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PRELIMINARY RESULTS FOR THE COCHLEAR CORPORATION MULTIELECTRODE INTRACOCHLEAR IMPLANT IN SIX PRELINGUALLY DEAF PATIENTS

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ABSTRACT

The preliminary results from this study indicate that some prelingually deaf patients may get worthwhile help from a multiple-electrode cochlear implant that uses a formant-based speech processing strategy. It is encouraging that these improvements can occur in young adults and teenagers. The results for two children are also encouraging. A 10-year-old child obtained significant improvement on some speech perception tests. It was easy to set thresholds and comfortable listening levels on a 5-year-old child, and he is now a regular user of the device. There are, however, considerable variations in performance among the prelingual patients, which may be related to the following factors: whether they have had some hearing after birth, the method of education used, the motivation of the patient, and age at implantation.

To study the possible benefits of cochlear implantation for the prelingually deaf, research has been carried out on a small group of patients. This report presents the protocol used for six patients, and some preliminary speech perception data. The research is being performed using a multidisciplinary team consisting of audiologists, educators of the deaf, engineers, otologists, psychologists, psychophysicists, speech pathologists, and speech research scientists.

PROTOCOL

The overall management of patients is designed for the assessment and training of speech perception and production, and language skills over a long period of time. The patient is first assessed to determine whether he or she has a profound-total hearing loss. The patient is then given a trial, with training, using a hearing or tactile aid for a minimum of six months before reassessment. If no satisfactory progress has been made, surgery to insert the multiple-electrode cochlear implant is performed. The patient is assessed three months postoperatively to determine the immediate effects of implantation. Training continues postoperatively and the patient is reassessed at six-month intervals for a number of years.

The management protocol for the preoperative and postoperative assessment and training of patients has been developed by our interdisciplinary team and is still evolving. Within the protocol certain areas of assessment are specified, but the individual tests are varied to meet the developmental age and language skills of the patient.

The protocol is shown in Tables 1, 2, and 3, for speech perception, speech production, and language skills.

Table 1 provides the protocol for the assessment of speech perception. Speech percpetion is first as-

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Table 1. Assessment of Speech Perception in Children

Segmental—vowels and consonants	
Identification	
CVC-VCV confustion studies	
PLOTT test[1]	
Feature analysis	
Suprasegmental—prosody	
MAC battery[2]	
Words	
Closed-set	
ANT[3]	
MST[4]	
NU-CHIPS[5]	
Open-set	
AB words[22]	
Sentences	
BKB sentences[6]	

Table 2. Assessment of Speech Production in Children

Segmental—vowels and consonants	
PLE[7]	
CVC-VCV production and analysis	
Suprasegmental—prosody	
PLE[7]	
Words	
Edinburgh articulation test[8]	
Sentences	
Intelligibility[9]	
Process analysis[10,11]	

Table 3. Assessment of Language in Children

Receptive language—semantics and syntax	
PPVT[12] receptive vocabulary	
Preschool language scale[13]	
Development language scale[14]	
Expressive language—semantics and syntax	
Descriptive analysis of language samples	
Mean length of utterance[15]	
LARSP[16]	
Semantic analysis[17]	
Formal language tests	
Grammatical analysis of elicited language[18–20]	
Communication skills	
Interactional language measures[21]	

sessed at a segmental or phonetic level for vowels and consonants. For example, the PLOTT[1] test is a two-alternative forced choice procedure for the assessment of vowel and consonant characteristics.

The suprasegmental aspects of speech are assessed in older children using part of the Minimal Auditory Capabilities (MAC) battery.[2] Word perception can be assessed in young children using closed-set tests, for example, the Auditory Numbers Test (ANT),[3] the Monosyllable Spondee Trochee (MST),[4] the NU-CHIPS test,[5] which is a four-alternative forced choice test. Open-set word tests are given to older children. When testing for key word recognition in sentences, the BKB[6] sentences of Bench and Bamford are used.

Table 2 shows the protocol for the assessment of speech production. Speech production is assessed at a segmental level using the Phonetic Level Evaluation (PLE)[7] procedure developed by Ling. The patient is also asked to produce vowels in a consonant-vowel-consonant (CVC) context, and consonants in a vowel-consonant-vowel (VCV) context. The suprasegmental aspects of speech production are also assessed using the PLE.[7] Word production is assessed using the Edinburgh Articulation test,[8] and the ability of patients to produce words in sentences by the Intelligiblity Test of McGarr.[9] In addition, process analysis[10,11] of a spontaneous speech sample is performed.

Not only is it important to assess speech perception and production at segmental, suprasegmental, word, and sentence levels, but it is considered equally important to assess the receptive and expressive language and communication skills. The protocol, with examples, is shown in Table 3. The semantics and syntax of receptive language are assessed using the Peabody Picture Vocabulary Test (PPVT)[12] and the preschool language scale of Zimmerman and colleagues,[13] or alternatively the development language scale of Reynell.[14] The semantics and syntax of expressive language are assessed using the mean length of utterance,[15] the Language Assessment Remediation and Screening Procedure of Crystal (LARSP),[16] and semantic analysis of a language sample using the procedures of Bloom and Lahey.[17] A grammatical analysis of elicited language is also performed.[18–20] Finally, communication skills are assessed using interactional language measures of Cole and St. Clair-Stokes.[21]

PATIENT HISTORIES

Six prelingually deaf patients have received the Cochlear Corporation multiple-electrode cochlear implant (three adults, one teenager, and two children). The first patient, Pre-1, was diagnosed as having a profound-total hearing loss at the age of 15 months following meningitis. He had a hearing aid fitted at 15 months and was educated almost entirely by signing. His speech was at a 25% level on the McGarr Intelligibility Test and his speech reception vocabulary was at a five-year-old level. He received the implant at the age of 25 years and has had the device for 3.3 years. He is an occasional user of the device.

The second patient, Pre-2, was diagnosed as having a profound-total loss at 3 years of age. The cause of deafness was not known but it was believed to be congenital. She had a hearing aid fitted at age 3 and was educated almost entirely by signing. Her speech was at an 8% level on the McGarr Intelligibility Test, and her speech reception vocabulary was at a 5-year-old level. She received the implant at the age of 24 years and has had the device for 3.0 years. She is an occasional user of the device.

The third patient, Pre-3, was diagnosed as having a profound-total hearing loss at the age of 16 months due to meningitis. He was fitted with a hearing aid soon afterward and educated using cued speech. His speech was at a 44% level on the McGarr Intelligibility Test, and his speech reception vocabulary was at a 6-year-old level. He had a cochlear implant at the age of 14 years and has been wearing it for 1.5 years. He is a regular user of the device.

The fourth patient, Pre-4, an adult, was diagnosed as having a severe-profound hearing loss at the age of 3 which became a profound-total loss over the next fifteen years. The cause of deafness is unknown but is presumed to be congenital. This patient is different from the first two adults in that she had some residual hearing in the first four years of life. She is also different from the first two because she was educated by auditory/oral means in a normal school setting and, although her speech was at the 25% level on the McGarr Intelligibility Test, she had better communication skills than the first two adults. She also had a higher speech reception vocabulary (7 years 3 months). She received the device in the worse ear at the age of 22 and has been using it for 1.0 year. She is a regular user.

The fifth patient, Pre-5, was diagnosed as having a profound-total hearing loss at the age of 3.5 years due to meningitis. He was fitted with a hearing aid soon afterward and educated by total communication. His speech was at a 0% level on the McGarr Intelligibility Test, and his speech reception vocabulary at a 5 year 11 month old level. He received the new "mini" cochlear implant designed for children (Fig. 1) at the age of 10 years and has been wearing it for 1.0 year (Fig. 2). He is a regular user of the device and is now spending most of his time in a normal classroom setting.

Figure 2. The 10-year-old patient using the new "mini" cochlear implant incorporating a magnet in the headset for easy attachment and alignment with the underlying receiver coil.

The sixth patient, Pre-6, is a 5-year-old boy who became profoundly-totally deaf at the age of 3 following meningitis. He had binaural high-gain, low-frequency emphasis hearing aids fitted one month after recovery. He commenced habilitation in a cued speech setting. Six months prior to implantation he had a trial with a "Tactaid I" tactile device, and preferred this device to his hearing aids. Prior to implantation he had a speech reception level of 2 years of age on the PPVT. His speech intelligibility was very poor, as he only used a few one-word utterances. During the preoperative evaluation he also received some cross-modality training in scaling the intensity of light and electrotactile stimulation to help postoperatively in setting threshold, comfortable loudness, and discomfort levels for electrical stimulation. During this training he was given blocks of different sizes and trained to point to the smallest block for a low level of stimulation, and to the bigger blocks for higher or uncomfortable levels of stimulation. This child also received the new "mini" cochlear implant (Fig. 3).

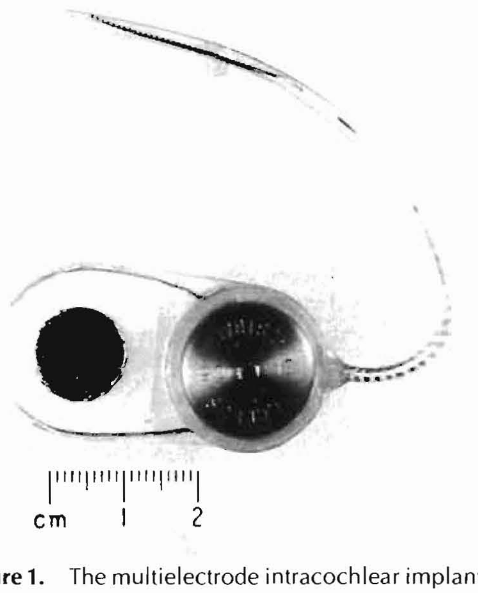

Figure 1. The multielectrode intracochlear implant for children.

PRELIMINARY RESULTS

Some preliminary speech data are presented.[23] In interpreting the results it is important to note that some patients have had limited formal training with speech perception for a variety of reasons. The first two adults sign and have difficulty in changing their system of communication. The oral adult, Pre-4, lives 1,000 km away, and although using the device

Figure 3. The 5-year-old child using the "mini" cochlear implant.

regularly, has had little formal training. The prelingually deaf teenager has had formal training during the holidays, but this cannot be easily fitted into the school program. He has home visits from our staff.

The 10-year-old prelingually deaf child, shown in Figure 2, has regular visits from our staff and is now having most of his lessons in a school with normal-hearing children. His training has concentrated on an auditory-oral approach to maximize the use of the new auditory information provided by the implant.

Following the operation on the 5-year-old child there was no difficulty in setting thresholds and comfortable listening levels for his individual electrodes. This was done by training him to relate the intensity of the electrical stimulus to the size of blocks in a similar manner to the procedure used preoperatively as previously discussed. The procedure was made easier by encouragement from the 10-year-old participating at the same time. He acted in the capacity of a behavioral model. The 5-year-old child now wears the implant for approximately 12 hours during the day; he puts it on when he gets up in the morning and takes it off before going to bed. He tells his parents and teachers when it is not working so that the batteries can be replaced. His educational management has continued in a cued speech environment, and steps are being taken to increase the amount of auditory training. As this child (see Fig. 3) has only recently received the implant, and as his speech and language were poor prior to surgery, no postoperative data are yet available.

The results for a test of suprasegmental recognition, the male/female discrimination that is based on voicing, is shown in Table 4. The scores for the oral adult, Pre-4, and the teenager, Pre-3, were significantly above chance, and higher than scores for either of the first two adults, Pre-1 and Pre-2.

The results for vowel identification are shown in Table 5, for electrical stimulation alone, lip-reading alone, and electrical stimulation plus lip-reading. First, all patients were able to obtain some vowel identification information for electrical stimulation alone. For patients Pre-1 and Pre-2 they were low and may be related to duration cues. The scores for the other patients were higher, which may be related to the use of place pitch information. However, for patients Pre-1 through 4 there is little improvement when electrical stimulation is combined with lip-reading compared to lip-reading alone. The lip-reading score were high for the oral patients Pre-3 and Pre-4, so further improvement was not likely. The increased scores for lip-reading combined with electrical stimulation compared to lip-reading alone in the child Pre-5 were significant at the 0.01 level.

The results for consonant identification are shown in Table 6. The electrical alone scores for Pre-4 and Pre-5 were higher than for Pre-1, Pre-2, and Pre-3. There was also some improvement when electrical stimulation was combined with lip-reading for all patients except Pre-3.

Finally, it is important to determine how all these tests relate to the patients' perception of open-sets of words and running speech. These tests are to be performed in all patients in the future, but only preliminary results for some patients are available. For the adults Pre-1 and Pre-2, their language level and communication skills were initially very poor, and their perception of words and running speech is still very difficult to assess.

The teenager Pre-3 has recently undertaken tracking tests and the results for his first five sessions are shown in Figure 4. He has shown an average 30% improvement in tracking rate from 25.4 words per minute to 33 words per minute when using the

Table 4. Percent Correct Scores for Four Prelingual Patients in the Male/Female Identification Test

Patient	%
Pre-1	44
Pre-2	68
Pre-3	80*
Pre-4	76*

*$P < 0.01$

Table 5. Percent Correct Scores for Vowel Identification for Five Prelingual Patients

Patient	*Months*	*E (%)*	*V (%)*	*EV (%)*
Pre-1	6	18	39	46
Pre-2	6	14	54	50
Pre-3	2	24	84	84
Pre-4	1	(51)*	88	93
Pre-5	3	24	44	65⁺

*In the E condition for Pre-4, six instead of eleven vowels were used

⁺$P < 0.01$, V versus EV conditions

Note: E = multi-electrode stimulation alone, V = lip-reading alone, EV = electrical stimulation combined with lip-reading

Table 6. Percent Current Scores for Consonant Identification for Five Prelingual Patients

Patient	*Months*	*E (%)*	*V (%)*	*EV (%)*
Pre-1	6	12	33	40
Pre-2	6	8	26	30
Pre-3	1	7	31	31
Pre-4	2	(31)*	47	65⁺
Pre-5	3	17	42	50

*In the E condition for Pre-4, six instead of twelve consonants were used

⁺$P < 0.01$, V versus EV conditions

E = multi-electrode stimulation alone, V = lip-reading alone, EV = electrical stimulation combined with lip-reading

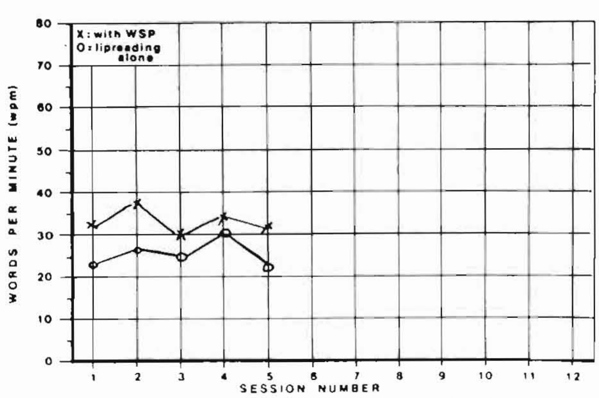

Figure 4. The speech tracking scores for the 14-year-old (Pre-3) in the lip-reading alone and lip-reading with his wearable speech processor.

cochlear implant combined with lip-reading, compared with lip-reading alone. This is an encouraging result as it indicates that a 14-year-old can obtain some benefit in the perception of running speech.

The oral adult, Pre-4, had the open-set CNC word and CID sentences tests administered in the lip-reading alone and lip-reading plus electrical stimulation conditions. The results six months postoperatively are shown in Table 7. The differences between the lip-reading alone and combined scores were significant at the 0.01 level for both tests. For our 10-year-old (Pre-5), we are encouraged by his initial improvements in vowel discrimination. Word and running speech tests have not yet been done.

Table 7. Percent Correct Scores for Open-Set Tests, Patient Pre-4

Open-set	%
CNC words	
Lip-reading alone	30
Electrical + lip-reading	56*
CID sentences	
Lip-reading alone	43
Electrical + lip-reading	80*

*$P < 0.01$

DISCUSSION

This study has shown significant speech perception test scores for male/female identification, vowels, consonants, and open-sets of CNC words and CID sentences for a prelingually deaf adult patient (Pre-4) who was severely deaf at the age of three but became profoundly deaf soon afterward. There were significant speech perception scores for vowels in a 10-year-old child (Pre-5) who became profoundly deaf at the age of 3.5 years. The teenager (Pre-3) who became profoundly deaf at 1.3 years had significant male/female identification scores, but poor scores for vowel and consonant identification. There was, however, an improvement in speech tracking for electrical stimulation plus lip-reading compared to lip-reading alone. On the other hand, the two adults (Pre-1 and Pre-2), who were deaf at 1.25 years and birth respectively had poor speech perception scores. Although the number of patients is small, there may be a trend for speech perception performance to be better where there was some residual hearing after birth or the patient went deaf after the age of 3.

It is also interesting to compare the speech perception results with the psychophysical performance of the patients for intensity, rate, and place discrimination.[24] In the study by Tong and associates[24] psychophysical testing was extensive in patients Pre-1, Pre-2, and Pre-3, and some data were obtained from Pre-4. The results showed that patients Pre-1 and Pre-2, who had little speech recognition, had no rate or place discrimination, and little ability to discriminate intensity. On the other hand, the teenager (Pre-3) developed quite good rate discrimination over a twelve-month period. This would account for his ability to make male/female discrimination and explain the improvement in his speech tracing score for electrical stimulation combined with lip-reading compared to lip-reading alone. The patient Pre-4 had satisfactory place and rate discrimination which was comparable to that of a poor-average postlingually deaf patient.

The method of education used could also be a factor influencing the overall results. Pre-1 went deaf at the same age as Pre-3, both from meningitis. However, Pre-1 was taught to sign and Pre-3 was taught cued speech. The speech perception and psychophysical results were better for Pre-3.

As Pre-1 and Pre-2 signed, it was difficult to communicate with them, and the fact that they signed and had poor receptive language meant that speech perception testing was very difficult. These factors could also have led to poor motivation in Pre-1 and Pre-2 during auditory training sessions.

Finally, it is encouraging that, in the 5-year-old child, thresholds and comfortable listening levels can be established for each electrode, and that this can be done with relative ease using prior conditioning to other stimuli, such as visual and electrotactile ones.[25]

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