I n the United States, the auditory brainstem implant—a sensory device recommended for individuals with profound hearing loss who are not eligible for a cochlear implant (CI)—is clinically indicated for teens and adults with neurofibromatosis type 2 (NF2). During the past 10 years, however, surgeons outside of the U.S. have begun implanting adults and children with non-NF2 deafness, and have had some success. Based on these early findings, families from the United States began traveling to Europe so that their children could undergo this surgical procedure, but not without incurring great personal and financial hardship. Of greater significance, this procedure has not been subjected to any regulatory oversight.

For these reasons, a controlled, regulated study of pediatric ABI safety and early efficacy was deemed to be long overdue. In response to this need, the House Research Institute (HRI) applied for and received approval from the Food and Drug Administration (FDA) to initiate a clinical trial in young children.

**ORIGINS OF THE ABI**

The ABI external processor and transmitter are similar to the components of a CI, as shown in the photo on page 5. However, the ABI electrode “paddle” bypasses the cochlea and is placed directly on the cochlear nucleus of the auditory brainstem, as shown in the illustration on page 8.

The ABI was the innovation of William House, DDS, MD, and William Hitselberger, MD, who in 1979 implanted an adult female diagnosed with neurofibromatosis type 2 (Ann Otol Rhinol Laryngol Suppl 1982;91[2 pt 3]:117-124). The first device was a handmade single-electrode system. A feasibility study followed, and a small group of adults with NF2 were implanted (J Rehabil Res Dev 1987;24[3]:9-22). Results showed promise, leading to a collaboration with Cochlear Limited to develop the Nucleus multichannel ABI and sponsor an FDA clinical trial for adults with NF2 (Otolaryngol Head Neck Surg 1993;108[6]:624-633; Otolaryngol Head Neck Surg 1993;108[6]:634-642).

The Nucleus 24 ABI received formal FDA approval in October 2000 for individuals with NF2 age 12 and older. Although auditory perceptual abilities with the ABI were shown to be inferior to those of non-NF2 cochlear implant users, the NF2 ABI subjects were able to identify words in a closed set, and a few achieved open-set speech recognition (J Neurosurg 2002;96[6]:1063-1071).

Today, use of the auditory brainstem implant is standard of care in patients with NF2 who are not eligible for a cochlear implant.

**New Trial Opens Door to Auditory Brainstem Implant Research in Children**

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NON-NF2 PATIENTS FROM EUROPE

Implantation of the ABI in non-NF2 patients was first carried out in Verona, Italy, by Vittorio Colletti, MD. In 2006, he reported summary data on 80 patients fitted with ABIs, 18 of whom were children and 54 of whom had non-tumor disease of the cochlear nerve or cochlea (Adv Otorhinolaryngol 2006;64:167-185).

At one year postimplantation, the non-tumor patients achieved open-set speech recognition scores ranging from 12 percent to 100 percent (mean = 59%), whereas scores of NF2 patients ranged from 5 percent to 30 percent (mean = 11%).

A series of psychophysical tests was conducted on 25 non-tumor and 14 tumor patients from 1999 to 2004, with a follow-up time of at least one year (Adv Otorhinolaryngol 2006;64:167-185). Although most patients across the two groups improved in communication abilities and awareness of environmental sounds with the ABI, non-NF2 recipients demonstrated even better auditory outcomes, and, in fact, some were shown to perform at a level commensurate with CI performance.

Sennaroglu, Ziyal, Atas, et al reported ABI outcomes in 11 prelingually deaf children (age 30 to 56 months at implantation) in Ankara, Turkey, with different cochlear malformations (Otol Neurotol 2009;30[6]:708-715). Ten of the children received the Nucleus 24 ABI, and one child received the Med-El 100 ABI.

Six children were able to discriminate among different sounds by three months following ABI activation. After 15 months, two children correctly recognized 20 percent and 80 percent of sentences, and 45 percent and 95 percent of words, respectively.

Most of the children experienced minimal nonauditory side effects during device activation. These included facial stimulation, vertigo, or swallow or gag reflex. The side effects were controlled by turning off the electrode or decreasing the current level.

No significant intraoperative or postoperative complications due to device activation or long-term use were reported in any of these studies.

COCHLEAR NERVE DEFICIENCY

Most recently, Colletti, Wilkinson, and Colletti analyzed data from a group of children who initially underwent cochlear implant surgery but did not advance in their auditory skill development (Ann Otol Rhinol Laryngol; in press).

The children had been diagnosed with cochlear nerve deficiency. Absence of cochlear nerves was confirmed at the time of ABI surgery.

We have observed that children using the auditory brainstem implant rely heavily on visual cues.
Scores on the Categories of Auditory Performance were significantly improved with the auditory brainstem implant (Ann Otol Rhinol Laryngol Suppl 1995;166:312-314).

Notably, children with cognitive deficits gained some benefit from the ABI, but not as much as typically developing ABI recipients did. Additionally, children implanted before age 3 had higher scores than children implanted at older ages.

The decision about whether to place a CI in a patient with cochlear nerve deficiency is never an easy one, and the present techniques of imaging and electrophysiology are not fully predictive of outcome. The ABI is a potential alternative to a cochlear implant in select cases.

**CHILDREN FROM THE U.S.**

With U.S. families traveling abroad for ABI surgery, access to a local clinic for device programming and follow-up assessment has become a necessity.

To date, we have managed five pediatric ABI recipients. While results have varied, rate of growth in speech recognition for several of these children is within the range observed for CI users, although at the lower end of average (Otol Neurotol 2008;29[2]:251-257; J Am Acad Audiol 2012;23[6]:412-421).

We have observed that children using the auditory brainstem implant rely heavily on visual cues. For some children, oral language has not yet developed to the point that it can provide the basis for their functioning in mainstream education, despite the provision of support services.

Visual language may continue to be the primary communication mode of children with an ABI, even as they clearly demonstrate the ability to hear environmental sounds and understand some speech.

Many children who received an auditory brainstem implant developed strong sign skills prior to implantation, having gotten no benefit from other auditory devices. Since it is not possible at this time to predict who among ABI candidates is likely to develop open-set discrimination skills and who is not, it is our belief that children receiving ABIs should continue to use their visual language skills while they participate in auditory/oral habilitation.

As these skills develop, the language foundation obtained through sign may help to bridge a transition to the use of oral language. As oral language skills develop, Cued Speech may be of particular benefit, since it uses hand signals to differentiate sounds that are not distinguishable through speech reading.

**HRI CLINICAL TRIAL**

The HRI clinical trial is a collaborative effort between the House Research Institute, House Clinic, and Children’s Hospital Los Angeles. The overall objective of this trial is to evaluate surgical and device-related safety issues in 10 non-NF2 children (with and without a CI).

In terms of inclusion criteria, patients must have bilateral profound sensorineural hearing loss and a diagnosis of cochlear aplasia, complete cochlear ossification (post-meningitis), or cochlear nerve deficiency, and be between the age of 24 and 60 months (with exceptions).

The ABI is a potential alternative to a cochlear implant in select cases.

Strong family support is also required, including language proficiency of both parents or legal guardians in the child’s primary mode of communication and primary educational mode of communication, or in another form of visual support for communication.

Parents must have reasonable expectations, as determined informally by the clinicians and psychologist, such as an awareness of the parental role in rehabilitation and of the benefits and limitations of auditory brainstem implant, and an understanding that the child may not develop spoken language as a primary mode of communication or sufficient oral language skills to allow maximum academic progress in an oral environment.

On the other hand, an exclusion criterion is the presence of cognitive or developmental delays that would be
expected to interfere with the child’s ability to cooperate in testing or device programming or with the development of speech and oral language, or would make an implant and subsequent emphasis on aural/oral communication not in the child’s best interest.

Anomaly/pathology involving the brain stem or cortex, retrocochlear pathology resulting from NF2 or other types of cranial nerve/brain stem tumors, and coexisting medical conditions that require irradiation of the brain stem or auditory cortex are also reasons for exclusion.

**PROTOCOL OVERVIEW**

Children enrolled in the clinical trial will be evaluated to determine benefit from amplification or cochlear implants already in use.

For those with cochlear implants, optimal programming of their CI processors will be confirmed, or mapping will be adjusted. They will then be evaluated with sound-field threshold and speech-perception measures appropriate to their age and level of development.

Children who have not received a cochlear implant because it is not anatomically possible will be assessed with optimally programmed hearing aids to document lack of benefit.

Patients must be free of any medical comorbidities that might affect their ability to undergo safe administration of a general anesthetic for a craniotomy. Patients will be assessed by their pediatrician, the team anesthesiologist, and the neurotologists and neurosurgeons prior to being deemed a candidate for the study.

**SURGICAL TECHNIQUE**

In adults, ABIs can be placed via either the retrosigmoid or translabyrinthine approach. In the young pediatric patient, however, the mastoid is not well developed, and the retrosigmoid approach must be used. This approach has been demonstrated to be safe, with a low complication rate in both adults and children (Otol Neurotol 2010;31[4]:558-564).

Typically, the most important landmark for identifying the cochlear nucleus area is the VIII cranial nerve because the cochlear nucleus complex may be prominent in the prolongation of this nerve. In children with cochlear nerve aplasia, this landmark is lacking. The projection of the IX cranial nerve is followed, directly leading to the lateral recess.

After clear identification of the cochlear nucleus area, the ABI device is prepared for insertion. The receiver body is held in place using its magnet. The ground electrode is then placed deep to the temporalis muscle immediately superior to the external ear canal.

Under high-power magnification, the electrode array can be completely inserted into the lateral recess with the aid of a small forceps. The correct position of the electrode is optimized with the aid of electrically evoked auditory brainstem responses (eABRs).

**PROGRAMMING NOTE**

Initial programming of the ABI processor is performed with the use of eABR measurements to determine the current level that produces an identifiable waveform without prompting serious nonauditory responses.

Subsequent mapping is performed with the same behavioral approaches used to program CI processors in young children: visual reinforcement techniques for toddlers and conditioned play techniques for preschoolers.
Several tools that are helpful in CI mapping are not available for use with ABIs, including neural response telemetry and stapedial reflex measures, so a child’s ability to perform a conditioned task is especially helpful.

It is likely that longer pulse durations than are typically seen with CI maps will need to be employed in order to produce responses without nonauditory side effects.

And unlike monopolar cochlear implant maps, ABI maps may require very significantly different pulse durations and current levels across electrodes, so it is essential to measure individual electrodes rather than interpolate from a few measured electrodes.

Nonauditory side effects or signs of uncomfortable sensations anywhere in the body can be difficult to see in very young children. These side effects may include evidence of distress, dizziness, coughing, or gagging. Any such response should be analyzed carefully to determine whether the behavior is connected to presentation of the stimulus or coincidental.

Although nonauditory side effects often subside with time in adult ABI patients, they should be avoided in children, who are not yet good reporters, through alterations in programming.

Notably, the speech recognition test protocol is similar to that used in the national Childhood Development after Cochlear Implantation (CDaCI) study, which will enable comparison of speech recognition outcomes among children with the ABI, CI, and normal hearing (Audiol Neurotol 2006;11[4]:259-268; Cochlear Implants Int 2007;8[2]:92-116; JAMA 2010;303[15]:1498-1506).

LONG IN COMING
It has been 34 years since the first adult patient was implanted with an ABI by surgeons at the House Research Institute. A pediatric ABI trial has been long in coming, and the recent FDA approval for a safety/feasibility study is an essential first step.

Through this five-year trial, we hope to better understand the influence of the intervention on the auditory and communication development of children born with nonfunctioning auditory nerves.

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EVALUATING SAFETY AND EFFICACY
The children enrolled in this clinical trial will be tracked for three years, in accordance with the FDA protocol.

During the first 12 months, records will be maintained to document complications related to surgery and device programming.

Feasibility will be indicated by the number of participants with access to sound in the speech spectrum at 12 months post-ABI activation. Access to sound will be measured by sound-field thresholds on the ABI side (0.25, 0.5, 1, 2, 3, 4 kHz), and mapping will be considered successful if thresholds are better than or equal to 50 dB HL.

The following three milestones from the Meaningful Auditory Integration Scale (MAIS; Am J Otol 1991;[12 suppl]:144-150) or Infant–Toddler Meaningful Auditory Integration Scale (IT-MAIS; Advanced Bionics’ Loud & Clear! newsletter; volume 4, issue 1) will be examined:

1. The child wears the device consistently throughout the day.
2. Vocal behavior is positively affected when the ABI is activated.
3. The child frequently alerts to environmental sounds.

In addition to the one-year safety/feasibility study, an early efficacy study will be conducted to track communication outcomes for an additional two years. This extended protocol incorporates behavioral measures in the developmental domains of speech perception/recognition, speech–language, and adaptive behavior.

References on Tap
Access the hyperlinks (shown in gray) in this article and throughout the issue by reading it on HJ’s free iPad app: bit.ly/AppHearingJ.