The Effect of Early Cochlear Implantation on Oral Language: A Review of the Literature

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The Effect of Early Cochlear Implantation on Oral Language: A Review of the Literature

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Current research suggests that implantation of cochlear implants before 2 years of age significantly impacts oral language development, specifically in increased rate of oral language development (Holt & Svirsky, 2008; Kirk, Miyamoto, Lento et al., 2002; Kirk, Miyamoto, Ying, Perdew, Zuganelis, 2002; Tomblin, Barker, Spencer, Zhang, Gantz, 2005). In addition, children who have been implanted early (between 12 months and 2 years of age) have been shown to obtain age-appropriate language skills, whereas children who have been implanted later (after 2 years of age), or not implanted at all, do not (Hammes et al., 2002; Nicholas & Geers, 2007; Svirsky, Robbins, Kirk, Pisoni, Miyamoto, 2000). Because of the documented benefits of early implantation, researchers have recently pushed to lower the current minimum age of implantation to below 12 months of age. Although research suggests improvements in language development with early implantation, surgery at such a young age is considered to be risky and controversial (Holt & Svirsky, 2008; Waltzman & Roland, 2005).

The Cochlear Implant

A cochlear implant is a prosthetic device that provides electrical stimulation to the auditory nerve, bypassing the hair cells in the cochlea. The implant has an external component and an implanted component. The external portion has three parts: a microphone, speech processor, and a transmitter. The receiver is implanted just under the skin behind the ear and the electrode is implanted inside the cochlea itself (Advanced Bionics, 2008; Laurent Clerc National Deaf Education Center, 2007). The external microphone picks up sound from the environment. The speech processor selects and arranges sounds picked up by the microphone to be coded into digital instructions to send to the transmitter. The transmitter sends this code through the skin to the implanted portion, which contains a receiver. The implant uses the digital code to send
electrical impulses to the appropriate electrodes within the cochlea to directly stimulate the auditory nerve. The National Institute on Deafness and Other Communication Disorders (NIDCD) explains that cochlear implants are different from hearing aids in that the latter amplify sound for people with damaged ears. The cochlear implant, however, bypasses the entire damaged portion, usually the sensorineural pathway, of the ear and directly stimulates the auditory nerve (2008).

The NIDCD (2008) reports that people with cochlear implants do not hear like people with normal hearing. In normal hearing, sound travels through the middle ear by vibrating the tympanic membrane (ear drum), which then sets the malleus, incus, and stapes into vibration. The stapes sits on the oval window of the middle ear, which is the pathway into the inner ear. The movement of the stapes footplate in the oval window causes a disturbance in the fluid of the cochlea. This disturbance causes tiny hair cells to move back and forth, allowing electrical impulses to be sent to the auditory portion of the auditory nerve. The auditory nerve then sends these impulses to the brain, where the signal is interpreted as sound (Advanced Bionics, 2008).

In cases of profound sensorineural hearing loss very few hair cells remain in the inner ear, and hearing aids may not provide sufficient amplification or too few hair cells exist to provide information to the auditory nerve. In this case there is no problem with the outer or middle ear, known as the conductive pathway, and often no damage to the auditory nerve itself; it is the link between the conductive pathway and the auditory nerve that interrupts normal hearing. A cochlear implant can overcome the effect of this damage on hearing, to some extent, by conducting the sound straight from the environment to the auditory nerve (Advanced Bionics, 2008).
In the “normal” ear, the basilar membrane, located inside the cochlea, is responsible for coding the incoming acoustic information. High frequency sounds send traveling waves in the fluids of the cochlea that cause the greatest amplitude of vibration of the basilar membrane at its base. Low frequency sounds create traveling waves with the greatest amplitude at the apex of the basilar membrane (Loizou, 1998). In a multi-channel cochlear implant, an electrode array is inserted into the scala media of the cochlea. The speech processor analyzes the frequencies of the speech signal and sends the information to an electrode responsible for a specific frequency band. Although this allows for different frequencies to be heard and interpreted, there are a limited number of electrodes that can be inserted; thus, cochlear implants are only able to decode a small number of frequencies (Loizou, 1998). It is for this reason that it is said that people with cochlear implants do not hear like normal-hearing individuals (NIDCD, 2008).

The current criteria for eligibility for cochlear implantation include people at least 12 months of age, with bilateral severe to profound hearing loss who receive no benefit from traditional amplification (NIDCD, 2008). A trial period with hearing aids is required before cochlear implantation, to ensure that there will be no benefit on speech and language from traditional amplification (Integris Health Inc., n.d.). The American Speech-Language-Hearing Association (2008) adds that children who are candidates for cochlear implantation must have no medical conditions that would make surgery risky, and must have support from their educational program. These children must also be willing to be involved in intensive rehabilitation programs.

**Implantation Surgery**

Recently researchers have encouraged that eligibility for implantation be lowered to below one year of age, because of the perceived benefits to language and speech development from auditory stimulation. The critical period for language learning continues until seven years
of age (Waltzman & Roland, 2005). After age seven, most of the tools for communicative competencies are in place, and language and communication learning are more difficult to accomplish (Waltzman & Roland, 2005). Research has revealed that the developing auditory system demonstrates plasticity, which decreases with age. Also, myelination of neurons, which occurs early in life, allows for neural connections to develop. Both of these factors influence development of learning and memory (Dettmen, Pinder, Brigss, Dowell, & Leigh, 2007). If the child receives little to no auditory stimulation early in life, the auditory system will not mature fully and complete myelination of neurons may not occur. Dettmen et al. say, “the earlier that a child receives a cochlear implant, the greater is the child’s potential to benefit from these critical periods of neural development” (2007, p. 11s).

Although it seems essential for deaf children to be implanted earlier to take advantage of neural plasticity and neural development, surgery for children younger than one year carries some serious risks. Children younger than one year who undergo surgery are at greater risk for anesthetic complications, and the risk of cardiac arrest during surgery due to anesthesia increases with decreasing age (Dettmen et al., 2007; Holt & Svirsky, 2008). Research from the Pediatric Perioperative Cardiac Arrest Registry showed that of all cardiac arrests (238 pediatric cases were claimed), 55 percent occurred in children younger than 12 months and 43 percent in children younger than 5 months of age (Dettmen et al., 2007, p. 12s). Increased risk of respiratory failure in young children can also be attributed to anesthesia, especially if there are other medical conditions present (Waltzman & Roland, 2005). In addition to anesthetic complications, total blood volume is lower in young children than in older children and adults; therefore, special care during surgery needs to be taken so that blood loss is kept to a minimum (Waltzman & Roland, 2005).
The risks associated with surgery in infants can be reduced when considering surgery for cochlear implantation. It is known that the risk of complications increases in cases of emergency surgery, particularly when a pediatric anesthesiologist is not available. Cochlear implantation is a scheduled surgery, and would almost never be considered an emergency (Holt & Svirsky, 2008); the use of nonpediatric anesthesiologists in surgeries of young children is usually found in cases of emergency procedures. Research has shown that the use of a pediatric anesthesiologist greatly reduces the chances of anesthesia-related complications (Holt & Svirsky, 2008; Waltzman & Roland, 2005). Holt and Svirsky state findings by Keenan et al. reporting the following:

The incidence of anesthesia-induced cardiac arrest in infants younger than 1 yr over a 70-yr period was 19.7 per 10,000 anesthetic procedures when a nonpediatric anesthesiologist was present, whereas no incidences were reported when a pediatric anesthesiologist was present (2008, p. 496).

Lastly, the risk of respiratory arrest increases when there are other medical conditions present, but most of the children undergoing cochlear implantation are considered healthy or have a mild systemic disease such as mild diabetes (Holt & Svirsky, 2008). Generally good health greatly reduces the risks involved in surgery in children younger than 12 months of age.

**Language Development and Cochlear Implantation**

Earlier cochlear implantation has many perceived benefits for children with hearing loss; one is that children implanted earlier have more rapid oral language development because they begin with a smaller delay in language. In one study, conducted by Svirsky, Robbins, Kirk, Pisoni, and Miyamoto (2000), language development of children with profound hearing loss was examined before and after cochlear implantation using the Reynell Developmental Language Scale, which assesses language structure, vocabulary, and language content, as well as receptive
ability. This test involves many tasks varying in length and complexity, which reflect real-world communication compared to other tests that only examine single-word vocabulary skills (Kirk et al., 2002). Svirsky et. al (2000) examined twenty-three children at 6, 12, 18, 24, and 30 months post-implant. The data generated in the study were compared to normative data of 1,319 children with normal hearing. The results of this study showed that there was a significant difference between expected language development for children with hearing loss and the observed development in the children who had cochlear implants (Svirsky et al., 2000). The researchers found that “the observed scores exceeded the predicted scores by a larger amount with each successive interval” (Svirsky et al., 2000, p. 155). The predicted scores were based on the data from a previous study (Svirsky, in press), generated from deaf children who were not implanted. This suggests that as the children aged, the difference between the predicted score and the observed score increased, and the difference between the language performance of the children with hearing loss and those with normal hearing loss decreased over time. Also, if language scores increase at successive intervals, the earlier a child is implanted, the more likely the child will obtain age-appropriate levels by the time they reach school-age. The researchers additionally noted that children with hearing loss begin with a language delay with respect to normal hearing children, and use of the implant stopped this delay from increasing over time. The data suggest, “earlier implantation in deaf children would result in smaller delays in language development” (Svirsky et al., 2000, p. 156).

A study conducted by Kirk, Miyamoto, Ying, Perdew, and Zunganelis (2002) examined the language delay of children with hearing loss. One hundred and six participants were included in the study. All of the children were prelingually deafened, with severe-to-profound hearing loss. The Reynell Developmental Language Scales was used to assess expressive language
development of the participants. The study examined age at implantation and length of implant use as dependent variables. The results showed that increased use of the implant dramatically improved oral language abilities (Kirk, Miyamoto, Ying et al. 2002, p. 137). The longer the child used the cochlear implant, the more advanced the language skills. Additionally, the results showed that “children who were implanted prior to 2 years of age had the highest expressive language quotient at baseline and at subsequent test intervals” (Kirk, Miyamoto, Ying et al., 2002, p. 137). The children who were implanted earlier showed more advanced expressive language skills compared to those implanted later. These results also support the hypothesis that the earlier the children are implanted, the smaller the gap between language age and chronological age (Kirk, Miyamoto, Ying et al., 2002, p. 141). The researchers reported that earlier implantation minimized the initial delay in oral language and promoted age-appropriate language skills. These results are consistent with the findings of Svirsky et al. (2000).

In addition to reducing and/or stopping the delay in language development, cochlear implants can alter the rate at which children with hearing loss develop oral language. Children with hearing loss who are not implanted acquire language, but at a very slow rate, with language growth due primarily to maturation (Miyamoto, Svirsky, and Robbins 1997). A study conducted by Miyamoto et al. (1997), examined the difference between language development of children with hearing loss who have been implanted and those who have not been implanted. Eighty-nine children who were suitable candidates for cochlear implants, but had not received them, were used as the subjects, as were twenty-three children who had received implants at an average age of 50 months. The groups of children in this study were assessed using the Reynell Developmental Language Scales. The results showed that the profoundly deaf children who had not been implanted acquired language at less than half the rate of hearing peers, with about 5
months of oral language growth in 1 year (Miyamoto et al., 1997, p. 155). The implanted children acquired language at a much faster rate than what was expected from maturation alone (Miyamoto et al., 1997, p. 156). The children who were implanted began language development with a substantial delay in comparison to hearing peers initially, but then began to develop language at about the same rate as hearing peers after implantation, with 1 year of language growth in one year’s time (Miyamoto et al., 1997). These researchers additionally found that there was no plateau in oral language learning for the implanted group. Although the implanted children were still significantly behind their hearing peers in oral language development, they were developing language at a similar rate (Miyamoto et al., 1997, p. 156).

A study conducted by Tomblin, Barker, Spencer, Zhang, and Gantz (2005) examined how age at implantation can affect the rate of language growth and development. The researchers noted that early implantation capitalizes on the concepts of sensitive periods and neural plasticity. Early auditory stimulation through the use of cochlear implants allows for children to take advantage of the sensitive period where the brain shows maximal plasticity, and also allows for auditory pathways to develop normally. Tomblin et al. (2005) hypothesized that age at initial stimulation can affect the rate at which oral language develops. Twenty-nine children with profound, bilateral hearing loss were examined in this study. The average age of implantation was 21 months, 6 days. Language measures included a parental response inventory and the Preschool Language Scale-3, a test which assesses expressive language development by examining vocal development, social communication, semantics, structure, and integrative thinking skills. The results showed that although the language levels of children with cochlear implants lagged behind those of normal peers, the scores of the implanted children were significantly better than those reported by Svirksy et al. (2000) for children with hearing loss.
without implants (Tomblin et al., 2005). Researchers found a negative correlation coefficient of -0.67 at 24 month post-implant between age of implantation and expressive language quotient. This suggests that the younger children were implanted with cochlear implants, the higher the expressive and receptive language abilities the children attained (Tomblin et al., 2005).

Additionally, the “relationship between rate of language growth and age at initial stimulation increased as age at initial stimulation decreased” (Tomblin et al., 2005, p. 863).

Kirk, Miyamoto, Lento et al. (2002) found results similar to those of Tomblin et al. (2005), supporting that age at implantation affects rate of language development. Seventy-three children with prelingual severe to profound hearing loss with implantation before five years of age, were subjects. The children were separated into two groups, depending on communication mode: oral communication or total communication. Within each communication mode group, children were separated into groups based on age at implantation: those implanted before three years of age and those implanted after three years of age. The Reynell Developmental Language Scales was used to assess oral language development. In both groups, children who were implanted before three years of age developed expressive language skills faster than those with later implantation (Kirk, Miyamoto, Lento et al., 2002). In addition, children who used oral communication developed oral language faster than those who used total communication (Kirk, Miyamoto, Lento et al., 2002).

Nicholas and Geers (2007) studied how age at implantation affects oral language development, as well as how length of implant use and pre-implant aided hearing affect language development. Children at 3.5 years of age and 4.5 years of age were examined. Twelve children with normal hearing were used as the reference group. Seventy-six children who had been implanted between their first and third birthdays were used as the test group. All children were in
the average range on a nonverbal intelligence test. Language samples were obtained through a videotaped 30-minute play session with the parent, taken twice for each child, one at 3.5 years and one at 4.5 years. The language samples were measured and compared for total number of words, number of different word roots, number of bound morphemes, number of different bound morphemes, and mean length of utterance. The researchers found the following:

Expected scores of children who received an implant at 12-18 months of age were consistently higher than those of children who received an implant at older ages, even with the same duration [of cochlear implant use]. However, almost-identical expected language performance was predicted for any given duration of use when children received an implant at 24 months of age or later (Nicholas & Geers, 2007, p. 1059).

Age at implantation plays a larger factor in language development than length of device use (Nicholas & Geers, 2007). However, Nicholas and Geers found that age at implantation does not play a significant role in rate of language growth. The rate of language growth was the same regardless of implant age in their study (2007).

Because of the perceived benefits of early implantation, researchers have advocated lowering the age at implantation to below 12 months of age. One of the main benefits of implanting early is that it "ensures that the child receives the maximum amount of auditory information during this critical period, thus reducing the effects of auditory deprivation" (Colletti et al., 2005, p. 445). Colletti et al. (2005) examined the effects of implanting before the age of 12 months in ten children. The ages of the children at time of implantation ranged from 4 to 11 months, with a mean age of 9.5 months. Because the children examined were too young to be assessed for language, babbling was assessed to examine the onset of speech production, which
is an important precursor to expressive language development. The onset of babbling in the test group was compared with a group of 10 normal-hearing peers. The researchers found that at later follow-ups (12-24 months), the children who had been implanted later showed a less rapid increase in performance. Additionally, "when comparing children implanted during the first year of life with those implanted between 12 and 36 months, there is approximately a delay of 1 year in reaching the same performance level" in the 12 to 36 month implant group (Colletti et al., 2005, p. 447). Babbling began shortly (within 3 months of activation) for all children implanted, irrespective of age at implantation. The children who were implanted between 5 to 6 months had an average onset of babbling at age of 7 to 8 months. However, the children who were implanted between 10 to 11 months did not start babbling until one year of age, which is a slight delay compared to normal hearing peers (Colletti et al., 2005). Because of the perceived risks of surgery below 12 months of age, problems with surgery and recovery were examined; however, no complications were seen in surgery and the speech and language outcomes were positive. The results of this study demonstrate that the benefits of implantation before 12 months may outweigh the risks.

A study conducted by Dettman, Pinder, Briggs, Dowell, and Leigh (2007) found similar results to those of Colletti et al. (2005) regarding rate of language growth. One-hundred-six children participated in this study; all had received implants before the age of 24 months. The subjects were divided into two groups. Group 1 comprised 19 children who received implants before the age of 12 months, with a mean implantation age of 0.88 years. Group 2 consisted of 87 toddlers who had a mean implantation age of 1.6 years. The Rhode Island Test of Language Structure was used to assess language, specifically aspects of preverbal and verbal interaction including pragmatics, attachment, play, gesture, and 93 language expression milestones. The
researchers found the rate of language growth for Group 1 was significantly better than the rate of growth for Group 2 (Dettman et al., 2007). In addition, the poorest growth rate in Group 1 was equivalent to the average Group 2 growth rate (Dettman et al., 2007). Again, as in Colletti and colleagues’ study, no surgical complications were seen in those implanted before 12 months of age. The results from these two studies show that the language and developmental benefits of implantation before 12 months outweigh the risks.

One study conducted by Hammes et al. (2002) examined how children who are implanted early (before 30 months of age) attain age-appropriate skills, looking at maturation of the auditory pathway and the critical age of spoken language development. The study hypothesized that the auditory stimulation provided by a cochlear implant in infancy allows for normal maturation of the auditory pathways. Forty-seven children implanted between the ages of 9 and 48 months were included in this retrospective analysis. Several language measures were used in this study, depending on the child’s age, attention span, and overall ability levels. These measures included the Skills for Hearing Impaired Children, Preschool Language Scales-3, Clinical Evaluation of Language Fundamentals P or III, and the Oral and Written Language Scales. The results of this study showed that although most children showed an initial delay in language ability, the majority of the infants demonstrated a language-learning rate similar to peers with normal hearing following cochlear implantation. Hammes et al. (2002) found the following:

Four of the 10 children who underwent implantation between 9 and 18 months of age had acquired spoken language skills within 6 months of their chronological age. Only 1 of 13 children who underwent implantation between 19 and 30
months of age met this standard, and none of the children who underwent
implantation after 30 months of age achieved this level of performance (p. 76).

One of the likely factors the researchers site for this significant increase in language skills for the
early implanted group is that early auditory stimulation results in more normal development of
the auditory pathways. These infants benefit from the critical periods of neural development that
are essential for development of oral language (Hammes et al., 2002, p. 77).

Two studies have found that although there is a small benefit to implanting before 12
months, it is not significant enough to lower the age of implantation (Holt & Svirsky, 2008;
examined 96 children, divided into four groups based on age at implantation. Group 1 (n = 6)
was implanted between 6 and 12 months of age, Group 2 (n = 32) was implanted between 13 and
24 months, Group 3 (n = 37) was implanted between 25 and 36 months, and Group 4 (n = 21)
was implanted between 37 and 48 months. Children were examined using the Reynell
Development Language Scales. Children were measured both pre-implantation and at six-month
intervals after initial stimulation. The results showed that although most of the children were
delayed in language skills regardless of implant age, “...there was a trend for more children in
the younger age-at-implantation groups to perform within 2 SDs of the mean of normal-hearing
children than for children in the older age-at-implantation groups” (Holt & Svirsky, 2008, p.
505). However, there was no significant difference between Group 1 and Group 2 compared to
the difference in scores between Group 2 and Group 3. This suggests no large advantage to
implanting before 12 months of age (Holt & Svirsky, 2008).

Miyamoto et al. (2008) also examined oral language development for children implanted
under 12 months of age. Children were separated into three groups. Eight children were
implanted under 12 months of age, thirty-eight children were implanted between 12 months and 23 months of age, and forty-five children were implanted between 24 and 36 months of age. All children had 2-3 years of implant experience before testing. The Reynell Developmental Language Scales was used to measure oral language development. The results revealed that children who were implanted below the age of two years performed better than those implanted after the age of two (Miyamoto et al., 2008). The children who were implanted below one year of age scored slightly better than those implanted between one and two years of age. But, because of the limited number of children in the group implanted younger than 12 months, the findings should be interpreted cautiously. It is necessary that another study be conducted with a larger sample size for implantation age under 12 months (Miyamoto et al., 2008).

**Conclusion**

Research in the area of cochlear implantation has supported the idea that earlier implantation results in greater oral language growth and achievement. In each of the studies reviewed, earlier implantation (before 2 years of age) resulted in an increased rate of language development when compared with children implanted later than two years of age (Holt & Svirsky, 2008; Kirk, Miyamoto, Lento et al., 2002; Kirk, Miyamoto, Ying, Perdew, Zuganelis, 2002; Tomblin, Barker, Spencer, Zhang, Gantz, 2005). Additionally, children implanted early have been shown to attain age-appropriate language skills, where children who were implanted later (after 2 years of age) or received no implant do not attain these high levels of oral language development (Hammes et al., 2002; Nicholas & Geers, 2007; Svirsky, Robbins, Kirk, Pisoni, Miyamoto, 2000).

These results have several implications for audiologists and speech-language pathologists. Because early intervention is key for children with hearing loss in attaining age-
appropriate language skills, identifying the hearing loss early is just as important. The implementation and continuation of newborn hearing screenings is essential in identifying children with severe to profound sensorineural hearing loss early. Additionally, children with hearing loss must undergo a trial period with hearing aids before cochlear implantation, so it is imperative that audiologists fit children with hearing aids as soon as the hearing loss is identified. Speech-language pathologists are an essential part of the cochlear implant team. These professionals must be involved in extensive speech and language therapy as soon as the child’s implant is turned on. It is vital that both audiologists and speech-language pathologists are also advocates for early identification and intervention. Parents may not know the benefits of early speech-language-hearing treatment and it is the professional’s job to inform the parent of the advantages early implantation can have.

Clearly, further research is needed about the effects of cochlear implantation in children younger than 12 months of age. The studies examined in this review all have very small sample sizes for the group implanted younger than 12 months (Colletti et al., 2005; Dettman et al., 2007; Holt & Svirsky, 2008; Miyamoto et al., 2008). Also, because very early implantation (before 12 months) is still new, longitudinal studies examining the language abilities of those children are necessary. In many of the studies discussed, the children were too young to respond to standardized language measures, so longitudinal research is needed to examine the language outcomes several years after early implantation (Kirk, Miyamoto, Lento et al., 2002; Miyamoto et al., 1997).

In addition to further study of children implanted below 12 months of age, new objective measures of examining whether acoustic amplification has provided enough stimulation for normal development of central auditory pathways is needed (Sharma, Martin, & Roland et al.,
Measuring maturation of central auditory pathways through P1 cortical auditory evoked potentials is an objective tool clinicians can use before measuring actual speech and language development. Maturation of central auditory pathways is an important precursor to speech and language development. Decreased P1 latencies are a sign of maturing and/or matured central auditory pathways. By measuring P1 latencies of implanted children and comparing results to normative data of children with normal hearing, clinicians can determine the maturation of central auditory pathways, and can therefore predict the prognosis for normal speech and language development (Sharma et al., 2005). Further research is needed to examine whether this objective test should become part of the standardize test battery audiologists and speech-language pathologists use in evaluating and assessing a child’s benefit from cochlear implantation (Sharma et al., 2005).
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