Chapter 8

Assistive Devices for the Hearing-Impaired Child

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Introduction

With the implementation of universal newborn hearing screening (UNHS) programs in the United States and the rapid increase in the number of states and birthing facilities conducting UNHS, the average age of identification of newborns with hearing loss has decreased over the last 20 years from approximately 30 months to 6 months or less. Although infants and young children are being identified earlier, those who have a hearing loss or are deaf will likely fall behind their hearing peers in language, cognition, and social-emotional development. Hard-of-hearing or deaf infants who receive intervention before 6 months maintain language development commensurate with their cognitive abilities through the age of 5 years.

Intervention in the forms of hearing aids, FM systems, and/or cochlear implants is the single most important component to help the hearing-impaired child access sound. When fitted appropriately, they will, in most instances, enable the child to maximize their use of residual hearing. If the child is receiving appropriate aural rehabilitation, speech and language can develop at or near an age-appropriate pace.

No assistive device will enable a hearing-impaired child to perform normally in all listening situations. Hearing aids and cochlear implants for children should make speech audible at a comfortable level and provide as many acoustic cues as possible without over-amplifying 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 various real-world listening environments.

There is always a need to base clinical decisions on research, but the pace of technological innovation in hearing aids and cochlear implants has begun to exceed that of supporting research.
Today’s advanced features and styles of hearing aids (noise reduction, directional microphones, receiver-in-the-ear, open-canal, etc.) are being fitted on children. In the absence of research to support the outcomes of such fittings, every audiologist who fits devices on children and infants has the responsibility to verify those fittings. (For more on open-canal and receiver-in-the-ear devices for children, see McCreery, 2008.) The same can be said for audiologists who program and maintain the settings/map on a child’s cochlear implant; verification and validation of its success is mandatory.

A hearing aid manufacturer’s default setting (i.e., “first fit”) should not be used in an initial fitting of new amplification on infants and young children. Fitting a hearing aid without independent verification is inappropriate. Research indicates that for average speech input, the same audiogram and typical real ear to coupler difference (RECD) for a 6 month old (the difference in recommended gain) can be up to 21 dB between hearing aid brands. The discrepancies between recommended gain settings from different manufacturers are even greater when the input is loud speech. Generally speaking, the first fits of some manufacturers provide too much amplification, while others provide too little. Neither scenario is appropriate for a patient attempting to learn speech and language.

Identification and accurate quantification of a hearing loss is the first step in a successful amplification protocol.

Amplification in the Form of Hearing Aids

When an infant or young child is identified with hearing loss, the intervention process begins. Counseling a family of a child with a newly identified hearing loss is an ongoing process and beyond the scope of this chapter. For further information on family counseling, the reader is referred to the appropriate chapters of this publication and to Babies and Hearing Loss: A Guide for Families about Follow-Up Medical Care.

Intervention usually begins with the making of custom earmolds. No child is too young for earmold impressions. The physical fit of earmolds is important for both comfort and retention. Earmolds should be made of a soft material (vinyl is preferable) for safety and comfort and need to be replaced whenever feedback occurs at optimal settings, fit becomes loose, or comfort issues arise. Retention devices and options include Huggies™, toupee tape, retention cords (Critter Clips™), and headbands. Of course, the fitting process involves counseling the parents on care and maintenance of the hearing instruments.

Real Ear to Coupler Difference (RECD)

Measuring the RECD is the logical first step in the process of fitting hearing aids. It can be defined as the difference in decibels between the sound pressure level (SPL) at a measurement point in the ear canal and the SPL in a 2 cc coupler for a specified input signal. The RECD is used to adjust the electroacoustic characteristics (frequency and gain) of chosen amplification, so the final output in the real ear will be correct for an individual child.

This measurement is especially important when real-ear aided response (REAR) cannot be measured (i.e., with a very young or noisy child). The RECD converts...
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RECD can be measured while the infant or child is sedated or asleep for auditory brainstem response (ABR) testing or while in a natural sleep state. For older children, using a mirror is suggested, so the child can watch what is happening. It is helpful to use Oto-ease™ or wrap the probe tube and earmold (or foam tip) together with clear plastic wrap and insert them into the ear canal together. The insertion depth of the probe tube should be about 10-11 mm from the ear canal opening. The cord from the probe microphone should be clipped on the child’s opposite shoulder (cord draped in front), so the microphone lies snugly against the child’s cheek.

RECD is most useful for predicting real-ear output when measuring the hearing aid in a 2 cc coupler. It allows us to know the difference between output SPL in the real ear and in the 2 cc coupler. Using RECD, real-ear hearing aid output can be predicted to within approximately 2 dB. Simply stated, the RECD is used to convert performance measured in a 2 cc coupler into real-ear hearing aid performance.

RECD can be measured while the infant or child is sedated or asleep for auditory brainstem response (ABR) testing or while in a natural sleep state. Whenever possible, the patient’s own earmold should be used for measuring RECD. When a new earmold is made, RECD should be measured again. Using a patient’s own earmold provides more accurate real-ear measurement. The RECD differs depending upon whether a foam tip or custom earmold is used, mainly in the high frequencies. With a foam tip, the RECD is reduced in frequencies around 3000 to 4000 Hz; with an earmold, the increased length of the tubing causes a reduction around 2000 Hz.

Audiological information about hearing thresholds is typically obtained via insert earphones and foam tips, but when possible, audiological information should be obtained using the child’s own earmolds. If an RECD cannot be obtained on both ears, one ear is usually a good predictor of the other ear and preferable to using an age-appropriate average RECD.

To measure an RECD:
1. Calibrate the real-ear measurement system.
2. Enter the audiogram (dB HL thresholds or ABR thresholds).
3. Present the chosen stimulus in a standard 2 cc coupler via an insert earphone. The SPL measured is the coupler response.
4. Place a probe microphone in the child’s ear canal with the custom earmold (or insert probe tip) to deliver the same signal that was delivered to the coupler to the ear. The SPL measured is the child’s real-ear unaided response. The difference between the real-ear unaided response and the coupler response is the RECD. Many real-ear measurement systems make this calculation automatically. The RECD is added to the hearing threshold.
aid response measured in the coupler to predict the real-ear response. A positive RECD value (in dB) indicates how much levels measured in the real ear exceed levels measured in the coupler. The smaller the ear canal, the greater the SPL measured at the tympanic membrane and the greater the RECD.

Measuring the real-ear unaided response with a foam tip.

A RECD on the Audioscan RM500.

A vent in an earmold, myringotomy tubes, slit leaks, and middle ear effusion can affect the RECD. If there is a roll-off in the low frequencies of -1 to -5 dB on the RECD, it usually indicates there is a slit leak, a vent larger than 1 mm, or a hardened earmold tubing. If the roll-off is large in the low frequencies (-10 dB or greater), there may be a perforation or tympanostomy tube. Larger positive values in the low- and mid-frequencies can mean middle ear effusion.

RECDs have large, individual variability regardless of age; therefore use of average RECDs is not recommended. As a last resort, when an RECD cannot be measured, an age-appropriate average RECD may be used.

Using the RECD has many clinical benefits. It requires the child’s cooperation for only one measurement rather than multiple real-ear measurements.
After the child's RECD has been measured, all hearing aid response shaping to reach targets can be performed without the patient present. Using the RECD instead of multiple real-ear measures greatly reduces the degree of cooperation and length of time required from the child in the fitting process.

5. Choose your prescriptive formula. Both DSL and the NAL formulas use the measured RECD to produce gain and frequency response targets.

Selection

Selection of a hearing instrument can occur before or after measurement of the RECD. Verification of a hearing instrument and its gain/output characteristics is best achieved with probe-microphone and RECD measures using speech signals presented at multiple input levels. This allows the audiologist to evaluate the hearing aid and its performance across a range of listening levels.

During the selection process, appropriate circuitry and processing schemes should be determined based on the degree, configuration, and type of hearing loss, as well as on family and economic factors. Table 1 is adapted from the Minnesota Department of Health, Minnesota Newborn Hearing Screening Program, Recommended Protocol for Pediatric Amplification (2005).

Validation

Validation of aided auditory function must closely follow fitting and verification of amplification. Validation is an ongoing process that involves monitoring of the instrument itself as well as the child's performance with it. Both objective and subjective measures should be used.

Objective measures, such as speech-perception tests, are helpful in assessing the child's performance with amplification. Subjective questionnaires distributed to teachers and parents can also be used for validation. While functional gain measurement is not recommended for verifying the electroacoustic characteristics of the hearing aid, it can have a place in validation. Aided sound field thresholds can add important information and may be used in conjunction with real-ear measures to ensure that the child is receiving appropriate benefit.

Cochlear Implants: The Basics

Cochlear implants 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 then transmitted to the brain for interpretation. Cochlear implants bypass damaged or missing outer hair cells in the cochlea that would normally code sound.

All cochlear implants, regardless of manufacturer, have common components, but there are many variations in the methods used to process sounds, transmit information to the internal implant, and stimulate the electrodes. There are numerous and different electrode arrays available from each of the manufacturers.

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 pinna. This receives power and decodes instructions from the speech processor to control the electrical stimulation delivered to the electrodes in the cochlea. It receives stimulus information via FM radio waves from the external coil housed in the headpiece. This method of coupling is called a transcutaneous link.
Remote Microphone Technology

- FM systems should be considered when the child becomes older and more mobile and needs to listen from greater distances.
- FM technology is the system of choice to improve SNR (signal-to-noise ratio).
- Most hearing aid companies offer an FM-compatible boot for their hearing aids.

Directional microphones should be considered for older children to improve SNR when FM technology is not being used.

- Very young children need to hear environmental noise and distant speech from all directions to maximize language and speech development; therefore, directional microphones are not recommended for very young children.
- Tele-Coil (T) for telephone usage and microphone-telecoil (M-T) switching option and direct audio input (DAI).

The physical fit of the hearing aids and earmolds is important for both comfort and retention.

- Earmolds should be made of a soft material for safety and comfort.
- Earmolds should be replaced at least 3–4 times a year and whenever feedback is excessive at optimal settings or the fit becomes loose or comfort issues occur.

### Table 1
Recommended Protocol for Pediatric Amplification

<table>
<thead>
<tr>
<th>Flexibility</th>
<th>Safety Features</th>
<th>Behind-the-Ear Hearing Aids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility in setting the electroacoustic parameters of the hearing aid is essential.</td>
<td>Tamper-resistant battery compartment.</td>
<td>Behind-the-ear hearing aids are the style of choice for most children.</td>
</tr>
<tr>
<td>Advanced technology (digital and digitally programmable) hearing aids and the use of multiple channels should be considered when the audiometric configuration requires gain or output modifications in specific frequency regions.</td>
<td>Volume control covers or the ability to disable the volume control.</td>
<td>In-the-ear hearing aids are not generally recommended for infants and young children due to their small ear canal sizes and rapid growth of the outer ear.</td>
</tr>
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</table>

Binaural Amplification

- Binaural amplification should always be provided to young children with binaural hearing loss, unless there is a medical contraindication.
Electrode Array

An electrode array stimulates any residual auditory nerve fibers along the modiolus and in nVIII. Cochlear implant electrodes are designed for placement in the scala tympani of the cochlea (relatively close to the spiral ganglion cells), which is best for localized stimulation of the auditory nerve. 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 cochlea—neurons near the base of the cochlea (first turn) respond to high-frequency sounds, and neurons in the apex of the cochlea respond to low-frequency sounds.

Insertion of an electrode array must not cause excessive damage to the cochlea. 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. Manufacturers offer multiple electrode array designs, lengths, and features. All electrode arrays must have a ground electrode.

Multi-channel devices have up to 22 active electrodes. Research has indicated that the more electrodes, the better the speech perception. However, this is not a one-to-one relationship, as many individuals achieve very good speech perception without the use of all the electrodes in their array. Speech perception ability has also been shown to correlate positively with depth of electrode insertion. Placement closer to the modiolus provides better place coding of frequency and requires less current. Hearing thresholds are thought to be better when the electrodes are closer to spiral ganglion cells, which provides a more localized current flow. One way to get an electrode array to lie closer to the modiolus is for the array to be pre-curved; however, not all electrode arrays are pre-curved. A straight electrode array may cause trauma to the cochlea during insertion, but this is certainly not the case in all instances and depends heavily upon the skill of the surgeon. Insertion tools are used for appropriate placement of the electrode array.

Stimulating Electrodes

There are two electrode stimulation modes. Each has intricate processes that 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.

Monopolar. Monopolar stimulation indicates that each electrode is stimulated with reference to a ground electrode—remote from the cochlea. This remote electrode can be on the internal device or on the end of a silastic tube that 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 cochlear implant maps, because the amount of current required to elicit perceptible stimulation is less than in bipolar, which increases battery life.

Rate of Stimulation

The rate of stimulation defines the number of electrical current pulses per second that may be presented across the electrode array. Newer devices provide higher rates of stimulation. Higher rates improve the representation of temporal information by providing finer amplitude variations through finer control of the rate and population of nerves excited. However, research has also shown that faster rates do not correlate with better speech perception in all individuals.
External Components

Microphone. The microphone, which is typically housed in/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. 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 understanding speech in noisy situations. Directional microphones emphasize sounds in front of the microphone and suppress sounds emanating from other locations. All three manufacturers have multiple microphone options available to reduce wind noise, enhance localization, assist with speech understanding in background noise, and many more. All manufacturers have programs/features to allow the microphone(s) to be self-adjusting to the listener's environment.

Speech processor. The speech processor of a cochlear implant uses sound from the microphone to create a set of electrical stimuli for the electrodes. 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. This can vary by manufacturer, program, etc. The speech processor takes the electrical signal, which contains temporal and spatial patterns of stimulation, and transmits it via a cord to the headpiece.

Headpiece. The headpiece houses the external coil of the cochlear implant and is held in place over the internal receiver/stimulator (internal coil) with magnets. The headpiece transmits sound via FM radio waves to the internal receiver-stimulator, which decodes the signal and controls the electrical current in each electrode.

Creating a Map: The Basics

Two psychophysical measures are needed 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. Cs or Ms are maximum stimulation levels—the loudest sound that can be listened to comfortably for a sustained period of time. These two measures are desirable for each electrode, although some current cochlear implant software can allow for these measures (one or both) to be foregone. For children, methods of determining these levels are similar to those used for diagnostic audiology. For infants, very young children, or individuals who cannot respond behaviorally, telemetry may be used to assist in the creation of a map.

Telemetry

Telemetry is the exchange of information from the external components of the cochlear implant through a transcutaneous link (FM radio waves) to the internal
Critical information that must be conveyed to all potential recipients or their family is that a cochlear implant is a communication device not a cure for hearing loss.

components of the cochlear implant. Bidirectional exchange of information allows transmission of data from the implanted components to the external coil and speech processor. Telemetry can give information about the status of the implanted receiver, impedances of implanted electrodes, and voltages of unstimulated electrodes. It also offers the opportunity to record neural-evoked potentials by stimulating nerve fibers to cause compound action potentials. Voltage generated by an active electrode can be measured to help determine the state 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 cochlear implant is necessary.

Each cochlear implant manufacturer calls telemetry something different. Neural Response Telemetry (NRT) is the term used by Cochlear Americas Corporation (2011), Neural Response Imaging (NRI) is the term used by Advanced Bionics Corporation (2011), and Auditory Neural Response Telemetry (ANRT) is the term from MED-EL Corporation (2011). For purposes of this chapter, all will be referred to as telemetry.

With telemetry, compound action potentials of the nVIII can be generated, which is an indication of how much neural activity stimulation is being caused. This information can be used to estimate where threshold and comfort/maximum stimulation levels may be. Evoked compound action potentials (ECAPs) can give an objective and non-invasive 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 Ms/Cs, usually closer to the M/C levels.

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

Candidacy

Determination of candidacy for a cochlear implant requires assessing a person’s suitability based on many factors. Critical information that must be conveyed to all potential recipients or their family is that a cochlear implant is a communication device not a cure for hearing loss. Preoperative expectations largely shape postoperative satisfaction! Communication disorders, especially in children, require a multifaceted rehabilitation program. Processing, speech, language, cognition, and attention are among the areas that need to be addressed. Regardless of manufacturer, cochlear implant users overall perform equally well on measures of speech perception. For adults, three cochlear implant companies have come together to support and recommend a minimum speech test battery (MSTB; 2011). Table 2 shows these three manufacturers’ candidacy criteria.
Table 2
Manufacturers’ Cochlear Implant Candidacy Criteria

<table>
<thead>
<tr>
<th>MED-EL General</th>
<th>Cochlear Americas Corporation</th>
<th>Advanced Bionics Corporation</th>
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<tbody>
<tr>
<td><strong>Infants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 12 to 23 months</td>
<td>• Profound bilateral sensorineural hearing loss.</td>
<td>• 12 months through 17 years of age.</td>
</tr>
<tr>
<td>• No progress in auditory skill development with hearing aids and intervention.</td>
<td></td>
<td>• Profound, bilateral, sensorineural hearing loss (&gt;90 dBHL).</td>
</tr>
<tr>
<td>• &lt;30% open-set speech recognition.</td>
<td></td>
<td>• Limited or no benefit from appropriately fitted hearing aids.</td>
</tr>
<tr>
<td><strong>Children</strong></td>
<td></td>
<td><strong>Real-world experiences that might suggest the need for a cochlear implant evaluation. With hearing aids:</strong></td>
</tr>
<tr>
<td>• 2 to 17 years of age</td>
<td>• Pre- or post-linguistic onset of hearing loss.</td>
<td>• Delayed or lack of speech and language development.</td>
</tr>
<tr>
<td>• Severe-to-profound bilateral sensorineural hearing loss.</td>
<td>• &lt;30% open-set speech recognition.</td>
<td>• Rarely responds to name.</td>
</tr>
<tr>
<td>• &lt;30% open-set speech recognition.</td>
<td></td>
<td>• Lack of social interaction with children and adults.</td>
</tr>
<tr>
<td><strong>Adults</strong></td>
<td></td>
<td>• Emphasis on auditory development in child’s education or therapy environment.</td>
</tr>
<tr>
<td>• Moderate-to-profound bilateral sensorineural hearing loss.</td>
<td>• &lt;50% sentence recognition in ear to be implanted (aided).</td>
<td><strong>Adults</strong></td>
</tr>
<tr>
<td>• &lt;60% in contralateral ear and binaurally (aided).</td>
<td></td>
<td>• 18 years of age or older.</td>
</tr>
<tr>
<td><strong>Pediatrics</strong></td>
<td></td>
<td>• Severe-to-profound, bilateral, sensorineural hearing loss (&gt; 70 dBHL).</td>
</tr>
<tr>
<td>• 12 months through 17 years of age.</td>
<td>• Profound, bilateral, sensorineural hearing loss (&gt;90 dBHL).</td>
<td>• 50% or less on a test of open-set sentence recognition (HINT: Sentences).</td>
</tr>
<tr>
<td>• Limited or no benefit from appropriately fitted hearing aids.</td>
<td></td>
<td><strong>Real-world experiences that might suggest the need for a cochlear implant evaluation. With hearing aids:</strong></td>
</tr>
<tr>
<td><strong>Real-world experiences that might suggest the need for a cochlear implant evaluation. With hearing aids:</strong></td>
<td></td>
<td>• Cannot understand most phone conversations.</td>
</tr>
<tr>
<td>• Delayed or lack of speech and language development.</td>
<td></td>
<td>• Difficulty understanding conversations in groups or noisy places.</td>
</tr>
<tr>
<td>• Rarely responds to name.</td>
<td></td>
<td>• Rely heavily on lip-reading.</td>
</tr>
<tr>
<td>• Lack of social interaction with children and adults.</td>
<td></td>
<td>• Limited social, educational, or professional life options.</td>
</tr>
<tr>
<td>• Emphasis on auditory development in child’s education or therapy environment.</td>
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</table>

A cochlear implant is designed for:
- Children with profound sensorineural hearing loss in both ears. Age at implantation may be as young as 12 months, depending on individual circumstances and local practices.
- Adults with severe-to-profound sensorineural hearing loss in both ears.
- Individuals who receive little or no benefit from hearing aids.
- Individuals with access to education and rehabilitation follow-up programs.
The Role of Amplification in Cochlear Implant Candidacy for Children

All three of the manufacturers recommend use of an “appropriately fitted hearing aid” prior to implantation for infants and young children. Appropriately fitted is defined by aided word recognition performance. “Limited benefit” from hearing aids or a lack of progress in auditory skill development is one of the criteria used to determine candidacy. Speech perception tests and parent questionnaires are also used in cochlear implant candidacy assessment. Only one company recommends a specific length of time for a hearing aid trial. All companies agree that if a child is post-meningitic, the hearing aid trial, as well as speech perception testing, may be waived due to the threat of ossification.

While the manufacturer and U.S. Food and Drug Administration (FDA) candidacy guidelines were created (and are continually modified) to protect the patient from any unnecessary invasive procedures, they are not always followed closely in the real world. Research has demonstrated conclusively that the younger a child is implanted, the greater the chances of success in multiple areas, such as academics, self-esteem, speech perception and production, etc. Speech perception performance in cochlear implant users overall has exceeded any expectations the audiology profession ever had. Because of these demonstrated positive outcomes, pediatric audiologists may choose to recommend a cochlear implant before the hearing aid trial is completed. The exceptional performance cochlear implant users are exhibiting—particularly young children—creates a sense of urgency to implant the child with a severe-to-profound hearing loss while bypassing amplification.

Currently, the FDA is being petitioned to decrease the age of implantation from 12 months to 6 months of age.

Summary

Fitting hearing aids and/or cochlear implants on infants and young children is a vital function of being a pediatric audiologist. It is critical that all audiologists working with children have exceptional knowledge of both hearing aids and cochlear implants. Pediatric audiologists have a responsibility to ensure that all assistive devices are appropriately fitted and maintained. It must be the ultimate goal for each child to receive maximal benefit from their assistive technology (the best possible speech perception and production, academic success, emotional adjustment, social competence, and occupational preparation) and be equipped to lead a healthy, productive life.
References

Advanced Bionics Corporation Candidacy Criteria. (2011, November). Personal communication with M. Wait, Clinical Specialist, Southwest Region.


