The Laryngoscope
Lippincott Williams & Wilkins, Inc.

Cochlear Implantation in Patients with Substantial Residual Hearing

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Objectives: **Cochlear implantation is an effective means for providing auditory rehabilitation in adult patients with severe to profound sensorineural hearing loss. It has been hypothesized that patients with substantial, preoperative residual hearing would be excellent cochlear implant candidates because of surviving neural populations and a lack of auditory deprivation. The purpose of this study is to describe the outcomes of patients with substantial residual hearing who have undergone cochlear implantation.** ***Study Design:*** **Retrospective chart review of patients with substantial preoperative residual hearing who underwent cochlear implantation.** ***Methods:*** **Chart reviews were completed for patients with substantial residual hearing who underwent cochlear implantation (City University of New York Sentence Test [CUNY] > 60%, Hearing in Noise Test sentences presented in quiet [HINTQ] > 50%, or Consonant-Nucleus-Consonant [CNC] > 20% in the ear to be implanted). Preoperative and postoperative measures of audiologic performance as well as complications were assessed.** ***Results:*** **All 12 patients who met inclusion criteria ultimately surpassed their preoperative aided performance level after implantation and gained significant benefit from their cochlear implant. At 6 months postimplantation, mean CUNY, HINTQ, and CNC scores were 93%, 78%, and 48% in the implant ear alone, respectively. However, progress was slower than expected for many patients, and at least one patient took 1 year to surpass his preoperative performance level. There were no complications from surgery in this selected group of patients.** ***Conclusions:*** **Patients with some degree of residual hearing do benefit from cochlear implantation. However, there may be an initial decline in performance as compared with preoperative levels. This decline is overcome in time in this patient population. These patients need to be counseled accordingly.** ***Key Words:*** **Cochlear implant, residual hearing.**

Laryngoscope, **114:2218–2223, 2004**

INTRODUCTION

Cochlear implants have proven to be an effective means of auditory (re)habilitation for both adults and children. Nearly all adults with postlingual-onset hearing loss (HL) can expect to receive sound awareness, enhanced lip-reading, and substantial closed-set speech perception with a cochlear implant.[1–3] Some degree of open-set speech perception can also be expected in most patients. However, it remains difficult to predict how well an individual patient will perform after cochlear implantation.

Numerous studies suggest that the duration of deafness is a critical factor for predicting performance with a cochlear implant.[4–10] That is, prolonged durations of deafness have been associated with poorer performance. Whether this is a central nervous system or a peripheral auditory phenomenon remains unknown.

Current audiologic recommendations for adult cochlear implant candidacy are severe to profound sensorineural HL and best-aided Hearing in Noise Test sentence scores in quiet (HINTQ) of less than 40% to 60%. In our program, occasionally, patients with greater degrees of residual hearing but significant self-perceived handicap using their best-aided auditory condition have undergone cochlear implantation. The purpose of this study was to describe the performance of these patients with substantial preoperative residual hearing.

MATERIALS AND METHODS

From November 2001 to November 2003, 92 adult patients received a total of 100 cochlear implants at the University of North Carolina–Chapel Hill (UNC-CH). After obtaining permission from the UNC-CH internal review board, a retrospective search of the cochlear implant database and the medical record was performed to identify those patients previously receiving implants that had substantial preoperative hearing. Audiologic, operative, and postoperative data were sought.

Audiologic Testing

Objective measures of hearing are routinely obtained on all patients that undergo cochlear implantation at our institution. Speech perception testing may include both measures of word

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Editor's Note: This Manuscript was accepted for publication May 12, 2004.

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DOI: 10.1097/01.mlg.0000149462.88327.7f

recognition (Consonant-Nucleus-Consonant [CNC]) and sentence recognition in both quiet (Central Institute of Deafness sentence test [CID], City University of New York sentence test [CUNY], and HINTQ) and noise (HINT + 10dB signal to noise ratio). CNC word scores were presented using 50 test-word lists from a commercially available compact disc (1996 Version) developed by the House Ear Institute (Los Angeles, CA).[11] All word and sentences scores are reported as a scaled score from 0% to 100% correct. For the present study, substantial preoperative residual hearing was defined as CUNY sentence score greater than 60%, HINTQ score greater than 50%, or CNC word score than 20% in the ear to be implanted. All patients had significant self-perceived hearing handicap using their best-aided auditory condition and were thus considered to be potential cochlear implant candidates. Exclusion criteria for this study included revision surgery, inability to speak English, and patients receiving a second cochlear implant in the opposite ear. A total of 12 patients met criteria. Study group characteristics are shown in Table I.

Postoperative performance was determined with the patient receiving auditory stimulus from the cochlear implant alone without the use of a hearing aid in either ear. In addition, masking noise was played to the nonimplanted ear when stimuli were above unaided thresholds in that ear. The purpose of the present study was to determine whether, when, and to what degree the patient's auditory perception abilities surpassed their preoperative, aided performance level in the implanted ear alone. During the early postoperative period, patients were encouraged to not wear their contralateral hearing aid to increase their experience with their cochlear implant. Few patients underwent auditory-based intervention in the postoperative period.

CUNY, HINTQ, and CNC scores were available before and after surgery at 1, 3, 6, and 12 months for most patients. Because there were varying degrees of performance before implantation, the preoperative score was subtracted from the postoperative score at the various testing intervals to generate change scores from baseline. Means were computed for both raw scores and change scores at each time interval. Raw data were also plotted by individual subject to visualize the absolute changes. Significance testing was performed for pair wise comparisons at the various follow-up intervals using paired t tests. Significance was set at $P < .05$.

RESULTS

Surgery was generally uncomplicated. There were no intraoperative cerebrospinal fluid leaks or facial nerve injuries. Eleven of 12 patients had complete electrode insertions. In the remaining case, a MED-EL Combi 40+ device (MED-EL Corporation, Innsbruck, Austria) was inserted up to the ninth electrode, leaving electrodes 10 to 12 outside of the cochlea; this represents approximately 21 mm insertion depth, comparable with that obtained in a full insertion with the other device in this study. After surgery, 3 (25%) of 12 patients had vestibular complaints of vertigo or imbalance that were transient in nature. There were no wound infections or cerebrospinal fluid leaks. No patient retained any measurable residual hearing in the ear implanted.

Mean (±SD) scores before and after device activation are shown for the 12 patients at the various follow-up intervals in Figure 1. With the exception of CUNY scores at the 1 month interval, average postoperative performance was better than preoperative performance at all intervals and appears to be improving with time. Figure 2 illustrates the mean change scores (postoperative minus preoperative score) for each test interval. Statistical analysis using pair wise comparisons revealed significant ($P < .05$) improvements in CUNY scores at 6 months, HINTQ scores at 3 months, and CNC scores at 3, 6, and 12 months. Although statistical significance was not met for the remaining time points, the trend was toward improvement compared with preoperative scores. The drop in average CUNY score at 1 month postimplantation likewise did not represent a significant change from the preoperative score ($P = .169$).

Figures 3, 4 and 5 show the raw patient data for CUNY, HINTQ, and CNC scores, respectively. A large proportion of patients had an initial worsening in performance on all three tests at both the 1 and 3 month postimplantation intervals. However, all patients but one

TABLE I.
Cochlear Implant Recipient Characteristics.

Patient No.	Age at Implantation	Device	Preoperative CNC	Preoperative CUNY	Preoperative HINTQ
1	70	MED-EL Combi 40+	6	61	8.5
2	61	Nucleus 24	10	69	26
3	74	MED-EL Combi 40+	36	87	58.5
4	81	MED-EL Combi 40+	4	80	25
5	70	MED-EL Combi 40+	26	49	65.5
6	79	Nucleus 24	12	74	37.5
7	71	MED-EL Combi 40+	22	83	44
8	68	Nucleus 24	10	60	N/A
9	60	MED-EL Combi 40+	8	85	51.5
10	67	MED-EL Combi 40+	4	80	59
11	60	MED-EL Combi 40+	36	91	N/A
12	62	MED-EL Combi 40+	16	74	22.5

Shaded areas indicate testing parameters for which the patient met criteria for substantial residual hearing.
MED-EL Combi 40+ (MED-EL Corporation, Innsbruck, Austria); Nucleus 24 (Cochlear Corporation, Englewood, CO).
CNC = Consonant-Nucleus-Consonant; CUNY = City University of New York Sentence Test; HINTQ = Hearing in Noise Test sentences presented in quiet.

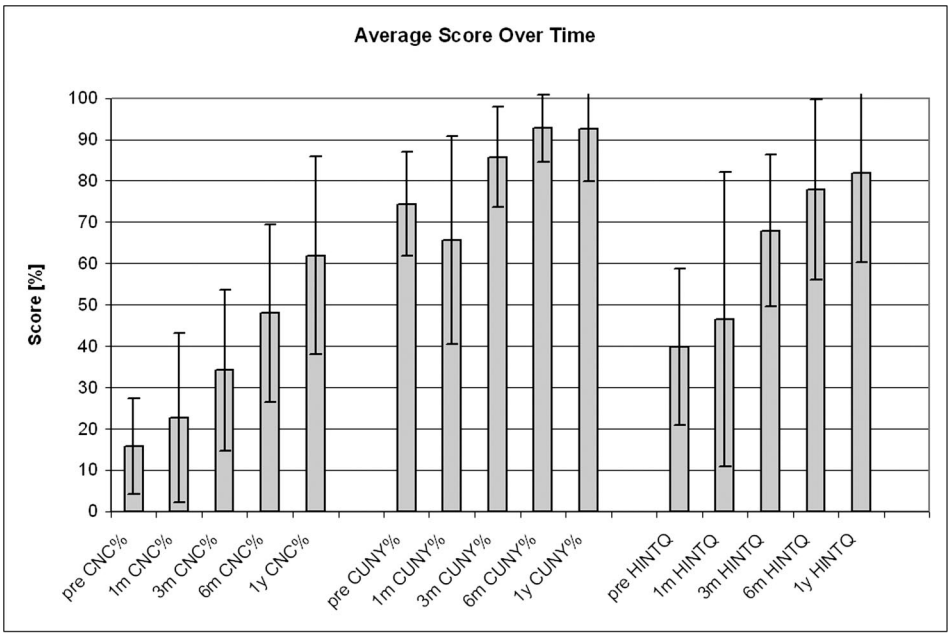

Fig. 1. Average performance over time. Average scores for Consonant-Nucleus-Consonant (CNC), City University of New York Sentence Test (CUNY), and Hearing in Noise Test sentences presented in quiet (HINTQ) in the preoperative and postoperative time periods. Error bars represent SD.

reached or surpassed their preoperative performance by 6 months of implant usage. All patients with 1-year data (n = 4) have surpassed their preoperative performance level at 1 year.

DISCUSSION

The present study reports the benefits of full-length electrode cochlear implantation in a group of patients with substantial residual hearing. In this study, all patients had either preoperative CUNY scores greater than 60%, HINTQ scores greater than 50%, or CNC scores greater than 2O% when tested in the best-aided condition for the ear to be implanted. Mean preoperative CUNY, HINTQ, and CNC scores were 74%, 40%, and 16%, respectively. This level of residual functional hearing compares favorably with those patients reported by Gantz and Turner,[12] who underwent short-length electrode insertion with preservation of hearing and combined electrical-acoustic stimulation. In that study, mean preoperative CUNY and CNC scores were 73% and 16%, respectively. To our knowledge, there are no previous reports of full-length electrode implantation in patients with this degree of preoperative residual hearing. It is important, however, to recognize that all of our patients had severe to profound sensorineural HL and significant, self-perceived disability before surgery despite adequate amplification.

The results of the present study clearly demonstrate that patients with substantial residual hearing can obtain

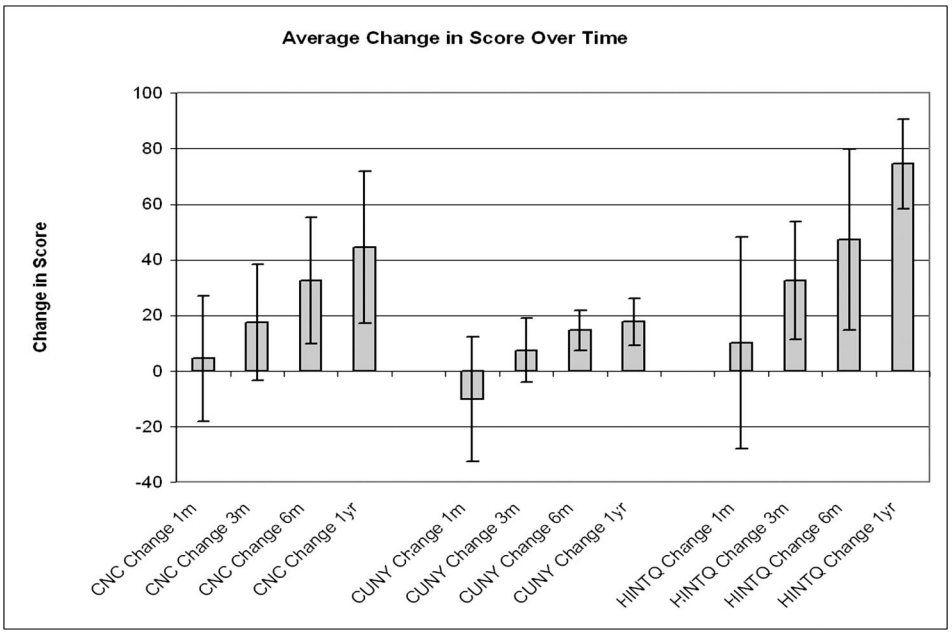

Fig. 2. Mean change in performance over time. Mean change from preoperative mean scores. Error bars represent SD. CNC = Consonant-Nucleus-Consonant; CUNY = City University of New York Sentence Test; HINTQ = Hearing in Noise Test sentences presented in quiet.

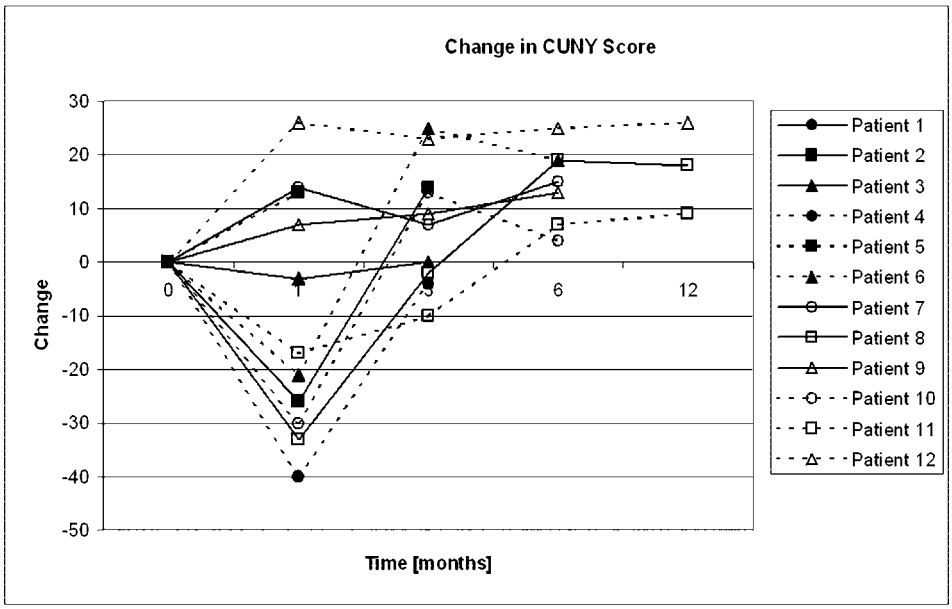

Fig. 3. Individual change in City University of New York Sentence Test (CUNY) performance. Individual patient performance over time as a function of change from preoperative score.

benefit from full-length cochlear implantation given the current available technology. All patients ultimately surpassed their preoperative aided performance level after implantation and gained significant benefit from their cochlear implant. At 6 months postimplantation, mean CUNY, HINTQ, and CNC scores were 93%, 78%, and 48% in the implant ear alone, respectively. Individuals experienced a mean improvement in CUNY, HINTQ, and CNC scores of 15%, 47%, and 33%, respectively. The relatively small change in CUNY scores likely represents a ceiling effect for this particular indicator. At 1 year, the present study had four patients with available data. The mean CNC score for these patients was 62%. This value again compares favorable with those reported by Gantz and Turner,[12] who used combined electrical-acoustic stimulation without a contralateral hearing aid. In that study, mean CNC scores were approximately 70% in similar testing conditions after 1 year of use. Actual performance of the patients in the present study, in daily listening situations, may be even better because some patients wear contralateral hearing aids in addition to their cochlear implants. This benefit was not quantified in the present study.

It is critical to recognize that progress after cochlear implantation in the patients in the present study was slower than expected, and at least one patient took 1 year to surpass his or her preoperative performance level. In fact, some patients had reductions in performance at the earliest follow-up intervals. During this time period, patients were encouraged not to wear their contralateral hearing aid to facilitate adaptation to the implant signal. This was frustrating for some patients and required sup-

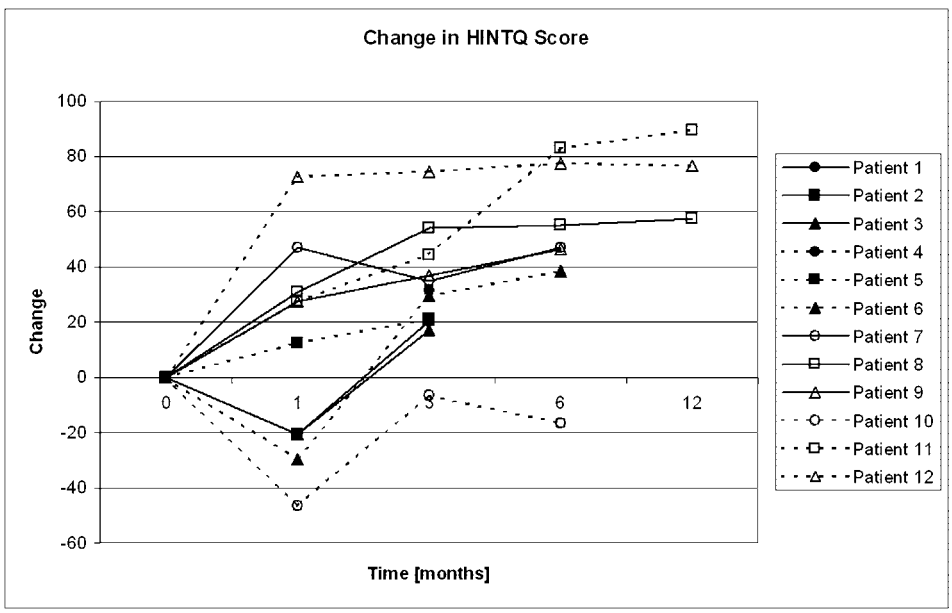

Fig. 4. Individual change in Hearing in Noise Test sentences presented in quiet (HINTQ) performance. Individual patient performance over time as a function of change from preoperative score.

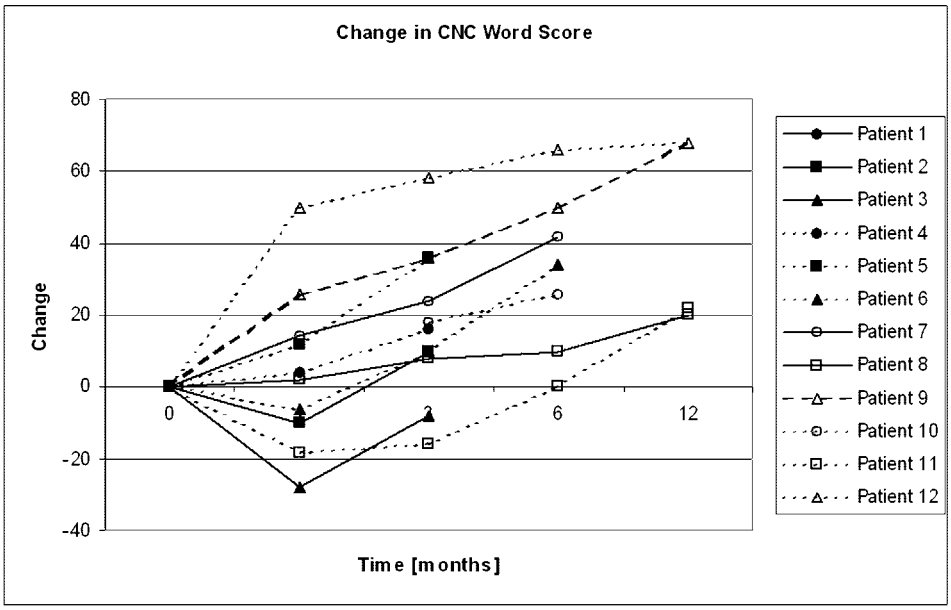

Fig. 5. Individual change in Consonant-Nucleus-Consonant (CNC) performance. Individual patient performance over time as a function of change from preoperative score.

port during this period of adjustment. Most of our patients did not undergo auditory-based intervention in the postactivation period. This type of therapy may be useful for patients during this period of acclimation.

Full-length cochlear implantation for patients with substantial residual hearing has a number of advantages over partial electrode insertion with hybrid electrical-acoustic stimulation. Importantly, if hearing is lost from the implant operation or progressive pathologic changes within the cochlea from the electrode array or underlying ear disease, the entire frequency spectrum of neural populations are covered with electrodes without the need for revision surgery. The surgical problems regarding conversion of a partial length electrode with potential fibrotic obstruction of the cochlea to a full-length electrode is also avoided.[13] Moreover, the concern regarding a possible frequency gap between electrically and acoustically stimulated regions of the cochlea is obviated. This was apparently the problem for the initial group of patients implanted by Gantz and Turner[12] with a 6 mm long electrode array.

For the most part, recommended audiologic criteria for cochlear implantation have been established well below the average postimplantation performance scores for most cochlear implant recipients. For instance, current recommendations for implantation are best-aided HINTQ scores of less than 40% to 60% (Table II). In our program, 95% of implanted postlingual adults attain this level of performance by 1 year of use (excluding revisions, bilateral implantations, and non–English-speaking patients over the same time period). This conservative approach, although appropriate, does not allow an understanding of the effect of greater degrees of preoperative residual hearing on performance. It is important to recognize that many patients that do not meet the aforementioned criteria will ultimately have progressive HL with time and become cochlear implant candidates.

Is it better to implant a patient with significant residual hearing or wait for them to meet current audiologic criteria? On one hand, delayed implantation results in pathologic and adaptive processes to occur within the auditory system that may impair a patient's future performance potential. By contrast, delaying implantation may allow these patients the opportunity to benefit from newer technologies. Patients who wait will also experience the negative effects of HL, with its resulting communication disability. With this mind, these patients may actually perceive the positive effects of implantation to a greater

TABLE II.
Cochlear Implant Candidacy Criteria.

Company	Device	Speech Criteria (Best Aided Condition)	PTA Criteria
MED-EL	Combi 40+	HINT <40%	>70 db
Advanced Bionics	Clarion HiResolution	HINT <50%	>70 dB
Cochlear	Nucleus 24	HINT <50%, ear to be implanted HINT <60%, opposite ear or binaural	Moderate to severe loss in low frequencies; profound loss in mid-high frequencies

Recommended criteria for cochlear implant candidacy from the manufacturers of the three cochlear implants currently commercially available in the United States.

MED-EL Combi 40+ (MED-EL Corporation, Durham, NC); Clarion HiResolution (Advanced Bionics Corporation, Sylmar, CA); Nucleus 24 (Cochlear Corporation, Englewood, CO).

HINT = Hearing in Noise Test; PTA = pure tone average.

degree. Ultimately, the decision to undergo cochlear implantation is one made by a patient and his or her cochlear implant team. It is the duty of the clinicians to educate the patients regarding this dilemma. In this patient population, counseling should include the inherent loss of residual hearing,[14] early decline in auditory function, and possible vestibular side effects. Patients can expect to perform at or above their preoperative level after 6 months of use.

Over the years, improvements in speech perception abilities for patients with cochlear implants have resulted from a better understanding of a number of patient-specific factors as well as advances in technology. From a device perspective, the major advances appear to have been related to the development of better speech coding strategies and stimulation paradigms.[2] Patient factors that have been identified as predictors of poor performance include prolonged durations of deafness with a lack of auditory stimulation, severely diminished spiral ganglion cell counts, severe cochlear dysmorphology, associated mental handicaps, mixed communication modes, and a lack of auditory-based intervention.[4–6,8–10,15] Presumably, patients with substantial residual hearing avoid the negative effects of spiral ganglion cell loss and prolonged durations of deafness.

Several short-comings of this study are worth noting. First, the retrospective nature of this study did not allow for standardized inclusion criteria, testing paradigms, and outcomes assessment. Fortunately, objective measures of performance are assessed in all patients in our program at standard test intervals. Unfortunately, testing conditions that evaluate residual hearing after implantation and performance with and without a contralateral hearing aid were not undertaken. Moreover, quality of life measures and vestibular system impact was not assessed.

Future studies should prospectively study full-length cochlear implantation in patients with substantial residual hearing. Attempts to compare these patients with those with short-length electrode implants that use combined electrical and acoustic stimulation as well as those without substantial residual hearing should be made. Longer follow-up data are also needed to determine both long-term results as well as the progression of HL in these populations.

CONCLUSIONS

The indications for cochlear implantation have continued to become more liberal with improvements in device technology and experience of implant centers. As criteria have become more and more lenient, the concern for implantation with resulting loss of residual (i.e., native) hearing has grown. Some have approached the issue by attempting hybrid, electrical-acoustic stimulation. Other centers have attempted to maximize the probability of residual hearing preservation with full-length implantation with limited success. Certainly, at some level, device performance is the limiting factor for patient outcomes. The current study suggests that patients with CUNY scores greater than 60%, HINTQ scores greater than 50%, or CNC scores greater than 20% may be cochlear implant candidates as long they are substantially handicapped in their best-aided condition. At what level of residual hearing this is, remains to be determined. These patients should be highly motivated, and they should understand that implantation might not immediately correct their hearing problem. Rather, a more prolonged course of adaptation should be anticipated, with excellent results over time.

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