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Research paper

Delayed loss of hearing after hearing preservation cochlear implantation: Human temporal bone pathology and implications for etiology☆

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ABSTRACT

After initially successful preservation of residual hearing with cochlear implantation, some patients experience subsequent delayed hearing loss. The etiology of such delayed hearing loss is unknown. Human temporal bone pathology is critically important in investigating the etiology, and directing future efforts to maximize long term hearing preservation in cochlear implant patients. Here we present the temporal bone pathology from a patient implanted during life with an Iowa/Nucleus Hybrid S8 implant, with initially preserved residual hearing and subsequent hearing loss. Both temporal bones were removed for histologic processing and evaluated. Complete clinical and audiologic records were available. He had bilateral symmetric high frequency severe to profound hearing loss prior to implantation. Since he was implanted unilaterally, the unimplanted ear was presumed to be representative of the pre-implantation pathology related to his hearing loss. The implanted and contralateral unimplanted temporal bones both showed complete degeneration of inner hair cells and outer hair cells in the basal half of the cochleae, and only mild patchy loss of inner hair cells and outer hair cells in the apical half. The total spiral ganglion neuron counts were similar in both ears: 15,138 (56% of normal for age) in the unimplanted right ear and 13,722 (51% of normal for age) in the implanted left ear. In the basal turn of the implanted left cochlea, loose fibrous tissue and new bone formation filled the scala tympani, and part of the scala vestibuli. Delayed loss of initially preserved hearing after cochlear implantation was not explained by additional post-implantation degeneration of hair cells or spiral ganglion neurons in this patient. Decreased compliance at the round window and increased damping in the scala tympani due to intracochlear fibrosis and new bone formation might explain part of the post-implantation hearing loss. Reduction of the inflammatory and immune response to cochlear implantation may lead to better long term hearing preservation post-implantation.

1. Introduction

The cochlear implant is a highly successful neural prosthesis, which restores or improves speech understanding in patients with severe to profound sensorineural hearing loss. Over the past three decades, the criteria for cochlear implant candidacy have expanded considerably due to improvements in both cochlear implant performance and the ability to preserve residual hearing with cochlear implantation. On March 20 2014, the United States Food and Drug Administration approved the Nucleus® Hybrid™ L24 Cochlear Implant System (Cochlear Limited, New South Wales, Australia) for patients with severe to profound high frequency sensorineural hearing loss, yet normal to moderately impaired low frequency

Abbreviations: ABR, Auditory Brainstem Response (ABR); SGN(s), spiral ganglion neuron(s); dB, decibels; Hz, Hertz; KHz, kilohertz; mm, millimeters

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hearing (www.fda.gov). After multiple clinical trials demonstrating the feasibility of hearing preservation and benefits of shorter electrodes intended for combined electric and acoustic stimulation (Gantz and Turner, 2004; Gantz et al., 2009; Lenarz et al., 2013), cochlear implantation for patients with significant residual low frequency hearing has transitioned from an investigational procedure to routine care.

Initial preservation of residual hearing after cochlear implantation can be achieved to varying degrees in 50%–100% of cases (Lenarz et al., 2013; Adunka et al., 2013; Huarte and Roland, 2014; Usami et al., 2014; Gstoettner et al., 2009). When residual hearing is preserved, patients may utilize both electric and acoustic hearing in the implanted ear. The benefits of combined electric and acoustic hearing in the same ear include better hearing in background noise and in quiet, and better spatial localization (Reiss et al., 2012a; Gantz et al., 2009; Turner et al., 2008; Gantz and Turner, 2004; Gifford et al., 2014; Kiefer et al., 2005). These benefits occur when the preserved hearing is in the functional acoustic range (less than 90 dB pure tone average for 125 Hz to 1.5 KHz) (Roland et al. submitted 2015; Gantz et al., 2015). Furthermore, preservation of low frequency hearing is important for music appreciation in patients with electric-acoustic implants (Golub et al., 2012; Woodson et al., 2009).

While many patients with preserved hearing after implantation maintain that hearing level, a subset of these patients experience progressive hearing loss over the months following cochlear implantation. Delayed post-implantation hearing loss has been reported in 15–56% of patients with initially preserved hearing (Gifford et al., 2013; Reiss et al., 2012b; Van Abel et al., 2015; Lenarz et al., 2013; Adunka et al., 2013). In the Hybrid 10 clinical trial, for example, although only 2 out of 87 patients were found to have total hearing loss at the initial one month follow up, an additional 6 patients progressed to total hearing loss between 3 and 24 months after implantation (Gantz et al., 2009). Furthermore, between 3 and 12 months after implantation, hearing loss progressed more than 30 dB in 25% of the patients (Gantz et al., 2009).

The etiology of this delayed hearing loss after implantation is not well understood. Possible etiologies include (1) inflammatory cascade (O'Leary et al., 2013) and immunogenic response (Nadol et al., 2008), (2) excitotoxicity from electrical stimulation (Kopelovich et al., 2015), (3)delayed degeneration of hair cells (Eshraghi et al., 2007), spiral ganglion neurons, or their synapses, (4) delayed effects of trauma to intracochlear structures such as the stria vascularis or spiral ligament, (5) progressive alterations in cochlear mechanics due to intracochlear fibrosis and/or new bone formation, or other disease processes such as intracochlear otosclerosis, and (6) post-implantation conductive hearing loss (Chole et al., 2014). Understanding the etiology of delayed post implantation hearing loss is critical for guiding both clinical management of cochlear implant patients with significant residual hearing and future research directed toward improving hearing preservation with cochlear implantation.

Here we present the human temporal bone pathology from a patient implanted during life with the Iowa/Nucleus Hybrid S8 cochlear implant, who had delayed loss of initially preserved hearing after implantation. Multiple potential mechanisms of the delayed loss of residual hearing based on the histopathologic findings and cochlear mechanics are discussed.

2. Materials and methods

2.1. Case report

This 70 year old man had slowly progressive, high frequency sensorineural hearing loss that was first diagnosed at approximately 30 years of age. As a factory worker, he had occupational noise exposure for many years. He also had two brothers with hearing loss of unknown etiology and unknown age of onset. The etiology of his hearing loss was presumably related to genetic predisposition and noise exposure.

He was fitted with binaural amplification at age 42. He had progressive hearing loss, and underwent a cochlear implant evaluation because of limited benefit from his binaural amplification (Fig. 1A, Table 1). At age 63, he underwent cochlear implantation of the left ear with the Iowa/Nucleus Hybrid S8 electrode Freedom cochlear implant (Cochlear Americas, CO, USA). The Hybrid S8 electrode array is 10 mm in length with 6 channels distributed over the distal 4.3 mm (Fig. 2). A canal wall up mastoidectomy with facial recess approach was used, and a 0.5 mm cochleostomy was drilled anterior and inferior to the round window. A “soft surgical technique” was employed; this included reduced drill speed, atraumatic opening of the cochlear endosteum with a microinstrument (rather than entry into the cochlea with the drill), avoidance of suctioning once the scala tympani was opened, and slow insertion of the electrode. All 6 electrode contacts were fully inserted, and the cochleostomy was sealed with fascia.

An initial post-operative audiogram at 4 weeks after implantation demonstrated preservation of residual low frequency hearing at a level of moderate to severe hearing loss (Fig. 1B). A follow up audiogram at 18 weeks after implantation identified progression of left sided hearing loss to a profound level (Fig. 1C). The patient did not report a sudden decrement in his hearing or cochlear implant performance. He was treated with oral prednisone, but the left sided hearing loss did not recover (Fig. 1D).

Of note, he did not receive excessive electrical stimulation of his cochlear implant. Levels of stimulation for his cochlear implant between 4 and 18 weeks were similar, for example, to levels typically programmed for Nucleus® Contour Advance™ implantees (Cochlear Ltd., Australia) (Fig. 3A). The impedances of the 6 electrodes in his S8 cochlear implant did not increase over time (Fig. 3B). At 6 months, the impedances for electrodes 4 and 5 decreased (Fig. 3B). This correlated with the general timing of hearing loss, however, the reason for the decrease in impedances in these electrodes is not clear.

At 4 years post-implantation, the performance as measured by CNC word recognition was 28% for the left CI alone and 73% in the bimodal condition (left ear with electric stimulation via cochlear implant and right ear with hearing aid) (Table 1). Since he had significant benefit in the bimodal condition, he continued to wear his left cochlear implant (with electric stimulation only) and right hearing aid.

The patient passed away 7 years after cochlear implantation due to complications of bladder cancer.

2.2. Histologic preparation

Both temporal bones were removed at 35 h after death, and fixed in formalin. High resolution temporal bone protocol thin slice (0.5 mm collimation) multidetector computed tomography (CT) imaging was performed on the specimens. The cochlear implant electrode was removed from the implanted left temporal bone. The specimens were then decalcified in ethylenediamine tetra-acetic acid, dehydrated in graded alcohols, embedded in celloidin, and serially sectioned in the axial plane at a thickness of 20 um. Every 10th section was stained with Hematoxylin and Eosin and mounted on a glass slide for histologic examination (Merchant, 2010).

A 2 dimensional (2D) reconstruction of each cochlea was performed (Merchant, 2010). In this method, tangential sections at the level of the inner and outer pillar cells are used to calculate the cochlear duct length. Cell counts of inner hair cells, outer hair cells,