

Bilateral cochlear implantation: current concepts

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Purpose of review

Recent experience has shown an advantage of bilateral cochlear implantation over unilateral implantation. These documented benefits include improved speech perception in noisy environments and improved sound localization. Recently, investigators have studied the long-term benefit, evaluation of neural integration, programming, vestibular effects, and complications of bilateral cochlear implantation. This article summarizes the current research endeavors to improve our understanding and utilization of bilateral cochlear implantation.

Recent findings

Numerous positive benefits of bilateral cochlear implantation have been confirmed. Patients receive significant head shadow benefit from bilateral implantation, and obtain nominal benefits from summation and squelch effects. Sound localization benefits have been confirmed. Speech perception in noise with bilateral implantation is significantly better than unilateral implantation and continues to improve 24 months after implantation. Areas for further improvement have also been identified. Despite technological improvements in speech processing strategies, measured intraaural time differences in bilateral cochlear implant recipients remain considerably greater than those with normal hearing. Programming challenges persist to optimize sound processing with bilateral implants. Vestibular effects of bilateral cochlear implantation appear safe but need further study. Important considerations including the duration of implant function, long-term complication rate, and improvements in implant technology will continue to strongly influence the role of bilateral cochlear implantation.

Summary

Bilateral cochlear implantation provides advantages over unilateral implantation including improved speech perception in noise and improved sound localization. Further research is needed to define the optimal indications and to maximize the benefit of bilateral implantation.

Keywords

bilateral cochlear implantation, complications, neural integration, sound localization, vestibular effects

Introduction

Unilateral cochlear implantation has been an effective method of providing auditory rehabilitation for people with severe to profound sensorineural hearing loss. However, its benefits have been limited. Given that normal hearing relies on binaural stimulation, recent experimental studies have begun to investigate the improved performance of bilateral cochlear implantation. Tyler *et al.* [1] discussed several definitions and problems with trying to initiate binaural hearing with cochlear implants and reviewed the status of bilateral cochlear implantation in 2003. Short-term studies at that time showed that patients with bilateral cochlear implants clearly benefited from a head shadow effect, and possibly benefited from summation and squelch effects. Small studies also showed an improvement in sound localization for patients with bilateral implants. Since 2003, the number of patients implanted bilaterally has continued to grow and numerous studies including multi-center trials sponsored by the implant manufacturers have further investigated the benefits of bilateral implantation. Important studies have examined the long-term speech and sound localization benefits of bilateral implantation, neural integration, programming and other aspects of bilateral single-stage and bilateral sequential implantation, and complications. In addition, the processor technology of cochlear implants has continued to improve, hopefully correlating to better performance and enhanced ability to benefit from bilateral implantation. The purpose of this article is to review the current studies that have been published on bilateral cochlear implantation.

Improved speech perception

Recent studies have confirmed the ability of bilateral cochlear implantation to improve speech perception compared with unilateral implantation, particularly in noisy environments. This benefit primarily is a result of the head shadow effect. This effect arises from the 'shadowing' of one ear (and corresponding implant) by the head and shoulders to the noise source, essentially acting as an acoustic baffle. Thus, it is a monaural, purely physical effect. However, small benefits in summation effects (improvement in hearing threshold from redundant information presented to each ear) and squelch effects (improvement in hearing threshold from brainstem processing of interaural time and intensity differences) continue to be reported, suggesting that patients may be able to neurally integrate inputs from both implants to enhance speech perception over time.

Schleich *et al.* [2] examined the speech reception thresholds in 21 patients with bilateral MED-EL COMBI 40/40+ (MED-EL Corp, Innsbruck, Australia) implants

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placed sequentially. The mean experience with the most recent implant system was 34 months. The test condition used an adaptive signal to noise ratio to minimize floor and ceiling effects. A head shadow (monaural) effect of 6.6 dB, squelch (binaural) effect of 1.1 dB and summation (binaural) effect of 1 dB were noted when bilateral implantation was compared with the best unilateral implant. Das *et al.* [3] reported two year results from a single institution of an ongoing MED-EL multi center study examining the benefits of bilateral cochlear implantation with the MED-EL COMBI 40+ device both implanted in a single stage in nine patients. In this study, the percent correct of consonant–nucleus–consonant (CNC) word lists tested in quiet conditions were followed over time (Fig. 1) with the average score continually rising to 74% correct at 2 years following implantation with an improvement over the better unilateral implant performance of 3–11% and an improvement over the poorer unilateral implant performance of 11–14%. This study also tested speech perception in noise using an adaptive signal to noise ratio and found robust head shadow benefits and a smaller summation effect which appeared after 6 months following implantation. A small squelch effect appeared after 1 year following implantation and appeared to increase in magnitude over time, suggesting that it was a late emerging effect. Interestingly, at 2 years after bilateral implantation, three of the nine patients were able to be tested with a signal to noise ratio of 0. That is, they were able to correctly report at least 40% of sentences presented at the same dB level as the noise, a situation that mimics crowded rooms and which currently plagues unilateral implant users.

Laszig *et al.* [4] examined 22 patients that were simultaneously implanted and 15 sequentially implanted with the Nucleus 24 implant (Cochlear Ltd, Sydney, Australia). These patients received a binaural benefit in Freiburger word lists over the poorer unilateral implant by an average of 9% at 6 months, but 0% at 6 months over the better unilateral implant. However, at 6 months following

implantation, these patients did have a 4% improvement in Oldenburg (OLSA) sentence scores. Speech perception in noise testing was performed using adaptive signal to noise ratios which resulted in a head shadow benefit at 6 months following implantation of 11.4 dB, with a small squelch effect reported in only part of the testing.

In conclusion, current ongoing studies of patients with bilateral implantation show significant improvements in speech perception in quiet and noisy environments over unilaterally implanted patients. Caution should be exercised in drawing definitive conclusions from these studies given the small sample sizes of bilaterally implanted patients.

Improved sound localization

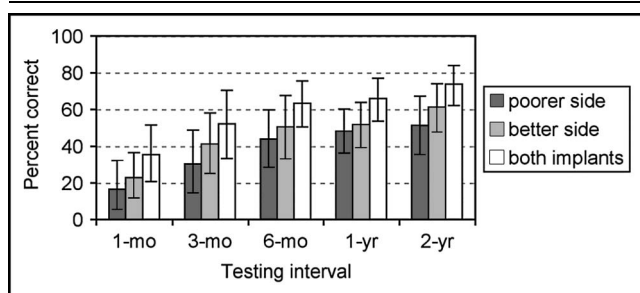
Recent studies have also confirmed the benefit of improved sound localization with bilateral implantation. Nopp *et al.* [5] examined 20 patients bilaterally implanted with MED-EL COMBI 40/40+ implants. Sound localization was tested in an anechoic chamber with nine speakers at 22.5 degree intervals. All but two patients had substantial improvements in their sound localization ability when using both implants instead of one, improving by more than 30 degrees on average with greater consistency. The two patients who did not show a bilateral benefit were both deafened in early childhood.

Grantham *et al.* [6] examined 22 patients bilaterally implanted with MED-EL COMBI 40+ implants. They found that these participants performed consistently better than chance due to their ability to process interaural level differences. Interestingly, they also noted that a few unilateral implant users performed better than chance, though with a higher error rate than bilateral implant users. Ashmead *et al.* [7] examined auditory distance perception in these patients. There was little difference in performance between bilateral and unilateral implant users. In conclusion, these studies confirm the marked benefit in sound localization for bilateral cochlear implant users. This benefit in spatial perception and increased safety is significant and difficult to quantify in cost–benefit analyses. Further research is needed to elucidate the critical time period for the development of sound localization and to quantify the benefit that bilateral implants provide.

Neural integration

The problems with neural integration from bilateral cochlear implant stimulation are eloquently described by Wilson *et al.* [8]. Further research to understand the neural mechanisms of listening in noise and exploit these mechanisms with cochlear implant technology continue to be intensely investigated. May *et al.* [9•] recently reported elegant studies on behaviorally trained cats with transected efferent olivocochlear axons and their subsequent ability to localize sound. Interestingly, the lesioned cats maintained excellent directional hearing under quiet

Figure 1. CNC percent accuracy over time in bilateral users



This figure shows the mean (+/– SD) percent correct of CNC word scores in quiet testing conditions versus time for nine patients with bilateral MED-EL COMBI 40+ implants received in a single stage operation. SD, standard deviation; CNC, consonant–nucleus–consonant.

conditions, but performed poorly on sound localization with background noise. The magnitude of this deficit also decreased with time, implying that auditory compensation was possible to a small degree.

Laback *et al.* [10] recently reported on the sensitivity to interaural level and time differences of two bilateral cochlear implant patients receiving MED-EL COMBI 40/40+ implants using a continuous interleaved sampling (CIS) speech processing strategy. Just noticeable differences for interaural level differences were only about 1 dB higher than normal hearing subjects. Interaural time differences, however, were approximately a factor of 2 greater in the bilateral cochlear implant patients compared with normal hearing subjects. The best just noticeable difference in interaural time difference for the bilateral cochlear implant patient was 259 μ s. The authors concluded that bilateral cochlear implants provide relevant interaural level differences sufficient to localize sound, however, the CIS speech processing strategy, which its loss of temporal fine structure in the input signal, may not be the optimal strategy to preserve interaural time difference information.

Programming

Recent studies have also begun to investigate the challenges that will be present in optimally programming bilateral devices either simultaneously or sequentially implanted in patients. Baumgartner *et al.* [11] highlighted this challenge with their review of 30 patients with sequential bilateral implants performed over the last nine years. Multiple combinations of older versus newer implants were used, as well as implants from different manufacturers in the same patient. The authors concluded that to obtain a performance benefit of bilateral implantation, two multi-channel fast stimulators in quite symmetric fitting parameters are mandatory. Bromberg *et al.* [12] examined whether differences in depth of insertion should be compensated for in programming three adults with simultaneous implantation with bilateral Nucleus 24 implants. At 16 weeks following implantation, no significant differences were found in the place–pitch map compared with the default map, with two of the three patients preferring the default map. Further studies and experience will be needed to optimize mapping for patients with bilateral implants of a multitude of combinations and clinical presentations.

Vestibular effects

Cochlear implantation has the potential risk for vestibular system damage and/or stimulation with resultant dysfunction. With the advent of bilateral cochlear implantation, this risk takes on increasing importance. Buchman *et al.* [13•] recently reported in a prospective observational study of 86 patients undergoing unilateral cochlear implantation with numerous important findings. Most

importantly, unilateral cochlear implantation usually did not result in substantial vestibular impairment; on the contrary, most patients reported both subjective and objective improvements in vestibular function after device activation. Excluding patients with preoperative areflexia or hyporeflexia, 29% of patients had significant decreases in total caloric responses in the implanted ear; however, most were accompanied by decreases in total caloric response in the unimplanted ear as well. Interestingly, in only one patient did the implanted ear decrease substantially in bithermal caloric response with an increase in responsiveness in the non-implanted ear. The author concluded that the risk for bilateral loss from bilateral cochlear implantation would be approximately 5% for adults and substantially less for children. Even with this risk, bilateral loss may not translate in disabling vestibular systems.

Buchman *et al.* [14] also prospectively followed the vestibular effects of 15 patients who received bilateral cochlear implants. Four patients had substantial improvement in their self-perceived handicap from dizziness, eight patients had no significant change, and three patients worsened. Electronystagmography testing was unable to demonstrate significant changes in vestibulo-ocular reflex (VOR) responsiveness. Further studies with long-term follow up are needed to fully assess the risks of bilateral cochlear implantation on the vestibular system.

Complications

Cochlear implantation provides a safe and reliable benefit to patients; as with all surgical procedures, complications occur. The advent of bilateral cochlear implantation and well the need to revise previous unilateral implantation with a contralateral implant brings additional risk to the procedure. Das *et al.* [3] reported an average operating time of 4 h 16 min for bilateral simultaneous implants with no major intraoperative complications for nine patients. Implants were performed sequentially in entirety, with bipolar electrocautery used for the second side. Four of nine patients developed postoperative vertigo, which in one patient took 5 months to resolve, two patients complained of dysgeusia, and two patients developed postoperative hematomas, both on the initial implant side. One of these patients required needle aspiration to drain this hematoma post-operatively.

Conclusion

Bilateral cochlear implantation provides improvements in speech perception in quiet and noisy environments and sound localization over unilateral cochlear implantation. Further improvements in performance can be expected with a greater understanding of the neural pathways and integration of binaural hearing along with improvements in implant programming and technology. Bilateral cochlear implantation may have additional beneficial

effects in vestibular function and is safe, with little additional risk compared with unilateral implantation. Further studies are required to fully assess whether the benefit is worth the additional cost and risk.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

- 1 Tyler RS, Dunn CC, Witt SA, *et al.* Update of bilateral cochlear implantation. *Curr Opin Otolaryngol Head Neck Surg* 2003; 11:388–393.
- 2 Schleich P, Nopp P, D'Haese P. Head shadow, squelch, and summation effects in bilateral users of the MED-EL COMBI 40/40+ cochlear implant. *Ear Hear* 2004; 25:197–204.
- 3 Das S, Buss E, Clark MS, *et al.* Long-term effects of bilateral cochlear implantation in post-lingually deafened adults. Tenth Symposium on Cochlear Implants in Children, March 15–19, 2005. Dallas, Texas.
- 4 Laszig R, Aschendorff A, Stecker M, *et al.* Benefits of bilateral electrical stimulation with the Nucleus cochlear implant in adults: 6-month postoperative results. *Otol Neurotol* 2004; 25:958–968.
- 5 Nopp P, Schleich P, D'Haese P. Sound localization in bilateral users of MED-EL COMBI 40/40+ cochlear implants. *Ear Hear* 2004; 25:205–214.
- 6 Grantham DW, Ashmead DH, Ricketts TA, *et al.* Sound localization in the horizontal plane by unilaterally and bilaterally implanted adults. Tenth Symposium on Cochlear Implants in Children, March 15–19, 2005. Dallas, Texas.
- 7 Ashmead DH, Wall RS, Grantham DW, *et al.* Auditory distance perception by unilaterally and bilaterally implanted adults. Tenth Symposium on Cochlear Implants in Children, March 15–19, 2005. Dallas, Texas.
- 8 Wilson BS, Lawson DT, Muller JM, *et al.* Cochlear implants: some likely next steps. *Annu Rev Biomed Eng* 2003; 207–249.
- 9 May BJ, Budelis J, Niparko JK. Behavioral studies of the olivocochlear efferent system. *Arch Otolaryngol Head Neck Surg* 2004; 130:660–664.
- Eloquent animal study analyzing the effect of transecting olivocochlear efferent stimuli on sound localization
- 10 Laback B, Pok SM, Baumgartner WD, *et al.* Sensitivity to interaural level and envelope time differences of two bilateral cochlear implant listeners using clinical sound processors. *Ear Hear* 2004; 25:488–500.
- 11 Baumgartner WD, Jappel A, Frei K, *et al.* Bilateral cochlear implantation nine years results. Eighth international cochlear implant conference. May 10–13, 2004 Indianapolis, Indiana. 2004.
- 12 Bromberg B, Shapiro W, von Hoesel R, *et al.* Evaluation of offset effects with subjects implanted bilaterally with the Nucleus 24 cochlear implant system. Eighth international cochlear implant conference. May 10–13, 2004 Indianapolis, Indiana 2004.
- 13 Buchman CA, Joy J, Hodges A, *et al.* Vestibular effects of cochlear implantation. *Laryngoscope* 2004; 114:1–22.
- Prospective study analyzing the vestibular effects on 86 patients who underwent cochlear implantation
- 14 Buchman CA, Pillsbury HC, Higgins C. Vestibular effects of bilateral cochlear implantation. Eighth international cochlear implant conference. May 10–13, 2004 Indianapolis, Indiana. 2004.