M	2	Vocational
4		3.0	18.2	Unknown		T	O	O	M	M	M	1	High school
5	1.0	3.0	18	Meningitis		T	O	O	SFD	M	M	0	High school
6		3.0	18	Unknown		O	O	O	M	M	M	1	Vocational
7		3.0	18.2	Unknown		O	O	O	M	M	M	0	High school
8	1.0	3.8	18.8	Meningitis	Y	O	O	O	M	M	M	1	Vocational
9		2.8	17.6	Unknown		O	O	O	PT	PT	M	2	High school
10		3.0	17.9	CMV	Y	O	SL	SL	M	SFD	SFD	3	Vocational
11		3.0	17.7	Unknown		T	O	O	SFD	M	M	1	Junior high
12	1.9	6.9	21.5	Meningitis		O	O	O	M	M	M	0	University
13		3.0	17.5	Genetic		O	O	O	M	M	M	1	Vocational
14 (NU)	2.0	9.0	23.4	Meningitis		T	T	T	SFD	SFD	SFD	2	University
15 (NU)	1.8	8.8	23.2	Meningitis		O	O	O	M	M	M	2	Vocational
16		7.0	20.9	Usher		O	T	T	M	M	M	3	Vocational
17		2.6	16.5	Genetic		T	T	T	M	M	SFD	0	Junior high
18	2.4	7.7	21.5	Viral		T	O	O	SFD	M	SFD	1	Working
19		2.5	16.1	CMV	Y	T	T	T	SFD	SFD	SFD	1	Junior high
20		2.5	16.1	Unknown		O	T	O	M	SFD	M	0	Junior high
21	0.5	7.5	21.3	Meningitis		O	O	O	M	SFD	M	3	High school
22		7.5	20.9	Unknown		O	O	O	M	M	M	0	University
23		2.3	15.8	Unknown		O	O	O	M	M	M	0	Junior high
24		5.5	18.9	Genetic		O	O	O	SFD	M	M	2	High school
25		5.0	18.5	Unknown		O	O	T	M	M	SFD	2	Vocational
26		5.9	19.1	Unknown		O	O	O	SFD	M	M	1	Vocational
27	1.2	8.2	21.3	Meningitis		O	O	O	M	M	M		Vocational
28		7.8	20.9	Unknown		O	O	O	M	M	M	2	High school
29		6.0	19	Unknown		O	O	O	M	M	M	NR	Vocational
30		3.0	16.1	Unknown		O	O	O	M	M	M	0	Junior high
31		7.6	20.6	Unknown		O	O	O	M	M	M	0	University
32		2.2	15.2	Genetic		O	O	O	M	M	SFD	0	Junior high
33		3.0	15.7	Unknown		T	O	T	SFD	M	SFD	1	Junior high
34		3.5	16.2	Unknown		O	O	O	M	M	M	1	Junior high
35	2.2	6.6	19.3	Meningitis		T	O	O	SFD	M	M	1	High school
36		2.7	15.3	Usher		O	O	O	M	M	M	0	Junior high
37		4.5	16.7	Unknown		O	O	O	M	M	M	2	Junior high
38		2.7	15.0	Genetic		O	O	O	M	M	M	1	Junior high
39		2.6	14.8	Unknown		O	O	O	M	M	M	1	Junior high
40		3.0	15	Unknown		O	O	O	M	M	M	1	Junior high
41		5.0	17	Unknown		O	T	T	M	SFD	SFD	NR	Special class
42		4.0	16.1	Unknown		O	O	O	M	M	M	0	Junior high
43		5.0	17.1	Unknown		T	T	T	M	PT	M	3	Vocational
44		5.3	17.2	Unknown		O	O	O	M	M	M	1	High school
45		3.3	15.3	Unknown	Y	O	O	O	SFD	SFD	SFD	NR	Special class
46		5.3	17.1	Unknown		O	O	O	M	M	M	1	High school
47		2.7	14.4	Unknown		O	T	T	M	PT	M	NR	Special class
48		6.4	18	Anoxia		O	O	O	M	M	M	NR	Vocational
49		7.8	19.4	Unknown		T	T	T	SFD	SFD	SFD	NR	Vocational
50		3.3	14.8	Unknown		O	O	O	M	M	M	1	Junior high
51		3.7	15.2	CMV	Y	O	O	O	SFD	SFD	SFD	NR	Special class
52		5.0	16.5	Unknown		O	O	O	M	M	M	2	Junior high
53		6.6	18.1	Usher		T	T	T	SFD	SFD	M	2	High school
54		2.0	13.7	Usher		O	O	O	M	M	M	0	Junior high
55		2.6	13.9	Unknown		O	O	O	M	M	M	0	Junior high
56		3.5	14.8	Unknown	Y	T	T	T	SFD	SFD	SFD	2	Special class
57		7.8	19	Unknown		O	O	O	M	M	M	NR	Working
58		6.6	17	Unknown		T	T	T	SFD	SFD	SFD	2	Junior high
59	0.5	10.0	21	Meningitis		O	O	O	M	M	M	0	University
60		2.5	13.6	Unknown		O	O	O	M	M	M	0	Junior high
61		3.0	13.9	Unknown		O	O	O	M	M	M	0	Junior high
62		5.7	16.5	Usher		O	O	O	M	M	M	0	Junior high
63		2.3	13.1	Unknown		O	O	O	M	M	M	0	Junior high

(Continued on next page)

TABLE 1. *Continued*

Patient	Age (yr) At onset	At implant	Current	Pathogenesis	Associated disability	Communication mode Initial	5 years	10 years	Education placement Initial	5 years	10 years	Delay (yr)	Academic/ occupational status
64		7.3	18	Unknown	Y	T	T	T	SFD	SFD	SFD	NR	Special class
65		3.9	14.5	Unknown		T	O	O	M	M	M	0	Junior high
66 (NU)	2.0	14.0	24.6	Meningitis		O	O	O	M	M	M	NR	Working
67		3.0	14.1	Unknown		O	O	O	M	M	M	1	Junior high
68		3.5	14	Unknown		O	O	O	M	M	M	2	Junior high
69		3.7	14.1	Unknown		O	O	O	M	M	M	3	Special class
70		5.5	15.8	Unknown		O	O	O	M	M	M	3	Vocational
71		4.5	14.9	Genetic		T	O	O	PT	M	M	1	Junior high
72		8.0	18.4	Genetic		T	O	O	PT	M	M	0	High school
73		2.0	12.4	Unknown	Y	O	O	O	M	M	M	1	Elementary
74		6.0	16.2	Unknown		O	O	O	M	M	M	2	Junior high
75		3.8	13.9	CMV		SL	T	T	M	SFD	SFD	1	Junior high
76		6.0	16.1	Unknown		T	O	O	M	M	M	1	Junior high
77		5.7	15.8	Genetic		T	O	O	M	M	M	2	Junior high
78		6.6	16.8	Unknown		O	O	O	M	M	M	1	High school
79		6.9	17	Unknown		T	T	T	SFD	SFD	SFD	1	Vocational
80		3.6	13.7	CMV	Y	O	O	T	M	SFD	SFD	2	Elementary
81		7.8	17.8	Unknown		O	O	O	PT	PT	M	2	High school
82		1.9	11.9	Unknown		O	O	O	M	M	M	0	Elementary

[a]M, mainstream; NR, nonrelevant; NU, nonuser; O, oral; PT, part time; SFD, school for the deaf; SL, sign language; T, total; Y, yes.

antibiotics administration. His device was finally explanted and reimplanted on the contralateral side.

The length of time from the date of initial implantation to reimplantation of a second device ranged from 1.2 to 12.7 years. Of the 11 children who received reimplants, 5 received a Nucleus CI 22, and 6 received a CI 24.

Table 2 shows the number of active electrodes in the long term in the 71 children who received implants and did not experience any device failure and in the 11 children who received reimplants. All children, including those who received reimplants, demonstrate a fully functioning implant system. Most children with complete insertion have a number of active electrodes superior to 15 out of 22 electrodes. Six children have a number of active electrodes between 12 and 15 and still demonstrate good performance (Tables 2 and 3).

Device Use

After 10 years of implant experience, 79 children (96%) reported that they always wear the device and continue to gain considerable benefit from it. Three children are nonusers (Patients 14, 15, and 66). Patients 14 and 15 were deafened by meningitis and received an implant several years later. Patient 14 continued to attend a school for the deaf using sign language as the main mode of communication. He is currently studying in a university. Patient 66 was deafened by meningitis at the age of 1.5 years and received an implant at the age of 14 years. He showed a total ossification of the cochlea, and a double-array electrode was inserted. His performance with the implant was very poor.

Speech Discrimination

Figure 1 shows the distribution of PBK word scores after 10 years of implant use. The average percentage of words identified correctly on the PBK word test was 72% (SD, ±26%; range, 0–100%; median, 82%). Five children, including the 3 nonusers, scored 10% or less.

In noise, the average percentage of words identified correctly was 44.5% (SD, ±28%; range, 0–94%; median, 50%).

Regarding CDT, the mean score was 55.3 words per minute (SD, ±30 words/min; median, 58 words/min; range, 0–105 words/min). Using telephone, the mean score was 33 words per minute (SD, ±22 words/min; median, 32 words/min).

All implant users gain considerable benefit from CI, except five (Patient 10 had a severe cerebral palsy, Patient 21 showed extensive labyrinthitis ossificans with a partial insertion of the electrode array, Patient 48 had many difficulties with the implant because of bilingualism [parents only talking in Arabic], Patient 56 had many associated disabilities, and Patient 57 demonstrated serious psychological problems) (Table 3).

Development of Speech Perception

The results of PBK word recognition and CDT scores at 5 and 10 years after implantation are shown in Figures 2 and 3 and Table 3. The PBK word recognition increased by a mean value of 7% from 5 to 10 years, whereas the CDT scores increased by a mean value of 20 words per minute. The difference is highly significant ($p < 0.001$, t test for paired data).

Speech Production

The results on the SIR after 10 years of implant experience are shown on Figure 4 and Table 3; the median value was 4. Fifty-four of 82 children (66%) developed connected speech intelligible to the average

TABLE 2. *Device used, device failures, current speech encoding strategy, and current number of active electrodes*[a]

Patient	First device	Reimplantation	Time interval to reimplantation (yr)	Cause of failure	Current strategy	Active electrodes
1	Nucleus CI 22	Nucleus CI 22	3.5	Defective manufactural device	SPEAK	18/22
2	Nucleus CI 22	Nucleus CI 24 RST	11.2	Internal device failure	ACE	20/22
3	Nucleus CI 22	Nucleus CI 24M	9.1	Pain over implant site	SPEAK	20/22
4	Nucleus CI 22				SPEAK	19/22
5	Nucleus CI 22				SPEAK	14/22
6	Nucleus CI 22	Nucleus CI 22	4.7	Internal device failure	SPEAK	19/22
7	Nucleus CI 22				SPEAK	20/22
8	Nucleus CI 22				SPEAK	16/22
9	Nucleus CI 22				SPEAK	20/22
10	Nucleus CI 22				SPEAK	20/22
11	Nucleus CI 22				SPEAK	18/22
12	Nucleus CI 22				SPEAK	20/22
13	Nucleus CI 22	Nucleus CI 24 RST	12.7	Pain over implant site	ACE	17/22
14 (NU)	Nucleus CI 22				SPEAK	18/22
15 (NU)	Nucleus CI 22				SPEAK	16/22
16	Nucleus CI 22	Nucleus CI 22	3.1	Infection	SPEAK	17/22
17	Nucleus CI 22				SPEAK	18/22
18	Nucleus CI 22				SPEAK	17/22
19	Nucleus CI 22				SPEAK	19/22
20	Nucleus CI 22				SPEAK	17/22
21	Nucleus CI 22				SPEAK	Partial insertion
22	Nucleus CI 22				SPEAK	18/22
23	Nucleus CI 22				SPEAK	19/22
24	Nucleus CI 22				SPEAK	20/22
25	Nucleus CI 22	Nucleus CI 24M	4.7	Leakage	SPEAK	20/22
26	Nucleus CI 22	Nucleus CI 22	1.2	Defective manufactural device	SPEAK	19/22
27	Nucleus CI 22	Nucleus CI 24M	4.2	Defective manufactural device	SPEAK	20/22
28	Nucleus CI 22	Nucleus CI 22	3.2	Defective manufactural device	SPEAK	18/22
29	Nucleus CI 22				SPEAK	19/22
30	Nucleus CI 22				SPEAK	20/22
31	Nucleus CI 22				SPEAK	17/22
32	Nucleus CI 22				SPEAK	20/22
33	Nucleus CI 22				SPEAK	20/22
34	Nucleus CI 22				SPEAK	20/22
35	Nucleus CI 22				SPEAK	19/22
36	Nucleus CI 22				SPEAK	19/22
37	Nucleus CI 22				SPEAK	19/22
38	Nucleus CI 22				SPEAK	20/22
39	Nucleus CI 22				SPEAK	18/22
40	Nucleus CI 22				SPEAK	19/22
41	Nucleus CI 22				SPEAK	20/22
42	Nucleus CI 22				SPEAK	19/22
43	Nucleus CI 22				SPEAK	19/22
44	Nucleus CI 22				SPEAK	15/22
45	Nucleus CI 22				SPEAK	13/22
46	Nucleus CI 22				SPEAK	12/22
47	Nucleus CI 22				SPEAK	18/22
48	Nucleus CI 22				SPEAK	16/22
49	Nucleus CI 22				SPEAK	18/22
50	Nucleus CI 22	Nucleus CI 24 RST	7.0	Trauma to electrode array	ACE	20/22
51	Nucleus CI 22				SPEAK	20/22
52	Nucleus CI 22				SPEAK	20/22
53	Nucleus CI 22				SPEAK	17/22
54	Nucleus CI 22				SPEAK	19/22
55	Nucleus CI 22				SPEAK	19/22
56	Nucleus CI 22				SPEAK	20/22
57	Nucleus CI 22				SPEAK	17/22
58	Nucleus CI 22				SPEAK	15/22
59	Nucleus CI 22				SPEAK	20/22
60	Nucleus CI 22				SPEAK	16/22
61	Nucleus CI 22				SPEAK	19/22
62	Nucleus CI 22				SPEAK	18/22
63	Nucleus CI 22				SPEAK	20/22
64	Nucleus CI 22				SPEAK	20/22
65	Nucleus CI 22				SPEAK	19/22

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TABLE 2. *Continued*

Patient	First device	Reimplantation	Time interval to reimplantation (yr)	Cause of failure	Current strategy	Active electrodes
66 (NU)	Nucleus CI 20 + 2				SPEAK	Double array
67	Nucleus CI 22				SPEAK	20/22
68	Nucleus CI 22				SPEAK	20/22
69	Nucleus CI 22				SPEAK	20/22
70	Nucleus CI 22				SPEAK	16/22
71	Nucleus CI 22				SPEAK	19/22
72	Nucleus CI 22				SPEAK	17/22
73	Nucleus CI 22				SPEAK	16/22
74	Nucleus CI 22				SPEAK	18/22
75	Nucleus CI 22				SPEAK	20/22
76	Nucleus CI 22				SPEAK	19/22
77	Nucleus CI 22				SPEAK	17/22
78	Nucleus CI 22				SPEAK	14/22
79	Nucleus CI 24M				SPEAK	20/22
80	Nucleus CI 22				SPEAK	20/22
81	Nucleus CI 24M				SPEAK	20/22
82	Nucleus CI 24M				SPEAK	20/22

[a]ACE, advanced combination encoders; NU, nonuser; SPEAK, spectral peak.

listener (Category 5 of the SIR scale) or to the listener with little experience of deaf children's speech (Category 4 of the SIR scale).

Receptive Language Level

The results on the PPVT-R after 10 years of implant experience are shown on Figure 5; the median value was 2. This means that 62 (75%) of 82 children scored below the median value of their hearing peers of equivalent age.

Evolution of Mode of Communication and Placement Over Time

Table 1 and Figures 6 and 7 show the evolution of communication mode and educational placement over time. Initial emphasis was placed on mainstreaming and on oral/aural mode of communication (74% of the children were placed in a mainstream, 73% were using oral communication as the mode of communication, only 21% were enrolled in a school for the deaf, and 5% were in part time).

Very few changes were observed during the subsequent 10 years. The 60 children who were initially using an oral mode of communication continued to use this mode of communication, except 1. Of the 21 children initially using total communication, 11 continued to use this communication mode and 10 moved to oral. Of the 61 children initially placed in a mainstream school, only 5 (8%) decided to move to a school for the deaf because they had many difficulties in their academic cursus. Of the 17 children who initially attended a school for the deaf, 11 were maintained in this status and 6 moved to a mainstream school. The 4 children in part time moved to a mainstream school.

At the time of the final evaluation, 79% were using oral communication, 20% total, and 1% sign; 78% were placed in mainstream, and 22% were attending a school for the deaf.

Academic/Occupational Status

The children are now aged 12 to 20 years; more than half attend compulsory/secondary education at the time of the study in a variety of educational provisions, preparing for academic examinations. Thirty-two are currently at junior high school level, 14 at high school level, and 3 children still attend elementary schools. Six additional children are enrolled in a special unit for children with disability where they receive general and professional education. Seventeen are in further noncompulsory education studying a range of subjects at vocational levels. Six subjects attend universities. Three already have a professional activity (Fig. 8).

All children attending high schools are placed in mainstream and receive no additional support. Twenty-six (81%) of 32 children attending junior high schools are placed in mainstream and half of them receive additional educational and speech therapy support; six (8%) are in a school for the deaf.

Regarding children attending junior high schools and high schools, 17 (37%) of 46 are in a classroom appropriate to their age (no delay), 17 (37%) had a 1-year delay, 11 (24%) had a 2-year delay, and 1 (2%) had a 3-year delay. The 46 children enrolled in junior high and high schools achieved a mean score of 12.4 (SD, ±3.2; range, 6–19; median, 12) for mathematics, 11.4 (SD, ±2.3; range, 5–17; median, 11) for French expressive language skills, and 12.4 (SD, ±2.8; range, 5–18; median, 13) for foreign language skills (Fig. 9).

Predictors of Performance

A univariate analysis using Pearson χ^2 test was performed to check each outcome measure to determine whether the number of children scoring above or below the median was different in each subset of the category of qualitative factors (Table 4). A younger age at implantation was associated with better speech perception, speech production performances, and vocabulary

TABLE 3. *Main outcome measures and academic/occupational status for the 82 children*[a]

Patient	PBK scores (%)		CDT scores (w/mn)		Words in noise after 10 years (%)	CDT via telephone after 10 years (w/min)	Speech intelligibility rating after 10 years	Receptive language level after 10 years	Academic status	Math scores (/20)	French scores (/20)	Foreign language scores (/20)
	5 years	>10 years	5 years	>10 years								
1	70	84	55	84	40	55	5	4	University	NR	NR	NR
2	75	78	37	84	50	50	5	3	Vocational	NR	NR	NR
3	65	88	40	95	80	65	5	2	Vocational	NR	NR	NR
4	90	90	50	101	89	48	5	4	High school	10	10	14
5	90	86	35	101	80	66	5	3	High school	16	14	16
6	80	74	45	75	0	54	4	5	Vocational	NR	NR	NR
7	90	98	47	99	85	85	5	3	High school	14	12	10
8	40	55	34	53	45	28	5	2	Vocational	NR	NR	NR
9	50	60	38	58	30	30	5	2	High school	12	9	10
10	0	0	0	0	0	0	1	1	Vocational	NR	NR	NR
11	60	84	42	61	70	44	3	2	Junior high	16	9	16
12	68	76	45	68	55	22	4	5	University	NR	NR	NR
13	40	20	20	20	10	0	3	1	Vocational	NR	NR	NR
14 (NU)	0	5	0	0	0	0	2	1	University	NR	NR	NR
15 (NU)	0	0	0	5	0	0	2	1	Vocational	NR	NR	NR
16	50	60	25	22	0	15	2	1	Vocational	NR	NR	NR
17	70	82	40	90	68	77	5	3	Junior high	13	15	13
18	60	64	20	19	40	7	2	2	Working	NR	NR	NR
19	50	62	20	34	60	25	3	2	Junior high	6	9	5
20	70	88	28	84	79	65	5	5	Junior high	14	11	13
21	0	0	0	0	0	0	3	3	High school	11	5	9
22	45	58	35	50	48	19	5	5	University	NR	NR	NR
23	80	94	28	77	40	73	5	3	Junior high	14	10	10
24	60	88	15	50	50	30	4	3	High school	12	8	13
25	70	62	35	55	0	0	4	2	Vocational	NR	NR	NR
26	78	86	40	64	20	30	5	2	Vocational	NR	NR	NR
27	25	47	10	15	0	0	2	2	Vocational	NR	NR	NR
28	55	42	20	16	0	0	4	2	High school	12	11.5	12
29	60	60	37	44	60	20	3	1	Vocational	NR	NR	NR
30	95	100	60	84	65	52	5	4	Junior high	12	11	10
31	80	60	30	32	37	20	4	2	University	NR	NR	NR
32	80	96	30	76	50	34	4	3	Junior high	12	15	13
33	80	88	26	81	78	36	5	2	Junior high	11	11	12
34	75	94	49	88	60	68	5	5	Junior high	15	14	14
35	80	82	25	58	37	56	4	3	High school	13	10	10
36	95	92	79	105	90	79	5	6	Junior high	19	17	18
37	70	82	25	44	70	30	4	1	Junior high	7	11	11
38	78	90	59	80	52	45	5	3	Junior high	12	10	9
39	85	94	42	76	30	48	4	4	Junior high	6	10	7
40	86	84	50	70	94	34	5	3	Junior high	18	12	13
41	30	56	0	0	0	0	2	1	Special class	NR	NR	NR
42	65	98	46	62	89	38	5	2	Junior high	10	8	11
43	40	76	15	39	15	20	2	1	Vocational	NR	NR	NR
44	66	80	34	45	20	21	4	3	Junior high	14	9	14
45	58	88	25	41	27	22	4	1	Special class	NR	NR	NR
46	90	84	52	67	50	40	5	3	High school	12	12	14
47	75	82	20	33	70	40	3	3	Special class	NR	NR	NR
48	15	10	0	0	0	0	2	1	Vocational	NR	NR	NR
49	73	78	56	61	21	35	4	2	Vocational	NR	NR	NR
50	80	84	59	96	8	72	5	3	Junior high	10	9	
51	72	74	30	43	53	25	3	1	Special class	NR	NR	NR
52	95	95	50	67	60		4	2	Junior high	12	11	11
53	66	88	23	45	50	28	4	2	High school	7	11	11
54	86	96	57	76	61	42	5	3	Junior high	17	15	17
55	96	98	58	88	78	60	5	3	Junior high	16	13	14
56	0	20	0	0	0	0	1	1	Special class	NR	NR	NR
57	30	20	0	0	0	0	2	1	Working	NR	NR	NR
58	45	56	20	23	8	15	3	3	Junior high	12	11	12
59[b]									University	NR	NR	NR
60	96	96	55	90	90	44	5	4	Junior high	12	13	15
61	66	90	50	96	90	45	5	5	Junior high	15	15	17
62	88	90	77	90	61	40	5	5	Junior high	14	12	11

(Continued on next page)

TABLE 3. *Continued*

Patient	PBK scores (%)		CDT scores (w/mn)		Words in noise after 10 years (%)	CDT via telephone after 10 years (w/min)	Speech intelligibility rating after 10 years	Receptive language level after 10 years	Academic status	Math scores (/20)	French scores (/20)	Foreign language scores (/20)
	5 years	>10 years	5 years	>10 years								
63	82	86	50	81	80	32	5	4	Junior high	18	15	15
64	35	40	16	30		15	2	2	Special class	NR	NR	NR
65	82	97	40	70	37	30	5	3	Junior high	12	12	12
66 (NU)	0	0	0	0	0	0	3	1	Working	NR	NR	NR
67	80	74	42	75	70	66	4	3	Junior high	8	11	12
68	70	78	50	35	40	0	2	2	Junior high	11	9	NR
69	80	90	23	40		20	3	2	Special class	NR	NR	NR
70	45	74	29	33	30	13	4	2	Vocational	NR	NR	NR
71	80	73	34	58	30	20	4	2	Junior high	10	13	11
72	80	82	60	75	69	40	3	3	High school	10	12	13
73	92	92	40	83	50	46	5	2	Elementary	10	8	NR
74	60	70	50	50	68	35	3	2	Junior high	9	9	13
75	72	80		30	40	15	3	1	Junior high	10	11	
76	90	80	50	64	20	61	4	3	Junior high	17	14	16
77	80	82	28	41	40	16	4	1	Junior high	10	11	8
78	80	90	100	98	55	60	5	5	High school	19	14.5	17
79	84	78	36	49	60	32	4	2	Vocational	NR	NR	NR
80	98	98	60	80	75	40	5	1	Elementary	10	10	NR
81	65	78	32	40	50	25	4	1	Junior high	12	11.5	14
82	88	92	42	68	45	50	5	3	Elementary	17	15	NR

[a]CDT, connective discourse tracking; NR, nonrelevant; NU, nonuser; PBK, Phonetically Balanced Kindergarten. Academic performances were obtained for the 41 children attending junior high and high schools.
[b]Patient 59 was lost at follow-up.

skills; 67.4% of children who received implants before the age of 4 years demonstrated open-set PBK scores greater than the median (versus 18% on those who received implants after the age of 4 years), 72% (versus 23.7%) CDT scores greater than the median, 65% (versus 12%) SIR greater than the median, and 62% (versus 36%) PPVT-R scores greater than the median. The children with associated disabilities had significantly lower scores on CDT and PPVT-R. The children placed in schools for the deaf had significantly lower scores on CDT, SIR, and PPVT-R. Children initially using total communication also demonstrated significantly lower scores on PBK and SIR after more than 10 years. On the contrary, the number of active electrodes had no significant effects on the outcome measures.

A one-way ANOVA was performed to determine the impact of a single factor on outcome quantitative measures (Table 5). All outcome measures were significantly higher in the group of children who received

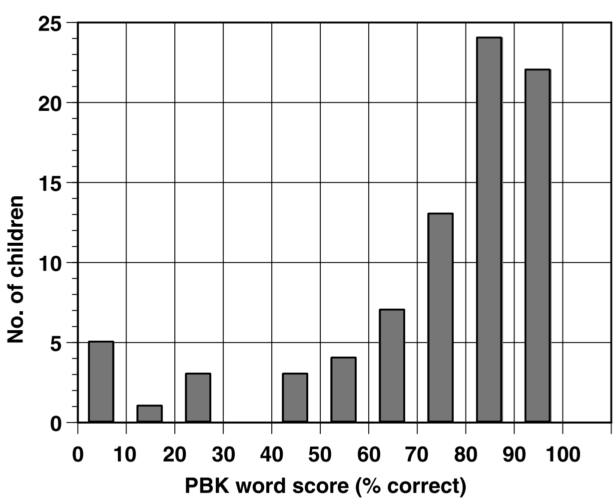

FIG. 1. Graph showing the distribution of PBK word scores (percentage of correct responses) after 10 years of implant use.

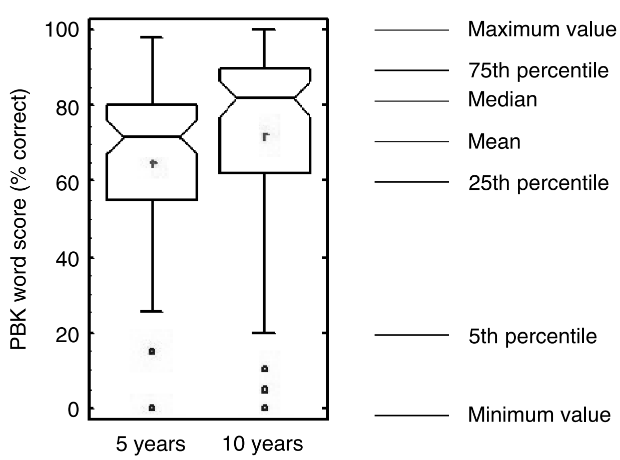

FIG. 2. Dual box-and-whisker plot showing the open-set PBK word understanding at the age of 5 years and at the age older than 10 years, with a 95% median notch.

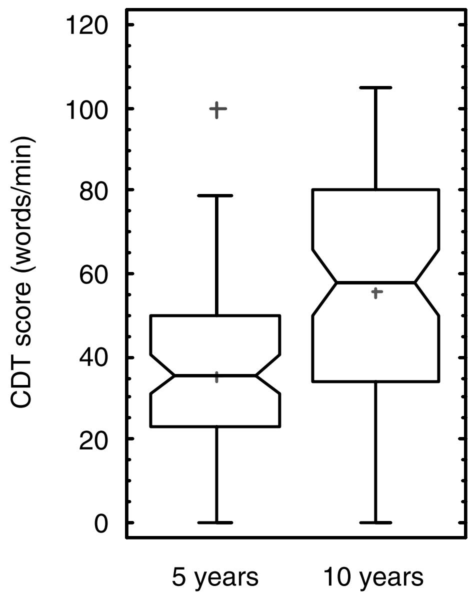

FIG. 3. Figure showing the mean standard scores for CDT at the age of 5 years and at the age older than 10 years.

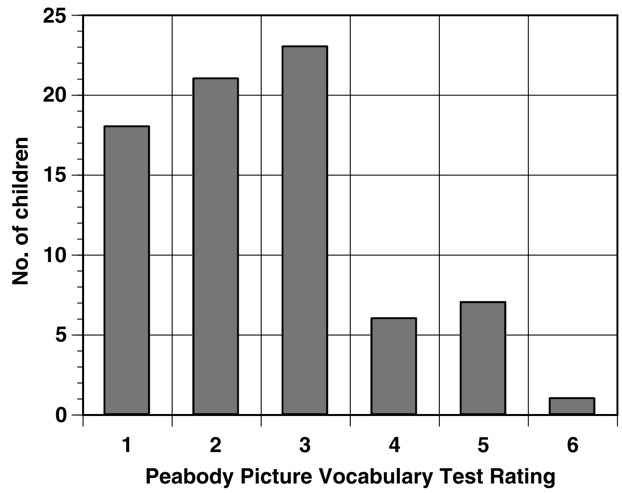

FIG. 5. Graph showing the distribution of PPVT-R rating after 10 years of implant use. The test was scored on a six-point hierarchical scale indicating the receptive language level relative to the normally hearing peers of equivalent age (1, <10th percentile; 2, 10th–25th percentile; 3, 25th–50th percentile; 4, 50th–75th percentile; 5, 75th–90th percentile; and 6, >90th percentile).

implants before the age of 4 years. PPVT-R was also significantly reduced in the group of children with associated disability, in children initially attending a school for the deaf, and in children using total communication.

A multivariate analysis using a stepwise logistic regression was performed to screen the available list of independent variables and to select only those that are important in describing the dependent variables. The result was expressed as odds ratio, which represents a multiplicative factor of the basic risk (the higher the odds ratio, the higher the risk). The strongest influence was observed on the age at implantation; an older age at implantation increases the risk of a PBK score being lesser than the median value by a factor of 9.4 and the risk of a CDT score being lesser than the median value by a factor of 15.1 (Table 6).

Finally, a multifactor ANOVA was performed to determine the impact of multiple factors on a single quantitative outcome measure. It confirmed that the age at implantation and the association of disability were the main factors that could account for the results (Table 7).

In conclusion, we will finally consider as the most accurate model the multivariate analysis using a stepwise

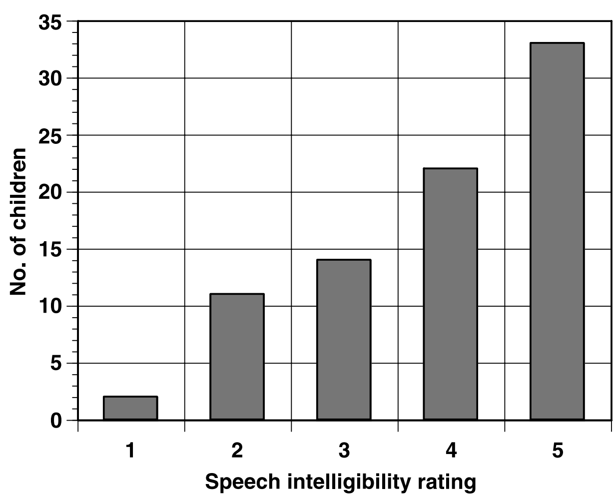

FIG. 4. Graph showing the distribution of the SIR after 10 years of implant use.

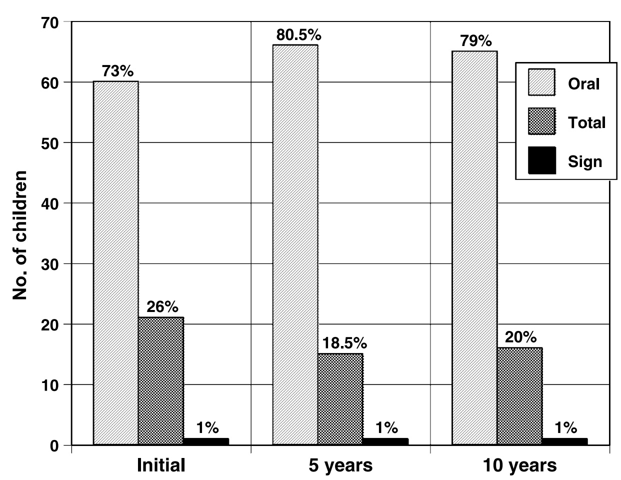

FIG. 6. Graph showing the evolution of communication mode over time.

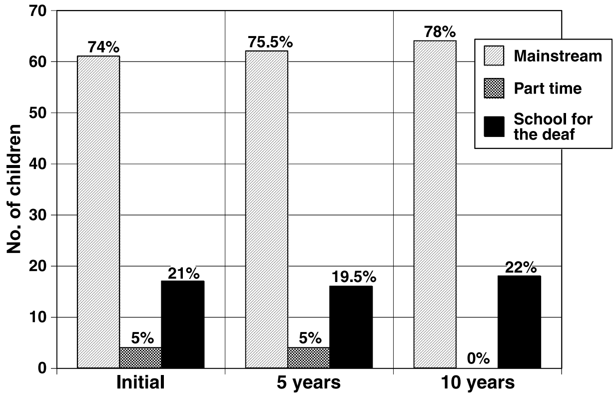

FIG. 7. Graph showing the evolution of educational placement over time.

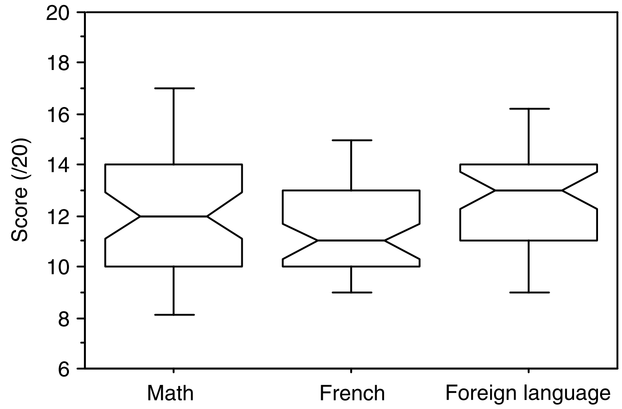

FIG. 9. Box-and-whisker plot showing the academic performance in children attending junior high and high schools (n = 46).

logistic regression because it is the most independent of variables distribution.

DISCUSSION

This study shows that most prelingually deafened children who received implants derive major benefits from cochlear implantation in the long term. The overall rate of implant use (96%) could be considered as excellent and is in accordance with previous reports of follow-up (15–16). The 3 causes of abandonment of the implant device could be explained by a delayed implantation or an implantation on a totally ossified cochlea.

Of the 82 children who received implants, 11 experienced device failure and/or a medical complication requiring reimplantation. All children received the CI 22 device, which was replaced in November 1993 by Cochlear Corporation by a new device that addressed the most common technical failures that occurred at that time. The cumulative survival rate after more than 10 years is 88%, which is in accordance with a previous report on a long-term follow-up in children (16) and with the December 2005 CI 24M reliability report published by Cochlear Corporation (23). This rate, however, should be reevaluated if we considered that 4 implants presented an internal electronic defect (inverted capacity) acknowledged by the company shortly after implantation and showed its effect several months later. All children could have reimplantation without complications and demonstrated performance results equal to or better than their performance with the original implant.

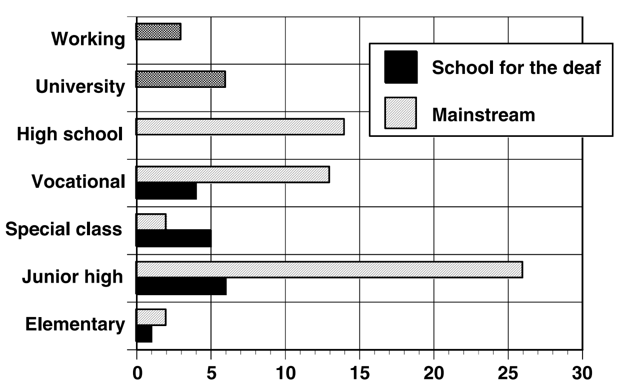

FIG. 8. Bar chart showing the educational and vocational status according to current educational placement (*special class* indicates special education unit for children with disability). The age range in the French academic system is as follows: elementary, 6–11 years; junior high school and special class, 12–15 years; high school and vocational school, 16–18 years.

This study confirms that the children's speech perception skills continue to develop beyond 5 years of CI experience. The average word recognition score for the PBK test measured in the present study after 5 years (65%) is in accordance with the average scores measured on the same follow-up interval in a previous study (65.4%) (13). A plateau is not reached in all children after 5 years of implant use; 49 (60%) of 82 children on the open-set PBK word score and 61 (74%) of 82 on the CDT score continued to improve scores significantly. The difference was more pronounced for the CDT score. However, when comparing these data with those obtained from the same children in our previous studies (3,6), it is clear that the major steps of the acquisition of auditory abilities occur within the first 5 years of implant use.

After 10 years of implant use, 79% (65 of 82 children) could use the telephone. These results are in accordance with the report of the team of Nottingham showing that 60% of the children could use the telephone (10). However, the number of words correctly understood per minute by using the telephone remains very poor, which indicates that telephone conversation is a very difficult task for the children with implant. This explains why the children with implant usually restrict the telephone use to known speakers (family, friends, and speech therapist).

Regarding speech production, our results are comparable with those published by the Nottingham team on

TABLE 4. *Univariate analysis using Pearson χ^2 test*[a]

Pearson χ^2 test	Age at implant (yr) <4	Age at implant (yr) >4	Associated disability No	Associated disability Yes	Educational placement M	Educational placement PT	Educational placement SFD	Communication mode Oral	Communication mode Total	Active electrodes >15	Active electrodes <15
PBK											
% Above median	67.4	18	45	33	47	0	41	50	27	42	66
p	<0.00001[c]		NS			NS		<0.06[b]		NS	
CDT											
% Above median	72	23.7	53	22	56	25	29	52.5	41	50	50
p	<0.001[c]		<0.08[b]			<0.08[b]		NS		NS	
SIR											
% Above median	65	12	41	33	47	25	17	46	22	40	50
p	<0.00001[c]		NS			<0.05[c]		<0.07[b]		NS	
PPVT-R											
% Above median	62	36	55	0	58	25	25	54	38	48	80
p	<0.02[c]		<0.003[c]			<0.03[c]		NS		NS	

[a]CDT, connective discourse tracking; M, mainstream; NS, statistically not significant; PBK, Phonetically Balanced Kindergarten; PPVT-R, Peabody Picture Vocabulary Test-Revised; PT, part time; SFD, school for the deaf; SIR, speech intelligibility rating. Statistical significance was set at $p \leq 0.05$.
[b]With trend toward significance.
[c]Statistically significant.

English-speaking children (16). They found that after 10 years of CI use, 77% of all subjects developed connected speech intelligible to the average listener (SIR 5) or to the listener with little experience on deaf person's speech (SIR 4), whereas 67% of our children with implant developed a similar level of speech. It is very interesting to find comparable results between English- and French-speaking children who received implants in different countries.

Very few studies analyzed the vocabulary knowledge in the long term of children who received implants. Manrique et al. (24) showed that children who underwent cochlear implantation before the age of 2 years had a 1-year delay in PPVT-R performance as compared with a normally hearing population after 3 years of implant use and that children given implants at an older age showed a slower acquisition of vocabulary skills. Our study demonstrating that 75% of our children who received implants scored lesser than the median value of their normally hearing peers confirms this finding in the long term.

A number of variables have been already identified to account for the outcomes of children with cochlear implants. We focused our statistical analysis on four predictive factors (i.e., age at implantation, associated disability, communication mode, and educational placement).

Previous studies performed in the first 5 years after cochlear implantation showed that the age at implantation was the main variable that accounted for the results

TABLE 5. *One-way analysis of variance*[a]

One way ANOVA	Age at implant (yr) <4	Age at implant (yr) >4	Associated disability No	Associated disability Yes	Educational placement M	Educational placement PT	Educational placement SFD	Communication mode Oral	Communication mode Total	Active electrodes >15	Active electrodes <15
PBK											
Mean	81	60	72	58	71	73	68	71	71	72	58
p	<0.0004[c]		0.25[b]			0.3[b]		0.6[b]		0.7[b]	
CDT											
Mean	68	39	57	40	58	57	44	56	52	55	51
p	<0.00001[c]		0.14[b]			0.2[b]		0.4[b]		0.9[b]	
SIR											
Mean	4.3	3.4	3.9	3.2	4	4.4	3	4	3.5	3.8	4.1
p	<0.0005[c]		0.2[b]			0.1[b]		0.1[b]		0.6[b]	
PPVT-R											
Mean	2.8	2.3	2.7	1.4	2.8	2	2	2.7	2.2	2.5	2.6
p	<0.05[c]		<0.004[c]			0.03[c]		0.03[c]		0.8[b]	

[a]ANOVA, analysis of variance; CDT, connective discourse tracking; M, mainstream; PBK, Phonetically Balanced Kindergarten; PPVT-R, Peabody Picture Vocabulary Test-Revised; PT, part time; SFD, school for the deaf; SIR, speech intelligibility rating. Statistical significance was set at $p \leq 0.05$.
[b]Statistically nonsignificant.
[c]Statistically significant.

TABLE 6. *Multivariate analysis using a stepwise logistic regression*[a]

	Age at implant (>4 yr versus <4 yr)	Associated disability (yes versus no)	Educational placement (SFD versus mainstream)	Communication mode (total versus oral)
PBK				
Odd ratio	9.43	NS	NS	NS
95% Confidence interval	3.3–27.7			
CDT				
Odd ratio	15.15	14.8	NS	NS
95% Confidence interval	4.7–50	2.3–93.3		
SIR				
Odd ratio	12.7	NS	NS	NS
95% Confidence interval	4–40			
PPVT-R				
Odd ratio	2.6	NS	3.96	NS
95% Confidence interval	0.97–6.9		1.1–14.6	

[a]CDT, connective discourse tracking; NS, statistically not significant; PBK, Phonetically Balanced Kindergarten test; PPVT-R, Peabody Picture Vocabulary Test-Revised; SIR, speech intelligibility rating.

(6–8,24–30). Our study confirms that children who received implants before the age of 4 years demonstrated better speech perception, speech production performances, and vocabulary skills as compared with children who received implants at an older age. However, there were instances of high-achieving individuals who received implants at the age of 7 years and older. Other authors have published that children with delayed implantation can obtain considerable benefits with open-set speech understanding (31). These results tend to demonstrate that it might be worthwhile in certain cases to perform an implantation after a long period of auditory deprivation.

There is evidence that some additional disabling conditions interfere with performance after implantation (31–33). This study also confirms that children with multiple disabilities can obtain demonstrable benefits from cochlear implantation, although speech perception and language outcomes are reduced when compared with those of children without additional disability other than deafness.

Regarding communication mode and educational placement, this study revealed very few changes during the postimplant period. This is rather odd because other studies have reported more important changes toward oral communication (12,34). This discrepancy can be explained by the fact that the policy regarding the management of profound deafness in childhood in France and in our center emphasizes an oral/aural communication mode and mainstreaming. This is why 75% of our children are using oral communication as the primary mode of communication and are placed in mainstream as soon as the early postimplant period. This policy may be different in other countries, explaining why more important changes are observed in the first years after implantation.

Concerning the role of these factors, the literature is somewhat confusing. One educational variable frequently examined in relation to implant benefit is the communication mode. This variable is most often dichotomized into oral communication and total communication. Although there is evidence that children enrolled in oral communication programs demonstrate better speech perception, speech production, and language improvement after implant than do those in total communication programs (28–29,34–35), other studies indicate greater vocabulary improvement on children enrolled in total communication programs (36). Our study confirms that children initially enrolled in oral communication tend to have better scores than do children in total communication (Table 4); however, a robust statistical analysis using multiple regression failed to retain communication mode as a significant contributor of the variance of the measures, probably because the age at implantation, educational placement, and communication might not be completely independent variables.

TABLE 7. *Multifactor analysis of variance*[a]

	Age at implant	Associated disability	Educational placement	Communication mode	Active electrodes
PBK	$p < 0.00001$	$p < 0.01$	NS	NS	NS
CDT	$p < 0.00001$	$p < 0.003$	NS	NS	NS
SIR	$p < 0.0001$	$p < 0.004$	NS	NS	NS
PPVT-R	$p < 0.002$	$p < 0.001$	NS	NS	NS

[a]CDT, connective discourse tracking; NS, statistically not significant; PBK, Phonetically Balanced Kindergarten; PPVT-R, Peabody Picture Vocabulary Test-Revised; SIR, speech intelligibility rating. The outcome measures used were open-set PBK word scores, CDT scores, SIR, and PPVT-R ratings. The independent variables were the age at implant (before/after 4 years), associated disability (yes/no), communication mode (oral/total), educational placement (mainstream/part time/school for the deaf), and number of active electrodes (>15/<15).

Moreover, the dichotomic separation between oral and total communication is not so clear-cut. Cued speech was used by some cochlear implant recipients in the early stages after cochlear implantation (37). Most of our children in total communication also have very good capabilities in oral communication. The communication mode of some children has also changed during the first years after the implantation and the final evaluation.

The role of educational placement must also be interpreted with caution. Our study, like some others (28–29,34,38–39), tends to demonstrate that educational environments that incorporate exposure to normally hearing peers were also associated with higher speech perception, speech intelligibility, and language skills. These results emphasize the role of normally hearing peers for the speech training of cochlear implant recipients. However, logistic regression analyses again failed here in retaining this parameter as a significant contributor of the variance of outcome measures. The main reason is that this parameter is not independent from the other qualitative factors and from the main outcomes. It is difficult to assess whether mainstreaming is the cause or the consequence of good speech perception performance after implant. It should also be considered that many of the children enrolled in schools for the deaf were placed in these special units because they could not follow the cursus of mainstream schools for various reasons (insufficient language development, associated disability, or lack of parental support).

The present study is one of the first to offer long-term achievement and educational and vocational outcome data from a cohort of prelingually deafened children who grow up with access to the information provided by a CI. The cohort was mainly educated within a mainstream environment in public schools. Three of them have got a job and are currently working; six are attending universities. Among the 73 remaining children, 42 (58%) attend compulsory/elementary or secondary education in mainstream schools using oral/aural communication, with a variety of support levels ranging from regularly having a note taker in lessons to having an occasional visit from a teacher of the deaf. Sixteen children (22%) are enrolled in a school for the deaf and receive general and vocational education in junior high schools, special units for children with disability, or vocational classrooms. Approximately half of these children in the age range of 12 to 15 years are in special classrooms where they receive mainly vocational education.

This study showed that the first generation of CI users demonstrate satisfactory academic performances that allow most of them to advance to the next grade level. It must be emphasized that the French national education system (21–22) was not designed to perform grading among students; the achievement of a mean score of 10 on a scale of 20 on basic subjects is required of a student to pass a grade level and to advance to the next. It would thus be very hazardous to draw any conclusion comparing the academic performance of children who received implants with that of their hearing peers. This study also demonstrates the ability of CI recipients to develop competency in a second spoken language (40–41).

CONCLUSION

In conclusion, this long-term report on 82 subjects with more than 10 years of implant use shows that cochlear implantation is a safe and reliable technique. The fact that many profoundly hearing-impaired children using CIs can develop functional levels of speech perception and production, attain age-appropriate oral language, develop competency level in a language other than their primary language, and achieve academic performance similar to that of normally hearing children is a challenge that nobody would have expected 10 years ago. It is reasonable to assume that the expected benefit of children who receive implants now using new devices and more sophisticated speech strategies may surpass the outcomes reported in the present study.

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