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New Directions in Pediatric Cochlear Implantation¹

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Abstract. Cochlear implantation has been an approved surgical intervention for children (2-18 years) with profound deafness for nearly 10 years. The last decade has brought technological advances in cochlear implant designs with concomitant improvements in patient performance and subsequent broadening of cochlear implant candidacy. Although average performance levels clearly establish the efficacy of pediatric cochlear implantation, individual communication abilities vary widely. This, controversy exists regarding the appropriate expansion of evolving technology into new patient populations. In this chapter, we review current implant technology, patient selection criteria and performance results for pediatric cochlear implant recipients and consider the challenges inherent in the broadening of cochlear implant candidacy.

Introduction

In 1990, the Food and Drug Administration first gave approval for cochlear implantation in children aged 2 to 18 years. Initially, children who received a cochlear implant (CI) had total, profound deafness and were usually older than five years of age. Early speech perception results demonstrated that pediatric CI users displayed substantial closed-set abilities (e.g., wherein children identify a word by selecting from a limited set of response alternatives), but only minimal open-set spoken (i.e., wherein no response alternatives are provided) word recognition abilities (Osberger et al., 1991; Staller, Beiter, Brimacombe, Mecklenberg, & Arndt, 1991). The data collected from 80 children as part of the FDA pediatric clinical trials of the Nucleus 22-channel cochlear implant system using a feature-extraction speech processing strategy, and reported by Staller (1998) illustrated the early speech recognition performance levels. The mean age at onset of deafness for this group of children was just under 3 years, and their mean age at implantation was almost 10 years. On average, children achieved monosyllabic word recognition scores of only 10% words correct and the majority of children tested could not correctly identify any individual words through listening alone. Since then, as cochlear implantation has been extended clinically to younger children, and with continued improvements in electrode design and signal processing (Wilson, 1993; Wilson et al., 1991; Wilson et al., 1993), children with CIs have achieved much higher levels of open-set word recognition (Cowan et al., 1997a; Cowan et al., 1997b; Kirk, Pisoni & Osberger, 1995; Miyamoto, Kirk, Svirsky & Sehgal, in press; Osberger, Fisher, Zimmerman-Phillips, Geier & Barker, 1998; Sehgal, Kirk, Svirsky & Miyamoto, 1998; Zimmerman-Phillips, Osberger & Robbins, 1997). For example, Eisenberg and her colleagues (Eisenberg, Martinez, Sennaroglu & Osberger, in press) reported mean PB-K scores of approximately 50% words correct for oral pediatric CI users. Open-set word recognition is an important diagnostic yardstick for determining cochlear implant success because it indicates that these children have established neural representations of words in their long-term lexical memory, a process that is fundamental to the development of spoken language (Woodward & Markman, 1997). Although these average results are very encouraging and clearly establish the efficacy of CIs, individual patients vary greatly in outcome (Osberger et al., 1991; Staller et al., 1991; Staller, 1998; Zimmerman-Phillips, Osberger & Robbins, 1997; Fryauf-Bertschy, Tyler, Kelsay & Gantz, 1992; Fryauf-Bertschy et al., 1997; Miyamoto et al., 1989; Tyler et al., 1997a; Tyler et al., 1997b; Tyler et al., 1997c). Some children can communicate extremely well using the auditory/oral modality and acquire age-appropriate language skills, whereas other children may display only minimal spoken word recognition skills and/or demonstrate severe language delays (Bollard, Chute, Popp & Parisier, 1999; Pisoni, Svirsky, Kirk & Miyamoto, submitted; Robbins, Ballard & Green, 1999; Robbins, Svirsky & Kirk, 1997; Svirsky,

Sloan, Caldwell & Miyamoto, 1998; Tyler et al., in press). Accounting for this enormous variability in the effectiveness of CIs on a wide range of outcome measures presents the most serious challenge facing cochlear implant clinicians and researchers today. Gaining an understanding of the nature of the individual differences and sources of variability in cochlear implant outcomes is crucial for predicting individual benefits prior to implantation, and for selecting appropriate intervention strategies following implantation.

Despite the variability in individual outcomes, cochlear implantation is no longer questioned as a therapeutic option for selected profoundly deaf children. However, in part because the outcomes are not guaranteed, controversy exists regarding the appropriate expansion of evolving technology into new patient populations. The current trend toward earlier implantation and the implantation of children with more residual hearing mandates careful documentation of performance limits with cochlear implants as well as with nonsurgical alternatives (e.g., hearing aids). Only through rigorous longitudinal studies will these issues be clarified. In this chapter we review current implant technology, patient selection criteria and performance results for pediatric cochlear implant recipients and consider the challenges inherent in the broadening of cochlear implant candidacy.

Background

Pediatric Cochlear Implant Selection Criteria

Current selection criteria for pediatric cochlear implantation are as follows:

- 18 months of age or greater
- Profound bilateral sensorineural hearing loss (SNHL)
- No appreciable benefit from hearing aids
- No medical contraindications
- High motivation and appropriate expectations
- Enrolled in program that emphasizes development of auditory skills

Pediatric cochlear implant recipients can be divided into three categories with significantly different expected performance outcomes:

1) Congenitally or early-deafened young children. Congenital or early-acquired deafness is the most frequently encountered type of profound sensorineural hearing loss. Cochlear implantation is performed with the anticipation that sufficient acoustic input can be provided to allow the child to perceive a speech signal linguistically. The acquisition of communication skills is typically a difficult process for these children.

2) Congenitally or early-deafened adolescents. When cochlear implantation is considered in adolescence or young adulthood for a patient who has had little or no experience with sound because of congenital or early onset deafness, caution must be exercised because this group has not demonstrated high levels of success with electrical stimulation of the auditory system.

3) Postlingually deafened children. Children who become deaf at or after age 5 are generally classified as postlingually deafened. Even though these children have developed many aspects of spoken language before the onset of their deafness, they demonstrate rapid deterioration in the intelligibility of their speech once they lose access to auditory input and feedback.

Early implantation can potentially ameliorate this rapid deterioration in speech production and perception abilities. However, a postlingual onset of deafness is an infrequent occurrence in the pediatric population.

Cochlear Implant Systems

The cochlear implant devices available for implantation, as well as the speech processing strategies used, continue to undergo technological improvements. Currently, three types of multi-channel, multi-electrode cochlear implant devices are commercially available for children in the United States. These devices have several characteristics in common. All have an electrode array that is surgically implanted into the cochlea and an external unit, consisting of a microphone that picks up sound energy and converts it to an electric signal and a signal processor that modifies the signal, depending on the processing scheme in use. The processed signal is amplified and compressed to match the narrow electrical dynamic range of the ear. (The typical response range of the ear to electrical stimulation is on the order of only 10 to 20 dB, and even less in the high frequencies.) Transmission of the electrical signal across the skin from the external unit to the implanted electrode array is most commonly accomplished by the use of electromagnetic induction or radio frequency transmission. The neural elements stimulated appear to be the spiral ganglion cells or axons. These devices use place coding to transfer frequency information in addition to providing temporal and amplitude information.

The Nucleus 22-channel (and recent 24) cochlear implant is currently the most commonly used multi-channel system. The Nucleus implantable electrode array consists of platinum-iridium band electrodes placed in a silastic carrier (Clark, 1987). Several generations of speech processors have been employed with the Nucleus multi-channel cochlear implant. The initial Nucleus speech processors used a feature-extraction scheme in which selected key features of speech were presented through the implanted electrode array. An early speech processing strategy, the F0-F1-F2 strategy, primarily conveyed vowel information, including the first and second formant frequencies and their amplitudes, as well as voice pitch. A later coding scheme, the MULTIPLEAK strategy, presented these acoustic features along with additional information from three high-frequency spectral bands to aid in consonant perception. The current Nucleus speech processing strategy is the Spectral Peak (SPEAK) strategy. This strategy uses a vocoder in which a filterbank consisting of 20 filters covering the center frequencies from 200-10,000 Hz is employed. Each filter is allocated to an active electrode in the array. The filter outputs are scanned and the electrodes that are stimulated represent filters that contain speech components with the highest amplitude. Depending on the acoustic input, the number of spectral maxima detected, and thus the number of electrodes stimulated, on each scan cycle can vary from one to 10, with an average of six per cycle. The rate at which the electrodes are stimulated varies adaptively between 180-300 pulses per second.

The Clarion multichannel cochlear implant has an eight-channel electrode array that utilizes a radial bipolar configuration through electrode pairs positioned adjacent to the osseous spiral lamina in a 90-degree orientation (Schindler et al., 1986). The Clarion multi-channel cochlear implant offers two types of speech processing strategies: Simultaneous Analog Stimulation (SAS) and Continuous Interleaved Sampling (CIS). Both strategies represent the waveform or envelope of the speech signal (Wilson et al., 1991). The Clarion SAS strategy first compresses the analog signal into the restricted range for electrically-evoked hearing, and then filters the signal into a maximum of eight channels for presentation to the corresponding electrodes. Speech information is conveyed via the relative amplitudes and the temporal details contained in each channel. The CIS strategy filters the incoming speech into eight bands, obtains the speech envelope and compresses the signal for each channel. Stimulation consists of interleaved digital pulses that sweep rapidly through the channels at a rate of 833 pulses per second when using all eight

channels for a maximum pulse rate of 6,664 pulses per second ($8 \times 833 = 6,664$). With the CIS strategy, rapid changes in the speech signal are tracked by rapid variations in pulse amplitude. The pulses are delivered to consecutive channels in sequence to avoid channel interaction.

The MED-EL COMBI 40-Cochlear Implant system utilizes the CIS (continuous interleaved sampling)-strategy that provides both spectral and temporal resolution. Up to eight active electrodes can be utilized. The electrode array used has the capability of deep insertion into the apical regions of the cochlea (Gstöttner, Baumgartner, Franz & Hamzavi, 1997). The MED-EL has the capacity to provide the most rapid stimulation rate of any of the currently available implants (maximum of 12,000 biphasic pulses per second) (Hochmair, 1996).

Surgical Implantation

Cochlear implantation in both children and adults requires meticulous attention to the delicate tissues and small dimensions. Skin incisions are designed to provide access to the mastoid process and coverage of the external portion of the implant package while preserving the blood supply of the postauricular skin. The incision employed at the Indiana University Medical Center has eliminated the need to develop a large postauricular flap. The inferior extent of the incision is made well posterior to the mastoid tip to preserve the branches of the postauricular artery. From here the incision is directed posterior-superiorly and then directed superiorly without a superior anterior limb. In children, the incision incorporates the temporalis muscle to give added thickness. A pocket is created for positioning the implant induction coil. Well anterior to the skin incision, the periosteum is incised from superior to inferior and a posterior periosteal flap is developed. At the completion of the procedure, the posterior periosteal flap is sutured to the skin flap compartmentalizing the induction coil from the skin incision. A bone well tailored to the device being implanted is created and the induction coil is fixed to the cortex with a fixation suture or periosteal flaps.

Following the development of the skin incision, a mastoidectomy is performed. The horizontal semicircular canal is identified in the depths of the mastoid antrum, and the short process of the incus is identified in the fossa incudis. The facial recess is opened using the fossa incudis as an initial landmark. The facial recess is a triangular area bounded by: 1) the fossa incudis superiorly; 2) the chorda tympani nerve laterally and anteriorly; and 3) the facial nerve medially and posteriorly. The facial nerve can usually be visualized through the bone without exposing it. The round window niche is visualized through the facial recess approximately 2 mm inferior to the stapes. Occasionally, the round window niche is posteriorly positioned and is not well visualized through the facial recess or is obscured by ossification. Particularly in these situations, it is important not to be misdirected by hypotympanic air cells. Entry into the scala tympani is best accomplished through a cochleostomy created anterior and inferior to the annulus of the round window membrane. A small fenestra slightly larger than the electrode to be implanted (usually 0.5 mm) is developed. A small diamond burr is used to "blue line" the endosteum of the scala tympani, and the endosteal membrane is removed with small picks. This approach bypasses the hook area of the scala tympani allowing direct insertion of the active electrode array. After insertion of the active electrode array, the round window is sealed with small pieces of fascia.

Special Surgical Considerations

In cases of cochlear dysplasia, a CSF gusher may be encountered. The senior author prefers to enter the cochlea through a small fenestra and tightly pack the electrode at the cochleostomy with fascia. The flow of CSF has been successfully controlled in this way. In patients with severe malformations of the

labyrinth the facial nerve may follow an aberrant course. In these cases the most direct access to a common cavity deformity may be by a transmastoid labyrinthotomy approach. The otic capsule is opened postero-superior to the second genu of the facial nerve and the common cavity is entered directly. Four patients have been treated in this way with no vestibular side effects (McElveen, Carrasco, Miyamoto, Lormore & Brown, in press).

In cases of cochlear ossification, our preference is to drill open the basal turn and create a tunnel approximately 6 mm in length and partially insert a Nucleus electrode. This allows implantation of 10 to 12 active electrodes that has yielded very satisfactory results. Gantz (1988) has described an extensive drill out procedure to gain access to the upper basal turn. The benefits of this extended procedure are under investigation. Steenerson (1990) has described the insertion of the active electrode into the scala vestibuli in cases of cochlear ossification. This procedure has merit. However, the scala vestibuli is frequently ossified when the scala tympani is completely obliterated.

Results of Cochlear Implantation in Children

The Nucleus Cochlear Implant Systems

Pediatric clinical trials with the Nucleus 22-channel cochlear implant began in 1986, and in 1990 the FDA approved this device for use in children. The children originally implanted with the Nucleus 22-channel system used the F0-F1-F2 feature extraction speech processing strategy. Children implanted after 1989 were provided with the MPEAK strategy, and the SPEAK strategy was approved in 1994. Pediatric clinical trials for the Nucleus 24-channel device with the SPEAK strategy were initiated in April 1997 and FDA approval was received in June 1998.

One of the first large-scale reports of pediatric performance with the Nucleus cochlear implant was presented by Staller et al. (1991). They presented speech perception data from 80 children with the Nucleus 22-channel cochlear implant system who were tested as part of the FDA clinical trials. The mean age at onset of deafness was 2 years, 8 months and the mean age at implantation was 9 years, 10 months for this group of children. The children's performance was classified by the highest category of speech perception achieved. Comparisons were made between their speech perception performance preimplant and again at 12-months postimplant. After 12 months of cochlear implant use, 63% of the children showed significant improvements in the closed-set speech perception tasks and 46% of the children demonstrated significant improvements on at least one open-set speech perception task. However, open-set speech abilities were still relatively modest. Similar word recognition results were reported by Osberger et al. (1991) for 28 children. Their results demonstrated that the children's speech perception abilities improved significantly after implantation with the largest gains noted when stimuli were presented in the auditory-plus-visual modality (i.e., with visual and lipreading cues). Thus, the majority of the children tested with the early Nucleus cochlear implant processing strategies demonstrated at least some open-set word recognition and performance was generally good when both auditory and visual cues were available.

The introduction of newer generation Nucleus processing strategies yielded greater speech perception benefits in children just as in adults. Osberger et al. (1996) compared the performance of six children who used the F0-F1-F2 processing strategy with that of six children who used the MPEAK strategy. The children in each group were matched by age at onset of deafness and age at implantation. After one year of implant use, the children with the MPEAK device were significantly better at discriminating vowel height and consonant place of articulation cues on the Minimal Pairs test. However, the two groups did not differ after three years of cochlear implant use. The authors concluded that children

show an accelerated rate of learning with improved speech processing strategies. Similar improvements have been noted for children who switch from the MPEAK to the SPEAK processing strategies (Cowan et al., 1997; Sehgal et al., 1998; Cowan et al., 1995). Sehgal et al. (1998) compared word recognition scores for children who switched from an earlier processing strategy to the SPEAK processing strategy. They reported mean monosyllabic word recognition scores increased from 28% words correct with the earlier strategy to 58% words correct with the SPEAK strategy.

The Clarion Cochlear Implant System

Pediatric clinical trials of the Clarion multichannel cochlear implant system began in 1995 and the device received FDA approval for use in children in 1997. Zimmerman-Phillips et al. (1997) summarized the initial results of the children's preoperative performance with hearing aids compared with their postoperative performance with the Clarion device. The mean age of the group of children implanted by 1996 was approximately five years (N=124). Data were reported for children tested at three-months postimplant (N=60) and six-months postimplant (N=23). After only three months of device use, mean scores were higher than the preimplant performance and many of the children demonstrated some open-set speech recognition. By six months postimplant, mean word recognition scores were 23% for the PB-K and 38% for a test of word recognition in a sentence context, the Glendonald Auditory Screening Procedure, or GASP (Erber, 1982). In a second study, Osberger et al. (1998) examined the performance of children implanted with the Clarion device after the age of five years who had at least six months of device experience (N=30). The children were divided into two groups based on communication method. After six months of device use, children in the Oral group correctly identified an average of 27% of the words on the PB-K. The average PB-K word score for children in the Total Communication group was 8% correct.

The Med-El Cochlear Implant System

Pediatric FDA clinical trials for the Med-El device were initiated in 1998. To date, too few children in the United States have used their devices long enough to draw conclusions regarding the benefits to be received by these children.

Summary of Pediatric Results

In summary, children with multichannel cochlear implants demonstrate significant improvements in closed-set speech discrimination, enhanced lipreading ability, and most obtain some open-set speech understanding with their devices. The rate of auditory skills development seems to be increasing as cochlear implant technology improves and cochlear implant candidacy is broadened to include younger children and children with more residual hearing. For example, early studies reported significant increases in the discrimination of nonsegmental speech cues after only six months of implant use. However, significant increases in the discrimination of vowels and consonant features were not evident until 1.5 years of cochlear implant experience and auditory-only open-set skills continued to improve long after this time period. More recent studies have shown that many children achieve open-set speech recognition within the first year of device use (Miyamoto et al., in press; Osberger et al., 1998) but these skills still continue to develop over time (Fryauf-Bertschy et al., 1992; Fryauf-Bertschy et al., 1997; Osberger et al., 1996; Miyamoto et al., 1994; Miyamoto et al., 1996). In fact, Miyamoto et al. (1994) noted continued improvements in spoken word recognition even after five years of multichannel cochlear implant use. These findings highlight the need to conduct longitudinal studies in order to determine the ultimate benefits of implant use in children.

Demographic Influences on CI Performance in Children

Age at onset of hearing loss, age at time of implantation, length of cochlear implant use, communication mode and amount of residual hearing prior to implantation are all demographic factors that have been shown to influence performance results. Early results demonstrated that age at onset and duration of deafness significantly affected speech perception performance (Zimmerman-Phillips, Osberger & Robbins, 1997; Fryauf-Bertschy et al., 1992; Osberger, Todd, Berry, Robbins & Miyamoto, 1991). That is, the children with a later onset of deafness and a shorter period of auditory deprivation prior to implantation had better speech perception skills than children who were deafened earlier and had a longer duration of deafness prior to implantation. When only children with prelingual deafness (i.e., < three years) are considered, age at onset of hearing loss is no longer a significant factor. The speech perception performance of children with congenital deafness is similar to that of children with adventitious deafness acquired prior to age three years (Osberger, Todd, Berry, Robbins & Miyamoto, 1991).

Age at Implantation

Previous studies have shown that earlier implantation yields superior cochlear implant performance. For example, Fryauf-Bertschy et al. (1997) demonstrated that children implanted prior to age five had significantly better open-set word recognition than did those implanted at a later age. Similar results were reported by Miyamoto et al. (1997). Next, Waltzman and her colleagues conducted several studies to examine the speech perception abilities of children who were all implanted before the age of five years (between two and five years) (Waltzman & Cohen, 1998; Waltzman et al., 1997). Waltzman et al. (1995) reported the performance results of 14 children who were implanted prior to age three years and had used their device for at least three years. After one year of implant use, seven of the children demonstrated consistent open-set speech perception abilities. Following two years, this number increased to 13 children. The mean word recognition score at three-years postimplant was 47% correct. Similar performance results also were reported for a group of 11 children implanted prior to two years of age (Waltzman & Cohen, 1998).

Residual Hearing

The presence of preimplant residual hearing has also been shown to have a positive effect on postimplant speech perception performance. Zwolan and her colleagues (1997) compared the postoperative performance of 12 children who demonstrated some aided open-set speech recognition preimplant (the Borderline candidacy group) with that of 12 matched controls who had no preimplant speech recognition (the Traditional candidacy group). Candidacy for the study participation was based on preimplant binaural aided speech testing and the children were subsequently implanted in their poorer hearing ear. Thus, mean preoperative audiograms did not differ for the implanted ears in the two groups. By one year postimplant children in the Borderline group had significantly higher scores than children in the Traditional group on all six speech perception measures employed. The authors suggested that increased auditory experience prior to implantation facilitated the development of speech perception skills postimplant.

More recently, Gantz et al. (in press) demonstrated that children with greater residual hearing before implantation might achieve the highest levels of spoken word recognition with a cochlear implant. Gantz et al. suggested that children with limited preimplant residual hearing are better able to use the auditory information provided via a cochlear implant because they have more intact auditory systems, including inner hair cells, dendrites, ganglion cells, and central pathways, than their peers who have no preimplant residual hearing or word recognition.

Discussion

With the goal of universal detection of hearing loss in infants by three months of age, and appropriate intervention (e.g., amplification) by six months of age (American Academy of Pediatrics, 1994; 1999), it is likely that ever-increasing numbers of very young children will be identified as potential implant candidates. We know that early identification (i.e., by six months of age) and early intervention with HAs have a significant effect on language development in children with hearing loss (Yoshinaga-Itano, Sedey, Coulter & Mehl, 1998), but the spoken word recognition and receptive language benefits of early implantation in children with profound deafness have not been quantified and critical age limits for cochlear implantation have not been identified.

Cochlear implantation earlier than the current FDA accepted age of 18 months is feasible as the target organ, the cochlea, is adult size at birth. The small dimensions of the temporal bone must be accounted for but the facial recess and mastoid antrum that provide access to the middle ear for electrode placement are adequately developed prior to the age of one year. In fact, several centers have chosen to implant children under 18 months of age. Furthermore, implanting children under the age of eighteen months may have substantial advantages when the etiology of deafness is meningitis. Progressive intracochlear fibrosis and ossification may occur which can preclude standard electrode insertion. A relatively short time window exists during which this advancing process can be circumvented.

Nonetheless, implantation of the very young child remains controversial because the audiological assessment and management of this population is extremely challenging. As with older children, profound deafness must be substantiated and the inability to benefit from conventional hearing aids demonstrated. However, a compelling argument supporting implantation at the earliest possible time can be made because the development of speech perception, speech production, and language competence normally begins early in infancy. In addition, electrical stimulation has been shown to prevent at least some of the degenerative changes in the central auditory pathways caused by auditory deprivation (Matsushima, Shepard, Seldon, Xu & Clarl, 1991).

The extension of cochlear implantation to children with ever-higher levels of preimplant residual hearing should be approached cautiously. Surgical implantation of the electrode array results in the loss of residual hearing in that ear. Thus, cochlear implantation should not be considered unless it seems likely that a given child will receive more benefit from this device than from conventional amplification. Recently, mounting evidence has been found to suggest that some children with severe hearing loss may derive as much or even more benefit from a cochlear implant than from a well-fitted HA. In amplifying sound for an individual with hearing loss, an assumption is made that the acoustic-phonetic patterns of speech must be detected before they can be discriminated and recognized. To accomplish this goal, audibility across a broad frequency range is typically prescribed as a means of maximizing speech intelligibility (Skinner & Miller, 1983). This, in fact, has been the goal of most standard HA prescriptions. For severe-to-profound losses, however, supplying adequate gain across a broad frequency range can present a special challenge to the clinician. Moreover, achieving this amount of amplification may cause acoustic feedback, necessitating a reduction in gain and audibility (Skinner, Holden & Binzer, 1996). Another issue concerns the risk of delivering high levels of sound to the impaired ear. According to Macrae (1991a, b), the sound pressure level (SPL) required to achieve audibility for individuals with severe-to-profound hearing loss has the potential to destroy remaining hair cells due to excessive noise exposure. Thus, a trade-off may exist between providing audible speech and risking increased damage to inner ear structures. Lastly, there is some question as to the extent of benefit that may actually be realized by amplifying high frequencies to

audible levels for this magnitude of loss. Recent research has suggested that provision of adequate audibility for losses greater than 60 dB HL at 3000 Hz and higher does not improve speech recognition and may even degrade performance (Ching, Dillon & Byrne, 1998; Hogan & Turner, 1998; Turner, 1999). Preliminary research has suggested that some children with cochlear implants obtain spoken word recognition abilities that surpass those of other children with severe hearing loss (i.e., PTAs between 70-90 dB HL) who use well-fit HAs (Eisenberg et al., in press; Boothroyd, 1997; Levi, Eisenberg, Martinez & Schneider, 1998). Given the limitations imposed in providing high levels of amplified speech to children with severe-to-profound hearing loss, the evidence suggests that a cochlear implant could provide added benefit for a select population of children with this magnitude of hearing loss.

The encouraging results obtained with younger children and those who have some useful hearing prior to implantation have led investigators to push the boundaries of cochlear implantation criteria farther than ever before. With the continued evolution and expansion of cochlear implant candidacy it is crucial that we develop techniques to quantify hearing loss, to fit both hearing aids and cochlear implants, and to document the effects of implantation in these very young children.

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