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BILATERAL COCHLEAR IMPLANTS IN CHILDREN

by

Laurian J. Dicks

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A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
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Laurian J. Dicks

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Approved by:

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Introduction

In the past twenty years, the technology available for children with profound hearing loss has rapidly advanced. Children and their parents now have the opportunity to choose between a communication system that incorporates speech, both speech and sign, or sign only. A cochlear implant (CI) is a surgically implanted electronic device that provides children and adults who are deaf the ability to detect sound. Without access to auditory sensory information from birth (e.g., in the case of congenital deafness) normal neural-growth patterns do not occur to create a fully functional auditory sensory system (Sharma & Dorman, 2011). In the past, significant delays in language acquisition have been reported for children with profound sensorineural hearing loss, even with early hearing aid use and communication support (Nicholas & Geers, 2006; Sharma & Dorman, 2011).

Cochlear implants are the bridge for many children into the hearing world. The cochlear implant devices work differently than hearing aids. While hearing aids amplify all sounds in the environment, cochlear implants bypass the damaged portions of the ear and directly stimulate the auditory nerve (National Institute on Deafness and other Communication Disorders, 2011). Cochlear implants often provide the user with more access to the auditory signal and therefore, a better auditory experience than provided through hearing aids alone (Nicholas & Geers, 2007). However, not every child who is deaf is a good candidate for cochlear implantation, nor will every child who receives a cochlear implant attain significant benefits. Those children who have severe to profound sensorineural hearing loss who do not receive benefit from hearing aids and have best-ear aided pure-tone average thresholds poorer than 65dBHL are often considered good

candidates for at least one cochlear implant (Hsiao & Gfeller, 2012; Johnston, Duriex-Smith, Angus, O'Connor, & Fitzpatrick, 2009; Nicholas & Geers, 2007;). According to Nicholas and Geers (2007), 90% of families of children with deafness have no family history of deafness and want their children to communicate orally. Research supports that cochlear implantation early in the child's life increases the chances of the child developing age-appropriate spoken language (Ruggirello & Mayer, 2010; Litovsky, 2010).

Cochlear implants differ slightly, based on the manufacturer and on device specific variables such as the speech processor or number of stimulation channels provided. Once a decision is made to implant, parents must make a plethora of choices regarding many aspects of the implant. For example, they may be asked to decide on one of the many manufacturers who offer cochlear implants. They also must determine if they will pursue two cochlear implants (simultaneous bilateral), or one cochlear implant (unilateral) with the option of the child receiving a second implant later (sequential bilateral). Research is needed on a variety of issues related to implantation and how professionals and parents can positively impact the future development of children with cochlear implants. The following paper will discuss issues related to decision-making and include: central auditory system development, age of implantation, sequential bilateral cochlear implantation, simultaneous bilateral cochlear implantation, binaural hearing, bimodal hearing, music appreciation, and family environment.

Central Auditory System Development

Technology has greatly improved to identify children with hearing impairments earlier than ever before. Most states now require the screening of all infants for hearing impairment prior to hospital discharge. Children who do not pass the screening can now

undergo objective measures like auditory brainstem response (ABR), auditory steady-state response (ASSR), and otoacoustic emissions (OAEs), which can identify infants with profound sensorineural hearing loss shortly after birth (Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). In addition to new technology and screenings, the candidacy guidelines for age at implant have continued to change, resulting in a reduction in the average age of cochlear implant implantation in the United States (Nicholas & Geers, 2007). Many of the children now receiving cochlear implants are between 12 and 18 months of age (Tomblin et al., 2005).

Research has consistently shown a communication gap in oral language development between children who are deaf and children who have normal hearing. According to Houston, Stewart, Moberly, Hollich, and Miyamoto (2012), infants with hearing loss experience a period of degraded auditory access to linguistic interactions. This lack of opportunity to actively participate in social linguistic interactions is likely to impact language acquisition and communicative competence (Houston et al., 2012). Many researchers have identified a “sensitive period” of central auditory system development from birth to toddlerhood in children with and without hearing loss (Nicholas & Geers, 2007; Sharma & Dorman, 2011). Findings indicate that early implantation can reduce the amount of time the child is without auditory stimulation. In a study performed by Tomblin, et al. (2005), researchers found that delaying implantation negatively impacted the increasing gap of oral language development between children who are deaf and their normal-hearing peers. Sharma, Dorman, and Kral (2005) found that children who were born with sensorineural hearing loss and received a unilateral cochlear implant activated before 42 months had auditory evoked P1 response latencies that were almost identical to

those of children with normal hearing. However, when children were born with sensorineural hearing loss and received a unilateral cochlear implant after the age of 84 months, their auditory evoked P1 response latencies were “significantly longer than those of their normal-hearing peers” (Sharma et al., 2005, p.135).

Connor, Craig, Raudenbush, Heavner, and Zwolan (2006) identified children who received unilateral cochlear implants at younger ages and showed an early burst of growth immediately after implantation, which was not seen in older children who were implanted. Thus it seems access to auditory stimulation early on allows for children to take advantage of this sensitive period and generally outperform those who are implanted after the sensitive period (Sharma & Dorman, 2011). It is important to note that there is still significant variability in P1 development in children who were implanted within the sensitive period (Sharma & Dorman, 2011).

Age of Implantation

Earlier ages of implantation are shown to be a significant predictor of age-appropriate language skills. Ruggirello and Mayer (2010) researched fraternal twins, one with normal hearing and one with profound sensorineural hearing loss who was bilaterally implanted at 12 months of age. The researchers found exciting consequences for the early bilateral cochlear implantation. At 33 months of age, the twins were given the Preschool Language Scale-4 (PLS-4; Zimmerman, Steiner, & Pond, 2002), which is a standardized test of expressive communication and auditory comprehension (Ruggirello & Mayer, 2010). Results from the PLS-4 showed that the twin with bilateral cochlear implants scored 4 months above normal hearing peers in expressive language and ten months above in auditory comprehension score when compared to age-appropriate norms (Ruggirello

& Mayer, 2010). Although this case study needs replication on a larger scale, the research indicates that the gap between deaf and normal hearing children is reduced if activation of the cochlear implant is achieved early in the child's life (Ruggirello & Mayer, 2010).

In a study of 29 children with cochlear implants, researchers found that earlier implantation positively affected the growth of expressive language and that growth curve analysis showed that children implanted early (12 months of age or less) showed more expressive language growth than children who were implanted as toddlers. (Tomblin et al., 2005).

In general, the majority of research indicates that cochlear implantation at young ages enables oral language development. Children who experience prolonged periods without auditory input exhibit delays in oral language development (Nicholas & Geers, 2006). The degree of language development after cochlear implantation is variable and dependent on many factors, such as length of auditory deprivation, age of onset of deafness, and the chronological age of the child when implanted (Ruggirello & Mayer, 2010).

Sequential Bilateral Cochlear Implantation

Until about ten years ago, cochlear implant candidates were only implanted with one device. Since that time, many children implanted with one device have had surgeries to receive a sequential implant (Shafir, 2007). When pediatric sequential implantation was initially performed in the United States, the children were typically between the ages of five to twelve years and were already successful unilateral cochlear implant users (Litovsky, 2010). While a unilateral cochlear implant provides access to auditory information, bilateral cochlear implants users may receive expanded ability to experience spatial

hearing (e.g., localization; Litovsky, 2010). Therefore, many unilateral cochlear implant users are interested in the potential benefits of a second implant (Dunn, Tyler, Witt, Ji & Gantz, 2012).

A strong case is made in the literature for the benefit of bilateral cochlear implantation. In a study by Mather, Gregory, and Archbold (2011), 15 young people between the ages of 10 and 18 years received sequential bilateral implants. All 15 participants reported improvements in listening ability. The participants also reported that they would recommend sequential bilateral implants to their peers (Mather et al., 2011). Galvin, Mok, Dowell, and Briggs (2008) examined parental observation and the performance of 10 sequentially implanted children before and after their second implant. Parents reported that their children improved in ability to localize and communicate in noise. In addition, parents reported an increase in coping skills, sound awareness, and number of vocalizations. Some parents also reported that they felt more comfortable with two implants because in case of battery failure, the child still has access to auditory stimuli. In a study by Galvin, Hughes, and Mok (2010), researchers examined the amount of benefit adolescents (aged 11 to 20 years) acquired from gaining a second cochlear implant. Scores from the nine participants on the Speech, Spatial, and Qualities of Hearing Scale (SSQ) indicated performance on “everyday listening situations” and “spatial hearing” improved after 12 months of bilateral implant use. In a study by Steffens et al. (2008), researchers reported that sequential bilateral cochlear implant users gained high degrees of binaural advantage for speech recognition in noise and lateralization tasks. These researchers suggested that a majority of unilaterally implanted children are candidates for a second implant, if they received their first implant before their fourth birthday and are currently

less than 10 years of age. While there have been many positive findings surrounding sequential implantation, there is a group of children who received a second cochlear implant who do not utilize the second implant in their daily life due to a host of factors. This group of children has difficulty incorporating the signals from the two implants into one coherent signal. Most often, there are differences between the child's first and second cochlear implant because cochlear implant technology rapidly evolves. These differences are speculated as one reason for some children having difficulty incorporating the two signals into one coherent signal. Technological differences between the devices include different signal processing strategies, different internal arrays, and different number of channels available (Dunn et al., 2012).

Research supports the idea that children with sequential bilateral cochlear implants receive the best possible results when they are implanted at earlier ages with shorter gaps between surgeries because of changes that occur in the central auditory system (Johnston et al., 2009). While many children gain benefit from sequential bilateral implants, in terms of localization and understanding speech in noise, a new trend (simultaneous cochlear implantation) is emerging as an option.

Simultaneous Bilateral Cochlear Implantation

Research suggests benefits of a child receiving simultaneous bilateral implants includes increased awareness of environmental sounds, increased auditory brainstem and cortical evoked potential responses, increased performance on speech recognition in noise and sound localization tasks, and reduction/prevention of auditory deprivation due to bilateral stimulation (Johnston et al., 2009; Ruggirello & Mayer, 2010). The increase in performance with simultaneous bilateral implantation is thought to be related to binaural

benefits such as the head shadow effect, binaural squelch effect, and binaural redundancy. The head shadow effect can be explained as the ability of a listener to gain the best signal-to-noise ratio (SNR) based on the physical placement of the two implants on the head (Firszt, Reeder, & Skinner, 2008). The binaural squelch effect can be explained as the listener's central auditory system analyzing interaural timing differences (ITDs) and interaural level differences (ILDs) between the two ears (Firszt et al., 2008). As the child perceives binaural information, there is redundancy in the auditory signal, which allows the child to more accurately detect subtle changes in frequency or intensity of the signal (Firszt et al., 2008). All of the above benefits, except for the head shadow effect, require the two implants to work together, commonly called binaural integration in the central auditory system (Firszt et al., 2008). Although research supports simultaneous bilateral cochlear implantation to achieve these benefits, there are risks which need to be weighed against the potential benefits. Limitations of simultaneous bilateral cochlear implantation include facial nerve paralysis, damage to the vestibular system, and surgical risks associated with anesthetics (Johnston et al., 2009).

Binaural Hearing

An important benefit of bilateral cochlear implantation is the ability to gain binaural hearing. Binaural hearing supports listeners in real-life listening situations, such as noisy classrooms or restaurants when a listener must filter background noise as well gain information from the speaker (Firszt et al., 2008; Galvin et al., 2010; Litovsky, 2010; Steffens et al., 2008). The ability to localize sound is also important for safety reasons (Firszt et al., 2008). The benefit of bilateral cochlear implant use over unilateral cochlear implant use on speech perception in noise and localization tasks has been demonstrated in

multiple studies (Dunn et al., 2012; Firszt et al., 2008; Litovsky, 2010). Studies investigating sound localization are based on a testing design in which subjects sit in a booth with a horizontal arc of loudspeakers positioned around them. Researchers determine the localization error, or the smallest angle from the midline that the subject can reliably discriminate the minimum audible angle (Godar & Litovsky, 2010). Subjects with normal hearing display localization errors of 5-10 degrees. Subjects with a unilateral cochlear implant tend to have much higher errors, ranging from 50-60 degrees (Litovsky, 2010). If a subject has a bilateral cochlear implant as well as experience with the implant, the localization errors drop to between 20-30 degrees—a 20-40 degree improvement from subjects with unilateral implants (Litovsky, 2010). In 2010, Godar and Litovsky followed ten elementary age children as they transitioned from one cochlear implant to two cochlear implants. At baseline, the children's minimum audible angle was 44.8 degrees. Three months after bilateral activation, the groups mean minimum audible angle improved to 20.4 degrees. Finally, after one year of bilateral experience, the group's minimum audible angle was 16.8 degrees (Godar & Litovsky 2010). Clearly, bilateral cochlear implants can aid children in sound localization tasks, even if they receive their second during elementary school. It is important to note that the decrease in degrees of error over time can be partially explained by users gaining experience. Experience is important with bilateral implants as the auditory system reorganizes and refines spatial listening skills (Dunn et al., 2012; Godar & Litovsky, 2010; Shafer, 2007).

Bimodal Hearing

It has been demonstrated that bilateral cochlear implant users gain higher scores in localization and speech in noise tasks over unilateral users; however, some of the same

gains are found when unilateral cochlear implant users wear a hearing aid in the opposite ear. The use of a unilateral cochlear implant and a hearing aid in the opposite ear is referred to as bimodal listening. Research supports the continued use of a hearing aid after a child gains a unilateral cochlear implant. Ching, Incerti, and Hill (2004) conducted a study of 21 adults to investigate the benefit of using a hearing aid in the non-implanted ear for a cochlear implant user. Participants were unilaterally implanted and were evaluated in the areas of functional performance, speech perception, and horizontal localization. All study participants performed significantly better on the speech perception and localization tasks when using both the cochlear implant and hearing aid together instead of just the cochlear implant or hearing aid alone. In addition, scores on functional performance questionnaires were higher scores when using both the cochlear implant and the hearing aid than when using just the hearing aid or cochlear implant alone. In a separate study of 18 adults, Firszt et al., (2008) found that wearing a hearing aid in the contralateral ear in addition to a cochlear implant gave the user significant binaural improvements in localization, speech in noise tasks, and functional capabilities in everyday life over using just the cochlear implant. By keeping amplification in the non-implanted ear, the user is utilizing bimodal listening and avoiding asymmetrical auditory deprivation (Firszt, Reeder, & Skinner, 2008). While in the past, it was unclear how much benefit the cochlear implant user would gain from utilizing a contralateral hearing aid, the current research clearly demonstrates listener benefit. In fact, it is recommended that hearing aid use in the non-implanted ear be the standard applied in the rehabilitation of unilateral cochlear implant users (Ching et al., 2004; Firszt et al., 2008).

Music Appreciation and Cochlear Implants

While children with cochlear implants are able to gain access to auditory stimuli, they often struggle with the fine differences in language, such as pitch and timbre (Hsiao & Gfeller, 2011). Cochlear implants are unable to give listeners the same experience as a normal hearing listener when it relates to the fine variances in auditory information. Because children with cochlear implants hear auditory stimuli differently than children with hearing aids, it is important to note that music perception will also be different for these two groups (Hsiao & Gfeller, 2012). For example, the cochlear implant is often unable to transmit fundamental frequencies below middle C (i.e., 250 Hz), thus making pitch identification a problem (Hsiao & Gfeller, 2011). It is also critical to remember that expectations of benefit differ significantly for those who experience post-lingual deafness versus those that experience congenital deafness (Hsiao & Gfeller, 2012). Those with congenital deafness may not have a strong representation of high and low pitched sounds (Hsiao & Gfeller, 2012). While we know that many cochlear implant users can be successful in mainstream classrooms, there is less information on the expectations or modifications necessary for children with cochlear implants when it relates to music, such as music class or music lessons. Children with cochlear implants may be unable to attain the correct pitch when matching to a song due to the cochlear implant being unable to adequately represent the sound (Hsiao & Gfeller, 2011). However, many young children with normal hearing also have difficulty producing the correct pitch. With instructor modification (to reduce embarrassment), there are many benefits of singing out loud for children with cochlear implants (Hsiao & Gfeller, 2012). Signing melody and song lyrics provides the child with the ability to practice skills that are helpful for speech and listening. These skills include practicing duration and stress (i.e., the suprasegmental features),

their family also “had children with smaller vocabularies” (Holt et al., 2012, p. 848). This finding, coupled with future research could help families enhance their current environments to promote the child’s potential (Holt et al., 2012).

Family Environment

While much of language performance can be explained by known factors to increase proficiency, such as cochlear implant experience and early implantation, not all children gain equal benefit from early implantation, due to a host of other factors, which influence language growth. (Geers & Nicholas, 2012). These factors include, but are not limited to, family support, socioeconomic status, maternal influence, and family structure (Holt, Beer, Kronenberger, Pisoni, & Lalonde, 2012). Children from higher socio-economic status families may be more likely to gain access to medical treatment and be implanted earlier, which could positively impact later performance on language measures (Geers & Nicholas, 2012).

In a recent study, 45 families of children with cochlear implants completed a family environment questionnaire (Family Environment Scale- Fourth Edition; Moos & Moos, 2009) in addition to the PPVT (Dunn & Dunn, 2007), CELF (Semel, Wiig, & Secord, 2003), and PLS-4 (Zimmerman, Steiner, & Pond, 2002). Researchers found that family environment influenced the language outcomes of those who received at least one cochlear implant (Holt et al., 2012). Researchers found that families who reported a “higher emphasis on organization had children with fewer problems related to inhibition” (Holt et al., 2012, p. 848). Interestingly, families who self-reported higher emphasis on control in their family also “had children with smaller vocabularies” (Holt et al., 2012, p. 848). This

finding, coupled with future research could help families enhance their current environments to promote the child's potential (Holt et al, 2012).

Conclusion

As technology continues to change and researchers understand more about the central auditory system, recommendations for cochlear implantation will no doubt shift. Current research supports that children with congenital deafness are able to gain benefit from cochlear implants, increasing their expressive language (Nicholas & Geers, 2011). While research has shown great benefit from the implantation of young deaf children (under 36 months) in attaining normal or near normal age-appropriate language skills, some of these children are unilaterally implanted and their parents are wondering if they too could gain benefit from a second cochlear implant (Tomblin et al., 2004 ; Sharma & Dorman, 2011). Research supports benefit from binaural hearing, regardless of how it is achieved. More research is needed to determine if the benefits of bilateral implantation outweigh those achieved by early unilateral implantation and hearing aid use in the opposite ear. Nonetheless, the cochlear implant is not able to convey all the small subtleties of sound and thus these children will need accommodations to gain the most benefit from implantation (Hsiao & Gfeller, 2012).

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