

Patient Results for a Multiple-Channel Cochlear Prosthesis

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Abstract

Six patients implanted with multiple-channel cochlear prostheses and using take-home, wearable speech processors, were assessed three months postoperatively using the Minimal Auditory Capabilities (MAC) battery. Results showed statistically significant improvement on virtually all tests over their preoperative performance with a hearing aid. Four patients showed significant results for open set speech testing. Lipreading tests, using word and sentence material, showed significant improvement for all patients when the cochlear prosthesis was used with lipreading compared to lipreading alone. All the above tests were carried out without training with recorded material of an unfamiliar speaker. Improvements in communication speed of 55% to 126% over lipreading alone were obtained for the six patients as assessed by the speech tracking procedure. These results are for scores averaged over eight sessions of tracking with the two conditions (with and without cochlear prosthesis). The order of conditions was alternated at each session to control practice effects. The wearable speech processor is used all day every day by five patients, and four hours a day by one patient. Reported benefit is not only for communication but also for the recognition of environmental sounds. Four patients have attempted using the telephone with some success in a restricted context situation. One patient uses the telephone routinely without using any special coding strategies. Reported problems with the cochlear prosthesis are primarily related to background noise. Results for these six patients are consistent with those obtained for two patients implanted with a prototype multiple-channel prosthesis in 1978-1979.

Introduction

A total of eight patients have been assessed with the multi-channel cochlear prosthesis at the University of Melbourne. The first two patients were implanted with a prototype device in 1978 and 1979, and their results with various speech evaluation procedures have been reported and summarized in detail elsewhere (1). Briefly, these results indicated that some very significant benefit could be obtained for these patients when using the cochlear prosthesis with external speech processing, particularly when using the device in conjunction with lipreading. It was also shown that some significant understanding of speech was possible without lipreading (open-set) for both patients, although this was fairly limited.

These encouraging results with the prototype prosthesis led to the development by Nucleus Limited of a more refined and sophisticated device using the same basic design principles. An external speech processor was also developed to give the patients a convenient portable device for everyday use of the prosthesis. This paper summarizes the speech evaluation and other results for six patients recently implanted (late 1982) with the Nucleus multiple-channel hearing prosthesis.

Methods

Each patient underwent a six-month trial, including training, with a hearing aid or vibrotactile aid before surgery. Following this trial, patients were assessed with the aid using a modified version of the MAC battery (3) of speech discrimination tests. These tests were carried out with recorded material of an unfamiliar speaker. Lipreading assessment was also carried out using videotaped material of an unfamiliar speaker with and without the aid to assess whether any significant benefit was being obtained from use of the aid. The tests used were CID everyday sentences, CNC monosyllabic words and SPIN test sentences. No significant improvement in lipreading performance was obtained on any test for any patient when using their aid in conjunction with lipreading over lipreading alone.

Following surgery and recovery, patients underwent a rehabilitation program of approximately ten weeks duration which included the psychophysical testing required for fitting the patients' speech processor, counselling in the use of the device, some auditory and auditory-visual training, and ongoing evaluation and testing. Speech tracking (2) was used as a training and evaluation procedure during the program. Speech tracking requires the patient to repeat verbatim passages of text read by a tester. The tester uses a hierarchy of strategies to help the patient if the response is incorrect. Performance is measured in terms of words per minute repeated correctly and gives an indication of the patients' communication speed. This procedure was carried out under conditions of lipreading alone and lipreading with the cochlear prosthesis with the order of conditions alternated at each testing session to minimize intra-session practice effects. At the completion of the rehabilitation program, each patient was evaluated with their cochlear prosthesis using the MAC battery under the same conditions as the preoperative assessment with a hearing aid. The lipreading tests were also performed again (using different lists) with and without the cochlear prosthesis to assess the benefit obtained over lipreading alone when using the prosthesis.

Patients

Patient 1 was a 37-year-old male who developed a severe to profound hearing loss after treatment with ototoxic drugs at the age of 4-1/2 years. He gained some benefit from a hearing aid until the age of 21 years when he had a sudden total loss of hearing in the aided ear, leaving him with a total bilateral loss.

Patient 2 was a 62-year-old female who had gradual progressive hearing loss associated with chronic otitis media in her teens. Her hearing deteriorated further during pregnancy until in her early

thirties she was profoundly deaf in both ears. She has had no significant benefit from hearing aids since that time.

Patient 3 was a 22-year-old female who as a child had multiple ear infections associated with chronic central perforations of the tympanic membrane in both ears. She had a number of operations on both ears including myringoplasties and tympanoplasties. By the age of 14, she had a total bilateral hearing loss.

Patient 4 was a 23-year-old female who as a child had multiple ear infections associated with chronic central perforations of the tympanic membrane in both ears. She had a number of operations on both ears including myringoplasties and tympanoplasties. At the age of 14 she had a profound bilateral hearing loss and could not gain benefit from hearing aids. She had thus been profoundly deaf for nine years.

Patients 1 through 4 reported hearing sensation for stimulation at sites right across the 22-electrode array. Furthermore, they were able to discriminate the hearing percepts elicited at different sites across the entire array.

Patient 5 was a 74-year-old male who had a sudden loss of hearing at the age of 37 years, and became severely deaf. Since that time he lost hearing in steps, and became totally deaf nine years prior to surgery. Polytome x-rays showed resorption of bone over the apical and middle turns of the cochlea, and a narrow basal turn consistent with cochlear otosclerosis. At surgery, the round window niche was found replaced by bone, and the bone had to be drilled to a depth of approximately 3 mm before the scala tympani was entered. The electrode was then passed easily for a distance of 20 mm. At his first postoperative test session it was discovered that stimulating the more apical electrodes lying close to where the horizontal segment of the facial nerve crossed the apical and middle turns of the cochlea produced sound sensations. The two most basal electrodes sited in the area drilled caused pain in the ear, presumably due to stimulation of the tympanic branch of the glossopharyngeal nerve. These unpleasant side effects have restricted the usable length of the electrode array from 16 mm to 5 mm for this patient.

Patient 6 was a 65-year-old man who had a progressive loss of hearing in both ears due to acoustic trauma and recurrent otitis media. He had been profoundly deaf in the left and totally deaf in the right ear since 1966. In 1979, he had a multiple-channel cochlear implant operation in the left ear, but the receiver stimulator (not the electrodes) had to be explanted in 1982 due to infection around the package. This occurred following the creation of a sinus by pressure from the arm of his glasses on a prominent edge of the receiver stimulator. In view of encouraging speech perception results with the prototype device, this patient requested the improved cochlear prosthesis. In view of the infection in the left ear, it was considered desirable to operate on the right ear. This presented some difficulties as electrical stimulation of the promontory was negative, and he had a large exostosis in the auditory canal partly obscuring a scarred drum and central perforation. An operation was undertaken, the exostosis removed, the cochlea stimulated with a ball electrode placed on the round window, and the perforation grafted. The patient made a good recovery and a cochlear implant was subsequently performed. At surgery, there was a lot of scar tissue in the middle ear and some had penetrated

into the apical and middle turns of the cochlea through an area of resorbed bone. The electrode array was inserted for a distance of 20 mm. Following surgery, it was found that electrodes in the apical half of the electrode array displayed high thresholds for auditory sensation and were not discriminated by the patient, whereas electrodes in the basal half of the array were well discriminated. This patient was able to effectively use 10 of the 22 electrodes in the array. Table 1 summarizes the patient details.

TABLE 1

Summary of patients implanted with multiple-channel cochlear prostheses
at the University of Melbourne in 1982.

PATIENT	SEX	AGE	YEARS OF PROFOUND DEAFNESS	AETIOLOGY
1.	M	37	16	Ototoxic drugs
2.	F	62	30	Otitis media? Otosclerosis?
3.	F	22	4	Meningitis
4.	F	23	9	Otitis media Surgical trauma?
5.	M	74	9	Cochlear otosclerosis
6.	,	67	18	Acoustic trauma?

Results of speech testing

Results of the MAC battery tests, both preoperatively with hearing aid or tactile device and postoperatively with the cochlear prosthesis, are presented in Table 2. For the closed-set tests, a chance score is also given to allow the mean scores to be placed in perspective. Statistical analysis using a simple t-test showed that the results for each test were significantly better for the cochlear prosthesis than for the hearing aid or tactile device at the 95% level of confidence, except for the male/female speaker discrimination test

TABLE 2

Mean percent correct scores for six multiple-channel cochlear prosthesis patients both preoperatively with a hearing aid or vibrotactile aid and postoperatively using the prosthesis. Chance scores are also shown for the closed-set tests. All testing was carried out with no prior training using recorded material of an unfamiliar speaker.

DESCRIPTION OF TEST	CHANCE SCORE	HEARING AID*	COCHLEAR PROSTHESIS#
A. SUPRASEGMENTAL TESTS.			
1. One versus two syllables	50	77	96
2. Noise/voice test	50	69	96
3. Accented word test	25	47	80
4. Male/female test	50	68	83
5. Question/statement test	50	49	46
B. CLOSED-SET TESTS.			
1. Spondee same/different test	50	70	88
2. Four choice spondee test	25	37	78
3. Vowel test	25	33	51
4. Initial consonant test	25	25	43
5. Final consonant test	25	27	48
C. OPEN-SET TESTS.			
1. Spondee recognition	-	1	14
2. Monosyllabic words	-	0	5
3. Phoneme recognition	-	6	25
4. CID everyday sentences	-	0	9
5. Environmental sounds	-	13	27

* Presented at MCL for hearing aid: typically 90-95 dBA.

Presented at MCL for cochlear prosthesis: typically 70-75 dBA.

and the question/statement test. This indicates that this group of patients is performing significantly better on a wide range of auditory discrimination tasks, including open-set speech tests, than was possible without the cochlear prosthesis. However, it is important to consider these patients separately as the averaged results can be misleading if one or two patients have very good results. In Figures 1, 2 and 3, results for each of the patients are presented graphically for two suprasegmental tests (Figure 1), two closed-set speech tests (Figure 2)

and two open-set speech tests (Figure 3). The filled bars in each case show percent correct scores for preoperative testing with hearing aid and the open bars show the postoperative scores with the cochlear prosthesis. All patients show improvement on most of the tests with the performance varying from patient to patient. The largest discrepancy amongst patients is in the CID everyday sentence test for which patient 4 scored 38% whereas the other patients only picked up 2 or 3 words. Patient 4 also has the best scores on most of the other tests, but her superior ability to use the information from the cochlear prosthesis is clearly shown for the everyday sentence test. This particular result is consistent with the observation that this patient is able to routinely use the telephone in a normal fashion (without special codes). None of the other patients are capable of this at present, although patients 1, 3 and 5 have used the telephone in limited context situations.

Results of the postoperative lipreading assessment with and without the cochlear prosthesis are shown in Figures 4, 5 and 6. In each of the tests, the scores for lipreading with the cochlear prosthesis are better than for lipreading alone for each patient, although the magnitude of the improvement varies amongst patients and from test to test. One point of note here is that four of these patients (1, 2, 3, 4) are good lipreaders, one is moderately good (patient 6) and one is very poor (patient 5). Unfortunately, patients 5 and 6 have limited multiple-channel systems for the reasons outlined above and their performance on the MAC battery tests is poorer than the other patients. This means that there is no patient in this group who has a fully usable multiple-channel system and is a poor lipreader, for whom we might expect a considerable improvement on the lipreading tests. Nonetheless, the improvements seen are significant and consistent.

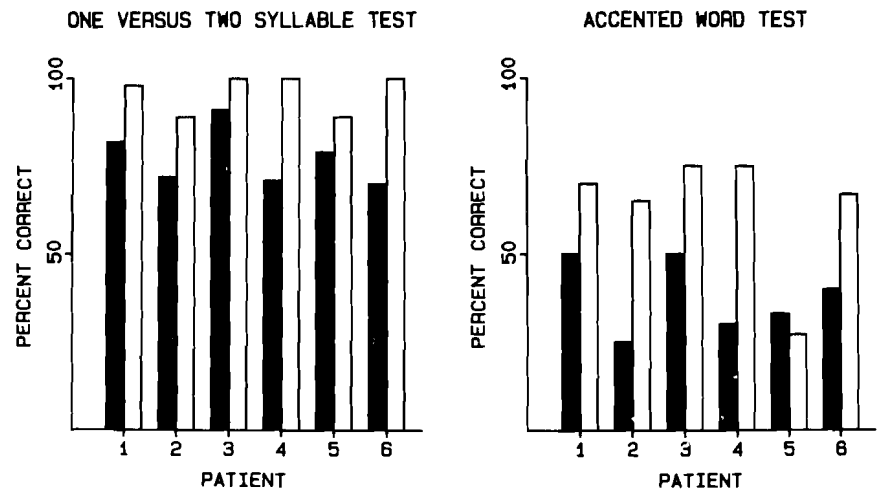


Figure 1: Percent correct scores on two suprasegmental tests from the modified MAC battery for six multiple-channel cochlear prosthesis patients both preoperatively with a hearing aid or tactile aid (filled bars) and postoperatively with the cochlear prosthesis (open bars). All tests were prerecorded with an unfamiliar speaker and presented at MCL which was an average 20 dB higher for the hearing aid than for the cochlear prosthesis.

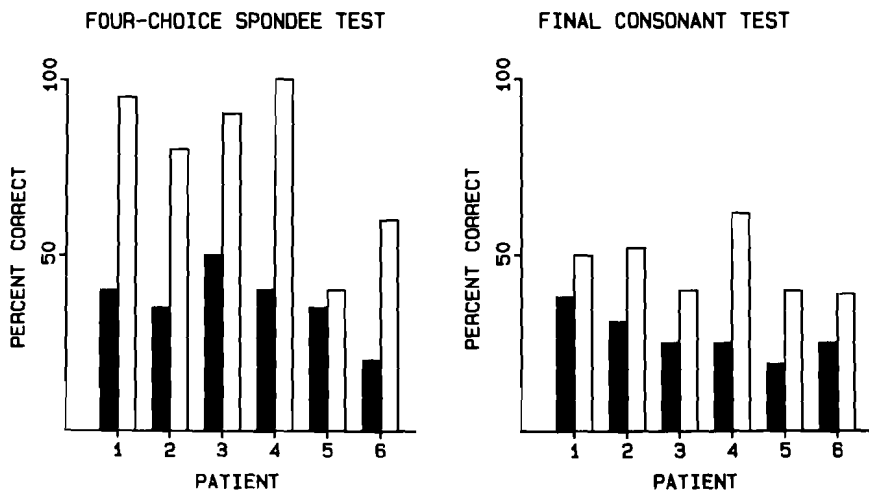


Figure 2: Percent correct scores on two closed set speech tests from the modified MAC battery for six multiple-channel cochlear prosthesis patients both preoperatively with a hearing aid or tactile aid (filled bars) and postoperatively with the cochlear prosthesis (open bars). All tests were prerecorded with an unfamiliar speaker and presented at MCL which was an average 20 dB higher for the hearing aid than for the cochlear prosthesis.

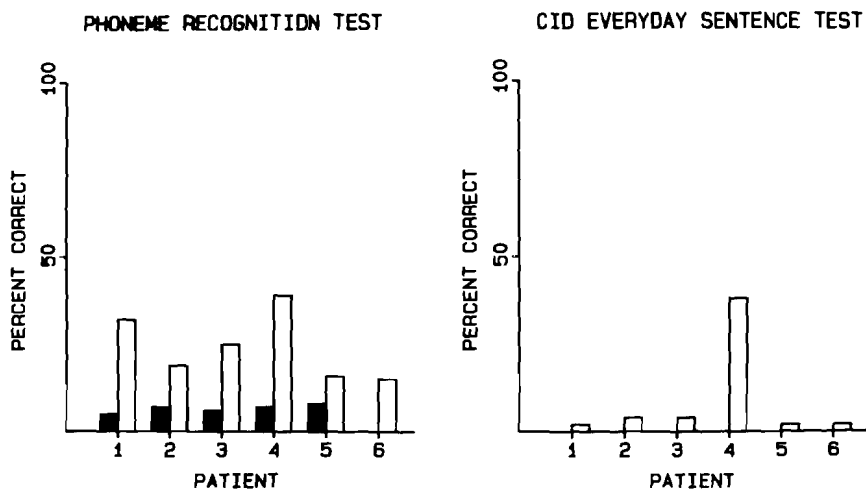


Figure 3: Percent correct scores on two open set speech tests from the modified MAC battery for six multiple-channel cochlear prosthesis patients both preoperatively with a hearing aid or tactile aid (filled bars) and postoperatively with the cochlear prosthesis (open bars). All tests were prerecorded with an unfamiliar speaker and presented at MCL which was an average 20 dB higher for the hearing aid than for the cochlear prosthesis.

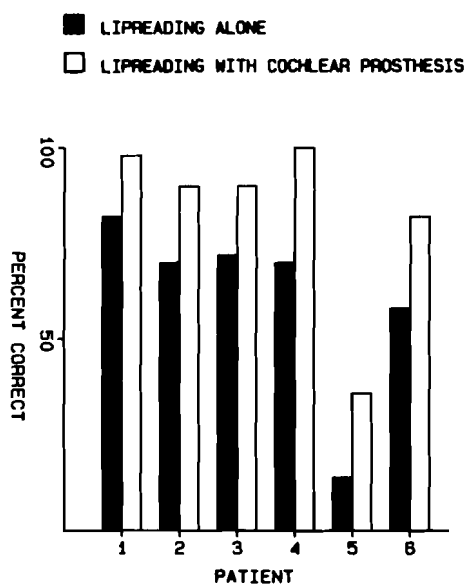


Figure 4: CID Everyday Sentence Test. Results of lipreading assessment with and without the cochlear prosthesis using the CID everyday sentence test for six multiple-channel cochlear prosthesis patients. All test material was recorded on videotape by an unfamiliar speaker and the "lipreading with cochlear prosthesis" condition presented first to load any intrasession practice effect onto lipreading alone.

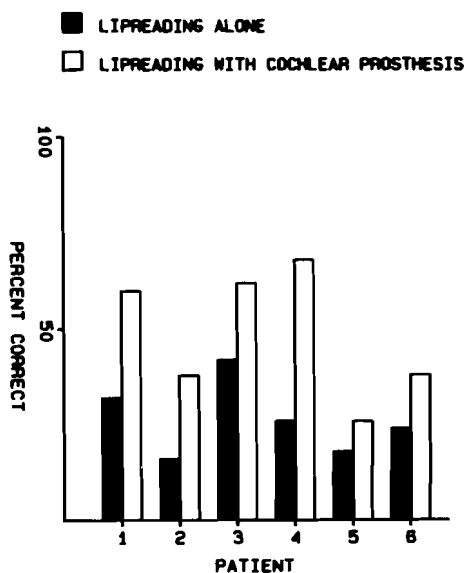


Figure 5: CNC Monosyllabic Word Test. Results of lipreading assessment with and without the cochlear prosthesis using the CNC monosyllabic word test for six multiple-channel cochlear prosthesis patients. All test material was recorded on videotape by an unfamiliar speaker and the "lipreading with cochlear prosthesis" condition presented first to load any intrasession practice effect onto lipreading alone.

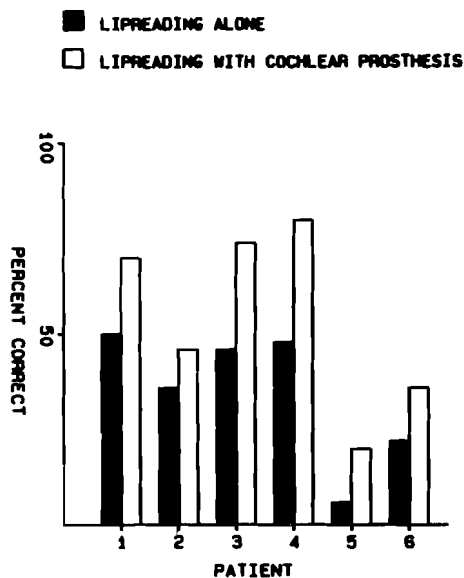


Figure 6: SPIN Sentence Test. Results of lipreading assessment with and without the cochlear prosthesis using the SPIN test sentences for six multiple-channel cochlear prosthesis patients. All test material was recorded on videotape by an unfamiliar speaker and the "lipreading with cochlear prosthesis" condition presented first to load any intrasession practice effect onto lipreading alone.

Speech tracking assessment

The speech tracking procedure (2) was used during rehabilitation as a training technique and to attempt to give some idea of the effect of the cochlear prosthesis on the patient's communication speed. Intra-session practice effects were controlled by alternating the order of conditions (lipreading alone and lipreading with prosthesis) at successive test sessions. The mean results of eight test sessions (6 for patient 5) showed improvements of between 55% and 126% when using the prosthesis.

Patient usage

The wearable speech processor is used all day every day by five of the patients and four hours a day by the sixth patient. Patients report the prosthesis as being useful for communication in one-to-one and group situations, for recognition and discrimination of environmental sounds, for watching television, and (for four patients) for using the telephone. Although all of the patients display some ability for open-set recognition of speech at the phoneme level, only one patient (patient 4) is able to perform well enough to have a fairly normal conversation without lipreading. Patients have not reported any uncomfortably loud sounds from the prosthesis, although some sounds have been reported as unpleasant, particularly continuous high frequency noise. Loud sounds are not encountered as each speech processor is programmed individually for a particular patient and restricts all

stimulation on any electrode to below the patient's "comfortable" level for that electrode. Patients find that listening to music does not give very successful results although they are able to discriminate it from other sounds and can generally pick up the rhythm of the music.

Environmental sounds

Environmental sounds have been a continued source of enthusiasm for the multiple-channel cochlear prosthesis patients as they are able to learn to recognize a wide variety of sounds around them without problem. This is probably because most environmental sounds are peculiar to a certain situation or context (e.g., at an airport one is likely to interpret a loud roar as an airplane engine rather than a waterfall which sounds similar). Patients are always anxious to relate stories about new sounds that they discover. The important thing about this multiple-channel system is that the patients are able to perceive quite a large range of sounds because of the pitch information available by stimulating different electrode positions. Some of the sounds reported by the patients as being recognized consistently are: telephone ring, dial tone and engaged signal; cars passing, turn indicator, car horns while driving; kettle whistles; door bells, bird calls and many others. Four patients are able to recognize their name when called from another room or from behind.

Tinnitus

The patients who had tinnitus preoperatively have found that their tinnitus is reduced on the implanted side when using the speech processor. The tinnitus has not disappeared in any case and tends to return to the preoperative level when stimulation is stopped. In no case has tinnitus been increased or initiated (for patients with no preoperative tinnitus) by the electrical stimulation.

Speech production

No formal studies have been carried out regarding speech production as yet, but reports from family and friends of the patients indicate that control of voice level has greatly improved. Other changes have been noted in terms of naturalness and clarity, and one patient has been able to learn how to say a number of new words (this patient went deaf at 4 1/2 years and thus has some limitations in vocabulary). All patients' speech was recorded on audio tape preoperatively, and a formal study of their speech production changes is to be undertaken.

Problems with the multiple-channel cochlear prosthesis

All six patients implanted in 1982 made good recoveries from surgery and have had no medical complications or problems since then. Once patients had been fitted with their speech processors, two problems became evident with the system as it was. The positioning of the external coil unit was not firm enough for continued operation of the device during physical activity and the understanding of speech was severely affected by quite moderate levels of background noise. This second problem is not a new one to anyone who has been involved with hearing aids. It has been overcome to a certain extent by the

development of a special miniature directional microphone mounted on the headset which holds the external coil. The positioning problem has been solved by the development of a headset and coil unit which holds the coil firmly enough to retain positioning during physical activity, but is light enough and unobtrusive enough to be aesthetically acceptable and comfortable for all day use. Only one patient (patient 5) has had non-auditory sensations elicited by electrical stimulation, and this is easily controlled by not using the electrodes concerned in this patient's speech processor. However, this leaves him with a limited multiple-channel system compared with the other patients, and he shows poorer speech discrimination.

Conclusion

Results of the pre and postoperative testing using the MAC battery tests showed significant improvement for all six patients on closed set and open set tests when using the cochlear prosthesis as compared to conventional hearing aids. Results varied from patient to patient with factors such as age, length of deafness, and aetiology contributing to overall performance. Lipreading assessment showed improved results for all patients when using the cochlear prosthesis over lipreading alone for word and sentence material. Speech tracking also showed improvement over lipreading alone in a communication situation. All patients are daily users of the device and report help with communication and environmental sounds. No adverse side effects have been reported from use of the cochlear prosthesis at this stage.

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