

Hearing Preservation in Cochlear Implantation for Electric Acoustic Stimulation

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Objective—To evaluate the possibility of preservation of low-frequency hearing in atraumatic cochlear implant electrode insertion procedures for combined, ipsilateral electric and acoustic stimulation.

Material and Methods—A total of 21 patients were implanted with a MED EL C40+ cochlear implant using an atraumatic electrode insertion technique to preserve residual low-frequency hearing. Pure-tone audiometric thresholds were measured pre- and postoperatively to evaluate the degree of preserved hearing. Speech discrimination tests in quiet and with background noise were performed in a patient with successful hearing preservation.

Results—Using the atraumatic electrode insertion procedure with an insertion depth of 360° (18–24 mm), hearing preservation could be achieved in 18/21 patients (85.7%). Three patients (14.3%) lost their residual low-frequency hearing after the implantation. Residual hearing was preserved completely in 13 patients (61.9%) and partial hearing preservation was possible in 5 (23.8%). Preliminary speech discrimination tests showed a dramatic benefit for the combined electric and acoustic stimulation mode compared to cochlear implantation alone.

Conclusion—Preservation of low-frequency hearing in cochlear implantation is possible in patients implanted because of profound high-frequency deafness. With the development of new, more atraumatic electrode designs, preservation of residual hearing should be further improved. *Key words:* atraumatic electrode insertion, auditory stimulation, hearing conservation, hybrid implant, neurostimulation.

INTRODUCTION

During the last decade, successful treatment of severe-to-profound hearing loss became possible using cochlear implants. Improvements in the design of the implant and the surgical procedure widened the indication criteria. In addition to completely deaf patients, subjects with residual hearing and monosyllable discrimination scores of $\leq 30\%$ became eligible for cochlear implantation. In our department the mode of electric and acoustic stimulation (EAS) of the auditory system has been used since 1999 (1–3). The main principle of this new modality is to stimulate the non-functioning high-frequency areas of the cochlea with a cochlear implant and preserve the low-frequency portions of the cochlea for acoustic stimulation. Candidates for EAS stimulation should have relatively good low-frequency hearing (20–60 dB up to 1 kHz) and substantial hearing loss for frequencies > 1 kHz.

An atraumatic surgical procedure is crucial for EAS stimulation. The electrode carrier should be soft and smooth. Before insertion in vivo, new electrodes should be tested in studies involving human temporal bone (4). The angle and location of the cochleostomy hole must ensure that the electrode can be slid along the lateral cochlear wall. Perimodiolar electrodes have been shown to cause greater trauma to cochlear structures (5–8) and cannot be used for EAS implantation. The insertion depth in our series was 360° (18–24 mm). This offers the advantage of good

cochlear implant function with the electrodes making a full turn around the modiolus. However, the part of the cochlea containing functioning hair cells (the apex) remains free of electrodes, reducing the risk of mechanical damage to cochlear structures as compared to deep electrode insertions (9).

The purpose of this investigation was to evaluate atraumatic electrode insertion procedures with regard to the possibility of preserving residual hearing in patients implanted for combined, ipsilateral EAS.

MATERIAL AND METHODS

A total of 21 patients with complete deafness in high-frequency portions of the cochlea and residual hearing in the low frequencies were implanted according to the criteria for atraumatic insertion. Patients received either a Combi 40+ Medium (C 40+M) or a standard C40+ array. The C 40+ M electrode has a reduced contact spacing of 1.9 mm (compared to 2.4 mm in the standard array) with a distribution length of electrode contacts of 22 mm (compared to 27.4 mm in the standard array) which is most suitable for 360° insertions (18–24 mm). The 1-kHz region of the cochlea is the borderline area between the two stimulation modes of EAS.

As mentioned before, our EAS patients had rather well-preserved low-frequency hearing, with thresholds of 20–60 dB for frequencies ≤ 1 kHz and severe-to-profound hearing loss for frequencies > 1 kHz. Preoperative pure-tone audiometric evaluations were

found to be stable over time, excluding progressive hearing loss. Preoperative monosyllabic word scores did not exceed 40% in the best-aided condition.

Surgically, a mastoidectomy was performed using a posterior tympanotomy approach, followed by an atraumatic cochleostomy. The cochleostomy hole was drilled caudally at the promontorial bone to avoid trauma to the basilar membrane. To avoid contamination of intrascalar structures, the endost remained intact until all drilling procedures had finished. Corticosteroids were administered topically and systemically for inner ear protection. Sealing of the cochlea was improved by using a circular fascia graft, which was placed around the electrode just prior to insertion. Fibrin glue and muscle were used to complete the sealing of the cochleostomy hole. Details of the surgical procedure have been described previously (3).

After implantation, each patient underwent a X-ray (10, 11) for verification of correct electrode positioning and insertion depth. Pure-tone audiometry was performed preoperatively and 1 week and 3 months postoperatively. Further audiometric testing was performed at least once a year.

One subject underwent additional speech discrimination tests postoperatively to document the effect of simultaneous stimulation of both modes. These tests

included Freiburg monosyllables in quiet and the HSM sentence test in quiet and with signal-to-noise ratios (SNRs) of 15 and 10 dB.

RESULTS

A total of 21 patients (15 females, 6 males; mean age at implantation 49.8 years; range 15–74 years) were implanted between 1999 and 2003 in Frankfurt and Vienna. Sixteen right and five left ears were implanted. Characteristics of the patients are shown in Table I.

No complications of the surgical procedures were observed. The insertion depth ranged from 18 to 24 mm (mean 20.3 mm). Postoperative X-rays showed that the array made at least 1 turn around the modiolus (360°), so that all implantations were considered to stimulate sufficient spiral ganglion cells. All patients use their cochlear implant on a daily basis.

Preservation of low-frequency hearing was achieved in 18/21 patients (85.7%). Complete hearing preservation (average of <10 dB difference pre- and post-operatively) was accomplished in 13 patients (61.9%). Partial preservation of residual hearing was possible in 5 patients (23.8%) and total loss of low-frequency function occurred in 3 (14.3%). For details see Fig. 1. All thresholds measured remained stable over time. Follow-up times ranged from 4.3 to 55.9 months

Table I. Patient characteristics

Patient No.	Sex	Date of implantation	Age at implantation (years)	Hearing preservation	Side	Implant	Insertion (mm)	Change (dB)
1	F	1/12/99	50	Partial	R	C40+	24	14.6
2	F	4/20/99	40	Complete	R	C40+	20	5.0
3	F	11/29/99	46	Complete	R	C40+	20	6.4
4	M	3/29/00	65	No	L	C 40+M	16	
5	F	4/18/00	42	No	L	C 40+M	20	
6	F	8/22/00	45	Complete	R	C40+	19	8.6
7	F	9/14/00	5	Complete	R	C40+	24	0.7
8	F	10/23/00	57	No	R	C40+	22	
9	M	1/27/01	64	Partial	R	C 40+M	19	21.7
10	F	6/10/01	59	Partial	R	C40+	20	14.8
11	F	7/3/01	33	Complete	L	C 40+M	20	4.0
12	F	9/19/01	48	Complete	R	C 40+M	20	5.0
13	F	9/19/01	74	Partial	R	C 40+M	20	20.0
14	F	2/22/02	58	Complete	L	C40+	20	2.5
15	M	5/29/02	64	Partial	R	C 40+M	20	17.5
16	M	7/6/02	39	Complete	R	C40+	20	1.3
17	M	7/18/02	30	Partial	L	C 40+M	20	12.5
18	F	10/22/02	70	Complete	R	C 40+M	21	4.2
19	F	12/6/02	47	Complete	R	C 40+M	23	5.0
20	F	2/4/03	66	Complete	R	C40+	20	5.0
21	M	4/9/03	44	Partial	R	C 40+M	18	40.0
Min.			5				16	0.7
Max.			74				24	40.0
Mean			49.8				20.3	10.5

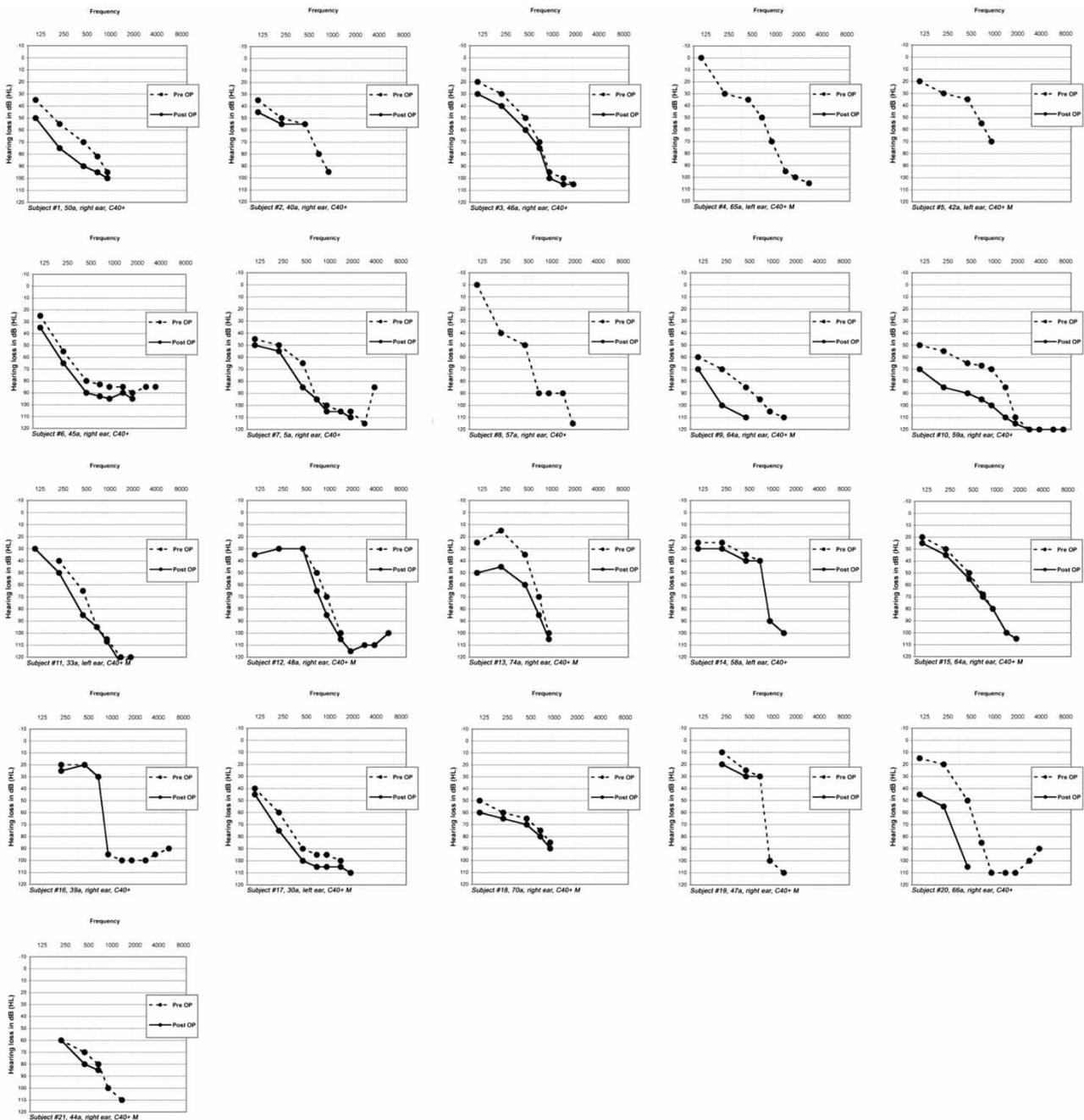


Fig. 1. Pure-tone audiometric thresholds determined pre- and postoperatively in the 21 patients implanted for EAS.

(mean 26.6 months). The results of speech discrimination tests for one patient (Freiburg monosyllables in quiet and sentence discrimination tests in quiet and background noise) are presented in Figs. 2 and 3. In all tests the patient performed better in the EAS mode compared to the cochlear implant-alone mode. Three months after the EAS training a 90% discrimination score for monosyllables was evident (Fig. 2). In background noise the synergistic effect of the EAS mode was found to be dramatic (Fig. 3).

DISCUSSION

The preliminary speech discrimination results reported in this paper document a vast benefit for EAS compared to conventional hearing aids or cochlear implants alone. These data prove the effectiveness of this new stimulation mode and stress the importance of hearing preservation during surgery. In the 21 patients implanted for EAS, total loss of residual low-frequency hearing could only be seen in 3. All other patients (85.7%) benefited from the EAS

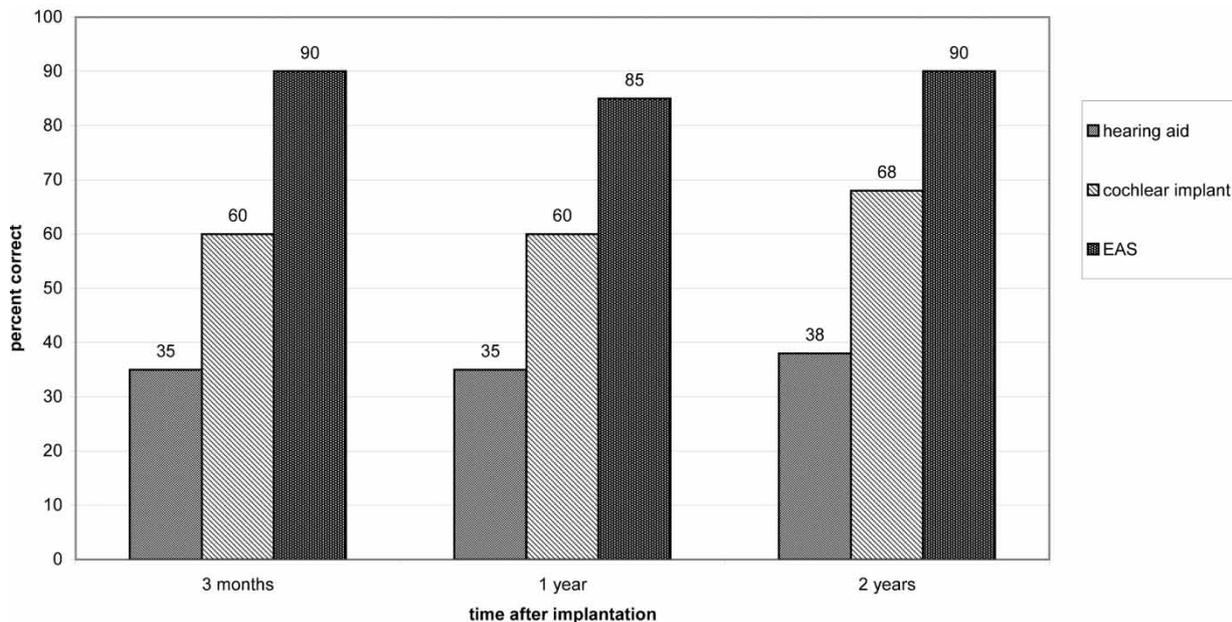


Fig. 2. Discrimination of Freiburg monosyllables for a EAS patient tested with a conventional hearing aid alone, a cochlear implant alone and combined, ipsilateral EAS.

mode. However, even with their cochlear implants alone (without using their hearing aids) our patients performed better than other comparable cochlear implant patients with full electrode insertion and no residual hearing.

The effect of chronic electric stimulation on the auditory system has been examined by several authors. Leake et al. (12) described that chronic electric stimulation leads to survival of neural structures in

the spiral ganglion. Fayad et al. (13) related post-mortem morphologic parameters to functional results obtained during life. Spiral ganglion cell counts have been published by other authors (14–16). A minimum number of neural structures have to be active to provide electric stimulation (17). In the EAS mode, hair cells and neural structures in the apical, low-frequency parts of the cochlea are stimulated via acoustic transmission. In the basal cochlear turn,

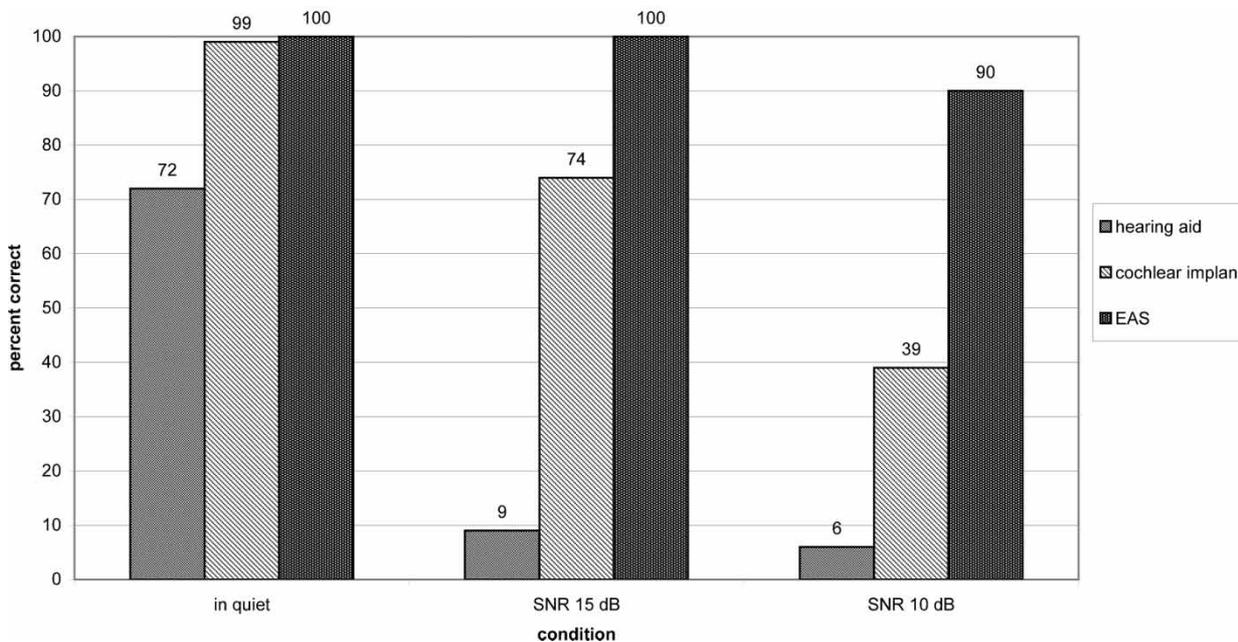


Fig. 3. HSM sentence discrimination tests for a EAS patient tested with a conventional hearing aid alone, a cochlear implant alone and combined, ipsilateral EAS 1 year after implantation.

electrode contacts stimulate surviving dendrites and spiral ganglion cells. An atraumatic surgical procedure increases the chance of maximal survival of neural cochlear structures. This may be the reason why our patients performed above average with their cochlear implants alone.

Preservation of the function of the organ of Corti in the cochlear apex is crucial for the EAS mode. During surgery, trauma to cochlear structures may occur at different locations. The location of the cochleostomy hole is important for avoiding trauma to basal cochlear structures. However, unpublished results from our temporal bone laboratory show that an inferior cochleostomy reduces the risk of fracture of the osseous spiral lamina during electrode insertion. Loss of perilymphatic fluid during surgery should be minimized by opening the endosteum after all drilling has been finished.

Application of otoprotective drugs into the scala tympani has been described (18). Experimental research is currently focusing on these issues and preliminary results show that glucocorticosteroids should act as otoprotective drugs and reduce the risk of apoptosis in delicate cochlear structures.

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