Partial Deafness Cochlear Implantation at the University of Kansas: Techniques and Outcomes

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Abstract

Background: One of the most significant recent advances in cochlear implantation is the implantation of patients with residual hearing. These patients have a downsloping sensorineural hearing loss with poor speech discrimination and perform poorly with standard amplification. Studies using a variety of different electrode designs have demonstrated that it is possible to implant an inner ear and preserve residual hearing. Initial studies have demonstrated that a combination of residual acoustic hearing in the low frequencies with electrical stimulation in the mid- to high frequencies resulted in superior hearing performance in background noise.

Purpose: The objective of this study was to determine the effect of electrode insertion depth on hearing preservation.

Study Sample: Eighteen patients with mild to severe hearing loss in the low frequencies combined with poor word recognition were recruited for the study.

Intervention: Cochlear implantation.

Data Collection and Analysis: Pre- and postoperative hearing test, Hearing in Noise Test, and consonant–nucleus–consonant testing. Data analysis was performed with Kruskal Wallis and Mann-Whitney testing.

Results: In our study of 18 patients implanted with a Med-El PulsarCI100 we demonstrated the ability to preserve residual hearing with implant insertion depths ranging from 20 to 28 mm, giving us the possibility of near complete cochlear frequency coverage with an implant array while preserving residual hearing. These patients performed well both in quiet and in 10 dB signal-to-noise ratio conditions.

Conclusion: Hearing preservation was achievable even with deep implant insertion. Patients performed well in combined acoustic and electric conditions.

Key Words: Cochlear implant, electroacoustic stimulation, hearing preservation, partial deafness cochlear implantation

Abbreviations: CNC = consonant–nucleus–consonant; EAS = electroacoustic stimulation; FDA = Food and Drug Administration; HINT = Hearing in Noise Test; PTA = pure-tone average; SNR = signal-to-noise ratio

It is estimated that more than 31 million Americans are hearing impaired, most of whom do not have profound sensorineural hearing loss (Kochkin, 2005). The most common form of hearing loss in adults is high-frequency sensorineural hearing loss, which makes it difficult to distinguish speech sounds, particularly consonants. Their hearing function deteriorates further in background noise. These patients are often frustrated with hearing aids or do not benefit from them due to poor word-understanding abilities. Cochlear implants have become a useful tool for the treatment and rehabilitation of severe to profound hearing losses.

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Those with good low-frequency hearing and poor high-frequency hearing were initially not considered cochlear implant candidates as preservation of residual hearing was not thought to be possible due to the trauma sustained from electrode insertion (Sohmer, 2007). However, with improved electrode designs and surgical technique, indications for cochlear implants have extended to those who have essentially good, or aidable, low-frequency hearing and severe high-frequency loss above 1000 Hz. With a less traumatic surgical approach, low-frequency hearing can be preserved, resulting in low-frequency auditory perception and mid- to high-frequency electric perception (Gantz and Turner, 2003; Adunka et al, 2004a; Adunka et al, 2004c; Gstoettner et al, 2004; Kiefer et al, 2004; Turner et al, 2004; Kiefer et al, 2005; Gstoettner et al, 2008; Gantz et al, 2009).

Several studies have shown that patients listening in the electroacoustic stimulation (EAS) condition perform better in background noise and have improved music appreciation as compared to those in the implant-only condition (Turner et al, 2004; Skarzynski et al, 2006; Baumgartner et al, 2007; Behr et al, 2007; Lorens et al, 2008; Gantz et al, 2009; Skarzynski et al, 2009). Gantz and colleagues used a short electrode to demonstrate the feasibility of hearing preservation in cochlear implantation. Traditional long electrode users have shown poor pitch perception as compared to normal-hearing persons, especially in complex tasks such as music perception. Acoustic low-frequency hearing is important for pitch and spectral resolution. In this initial study 13 volunteers were implanted to a depth of 6 to 10 mm from the cochleostomy (Gantz and Turner, 2004; Gantz et al, 2004; Gantz et al, 2006). Following implantation, their ability to recognize familiar melodies was significantly more accurate than that of standard cochlear implant users. Furthermore, they performed better in speech in noise than the standard implant users. Another study done by James and colleagues showed improved speech recognition in noise with the EAS approach. The Nucleus Contour Advance™ was implanted in 12 patients with insertion depths ranging between 17 and 19 mm. An in-the-ear hearing aid was fit in the ipsilateral ear to amplify the preserved low frequencies. They measured a 20% improvement with speech in quiet along with a 3 dB improvement in signal-to-noise ratio (SNR). Subjectively, patients were very satisfied with the bimodal hearing (James et al, 2005). Garcia-Ibanez and colleagues (2009) implanted the Nucleus Contour Advance up to 17 mm for the purpose of preserving residual hearing. They found that hearing thresholds were measurable postoperatively in 71–86% of their subjects. Thirty-six percent of these patients had preservation of thresholds within 10 dB of their preoperative thresholds, and approximately 67% had preservation within 20 dB HL of the preoperative thresholds (Garcia-Ibanez et al, 2009). Hearing preservation was thus attainable with a variety of different electrode designs with insertion depths to approximately the 1000 Hz region of the cochlea.

The purpose of our study was to evaluate the potential of deeper-insertion cochlear implantation. Potential benefits of this approach include increasing the frequency coverage of the cochlea while preserving residual structure. This may be beneficial in terms of ensuring survival of neurotrophin-producing cells in the cochlear apex and may preserve balance function in the implanted ear.

METHOD

Surgical Approach

The extended round window approach was used in all cases. After performance of a mastoidectomy and facial recess (posterior tympanotomy) approach to the middle ear, all bone dust was irrigated out of the wound. Hemostasis was obtained, and 0.5 cc of Decadron 10 mg/ml was applied to the round window niche. The bony overhang of the round window niche was then carefully removed with a 1 mm diamond burr, and the round window was clearly visualized by testing the round window reflex. For the extended round window approach the bone anterior inferior to the round window was removed, keeping the scala tympani endosteum intact. The wound was once again irrigated, and Healon™ was used to cover the round window and endosteum. The endosteum was then opened with a small pick, and the implant electrode was carefully inserted. For round window insertion, the implant was inserted through an incision in the anterior midportion of the round window (Fig. 1). All patients were implanted with Med-El PuslarCI100 using either the standard (H) or medium (M) electrode arrays. These electrodes have 12 contacts distributed over 28 or 24 mm, respectively. The opening into the scala tympani was sealed with a small piece of fascia, and the wound was closed. Depth of the electrode was confirmed radiographically.

Subjects and Outcomes Measures

A total of 18 implant candidates, 5 males and 13 females, with varying degrees of hearing loss were recruited. Ages ranged from 26 to 84, with a mean age 63.17. Thresholds ranged anywhere from normal sloping to profound to severe to profound. Word discrimination scores tested via the Hearing in Noise Test (HINT) sentence test fell within Food and Drug Administration (FDA) or Medicare guidelines for implantation in the best-aided condition. FDA guidelines state that understanding ability must be less than 50% in the ear to be implanted and no better than 60% in the contralateral

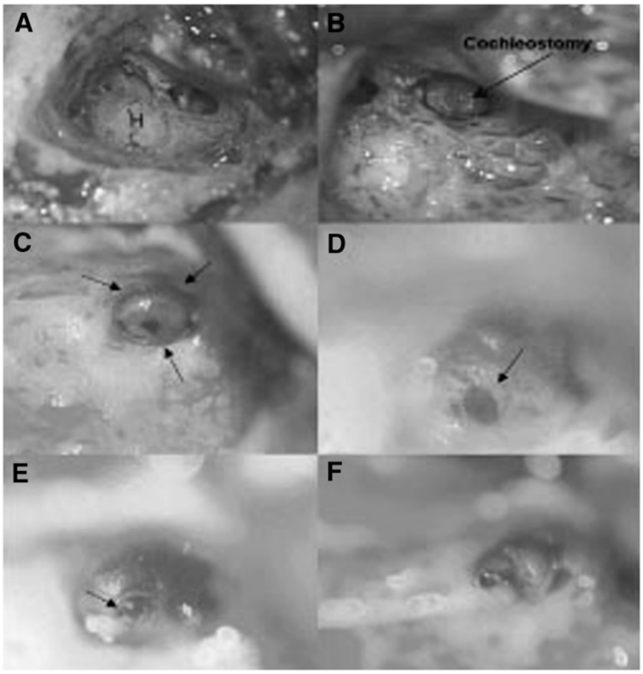

Figure 1. Comparison of standard cochleostomy to round window insertion of a cochlear implant. For all cochlear implant approaches, the middle ear is approached via a facial recess approach/posterior tympanotomy (A). The cochleostomy is placed anterior to the round window (B). To approach the round window, the posterior tympanotomy (arrows, C) needs to be significantly wider. Next the bony overhang over the round window niche is removed with a 1 mm diamond burr, allowing complete visualization of the round window (arrow, D). The round window is covered with a thin layer of hyaluronic acid, and a small slit is made with an arachnoid knife (E). Finally the electrode is inserted (F), and the niche is sealed with a tissue graft.

ear. Medicare's criteria state that speech understanding must be less than 40% bilaterally (Huart, 2009). The etiology of the hearing losses for the participants is unknown. Prior to implantation, all patients underwent blood testing to screen for autoimmune inner ear disease and had an MRI scan to rule out retrocochlear losses. Laboratory work was negative for autoimmune inner ear disease for all patients. MRI scans were also negative for cochlear malformation or retrocochlear pathology. The participants further denied any family history of hearing loss.

Informed consent was obtained prior to testing, and the protocol was approved by the University of Kansas Medical Center human subjects board. Pure-tone thresholds were obtained before surgery and two weeks postoperatively using insert earphones. An example of a pre and post audiogram is shown in Figure 2. The HINT and consonant–nucleus–consonant (CNC) word tests were administered in order to evaluate word-discrimination and word-recognition abilities. Sentences and words were presented with the patient seated in a sound-treated booth at 0 degrees azimuth

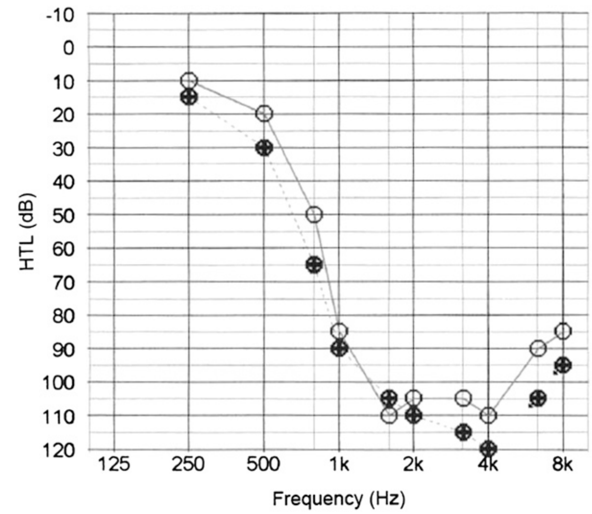

Figure 2. Example audiogram pre (open circle) and post 24 mm implant (crossed circles) performed with a Med-El standard electrode. Insertion was carried out via a round window approach and had remained stable over 18 mo.

at 70 dB SPL via recorded voice. The tests were administered in three conditions: acoustic only, implant only, and electric plus acoustic (EAS) in the ipsilateral (implanted) ear. To ensure that the patient was only hearing with electric stimulation, both ears were plugged with an earplug to eliminate any acoustical hearing. The ipsilateral earplug was then removed for the EAS condition. A contralateral hearing aid was not used in any of the patients in order to isolate the implanted ear. HINT testing was also performed in a +10 dB SNR in the electric and EAS conditions. After the sentences or words were presented, the patients were asked to repeat back any words that they may have understood and were encouraged to guess if unsure. Scores were based on words repeated back correctly in each sentence and divided by the total number of words possible.

Statistics

Outcomes were analyzed by Kruskal Wallis and Mann-Whitney testing administered using SPSS v. 17.0. Significance was set at $p < .05$.

RESULTS

Residual hearing was preserved in all 18 patients. The change in pure-tone averages was calculated using 250, 500, and 750 Hz. This change was graphed as a function of insertion depth and is shown in Figure 3. There is no clear relationship between insertion depth and amount of hearing preserved, indicating that the apical region of the cochlea can be reached without compromising hearing thresholds ($r^2 = 0.091$). The advantage of residual hearing used in conjunction with electric

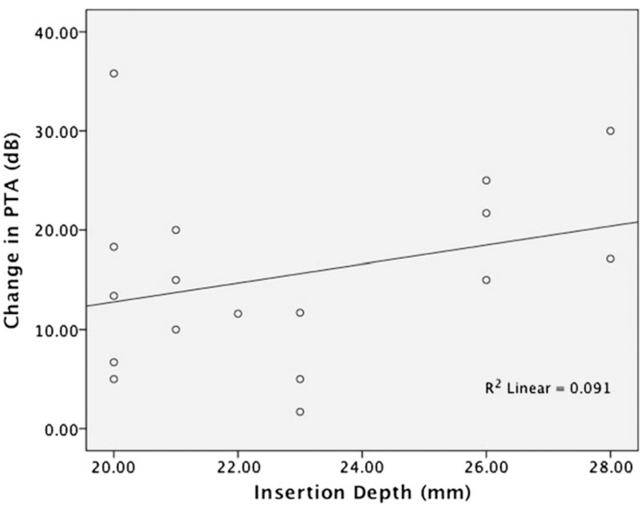

Figure 3. Effect of electrode insertion depth on postoperative change in hearing. Using a round window insertion approach, there was no clear relationship between implant insertion depth and change in postoperative pure-tone average (PTA). The PTA was chosen as an outcome measure since all of the patients we implanted had residual low-frequency hearing. This demonstrates that access to the low- to midfrequency region of the cochlea is possible with hearing preservation.

stimulation was measured using the HINT test presented in quiet and +10 dB SNR as well as CNC word lists. Outcomes for the quiet condition are graphed in Figure 4. The preoperative HINT score in quiet had a mean of 24.3% correct. When testing in the electric-only condition, the mean score improved to 75.3% correct. When presented in the acoustic plus electric condition, the mean score was 69.9% correct. This represents a significant difference in the aforementioned three conditions ($p \leq .001$). The Mann-Whitney test was then performed to find that there were statistical differences in the preoperative and electric-only conditions ($p \leq .001$) as well as the preoperative and EAS conditions ($p \leq .001$). There was, however, no statistical difference between the electric and EAS conditions ($p = .573$).

Patients tested in the +10 dB SNR condition showed preoperative scores of 25.7% correct. Mean scores improved to 64.33% correct in the electric-only condition and to 65.89% correct in the EAS condition. The Kruskal-Wallis test confirmed a significant difference between groups ($p = .001$). Similar to the electric-only condition, the Mann-Whitney test showed a significant difference between preoperative scores and postoperative HINT in the electric-only condition ($p = .001$) in addition to significant differences in preoperative and postoperative HINT scores in the EAS condition ($p \leq .001$). There was no statistical significance evident when the two postoperative conditions were compared ($p = .955$; Fig. 5).

Speech understanding outcomes were also measured using CNC word lists (Fig. 6). Preoperative mean scores were 16.67% correct out of 50 words. Scores improved to an average of 38% correct in the electric-only condition

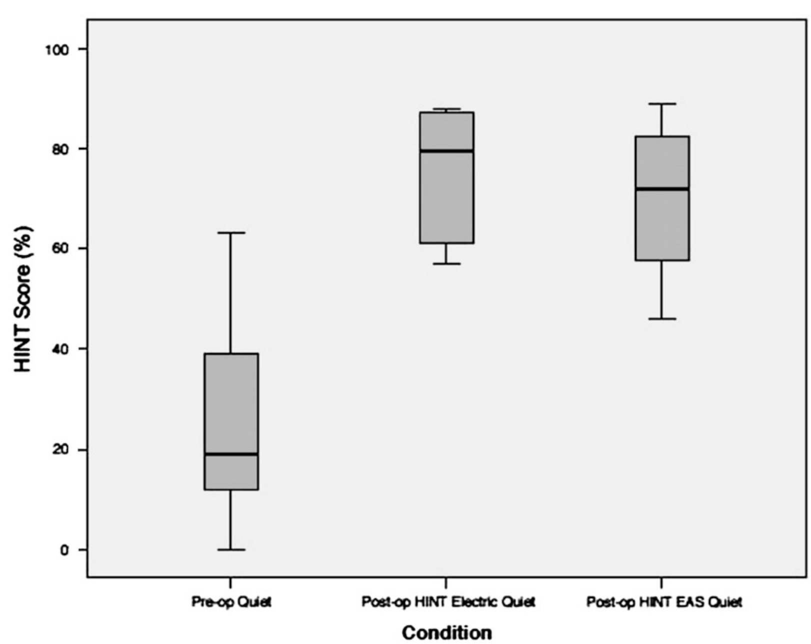

Figure 4. Postoperative performance in quiet. This box plot summarizes the preoperative and postoperative Hearing in Noise Test (HINT) scores recorded in two conditions: (1) electric only and (2) electroacoustic stimulation (EAS). The black line represents the median HINT score. The boxes represent the 25th through the 75th percentile, whereas the lower and upper lines represent the standard deviation. Preoperative HINT scores had a median of 19%. Postoperative activation of the implant resulted in significant improvement in HINT scores for both the electric-only and EAS conditions. Electric-only scores had a median of 79.5%, and EAS HINT scores averaged 72%. There is no statistical difference between the electric-only and EAS conditions.

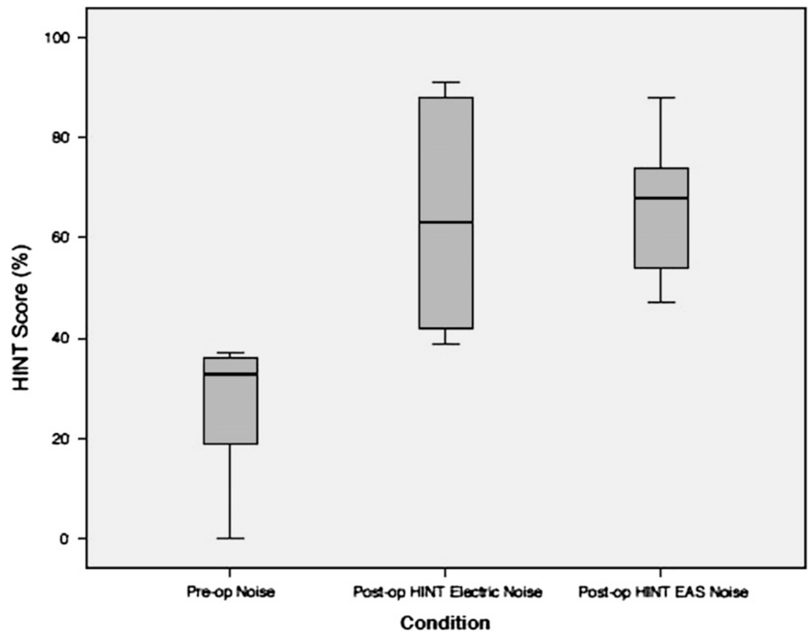

Figure 5. Postoperative performance in noise. The box plot summarizes the pre- and postoperative Hearing in Noise Test (HINT) scores when presented in +10 dB signal-to-noise ratio. Preoperative scores demonstrated a median of 33%. Postoperative median scores were 63% and 68% in the electric and electroacoustic stimulation (EAS) conditions, respectively. The black line represents the median HINT score. The boxes represent the 25th through the 75th percentile, whereas the lower and upper lines represent the standard deviation. There was statistical significance in preoperative scores and the electric condition and preoperative scores and the EAS condition; however, there was no statistical difference in the electric and EAS conditions.

and to 47.1% in the EAS condition. Using the statistical tests mentioned above, results were consistent in that a statistical difference was found when comparing preoperative scores to postoperative scores in the two different conditions: (1) electric only, $p = .004$; (2) EAS, $p = .000$. However, no statistical difference was found when comparing the two postoperative CNC scores ($p = .193$).

DISCUSSION

In our group of patients, insertion of a thin electrode array via a round window approach was able to achieve hearing preservation. In contrast to other studies, we were able to achieve insertions of up to 28 mm with preservation of residual hearing (Fig. 3). In temporal bone studies, insertions that extend beyond 360 degrees (about 20 mm) showed increased cochlear trauma (Adunka and Kiefer, 2006). This was not observed in this series of patients since preservation of hearing serves as a proxy for evaluation of damage apical to the implant. One potential advantage of a deeper implantation is the ability to stimulate apical regions of the cochlea should hearing deteriorate over time.

Although short electrodes have been shown to be beneficial for speech understanding, deep insertions also have advantages, even for hearing preservation candidates. With limited access to the apical regions, the implant may be less effective in the event that the residual hearing is lost. Frequency allocations may be reassigned to the apical end; however, Reiss and colleagues (Reiss et al, 2007; Reiss et al, 2008) suggest that it may require a significant amount of time for the users to adjust to the frequency shift.

Gstoettner and colleagues (2004) found that deeper insertions could be achieved with the Med-El electrode arrays. This is significant since implantation to 20 mm is predicted to give patients electrical hearing through the 1000 Hz range, leaving the apical, hearing portion of the cochlea intact. Twenty-one patients were implanted with insertion depths ranging from 18 to 24 mm. Hearing was successfully preserved in 85.7% of the patients. Compared to the electric-only condition, all patients performed better in the EAS condition. A key component to preserving hearing in these cases was found to be an atraumatic ("soft") surgical approach (Gstoettner et al, 2004).

Newer electrode designs have tried to combine thin, atraumatic insertion with implantation to at least 20 mm (Adunka et al, 2004b). Potentially even deeper insertion into the cochlea with limited damage is possible. Baumgartner and colleagues implanted 23 adults with a specialized flexible 31 mm electrode manufactured by Med-El. The electrode features five single contacts in the apical end and seven pairs across the rest of the array. With this design, the apical end is much thinner. Hearing preservation was achieved in four cases up to 12 mo. Improvements were seen with monosyllabic words as well as hearing in noise (+10 dB SNR), with mean scores of 54% and 57%, respectively.

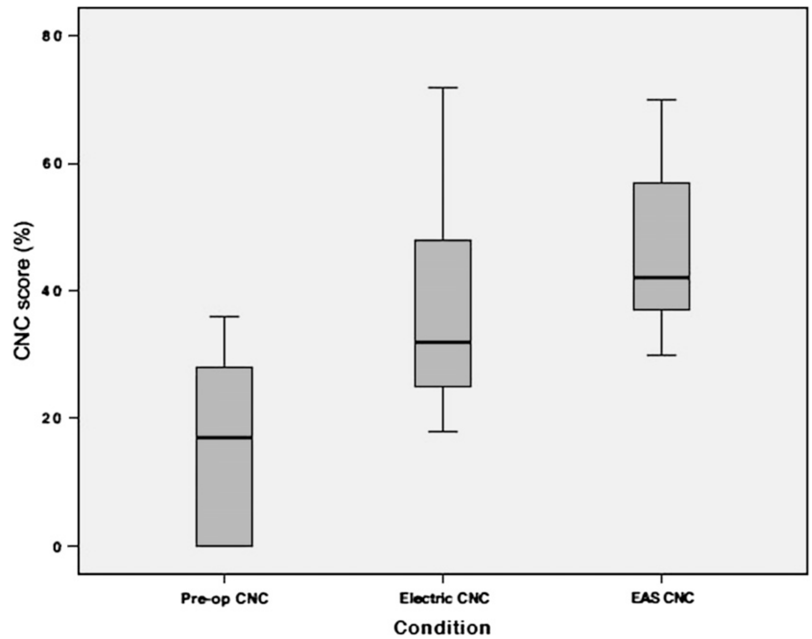

Figure 6. Change in consonant–nucleus–consonant (CNC) recognition after implantation. Preoperative scores had a median of 17% correct. Postoperative scores improved to a median of 32% correct in the electric-only condition and 42% in the electroacoustic stimulation (EAS) condition. The black line represents the median CNC score. The boxes represent the 25th through the 75th percentile, whereas the lower and upper lines represent the standard deviation. There is a significant difference in the preoperative score vs. both the postoperative electric-only and EAS conditions; however, there was no significant difference in the two postoperative conditions.

Findings from our study indicated a significant improvement in speech understanding with the use of a cochlear implant in patients with residual hearing compared to their performance with standard hearing aids. Interestingly, the residual acoustic hearing did not improve speech discrimination scores significantly over electric hearing alone. These results are contrary to the literature that suggests that electric acoustic hearing is superior to electric hearing alone. It is important to note that there was a large range in scores whereby some individuals did perform as well in the EAS condition as compared to other studies that have been published. Several variables may have played a role in speech discrimination, for example, whether the patient was properly fit with standard hearing aids and whether the ear was properly stimulated prior to surgery. Age may have also played a role, in that the geriatric population may have more difficulty in distinguishing and adjusting to the mixed signals. Our age range was quite large, which may have influenced the mean scores.

Additional theoretical benefits include the potential for the preservation of structures apical to the implant. Recent temporal bone histopathology studies have demonstrated degeneration of both supporting cells and spiral ganglion neurons apical to the tip of an implant when compared to the contralateral, unimplanted side (Khan et al, 2005). If an implant electrode migrates through the scala media to the scala vestibule, as suggested by Finley and colleagues (2008), the resulting inflammation may result in degeneration of residual functioning portions of the cochlea and poorer outcomes. Some animal studies have also suggested that traumatic insertions affected spiral ganglion survival (Leake et al, 2008). Lack of hearing loss with deeper insertions suggests that it is possible to maintain the apical structures of the cochlea while being able to electrically stimulate very low frequencies.

CONCLUSION

Atraumatic cochlear implantation has shown benefit in preserving hearing. Contrary to other studies we have not seen a difference in the performance of our patients in the electric-only versus the EAS condition in background noise. This is mainly due to our patients' excellent performance in the electric-only condition. Future studies will focus on understanding the physiological differences that affect performance in these different groups.

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