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Cochlear Histopathology as Seen in Two Patients with a Cochlear Implant Electrode with Positioner Short Title: Histopathology in Two Patients with Positioner

Takefumi Kamakura, M.D., Ph.D.^{1,2} and Joseph B. Nadol Jr., M.D.^{1,2}

¹Human Otopathology Laboratory, Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, Boston, MA

²Department of Otology and Laryngology, Harvard Medical School, Boston, MA

Abstract

Hypothesis—This study reports the cochlear histopathology of two cases who during life underwent cochlear implantation with a positioner.

Background—A silastic positioner introduced by the Advanced Bionics Corporation in 1999 was designed to position the electrode of the cochlear implant close to the modiolus. The positioner was recalled in the United States in July 2002 because of an apparent higher incidence of bacterial meningitis in patients in whom the positioner had been placed.

Methods—Four celloidin-embedded temporal bones from two patients with cochlear implants with a positioner from the temporal bone collection of the Massachusetts Eye and Ear Infirmary were included in the study. In a previous study, we reported histopathologic findings in Case 1, and in this report, we present the findings in a second case in a 94-year-old woman (Case 2), and the similarities and differences between the two cases. All four specimens were prepared for histologic study by conventional techniques and 2-D reconstruction.

Results—Evidence of insertion trauma was seen in all three implanted specimens. More significant trauma was found in Case 2 than Case 1 including disruption of the osseous spiral lamina and the basilar membrane. In addition, there was more new fibrous tissue and bone in Case 2 than Case 1. There was a large fluid space in all three implanted temporal bones around the electrode and positioner.

Conclusion—The findings seen in the two cases may help to explain the increased risk of meningitis in patients implanted with a positioner.

Keywords

Histopathology; cochlear implant; positioner; fibrous sheath; insertion trauma; osseous spiral lamina; human

Corresponding Author: Joseph B Nadol Jr., Human Otopathology Laboratory, Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, MA, 02114, Phone: (617) 573-3652, Fax: (617) 573-3939, joseph_nadol@meei.harvard.edu.

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Introduction

An electrode combined with a silastic positioner was introduced by the manufacturers of the Clarion® cochlear implant system (Advanced Bionics Corporation) in 1999. This positioner was designed to achieve juxtaposition of the implanted electrode to the modiolus, in order to improve frequency selectivity and to reduce power consumption. Electrophysiologic studies have indicated that the threshold of the evoked auditory brainstem response is lower in an ear with a positioner as compared to an ear without the positioner (1, 2). Validation of a more perimodiolar position of the electrode has been reported in histologic (3, 4, 5, 6, 7) and radiographic (5, 8) studies of cadaveric human temporal bones. However, considerable trauma to the basilar membrane and the osseous spiral lamina was also reported in these cadaveric specimens (5, 6, 7, 9).

In July 2002, the positioner was voluntarily recalled in the United States due to an apparent higher incidence of bacterial meningitis in patients who had undergone cochlear implantation with the positioner (10). Possible causes for a higher incidence of otogenic meningitis following cochlear implantation with positioner (11, 12) have been proposed. Arnold et al. (11) suggested a fluid leak at the cochleostomy caused by incomplete packing, a mismatch between the diameter of the cochleostomy and electrode, rupture of the cochleostomy seal, and the apposition of a two silicone components such as the electrode with positioner as possible causes of meningitis. Wei et al. (12) concluded in an animal study that severe surgical trauma to the osseous spiral lamina and modiolus may increase the risk of pneumococcal meningitis.

The Temporal Bone Laboratory at the Massachusetts Eye and Ear Infirmary has acquired four temporal bone specimens from two patients who had undergone cochlear implantation using the positioner bilaterally in Case 1 and unilaterally in Case 2 (Table 1). The clinical history of one patient (Case 1) has already been reported (13). The clinical history and histologic findings of Case 2 are presented herein. Although these two patients did not suffer from bacterial meningitis, the comparison of the histopathologic findings in the two patients may help to elucidate possible causes of a higher incidence of bacterial meningitis associated with the use of a positioner. In addition, significant trauma to the inner ear was found in all three ears implanted with a positioner.

Materials and methods

Case report – Case 2

This 94-year-old woman had a history of progressive bilateral sensorineural hearing loss for at least 25 years for which she wore hearing aids. The etiology of the hearing loss was not known; however a genetic etiology was suspected given that at least four generations were affected including the patient herself, and her mother, her son, who also received a cochlear implant, and finally the patient's granddaughter. An audiogram performed at the age of 82 (Figure 1) showed a bilateral sensorineural hearing loss of approximately 85 dB in both ears, and speech discrimination scores of 4% on the right and 8% on the left using NU6 word lists. At the age of 82, she underwent a right cochlear implantation using an Advanced Bionics High focus CII® cochlear implant with positioner. At eight years postoperatively,

she was seen in follow-up for reprogramming and her HINT score was 28% in the implanted ear corresponding to a CNC word score of less than or equal to 10%. Her past medical history included hypertension, shingles, several bouts of pneumonia, and a subdural hematoma drained at the age of 90.

Histological techniques

At 16.5 hours postmortem, both temporal bones of Case 2 were removed and fixed in 10% buffered formalin. After decalcification in ethylene diamine tetra-acetic acid (EDTA) the electrode array was removed and the positioner was retained within the cochlea during the remainder of the histologic preparation. The specimens were dehydrated in alcohol, embedded in celloidin, and sectioned at a thickness of 20 μ m in a horizontal axial plane. Every tenth section was stained with hematoxylin and eosin, and mounted on glass slides for subsequent reconstruction and study.

2-D and 3-D reconstruction of the cochlea

Every tenth section was studied by light microscopy. The serial sections of both temporal bones were reconstructed by conventional 2-D methods (14, 15). In addition, 3-D reconstruction was performed in order to evaluate boney deposition in Rosenthal's canal in the right implanted ear of Case 2. The technique for 3-D reconstruction has been described previously (16). Digital images of each mounted slide were captured at low power (1.25 $\times$) under a light microscope fitted with a high-resolution camera (Olympus BX51, Olympus DP71). These images were cropped, resampled, registered, and segmented using the Amira 6 reconstruction and modeling software (Mercury Computer System/TGS, San Diego, CA). Each 2-D images was segmented by identifying and tagging Rosenthal's canal and new bone inside the canal. Surface renderings of the segmented materials were generated and used to visualize the 3-D reconstruction. Using surface rendering, the volume of each material (Rosenthal's canal and new bone) was measured with the Amira's Volume Edit Tool.

Results

Case 2

Cochlear Duct—On 2-D reconstruction both cochleas possessed 2-1/2 turns. The length of the cochlear duct on the right side (implanted side) was 35.24 mm and 33.71 mm on the left (unimplanted side). In the implanted ear, there was severe fibrosis and new bone formation (Figure 2A, B) and no obvious remaining hair cells throughout the cochlea. In the left ear, loss of inner and outer hair cells was seen. There was no organ of Corti in the basal 18 millimeters of the cochlea.

Cochlear implant and positioner—Both the electrode array and the positioner could be followed in their tracks through the right cochlea. The electrode entered anterior to the cochlea at 4.0 mm from the round window. The electrode track extended in the scala tympani and in the spiral ligament apically to 25 mm from the round window. The positioner could be followed through the same cochleostomy to its termination at approximately 19 mm from the round window. The track of the positioner could be seen both in the scala tympani and scala vestibuli (Figure 2A). In the apical half of the basal turn, the electrode

array distal to the positioner was located in both the scala tympani and scala vestibuli and did not achieve a perimodiolar position (Figure 2A). The positioner created a track of large diameter which remained near the lateral cochlear wall and resulted in considerable disruption of the basilar membrane and upfracture of the osseous spiral lamina (Figure 2B). There was a continuous fibrous sheath surrounding the electrode array and the positioner both near the cochleostomy and apical to it.

The outline of the track of the positioner could be seen with the condenser of the microscope defocused (Figure 2C). There was a fluid space sometimes containing eosinophilic fluid between the positioner and fibrous tissue within the cochlea. In some sections, a foreign body reaction could be seen adjacent to the electrode array in the form of multinucleated foreign body giant cells and lymphocytic cell infiltration (Figure 2D).

In summary, where the electrode array consisted of both the positioner and electrode, the positioner seemed to occupy space between the electrode and the lateral cochlear wall and displaced the electrode itself closer to the modiolus in the basal turn. There was a fibrous sheath surrounding the electrode array and the positioner. The normal fluid space of the cochlea was largely obliterated by fibrous and osseous tissue. There was significant fracture/dislocation of the osseous spiral lamina and basilar membrane presumably caused by the positioner. A fluid containing space was identified around the track of the positioner.

Rosenthal's Canal—There was severe degeneration of the spiral ganglion cells in the implanted right ear. The corrected spiral ganglion cell count on the right side (implanted side) for segment I was 299 cells; segment II was 1,115 cells; segment III was 177 cells, segment IV was 449 cells. The total corrected spiral ganglion cell count was 2,040 which represents 12% of normal for age. The corrected cell count on the left side (unimplanted side) for segment I was 292 cells; segment II was 4,570 cells; segment III was 2,462 cells, segment IV was 1,822 cells. The total corrected spiral ganglion cell count was 10,146 which represents 61% of normal for age. New bone was present in Rosenthal's canal (Figure 2A), and 3-D reconstruction of Rosenthal's canal on the right revealed that 43.4% of the canal was occupied by new bone formation (Figure 3), and almost all of the remainder of Rosenthal's canal was filled with fibrous tissue.

Comparison between the two cases—We compared the similarities and differences among the four ears of the two cases in Table 2. In the three implanted ears, there were fractures of the osseous spiral lamina and disruption of the basilar membrane. However, the incidence of the fractures was greater in the right ear of Case 2 than either ear of Case 1. There were significant differences between two cases in spiral ganglion cells count, word recognition scores, the amount of fibrous tissue between positioner and electrode, and new bone formation within the cochlea and Rosenthal's canal.

Discussion

Wide variation in amount of perielectrode fibrous sheath and new bone

As shown in Table 2, there was a fibrous sheath around the electrode and positioner at the cochleostomy, but little between the electrode and positioner in Case 1 (13). In contrast,

there was an abundant fibrous sheath around/between the electrode and positioner in Case 2. Formation of a fibrous sheath around biomaterials involves a foreign body reaction, which consists of protein adsorption on the implant surface, inflammatory cell infiltration, macrophage fusion into foreign body giant cells, fibroblast activation, and fibrous encapsulation of the foreign body (17). Macrophages that attach and recognize an implanted biomaterial larger than 5 μm attempt to coalesce to form foreign body giant cells (18). The chronic inflammatory response includes granulation tissue identified by the presence of macrophages, infiltration of fibroblasts, and angiogenesis. Fibroblasts activated by macrophages and foreign body giant cells synthesize and deposit collagen that results in material encapsulation (17, 18). The foreign body giant cell infiltration and granulomatous reaction were observed in 27 of 28 temporal bones from individuals who had undergone cochlear implantation (19), but the degree of inflammatory cell infiltration varied among individuals. Possible causes of variation in the inflammatory reaction may include individual biologic variation, tissue response modifiers, or surgical trauma. Tissue response modifiers, such as corticosteroids, non-steroid anti-inflammatory drugs (NSAIDs), antifibrotic agents, and siRNAs, may inhibit the foreign body reaction. There was more evidence of surgical trauma in Case 2 as compared to Case 1 including widespread fracture and dislocation of the osseous spiral lamina and the basilar membrane. A traumatic insertion of a cochlear implant can produce new bone and fibrous tissue in human cases (20) and animal models (21).

Residual spiral ganglion cell count after cochlear implantation

A negative correlation between total amount of new fibrous and boney tissue and residual spiral ganglion cells in segment I of Rosenthal's canal has been reported in humans (20). Seyyedi et al. reported that the number of residual spiral ganglion cells is positively correlated with word recognition scores between ears of the same individual after cochlear implantation (22). These studies together suggest that insertion trauma of the cochlear implant may cause a poorer hearing outcome. In the present study, there was more new bone and fibrous tissue in the cochlea and Rosenthal's canal in Case 2 than in Case 1. In Case 2, new bone formation occupied 43.4% of the volume of Rosenthal's canal. The residual spiral ganglion cells count was markedly reduced on the implanted side compared to the unimplanted side, and the word recognition score was poor.

Possible causes of bacterial meningitis after cochlear implant

Arnold et al. (11) suggested that one of the possible causes for otogenic meningitis after cochlear implantation was the use of two apposed silastic components (electrode and positioner), which may prevent complete sealing of the electrode and positioner from the fluid space of the inner ear. Wei et al. (12) demonstrated that severe surgical trauma also increased the risk of bacterial meningitis in an animal model, and they suggested that the use of positioner increased the likelihood of trauma to the osseous spiral lamina and/or modiolus.

How long does the risk of positioner-related meningitis continue?

Lalwani et al. reported the longitudinal risk of meningitis with the use of a positioner (23). The risk of meningitis is highest within the first 24 months after implantation and

significantly reduced more than 96 months after implantation. However, a case of positioner-related meningitis about 120 months after implantation has been reported (23).

Conclusion

The histopathology of the cochlear implanted with an electrode positioner during life has been reported herein. More significant trauma was found in Case 2 than Case 1 including disruption of the osseous spiral lamina and the basilar membrane. In addition, there was more new fibrous tissue and bone in Case 2 than Case 1. There was a large fluid space in all three implanted temporal bones which may have a role in the increased risk of meningitis in patients implanted with a positioner.

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Figure 1. Preoperative audiogram of Case 2 at the age of 82. Speech discrimination scores were 4% on the right and 8% on the left using NU6 word lists.

Figure 2. Positioner (P) and electrode (E) in the right cochlea of Case 2

A: Positioner and electrode were seen in both scala tympani and scala vestibuli. New bone (NB) was also seen in Rosenthal's canal.

B: A higher power micrograph of the basal and middle turn of the cochlea. The positioner (P) created a track of larger diameter than that of the electrode (E₁) and remained near the lateral cochlear wall and resulted in considerable disruption of the basilar membrane with upfracture of the osseous spiral lamina (OSL). In the cochlea apical to the positioner, the electrode (E₂) lay against the lateral cochlear wall.

C: Millimeter 14 of the right cochlea of Case 2. The outline of the track of the positioner (O) could be easily seen with the condenser of the microscope defocused. There was a fluid space with enclosed eosinophilic proteinaceous fluid (EP), between the positioner and the fibrous tissue or the lateral cochlear wall.

D: Track of the cochlear implant (T) in the right temporal bone of Case 2 at millimeter 14. There were both foreign body giant cells (FBGC) and a lymphocytic infiltrate (L) adjacent to the electrode track (T).

Figure 3.
3-D reconstruction of Rosenthal's canal of the right temporal bone of Case 2 showing new bone (blue) within the spaces of the Rosenthal's canal (red).

Table 1

Demographic data in the two cases who in life underwent cochlear implantation with positioner.

	Case 1 (cited from (16))	Case 2
Age	74	94
Sex	Female	Female
Presumed cause of deafness	otosclerosis	genetic
Implanted ear	both	right
Duration of implantation (years)	8	12

Table 2

Comparison of similarities and differences among the four ears of the two cases.

Side	Case 1		Case 2	
	L	R	L	R
Otologic disease	Otosclerosis		Genetic etiology suspected	
Cochlear implant	Yes	Yes	No	Yes
Spiral ganglion cells (% normal age matched control)	55%	51%	61%	12%
Word recognition score (%)	66%	66%	-	<10%
Fibrous sheath between positioner and electrode (1–4+)	1+	1+	-	3+
Fluid space around positioner and electrode (1–4+)	4+	4+	-	1+
New bone formation	Basal turn	Basal~middle turn	No	All turns
Fibrous tissue	All turns	Basal~middle turn	No	All turns, severe
Endolymphatic hydrops	Yes	Yes	No	Yes
Perimodiolar position of electrode achieved	Yes	Yes	-	Yes
Fractures of osseous spiral lamina	Partial along the positioner	Intensive along the positioner	-	Throughout track of the positioner
Disruptions of basilar membrane	Throughout track of the positioner	Throughout track of the positioner	-	Throughout track of the positioner
New bone formation inside Rosenthal's canal	None	Yes	43.4% of volume of canal	