Rehabilitative Procedures for the Cochlear Implant Patient

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At the House Ear Institute, cochlear implant research has been ongoing for over 20 years. Ten years ago a wearable signal processor was developed in conjunction with the single-electrode implanted induction coil. A clinical trials program was initiated to investigate the implant in a number of patients over time. A major emphasis of the program has been to develop therapeutic procedures for helping patients make optimal use of the implant. The program is termed "Basic Guidance," and consists of an orientation on care and use of the implant, establishment of appropriate device settings, and initiation of the auditory training process. The materials developed particularly make use of the timing/intensity information provided by the implant. The procedures and materials used during Basic Guidance have been compiled into a series of manuals for working with implanted adults and children. These manuals are in current use at co-investigator sites around the United States and in foreign centers.

The cochlear implant is a prosthetic device which electrically stimulates auditory neurons in patients with profound sensorineural hearing loss. Electrically stimulating the auditory system is not a new concept. However, with the improvement in microsurgical techniques and the development of the mastoid facial recess surgical approach (House, 1959; Sheehy, 1959), restorative inner ear surgery has become feasible. While the cochlear implant at this stage in its development does not restore hearing to normal, it does give the deaf patient contact with the auditory environment in addition to enhancing communication. Because only limited auditory information is provided by the implant, specific therapeutic procedures are needed to help the patient derive maximum benefit from such a device.

The cochlear implant program at the House Ear Institute (HEI) has developed a clinically applicable program for the patient undergoing cochlear implant surgery. This paper will describe the HEI cochlear implant device and clinical program, summarize the results obtained to date, and present the procedures used for working with the implant patient.

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DESCRIPTION OF IMPLANT

Cochlear implant research has been ongoing at HEI for over 20 years. Ten years ago a wearable signal processor was developed for use in conjunction with the single-electrode implanted coil. While changes have been made in size of the signal processor and length of electrode, the design and functioning of the House implant have remained essentially the same. Details of the surgery and engineering have been previously reported (House, 1982; Danley and Fretz, 1982) and are summarized below.

The cochlear implant system consists primarily of two parts: the surgically placed internal electrode/induction coil system, and the externally worn signal processor (Figures 1 and 2). The surgical procedure takes approximately one to one and one-half hours. This involves a mastoidectomy and opening of the facial recess. The internal coil is secured in the temporal bone above and behind the ear, the active electrode is placed through the round window approximately 6 mm into the scala tympani, and the return electrode is placed in the temporalis muscle.

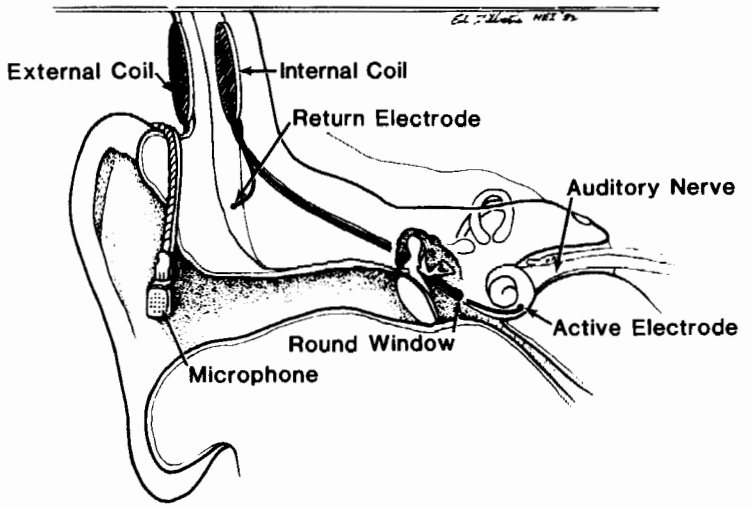

Figure 1. Single-electrode cochlear implant showing placement of the internal coil and electrode.

The implant is activated as acoustic stimuli are picked up by an electret microphone (usually mounted at ear level). The electrically converted signal is transmitted to the processor where it amplitude modulates a 16 kHz carrier wave. This modulated signal goes to an externally worn transmitter coil where it is electromagnetically induced across the skin to the internal coil and flows down the active electrode. Current flows to the return electrode, stimulating remaining nerve fibers and producing a sensation of sound.

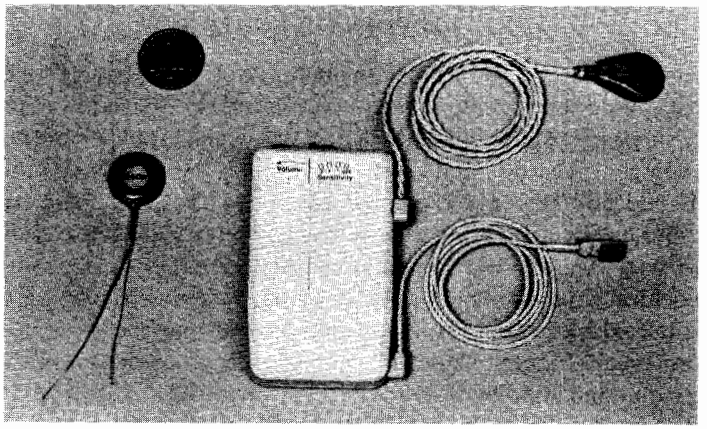

Figure 2. Cochlear implant internal electrode system and external coil, microphone, and signal processor.

CLINICAL TRIALS PROGRAM

The single-electrode cochlear implant used by HEI is undergoing clinical trials under the FDA regulations governing investigational medical devices. Currently, 26 other teams in the United States have implanted one or more patients as co-investigators with HEI in the clinical trials program. The goal is to gather and evaluate safety and efficacy data on the cochlear implant in a number of patients over time.

The HEI clinical program consists of the presurgical evaluation and informational counseling, surgery, training and follow-up testing. Further information about the clinical program for adults and children can be found in Berliner and House (1982) and Eisenberg et al. (1983). Briefly, patients are selected for the implant on the basis of medical, audiological, and psychological criteria. Children are additionally given speech and language evaluations. The primary considerations for selection are a confirmation of a profound hearing loss, and the inability to perform as well with appropriately fitted hearing aids as is likely with the implant. If the patient meets the selection criteria, then surgery is performed. Only one ear is chosen. In most cases this is the ear with the poorest response with aids. An exception to this would be an ear occluded with bone in the cochlea (as revealed on polytome x-rays). In such cases, the ear with the least amount of bone is chosen if that ear cannot receive significant benefit from aids.

Following a one to two month healing period, the patient returns to the clinic to be fit with the signal processor and begin the training program. Follow-up evaluations are scheduled at regular intervals.

RESULTS

Experience with more than 300 implanted patients gives us objective evidence that the implant can provide significant benefit to the profoundly deaf. Table 1 shows the current status of these patients. With the implant, auditory warble-tone thresholds can be obtained across the frequency range tested, 250 to 4000 Hz. Figure 3 presents mean preoperative unaided and hearing aid, and postoperative cochlear implant auditory thresholds in dB HL for implanted ears. This is shown in relation to the average speech spectrum. Forty-five percent of these patients cannot obtain auditory thresholds with a hearing aid that would permit detection of conversational level speech (i.e., aided detection/awareness thresholds greater than 55 dB HL), while 75% had speech detection thresholds greater than 45 dB HL. Implant thresholds are consistently within the intensity range of conversational level speech. The implant provides awareness of most moderate and loud sounds, as well as some soft sounds. Conversational speech, for example, can be detected in a quiet room at distances of 15 to 20 feet.

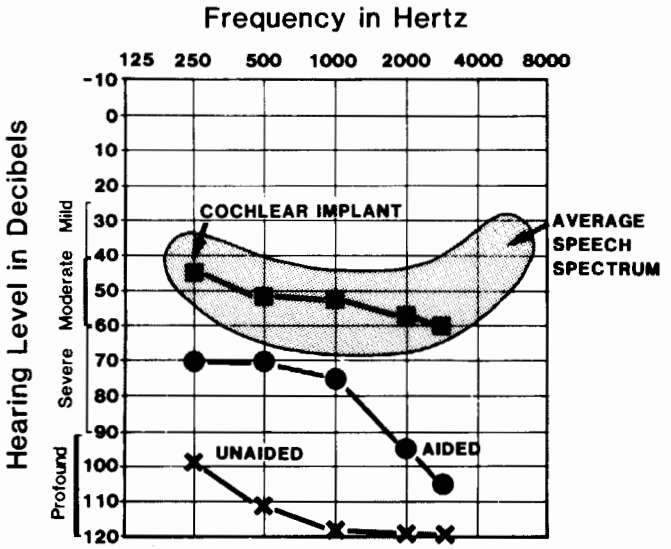

Figure 3. Mean preoperative unaided, hearing aid, and postoperative cochlear implant warble-tone thresholds in dB HL for implanted ears (N = 165). Also shown is the average speech spectrum. Aided and implant thresholds are tested in the soundfield, and sound pressure level values have been converted to hearing level. (Note: Aided thresholds obtained using the same procedures are available on only 130 patients. Preoperative unaided thresholds are included for 176 patients, although not all have yet been tested with an implant.)

Table 1
Single-Electrode Cochlear Implant Patient Status
July 15, 1983

	Adults	Children	Total
Users	200	55	255
Non-users	33	3	36
In Process	23	8	31
Device Failure	8	0	8
Non-stimulable	7	1	8
Deceased	7	0	7
	278	67	345

Functionally, the implant provides primarily duration and intensity information, with frequency discrimination being limited to frequencies below approximately 300 Hz. As a result, the patient receives the prosodic elements of speech, but no discrimination of speech in open sets. Patients can score above chance on closed-set auditory discrimination tasks that include speech and environmental sounds (Thielemeir et al., 1982).

Postlingually deaf patients have described what the implant sounds like and how that sound can be used. The sensation delivered by the implant is perceived as hearing in the ear. The sound is initially described as having a "mechanical" or "static-like" quality. Over time this changes to a more tonal or natural quality, but still is very distorted. Speech has been described as muffled, like a radio slightly off station, or talking into a handkerchief. Thus, the person may know that someone is speaking, but cannot understand the words.

Generally, patients are able to distinguish between voices and other sounds, and between male and female voices. They can hear their own voice and this allows better control of volume and pitch (Kirk & Edgerton, 1983). Hearing speakers' voices helps the patient's speechreading. Thus, communication is enhanced, giving more confidence and less tendency to withdraw from social settings.

Implant users report feeling safer because they can hear warning signals such as sirens and fire alarms. They feel more secure because they are able to hear doorbells, telephones, and someone calling out to get their attention. In their homes, patients usually learn to identify commonly occurring sounds. Some environmental sounds are described as sounding very natural; e.g., running water, footsteps, knocking on a door, clapping, hitting or banging on metal, shuffling cards, and crumpling paper.

The situations where the implant is not often helpful are those such as watching television, following conversation in a group, and listening in a very noisy environment. In spite of the limitations, however, most of the

implant patients use the device all day, everyday. Only 12% of these patients who have functioning devices choose not to use them on a regular basis (see Table 1).

The prelingually deaf adults who have been implanted can likewise make use of the timing/intensity patterns provided by the device. They report similar benefit such as contact with the environment, feeling more independent, more social, and some improvement in voice quality (but not necessarily intelligibility). However, the prelingual patients indicate that the implant has limited effect on their lives, as patterns and habits for living in a deaf world have been long established (Eisenberg, 1982).

As Table 1 indicates, there are a small number of patients for whom the implant does not provide auditory stimulation. In addition, the device may fail for mechanical reasons. In this case, the internal coil can be removed and replaced using local anesthesia.

REHABILITATION

A major emphasis of the HEI clinical program has been to develop therapeutic procedures for helping the patient make optimal use of the implant. The program is termed "Basic Guidance," and consists of an orientation on care and use of the implant, establishing of appropriate device settings, and initiation of the auditory training process. It encourages relaxed, unpressured use of the implant while providing early successes and suggesting strategies for continued learning. The training helps the patient establish initial patterns of practice which cover a wide variety of activities designed to permit quick grasp and utilization of the timing/intensity information provided by the implant.

The Basic Guidance period is 20 to 30 hours in duration, and is evaluative in nature. It includes measuring electrical thresholds and uncomfortable loudness levels using special equipment designed for this purpose, as well as auditory testing. Further, as the patient is learning to use the prosthetic device, the therapist is making judgments as to the device settings based on patient performance. Intensive or long-term therapy for development of specific skills may be offered (or recommended for referral) on an individual basis according to each patient's need. Guidance and support after the basic orientation is provided by mail contact and follow-up visits to the clinic. Home assignments provide patients with tasks that they can continue to practice as they wish.

Specific programs have been developed at HEI to provide procedures and materials for working with postlingually deaf adults, prelingually deaf adults, and children. The following discussion will summarize these three programs.

Postlingually Deaf Adults

The program developed for postlingually deaf adults (Norton et al., 1980)

consists of a reintroduction to the world of sound. Initial objectives include building a tolerance for sound and relearning to listen. This is similar to the gradual process suggested for the new hearing aid user and helps the patient become aware of the implant's advantages and limitations.

Development of critical listening abilities within a variety of situations comprises a major portion of Basic Guidance. Environmental sounds are used to provide improved contact with the auditory environment. Awareness and utilization of the prosodic elements of speech are implemented in auditory discrimination tasks. Speech materials have been developed which contrast elements of varying stress, syllabification, and duration (see Table 2).

Table 2

Examples of Speech Cue Training Materials used in Critical Listening Tasks with Cochlear Implant Patients

Stress Differentiation			
CANTALOUPE	vs	OCTOBER	
CAN/ta/loupe	vs	oc/TO/ber	
(STRONG/weak/weak)	vs	(weak/STRONG/weak)	
Monosyllables, Trochees, Spondees[a]			
MOVE vs MOTOR vs SAILBOAT			
Conversational Sentences			
I DON'T BELIEVE IT			(time cue)
i DON'T beLIEVE it			(loudness cue)
I DON'T BELIEVE IT			(inflection cue)
Consonant-Vowel-Consonant Rhyme Pairs			
(Final consonant differentiation)			
COP	vs	CAR	(unvoiced plosive vs voiced continuant)
LAB	vs	LAMB	(voiced plosive vs voiced continuant)
CAUSE	vs	COUGH	(voiced continuant vs unvoiced continuant)
FEED	vs	FEET	(voiced plosive vs unvoiced plosive)
TUG	vs	TOUGH	(voiced plosive vs unvoiced continuant)

[a]Adapted from the test developed by Erber & Alencewicz (1976).

Additional tasks during Basic Guidance include practice in monitoring the voice, use of strategies for reducing the barriers to communication, practice in the tracking method for speechreading (DeFilippo & Scott, 1978), and use of the telephone by means of a syllabic code.

Prelingually Deaf Adults

It has been consistently observed that prelingually deaf adults initially perceive the sensation delivered by the implant as a feeling or vibration in the head. Over time this sensation is perceived in the region of the ear as hearing (Eisenberg, 1982). Thus, it is essential that electrical stimulation initially be presented at near threshold levels and for short durations, gradually to be increased as tolerance builds and experience is gained.

The program developed for prelingually deaf adults has been described by Eisenberg (1980). This program takes a multisensory approach which integrates auditory input with visual and tactile information. Adjustment to sound may be difficult for this group of patients, so the procedures used at HEI attempt to make listening activities enjoyable and motivating.

Music and environmental sounds form the basis of the program. Music, in particular, has been found to be a successful therapeutic tool, because the timing and intensity information provided by the implant parallels the vibrotactile perceptions the deaf often receive when experiencing loud music. Thus, the parameters in music which are already known to the deaf are a natural starting point for introducing sound. By use of simple musical instruments (including the voice), newly implanted patients can experiment with sounds by producing them. Instructions regarding more abstract conceptualization, such as viewing sound being produced (e.g., by the therapist or a family member playing an instrument) and progressing to listening to sound on audiotape, is gradually introduced. In a more structured situation, the basic parameters of sound such as timing and intensity are taught using music, and differentiation tasks are set up to begin developing critical listening skills. They are then reinforced through a series of familiar associations (environmental sounds) which serve to convey the meaning and usefulness of sound.

The overall goal of this program is to stimulate an interest and curiosity about sound. The patient's motivation may be enjoyment, benefit, or a combination. If the patient wears the implant on a regular basis, then the objectives of this program are accomplished.

Children

The children's cochlear implant program began in July, 1980, when a 10½ year-old male underwent surgery. Over the next 18 months a pilot study was undertaken to determine children's performance with the implant, and to develop test protocols and therapeutic procedures based on these findings. Twelve deaf children of varying ages and etiologies were included in the pilot program. Results with these children were consistent with those found in adults. Mean auditory thresholds fell between 50 and 60 dB HL (59 and 64 dB SPL) across the frequency range. With the implant, these children were able to perform specific timing and intensity discrimination

which they could not achieve with hearing aids (Eisenberg & House, 1982). Based on these findings, a clinical trials program was established.

The Basic Guidance program developed for children (Eisenberg, 1983) has been based on knowledge gained from working with adult implant patients. The same principles of auditory training are used, but have been modified to account for cognitive levels and attention span. For example, children of preschool age show much slower progress than older children and adults. Activities planned for working with these young preschoolers provide the child with sound exposure and redundancy in nondemanding pleasurable situations. As with the other programs, this one progresses in a hierarchy of difficulty, beginning with the production of sound. At the same time, listening games (using music, environmental sounds, and speech) and behavioral audiometry train the child to respond to auditory stimuli through use of conditioning techniques. Once an awareness to sound has been achieved, discrimination activities are introduced.

Elementary school-aged children develop an awareness to sound much faster than the younger children, so auditory discrimination activities comprise the majority of the lessons. As with the adult programs, the basic parameters of sound are taught using simple musical instruments, environmental sounds (doorbells, sirens, footsteps, etc.), and speech/voice.

Parent counseling comprises a major portion of Basic Guidance. The parents are given instruction on care and use of the equipment. Troubleshooting the equipment is particularly important for parents of the young children. The parents are an integral part of each lesson plan in order to help them realize the benefits and limitations of the implant and to provide them with practice in working with the child following Basic Guidance.

After Basic Guidance, the child returns to her/his classroom setting, where the school continues its program for the child. The implant clinical staff works with the child's teacher, speech therapist, audiologist, etc. to integrate implant usage into the child's academic programs. The child's progress is continually monitored through contact with the parents and schools. Each child is seen at HEI for follow-up testing in audiology, speech/language, and psychology six months after Basic Guidance and annually thereafter.

CONCLUSION

The therapeutic procedures summarized have been found to be successful in helping the deaf patient acclimate to the cochlear implant. To date, over 300 patients have been fitted with the House implant using the Basic Guidance training programs. The materials and lesson plans developed at HEI have been compiled into a series of manuals and are being used at co-investigator sites around the United States and in foreign centers. An important result of the HEI program is the finding that the implant procedure is clinically feasible and can be performed in a variety of clinical

settings (Campos, 1976; Luetje, 1981; Maddox & Porter, 1983).

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