

Chapter 10

Cochlear Implants for Children Who Are Deaf or Hard of Hearing

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With the implementation of universal newborn hearing screening (UNHS) programs in hospitals and birthing centers throughout the U.S., the average age of identification of newborns who are deaf or hard of hearing (D/HH) has decreased over the last 20 years from approximately 30 to 48 months of age to 6 months or less. Although infants and young children who are D/HH are being identified earlier, they are at considerable risk for falling behind their hearing peers in language, cognition, and social-emotional development. However, infants who are D/HH who receive intervention before 6 months of age maintain language development commensurate with their cognitive abilities through the age of 5 years.

Technological interventions in the form of hearing aids (HA), FM/DM systems, and/or cochlear implants (CI) are the most important components that allow auditory access to those infants who are D/HH. When fitted appropriately, they will—in most instances—enable the child to maximize use of residual hearing. If the child is receiving appropriate family-centered early intervention, listening and spoken language can develop at or near an age-appropriate pace.

No assistive device will enable a child who is D/HH to perform normally in all listening situations. HAs and CIs for children should make speech audible at a comfortable level and provide as many acoustic cues as possible without overamplifying any sounds, especially loud sounds. Reception of soft speech is particularly important for incidental language learning (which

accounts for a very large portion of overall language learning), self-monitoring of speech, and ease of communication in real-world listening environments.

There is always a need to make evidence-based clinical decisions, but the pace of technological innovation in HAs and CIs has begun to exceed that of supporting research. Today's advanced features and styles of HAs (noise reduction, directional microphones, receiver-in-the-ear [RITE], open-canal, etc.) are being fitted on children. With a limited but growing body of research to support the outcomes of such fittings, every audiologist who fits devices on infants and young children has the responsibility to verify and validate those fittings. The same can be said for audiologists responsible for the settings/programs on a child's CI(s)—verification and validation of success is mandatory.

This chapter will provide an overview of CI devices and candidacy considerations for infants and young children.

CIs: The Basics

CIs have electrodes that are placed in the cochlea to stimulate the eighth nerve (nVIII). These electrodes produce electrical currents that induce compound action potentials in nVIII fibers, which are transmitted to the brain for interpretation. CIs bypass damaged or missing hair cells in the cochlea that would normally code sound.

All CIs, regardless of manufacturer, have several common components (see *Table 1*). There are, however, many variations in the methods used to process sounds, transmit information to the internal implant, and stimulate the electrodes. There are numerous electrode arrays available from each of the manufacturers, including a shortened array used with hybrid CIs (see below).

Internal Components

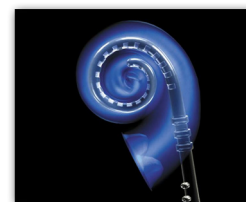
Implanted components must be biocompatible and not lead to long-term adverse tissue damage.

Receiver-Stimulator

One of the internal components is called the receiver-stimulator—sometimes known as the internal coil—which is implanted in a flattened or recessed portion of the skull, posterior to and slightly above the ear (or pinna). This receives a signal and decodes instructions from the speech processor. It converts the electrical signal into a digital code and converts again to electrical pulses, which are delivered to the electrodes in the cochlea. It receives stimulus information via the radio frequency (RF) external coil housed in the headpiece. This method of coupling is called a *transcutaneous link*.

Electrode Arrays

Multichannel devices have up to 22 active electrodes. Research has indicated more electrodes typically result in better speech perception. This is not a one-to-one relationship, however, as many individuals achieve very good speech perception without the use of all the electrodes in their array. An electrode array stimulates residual auditory nerve fibers along the modioli and in nVIII. CI electrodes are designed for placement in the scala tympani of the cochlea. Keeping the electrodes relatively close to the spiral ganglion cells is best for localized stimulation of the auditory nerve and minimizing potential cochlear trauma from surgery. Different electrodes—or closely spaced bipolar pairs of electrodes—ideally stimulate different subpopulations of cochlear neurons. Electrode arrays try to mimic the tonotopic organization of the cochlea by assigning frequencies in the same order as in the cochlea from high- to low-pitch sounds.



Placement closer to the modioli requires less current to achieve a response from the auditory nerve and in

turn requires less power for loudness perception. This placement may also

Research has indicated more electrodes typically result in better speech perception. This is not a one-to-one relationship, however, as many individuals achieve very good speech perception without the use of all the electrodes in their array.

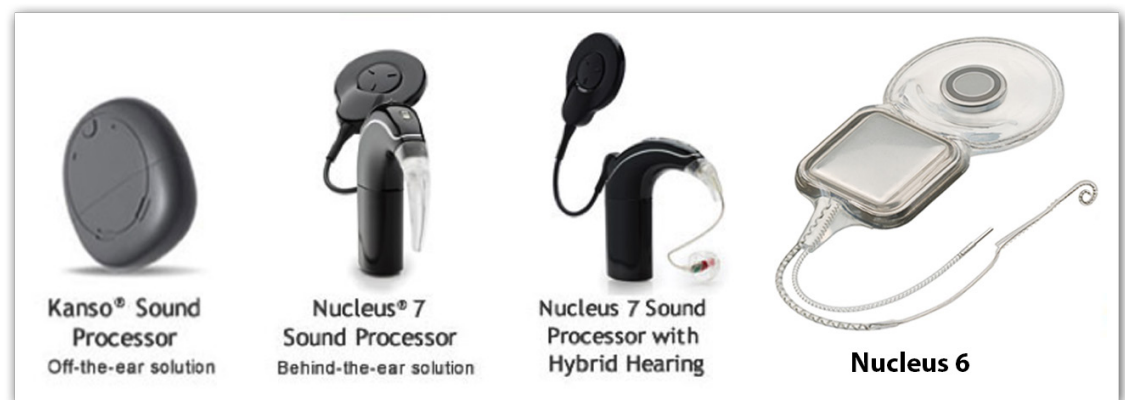
Table 1

CI Components of Three Manufacturers

Advanced Bionics Corporation



Cochlear Corporation



MED-EL



The goal when choosing placement method (traditional cochleostomy or round window), surgical tools, and choice of electrode is to reduce damage to the cochlea during insertion. Less cochlear damage using lateral wall electrodes inserted in the scala tympani through the extended round window typically correlates with better CI performance (i.e., better speech perception).

produce less channel interaction. Post-CI hearing thresholds are thought to be better when the electrodes are closer to spiral ganglion cells, due to more localized current flow. One way to get an electrode array to lie closer to the modiolus is to insert a pre-curved array. Not all available electrode arrays, however, are pre-curved.

Lateral wall electrodes are thought to be less traumatic for insertion into the cochlea. A recent focus of the CI manufacturers is attaining atraumatic insertion of the electrode array. Some arrays are touted as more atraumatic than others. If the basilar membrane or spiral lamina are not damaged (or infection does not occur), electrodes can be inserted without causing a significant loss of auditory neurons. A straight electrode array may cause trauma to the cochlea during insertion, but this is certainly not the case in all instances.

Successful placement depends heavily upon the skill and surgical preference of the surgeon and whether the electrode array is being inserted via a cochleostomy—through the round window or extended round window. Research suggests that electrodes placed in the scala tympani by way of the extended round window show better audiological outcomes. To ensure appropriate placement of the electrode array through the scala tympani, insertion tools are used in the majority of cases. Manufacturers offer multiple electrode array designs, lengths, and features. New electrode arrays on the market and experimental prototypes are straight, slimmer, shorter, and have a more flexible tip—or have any combination of these attributes. These design features have been shown to minimize insertion damage and help surgeons correctly steer the electrode to the correct positioning and depth inside the cochlea. The goal when choosing placement method (traditional cochleostomy or round window), surgical tools, and choice of electrode is to reduce damage to the cochlea during



insertion. Less cochlear damage using lateral wall electrodes inserted in the scala tympani through the extended round window typically correlates with better CI performance (i.e., better speech perception).

A shorter electrode array—intended specifically for partial insertion—is now available for those patients with normal or moderate low-frequency (up to 500 Hz) hearing and severe hearing loss (70 dB or greater) above 1000 Hz. This electrode array is intended to allow the patient to use electric and acoustic stimulation (EAS) in the same ear and attempts to preserve low-frequency residual hearing. Patients can use their natural low-frequency hearing with mid- to high-frequency electrical stimulation. Even persons with low-frequency hearing that would benefit from amplification (HAs) but have very poor mid- to high-frequency hearing may benefit from this hybrid CI (CI and HA in same ear). The available research literature shows that, compared with adult EAS patients, EAS in children allows similar, if not better, results for hearing preservation and achieving speech and language milestones. It is considered an effective treatment option for children with partial deafness.

Double electrode arrays designed for the ossified cochlea can be used on children who are post-meningitis. There are also shorter arrays, which can be used for post-meningitis ossified cochleae.

Current CIs:

- Are compatible with FM units.
- Have directional or multiple microphones.
- Incorporate Bluetooth technology.
- Can be connected to iPods, MP3 players, computers, phones, televisions, and gaming systems.
- Contain downloadable apps to adjust settings, volume, battery life, and alter personal auditory preferences.
- Have almost limitless ways to program through the speech processor.
- Have compatible waterproof accessories.
- Longer-lasting battery life.

All manufacturers offer multiple microphones—increasing the selectivity of the directional pattern to aid speech understanding in noisy situations.

Stimulating Electrodes

There are two electrode stimulation modes. Each incorporates intricate processes, which vary by manufacturer.

Bipolar. In a bipolar mode of stimulation, one intracochlear electrode is stimulated with reference to another nearby intracochlear electrode. Current flows between a pair of electrodes, with one serving as the ground electrode. This is often called *bipolar coupling*. Bipolar stimulation specifically refers to the ground electrode being positioned immediately adjacent to the active electrode. When the return and active electrodes are separated by one electrode contact, it is referred to as BP+1, BP+2, etc.

Monopolar. Monopolar stimulation means that each electrode is stimulated with reference to a ground electrode, which is remote from the cochlea. This remote electrode can be housed within the internal receiver/stimulator or on the end of a silastic tube, which extends from the internal receiver/stimulator. The latter design is called a *ball electrode* and is designed for placement under the temporalis muscle. The monopolar stimulation strategy is often used in CI programs, because the amount of current required to elicit perceptible stimulation is less than bipolar, which increases battery life. All contemporary CIs use monopolar stimulation as the default mode.

Rate of Stimulation

Current CIs deliver trains of biphasic electrical pulses to the electrode array and contacts within the cochlea. The rate of stimulation defines the number of these electrical current pulses per second (pps) that may be delivered to an individual electrode contact. Early devices had relatively slow stimulation rates (250 pps or less), but current devices can deliver as many as 5,000 pps. Higher rates (above 2,000 pps) improve the representation of temporal information by providing finer

amplitude variations through greater control of the rate and population of nerves excited. While there is much research to demonstrate consistent improvements in patient performance with rates >2,000, there is little research to support that rates above 2,000 pps provide better speech recognition. The optimal stimulation rate varies on an individual basis.

External Components

Microphone. The microphone, which is typically housed on the speech processor, is a device for picking up and processing incoming sound. It senses pressure variations in a sound field and converts them into electrical variations. These electrical signals are typically sent to a preamplifier to improve the signal-to-noise ratio—providing a boost in the higher frequencies. The microphone has a broad frequency response but minimizes responses to low-frequency vibrations, such as those produced by head and body movements. All manufacturers offer multiple microphones—increasing the selectivity of the directional pattern to aid speech understanding in noisy situations. Directional microphones emphasize sounds in front of the microphone and suppress sounds emanating from other directions. All three manufacturers have multiple microphone options available to:

- Reduce wind noise.
- Enhance localization.
- Assist with speech understanding in background noise.

All manufacturers have programs/features to allow the microphone(s) to be self-adjusting to the listener's environment. The microphone sends this modified signal to the external speech processor.

Speech processor. The CI speech processor uses sound from the microphone to create a set of electrical stimuli for the electrodes. The received signal is analyzed by a digital signal processor (DSP) to separate the input according to intensity,

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frequency, and time domains, which will be represented at the nVIII. Manufacturers devote a great deal of attention to developing new and improved processing schemes. Often the new schemes can be incorporated into existing processors via a software update. Occasionally, processor replacement is necessary to accommodate a new processing scheme. Replacement of the internal components is rarely, if ever, necessary to utilize new speech processing schemes. The speech processor transmits the processed electrical signal via a cord to the headpiece. The speech processor is powered by batteries—either standard or rechargeable. Typical battery life is greater than 12 hours for a body-worn processor and usually somewhat less for a behind-the-ear processor.

The speech processor component of the CI is activated and programmed approximately 1-5 weeks post-surgery. At this time, the audiologist will work with the patient to determine hearing threshold and comfort levels to be used for the speech processor program (map). This is only the beginning of many reprogramming appointments as the patient continues to acclimate himself/herself to auditory stimulus, localization of sounds, speech production, vocal perceptions, etc.

Headpiece. The headpiece houses the external coil of the CI and is held in place over the internal receiver/stimulator (internal coil) by magnets. The headpiece transmits the electrical signal—after converting it to an electromagnetic signal—to the internal receiver-stimulator via RF. The RF coil and its signal also serve as the power supply for the internal stimulator.

Creating a Map: The Basics

The audiologist will use two psychophysical measures to create a program or map—thresholds (T levels) and comfort/maximum levels (C levels or M levels, depending on manufacturer). Ts are minimal stimulation levels—or the softest

sound that can be reliably identified by the patient 100% of the time. C/Ms are maximum stimulation levels—the loudest sound that can be listened to comfortably for a sustained period of time. Obtaining these two measures for each electrode is desirable—although current CI software allows for one or both of these measures to be foregone. For children (and adults, when measured), methods for determining these levels are similar to those used in diagnostic audiology. For children, this could be visual reinforcement audiometry, conditioned play audiometry, or the typical “raise your hand” voluntary responses.

In the absence of both T and C/M measures, the map may be created using live voice. This method is more commonly used for adult patients with previous hearing experience. Upper limits are often set by increasing stimulation levels to the patient’s most comfortable listening level while listening to live speech. For infants, very young children, or individuals who cannot respond behaviorally, evoked stapedia reflex threshold (ESRT) testing is highly recommended to set upper stimulation levels. Telemetry can also be used to assist in the creation of a map.

Telemetry

Telemetry is the exchange of information from the external components of the CI through a transcutaneous link (RF waves) to the internal components.



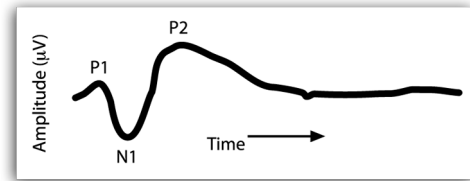
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The number of bilateral CI users worldwide is increasing. This is not unexpected. We are born with two ears, and we hear better when listening with both.

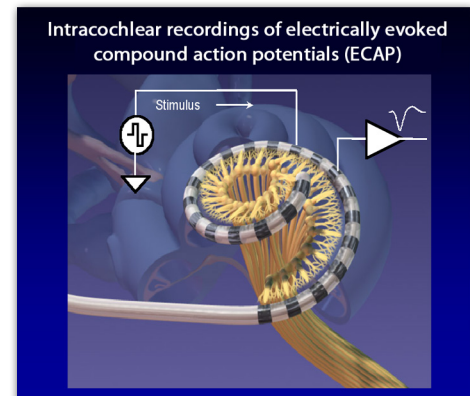
Bidirectional exchange of information allows transmission of data from the implanted components to the external coil and speech processor. Telemetry can provide information about the status of the implanted receiver, impedances of implanted electrodes, and voltages of unstimulated electrodes. It also offers the opportunity to record evoked potentials by stimulating nerve fibers to elicit compound action potentials. Voltage generated by an active electrode can be measured to help determine the status of the cochlea in that region. Measurement of electrode impedances is a routine procedure done immediately after implantation, as well as during every subsequent visit where programming or reprogramming of the CI is necessary.

Telemetry is called something different by each CI manufacturer. Neural Response Telemetry (NRT) is the term used by Cochlear Corporation, Neural Response Imaging (NRI) is the term used by Advanced Bionics, and Auditory Neural Response Telemetry (ANRT) is the term from MED-EL Corporation. For purposes of this chapter, all will be referred to as *telemetry*.

Using telemetry, compound action potentials of the nVIII can be generated, which is an indication of how much neural activity stimulation is causing. This information can be used to estimate threshold and comfort/maximum stimulation levels. Evoked compound action potentials (ECAPs) can provide an objective and noninvasive measure of neural function. The ECAP produces a waveform, usually with 2 peaks and 1 major trough—labeled P1, N1, and P2. ECAPs are stimulated on multiple electrodes. Each electrode will have a threshold established by eliciting multiple ECAPs using a threshold-seeking method. This information is used to assist in creating a map for the patient. Research has demonstrated the ECAP thresholds often fall somewhere between Ts and M/Cs, usually closer to the M/C levels.



ECAP waveform. The amplitude of the ECAP defined as the voltage difference between N1 and P2.



Intracochlear recordings of ECAPs.

Bilateral CIs

The number of bilateral CI users worldwide is increasing. This is not unexpected. We are born with two ears, and we hear better when listening with both. Bilateral CIs can be provided in the same surgery (simultaneous) or sequentially (two separate surgeries). Simultaneous implants are usually considered for patients who receive no benefit from acoustic amplification or have had meningitis. The support for simultaneous CI surgery is growing due to research concerning early intervention, early childhood development, and neural plasticity. However, the research is still inconclusive whether simultaneous bilateral CI surgery has statistically significant advantages over sequential bilateral CI surgery. A concern with simultaneous implantation is the need to keep the patient under anaesthesia for a prolonged period of time. Sequential implantation is best for children under the age of 8. Research has demonstrated that recipients older than 8 find integrating two implants more difficult, unless they have been wearing a HA on the other ear.

Critical information that must be understood by all potential recipients or their family is that a CI is a communication device and NOT a cure for hearing loss. Preoperative expectations significantly shape postoperative satisfaction!

There are multiple advantages to hearing with two CIs. Some of the benefits include:

- Better localization of sound—hearing in “surround sound.”
- Better hearing of speech in background noise.
- Binaural summation (sound is louder with two ears).
- Decreases impact of head-shadow effect.
- Keeps the auditory pathways stimulated—“use it or lose it.”
- Listening with less effort (less tiring, improved concentration).
- Improved music appreciation.

Subjective reports indicate that overall quality of life improved with two implants when recipients compared to themselves when using only one CI. Research also indicates that a CI on one ear and a HA on the other provides some of the benefits mentioned above.

Many studies have been done with adult bilateral CI recipients in controlled environments, as well as in everyday listening situations. Little research has been completed with children who are implanted bilaterally. A few studies on children have been done in controlled environments—none in the “real world.” There is no reason to believe, however, that the benefits afforded adults with bilateral implants would not also be available to children with two CIs. The current standard of care for newly identified infants and children who are D/HH is to recommend bilateral implants when all other candidacy criteria have been met.

Hybrid CIs

The purpose of a hybrid CI is to provide electrical stimulation to the nVIII for high-frequency sound input while preserving the low-frequency residual hearing of the user. Hybrid CI arrays are shorter and narrower than conventional electrode arrays. These electrode arrays are designed for lateral wall placement, as opposed to modiolar hugging. The external sound processor of a hybrid

system contains an acoustic component to deliver amplification for the lower frequencies. Some users wear an in-the-ear HA with a conventional CI to amplify the lower frequencies, although this is less common. Cochlear Corporation and MED-EL offer hybrid CIs. Currently, recipients must be 18 years of age or older.

Candidacy

Determination of candidacy for a CI requires assessment of patient suitability based on many factors. Critical information that must be understood by all potential recipients or their family is that a CI is a communication device and NOT a cure for hearing loss. Preoperative expectations significantly shape postoperative satisfaction!

Families who have chosen a listening and spoken language outcome for their children who are D/HH—or desire to have sound be a meaningful part of communication—have a variety of options to help their children access speech and environmental sounds. With significant advancements in HA technologies, real-ear fitting techniques, and the use of other hearing assistive technologies (HAT), children can hear unlike never before. There are times, however, that even with an appropriately fitted HA, children cannot access critical speech information that can help them develop their expressive and receptive language skills. At this critical juncture, a CI(s) may be recommended. For Part C coordinators, Early Hearing Detection and Intervention (EHDI) coordinators, and early interventionists, it is critical to understand the cochlear implantation process, especially as more parents choose this procedure for their children who are D/HH.

A primary goal for all children who are D/HH is to obtain communicative competence (Ganek et al., 2012) and minimize the effects of hearing loss on each child’s development. For those children who receive limited or no benefit from amplification, cochlear implantation is often a viable option, with associated

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positive outcomes in listening, spoken language, literacy, and social/emotional well-being (Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997; Geers, 2008; Geers & Moog, 1994; Geers, Tobey, & Moog, 2008). Because each child and family must be evaluated from a variety of perspectives, an interdisciplinary approach to determine candidacy is the existing standard of care. To arrive at a candidacy decision, the child undergoes medical, audiological, and speech-language evaluations. These evaluation results—along with the long-term communication and educational goals of the parents—lead to candidacy decisions that are family-centered and in alignment with the parents' desired outcomes.

The Process: An Interdisciplinary Approach

The decision to pursue cochlear implantation for a child who is D/HH requires careful consideration and thorough counseling. The success of an interdisciplinary approach depends upon collaboration among an effective team that includes the family as equal partners in the decision-making process. There are a number of considerations that may be unique to the child and family. The process includes the collection and consideration of medical and audiological findings and is further supported by evaluation by a speech-language pathologist (SLP), input from other interventionists and educators, and importantly from the family. Counseling and discussion with the family about the process, as well as short- and long-term goals, is essential. When undergoing the evaluation, the following questions should be addressed:

- Are there other noninvasive technologies available that can make sounds accessible to develop listening, spoken language, literacy, and social skills?
- Are there qualified intervention providers and family support services to help maximize the child's ability to learn to listen and communicate?

- Are there aspects of the child that will require consideration of other forms of communication, and if so, how will they be implemented to supplement benefits from the CI?
- Are there any safety issues that should be considered to minimize any potential risk for this surgery, programming, and/or intervention?

As the child and the family progress through the CI candidacy process, in addition to the above questions, the interdisciplinary team members must determine:

- Does the child meet the criteria for a CI based on the Food and Drug Administration (FDA) labeling (see *Table 2*)?
- If not, based on the research and clinical observations, could the child receive more benefits if he/she received the CI? What are those benefits?
- Does the family have the information needed to plan for the best possible outcome?

To answer these questions, the CI team will not only consider the audiologic and medical results but will also be evaluating the “whole” child and family unit (see *Table 3*; Winter & Phillips, 2009). The first step is to obtain a comprehensive history, including:

- Information on the incidence of hearing loss in the family.
- Birth history and review of complications or concerns.
- The results of newborn hearing screening.

Results of previous assessments will dictate the need for further evaluation under the domain of the physician, audiologist, and SLP. Other service providers who may be involved for some candidacy evaluations will be a social worker, counselor/psychologist, ophthalmologist, otolaryngologist, geneticist, school staff, and an interpreter.

Table 2
General FDA CI Guidelines for Children

Company	Device Name	Pediatric Approval Guidelines
Advanced Bionics	Implant: HiRes90K Processors: <ul style="list-style-type: none"> • Naida CI Q90 • Neptune 	12 months to 17 years <ul style="list-style-type: none"> • Profound, bilateral sensorineural hearing loss (>90dB). • Used appropriately fit HAs in children under 2 for at least 6 months and for children 2-7 years of age for at least 3 months with little to no benefit. <4 years <ul style="list-style-type: none"> • Failure to reach appropriate developmental milestones as measured by IT-MAIS or MAIS and/or <20% word recognition testing. >4 years <ul style="list-style-type: none"> • <12% on word recognition testing. • <30% on sentence recognition testing.
Cochlear™	Implant: Cochlear Nucleus® Profile Implant Processors: <ul style="list-style-type: none"> • The Kanso™ • Nucleus® 7 	2 to 17 years <ul style="list-style-type: none"> • Severe-to-profound bilateral sensorineural hearing loss. • Limited benefits from binaural HA trial with word recognition scores ≤30%. 12 to 24 months <ul style="list-style-type: none"> • Profound sensorineural hearing loss. • Limited benefits from binaural HA trial. Older Children <ul style="list-style-type: none"> • ≥30% on MLNT or LNT. Young Children <ul style="list-style-type: none"> • Lack of progress for 3-9 months with amplification and intensive aural rehabilitation.
MED-EL	Implant: MED-EL Cochlear Implant System—Synchrony Processors: <ul style="list-style-type: none"> • Sonnet • Rondo 	12 months to 17 years, 11 months <ul style="list-style-type: none"> • Bilateral, profound sensorineural hearing loss with at least a 90dB loss at 1000Hz. • 3-6 month HA trial. • Little or no benefits from appropriately fit binaural HAs. • Lack of progress in developing auditory skills with amplification and intensive aural rehabilitation. • Scoring <20% on speech recognition tests MLNT or LNT.

Table 3
Descriptions of CI Candidacy Evaluations

Candidacy Evaluation	Description
Audiological Evaluation	A comprehensive hearing assessment completed with and without the child's HAs. This may require more than one visit. It is essential that the child brings his/his HAs and earmolds to the evaluation.
Sedated ABR and Otoacoustic Emissions Tests	Per the JCIH statement, the child should have at least one objective measure of hearing sensitivity. Some children require sedation to obtain these test results. If an ABR has not been completed, then one may be recommended by the CI team.
CT Scan/MRI	A specialized x-ray to evaluate the anatomy of the inner ear. Some children are sedated for this procedure. It is important to determine the status of the cochlea and the internal auditory canal.
Medical Examination	The otologist/otolaryngologist will take a medical history, review the CT scan, and determine if there are any medical contraindications to surgery and make referrals to other medical specialties, as needed.
Speech-Language Evaluation	Formal and informal assessment of the child's communication abilities with his/her HAs. Communication goals are usually discussed at this appointment.
Developmental/Cognitive/Psychological Evaluation	Formal and informal assessment of the child's developmental milestones and capacity to learn.
Social Work Evaluation	To evaluate parent stressors and family support, the social worker will work with the family to navigate services needed to maximize the child's outcomes. Family expectations will also be discussed.
Educational Assessment	The child's school will be contacted regarding educational placement, support, and the need, if any, for inservice on CIs.
Other Assessments	A genetic evaluation and ophthalmology examination may also be recommended. Since 40% of children who are D/HH may have additional special needs, genetic testing may assist the family in making a decision about how to proceed.

With the family’s consent, the early intervention program, childcare program, and/or school of choice should be consulted to review the child’s response to current services and determine the educational needs of the child. Additional assessments may be required to determine candidacy for the CI—depending on the age of the child and the needs of the child or the family. *Table 3* provides a brief description of the evaluations the child and family may undergo to determine candidacy. The family—and the child, if old enough—may be asked to complete an expectation questionnaire to assist the professionals in realistic counseling. Once the evaluations are completed, the CI team members review the findings and make a recommendation to the family.

There are many tools that can guide the CI team to help families understand the potential benefits of cochlear implantation and participate in the planning of ongoing support and intervention. While CIs have been approved by the FDA, the team can pursue cochlear implantation outside of the FDA guidelines based on the published research guidelines, families, and the professional opinion of the CI team members. Obtaining a complete medical and audiological history and gaining an understanding of the family’s resources and challenges is essential. Counseling that addresses the many factors that affect outcomes can be reviewed and discussed. These may include:

- Anatomical, physiological, cognitive, developmental, and behavioral characteristics of the child.
- The child’s hearing history, including age at onset of hearing loss; degree of loss; and age at diagnosis.
- The use of technology, including age at HA fitting and consistency of use.
- Educational and therapeutic services that have been in place.
- Considerations of the family and environment.

The interdependence of these predictors is summarized in *Figure 1* (Teagle &

Eskridge, 2010). Using a candidacy checklist can also help identify these factors that may influence the outcomes. The Graded Profile Analysis (GPA; Daya et al., 1999), Children’s Implant Profile (ChIP; Hellman et al. 1991), the Cochlear Implant Candidacy—Children (CICC; Bradham, Lambert, Turick, & Swink, 2003), or the Modified ChIP (Barnes, Lundy, Schuh, Foley, & Maddern, 2000) are some tools that can guide the team in their discussions to identify strengths and needs as the family considers cochlear implantation. It is important to note that these tools are not meant to “grade” the family but to identify potential issues that could negatively impact meeting the family’s goals and expectations. In the era of having to justify payment for services, these measures can also serve as an “objective” tool in making the case for reimbursement for services rendered.

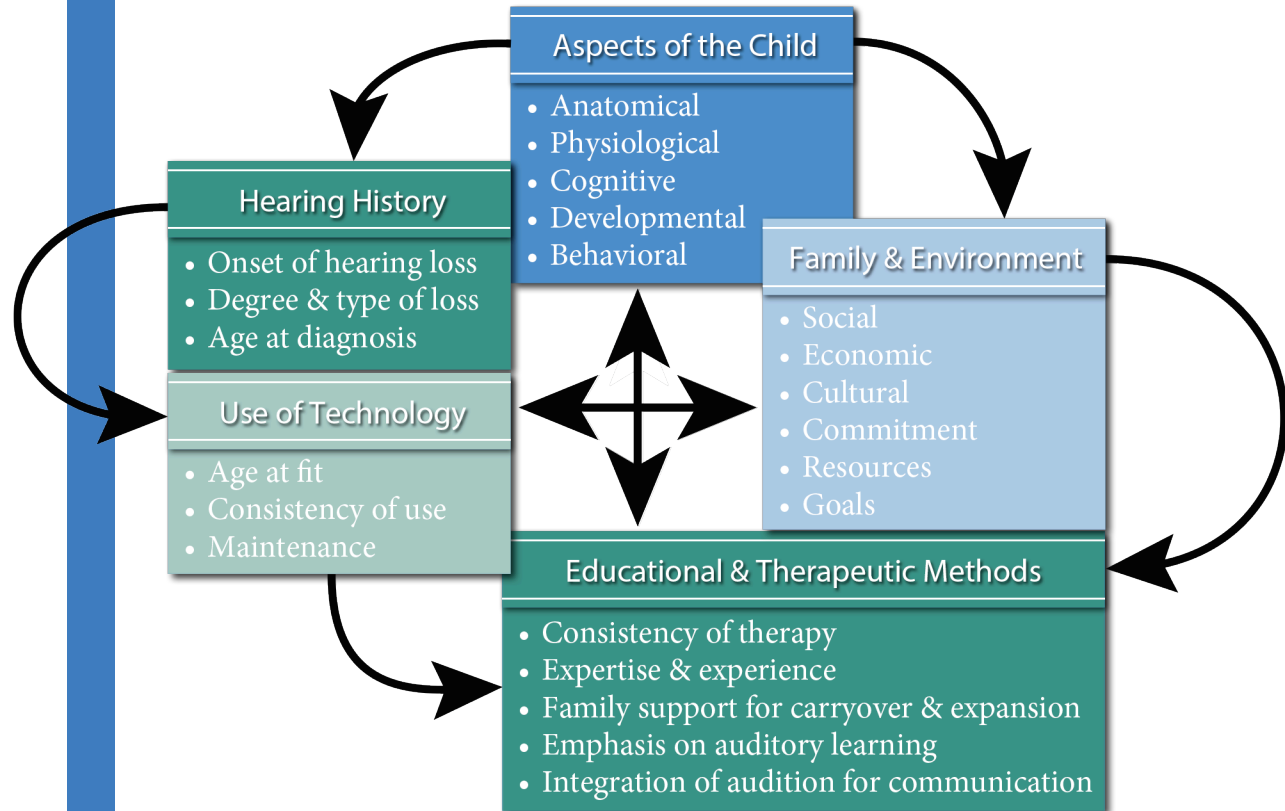
A multidimensional and interdisciplinary approach to the evaluation stage is important in providing patient-centered recommendations to each specific candidate and their family. To fulfill this objective, each team member should strive to provide thorough, valid, reliable, and individualized assessments for each patient. Once each team member has contributed their comprehensive results, the decision to pursue cochlear implantation can be explored by the family. With a thorough understanding of the process, the need for ongoing intervention, and the potential benefits to the child, families should be well equipped to make a decision that will have a profound impact on their child’s future. The recommendations fall into three categories:

- Proceed with the CI.
- Do not proceed (and why).
- Wait (and why).

It is not uncommon for families to want a second opinion. Every effort should be made to assist the family when seeking additional advice from other healthcare providers.

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Figure 1
Interdependence of Predictors for Pediatric Cochlear Implantation Candidacy



Armed with the necessary information, the physician discusses with the parents treatment options and ways to prevent further hearing loss or other related complications.

Medical/Physical Component

The role of the neuro-otologist/pediatric otolaryngologist/otologist precedes and extends far beyond performing the surgery. It includes—in collaboration with the audiologist—the diagnosis of hearing loss, degree and type of loss, and etiology. In addition, based on the physical evaluation and medical history, the surgeon considers the need for imaging (Computerized Tomography [CT] scan and/or Magnetic Response Imaging [MRI]) to evaluate the anatomical structures of the ear and brain. Based on other laboratory tests, the physician may also recommend additional medical

interventions and referrals. Armed with the necessary information, the physician discusses with the parents treatment options and ways to prevent further hearing loss or other related complications.

The search for etiology and the identification of other medical conditions can impact the sequence and timing of treatment. For children with complex medical histories and comorbid conditions or syndromes, referrals to neurology, genetics, ophthalmology, and other specialists are common (Buchman et al, 2008). The referral to these specialties is a collective aspect to patient care, because 40% of children with congenital hearing loss have comorbid diagnoses,

Because the presence of an implanted device can impact future imaging needs, discussion of the contraindications to future imaging studies must take place with the parents.

syndromes, or disorders (Maggs, Ambler, & Hanvey, 2017). In addition, over 400 genetic syndromes have been associated as comorbid diagnoses with the diagnosis of hearing loss (Maggs, Ambler, Hanvey, 2017). More commonly known syndromes include (Trairatvorakul & Wiley, 2015):

- Waardenburg Syndrome
- Alport Syndrome
- Jervell and Lange-Nielson Syndrome
- Usher Syndrome

It is imperative for professionals included in the candidacy process to refer families to specialties that can provide indepth results regarding family history and genetics. Professionals in these fields can also evaluate the family and child for other physical features indicating the occurrence of a comorbid syndrome or disorder. The following features and characteristics are commonly associated with comorbid syndrome or disorders:

- Facial alignment
- Ear tags
- Ear pits
- Wide-set eyes
- Loss of vision
- Microtia
- White forelock
- Atresia

Information gained during testing can provide families with genetic knowledge for present and future familial generations. Based on the results, the determination of CI candidacy and future services can be impacted.

Radiographic imaging is an important topic both before and after surgery. With a combination of CT scanning and MRI, it is possible for the surgeon to visualize both the bony and soft tissues of the ear and neural anatomy prior to performing surgery. These scans aid the surgeon in mapping out the pathway of implantation to minimize the risk of damage to the facial nerve (CN VII), tissue, and other structures in close proximity to the inner-ear cavity. Scans will also show surgeons problematic features that a CI

cannot overcome, such as severe cochlear malformation or an absent or diminished auditory nerve. For these reasons, it is critical for the surgeon to obtain and share this information with the team and parents, as it can significantly affect CI outcome (Adunka et al, 2007). Because the presence of an implanted device can impact future imaging needs, discussion of the contraindications to future imaging studies must take place with the parents.

The risks of surgery are typically discussed with the family by the surgeon (see *Table 4*). While it is rare to have complications in the hands of an experienced surgeon, parents must consider the possibilities during the decision-making process. Informed consent requirements dictate this discussion. Of particular importance is the increased risk of meningitis. Bacterial meningitis is a serious infection of the brain and the fluid surrounding it. Children who are D/HH who have CIs have a higher risk for meningitis, and additional vaccines are recommended. The Centers for Disease Control and Prevention (CDC) provides detailed information on this topic (<https://www.cdc.gov/vaccines/vpd/mening/hcp/dis-cochlear-gen.html>).

As the evaluation of candidacy unfolds, discussion among the team includes the ear of implant, type of electrode array, and determination of whether the child should be a unilateral, bimodal (i.e., a HA in one ear and a CI in the other ear), or a bilateral recipient (i.e., receive CIs in both ears). If it is decided to proceed with two CIs, the family and the surgeon will need to discuss sequential versus simultaneous cochlear implantation. Sequential CI surgery requires the child to undergo two surgical procedures within a span of time. If a sequential CI plan has been decided upon, the family and team must determine which ear would be the most beneficial to implant first and would provide the child with the most progress between surgeries. If a simultaneous CI surgery has been decided upon, the surgeon will implant the child bilaterally during the same procedure.

Table 4 Risks of Surgery

CI or Any Ear Surgery

The following list details the potential risks—while small—of CI surgery. Also listed are risks associated with any ear surgery, although relatively safe when compared to other surgeries (Nicholas & Geers, 2013).

CI	Any Ear
<ul style="list-style-type: none"> • Loss of remaining hearing in the implanted ear. • Higher risk for meningitis. • Facial nerve stimulation/ involuntary facial movement. • Inflammation/extrusion/swelling. • Soreness, redness, or breakdown of skin in area around the implant, which may need more medical treatment, surgery, and/ or removal of device. • Failure of surgery, possibly requiring removal of the implant. • Failure of implanted pieces, which may need replacing. • The CI may not work correctly , or it may cause your child to feel or hear odd or uncomfortably loud sounds. 	<ul style="list-style-type: none"> • Numbness/tenderness around implant site. • Neck pain. • Loss of feeling in face. • Change in taste. • Fluid leak. • Dizziness (vertigo). • Tinnitus or “ringing in the ears.” • Blood, fluid, or infection at the site or close to the site of surgery. • Skin reactions (rashes). • Pain, scarring, bleeding, and infection. • Anesthetic risks (medicines used to put the child to sleep) associated with the heart, lungs, kidneys, liver, and brain. • Children younger than 12 months are at even greater risk for anesthetic complications during surgery.

Current research now demonstrates that early implantation significantly improves a child’s growth in acquiring speech-language skills.

Continued research is supporting the use of simultaneous bilateral cochlear implantation, and these surgeries are becoming more frequent in countries like the United Kingdom (UK). After the UK’s National Institute for Health and Care Excellence (NICE) supported the use of simultaneous CI surgery in 2009, the country has seen an increase in the number of these procedures performed, as well as positive results for CI recipients. Between April 2015 and March 2016, the UK performed 480 pediatric CI surgeries, and 338 of these surgeries were simultaneous bilateral CIs. It is to be expected that countries similar to the UK will follow more flexible and individualized guidelines as the literature involving neural maturation,

early language development, speech intelligibility, and speech production continues to develop and expand.

Factors that will also determine how to proceed include:

- The age of the child.
- Degree of residual hearing.
- Family choice.
- Financial coverage/reimbursement rates.

Recent studies suggest that outcomes for bilateral cochlear implantation are impacted by the child’s age and the time between surgeries (Galvin et al., 2014; Spareboom et al., 2014). Current research now demonstrates that early implantation significantly improves a child’s growth in

acquiring speech-language skills. Nicholas and Geers (2013) compared the receptive language, expressive language, and receptive vocabulary scores of 27 children receiving CIs between 6-11 months and 42 children receiving CIs between 12-18 months. They concluded participants implanted before 12 months of age yielded better spoken language scores by 4 years old when compared to children receiving their CIs after 12 months of age. Other studies, such as Tomblin, Barker, Spencer, Zhang, and Gantz (2005), further support early cochlear implantation. They showed that children implanted earlier in life showed similar speech-language growth patterns when compared to their peers. Children implanted later in life showed an increased language gap compared to their normal hearing peers. In the presence of severe-to-profound hearing loss, earlier implantation—whether the first or second ear—yields better results.

For most pediatric CI recipients, post-operative recovery and discharge is completed in 24-48 hours. After discharge, the surgeon has less-frequent interactions with the child and family relative to the SLP and audiologist. It is important, however, to maintain this relationship should concerns about ear and hearing health or the need for future surgeries arise. Of course, everyone likes to share and celebrate individual progress and the opportunity to have a meaningful role in the child and family's life. Team dynamics and practices are shaped by retrospective knowledge of each child's outcome.

Audiology Component

While all members of the interdisciplinary team interact with a family, an audiologist often serves as the initial or primary point of contact once a child has been identified as being D/HH. For children who are identified at birth through a newborn hearing screening, there may be several audiologists involved in diagnosis, HA fitting, and ongoing assessment of hearing. The general goal of audiologic management is to determine and monitor

hearing thresholds and provide the best access to sound possible through HAs. If degree of hearing loss is severe to profound and the development of early communication milestones is delayed, a CI evaluation should be recommended, so parents can begin to consider this option as the child approaches the first birthday. While the FDA guidelines recommend cochlear implantation after 1 year of age, there are times when a CI will be recommended prior to the first birthday (e.g., child becomes D/HH as a result of bacterial meningitis).

Current research also supports earlier implantation at or before 12 months, if possible. This practice is increasing in popularity, as more literature supports early implantation. Children who are older with progressive or acquired hearing loss are often referred when communication challenges become difficult to address through the use of conventional amplification. An audiologist who serves on a CI team is typically responsible for:

- Collecting information about the child and family.
- Assessing hearing loss and benefit from amplification.
- Providing counseling about the implantation process, technology, and considerations for device use and follow-up care.

As mentioned previously, the FDA-approved criteria for pediatric cochlear implantation, which has been unchanged since 1990 (see *Table 2*), includes children who are 1 year of age or older, have severe-to-profound hearing loss (often interpreted as a pure tone average [PTA] of 90 dB HL or poorer), and/or demonstrate a lack of development in audition skills. Less-conservative criteria have been advocated for and supported by several studies. Not only are children under the age of 12 months being considered for implantation (Tajudeen, 2010), but children with lesser degrees of hearing loss and better speech perception performance are being considered (Carlson et al., 2015; Dettman et al., 2004;

While all members of the interdisciplinary team interact with a family, an audiologist often serves as the initial or primary point of contact once a child has been identified as deaf or hard of hearing.

The audiologic assessment should include both physiologic and behavioral assessments to determine ear-specific degree and type of hearing loss.

Gantz et al., 2000). The change in the severity of hearing loss criteria has caused children with partial hearing loss and asymmetric hearing loss to be considered for CI surgery (Maggs, Ambler, & Hanvey, 2017). With EAS technology, surgeons are now able to preserve functional low-frequency hearing while also supplying the child with electrical stimulation to the profound high-frequency hearing loss (Maggs, Ambler, & Hanvey, 2017).

Other studies support Maggs, Ambler, and Hanvey's (2017) research demonstrating children with partial hearing loss improve language performance with a CI rather than a HA (Wilson et al., 2016). Children with asymmetrical hearing loss have also shown positive results, because a unilateral CI has the ability to restore binaural hearing for children with this type of loss (Maggs, Ambler, & Hanvey, 2017). As more children receive CIs, and the benefits are documented, the candidacy criteria have expanded in practice. Consideration of the individual child and his/her unique circumstances and implementation of best clinical practices must drive decision making. Audiologists working with pediatric CIs must stay current on the evolving criteria for surgery and the positive outcomes of patients receiving CIs for a wide range of hearing loss and severity.

The audiologic assessment should include both physiologic and behavioral assessments to determine ear-specific degree and type of hearing loss. A diagnostic auditory brainstem response (ABR) assessment can provide a good estimate of hearing levels for children with sensorineural hearing loss. Typically, reliable behavioral testing of babies is possible using Visual Reinforcement Audiology (VRA) techniques starting at about 6 months of age. HAs can be fit on the basis of ABR results and refined once behavioral information is obtained. Cochlear implantation is usually deferred until a HA trial has been completed. However, there is evidence that children who have no-response ABR results are very likely to become CI recipients (Hang et al, 2015). Ideally, the family has

the opportunity to explore the child's use of noninvasive technologies in an environment that includes auditory intervention by a qualified therapist. For children with very limited residual hearing, the length of the HA trial should not be extended beyond the time it takes to resolve other considerations addressed in the CI evaluation, including acquiring medical information, treatment, and counseling.

Depending on the child's age and abilities, a battery of speech perception tests are used to document benefit from amplification. While no standard universal pediatric test battery has been recognized among CI teams, a number of tests have been developed or are routinely used in CI assessment. The commonly used tests are listed and briefly described in *Table 5*. Speech perception assessments must be selected that are appropriate for the child, since they can serve as a baseline to measure future progress. Because many children are too young and lack the communication skills to participate in speech perception assessments during candidacy evaluation, the audiologic assessment should include baseline auditory functional assessments. These functional assessments can include questionnaires like the Infant Toddler-Meaningful Auditory Integration Scales (IT-MAIS; Zimmerman-Phillips, Robbins, & Osberger, 2000) and/or LittEARS (Coninx et al., 2009) questionnaires, as well as aided testing in the sound booth and real-ear measures. The collaborative efforts of the audiologist, SLP, and early interventionist can combine to determine the benefit from amplification.

If the child is considered to be a CI candidate, a determination must be made regarding which device to use. Currently, there are three manufacturers with established histories who produce the technology (see *Table 2*). Current manufacturers include Advanced Bionics, Cochlear®, MED-EL. Some centers only offer the option of the CI system available from one manufacturer; whereas, other centers offer makes and models from all

Table 5
Description of Speech Perception Tests

Test	Age Recommendation	Description
Consonant Nucleus Consonant (CNC) Test (Peterson & Lehiste, 1962)	Recommended for older children and teens. This test is used to determine adult CI candidacy and includes less common vocabulary, which makes it more challenging than PB-k or LNT monosyllable word tests.	This test includes 10 lists of 50 monosyllabic words with equal phonemic distribution across lists, with each list having approximately the same phonemic distribution as the English language.
ESP Test (Moog & Geers, 1990)	Recommended for children with limited vocabulary who cannot participate in open-set word testing. Minimum of 2 years for low verbal version and minimum of 6 years for standard version per test developers but can be attempted for younger ages.	Two versions, including low verbal and standard—both closed-set. Can be presented via live voice or a recording. Low verbal test materials consist of objects (toys) instead of pictures. The standard version includes 36 words presented as 3
Hearing in Noise Test (HINT-C)	Sentence material that requires child to have vocabulary and auditory memory to repeat. Recommended once these skills exhibited. HINT is used for adult CI candidacy determination.	HINT-C includes multiple lists of 10 sentences that are five to seven words in length. Can be presented in competing noise for more challenging assessment.
Ling Six Sound Test (Ling & Ling, 1978)	Appropriate for any age once the child has learned to repeat on demand. These sounds (Learning to Listen Sounds) are used very often in therapy and therefore familiar to children.	The sounds used in this test are the vowels /a/ as in all, /u/ as in who, and /i/ as in be; and the consonants /m/ as in me, /S/ as in she, and /s/ as in so. These sounds include low-, mid-, and high-frequency components of speech. The ability to detect and discriminate these phonemes is the basis of scoring.
Lexical Neighborhood Test (LNT) (Kirk, Pisoni, & Osberger, 1993)	Appropriate for children ages 4-5 and older who can repeat words on demand.	This is a recorded open-set test of monosyllabic word recognition. The word list consists of 25 lexically “easy” words (high-frequency occurring words) and hard words (low-frequency occurring and more confusable). It is scored by both number of words and phonemes correct.
Multisyllabic Lexical Neighborhood Test (MLNT) (Kirk, Pisoni, & Osberger, 1996)	For children age 3 and older who can repeat on demand. It is often used before the LNT, as vocabulary is easier because of redundant cues of multisyllable words.	This is a recorded open-set test of multisyllabic word recognition. The word list consists of 12 lexically “easy” words and 12 lexically “hard” words scored by both number of words correct and number of phonemes correct.
Phonetically Balanced Kindergarten Test (PBK-50) (Haskins, 1949)	Recommended age is 4+ years, but children who will repeat what they hear, regardless of comprehension, can be tested to determine speech sounds perceived.	This is an open-set test of monosyllabic word recognition. Can be presented live voice or recorded. A full list consists of 50 phonetically balanced, one syllable, kindergarten words that the examiner phonetically transcribes to obtain a word and phoneme score.

Table 5
(continued)

Test	Age Recommendation	Description
Pediatric Baby Bio Sentences (Spahr, Dorman, Loisel, & Oakes, 2011)	As an alternative to HINT sentences, this test requires the child to have vocabulary and auditory memory to repeat. Recommended once these skills are exhibited. AZBio is used for adult CI candidacy determination.	A pediatric version of the AZBio sentence lists that uses a single female talker to evaluate speech understanding. Can be performed with 10-talker speech babble for noise environment.
Disclaimer	Age is a relative indicator of test appropriateness when children have developmental delays. All open-set tests subject to deflated scores due to articulation errors.	The chance score for open-set testing is 0%, but when highly practiced words are used, this is not valid. Recorded tests are ideal but often not realistic for young children. Testing in noise-controlled environments with calibrated materials is recommended.

Adapted from Advanced Bionics. (2010). *Test reference for cochlear implants candidacy and post-performance test.*

Beyond assessment, the CI team audiologist provides extensive counseling and information. In the process, he/she establishes a relationship with the child and parents and gains some insight about the family's acceptance of the diagnosis and the stage at which they are entering the decision-making process.

companies. In some cases, the surgeon will make a recommendation for a particular device based on the medical and radiologic examination. It is incumbent on the CI team to ensure that the family has access to unbiased information about each of the CI systems available and approved by the FDA. A family's personal preferences of the advanced features and technology should also be considered to ensure the device is appropriate for the child and family's daily life.

Continued advancements have allowed manufacturers to include products with waterproof technology, wireless processors, longer battery life, Bluetooth connection, streaming, smartphone applications, musical adjustments, and a variety of other personalized features. There is an abundance of information available to families via the Internet, including the manufacturer websites and social networking sites. Support groups and other CI recipients can also share personal experience and perspectives. It is important to note that not all sources of information provide accurate and unbiased information. In

the interest of preparing effectively for surgery and device programming and for achieving outcomes that meet the family's expectations, counseling from members of the CI team and shared decision making among the team members and the family is essential.

Beyond assessment, the CI team audiologist provides extensive counseling and information. In the process, he/she establishes a relationship with the child and parents and gains some insight about the family's acceptance of the diagnosis and the stage at which they are entering the decision-making process. Based on these observations and in communication with other team members lies the opportunity to consider some of these questions:

- Is the family responding from grief or anger?
- Have they idealized the process and created expectations of normal hearing?
- Are they cognizant of other developmental or medical issues the child might have, and does the team appreciate what these might be?

- Is the family’s preference for communication mode realistic, and are services in place to support this plan?

Counseling and support needs can be shared with the team to help resolve these and other important issues.

Finally, plans for appointments and services for the future should be discussed. During the first year following surgery, frequent device programming visits are needed to optimize the program and ensure audibility is maximized. A hearing test should be administered following surgery to measure remaining residual hearing. The typical child adapts to the electrical signal over time, tolerance increases, and as experience in hearing grows, children can play a larger role in providing feedback about hearing. At minimum, the following schedule is recommended for children:

- Initial stimulation (IS) occurs approximately 1 to 5 weeks after surgery
- 2 weeks post IS
- 1 month post IS
- 3 months post IS (dependent on need)
- 6 months post IS
- 9 months post IS (dependent on need)
- 1 year post IS
- Semiannual visits thereafter until age-appropriate speech-language development occurs—at which time, the child is seen annually or on as-needed basis.

During these appointments, hearing tests and speech perception assessments must be completed to guide programming, validate settings, and ensure appropriate progress is made. Families gain experience and confidence in managing the technology with coaching and instruction. The audiologist continues to be a source for new information and problem solving on issues related to device use, such as troubleshooting and device retention.

Speech-Language Pathology Component

For children who are D/HH and are being evaluated for possible cochlear implantation, it is vital that the SLP have the knowledge and skills to accurately assess the child’s present level of functioning to predict whether the child’s communication development can be enhanced with CIs. Child language development is influenced by multiple factors, including cognition, social relationships, and emotional development (Eisenberg, 2017). Therefore, when assessing CI candidacy, the impact on the entire child should be assessed, including secondary benefits, such as improved quality of life and the development of meaningful social-emotional relationships (Eisenberg, 2017). To ensure the SLP explores all aspects of a child’s life, a full assessment that includes semantics, syntax, morphology, pragmatics, phonology, speech, literacy, and auditory skills should be performed (Bradham, Houston, & Diefendorf, 2015). If the child is delayed or is at risk for delayed language development, then cochlear implantation may be the best option available.

When determining candidacy, most experienced SLPs serving children who are D/HH use speech-language assessments that are standardized on typically hearing children, with only a few exceptions. If the child who is D/HH is acquiring spoken language, the SLPs should use assessments that compare the child’s performance to what is considered to be typical development for the child’s age and cognitive development.

In addition to obtaining current and accurate audiological assessments on the child who is D/HH, SLPs also must obtain measures of functional listening skills, especially if the expectation is to use audition to develop spoken language. SLPs must document how the child is using his/her aided hearing in conjunction with amplification, hearing assistive technology (e.g., digital HAs and/or personal FM system), as well as how the child is responding to both environmental sounds and speech. For infants and toddlers,

For children who are D/HH and who are being evaluated for possible cochlear implantation, it is vital that the SLP have the knowledge and skills to accurately assess the child’s present level of functioning to predict whether the child’s communication development can be enhanced with CIs.

these auditory skills can be measured through play activities and in conjunction with parental or caregiver interviews, questionnaires, and informal assessments. For children ages 3 and above, more formal speech perception measures can be used, such as the Early Speech Perception (ESP) Test for Profoundly Hearing-Impaired Children developed by Moog & Geers (1990). In addition, clinicians may wish to use the Auditory Perceptual Test for the Hearing Impaired, 3rd Edition.

In conjunction with standardized measures, informal assessments are useful in determining how the child who is D/HH is functioning in their everyday environment, such as school, home, and in the community. Informal assessments can be given to the family, teacher, caregiver, SLP, or the child, depending upon his/her age. Informal assessments include, but are not limited to:

LittleEars Auditory Questionnaire
Kun-Inaker, Weichvold, Tsiakpini, Conix, & D'Haese, 2003

PEACH
Ching & Hill, 2007

Early Listening Function (ELF)
Anderson, 2002; Oticon, 2007

Children's Home Inventory for Listening Difficulties (CHILD)
Anderson & Smaldino, n.d.

Child Auditory Performance Scale (CHAPS)
Smoski, Brunt, & Tannahill, 1998

Listening Inventory for Education—Revised (LIFE-R)
Anderson, Smaldino, & Spangler, 2012

- LIFE-R Student Appraisal
- Teacher LIFE-R

Functional Listening Evaluation (FLE)
Johnson & Von Almen, 1993

Preschool Screening Instrument for Targeting Educational Risk in Preschool Children (Preschool SIFTER)
Anderson & Matkin, 2004

Informal Assessment of Fatigue and Learning
Anderson, 2014; Fukuda et al, 2010

Minnesota Social Skills Checklist for Students Who Are Deaf/Hard of Hearing
Minnesota Department of Education, n.d.

Social Communication Skills Pragmatics Checklist
Goberis, 1999; Simon, 1984

Placement and Readiness Checklists (PARC)
Johnson, 2011

Speech intelligibility is another way to assess speech development and can be measured in terms of overall intelligibility, including segmental and suprasegmental errors (Tye-Murray, 1994). Speech intelligibility is a critical area of assessment that may be overlooked by SLPs. Formal measures of speech intelligibility are limited, and the most common assessment is the CID Picture SPINE: Speech Intelligibility Evaluation (Monsen, Moog, & Geers, 1988). The Pediatric Speech Intelligibility (PSI) Test can also be given as an assessment of speech intelligibility for children who are D/HH (Jerger & Jerger, 1984; Jerger et al., 1980, 1981). However, due to the limited formal assessments of speech intelligibility, many SLPs develop their own assessments and will obtain a percent of words, phrases, and sentences that are correctly spoken by the child who is D/HH and understood by familiar and unfamiliar listeners.

The acquisition of suprasegmental and segmental skills can be assessed using instruments that were designed to evaluate the spoken language of children who are D/HH. The Ling Phonetic-Phonological Speech Evaluation (Ling, 2002) is commonly used for this purpose. Another assessment developed specifically for children who are D/HH and acquiring spoken language is the instrument Identifying Early Phonological Needs in Children with Hearing Loss (Paden & Brown, 1992). And finally, if the child has acquired some spoken language, most clinicians will use standard assessments, such as the:

Goldman-Fristoe Test of Articulation, 3rd Edition (GFTA-3)
Goldman & Fristoe, 2015

Khan-Lewis Phonological Analysis, 3rd Edition (KLPA-3)
Khan & Lewis, 2015

Word Association Syllables Perception (WASP)
Koch, 1999

Arizona Articulation Proficiency Scale, 4th Edition (Arizona-4)

As Tye-Murray (1994) notes, the assessment of a child's language by a SLP usually involves an evaluation of syntax, morphology, semantics, vocabulary, and

pragmatics. For infants and toddlers who are D/HH, practitioners may use assessments that measure performance across several developmental domains, such as:

Carolina Curriculum for Infants and Toddlers, 3rd Edition
Johnson-Martin, Hacker, & Attermeier, 2004

MacArthur-Bates Communicative Development Inventories
Fenson et al., 1993

Rossetti Infant-Toddler Language Scale
Rossetti, 1990

Receptive-Expressive Emergent Language Scale, 3rd Edition (REEL-3)
Bzoch, League, & Brown, 2003

Cottage Acquisition Scales for Listening, Language, and Speech (CASLLS)
Wilkes, 2003

Other common assessments include:

Preschool Language Scale, 5th Edition (PLS-5)
Zimmerman, Steiner, & Pond, 2002

Clinical Evaluation of Language Fundamentals—Preschool, 2nd Edition (CELF-Preschool-2)
Wiig, Secord, & Semel, 2004

Reynell Development Language Scales
Reynell & Gruber, 1990

These are broad-based receptive and expressive language evaluations that provide standard and/or percentile scores. If the child has developed some language and is a preschooler or older, other assessments may be employed, such as:

Peabody Picture Vocabulary Test, 4th Edition (PPVT-4)
Dunn & Dunn, 2006

Test of Auditory Comprehension of Language, 4th Edition (TACL-4)
Carrow-Woolfolk, 2014

Bracken Basic Concept Scale, 3rd Edition (BBCS-3)
Bracken, 2006

Comprehensive Test of Spoken Language, 2nd Edition (CASL-2)
Carrow-Woolfolk, 2017

Expressive Vocabulary Test, 2nd Edition (EVT-2)
Williams, 2006

Oral-Written Language Scales, 2nd Edition (OWLS-2)
Carrow-Woolfolk, 2011

Test of Pragmatic Skills, 2nd Edition
Phelps-Terasaki & Phelps-Gunn, 2007

While this list of language assessments is not exhaustive, most practitioners who assess language acquisition of children who are D/HH to determine candidacy for cochlear implantation will use at least some of these evaluations in their preferred diagnostic protocol. Of course, preferences based on clinical and professional experiences, as well as other factors related to a child's unique case history and learning needs, also influence the selection of communication measures and assessments.

Another essential component that must be considered is the type and frequency of intervention services required to help the child achieve speech-language milestones that align with their typically developing peers. Families have more options now than ever before for learning to maximize the development of spoken communication following implantation. Some alternatives include OPTION programs, AG Bell's Cert AVT, and telehealth services. Whatever option is chosen, family involvement is key to optimal success.

It is important to identify programs and professionals who have received training and/or have experience in developing spoken language through listening. There are several tools available on the web to guide parents, but some questions to consider are shown in *Table 6*.

Conclusion

Determining if a child is a candidate for cochlear implantation requires an interdisciplinary team approach that places the family at the center of the decision-making process. Once the child is identified as being D/HH, parents should be informed about all of the technological options available to them, including CIs. The CI team—comprised of at least a surgeon (i.e., otolaryngologist, otologist), audiologist, and SLP—will complete comprehensive medical, audiological, and speech-language assessments to ascertain if cochlear implantation would be beneficial to the child. The team

Table 6

Questions to Consider When Identifying Programs and Professionals

Question 1

Is the therapist focused on helping the child acquire and use auditory information, and does the therapist expect the child to gain most information through listening?

Does the Therapist . . .

- Draw the child's attention to new and novel sounds?
- Include different types of listening activities, use whispered and tape-recorded speech and music, and help your child discriminate sounds and speech in noisy and quiet environments?
- Observe and coach you as you speak to or work with your child—pointing out problems and solutions—and teaching you how to make sound meaningful to your child all day long?

Question 2

Is the therapist aware of how the environment affects listening?

Does the Therapist . . .

- Explain how background noise can interfere with understanding?
- Instruct you about how to care for and maintain HAs/FM systems/CI, check batteries, and do listening checks?
- Require your child be seen for periodic checks of the hearing technology?
- Suggest that family members become good monitors of the auditory environment and support the attitude that parents expect the child to hear?
- Work to help the child be aware of his/her own voice so that they work to match what he/she says with he/she hears others say?

Question 3

Does the therapist have a good understanding of how children learn through their hearing?

Does the Therapist . . .

- Note instances when your child has perceived some meaningful aspect of sound and draw this to the parent's attention?
- Encourage the child to develop an auditory memory for familiar sounds in the environment and familiar voices and provide opportunities to use developing auditory memory skills?
- Avoid touching or tapping the child to obtain his or her attention and speaking to your child even when his/her eyes are focused away from the clinicians' face?
- Repeat a message auditorily, if vision was first needed to gain the child's attention or used to help the child understand?

Table 6 (continued)

Question 4

Does the therapist encourage the parent to think of the child's speech-language in terms of normal development?

Does the Therapist . . .

- Talk naturally with the child—speaking without exaggerated facial movements (especially mouth and tongue) and without sign language?
- Emphasize the sounds of speech in games of vocal play the way that mothers do with infants who hear normally?
- Have high expectations for the child to eventually learn to follow speech through his/her HAs or CI and learn to talk?
- Use auditory age-appropriate language?
- Use natural expressions appropriate to the child's age and language level?
- Use familiar books, nursery rhymes, songs, and other culturally-based materials in therapy?
- Have knowledge of the levels of normal developing speech-language and base explanations of your child's progress on these developmental models?
- Explain language, speech, and listening in parent-friendly language?
- Understand, use, and teach effective listening strategies, such as pausing in expectation of hearing something meaningful?
- Encourage your child to use babbling and jargon as normal hearing infants do, rather than push the child to imitate speech sounds, syllables, or words?
- Help your child participate educationally and socially with children who have normal hearing by supporting them in regular education classes?

Question 5

Does the therapist demonstrate a positive relationship with parents, family, and child, and is the therapist concerned about developing a healthy, informative, and supportive parent guidance program?

Does the Therapist . . .

- Encourage you to ask questions regarding what the therapist is doing without making you feel uncomfortable?
- Encourage parents to meet other families and adults who live with profound hearing loss?
- Discuss weekly goals in terms of long-term goals so that parents understand how auditory processes are developed over time?
- Encourage parents to be objective about their child and his/her program and discourage feelings of dependency upon the therapist?
- Explain all these things in words that you understand?



Photo courtesy of Cochlear Americas

discusses these findings with family and provides information about candidacy and potential outcomes, including the support that will be essential to achieve the desired communication and academic outcomes expressed by the family.

Once the child recovers from CI surgery and the device(s) are activated, the real journey begins. Consistent audiological support with CI programming is required to ensure the speech processor program has been optimized, and the implant is working properly. Additionally, the child must receive appropriate early intervention services that will focus on teaching the child to associate meaning

with the auditory information provided by the CI(s). As hearing with a CI(s) is quite different than listening with HAs, the newly implanted child and family should receive weekly speech-language therapy that has a strong auditory component. These services should be provided by an early interventionist or clinician who is well trained and experienced in delivering these services. The goal is to assist the family to integrate listening and communication into the daily routines that occur in the home. Through consistent, timely, and well-coordinated early intervention services, young children with CIs often can achieve language outcomes that rival their hearing peers.

Once the child recovers from CI surgery, and the device(s) are activated, the real journey begins.



Photo courtesy of Advanced Bionics

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