Improvement in Speech Perception and Production Abilities in Children Using a Multichannel Cochlear Implant

Susan Waltzman, PhD; Noel L. Cohen, MD; Lynn Spivak, PhD; Elizabeth Ying, MS; Diane Brackett, PhD; William Shapiro, MA; Ronald Hoffman, MD

Nine children received the Nucleus® multichannel cochlear prosthesis. The preoperative evaluation consisted of assessments of auditory function, speech recognition, linguistic skills, and speech production. There were no surgical complications, and recovery in all patients was uneventful. The device was programmed 4 to 5 weeks following surgery, and all children were conditioned to the task. Postoperative training began immediately following device stimulation and is ongoing. Auditory skills and speech production scales were devised to monitor each child's progress. All children have shown varying degrees of improvement in auditory skills and speech production using the implant alone.

INTRODUCTION

Over the past 6 years, the House-3M® single-channel cochlear prosthesis has been implanted in several hundred children with a wide range of results, varying from sound awareness, to improved perception of suprasegmental aspects of speech, to some open-set speech discrimination.[1-4] Although the published data show the superiority of multichannel cochlear implants over single-channel devices in the postlingually deafened adult population,[5-7] it remains to be determined whether this difference will exist in prelingually and perilingually deaf children. Several issues must be addressed in order to evaluate the potential benefits of multichannel cochlear implants to deaf children, including the extent and nature of preoperative and postoperative training, the assessment techniques used preoperatively and postoperatively, and the methods of programming. The factors which may influence the success of an adult, *i.e.*, age of onset, cause of deafness, and length of deafness, must be evaluated for the child as well.

Presented at the Meeting of the Eastern Section of the American Laryngological, Rhinological and Otological Society, Inc., Toronto, Ontario, January 27, 1989.

From the Department of Otolaryngology (S.W., N.L.C., L.S., W.S., R.H.), New York University School of Medicine; and the New York League for the Hard of Hearing (E.Y., D.B.), New York, NY.

Send Reprint Requests to Susan Waltzman, PhD, Department of Otolaryngology, New York University Medical Center, 550 First Avenue, New York, NY 10016.

MATERIALS AND METHODS

Nine profoundly hearing-impaired children aged 2 to 10 years were implanted with the Nucleus® multichannel cochlear prosthesis (Table I). Medical evaluations, including computed tomography scans, were carried out before the administration of the testing protocol in order to rule out medical contraindications to surgery. Administration of the Food and Drug Administration-approved testing protocol,[8] partially outlined in Table II was then attempted on all children.

Following the completion of the initial evaluations, preoperative aural/oral training was begun and continued until the clinician believed the patient had reached a plateau in linguistic progress. This period ranged from 4 months to 1 year, according to the nature and scope of the child's previous training, the child's rate of progress, and to some degree, the child's age.

All training was conducted at the New York League for the Hard of Hearing or by local clinicians using programs designed for the child. Frequency modulation (FM) systems provided the best amplification for these children and were used in place of conventional hearing aids during the preoperative period. Following the preoperative training, the post-training evaluations (Table III) were completed; if the patient was deemed an appropriate candidate for implantation, surgery was scheduled.

Device stimulation took place approximately 1 month after surgery. Postoperative training began immediately following device stimulation and is ongoing. The therapeutic goals are based on the four levels of auditory development: detection, discrimination, identification/recognition, and comprehension. The stimuli used are dependent on and selected according to the child's performance during the preoperative evaluations and stimulation sessions. Attention is paid to both the suprasegmental and segmental aspects of the speech signal. The activities are derived from age- and language-appropriate tasks that interest the child.

Due to the lack of appropriate preoperative and postoperative assessment tools for young children, there was no systematic way to monitor the progress of each child. Because it is important to develop and continually modify the training programs according to each child's changing skills and needs, a Scale of Auditory Percep-

TABLE I.
Population.

Patient	Surgery	Age (Yrs)	Length of Deafness	Cause of Deafness
1	09/10/87	9.9	6 years	Meningitis
2	09/15/87	4.1	3 years	Meningitis
3	01/28/88	2.6	9 months	Meningitis
4	02/11/88	9.1	5.5 years	Meningitis
5	02/25/88	10.1	7.5 years	Meningitis
6	05/24/88	3.9	2 years	Meningitis
7	07/26/88	2.9	2.6 years	Meningitis
8	10/06/88	2.4	Congenital	Unknown
9	11/10/88	3.1	Congenital	Unknown

TABLE II.
Partial List of Tests Included in the Nucleus Protocol for Children.

Sound Effects Recognition Test (SERT)
Monosyllable, Trochee, Spondee (MTS)
Iowa Battery
Vowel Recognition
Consonant Recognition
Word Intelligibility by Picture Identification (WIPI)
Peabody Picture Vocabulary Test—Revised (PPVT)
MAC Battery
Central Institute for the Deaf Everyday Sentence Test (CID)
Northwestern University Monosyllabic Word Test (NU-6)
Northwestern University—CHIPS (NU-CHIPS)
Phonetic Task Evaluation (PTE)
Discrimination After Training (DAT)
Auditory Numbers Test (ANT)
McGarr
Test of Auditory Comprehension (TAC)
THRIFT
Craig Lipreading Test
Grammatical Analysis of Elicited Language (GAEL)
Fundamental Speech Skills Test (FSST)
Speech Pattern Contrast (SPAC)

tion/Production (SAPP) was developed (Table III). The scale incorporates levels of increasing difficulty, *i.e.*, detection, identification, and repetition of suprasegmental and segmental aspects of the speech signal.

Realizing that production provides another estimate of what the child perceives, a speech production skills summary was also included.[9] The test is performed biweekly, and the clinicians for those children residing out-of-town are asked to return the tests to the implant center. This, in addition to frequent phone conversations, allows for improved monitoring of and planning for the out-of-town children as well as the local children. In addition to using the SAPP, the battery of tests required by the protocol have been performed or attempted preoperatively, at 6 months, and at 1 year.

RESULTS

There were no surgical complications in any of the children; their recovery was uneventful, although patient 2 had only partial insertion due to ossification.

The ability of a child to condition to the programming task was not necessarily age-related, but was somewhat dependent on task training techniques carried out between the times of surgery and stimulation. Table IV shows the length of time required for each child to gain usage of all appropriate electrodes. Although initially it appeared that the younger children were taking longer to program, the oldest patient (patient 5) proved to be the most unreliable. However, she received the least amount of training in preparation for this task since she lived a distance away, and

TABLE III.
Scale of Auditory Perception/Production.

Name

Date

	DETECTION	IDENT.	REPEAT BACK	ACT ON
RESPONDS TO:.				
Name				
Environmental Sounds				
SYLLABIC NUMBER				
ba vs ba-ba-ba-ba				
ba				
ba-ba				
ba-ba-ba				
ba-ba-ba-ba				
boy (1)				
baseball (2)				
umbrella (3)				
PITCH				
High				
Low				
High to Low				
Low to High				
DURATION				
Long				
Short				
Long-Long				
Short-Long				
Long-Short				
LOUDNESS				
Soft				
Loud				
SPEECH SPECTRUM				
a				
ee				
oo				
sh				
s				
VOICING				
ba/pa				
ta/da				
ka/ga				
PLACE				
ba/pa				
ma/na				
ya/wa				
MANNER				
ba/ma				
ba/wa				
ha/ka				
SPEECH SKILLS SUMMARY				
Vocal Quality				
Pitch: stable, unstable, voice breaks				
appropriate, too high, too low				
Nasality: adequate, hypernasal, hyponasal				
Vocal/Verbal Output:				
Quality: increase, decrease, same				
List:				

TABLE IV.
Length of Time Needed to Program the Speech Processor and Number of Electrodes in the Program.

Patient	Week 1	2	3	4	5	6	7	8	Final
1	20								20
2	3	4	4	7	7	6	7	8	12
3	10	11	11	18	18	18	18	19	19
4	18	18	18	20	20	19			19
5	13	13	21	21	21	20			20
6	22								22
7	22								22
8	22								22
9	22								22

she refused to wear her hearing aid (in the opposite ear) during the interval between surgery and stimulation.

It is believed that the increased experience of the audiologists in programming the children was a factor with the later children. In addition, the amount of task-related training time was increased after the first few patients were programmed.

Table V shows data for some of the tests in the protocol which can be administered to the patients who have reached the 6-month and 1-year evaluation periods. Overall, patient 1 showed improvement on all tests. He has also improved in terms of communicative effectiveness and speech intelligibility.

Patient 2, who was unable to perform any of the tests until 1 year following implantation, achieved scores of 100% on vowel recognition and 44% on consonant recognition using the implant alone. The WIPI results showed increased audition and lipreading benefits following implantation. The production of both vowels and consonants has increased and been incorporated into his speech pattern.

Patient 3, who could not perform the tests preoperatively, achieved a score of 28% on the WIPI using the implant alone at the 6-month evaluation. Her verbal output has increased dramatically, her vowels and consonants are more precise in their production, and she has incorporated intonation patterns into her speech.

Patient 4 showed no improvement on the suprasegmental portions of the test battery, but had improved scores on the Craig when the implant was used in conjunction with lipreading. To date, there have been minimal changes in her speech-production skills.

Patient 5 improved on several of the suprasegmental tests. The most noticeable post-implant change in patient 5 has been an increase of awareness and detection of speech information and ease of alerting.

The most glaring result is that because of the ages of several of the subjects, there was no standardized way to evaluate their abilities. The only suprasegmental test which all of the first five patients were able to perform was the DAT. Figure 1 shows that mean

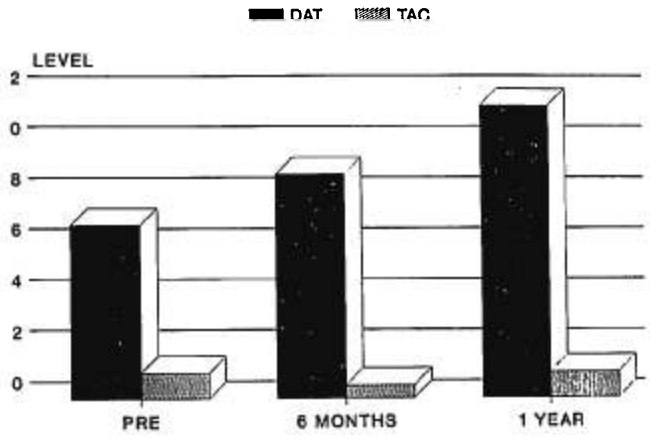

Fig. 1. Preoperative and postoperative results for the DAT and TAC. Mean DAT scores for patients 1–5 are reported for the preoperative and 6-month results. The 1-year DAT result is for patient 1. All TAC results are for patient 1.

performance on this test improved following implantation. The only segmental-features test that all patients could perform were portions of the THRIFT. None of the children scored above chance, either preoperatively or postoperatively, on this test. Very little change was also noted on the TAC, although this test was too difficult for all but patient 1.

The tests listed in the protocol were attempted preoperatively, but not completed, on patients 6 through 9 because of their ages and lack of linguistic skills. None of these children have reached 6-month evaluation level. The SAPP was developed immediately before the implantation of patient 6. Both preoperatively and to date postoperatively, patients 6 through 9 have been monitored using the SAPP.

Before implantation, none of the children was able to perform any of the suprasegmental or segmental tasks required on the SAPP using audition alone, since the children did not benefit from amplification and were essentially nonverbal. Using the SAPP postimplantation, all children alert to a variety of sounds, either spontaneously or in a set-to-listen mode.

Patient 6 has reached the identification and repeat-back stages through the speech spectrum level. Recently stimulated, patient 7 has reached the detection stage for name, environmental sounds, and speech spectrum levels, mainly in a set-to-listen mode. Patient 8 has reached the detection stage for name, environmental sounds, and speech spectrum levels, while reaching the identification stage for the lowest rung in the syllabic number stage. Patient 9 now responds to his name and environmental sounds. In addition, all of these children have shown increases in spontaneous vocalizations as documented on the SAPP.

DISCUSSION

The data have shown varying degrees of improve-

TABLE V.
Preoperative and Postoperative Test Results.

	MTS Chance = 33%			SERT Chance = 25%			MAC S/D* Chance = 50%			MAC N/V* Chance = 50%			Iowa M/F* Chance = 50%			Iowa No. of Syllables* Chance = 25%		
Patient	Pre	6 Mo	1 Yr	Pre	6 Mo	1 Yr	Pre	6 Mo	1 Yr	Pre	6 Mo	1 Yr	Pre	6 Mo	1 Yr	Pre	6 Mo	1 Yr
1	24	46	62	10	20	20	50	65	75	45	48	53	30	35	60	25	42	42
2	CNT	CNT	CNT	CNT	40	55	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT
3	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT	CNT
4	29	16	CNT	50	40	CNT	55	40	CNT	55	70	CNT	60	45	CNT	38	67	CNT
5	16	38	CNT	33	35	CNT	60	50	CNT	25	58	CNT	55	35	CNT	8	46	CNT

*Suprasegmental test. S/D = Same/Different; N/V = Noise/Voice; M/F = Male/Female; CNT = could not test.

ment in all of the children, although the most dramatic gains in both perception and production have occurred in the younger children. The older children, with a relatively longer duration of deafness, have shown slower progress.

We have been impressed by the relative ease with which the electrodes can be programmed for threshold when proper training is used. Although the programming for comfort levels is somewhat more tenuous in the younger children and needs frequent reassessment and readjustment, it did not appear that this affected the child's usage of, or benefit from, the device. The children, however, were initially more comfortable and adjusted to wearing the device more rapidly when the dynamic ranges were underestimated rather than made too loud.

One of the many crucial issues which needs to be addressed concerns the clinician's ability to adequately preoperatively assess a child's candidacy and to monitor and document the child's postoperative progress. In our first few patients, we lacked the ability to perform either task competently when relying solely on the approved protocol. The tests were not age- or task-appropriate for much of our population, and the required administration was too infrequent to allow proper monitoring of the child's auditory and linguistic skills. The SAPP was developed to fill this gap. It has been found that, aside from the value of careful and frequent monitoring in planning an appropriate therapy program, negative changes in either perception or production have been the first indications that adjustments to the minimum audible pressure might be indicated. In addition, we have been able to document the postoperative improvements that we, the parents, and the teachers have been acutely aware of but are unable to show using currently standardized tests. Initially, the gains are seemingly small, *e.g.*, awareness of sound in certain listening conditions or increased vocalizations. However, in a nonauditory and nonverbal child, these are significant gains worthy of documentation and are necessary precursors to the development of linguistic skills. Using a single scale for all of the children in the program has enabled the data to be viewed in a manner that accurately reflects the progress of each child in addition to the status of the group as a whole.

The need for development of standardized speech perception tests for the very young nonverbal or low-verbal child has rapidly become a major area of investigation. Geers and Moog[10] recently described the Low-Verbal Early Speech Perception Test, which includes sections that test pattern perception and word identification; this test has been added to the Nucleus protocol. Other investigators are also developing speech perception tests for young children. We have been involved in some of these clinical trials and believe that they are most promising; however, until they are readily available, we advocate using any appropriate tool in the assessment of the prelinguistic child and the monitoring of postimplantation progress.

All nine children implanted with the Nucleus multichannel cochlear prosthesis showed improvement following implantation. The need for appropriate assessment and monitoring tools is underscored by the lack of formal test results.

BIBLIOGRAPHY

1. Berliner, K.I., Eisenberg, L.S., and House, W.F.: The Cochlear Implant: An Auditory Prosthesis for the Profoundly Deaf Child. *Ear Hear*, 6(suppl):1S–69S, 1985.
2. Berliner, K.I. and Eisenberg, L.S.: Our Experience With Cochlear Implants: Have We Erred in Our Expectations? *Am J Otol*, 8:222–229, 1987.
3. Eisenberg, L.S.: Perceptual Capabilities With the Cochlear Implant: Implications for Aural Rehabilitation. *Ear Hear*, 6(Suppl.):60S–69S, 1985.
4. Thielemeir, M.A., Tonokawa, L.L., Petersen, B., *et al.*: Audiological Results in Children With a Cochlear Implant. *Ear Hear*, 6(Suppl.):27S–35S, 1985.
5. Tye-Murray, N., Gantz, B., Kuk, F., *et al.*: *Word Recognition Performance of Patients Using 3 Different Cochlear Implant Designs.* International Symposium on Cochlear Implants, Duran, 1987.
6. Gantz, B., Tyler, R., *et al.*: Evaluation of Four Cochlear Implant Designs. *Ann Otol Rhinol Laryngol [Suppl]*, 96:145–147, 1987.
7. Gantz, B.J., Tyler, R.S., *et al.*: Evaluation of Five Different Cochlear Implant Designs: Audiologic Assessment and Predictors of Performance. LARYNGOSCOPE, 98:1100–1106, 1988.
8. *Children's Procedures & Protocols Manual,* Cochlear Corporation, 1987.
9. Osberger, M.J.: Speech Production in Profoundly Hearing-Impaired Children With Reference to Cochlear Implants. *Cochlear Implants in Young Deaf Children,* pp. 257–281, 1989.
10. Geers, A.E. and Moog, J.S.: Evaluating Speech Perception Skills: Tools for Measuring Benefits of Cochlear Implants, Tactile Aids, and Hearing Aids. *Cochlear Implants in Young Deaf Children,* pp. 227–256, 1989.