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Implantation of the completely ossified cochlea: An image-guided approach

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Abstract

Objectives—To report a novel modification of the cochlear drill-out procedure that utilizes customized microstereotactic frames as drill guides.

Patient(s)—A 34-year-old man with an 18-year history of profound bilateral hearing loss and completely ossified cochleae that underwent a prior unsuccessful conventional cochlear drill-out procedure in the contralateral ear.

Interventions—Image-guided cochlear implantation using customized microstereotactic frames to drill linear basal and apical cochlear tunnels.

Main outcome measures—Transfacial recess cochlear drill-out procedure with full electrode insertion.

Results—Two linear paths were drilled using customized microstereotactic frames targeting the proximal and distal basal turn followed by a full split array insertion. Postoperative imaging confirmed two cochlear tunnels straddling the modiolus with adequate clearance of the facial nerve and internal carotid artery. The patient received auditory benefit with device use and did not experience any surgical complication.

Conclusions—Successful cochlear implantation in the setting of total scalar obliteration poses a significant challenge. Image guidance technology may assist in navigating the ossified cochlea facilitating safe and precise cochlear tunnel drilling.

Keywords

cochlear implantation; ossified cochlea; image guidance; hearing loss; minimally-invasive

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Conflicts of interest: Robert F Labadie, Benoit M Dawant, and Jack H Noble have pending patent applications on various components of the technology, which was used to perform the surgery described. Robert F Labadie is a consultant for Cochlear Corp., MED-EL GmbH, and Ototronix, LLC.

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INTRODUCTION

Despite early childhood vaccination programs, bacterial meningitis remains a common cause of acquired pediatric deafness. Severe-to-profound hearing loss occurs in approximately 10% of patients following bacterial meningitis, 80% of which develop varying degrees of labyrinthitis ossificans.^{1,2} In spite of progressive cochlear ossification, temporal bone specimens procured from patients with a history of meningitis demonstrate that sufficient populations of spiral ganglion cells may survive and clinical studies have confirmed that many subjects gain auditory benefit from electrical stimulation.^{2,3}

Over the last several decades, image guidance technologies have undergone tremendous refinement and have gained increasing popularity in the surgical community. One such method, developed at the authors' institution for cochlear implantation, involves using customized microstereotactic frames to drill linear paths from the mastoid cortex to the cochlea.⁴⁻⁷ The microstereotactic frame is designed to mount on three bone-anchored fiducial markers and to constrain a drill along a path determined safe from a temporal bone computed tomography (CT) scan. Such constrained linear drilling may be particularly useful in navigating the ossified cochlea given restricted access through the facial recess corridor, close proximity to vital structures including the facial nerve, modiolus, and internal carotid artery and obscured surgical landmarks from neossification.⁸ We report use of such a system for cochlear drill-out in a patient with complete cochlear ossification. Proximal and distal basal turn access permitted full split array electrode insertion after an unsuccessful attempt was made on the contralateral side using conventional technique. Herein, we present the clinical history, surgical technique and outcome of this index patient.

CASE DESCRIPTION

An otherwise healthy 34-year-old male with bilateral profound hearing loss was referred for cochlear implant candidacy evaluation. At the age of 16 years, the patient was diagnosed with bacterial meningitis and experienced sudden bilateral deafness and since that time has remained dependent on manual communication. Fine-cut CT of the temporal bones revealed complete cochlear ossification (Figure 1A) and magnetic resonance imaging confirmed an absence of inner ear fluid signal on T2-weighted sequences. The patient was counseled on the risks of cochlear implant surgery and the potential limited benefit given an 18-year history of auditory deprivation in addition to total cochlear ossification.

After obtaining consent, the patient was brought to the operating room for a right-sided conventional cochlear implant drill-out procedure. Following a mastoidectomy and facial recess approach, the middle ear was entered. Using a 1mm diamond burr, a cochlear drill-out was attempted. Given extensive ossification, it was difficult to decipher ossified cochlear lumen from endochondral bone. The decision was made to terminate the procedure without electrode placement. The first operation took 1.5 hours but was unsuccessful.

Following his first surgery, the patient expressed interest in proceeding with a second attempt on the contralateral side. Given the difficulties encountered on the right side, the decision was made to utilize intraoperative image guidance. An institutional review board (IRB)-approved research protocol using custom microstereotactic frames to target the cochlea was presented to the patient, and informed consent was obtained.

The Med-El split array (GB; Innsbruck, Austria) was chosen for implantation. This device contains two active lead wires and a single ground electrode. The basal array contains 14 electrode contacts paired into 7 channels with a recommend insertion depth of 9.6 mm, while the apical array houses 10 electrode contacts paired into 5 channels with an ideal insertion depth of 7.4 mm.

Prior to surgery, a fine-cut temporal bone CT was processed to automatically segment the concerned structures of the temporal bone including the facial nerve, chorda tympani, ossicles, and external auditory canal using atlas-based segmentation algorithms (Figure 1B).^{9,10} The surgeon then manually selected two drill paths; one to target the basal turn and another to target the second turn of the cochlea, creating two tunnels straddling the modiolus (Figure 1C&D).

During surgery, a postauricular incision was made and three bone-anchored fiducial markers were implanted. An intraoperative CT scan was acquired using the xCAT ENT system (Xoran Technologies, Ann Arbor, MI). This intraoperative CT was rigidly registered to the preoperative CT.¹¹ The preplanned trajectories were then transformed to the intraoperative CT, and the three fiducial markers were localized. Based on the fiducial markers and the planned trajectories, two customized microstereotactic frames were designed and manufactured such that they would mount on the three fiducial markers and constrain the drill along the planned trajectories to the desired depth.^{5,7} The two microstereotactic frames were sterilized and made available to the surgeon for drilling.

Following CT acquisition, a mastoidectomy and facial recess was performed without exposing the mastoid segment of the facial nerve or chorda tympani. The mastoidectomy was performed to allow placement of the split array, which would not be possible via two linear drilled channels. The stapes was identified, the incudostapedial joint was divided and stapedial tendon was cut. The stapes suprastructure was then removed, leaving the footplate undisturbed. The microstereotactic frames for the basal and apical tunnels were then sequentially mounted on the fiducial markers and used to drill the two planned paths using a 1.6 mm diameter twist drill bit. Drilling was successfully performed without damage to any critical structures. A 1.3 mm flexible endoscope (Karl Storz, Tuttlingen, Germany) was then used to view the drilled channels (Figure 2A&B).

A tight subperiosteal pocket was fashioned, a trough for the fantail and electrode leads was created, and the receiver-stimulator package was placed. Full insertions of both the basal and apical electrodes were achieved and the inferior and superior cochlear tunnels were packed with fascia on the side opposite the modiolus in order to hold the electrodes in optimal position. Intraoperative electrode impedances and Auditory Nerve Response Telemetry™ (ANRT) were performed, and postoperative CT was acquired to document electrode position (Figure 3A–C).

Results

The split array was successfully implanted without injury to adjacent structures. The minimum distance between the petrous carotid and basal tunnel was 3 mm. Both arrays received a full insertion and intraoperative electrode impedances were within normal range. No detectable evoked compound action potential responses were elicited during intraoperative ANRT, which was not surprising given the extent of ossification and prolonged duration of deafness. The second procedure took a total of 4.5 hours including 1 hour 10 minutes for placing fiducial markers and CT scanning, a 1 hour delay due to a technical issue with creating a microstereotactic frame, and 2 hours and 20 minutes of surgical time. The patient awoke with House-Brackmann grade 1 (of 6) facial nerve function and did not experience delayed facial nerve paresis, vestibulopathy, or dysgeusia. Initial activation was performed 16 days following surgery. During initial testing, the patient reported auditory percepts from several channels and denied symptoms of aberrant non-auditory stimulation.

DISCUSSION

In order to optimize outcomes, the primary tenants of cochlear implant surgery should be observed. Electrodes should be placed in close proximity to the modiolus, injury to surviving neurosensory elements should be minimized and a full electrode insertion is desirable. Successful cochlear implantation in patients with complete cochlear obliteration remains challenging. Even in the hands of experienced surgeons, drill-out techniques are technically demanding given restricted exposure and tight anatomical confines of the middle ear, loss of surgical landmarks from dense neo-ossification and close proximity to vital structures including the internal carotid artery and facial nerve.

In 2003, Raine and colleagues provided the first report of an image-guided cochleostomy procedure.⁸ Similar to the presented case, they performed a two-tunnel cochlear drill-out procedure and implanted a split array. Using the Medtronic Xomed LandmarX system (Medtronic-Xomed, Jacksonville, FL), a surgical drill was fitted with a small infrared emitting diode and registered to a reference head frame. Eight fiducials were used to register the patient to the preoperative CT. Manual drilling was performed while verifying location and course with the surgical navigation system. Postoperative imaging and auditory performance was not reported.

In 2009, Barker and colleagues evaluated the benefit of intraoperative cone-beam CT during cochlear implantation using a cadaveric ossified cochlea model.¹² They cited several theoretical advantages of intraoperative CT guidance compared to conventional surgical navigation systems. First, image guidance based on preoperative CT is generally limited to ~2 mm accuracy. Second, preoperative images do not permit assessment of anatomical changes incurred during the course of surgery. Finally, without intraoperative CT, electrode placement cannot be adequately evaluated.

At the authors' institution, a customized, bone-mounted, drill guide system has been developed to perform minimally-invasive image-guided cochlear implantation with submillimetric accuracy.⁴⁻⁷ We present the first report, adapting this system, to perform a cochlear implant drill-out procedure demonstrating the feasibility, safety, and potential benefits of this approach. While the image-guided procedure took 3 times longer than the conventional approach, it was successful. We anticipate that in the future, the total operative time will decrease as a result of improved operator familiarity and further refined technology. While still an experimental prototype and not yet commercially available, such technology seems ideal for navigating the ossified cochlea where the surgeon must operate through a narrow corridor and critical structures including the carotid artery, facial nerve, and modiolus lie in close proximity.

CONCLUSION

Implantation of the ossified cochlea remains challenging. Conventional cochlear drill-out strategies are technically demanding, requiring that the surgeon estimate the location of the modiolus and internal carotid artery amidst dense neo-ossification. We present a novel modification of the cochlear drill-out procedure that utilizes customized microstereotactic frames as drill guides. Using such a system, we were able to safely and accurately approximate the scalar course, creating two cochlear tunnels in close proximity to the modiolus through a standard facial recess approach for a patient with completely ossified cochleae.

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Figure 1.

A) Preoperative axial CT of the left temporal bone. B) Enlarged view (corresponding to red box, Figure 1A) with results of automatic segmentation (ossicles = light blue; descending segment of the facial nerve = light purple). C) Preoperative trajectory scheme used for the cochlea drill-out procedure. The transfacial recess basal and D) apical tunnels were planned using a preoperative CT scan.

Figure 2.

A) Intraoperative view after opening the facial recess and drilling the basal (inferior) and apical (superior) tunnels (endoscopic view of the ossified cochlea within the apical tunnel in small black box, lower right hand corner). B) Intraoperative view after placement of split array electrodes.

Figure 3.

Postoperative CT with superimposed trajectory plans for the A) basal and B) apical electrode tunnels. C) Postoperative oblique coronal CT demonstrating a coplanar view of the two split electrodes (white arrow = basal electrode; black arrow = apical electrode).