

Monitoring of Cochlear Function During Cochlear Implantation

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Objective: To report the feasibility of monitoring cochlear function during cochlear implantation. **Study Design:** Case report. **Setting:** Tertiary care referral center. **Methods:** A child with audiologic features typical of bilateral auditory neuropathy underwent cochlear implantation. The scala tympani was entered inferior and slightly anterior to the round window membrane margin and smooth electrode insertion was achieved. Using single polarity click stimuli, the cochlear microphonic was measured at several steps during surgery. **Results:** Cochlear microphonics were present at all stages during the implantation process and were clearly distinguished from neural responses by stimulus polarity inversion and constant latencies, despite changes in stimulus level. With the electrode in situ, amplitudes were smaller but persisted until the final measurement at 10 minutes after insertion. At follow-up 2 weeks after surgery, behavioral audiometry results indicated profound hearing loss in the operated ear. **Conclusions:** This paper demonstrates the feasibility of monitoring cochlear function during cochlear implantation. The routine surgical approach did not appear to adversely affect the functional measurements. Standard size, full electrode insertion did diminish the amplitude of the cochlear microphonics, possibly as a result of intracochlear mechanical impairment. Ultimately, profound hearing loss was documented, indicating that factors other than immediate changes induced by electrode insertion were likely responsible for the loss of cochlear function. **Key Words:** Cochlear implant, auditory neuropathy, cochlear nerve, inner ear, cochlear microphonics.

Laryngoscope, 116:1017–1020, 2006

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Editor's Note: This Manuscript was accepted for publication February 24, 2006.

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DOI: 10.1097/01.mlg.0000217224.94804.bb

INTRODUCTION

A number of investigators have described measurable residual hearing in the implanted ear in up to 50% of patients following cochlear implant surgery. While the preservation of measurable residual hearing was of interest in terms of implantation sequelae, it did not appear to influence speech perception abilities in these patients. Not until the introduction of combined electric acoustic stimulation (EAS) in 1999¹ did preserved residual hearing become of increased significance. EAS combines low-frequency acoustic stimulation of residual cochlear apical hair cells with ipsilateral basal cochlear electric stimulation. Implicit in this technique is the preservation of cochlear function in the low frequencies after electrode insertion. Using this bimodal or hybrid stimulation, preliminary results have been promising, with marked improvements in both speech perception in quiet and in noise when compared to the results obtained with the cochlear implant alone.^{2,3} Thus, hearing preservation in patients undergoing cochlear implant surgery has gained new significance for this selected clinical application.

Surgical techniques for hearing preservation in EAS surgeries are somewhat different from those described for routine cochlear implantation. Although "soft" surgical techniques were introduced as early as 1993,⁴ these approaches only maintained a critical number of excitable neural elements rather than functional hearing. Two groups of investigators have developed the current surgical techniques for hearing preservation attempts in EAS cases.^{5,6} Using principles akin to stapedectomy surgery, these surgeons have been able to preserve residual hearing in a significant number of cases. Nevertheless, iatrogenic hearing loss still occurs in some cases, the cause of which remains speculative.² A better understanding of these factors could obviously improve the preservation of residual hearing in patients in whom EAS is being considered. In this regard, a method for monitoring cochlear function during implantation could be very helpful for better understanding the cause of and ultimately the prevention of cochlear implant-induced hearing loss.

Auditory neuropathy is a clinical syndrome characterized by the presence of otoacoustic emissions and/or cochlear microphonics suggesting normal outer hair cell

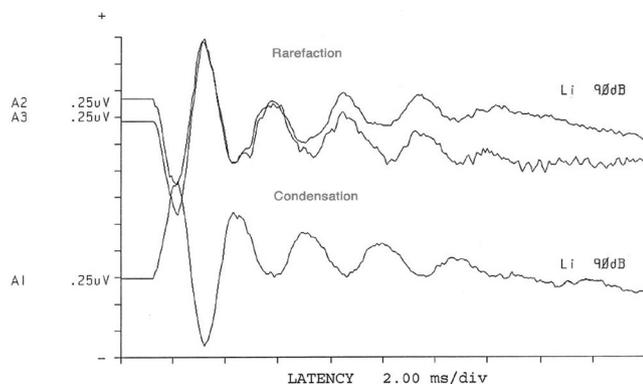


Fig. 1. Two-channel recording of toneburst (90 dBn hearing level) evoked cochlear microphonics before draping. A single cycle 250-Hz toneburst was shaped by a Blackman window with a 2 msec rise/fall times and no plateau. Although nominally centered at 250 Hz, spectral analysis shows this stimulus to include energy broadly distributed below about 500 Hz. A time window of 20 msec is shown, whereas the cochlear microphonics were recorded in the first 5-msec after the stimulus. Condensation and rarefaction runs are shown.

function in conjunction with absent or grossly abnormal auditory brainstem responses.⁷ Auditory neuropathy is thought to account for up to 10% of newly diagnosed cases of hearing loss in children.⁸ Cochlear implants have been shown to be useful for patients severely affected by auditory neuropathy, presumably through electric synchronization of disordered auditory nerve impulses.⁹ Since auditory neuropathy patients have significant residual cochlear function and commonly undergo cochlear implantation, we speculated that this group of patients would represent an ideal model system for studying the effects of CI on cochlear function. This report describes the feasibility of intraoperative monitoring of cochlear function during various stages of cochlear implant surgery in a patient with auditory neuropathy.

MATERIALS AND METHODS

Patient

A 1-year-old male child with a history of prematurity presented with symmetric bilateral moderate to severe hearing loss (reproducible thresholds between 45 and 65 dB). Auditory brainstem response testing revealed cochlear microphonics bilaterally with absent distal waves indicating auditory neuropathy (Fig. 1). Distortion-product otoacoustic emissions were absent in both ears, however.¹⁰ Rapid plasma reagin, connexin 26, and magnetic resonance imaging testing results were normal. Subsequently, the child received nearly 1 year of conventional binaural amplification and intensive speech therapy using an auditory-verbal approach. During this time period, the parents noted significant fluctuations in hearing and, although some progress was observed, the child continued to be significantly delayed (no better than chance on closed-set tests) for speech and language development, prompting cochlear implant evaluation. After extensive evaluation and counseling, cochlear implantation was considered and ultimately undertaken at 2 years, 8 months of age.

Surgical Technique and Intraoperative Recordings

The patient was implanted using the typical cochlear implant approach that is currently being used at our institution.

Prior to site preparation, a nonsterile pediatric disposable Tiptrode (Viasys Health Care, Conshohocken, PA, U.S.A.) was placed in the external auditory canal, bilaterally. This device serves to both couple the acoustic stimulator to the ear and record evoked electrical activity through its gold-foil contact, thus eliminating the need for earlobe electrodes. The postauricular ear incision site was prepped and the nonsterile ear canal was excluded from the surgical field by reflecting the auricle anteriorly with Ioban drapes (3M, St. Paul, MN, U.S.A.). Following a transmastoid facial recess approach, step-by-step cochleostomy drilling was performed so electrophysiologic recordings could be made at each of the various steps. It is noteworthy that an EAS surgical technique as previously described^{5,6} was not employed in this case. Also, no adjunctive drugs such as topical or intravenous steroids or intracochlear lubrication were used. The cochleostomy was drilled using a 1-mm diamond burr attached to a high-speed (80,000 rpm) pneumatic drill (MicroMax; Ansbach, Stuart, FL, U.S.A.). The promontory was initially drilled in the region of the planned cochleostomy to the level of the scalar endosteum. Following electrophysiologic recordings, the scala tympani was opened with the diamond burr inferior and slightly anterior to the round window membrane to avoid damage to the spiral ligament. After further recordings, the cochleostomy was opened widely (1.4 mm) to allow insertion of the HiFocus electrode array of the HiRes 90 K cochlear implant system (Advanced Bionics, Sylmar, CA, U.S.A.). This thin and slightly curved electrode array is 20 mm in length with 16 electrode contacts.¹¹ The perilymph was evacuated during wide scalar opening. Measurements of the cochlear microphonics were then again made. All measurements were performed under general anesthesia and the surgical steps were documented photographically.

Electrophysiological Testing

The electrode montage consisted of a noninverting electrode placed at Fz with a ground electrode placed at Fpz and disposable Tiptrodes (see above) placed at A1 and A2 to provide the inverting inputs. The Traveler/Navigator Evoked Potential System (Biologic Systems, Mundelein, IL, U.S.A.) was used for recording. In general, the auditory brainstem response protocol included two main stimuli: a 100-msec click and a "single-cycle" 250-Hz toneburst. Two channel recordings with a bandwidth of 100 to 3000 Hz and a time window of 20 msec were used for click stimulation. The same time window with a bandwidth of 30 to 3000 Hz was used for toneburst recordings. The stimulation rate was 37.7 Hz, and 1500 sweeps per average were typically collected. Cochlear microphonics were distinguished from neural responses and stimulus artifact when (1) no latency shift was identified with variations in the stimulus level, (2) inversion of the click polarity (rarefaction and condensation) inverted the response polarity, and (3) disconnecting the sound tubing abolished the responses.¹²

RESULTS

Figure 2 shows a summary of the surgical steps and the corresponding electrophysiologic responses elicited using click stimuli presented at 90 dBn hearing level. Implantation was performed according to the method described above. No anatomic abnormalities were encountered during the approach. After the posterior tympanotomy, a small bony overhang was evident and removed over the round window. The cochleostomy was drilled immediately inferior and slightly anterior to the round window membrane and scala tympani¹³ was entered as described above.

Cochlear microphonics were evident during all stages of the procedure. Amplitudes of the cochlear microphonics

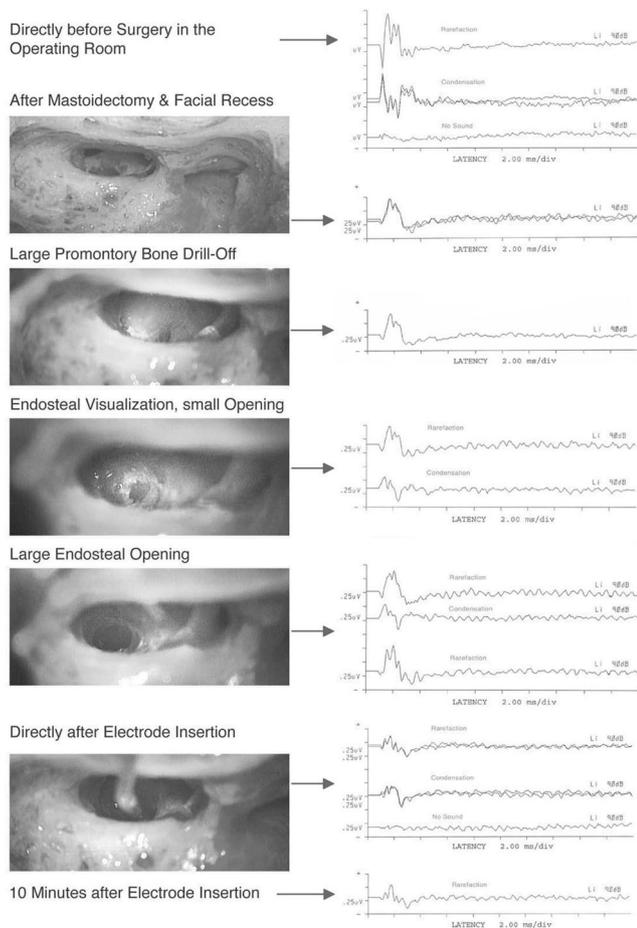


Fig. 2. Sequence of surgical steps with related click-evoked (90 dBn hearing level) cochlear microphonics. A two-channel recording was undertaken using a bandwidth of 100 to 3000 Hz and a time window of 20 msec (abscissa). The ordinate of each recording shows the resulting voltages measured in the far field. To confirm the presence of cochlear microphonics, each measurement was performed using a reversal in click polarity, which results in inversion of the recorded waveform. Amplitudes decreased after draping and after electrode insertion. Thus, drilling of the cochleostomy did not affect amplitudes of the cochlear microphonics. Surgical images were digitally enhanced.

were reduced somewhat as a result of sterile draping. Amplitudes of the cochlear microphonics remained constant during the entire surgical approach including drilling of the promontory to the level of the cochlear scala tympani endosteum, opening the endosteum with a drill, and further enlargement of the cochleostomy with perilymph evacuation. After complete electrode insertion, the amplitude of the cochlear microphonics diminished somewhat but remained robust. Ten minutes after electrode insertion and cochleostomy packing, a cochlear microphonic was still evident and quite similar in morphology and amplitude to that obtained previously. Electrode impedance and intracochlear evoked compound action potentials measurements using the manufacturer's software (Neural Response Imaging; NRI Advanced Bionics, Sylmar, CA, U.S.A.) were normal across the electrode array. After wound closure, a transorbital x-ray¹⁴ was obtained and

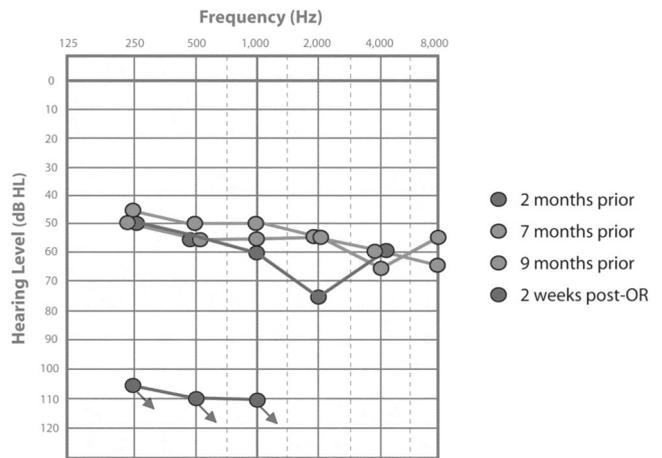


Fig. 3. Sequence of air conduction thresholds evaluated on the implanted ear via visual response audiometry (VRA) at different intervals before surgery and at 2 weeks postoperatively. No reproducible thresholds were measured after surgery, implying that residual hearing was lost on that ear.

confirmed a 360-degree intracochlear electrode placement. The patient's postoperative course was uncomplicated.

At the 2-week follow-up interval, the child underwent behavioral audiometric assessment using visual response audiometry. A profound hearing loss was evident in the implanted ear and contralateral thresholds remained unchanged from preoperative values. Figure 3 shows the child's unaided behavioral audiograms before and after implantation.

DISCUSSION

This report describes a technique for measuring cochlear function in patients undergoing cochlear implantation. The fact that patients with auditory neuropathy typically have some degree of residual cochlear function and many will undergo cochlear implantation surgery makes this group ideal for studying the potentially adverse effects of electrode insertion. Moreover, this technique may ultimately prove useful for functionally quantifying residual hair cell populations. Since preservation of residual hearing in the implanted ear is not an anticipated outcome in most cochlear implantation surgeries, no additional risks are incurred.

The findings of the study are noteworthy. Mastoidectomy, promontory drilling with a high-speed drill, scalar opening, and large cochleostomy with some perilymph evacuation did not diminish the amplitude of the measured cochlear microphonics. This evidence suggests that in the present case, the surgical approach did not severely affect the normal intracochlear physiologic mechanisms to the point that hair cell activation was lost. After electrode insertion, a notable drop in cochlear microphonic amplitude was immediately evident, although the cochlear microphonics remained measurable. This fact tells us that electrode insertion did not result in instantaneous, complete disruption of hair cell function. At the 10-minute postinsertion interval, the cochlear microphonic remained stable and again was easily measurable, implying persistent cochlear function. One potential explanation for the

reduction in cochlear microphonic amplitude might be altered intracochlear mechanics by the electrode array at the level of the basilar membrane. Kiefer et al.¹⁵ have demonstrated fixation of the basilar membrane after electrode insertion that can lead to hearing deterioration as well as to frequency shifts. The method of recording in this report, however, was not frequency specific and thus did not allow for such determinations. Investigations are now ongoing using frequency-specific stimuli similar to that shown in Figure 1.

Another interesting finding was that at the 2-week follow-up, no residual hearing in the implanted ear was measurable. Presumably, intracochlear events beyond the 10-minute postelectrode insertion interval were likely responsible for the loss of hearing. As the child had significant residual hearing preoperatively, the loss of hearing in the implanted ear is likely secondary to a loss of hair cell function. Unfortunately, repeat electrophysiologic measures of the cochlear microphonics obtained in the operating room under anesthesia could not be undertaken in the outpatient setting to corroborate these findings. Defining the temporal sequence of these events will be critical for better understanding of the mechanisms responsible for implant-induced cochlear dysfunction. Candidate processes that might be at work include ischemic injury, post-traumatic apoptosis, inflammation-induced cell loss, and loss of membrane potentials, to name just a few. Further studies are needed.

CONCLUSION

This report describes a technique for monitoring cochlear function during cochlear implantation in a patient with auditory neuropathy. The technique may prove useful for studying the effects of electrode insertion on residual hearing as well as functionally quantifying residual hair cell populations. The findings from such studies may prove to be important when hearing preservation approaches become commonplace. Future studies will explore various tonotopic regions of the cochlea, the temporal patterns of cochlear function loss, and modifications of

the current surgical procedure that may result in greater hearing preservation.

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