An Overview of Cochlear Implants in Relation to Aural Rehabilitation and Habilitation

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A short history of the cochlear implant procedure for adults with profound hearing impairment is given, the status of this group of patients is discussed, and some factors relating to hearing aid use versus a cochlear implant are noted. A section on the audiologic evaluation of post-implant patients is followed by an outline of some rehabilitative approaches. The final section considers some aspects of the cochlear implant with respect to young children.

The purpose of this paper is to present an overview of the cochlear implant procedure as it relates to aural rehabilitative considerations. Djourno and Eyries (1957) were the first to report on the use of an implant for direct electric stimulation of the cochlear nerve endings, previous attempts at electrical stimulation having involved the hair cells. Subsequent reports on direct cochlear nerve stimulation have been published by Doyle, Doyle, and Turnbull (1964), Simmons (1966), Michelson (1971), and House and Urban (1973). In these reports there were no cases of patients with implants who were able to understand speech in the absence of visual cues. One of these early devices, used by Michelson, is shown in Figure 1. It consisted of a bipolar electrode in the scala tympani with two wires terminating in a radio receiver coil surgically embedded in the mastoid cortex beneath the skin. The external (transmitter) coil was placed on the mastoid in apposition to the internal receiver. The signal from a wearable microphone-processor system was transmitted across the skin, from outer to inner coil, by inductive coupling with a radio frequency (rf) carrier.

A summary report was completed by Bilger (1977) on 13 patients who had received a single electrode implant by Michelson (1971) or by House (House

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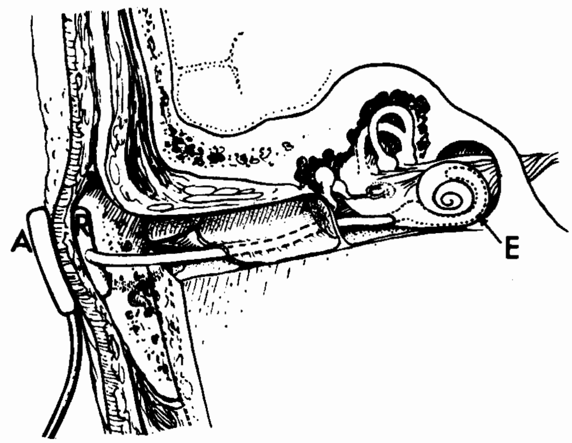

Figure 1. Diagrammatic representation of the implanted electrode-receiver. The electrode (E) extends about 11 mm into the scala tympani in the basal coil; it is inserted via the round window. The receiver (R) and electrode leads are fastened into position with methylmethacrylate. The receiver is driven (across the skin-subcutaneous gap) by the transmitter antenna (A) worn much like a bone conduction hearing aid. (From Merzenich et al., 1973).

& Urban, 1973), and who had travelled to the University of Pittsburgh for evaluation. In auditory testing (Bilger & Hopkinson, 1977) thresholds for narrow bands of noise were found at intensities in the range of 35-65 dB SPL. No understanding of everyday speech could be demonstrated and the patients could not identify any monosyllabic words on a children's speech discrimination list. On the other hand, a majority of patients scored significantly above chance in the identification of common environmental sounds presented in a four-alternative closed-set format, and a few were able to identify spondee words at better than chance from a set of 16 alternative choices placed in front of them. Also, lipreading scores were significantly better with the prosthesis than without it, but exceptions occurred. When tones were presented at octave intervals, the patients were generally able to discriminate differences between 125 and 250 Hz, but not between higher pairs of octave interval frequencies. Growth of loudness was essentially normal for lower frequencies (250 and 500 Hz) but not for the higher frequencies tested. Masking experiments revealed that the subjects could not separate foreground from background sounds.

Although several other versions of implantable electric stimulation devices have been introduced in several countries since the Bilger (1977) summary, the present paper is based primarily on knowledge gained from the House Ear Institute (HEI) device and a succession of University of California, San Fransisco (UCSF) devices.

POPULATION

The discussion will center first on adults with profound postlingual hearing loss, defined by thresholds greater than 90 dB HL in the 500-2000 Hz range. Etiologies have included drug ototoxicity, head injury, familial progressive loss, meningitis, otosclerosis, and viral agents. Undoubtedly, the onset of a profound hearing loss causes anguish that cannot be imagined by one who has not experienced it. The resulting communicative handicap is extreme. On the one hand, persons who experience such a loss can no longer communicate easily with normal hearers; on the other, they cannot fit comfortably into the community of the congenitally and prelingually deaf. As time goes on, however, most of them seem to find ways of coping that are more or less appropriate for them and others close to them. The well-known Ramsdell (1978) account of pervading depression and paranoia in World War II veterans with war-related profound loss has not been corroborated in the 50 or so UCSF patients that we have seen in the course of evaluating them as prospective implant patients. Their MMPI records, for example, have shown no significant trends. Similarly, Crary, Wexler, Berliner, and Miller (1982) found that a group of 46 patients with profound postlingual loss scored in the normal range on a battery of personality and affective measures. Nevertheless, most of the UCSF patients were found to be restricted in their vocational and social activities. Although some patients were more passive in accepting their sudden dependence on a few friends or family members, others became active in new ways; e.g., in learning fingerspelling and signing, in arranging for TDD's, captioned TV, and accessory alerting devices, and in becoming genuinely absorbed in how one might compensate for deafness. The sense of isolation frequently reported among the group was usually related to extreme difficulty and discomfort in many communicative situations.

One major positive factor is that these patients typically retain understandable speech, even after not hearing themselves for many years. Although some have difficulty in monitoring the loudness of their voices, others have been able to adjust vocal loudness satisfactorily through alertness to situational cues (sometimes with the help of a friend) and the use of tactile, kinesthetic, and proprioceptive feedback mechanisms.

Certainly not all of this group can be recommended for a cochlear implant. Some have major psychological and health problems. In the selection process a psychological-psychiatric evaluation, a thorough audiologic appraisal, and a complete physical examination and history are necessary.

HEARING AIDS VERSUS COCHLEAR IMPLANTS

Of primary importance in evaluating and selecting possible implant candidates is whether a hearing aid can be of benefit. Many of these patients receive only vibratory feeling from an aid, others experience great discomfort from the amplified sound despite the use of compression, and others complain of intolerable distortion. In such instances an implant might be useful. Most patients with some residual hearing, however, are able to obtain some benefit from a hearing aid (Fujikawa & Owens, 1978, 1979). The question of an implant for dissatisfied hearing aid users must be decided individually, preferably on the basis of performance measures. The pure-tone audiogram, alone, is not a good predictor of hearing aid satisfaction. At UCSF we have been using the Minimal Auditory Capabilities (MAC) battery (Owens, Kessler, Telleen, & Schubert, 1981) for hearing aid appraisal in the case of a hearing aid user contemplating an implant. The MAC consists of 13 auditory tests, covering a wide range of difficulty, and one lipreading test.

In a recent study (Owens, Kessler, & Schubert, 1982) three groups of patients were tested: (a) six patients who used an implant that provided single channel stimulation to an 8-bipolar multielectrode; (b) six "borderline" hearing aid users who were not particularly happy with their hearing aids and who scored 0% recognition on a list of the Northwestern University (NU-6) monosyllable word test; and (c) a comparison group of eight "satisfied" hearing aid users who scored from 12 to 26% on the NU-6. The comparison group scored notably higher than the other two groups on all the tests. The borderline and implant groups showed generally equivalent results except for a clear superiority of the borderline group on closed-set vowel and spondee recognition tests. Among the conclusions were that improvement in hearing with an implant could not be promised to a hearing aid user who recognizes some open-response speech materials (monosyllable words, spondees and sentences). When there is no recognition of open-response speech materials, other scores on the MAC must be considered. For example, a score above chance on the vowel test would weigh against an implant recommendation, as would an increment of around 20% in the lipreading score when amplification is introduced. A caveat is that the hearing aid user should also score above chance on the Noise versus Voice recognition test; i.e., satisfaction with hearing aid use is usually lacking if the instrument does not permit voice recognition, although not necessarily the recognition of a specific voice.

Baseline data are being analyzed on the MAC for profound-loss hearing aid users. As implants improve, changes will inevitably occur in the indications that would favor an implant over a hearing aid. At the same time, however, we might anticipate continued improvement in hearing aid design (Killion & Tillman, 1982).

REHABILITATIVE PROCEDURES

At present the assumption is that rehabilitative methods for post-implant patients will be much the same as those for hearing aid users with profound loss. As multichannel implant devices increase in sophistication, and as experimentation in signal processing continues, changes in the orientation and emphasis in post-implant rehabilitation may be indicated. An obvious example of the need for an individual approach lies in the comparison of a prelingual loss implant patient who has never heard sound and a postlingual patient who retains a memory for sound. To date, relatively few adults with prelingual loss have received an implant. According to a description of these few patients by Eisenberg (1982), the results are discouraging in terms of the usefulness of sound to them. In contrast, a few "stars" among the postlingual implant patients have been able to recognize some spondee words and some sentence materials (Eddington, 1983; Owens, Kessler & Raggio, 1983; Clark, Tong, & Dowell, 1983).

In any case, the first step is to define the nature and pattern of an individual's post-implant hearing by a series of appropriate tests. On the whole, recognition of open-response speech materials has hovered around zero for most implant patients. A report on MAC battery results for 12 HEI patients (Edgerton, Prietto, & Danhauer, 1983) indicated little or no recognition of open response stimuli. Subjects were able to recognize consonant sounds at above-chance levels in a closed-set format, but no vowels. Lipreading scores improved 24%, on the average, with the implant device activated as compared with a no-sound condition.

Other auditory test results for HEI post-implant patients (Thielemeir, Brimacombe & Eisenberg, 1982) present some difficulty in interpretation. For example, the warble-tone thresholds that are depicted across the 250-8000 Hz frequency range cannot be regarded as responses to discrete tones, as in an audiogram or hearing aid frequency response curve. That is, it has been shown (Merzenich, Michelson, & Schindler, 1973; Bilger, 1977) that pitch discrimination with a single electrode is limited to frequencies below 500 Hz; therefore, warble tones of 500, 1000, 2000 Hz, and higher would tend to sound the same to these patients. This is easily verified clinically by asking the patients what they hear when different pure-tone stimuli are presented.

It has also been shown (Merzenich et al., 1973; Bilger, 1977) that single-electrode implant patients can discriminate temporal and durational cues. Therefore, the guessing factor on a five-choice, closed-set test of environmental sounds would depend largely on the composition of the alternative choices. Given a stimulus of "singing" and the alternatives of "dial tone", "footsteps", "bass drum", and "typewriter", for example, the relatively steady signal of a person singing should be easily discerned among other choices available. Thus, chance performance may be much higher than the 20% assumed by the authors. In any case, a correct answer, possibly based on temporal and durational differences among alternative choices, as well as in guessing, should not be taken to mean that the patient in an everyday situation can, without visual cues, identify a sound as someone singing. In the everyday situation much would depend on the composition of competing sounds in addition to visual cues, perhaps in conjunction with auditory memory. For example, the barking of a dog may be heard by the patient as an undifferentiated sound if the dog is not seen. When the dog is seen to be barking, however, the patient would likely report the sound correctly and might even state that the sound is similar to what s/he remembered it to be.

Similarly, a third of the 12 words on the Monosyllable-Trochee-Spondee (MTS) are monosyllables, another third consists of spondee words (equal emphasis on each syllable), and the remaining third is composed of two-syllable words with the second syllable shorter than the first. All the words are placed before the patient during the test. The use of temporal and durational cues should enable her/him to assign the stimulus correctly to one of the three four-word groups. Accordingly, the chance score is more likely to be one in four (25%) rather than the one in twelve (8.3%) stated by the authors. Other durational and temporal differences among the consonants and vowels in each four-word set might increase the chance of a correct response to one in three or even one in two. Accordingly, in light of the available temporal and durational cues, it is probably unwise to infer that the reported score of 45% indicates an actual ability to recognize words.

Generally, the HEI implant in adults provides a somewhat enhanced lipreading ability, an awareness of gross environmental sounds, improvement in voice monitoring, and recognition of durational and temporal cues.

The general preoccupation with the restoration of sound by an implant has tended to overlook the fact that post-implant patients, who typically score 0% on the NU-6 test, continue to experience severe communication problems. They must rely heavily on lipreading; they have extreme difficulty in conversations with more than one person at a time; they can identify only a few gross sounds with audition alone; they cannot follow TV offerings without captions; they are deprived of telephone conversation; and they cannot understand speech. Accordingly, part of the rehabilitative program must emphasize counseling with respect to unfulfilled expectations and adjustment to an inordinate distortion of sound. As yet there are no hard data on the results of a rehabilitative program for post-implant patients.

METHODS AND MATERIALS

At UCSF we have been exploring some aural rehabilitative approaches for persons with profound postlingual loss who wear hearing aids, assuming that such approaches may be useful for implant patients as well. Because the experimental nature of the UCSF implant program limits the number of patients who are implanted, we have not had the opportunity to try these approaches with more than a few implant patients. In none of this work is there any presumption of originality, and no attempt is made to present a complete program.

Group Work

Three successive groups have each consisted of four or five patients, some with spouses, and two audiologists for a total of about 10 individuals per group. The work was directed to "here and now" experience rather than to preparation for experience outside the group. The audiologists and the spouses or friends of patients were bona fide group members receiving no special considerations in the discussions, role playing, and general interactions that transpired. Most of the energy and directions for the work came from the hearing impaired participants, who responded readily to the opportunity of ventilating their difficulties to interested, non-judgmental listeners. Information on hearing aids, TDD's, home hearing accessories, the nature of hearing, disorders of hearing, and the like were provided by the audiologists when questions arose. The only activity approaching a formal procedure was the presentation of lipreading materials following the "synthetic" method; i.e., stories and conversational materials were introduced in a way that patients sought meaning rather than verbatim understanding. Regarding the amount of time required, meetings for one-half day twice a week for a duration of 10 weeks seemed adequate. Pre- and post-measurement was not done because reliable test materials were not ready at the time. For future groups a self-rating scale and a lipreading test will be given before and after the program. Nevertheless, satisfactory quantification of the possible benefits accruing from this kind of activity may be difficult to achieve. The subjective observations of the audiologists and the unsolicited comments of the other group members, however, were consistently positive regarding the experience.

Individual Counseling

The Revised Hearing Performance Inventory (Lamb, Owens, & Schubert, 1983) has been helpful in providing pertinent discussion materials for individual patients, especially when the response of spouses (answering the items as they thought the patient should answer them) were compared with the patient's answers. The usual procedure of the audiologist is to follow the patient's lead in discussions, all the while trying to understand and check out this understanding in the Rogerian sense. If the patient brings nothing to the session, however, the responses on the Inventory items can be taken up in sequence. Items have been developed specifically for patients with profound postlingual loss as an addendum to the Revised Hearing Performance Inventory (Owens & Raggio, 1983). Referral is made if problems seem to go deeper than might be expected from the hearing loss, per se.

Tracking

A tracking activity is employed in which a talker (normal hearer) and listener (patient) sit face to face and carry on a two-person communication process (Owens & Telleen, 1981). The talker reads segments of materials adapted to the spoken idiom, and the listener must repond verbatim for each segment. Quantification is achieved by timing the process; that is, an increase in the number of words tracked per minute would indicate an improvement. When a blockage occurs, the listener is responsible for directing the talker in attempts at resolution — by responding with "please repeat", "say that another way", "say it slower", etc. The patient typically finds that the best response is to say what s/he hears, thus prompting the talker to either fill in the rest of the segment or make a correction. In providing feedback to the talker in this way, the patient is also developing the important skill of verifying the message. The patient's effort is directed to understanding the segments as wholes. For example, the better trackers are quick to request a rephrasing of a difficult segment rather than repetitions of a single word. In the tracking process, the listener receives auditory, visual, and (presumably) kinesthetic-proprioceptive cues concomitantly. Tracking can be used both as a training procedure and as a pre-post measure of hearing aid selection or a cochlear implant procedure.

Programmed Learning

An exciting development has been the interfacing of microcomputers and video cassette or video disc players for the purpose of bringing the power of programmed learning to bear in aural rehabilitation. Sims, Von Feldt, Dowaliby, Hutchinson, and Myers (1979) have described their Data Analysis Video Interactive Device (DAVID) employed at the National Technical Institute of the Deaf (NTID). The UCSF equipment consists of a Sony SLO 323 video cassette and an Apple II Plus computer with a Whitney interface. Prices of such equipment continue to decrease, promising widespread availability. Various materials can be tried first in a live situation and then videotaped and programmed for the rewarding, branching, and shaping procedures that form the essence of programmed learning. Measurement is inherent in the program itself in the form of success criteria to be met as learning progresses, and data can be stored for later analysis. The learner has access to visual, auditory, or auditory-visual presentation.

Dialogue

Written dialogues such as those found in English as a Second Language (ESL) Materials are especially helpful when a patient cannot brook experiences of failure beyond a certain point. These materials allow much flexibility in that several ways of responding are open to the patient. As the therapist reads his/her part, the patient can practice auditory-visual reception or each modality separately. Also, s/he can listen to the therapist while following the printed material, or memorize a printed passage immediately before watching the therapist say it. In reading her/his own part, the patient works toward appropriate speech-voice monitoring. Such dialogues serve well as a comfortable introduction to rehabilitative work for the patient since there is no threat of failure.

Homework

The major homework assignment given to both hearing aid wearers and implant patients is to practice reading orally to themselves and also to listen, perhaps while lipreading or following the text, as another person reads. Although this is probably the oldest of suggestions, oral reading activities would seem basic in adapting to any new kind of speech code that might be supplied by a prosthetic device with speech processing capabilities. Of course, a wide range of tape-recorded materials for auditory training and lipreading practice can be devised and assigned for home use, preferably after adequate demonstration.

Quantification

Tracking and programmed learning activities can be measured directly and specifically, but this is not the case, at present, for the group work, dialogue, counseling, and homework portions of the program mentioned above. The need for measurement, whether for profound loss hearing aid wearers or for implant patients, relates to questions such as: Which of the various prosthetic devices provide the most benefit? To what extent does an aural rehabilitative program enhance the value of a given device? What are the long-term results of using a given device? In evaluating the results of a comprehensive aural rehabilitative program, measurements of auditory and lipreading skills are required along with a self-rating scale on everyday communicative skills. One such combination might be the MAC battery, the Revised Hearing Performance Inventory with the addendum mentioned above, and the NTID videotaped sentences (Johnson, 1976) edited to provide spoken rather than written responses in order to reduce the testing time.

IMPLANTS FOR CHILDREN

A pressing question regarding cochlear implants is the extent to which they can provide auditory cues for the speech-language acquisition of young children with profound hearing loss who cannot benefit from hearing aids.

The term "deaf" or "deafness" is used frequently in this discussion, which deals mostly with congenital loss marked by little or no residual hearing. At the same time, some of the discussion applies to early postlingual profound loss. Only those children with no other known handicaps besides deafness are considered.

It is difficult to obtain an unqualified answer from a speech-language specialist regarding the most important age range for learning speech with normal hearing. Despite some general agreement on "yardsticks" in speech acquisition, variability around these markers is wide. Most specialists would agree that the age below 3 years is extremely important, but if they are asked about a crucial range, they might place the upper limit several months earlier than 3 years. Another difficult question involves the age at which the introduction of amplification may be too late for a child to optimize the learning of speech and language through the auditory modality. A similar question concerns the age above which a child with intelligible, age-appropriate speech can maintain this speech after the loss of auditory monitoring consequent to an onset of deafness. The lack of precise answers to these questions lies in the large sources of variability including the amount of residual hearing; general learning ability; specific abilities in the visual, auditory, tactile, and kinesthetic modalities; emotional and motivational factors; home support; and the availability of special teachers with appropriate training, equipment, and materials. The "young child" in the ensuing discussion will refer to an age under 4 years.

According to Berliner (1982), the workers at HEI have proceeded with implantation of young children, justifying this action by their experience with adult patients. The author recounts some discouraging statistics on the effects of deafness, reviews the results of HEI implants in adults, states that the potential benefits for children are even greater than those obtained by the adults, and concludes that the "risks" of remaining deaf, compared with the potential benefits from an implant, favor proceeding with clinical trials of implants in children.

Others who are working with implants or with hearing-impaired children have strong reservations at present. Personnel at hearing clinics have been receiving inquiries about the implant from parents of congenitally deaf children at an increasing rate and have often experienced difficulty in dissuading these parents from the idea that normal hearing can be restored in their child. Factual knowledge on which to base a decision is scarce, because the reports on the HEI post-implant adults tend toward the descriptive and anecdotal rather than toward controlled studies. Accordingly, one might hesitate more than usual in generalizing from adult to child populations, particularly in the case of childhood congenital loss.

The major published report on children to date is that by Eisenberg, Berliner, Thielemeir, Kirk, and Tiber (1983). In 23 profoundly deaf children implanted with the HEI device, the mean age was 10.2 years (range 3.4 to 17.5 years). Five of the 23 were age 5 years or younger. Seven of the 23 were born deaf and the remaining 16 were deafened after birth, 15 from meningitis and one from head trauma. Results with the implants were reported to be similar to those for adults in terms of threshold levels and responses to durational and temporal cues. An extensive account of this program was given, and some anecdotal reports and behavioral descriptions of the children were presented. It was stated, however, that pre- and post-implant speech and language data have not been collected for any one child because the current protocol was only recently initiated. Despite the lack of data on these children, the authors suggested that it is best not to wait for improved implants that might provide a better chance for speech understanding and maintained that quick intervention is especially important in cases of meningitis.

Hearing aids play a confusing role in this report. It states that if a child is wearing an appropriately fitted hearing aid, s/he must demonstrate an inability to discriminate selected auditory stimuli as well as the average implant user. If the child demonstrates such inability, s/he can receive an implant in the unaided ear. Two-thirds of the 23 children wear a hearing aid in the nonimplanted ear on the basis of the belief at HEI that each child should be fitted binaurally (hearing aid and implant) if a hearing aid offers any awareness of sound. As training with the implant progressed, many of the children began responding consistently to sound from their hearing aids. This was reported by teachers and parents and was observed in both younger and older children with both congenital and acquired deafness. The response to amplified sound from a hearing aid during post-implant training offers little information on the value of an implant. Rather, it implies that auditory training is beneficial for profoundly impaired children with hearing aids and that a period of such training should be mandatory before a decision to implant.

Concerns about Implants in Children

Downs (1981, pp. 567-568) has outlined some instances in which a child should not be an implant candidate. These include:

1. A child who can receive results with a hearing aid that are equivalent to the results that implants have been shown to produce. A hearing aid rehabilitation program utilizing all the techniques that are used for post-implant patients is thus mandatory before implant is considered.
2. A child whose parents cannot invest the time in the rehabilitation process that is requisite to a good outcome. Number of siblings, psychological stability, and socio-economic factors should be considered.
3. A child whose parents could not tolerate the necessity for periodic revisions of the implants, currently approximately every two years. Financial as well as psychological factors should be considered.
4. A child who has only one ear that is acceptable for an implant. One ear should be available for implant 20 or 30 years hence, when more effective techniques may have been developed.
5. A child who is not able to respond reliably to the psycho-physical measures that might be necessary to achieve alignment of the coils used in the equipment.
6. A child who is at risk for recurrence of otitis media.

Downs listed several categories for otitis pronicity: "close family members with recurrent otitis, history of otitis media with first bout under one year of age, bacterial meningitis caused by otitis media, upper respiratory allergies, cleft palate, Down's syndrome, prematurity, native American, and any child under eight years of age with an uncertain history of otitis media" (p. 568).

Regarding statement #3 above, Downs notes an objection by HEI to the effect that revisions are not necessary every two years. Nonetheless, revisions are often necessary, especially in light of mechanical problems that can occur. Regarding the financial aspects of an initial implant operation, the costs at present might be well over $10,000, beginning with several thousand dollars for the device and another several thousand for the surgical, hospital, and treatment costs. Furthermore, as Downs has indicated, the likelihood is strong that concentrated, specialized post-implant training will be required, and must be paid for, if the goal is the achievement of acceptable speech.

Other Considerations for Children:

A few additional aspects of implants in children are as follows:

1. The kind of sound that a child might hear with an implant is unpredictable. Histopathological studies to date have not provided sufficient predictive information on surviving nerve tissue in the individual case, and the presently employed preoperative promontory tests for viable nerve tissue, requiring a subjective response, are neither reliable nor appropriate for young children. Although Auditory Brainstem Response (ABR) testing with electrical stimulation of the promontory offers some promise of obtaining objective responses, this use of ABR has yet to be validated. If there is no viable nerve tissue, the child would not be expected to receive sound. If the child does hear sound, it might be noise primarily; e.g. s/he may hear a voice as pulses of noise, perhaps distinctly unpleasant. According to Thielemeir et al. (1982), some adult patients have initially described sound with an implant variously as "scratchy", "tinny", "crackling", "metallic", or like "the buzz of an electric drill", "humming on a comb covered with waxed-paper", or "the speech on Donald Duck". Over time, they may describe the sound as "more natural" but still "not normal". The most unwanted outcome would be that of a child experiencing the extreme discomfort of electrical stimulation that has been reported by several prelingual-loss adults (Eisenberg, 1982). It is uncertain whether this discomfort would eventually be accompanied by any useful sound. Whereas an adult can quietly discontinue use of an implant in any of these eventualities, a child might not have this freedom and might not be able to describe her/his distress, not having had previous experience with sound or possibly the language needed to express such experi-

ences. In this connection, it is not known why a certain proportion of adults (Berliner & House, 1982) discontinue the use of their single-electrode implants.

2. Animal studies have shown that ganglion cell degeneration can occur with electrical stimulation, and data on human adults have not yet provided evidence on stability of hearing for a period of more than a few years. Levels of electric stimulation being used in adults seem suitably low, at least for the short term, but whether these levels can justifiably be adopted for a young child over the long term that would be required is unknown. Conversely, mention should be made of the possibility that electric stimulation could have a positive effect on auditory nerve tissue. Leake-Jones and Rebscher (1983) observed that in a cat deafened with neomycin and exposed to continuous intra-cochlear electric stimulation, a marked proliferation of myelinated axons occurred in the areas stimulated. Wong-Riley, Walsh, and Leake-Jones (1981) found that auditory neurons in cats retain their ability to respond to subsequent stimulation after being deprived of normal input for a period of time. When the neurons were stimulated electrically, the level of oxidative enzyme activity was restored and maintained at close to normal levels. Related to these two studies is the work of Webster and Webster (1979) who reported an incomplete maturation of most brain stem auditory neurons in mice from postnatal auditory deprivation as well as from conductive hearing losses.
3. It will take a few years to evaluate the physical and psychological effects of implant surgery in young children. One question is whether play activities might be affected by the implant or vice versa. It is worth noting, for example, that Black (1977) found evidence of abnormal postural instability in all of 13 adults with single-electrode implants when they were visually deprived. Instability increased when cochlear stimulation was activated by the implant and, in four of the subjects, when noise was introduced. Although adults may not be seriously disadvantaged by such instability, it might be detrimental to children in their normal play and other activities.
4. Histopathologic findings in humans have shown disagreement regarding long term survival of auditory nerve fibers subsequent to damage from various etiologic agents. On the one hand, Hinojosa and Marion (1983) found an unexpectedly substantial number of surviving ganglion cells (usually equated with nerve fibers) in almost all of these cases regardless of etiology, and Spoendlin (1975) observed that about 10% of ganglion cells strongly resist retrograde degeneration, suggesting that a residual nerve supply might be expected in most instances. On the other hand, the findings of Lawrence and Johnsson (1973) and Otte, Schuknecht, and Kerr (1978) are more pessimistic, indicating that nerve degeneration continues, once begun.

IMPROVEMENT IN COMMUNICATION SKILLS WITH AN IMPLANT

Profound hearing loss that might occur in early childhood — from meningitis, for example — may be either postlingual or prelingual. It is most important to differentiate between the two. In either instance it is crucial, if communicative skills are to be improved with an implant, that the parents and child be motivated and that an expert teacher/therapist be given sufficient time with the child. Of course, high intelligence and a cooperative spirit on the part of the child are distinct assets. In regard to postlingual loss, it has already become evident that, when such conditions are met, a child who receives an implant can improve in communicative ability, even with only durational and temporal cues. One example is a child described by Eisenberg et al. (1982) whose speech began to deteriorate rapidly after profound hearing loss from meningitis at age 3 years and who could not benefit from a hearing aid. She received an implant at about age 3.5 years. During several weeks of post-implant habilitative work she reportedly made gradual progress in awareness of sounds and clarity of speech. A detailed appraisal of her speech subsequent to this initial post-implant period has not yet been published to my knowledge. A second example (Koch, 1983) is a teenage girl, age 13, who lost her hearing from meningitis at age 7 years and received only vibratory stimulation from hearing aids that she wore up to the time of her implant. Her progress in a special training situation had reached a plateau, and her speech was difficult for unfamiliar listeners to understand. Nevertheless, she was in an honors class in a regular school, attesting to her brightness and motivation. In auditory training work in the same special training situation during the past summer (1983), subsequent to an HEI implant, her progress in communicative skills was much greater than anyone could have foreseen, according to her therapist. Direct work with her speech was being postponed because some improvement seemed to be occurring spontaneously. Despite her enthusiasm about this child's improvement, the therapist was unwilling to generalize the results to other postlingual children to say nothing of those with prelingual loss. She stressed this particular child's brightness and motivation, the strong home support, and the availability of special pre- and post-implant training. The improvement in these two children probably takes place through a combination of such factors as an awareness of sound, the restoration of some prosodic cues, the discrimination of inter-syllable, inter-word, and inter-phrase demarcations, the use of auditory feedback and vocal monitoring, and the enhancement of lipreading skills. Until more is known of the approximately 50 children who have received implants at HEI to date, these two children with postlingual loss must be viewed as exceptional cases.

In the case of prelingual or congenital childhood hearing loss, an infinitely more cautious approach is indicated, and the need for research is urgent. It is questionable what communication skills a prelingually deaf child might be able to achieve with an implant device that provides only durational and temporal cues. The same holds, at present, for implant devices that are believed to provide greater information. Undoubtedly, the post-implant habilitation of prelingual children, compared with postlingual, demands much more skill, effort, and time. One of several intriguing questions pertains to the possible advantage accruing to a child who has achieved an early language base through sign language as opposed to a child who has not had this advantage.

ALTERNATIVES TO SINGLE-ELECTRODE IMPLANTS

Extracochlear Stimulation

It seems likely that much of the same auditory information inherent in the HEI implant may also be present with an electrode placed on the promontory (Douek et al., 1979; Fourcin et al., 1979; Rosen et al., 1981). The consideration of an extracochlear implant on the promontory or in the round window niche is of particular relevance to whether a child might be better served by waiting for a wearable multichannel device that provides a greater amount of information for speech recognition. Specifically, although a single electrode in the scala tympani can reportedly be replaced with one of the same kind, it is not known whether a single electrode can be replaced after a time by a multielectrode array for the better sound that might be provided. With an extracochlear electrode, the scala tympani can be preserved for such an array.

Multichannel Stimulation

The case for awaiting multichannel stimulation (several inputs to several electrodes) rests on bases including the following: (a) none of the descriptions of HEI single electrode implant users have given any evidence of speech recognition ability beyond a scattering of open-set spondee words in an occasional patient, whereas Eddington (1983) and Clark et al. (1983) have reported open-response speech recognition with wearable multichannel devices; (b) theoretically-oriented investigators seem generally in agreement that multichannel stimulation is more promising than single-channel for speech recognition; and (c) in cases where the hair cells are functioning only to sounds below 500 Hz, thus limiting the benefit of a hearing aid, the use of a multichannel implant, in contrast to a single channel, might provide discrete mid- and high-frequency information to the central processor by direct stimulation of any nerve fibers accomodating these frequency ranges.

Vibrotactile Stimulation

Research on the application of wearable vibrotactile stimulation for the profoundly hearing impaired is continuing, two of the most recent reports being by Roeser (1983) and Plant (1982). Whether a vibrotactile device provides generally the same communicative advantage as a single-electrode implant remains for study.

Total Communication

The use of the total communication approach in recent years and the emphasis on language acquisition has enabled hearing-impaired children to take maximum advantage of whatever stimuli will help them. Sign language, which is included in total communication, often becomes a major mode of input for children. The work of Schlesinger and Meadow (1972) has shown that signing offers the child an opportunity of achieving a language base at a very early age. Accordingly, there are strong arguments in favor of emphasizing sign language in a young child as soon as it is seen that amplification by a hearing aid may be of doubtful benefit in the acquisition of speech. In the course of arriving at a decision to implant a child who cannot beneficially use a hearing aid, it should be strongly suggested to parents that they read at least two books dealing with the role of sign language — one by Ogden and Lipsett (1982) and one by Spradley and Spradley (1978) — and discuss these writings with an interested and unbiased person versed in the education of the deaf. Additionally, it must be kept in mind that a certain proportion of children will probably continue to have extreme difficulty in achieving generally acceptable speech, regardless of seemingly satisfactory amplification (implant or hearing aid) and expert teaching. The search for ways to identify these children must be continued.

Comment

It would be fortunate if the implant is introduced to the families of hearing impaired children, not as a panacea for deafness, but as another kind of amplifying device that for some children may be more effective than a hearing aid for the learning of communication skills. Of paramount importance is early identification and careful appraisal by knowledgeable workers who, in concert with the parents, can plan the best habilitative approach. The audiologist holds key responsibility for the early identification of hearing loss, specifically pure-tone audiograms on children under the age of one year, and for seeing that habilitative work is undertaken with appropriate amplification. Where a hearing aid seems of doubtful benefit, manual communication should be considered as early as possible.

CONCLUSIONS

In this review of cochlear implants, stress has been placed on some unknown factors and consequent need for research. The advent of the cochlear implant has already attracted various practitioners, internationally, who are seeking ways to ameliorate the effects of profound hearing loss.

On the whole, the experience of postlingually impaired adults with implants has been encouraging, and improvement in implant devices, selection of patients, surgical procedures, and habilitative-rehabilitative programs can be expected. It is still too early, however, to attempt a prediction of the eventual contribution to be made by these devices.

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