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COCHLEAR IMPLANTS:

THE AUDIOLOGIST'S ROLE

by

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TABLE OF CONTENTS

LIST OF TABLES, FIGURES AND APPENDIX

INTRODUCTION

A hearing impairment may affect many aspects of life, regardless of when the loss is acquired. The hearing-impaired child faces difficulties developing language in a natural manner, which in turn adversely affects future verbal cognitive development (Sanders, 1982). The adult with an acquired hearing loss experiences problems in maintaining established life styles, retaining jobs, and preserving social and personal relationships (Sims, Walter, and Whitehead, 1982; Alpiner, 1978). Rehabilitation must be designed to minimize these effects as much as possible. A cochlear implant is a medical device that can help some profoundly deaf individuals perceive acoustic stimuli. Advocates of the cochlear implant believe the implant is a technological breakthrough that can provide an increased enrichment of daily life for hearing impaired persons (Mecklenburg, 1985a).

The cochlear implant is a device that is designed to restore hearing perception for profoundly deaf individuals by direct electrical stimulation of the remaining neuronal elements in the cochlea. The main goals of a cochlear prothesis include obtaining some auditory perception of environmental sounds (e.g., traffic noise, telephones ringing) and ultimately the ability to detect and discriminate speech to a greater

degree than that which is obtained by conventional amplification.

The basic premise underlying any type of cochlear prothesis was summarized by Keidel (1979, p.163).

> "Auditory processing is not the exclusive domain of the central auditory system. The nerve signals that leave the cochlea via the cochlear nerve are the end products of a series of complex, interlinked processes that take place partially in the mechanical domain and partially in the sensorineural one. Two main events stand out: 1) There is a systematic space/time distribution of signal components into a number of parallel nerve fibre channels, of which a maximum of about 30,000 are available; and 2) Each component that travels in a single given nerve fibre is encoded in the only form nerve fibres are equipped to handle (i.e., action potentials). In the two underlying processes of conversion, attributes of the original signals are accurately preserved. A reasonable degree of speech intelligibility, the ultimate aim of cochlear protheses, can only be restored if and when the prothesis is capable of handling these two tasks in a fair manner."

The complexity of coding in the auditory nerve makes it unlikely that a prothesis can exactly stimulate nerve fibers so normal functioning in the deaf ear is achieved. However, implants can provide some information regarding intensity and duration which should aid in lipreading and allow recognition of some sounds without visual cues. (Tong, Clark, and Seligman, 1980). Attempts have been made to provide some frequency information as well via rate of stimulation, as used with single electrode devices, and/or place of stimulation, as used with multi-electrode devices.

Clark, Shepherd, Patrick, Black and Tong (1983, p.191) stated that any electrical array must meet these certain design requirements:

"1) it must be atraumatic in insertion; 2) it must be biologically inert (i.e., biocompatible with the tissues); 3) current must be localized (i.e., should not predispose the patient to local infection); 4) only minimal damage should occur with chronic stimulation); 5) it must have mechanical stability (i.e., not prone to break as a result of repeated stress); and 6) fabrication must be practical (i.e., simple and inexpensive)."

There are currently several types of cochlear implant protheses in use. These are summarized in Appendix A. The basic philosophies of different manufacturers of cochlear implants vary in terms of: number of electrodes used for stimulation (i.e., single versus multi-electrode systems); stimulation regime (i.e., monopolar: current flows between an active and remote ground which stimulates a large population of remaining neurons and generates wide current spread; versus bipolar: current flows between two closely spaced electrodes which allows for a more localized site of stimulation); coding strategies (i.e., analog versus digital); and site of stimulation (i.e., intracochlear versus extracochlear). (Staller, 1985)

The development of an implant system involves a variety of professions including otology, audiology, speech science, psychoacoustics, electrophysiology, otopathology, polymer rheology, and biomechanical and electrical engineering (Radcliffe, 1984). Other

professionals become involved in the rehabilitation and counseling of cochlear implant patients both pre-operatively and post-operatively (e.g., speech/language pathologists, deaf educators, pyschologists).

Cochlear Implant Versus Hearing Aids

Hearing aids and vibrotactile devices are amplifiers. A hearing aid has the capability of making sound louder and possibly clearer due to an increase in loudness. A vibrotactile device is used to convey acoustical information through tactile stimulation in attempts to increase auditory awareness. A cochlear implant system is also an amplifying device in that the electrical signal is delivered to the patient at his/her most comfortable loudness level, however, the system possesses a speech processor which also selects key acoustical information (i.e., intensity, duration, and frequency) to be delivered to the implant user (Mecklenburg, 1985a). In addition, the implant works to translate this information into electrically coded signals that stimulate nerve fibers within the cochlea (Staller, 1985). Typical implant recipients have cohlear pathologies which allows for the stimulation of nerve fibers and makes use of the otherwise normal functioning auditory system.

A cochlear implant is similar to a hearing aid in the input stage in that acoustical energy is converted into electrical current by a microphone and is then processed by an amplifier, filter network, and compression circuit to accommodate the patient's perceptual characteristics. The difference between the two devices is in the output stage. Whereas a hearing aid transduces the electrical signal back to acoustic energy, the implant delivers an electrical signal through a stimulating electrode array (Staller, 1985, see Figure 1).

Figure 1

Hearing Aid Versus Cochlear Implant

(Staller,1985) Presented at the Denver Ear Institute Cochlear Implant Symposium, Denver, CO.

COCHLEAR IMPLANT   VS   HEARING AID

INPUT STAGE

ACOUSTIC ENERGY

ELECTRICAL ANALOG

OUTPUT STAGE

modified electrical analog   acoustic energy

cochlear stimulation   cochlear stimulation

electrical distribution   mechanical distribution

Implant Components

The goal of any implant system is to elicit those patterns of neural activity that the brain requires to understand speech (Miller, Tong, and Clark, 1984). Most implant systems can be divided into four major components. Miller et al. (1984) described these as including the following.

A. Neural Interface: this component generates controlled electrical currents which stimulate auditory nerve fibers.

B. External (speech) Processor: the speech processor is needed to transform information from the incoming acoustic speech signal into an electrical form which retains the important speech components but which can also be presented at a crude level through the neural interface of the prothesis.

The signal processing strategy utilized depends on which research center is developing and programming the device. Multi-electrode devices utilize a strategy which extracts information regarding intensity, duration, and frequency, whereas, single electrode/channel devices are capable of processing intensity and duration information and limited frequency information. The external signal is transmitted to the electrode(s) either through a percutaneous plug (i.e., direct electrical connection to the internal receiver) or a transcutaneous receiver

(i.e., data inductively transmitted to a receiver under the skin via a radio frequency carrier).

C. <u>Signal Transfer Hardware</u>: this consists of the internal receiver, external microphone, and external transmitter/connector. These components interact to produce electrical representations of acoustic stimuli and deliver this electrical stimuli to the neural tissue. A radio frequency carrier may be used to transmit this information across the skin to an internal receiver or a direct percutaneous connector. The radio frequency carrier is designed such that correct data obtained from a custom integrated circuit is required before any stimulation occurs. Therefore, the implant will be unable to generate stimulation in response to any external radio frequencies outside its acceptance band.

D. <u>Perceptual Mechanism</u>: the perceptual capabilities of each patient (i.e., how the patient will integrate and utilize acoustic information) will define his/her ability to make meaningful use of minimal auditory cues. The postlingually deafened adult may have to learn to analyze a new set of auditory experiences and integrate these with past speech processing experiences.

The most fundamental function of the implant system is to generate neural discharge patterns to the auditory nerve which may be modulated by external

signals. These signals are derived from an acoustic speech signal by a speech processor and then transferred to an electrode or electrodes at the neural interface. This results in a perceptual sensation of "sound" (Miller et al., 1984).

Single Versus Multi-electrode Arrays

There are a variety of electrode arrays utilized with a cochlear prothesis. Information may be transmitted through a single active electrode as a one dimensional time varying pattern or through several active electrodes as a multi-dimensional pattern (Miller et al., 1984). An active electrode can have an extra-cochlear placement adjacent to the round window or on the promontory (Hochmair-Desoyer and Hochmair, 1983) or the electrode(s) can be intracochlear, placed through the round window into the scala tympani (House and Urban, 1973; Mecklenburg, 1985a; Rebscher, Kessler, and Calvert, 1985; Dankowske, 1985; Ferreira, 1985).

The two primary theories regarding pitch perception, place pitch and rate pitch, often cause controversy over the selection of single versus multi-electrode systems. Therefore, the philosophies regarding delivery of frequency information to electrode(s) within the cochlea differ according to which theory the implant manufacturer maintains. According to the place pitch theory, the perception of pitch depends on which auditory nerve fibers are firing

impulses. Multi-electrode systems are designed around this theory. Rate pitch theorists maintain perception of pitch depends on how rapidly the fibers fire impulses. Implants that deliver the entire signal through one electrode are designed around the rate pitch theory (Kriewell, 1985). The probability is that both rate and place are involved in the perception of pitch in the normal auditory system.

In simple terms, a single electrode/single channel system consists of a device where all acoustical information is coded into an electrical signal applied to a single electrode. Such a system could involve stimulation within the cochlea or outside the cochlea. There are single electrode, multi-channel devices which extract certain acoustical features of speech and attempt to deliver this processed information to a single electrode (Hochmair, 1983). In contrast, a multi-electrode system contains a number of stimulation sites within the cochlea. The coding of acoustic information into electrical stimulation takes advantage of the naturally occurring tonotopic organization of nerve fibers in the cochlea (Hirshorn, 1985). In essence, apical electrodes are stimulated when low frequency energy is dominant and basal electrodes become active in response to high frequency energy. The amount of stimulation received is dependent on the

neural population reserve along the cochlea (Mecklenburg, 1985b).

Multi-channel systems employ a customized processing channel for each stimulating electrode. Theoretically, multi-channel speech processors that divide the speech spectrum in contiguous bands should allow subjects to discriminate between the higher frequency spectral components of speech due to the location of basal electrodes. Therefore, multi-channel stimulation as compared with single channel stimulation is believed to more accurately reflect normal auditory nerve excitation patterns (White, Merzenick, and Gardi, 1984).). However, White et al.(1984) discovered that when two or more electrode channels are stimulated, strong interactions between the channels can occur. Those interactions can then greatly alter the loudness and quality of the sensation evoked during multi-channel stimulation.

Clark, Black, Dewhurst, Forster, Patrick, and Tong (1977) stated that multi-electrode systems attempt to evoke temporal patterns in partially separate populations of auditory nerve fibers. In such cases, current flow must be highly localized so that stimulating electrodes at different sites produces different sensations (Chouard, 1978). This has been attempted by using closely positioned bipolar electrodes to either an array of active electrodes

interwoven with a common ground electrode (Clark, Patrick, and Bailey, 1979) or with a monopolar electrode array using a remote ground external to the cochlea (Berliner and Eisenberg, 1985a). Danley and Fretz (1982) concluded that common-ground and monopolar electrode arrays provide poorer current localization, however, this is sometimes offset by an adjustment of the value of the lower current threshold obtained by these arrays.

Psychophysical experiments described by Eddington (1983) indicated that behavioral responses (i.e., loudness and threshold measures) are substantially affected by changing the stimulus polarity of one channel when one or more than one channel are being stimulated simultaneously. Since interactions generated during simultaneous stimulation can occur, it might be useful to avoid them by stimulating each channel separately in time (i.e., temporally interlacing the stimuli across the channels). White et al. (1984) found simultaneous channel interactions declined with interchannel distance and the channel interactions were decreased with bipolar rather than monopolar stimulation.

Having a choice of stimulation sites is important for the perception of pitch due to the frequency selectivity of different groups of auditory nerve fibers (Farrer, Mangham, and Kuprenas,1984). The

damaged cochlea is unpredictable in its response to stimulation at different locations (Tong, Clark, and Seligman, 1980). Tong et al. (1980) stated that for some patients, there is orderly progression from high-to-low frequencies along the length of the cochlea. For others, the response is not as clear as frequency discrimination will be dependent on neural population in the cochlea. Therefore, multiple electrodes would allow for individual adjustments of stimulation amplitude at different electrode sites. Because of greater number of stimulation sites and thus increased information delivered to the brain, advocates of the multi-channel/multi-electrode systems suggest that patients do better with speech discrimination even on open-set discrimination tests without lipreading (Mecklenburg, 1985a, Mecklenburg and Brimacombe, 1985b)

Another argument supporting multi-channel over single channel systems was provided by Farrer et al. (1984, p.75):

> "In general, the multi-channel device allows recognition of more speech elements than the single device through a unique method of extracting and recording the important resonances of the voice and presenting them to the auditory nerve. It offers a choice of stimulation sites in the cochlea as well as several variable dimensions with which to code incoming acoustic signals."

Single channel/single electrode advocates argue their device is a proven one with more years of clinical trials and examinations and the present implant system has built-in potential for upgrading as

new devices are developed (Berliner, 1985). The
3M/House single channel/single electrode unit also has
the advantage of having received approval from the
Food and Drug Administration (FDA) for use with adults
and children (Berliner and Eisenberg, 1985b). The
NUCLEUS multi-electrode device also has FDA approval
for use with adults and they have recently received FDA
approval to use their device on children ages 10-18
years.

Comparisons between single and multi-electrode
systems have shown multi-electrode devices to be
superior in terms of speech recognition and
discrimination. Eddington (1983) found that speech
recognition results for open-set, unpracticed lists of
two-syllable words were better for multi-channel
systems than the best single channel results reported.
However, Eddington (1983) also pointed out that because
the processing schemes used by single channel patients
are different, drawing any firm conclusions regarding
the relative merits of the single channel and
multi-channel stimulation scheme is difficult.

Digital Versus Analog Coding Schemes

There are two major coding strategies utilized in
the different implant speech processors currently on
the market: analog versus digital coding.

A. <u>Analog</u>: This system utilizes an electrical signal which is comparable to the sound stimulus. Acoustic energy is converted into a direct electrical representation. The analog signal is compressed and filtered to compensate for the patients perceptual characteristics. This signal is then delivered to one or more electrodes (Hochmair, 1983). This type of system may introduce added noise but improves precision of timing and current level (Miller et al., 1984).

B. <u>Digital</u>: Digital coding schemes utilize a series of charge balanced electrical pulses to encode the speech signal. The incoming signal is processed and selected electrodes are stimulated corresponding to various formats of speech. Digital systems either generate a pulse each time the input signal crosses from a positive to negative voltage or determines the characteristics of the pulses (i.e., rate and intensity) by certain key features of the speech signal. This has also been referred to as feature extraction (Mecklenburg, 1985a, Mecklenberg and Brimacombe, 1985a).

The digital processing scheme has been reported to decrease transmission noise problems but this scheme also limits the precision of timing and current level (Miller et al., 1984).

Intra-cochlear Versus Extra-cochlear Devices

Extra-cochlear devices, those which are placed on the promontory, have the advantage of being safer to the internal auditory structures. However, such a device may limit the amount of frequency and intensity information delivered to the nerve fibers within the cochlea. Intra-cochlear devices are believed to be more advantageous than extra-cochlear devices as scala tympani electrodes require less current to evoke electrophysiological responses than do round window electrodes and, thus, intra-cochlear devices reveal more sensitive thresholds than extra-cochlear devices (Simmons,Lusted, Meyers, and Shelton, 1984). However, the placement of intra-cochlear devices do increase the risk of damaging the scala tympani.

Summary

The optimum coding scheme remains controversial at this time. Clearly, the merits of different coding strategies are difficult to assess due to the differences in assessment tests used by different investigators and to the differences between patient populations (Hochmair-Desoyer, 1984). In the future, it might eventually turn out that, depending on the amount of nerve survival, the complexity of the stimulation scheme will be chosen (Wallenberg, Hochmair-Desoyer, and Hochmair, 1985).

Children and prelingually deafened adults are not considered good candidates for multi-electrode devices due to their lack of experience with acoustic stimuli. Their lack of experience would create problems when trying to adequately adjust the speech processor because the patients would be unable to provide the necessary feedback to the clinician used to ensure adequate fitting (Kriewell, 1985). Kriewell (1985) stated current multi-electrode systems may limit the amount of information delivered to the cochlea due to the strategies currently utilized in multi-channel speech processors. Such strategies focus primarily on processing speech information and thus might not appropriately process environmental sound and, as a result, could be confusing to the patient.

THREE COMMON TYPES OF DEVICES

3M/House

The 3M/House system is a single electrode/single-channel system which consists of a processor, microphone, external transmitter, internal receiver, and a magnetic system (Berliner, Eisenberg, and House, 1985). The system has an electret microphone which converts acoustic energy into electrical current and transmits this current to a processor. A modulated electrical signal is directed to a transmitter coil and is electromagnetically induced across the skin to a transcutaneous receiver. The current is then transmitted to an active electrode which then flows to a ground electrode. The current flow stimulates auditory neural tissue and produces the perception of sound. (Berliner and Eisenberg, 1985a; Berliner et al., 1985; Berliner, 1985)

The electrodes are pure platinum and are used in a monopolar configuration with the active electrode implanted approximately 6mm into the scala tympani and the ground electrode in the temporalis muscle region. The speech processor uses a bandpass filter from 340 to 2700 Hz. The signal from the bandpass filter is used to amplitude modulate a 16k Hz sinusoidal carrier waveform. The modulator is highly nonlinear in terms of stimulation voltage at the electrode of the internal

receiver in relation to sound pressure level at the microphone (Fretz and Fravel, 1985).

3M/Vienna

There are two types of Vienna cochlear protheses: 1) a four-electrode intra-cochlear implant with four bipolar electrode channels; and 2) an extracochlear implant with a single active electrode. Both systems use an analog sound processing scheme that has the capability to cover a frequency range from 30 to 10k Hz (Hochmair-Desoyer, 1984).

With the extra-cochlear device, the electrode is placed on, not through, the round window. One of the biggest advantages of such a system is that there is very little risk of mechanical damage to the inner ear structures (Hochmair, 1983). The intra-cochlear, multi-channel device differs from the 3M/House device in that various frequency bands are amplified individually. The rationale for amplifying different frequencies by different amounts stems from the fact that high frequency speech signals are relatively weak. Therefore, high frequencies require greater amplification to stimulate the fibers of the auditory nerve adequately (Kriewell, 1985). Transmission of high frequency energy is a critical factor for speech discrimination as most of the consonant phonemes in the

English language consist of high frequency, low energy information.

A microcomputer is used to adjust the speech processor. The input signal to the stimulator is a continuous sine wave which varies in frequency in small increments from 100 to 4k Hz (Hochmair-Desoyer, Hochmair, Buriank and Stiglbrunner, 1983). A frequency stepped sweep (FSS) is used in conjunction with the patient's feedback to determine the frequency response for the sound processor. During stimulation, a constant amplitude and small increment in frequency can be heard equally loud at most comfortable loudness levels (Hochmair-Desoyer, 1984). Hochmair-Desoyer (1984) stated that the FSS method has the advantage of being quicker and easier for the patient.

NUCLEUS

The NUCLEUS multi-electrode/multi-channel system utilizes 32 bands of pure platinum electrodes (22 of which are active, 10 of which are used to provide a stiff support) arranged on a 25mm silastic carrier. The acoustic signal is converted into an electrical current and is transmitted via a radio frequency carrier of 2.5k Hz to a tuned external induction coil. The system utilizes an electromagnetic induction system between the external coil and the internal receiver (Mecklenburg and Brimacombe, 1985a, 1985b).

The design uses a feature extracting coding strategy which allows estimates of the voice pitch (Fo), first formant (F1), second formant (F2), and signal amplitude to determine the signal to be sent to the patient (Mecklenburg, 1985b). Electrode selection results from an estimate of F1 and F2 represented by dominant spectral energy within the range of 280-4k Hz (Mecklenburg, 1985a). Therefore, when high frequency peak energy is detected, a basal electrode corresponding to that frequency is selected for stimulation at the rate of the fundamental frequency. Conversely, a low frequency peak will stimulate an electrode which is more apically placed in the cochlea (Mecklenburg, 1985b). Reportedly, the addition of F1 information has led to and increased ability for the implant recipient to identify the acoustic features of voicing and nasality due to transmission of the low pitched F1 component (NUCLEUS Training Manual).

One of the systems major components is the microcomputer which allows stimulating levels to be variable across the different electrodes. A computer interface provides communication between the computer and the speech processor. There is a special erasable programmable read-only memory chip (EPROM) which allows the speech processor to be "mapped". Mapping involves identifying the threshold and maximum comfortable level (i.e., dynamic range) for each electrode. This

procedure requires approximately three hours to program and all of the electrodes can be reprogrammed as the patient's perceptions change due to increased implant usage and auditory experience (Mecklenburg, 1985a).

PATIENT SELECTION-ADULTS

General Considerations

A. <u>Age</u>: In the beginning years of patient selection, only those subjects who ranged in age from 18 to 65 years were considered as potential candidates (Maddox and Porter, 1983). In 1980, the House Ear Institute began implanting children as young as two years of age with approval from the Food and Drug Administration (Berliner, 1985). The multi-channel NUCLEUS system has just recently obtained FDA approval to implant children and has previously received FDA approval to implant adults (Mecklenburg, 1985b). While, there are other devices on the market (e.g., Storz and Symbion) which have FDA approval for clinical use, these devices are still under investigation.

B. <u>Etiology of Hearing Loss</u>: The most common etiologies among adult patients who have received a cochlear protheses (both single and multi-electrode systems) include: cochlear otosclerosis, ototoxicity, and meningitis. Other causes of hearing loss include Menieres disease, various congenital syndromes (e.g., malformations of the inner ear), trauma, and unknown factors which cause permanent profound sensorineural hearing loss. (Maddox and Porter, 1983; Eisenberg, 1985; Campos, 1985)

Information on the etiology of the hearing loss is important for assessing the condition of the cochlea (e.g., ganglion cell population). Schuknecht (as cited by Goin, 1985) concluded that approximately 10,000 ganglion cells are needed for successful speech discrimination and that approximately 3,000 of these must be in the apical region of the cochlea. Therefore, certain etiologies may preclude implantation. The chances for success with implantation is greater in those pathologies which preserve dendrites/ganglion cells. Promontory testing is used to help assess neural population reserve, however, this assessment procedure has questionable success.

Some of the etiologies which may preclude implantation are temporal bone fractures resulting in extensive cochlear damage; bilateral acoustic neuromas (e.g., von Recklinghausen's disease); congenital malformations of the bony and membranous labyrinths (e.g., Mondini's syndrome); and certain disease processes or syndromes in which deafness is present with other neurological or physical disabilities such as retinitis pigmentosa with associated blindness, severe head trauma, cerebrovascular accident and degenerative neurological disorders (Maddox and Porter, 1983). These etiologies could make implantation unfeasible or make the rehabilitation process too

complex and lengthy. Promontory testing, polytome X-Rays and CT scans may be used to assess the patency of the scali tympani and other inner ear structures (e.g., internal auditory meatus, transtympanic recess).

C. Hearing Acuity: Patients need to demonstrate the inability to receive and effectively utilize auditory cues. Patients who initially receive questionable or limited benefits from conventional amplification often demonstrate substantial gains in performance with such devices after a period of training (Fourcin, Rosen, Moore, Douek, Clarke, Dodson, and Bannister, 1979). However, there will be cases where conventional amplification gives little assistance. In such cases, the problem of selection of hearing aid versus cochlear implant centers around whether these patients show minimal but definite responses with conventional amplification (Brackmann, 1976). The selection of the best device would then be focused on whether responses with conventional amplification are at or lower than those found with implant patients.

The use of residual hearing as the main selection criteria may be complicated in cases where benefit from conventional amplification is received by one ear and no benefit is received by the opposite ear. Maddox and Porter (1983) stated there have been cases in which a cochlear implant was used successfully in conjunction

with conventional amplification. However, they stated that the ability to pre-operatively predict what additional benefits will be gained by the cochlear implant is difficult, if even possible.

D. <u>Congenital Versus Acquired Hearing Loss</u>: Both the House Ear Institute (single electrode) and the NUCLEUS (multi-electrode) have reported success with congenital and acquired hearing losses (Mecklenburg, 1985a; Berliner, 1985; Eisenberg, Berliner, Theilemeir, Kirk and Tiber, 1983; Eisenberg and House, 1982). However, a higher incidence of failures (i.e., nonusers) exists among patients with congenital losses (Berliner, 1985).

Maddox and Porter (1983) stated that those post-implant patients who do not use their implant do not perform more poorly on pre-operative objective audiological testing, however, their ability to subjectively make meaningful use of auditory cues may be inferior to patients who successfully utilize their implants. Therefore, it has been assumed that those patients with an acquired loss would be more likely to recognize and effectively utilize acoustic cues than would patients with congenital losses whose past auditory experiences have been severely limited.

The seemingly important variables which indicate predicted success or failure of an implant among persons with congenital losses include: age of

identification; previous experience with amplification; and type of communication used (i.e., oral versus total communication versus manual). Patients with a congenital hearing loss who were identified at an early age, exposed to auditory stimuli, and trained in an oral or total communication program have been shown to have a higher success rate with a cochlear prothesis (Maddox and Porter, 1983). However, these criteria alone do not guarantee success or failure with an implant.

E. <u>Additional Factors</u>: Several additional factors may make post-implantation rehabilitation exceedingly complex. Patients who are nonoral and rely solely on manual communication, those who exhibit poor language skills and/or minimal or unintelligible speech skills, and those who have multi-handicaps are less likely to be considered for the cochlear implant. Children and patients with congenital losses would involve additional rehabilitation needs that must be considered in patient selection. Financial and geographical considerations must also be assessed. In such cases, the responsibility of each institute's rehabilitation staff is to determine whether the staff are adequately prepared and trained to deal with these additional factors (Maddox and Porter, 1983).

Medical Assessment

A major factor in patient selection is the surgeon's beliefs the patient is a good candidate for implantation and the patient will reliably complete a rehabilitation program with full cooperation. The physician's pre-operative assessment typically includes the following (Goin, 1985):

A. Routine Physical Examination

B. Transtympanic electrophonic stimulation of the cochlea (i.e., promontory testing) in attempt to demonstrate intact neural function (i.e., ganglion cell population) within the cochlea and along the nerve VIII pathway (House and Edgerton, 1982).

C. Polytome x-rays of the inner ear to determine if fibrosis or calcification of the cochlea is present (utilized to evaluate the patency of the cochlea).

D. Evaluation of the middle ear to rule out effusion, recurrent otitis media, and round-window obliteration.

E. Cranioaxialtomography (CT) scan to further evaluate status of the cochlea and surrounding structures.

Although promontory testing is often utilized, a standardized electrical stimulation test designed to estimate nerve survival does not exist (Simmons, Mathews and Walder, 1979). However, this information is critical in the selection of a cochlear implant system. Simmons et al. (1979) stated that it makes little sense to place a complex multi-electrode system in a cochlea with a sparse nerve population and then expect to obtain better results than that from a single electrode system.

Post-operative assessment involves obtaining further x-rays of the inner ear to check the ground and active electrode placement and to determine if the electrodes are intact.

The physician is also concerned with the histopathology from an implanted electrode system as well as from the surgical risks. Berliner and Eisenberg, (1985b) discussed the potential damage that may occur as the result of surgical implantation. Mastoid surgery may result in infection, meningitis, or facial paralysis. To transverse the middle ear space and enter the cochlea may provide a potential pathway for the spread of otitis media to the inner ear system. Insertion of electrodes into the cochlea also may lead to trauma of the inner ear structures. Osteogenisis may be associated with mechanical damage or the presence of the electrode in the scala tympani.

The scala tympani begins to curve at approximately 10mm at which point the implanted electrode can possibly pierce the membranes of the inner ear resulting in a mechanical rupture of the basilar membrane, Reissner's membrane, and/or the osseous spiral lamina. The rupture of any of these structures will subsequently result in the diffusion of the perilymphatic and endolymphatic fluids. The perilymphatic fluid is toxic to hair/nerve cells and could significantly increase the amount of

sensorineural degeneration (Otte, Schuknecht, and Kerr, 1978; Burgio, 1985).

The possible long term damage to the cochlea must be considered particularly when implanting children. The cochlear nuclei are not completely developed until after birth. Therefore, if the prothesis is placed in the cochlea at too early an age, it could affect the maturity of the cochlear nuclei (Goin, 1985). However, auditory deprivation studies in lower mammals have revealed that the early deprivation of sound can cause an incomplete maturation of cells in the cochlear nucleus and, because this development takes place post-natally, the cochlear nucleus is thought to require auditory stimulation in order to develop completely (Webster and Webster, 1977, 1979). An enhancement of the auditory system may actually occur with early auditory stimulation. Thus, the implantation of children may enhance the maturation of the cochlear nucleus.

The possibility of mechanical rupture must also be taken into consideration when implanting the NUCLEUS multi-electrode system which extends approximately 22mm into the cochlea. Brand (as cited in Fretz and Fravel, 1985) stated tissue damage tends not to be directly related to any mechanical damage but rather to the deprivation of blood supply and tissue fluids which

subsequently results in deprivation of oxygen and nutrients.

Current studies have found the following histopathologic results from an implanted temporal bone (implanted with the 3M/House single electrode device) (Burgio, 1985):

1) Typical foreign body response (e.g., edema, possible infection)

2) No significant tissue growth in the middle ear

3) Round window well sealed by fibrous tissue thus providing a natural barrier between the middle and inner ear.

4) New bone growth was localized to the round window and lower basal turn at or near the opening made into the scala tympani for electrode insertion. The new bone was not along the length of the electrode and did not appear to adversely affect the nerve cell populations.

5) The 15mm electrode, which is inserted 6mm into the scali tympani, caused mechanical damage to cochlear tissues. As the electrode extended past the first turn of the cochlea, the amount of tissue damage increased as a result of damage to the cochlear duct which in turn results in degeneration of nerve fibers.

6) Large nerve cell survival

7) In 100% of the cases studied, insertions were safe to the basilar membrane and approximately 96% of electrode insertions were safe to the osseous spiral lamina (Radcliffe, 1984).

Psychological Assessment-Adults

Any cochlear implant candidate, both adult and child, must meet the following psychological criteria:

"1) no evidence of severe organic brain damage; 2) no evidence of psychosis; 3) no evidence of mental

retardation; 4) no behavioral/personality traits that would make completion of the rehabilitation program unlikely; and 5) no unremitting, unrealistic expectations about the implant on the part of the patient or the family" (Tiber, 1985, p.48).

An indepth interview is often included to measure motivation levels. Many patients request information on cochlear implants because of pressure placed on them by their significant others (Campos, 1985). Therefore, these interviews also provide information concerning the patient's expectations of the implant regarding both its benefits and limitations. Other factors which also must be considered include the patient's acceptance of his/her deafness, the amount of family support, and the commitment to post-implant rehabilitation.

Adverse psychological effects secondary to long-term stimulation and use of the cochlear implant have not yet been reported (Miller, 1979). Miller (1979) concluded that any psychological changes that do occur are generally positive. The use of a cochlear implant has often been shown to enhance communication skills, promote confidence in social settings, promote independence and provide positive feelings towards improved quality of life (Miller, 1979; House and Berliner, 1982)

Audiological Assessment-Adults

The audiological assessment for the profoundly deaf adult is difficult to perform with conventional suprathreshold tests. These protocols are typically unable to adequately assess the residual skills of the patient (Edgerton, Eisenburg, and Thielemeir, 1983). Therefore, the assessment of a patient's ability to receive and utilize auditory cues should not consist of conventional measurements alone.

One critical audiometric question is whether the patient will likely benefit more from a cochlear implant or from a hearing aid. Most clinics will not implant a cochlear prothesis in patients who receive clear benefits from amplification. This is based on the belief that frequency discrimination will be better with an appropriately fit hearing aid than a cochlear implant due to the unnatural method of stimulation generated by the electrical current versus that by the naturally occuring action potentials (Luetje, 1981; Mecklenburg, 1985a; Mecklenburg and Brimacombe, 1985b; Berliner, 1985; Hochmair-Desoyer, 1985). The audiologist must also decide whether another type of sensory aid (e.g., vibrotactile device) would provide the added cues and increase performance equal to those obtained with an implant. Some norms have been established for cochlear implant patient's performance on environmental sound tests and the

Monosyllable-Trochee-Spondee (MTS) test (Edgerton et al., 1983). Clinicians are encouraged to use this information to compare the patient's best aided performance with the range obtained from cochlear implant patients. In general, patients wearing hearing aids who perform at or above the average for cochlear implant users may not be considered good candidates for an implant. Such patients may be unlikely to receive any further benefits from a cochlear implant. Conversely, patients performing marginally or more poorly can be considered potential candidates for cochlear implantation.

Audiometric Evaluation

Audiometric assessment for adults usually includes the following measures (Edgerton et al., 1983; Luetje, 1981; Mecklenburg, 1985a):

UNAIDED EARPHONE

A. Pure-tone thresholds

B. Pure-tone uncomfortable loudness levels (UCL)

C. Speech detection threshold

D. Most comfortable level for speech

E. Monosyllable-Trochee-Spondee test (MTS)

F. Environmental Sounds test

G. Test for speechreading ability such as the CHABA-Everyday speech sentences (Silverman and Hirsh, 1955; Sims, 1975)

<u>AIDED SOUNDFIELD</u>

A. Warbled tone thresholds

B. Speech detection thresholds

C. Environmental sounds test

D. Minimal Auditory Capabilities battery (MAC)

The criteria utilized by the House Ear Institute when assessing aided performance includes: 1) obtaining an earmold prior to the evaluation to ensure that maximum benefit from the aid may be obtained; 2) output of the hearing aid is set at 130 dB SPL or less; 3) at least two sensory aids are evaluated (including a vibro-tactile aid); and 4) speech and environmental sound stimuli are presented at 70 dB SPL (Eisenberg and Berliner, 1983; Berliner, 1985).

The Mononsyllable-Trochee-Spondee (MTS) test provides data on two levels of perception: stress discrimination and word identification while utilizing a forced-choice format (Erber and Allencewicz, 1976). The Environmental Sounds test is a 20-item five-alternative forced-choice test (Edgerton et al., 1983). Patients are required to circle the sound they hear from the five answer choices on a response sheet.

The Minimal Auditory Capabilities (MAC) battery was designed by Owens, Kessler, and Schubert (1982) and is used to obtain interim audiometric indices on the relative benefits of cochlear implants and hearing aids for patients with profound postlingual sensorineural

hearing losses. The MAC battery consists of 13 auditory tests and one lipreading test. These subtests are designed to test the patient's ability to hear prosodic features, phonemes, noise versus voice, environmental sounds, sentence recognition, and one- and two-syllable word recognition.

Usually, the worse ear will be selected for implantation because if the implant were to be unsuccessful, the patient would have his/her better ear left unharmed. If there is not an ear difference, the patient's prefered ear is selected. If the patient has no preference, a decision is reached by the physician and the patient.

REHABILITATION-ADULTS

Rehabilitation typically begins about two months after surgery to allow for complete healing of the surgical wound. The initial phases of rehabilitation involve the fitting of the external equipment (i.e., speech processor) and the initial stimulation (Mecklenburg, 1985b; Hochmair-Desoyer, 1984). Adjusting the external stimulator to an appropriate level for each patient may take several weeks as the patient's perceptual preferences are likely to change with increased usage of the prothesis. The fitting procedure always includes the setting of some amplification (i.e., current flow) to guarantee that the patient's discomfort threshold level is not exceeded (Hochmair-Desoyer, 1984).

The fitting of a multi-channel processor can be quite complex. The NUCLEUS multi-channel system must be "mapped" which includes finding thresholds and comfortable loudness levels (i.e., dynamic range) for each electrode. This range tends to increase with continued use and thus, new "maps" have to be made as the rehabilitation progresses.

The cochlear implant produces electrical signals which the patient may perceive as a crackling, humming, or buzzing noise. This signal may have only a few of the parameters of the sound stimulus the patient may

recall as being characteristic of speech. This would only hold true for postlingually deafened adults. (Campos, 1981,1985; Maddox and Porter, 1983). Therefore, the therapy program must provide the patient with strategies to re-learn how to make meaningful use of acoustic stimuli. The patient with an implant will need to be reminded of the impact of long-term hearing loss as well as the probability of needing to reprogram the auditory processing system, if this is indeed possible (Campos,1985).

Most clinics require their patients to attend a minimum of 30-40 hours of postoperative therapy (Mecklenburg, 1985a; Hochmair-Desoyer, 1984; Berliner, 1985). The amount of post-surgical rehabilitation needed for each patient is variable. Some may simply need instructions regarding the use of the external instrumentation and a basic introduction to the effective use of minimal auditory cues. Others may require extensive therapy in auditory training, speech training, language therapy, voice monitoring, speechreading and environmental manipulation (Maddox and Porter, 1983).

The philosophies underlying therapy vary for each institution providing the aural rehabilitation for cochlear implant patients. As with many therapeutic programs, a controversy exists as to which method should be implemented. The issues of unisensory versus

multisensory; top-down (analytic) versus bottom-up (synthetic) approaches; home centered versus clinic centered programs; and unstructured versus structured approaches must be resolved (Eisenberg, 1985). Any therapeutic approach utilized must recognize the major levels of auditory processing and work toward obtaining skills at each level (Eisenberg, 1985; NUCLEUS manual). These levels include: 1) detection (presence of sound, attention, arousal); 2) discrimination (same-different); 3) identification or recognition (repeating, imitating); and 4) comprehension (Erber and Allencwicz, 1982).

At the most basic level, training may focus on detection of sound. After the patient demonstrates awareness of sound, activities focusing on discrimination and identification can be introduced using both linguistic and nonlinguistic stimuli (Eisenberg, 1985).

The initial stimulation is followed by intensive training in critical listening tasks, voice monitoring techniques, and reduction of known communication barriers. The latter is performed by practicing speechreading in a number of different communication situations, varying from the optimal to the poor. The patient is encouraged to deal with communication barriers in ways that will allow maximum communication to be achieved (Campos, 1981). Critical listening

tasks for speech cues involve a hierarchy of the many suprasegmental aspects of speech. Varied syllable differentiation usually begins with word stimuli and progresses to polysyllabic words, phrases and short sentences in which the stress varies in the initial, medial and final positions (Campos, 1981; NUCLEUS training manual).

A wide variation exists among cochlear implant patients' ability to use electrically stimulated auditory sensations. Some implant recipients may be able to integrate electrical stimulation and utilize this information to better understand speech. Other patients may be unable to integrate and use this information in a meaningful manner. The various factors which may influence an individual's ability to make use of electrical stimulation have been discussed earlier in this paper (e.g., age, etiology, age of onset, neural population reserve) (Hochmair-Desoyer, et.al., 1983).

The rehabilitation program designed for multi-channel implants will differ from that used for single channel systems due to the wider variety of sensations available for those with a multi-channel system (Mecklenburg, 1985b). With a multi-channel device, each electrode is potentially capable of producing different sensations. Therefore, there is a need to balance the incoming signal so that the

perceived sound is pleasant and the successful transmission of the most information is obtained (NUCLEUS training manual).

The goal for multi-channel implant patients is to develop two abilities: 1) the perception of prosodic information; and 2) the perception of pitch pattern recognition for understanding speech, which requires information derived from the second formant (NUCLEUS training manual). The new coding strategy of the NUCLEUS device also provides information on the first formant. These two categories are divided into different levels of performance which require different training activities. For example, the easier sessions may utilize materials stressing the simpler prosodic features of speech using fundamental frequency information, such as word length differences and male/female speaker discrimination. The more difficult tasks may include question/statement discrimination.

Those materials which use visual (i.e., speechreading) cues are also arranged from easy to most difficult. They may include: familiar sentences (e.g., everyday situations), contextual categories of phrases and words (e.g., farming, school, etc.), voiced versus non-voiced (CVs and words), and segmenting numbers of words in sentences. The NUCLEUS rehabilitation program uses the following training format: word length discrimination; sentence length

differences; noise and voice discrimination; male/female speaker identification; vowel length; closed-set sentences; closed-set words; accented words (stress identification); intonation (question/statement); vowel identification; consonant manner discrimination; clue sentence identification; consonant voicing discrimination; consonant place discrimination; open-set sentence recognition; open-set word recognition; speech tracking; telephone identification of simple words/phrases with a familiar speaker; and telephone use with an unfamiliar speaker (NUCLEUS training manual).

Most clinics offering cochlear implant rehabilitation utilize the speech tracking procedure developed by DeFilippo and Scott (1978) to evaluate a patient's success with open-set speech materials (Berliner, 1985; Mecklenburg, 1985a; Mecklenburg and Brimacombe, 1985b; Hochmair-Desoyer, 1985). This method involves an oral reading of an appropriately selected story, sentence by sentence. The patient must repeat each sentence or phrase verbatim. Patients are allowed ten minutes of intense speechreading per session and their scores are recorded as words correctly identified per minute. The results are then compared for speechreading alone, electrical stimulation and speechreading, and electrical

stimulation alone (DeFilippo and Scott, 1978; Berliner, 1985; Mecklenburg, 1985a).

DeFilippo and Scott's (1978) goal for the speech tracking procedure is to develope skills relevant to situational conversational use where conventional speechreading procedures failed. The tracking procedure differs from conventional speechreading procedures in that it utilizes connected speech as opposed to unrelated lists of sentences. This procedure also provides a measure of correct message reception as opposed to a two choice method. The developers speculated that

> "tracking with ongoing speech would require a
> wider range of perceptual and linguistic skills
> that can be applied, more or less efficiently,
> dependent on the display characteristics of the
> aid being used (p. 1186)."

After basic rehabilitation goals have been met, open-set speech discrimination and training on the use of the telephone may begin. The more successful implant patient may learn to recognize and discriminate between a dial-tone, a busy signal, and ringing as well as be able to carry on a limited conversation. The speaker on the other end could be taught to utilize a variety of effective common strategies such as the syllabic responses of "no", and "yes-yes" (Mecklenburg, 1985b; NUCLEUS training manual).

The training for critical listening for environmental sounds is carried out mainly in the

patient's home. The patient is given home assignments to increase an awareness of surrounding sounds and to become familiar with the implant system in terms of its range of operation and its limitations. This allows for a personal insight into the potential problems with the prothesis and allows the patient to monitor his/her own progress with sound detection and recognition.

Each patient is requested to keep a daily diary of all their auditory experiences with the implant including the number of hours the implant was used per day and the novel auditory sensations experienced. Following the initial 30-40 hours of in-clinic therapy, the rehabilitation staff determines whether additional therapy is warranted. When in-clinic therapy is terminated, patients are given a series of home assignments usually consisting of training materials provided in the clinical setting. The patient is encouraged to maintain contact with the rehabilitation staff via monthly reports in order that their progress can be monitored and any medical or equipment problems which may arise can be corrected. Most patients are asked to return to the institution every 6-12 months following the initial rehabilitation for re-evaluation, progress evaluations, and equipment adjustments. (Berliner,1985; Campos,1981; Mecklenburg and Brimacombe, 1985a)

Patient Reactions

Adult cochlear implant users may learn to utilize timing and intensity discrimination abilities that are not significantly different from the abilities of normal hearing subjects (Helmerich and Edgerton, 1982; Bilger, 1977; Wallenberg et al., 1985). The ability of most postlingual deaf adults to discriminate the signal's amplitude and temporal features is the key predictor of their speech understanding after implantation (Hochmair-Desoyer, Hochmair, Buriank, and Stiglbrunner,1983). However, Helmerich and Edgerton (1982) and Bilger (1977) have stated that a single electrode device significantly reduces pitch or frequency perception, perhaps due to lack of place pitch information. Furthermore, the ability to discriminate frequencies decreases as the frequency increases, secondary to reduced energy of high frequencies. Dent (1982) supported the position that single electrode devices limit frequency information secondary to the transmission of fundamental frequency and first formant information only. He stated that this limited frequency information may allow for some basic differentiations of speech prosody and manner of articulation but restricts a person's ability for the differentiation of the place of articulation.

Although cochlear implant users possess intensity discrimination abilities, most implant patients exhibit

an extremely limited electrical intensity dynamic range (Pfingst, 1984). The dynamic range is often less than 25 dB below 250 Hz and can be as little as 10 dB or less at higher frequencies (Michelson, 1971; Pfingst, 1984). Therefore, the patient may be unable to tolerat stimulation at levels needed to transmit the desired information.

PATIENT SELECTION-CHILDREN

The House Ear Institute began to implant children in 1980 as an experimental program (Eisenberg and House, 1982). To date only the 3M/House single electrode cochlear implant is approved by the United States Food and Drug Administration (FDA) as an experimental device for children younger than 10 years of age (Berliner et.al., 1985). Bacterial meningitis, trauma, ototoxicity, maternal rubella, deformities of the inner ear, toxemia, cytomegalovirus, and unknown causes are just some of the etologies of deafness in children who have been selected for implantation (Luxford and House, 1985).

The primary consideration when assessing the child's potential for implantation is the valid confirmation of audiometric results which demonstrate a profound sensorineural hearing loss. This is particularly true for young children whose behavioral responses are often inconsistent and inaccurate. Auditory brainstem evoked potentials are often utilized with these children to confirm the presence of a profound loss (Berliner, 1985).

The second major consideration during the assessment of children is how much actual benefit is gained from conventional amplification. Aided and unaided audiometric results are not always predictive

of the success or failure with hearing aids. This aspect is difficult to assess because of age-related limitations of the protocols, cognitive factors, and lack of experience with sound (Edgerton et al., 1983).

Berliner and Eisenberg (1985b) provided the following selection criteria for children. They must be at least two-years of age with a profound bilateral sensorineural hearing loss. The aided performance on the Test of Auditory Comprehension and the Discrimination After Training test in the ear selected for implantation must be poorer than or equal to the average test results obtained from children using a cochlear implant. The child must also have a history of an appropriate hearing-aid trial and auditory training. If no progress is seen with conventional amplification (i.e., no awareness to sound and no speech development), a cochlear implant should then be considered (Edgerton et.al., 1983).

The Test of Auditory Comprehension (TAC) (Trammell, 1976) evaluates the auditory comprehension of environmental sounds and speech in a sequenced hierarchy of difficulty (Berliner and Eisenberg, 1985b). The Discrimination After Training (DAT) test, developed by the House Ear Institute, was designed specifically for prelingual profoundly deaf children and adults (Berliner and Eisenberg, 1985b). The DAT is used to assess the subject's ability to utilize

auditory cues to make discriminations of speech or some of the nonsegmental aspects of speech. The training of test materials are incorporated as part of the test in an attempt to control, or at least minimize, the effect past auditory experience may play on test results (Thielemeir, Tonodawa, Peterson, and Eisenberg, 1985).

Medical Assessment

Typically, the same assessment protocol used for adults is also used for children (e.g., polytomes etc. to observe the status of the round window and basal turn of the cochlea in search of congenital anamolies of the inner ear or labyrinthine ossification).

Psychological Assessment (Tiber, 1985; Selmi, 1985)

A. Interviews: A variety of interviews are given to obtain information regarding the child's developmental history, educational history, communication method used by the family, social and emotional adjustments, parental expectations, and potential problem areas. These interviews also provide information regarding the parents' understanding of what is involved and the potential benefits and limitations of the cochlear implant. Specific tools utilized include the Child Behavior Rating Scale and the Cochlear Implant Questionaire. A pattern of parent-child

Interaction must emerge which indicates the family
will be able to effectively follow through with
the post-implant rehabilitation program.

B.   Intelligence Tests:

1.Stanford-Binet Forms L-M-for children 2-4
years
2.Wechsler Pre-School and Primary Scale of
Intelligence-for children 4-6 1/2 years
3.Wechsler Intelligence Scale for Children-
Revised-for children 6 1/2-16 1/2 years
4.Wechsler Adult Intelligence Scale-Revised-
for children 16 1/2-18 years

C.   Neuropsychological Tests:

1.Halstead-Reitan Test of Lateral Dominance
2.Bender-Gestalt
3.Wide-Range Achievement Test

Audiologic Assessment

The following audiometric results should be
obtained when possible (Berliner and Eisenburg, 1985b):

A. Tympanometry and otoscopy (rule out middle ear

pathology)

B. Acoustic reflex at 500, 1k, and 2k Hz measured

with a maximum stimulation output of 110 dB SPL

C. Warbled tone thresholds 250-4000 Hz

D. Speech detection thresholds

E. Speech uncomfortable loudness levels

F.   Brainstem   Evoked   Responses   (BSER)   when

appropriate (used for all children 6 years and

under)

Warbled tone thresholds and uncomfortable loudness levels (UCL) are obtained to select the gain and SSPL of the appropriate hearing aids used during the soundfield evaluation. The SSPL of the hearing aid is not to exceed 132 dB SPL.

Soundfield testing includes:

A. Warbled tone thresholds

B. Speech detection thresholds

C. Speech UCL's

D. Speech discrimination: These tests are performed with the hearing aid that provided the best aided warble-tone thresholds, with each ear being tested separately.

    1. <u>Discrimination After Training</u> (DAT)

    2. <u>Test of Auditory Comprehension</u> (TAC)

Finally, speech and language assessment is provided to evaluate the child's receptive language, expressive language, and phonology/articulation.

Post-implant Results

Most children who have been implanted with the 3M/House implant system had no measurable hearing at 250, 500, 1k, 2k, 3k, and 4k Hz. The aided soundfield thresholds rarely exceeded 80 dB SPL. Once implanted, these thresholds ranged from 59-64 dB SPL across the frequencies tested (Berliner and Eisenberg, 1985a;

1985b). The goal for setting the gain of the implant is to obtain warble-tone thresholds on the average of 45-60 dB HL across the frequency range of 250-4000 Hz (Thielemeir et al., 1985; Eisenberg and Berliner, 1983).

Additional benefits derived from a cochlear implant in children have been reported to include the following (Berliner, 1985; Tiber, 1985; Kirk and Hill-Brown, 1985):

A. Simple auditory discrimination

B. Detection of environmental sounds

C. Increased speech production skills

    1.increased vocalization

    2.improved voice quality (i.e., monitoring of intensity and pitch, and decreased vocal strain)

    3.improved speech rhythm (e.g., speech rate, stress, syllabification)

    4.improved imitative and spontaneous production of vowels and simple consonants

Based on a six month, post-implant psychological follow-up. the data have not indicated any adverse psychological effects (Tiber, 1985). Behaviorally, Tiber (1985) found a significant reduction in the implanted children's level of distractability and short-attention spans. These children are also

reported to have demonstrated an improved performance on certain psychological tests (i.e., Bender-Gestalt and WISC-R). However, maturation may have influenced these improved scores.

The House Ear Institute have reported that of the 205 children implanted, only 10 do not use the device. Eight of these 10 are teenagers and they reportedly refuse to utilize the device due to cosmetic reasons and/or peer pressure (Berliner, 1985). Table 1 presents a summary of data from the House Ear Institute as of September 15, 1985 regarding children with the 3M/House single electrode cochlear implant (Presented at the Denver Ear Institute's Cochlear Implant Symposium, Denver, Colorado, 1985).

TABLE 1: Cochlear Implantation of Children

AGE AT TIME OF SURGERY	2-5 YEARS	6-12 YEARS	13-17 YEARS
USERS	63	83	29
NONUSERS	2	0	8
DEVELOPMENTAL FAILURE	1	2	2
NONSTIMULABLE	0	1	1
IN PROCESS	3	8	1
DECEASED (unrelated to the implant)	0	1	0

Summary

In summary, the 3M/House cochlear implant has proven to be effective for some children, in that auditory thresholds can be obtained at levels which

allow profoundly deaf children to detect speech and environmental sounds as well as to make simple auditory discriminations (Thielemeir et al., 1985).

At minimum, the cochlear implant may allow profoundly deaf children to detect voice at a conversational level and perform auditory discriminations of different speech patterns in a structured situation. This may be due to the provision of information regarding the timing and intensity of speech as well as limited pitch information by the implant (Kirk and Hill-Brown, 1985). Thielemeir et al., (1985) reported that auditory performance appears to improve over time and that children who become deaf after two-years of age and utilized an oral communication method tended to also perform better than average with the cochlear implant. However, Kirk and Hill-Brown (1985) found improved speech production skills in children who were trained in both an oral or a total communication program.

REHABILITATION-CHILDREN

The initial phases of the rehabilitation program with children focus on parent counseling which is considered to be an integral part of the program. Decisions also must be made regarding internal settings of the implant signal processor based on electrical threshold and comfort level, as is done with adult patients. A rehabilitation program for children is dependent on the child's speech and language ability. The most important goal is to improve the child's ability to communicate. While obtaining intelligible speech may not be achieved, the cochlear implant may enable the child to detect environmental sounds and the child may also demonstrate an improvement in his/her pragmatic skills (Kirk and Hill-Brown, 1985). A variety of studies have shown that training the nonsegmental aspects of speech may improve the stress and intonation patterns of deaf speech and, in turn, might enable the listener to compensate foe segmental errors (Howarth and John, 1965; Smith 1975; Osberger and Levitt, 1979).

Following the basic therapy period (i.e., 30-40 hours), the child returns to his regular academic and therapeutic settings. The implant staff maintain contact with teachers, parents, and therapists. The House Ear Institute has initiated a School Contact

Program in order to maintain regular contact with personnel in the schools of implanted children. Selmi (1985) described the following objectives of this program: 1) to provide information to school professionals regarding cochlear implants including benefits and limitations; 2) to assist the school personnel in establishing realistic long-term educational goals; 3) to provide information on available materials that will maximize development of auditory skills in the implanted child as well as guide school professionals in choosing and evaluating auditory objectives; and 4) to develop a system whereby the House Ear Institute receives information from the schools on a regular basis (e.g., summaries of the child's progress, child's responses to classroom sounds etc.).

Summary

Initial results from this program indicate implanted children are able to increase certain auditory skills over time in a classroom setting (Selmi, 1985). Currently, only those children between the ages 13-18 years have demonstrated any decrements in the production of several non-segmental and/or segmental skills following implantation (Kirk and Hill-Brown, 1985). This is probably related to the reported unwillingness of some of the patients in this

age group to fully utilize their devices due to cosmetic reasons and peer pressure.

Although early research results seem encouraging, the number of subjects actually implanted is small. Because most of the assessment tools utilized are age-dependent, gathering long-term data is difficult as the implantation of children is a relatively new concept. Additional experience with those children already implanted is required before the benefits and limitations of cochlear implants in children can be fully defined (Kirk and Hill-Brown, 1985). Professionals and others working with implanted children must also consider the fact that cognitive and speech/language skills develop over time and will not drastically change in short-time periods as will other measures (e.g., audiological) regardless of whether the prothesis is on or off.

CONCLUSION

One of the most difficult decisions audiologists are going to face is a recommendation for or against a cochlear implant (Campos, 1985; Mecklenburg, 1985a; Dankowske, 1985). More than a dozen centers through-out the world have initiated independent clinical programs involving the electrical stimulation of auditory systems via cochlear implants. Each center has developed its own goals for rehabilitation and its own set of strategies for achieving these goals. The extent to which available scientific data have been utilized in developing rehabilitation procedures has varied considerably. Therefore, there is large variability in the success of rehabilitation programs and the reasons for success or failure are poorly understood (Pfingst, 1984).

There seem to be fewer candidates for cochlear implantation than one might suspect. At least 1/2 of the inquiries about cochlear implants are made by relatives of deaf individuals (Campos, 1985). A surprising number of these individuals appear to have never used a hearing aid or have tried one in limited ways and consequently rejected them. Another group of the inquiries are from dissatisfied hearing aid users who do achieve some degree of benefit. Many deaf individuals living in the deaf community express little interest in cochlear implantation. They also have the

right to determine whether or not they wish to become part of the "hearing" world.

Unfortunately, the medical, hospital, and product costs are not always underwritten by various funding sources. The medical and hospitalization costs for some multi-channel units may be underwritten by a research grant, however, these may involve no more than two volunteers per year (Simmons, 1985). Many insurance companies still maintain that implants are experimental and thus are not a reimbursable medical expense (Staller, 1985). This stance appears to be changing as the American Medical Association and the California Medical Association have taken the formal position that cochlear implants are an acceptable procedure for the treatment of deafness in postlingually deafened adults (Simmons, 1985). Approval from the FDA has also helped to remove the major barrier to more complete insurance coverage of the surgical procedure involved in cochlear implantation, however, insurance coverage may not include rehabilitation (Staller, 1985; Campos, 1985). However, many insurance companies are now providing reimbursement for both the surgical and rehabilitation costs.

There exists a controversy over any type of rehabilitation for deaf children (i.e., oral versus total communication versus manual versus acoupedics).

This controversy extends to the issue of cochlear implantation in children. Specific problems arise when trying to assess the success or failure of an implant with children. Children need ample time to experiment with hearing aids before determining that they receive no benefit from conventional amplification. This is more difficult to determine for children than it is for adults. Another problem may be encountered when trying to document changes directly related to the cochlear implant versus changes due to maturation. In most cases, each child serves as his/her own control due to the lack of normative data on the communication development of implanted profoundly deaf children (Berliner and Eisenberg, 1985b). Researchers may also compare the performance of implanted children to profoundly deaf children without an implant who are the same age (Eisenberg et al., 1983).

Good cochlear implant candidates are persons who are living in the hearing world and have strong motivation to continue to do so. This seems to be a critical factor in success. Those who have satisfactorily adjusted to their deafness and are living in a deaf community will typically not be good candidates (Berliner et al., 1985). Cochlear implants have gained increasing media attention and popularity over the past years. However, there are also professionals who criticize the influx of cochlear

implantation. Despite these criticisms, investigators of the cochlear implant believe that implants are here to stay (Berliner et al., 1985; Mecklenburg, 1985b). The implant has introduced a unique concept into the treatment of profound sensorineural deafness. This approach involves teamwork between a variety of professionals who must work together to maximize the potential benefits for the implant patient (Campos, 1985).

Most of the centers involved in clinical programs with cochlear implants have initiated some sort of system to evaluate the psychophysical characteristics of the electrical stimulation and at least two additional laboratories have conducted psychophysical evaluations of patients implanted with a variety of these devices (Bilger, 1977; Hochmair-Desoyer, 1984). One of the major goals of cochlear implantation is to provide the deaf patient the ability to understand running speech without speechreading. In fact, this goal has been achieved to a limited extent in a few patients under certain restricted conditions. However, in most of the patients implanted to date, speech understanding has been poor even under very structured circumstances (BuriOn, 1981; Michelson and Schindler, 1981; Clark et al., 1983). Further technological advancements and research are needed before cochlear implantation becomes a common treatment of profound

sensorineural deafness. Such advancements and research are presently being conducted and cochlear implantation may become an integral part of many professions, particularly audiology (Campos, 1985; Mecklenburg, 1985a; Mecklenburg and Brimacombe, 1985a; Hochmair-Desoyer, 1985). Therefore, audiologists must be prepared to identify potential implant candidates, refer them to appropriate sources, perform necessary evaluations, and be able to provide rehabilitative services. These qualifications will become increasingly necessary as the frequency of cochlear implantation increases, which the current trend indicates will transpire.

In summary, it is this author's opinion that cochlear implantation is a great achievement in the hearing health care profession. Those who are deaf and meet the candidacy criteria have, at last, an alternative treatment for their handicap. This helps promote a positive mental health by providing the likely probability that auditory experience will once again be a part of these persons' lives.

To date, the reports from the implant recipients have been optimistic. Implant recipients vary in terms of success and/or failure. Some will never adjust to the new auditory perceptions and may rarely, if ever, utilize their device. On the other extreme, there are recipients wearing their devices most of the time and

comprehending open set speech. One must keep in mind that the objective measures of open set speech discrimination do not truly represent the benefits obtained with cochlear implants. The subjective reports from implant recipients indicate far better performance than most objective measures demonstrate. For the most part, implant patients report a much improved quality of life based on performance in every day life, qualities that cannot adequately be measured by objective tests. The fact seems to be that implant recipients, in general, feel less isloated from the hearing world, much more a part of their everyday environment.

As research and development advances, a wider population of deaf individuals may be treated successfully with cochlear implants. The future implant patient may not have to meet the rigid candidacy criteria of present. Prelingually deafened adults have been implanted with single channel devices. Paralinguals, those who have acquired language but have been deaf a majority of their lives, have been implanted. The FDA has now approved the implantation of the NUCLEUS multi-electrode device for children 10-18 years of age. The list should continue to expand with time and experience in the field.

The audiologist's role in this process is critical. Without proper rehabilitation, the patient

may never learn to utilize the device to its potential as, to date, no implant system is able to restore hearing to a normal level. The amount of rehabilitation required per patient varies. Some will require minimal training including simply adjusting and fitting of external equipment. Others will require more intensive therapy including the training of both the suprasegmental and segmental components of speech. The program for rehabilitation differs with each device currently on the market. However, most programs establish a common goal: the patient shall understand speech at a higher level than that which is obtained with hearing aids.

The audiologist should maintain knowledge in this area as more patients may seek advice and information on cochlear implants. As a last hope of returning closer to the hearing world, many clients will be anxious about this new treatment for deafness. Accurate, realistic information will help identify potential candidates and help serve the hearing impaired population to a greater degree, a goal common to all audiologists.

APPENDIX A

Summary of the 8 Most Common Types of Implant Hardware

(Staller, 1985; ASHA, 1986)

TYPE OF SYSTEM	NUCLEUS	3M/House	3M/Vienna	BIOSTEM	STORZ	SYMBION	Hartmann	Berlin
CODING STRATEGY	Digital Feature Extract	Analog Filter Bank	Analog Filter Bank	Analog Digital Filter	Analog Filter Bank	Analog Filter Bank	Analog Filter Bank	Digital Feature Extract
STIMULATION REGIME	Bipolar	Monopolar	Monopolar	Monopolar	Bipolar	Monopolar	Monopolar	Monopolar
NUMBER OF CHANNELS	22	1	1	1	4	4	1	12
ACTIVE ELECTRODES	21	1	1	1	4	4	8	12
SITE OF STIMULATION	Intra-Cochlear	Intra-Cochlear	Extra-Cochlear	Intra-Cochlear	Intra-Cochlear	Intra-Cochlear	Extra-Cochlear	Intra-Cochlear
ELECTRODE DEPTH	25mm	6mm	0mm	3mm	24mm	22mm	0mm	0-3mm
APPROXIMATE COST	$11,000	$6,500	$6,000-$9,500	$4,500	$12,000	$11,000	$6,000	$9,000

64

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