Revision Cochlear Implantation Following Internal Auditory Canal Insertion

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**Objectives/Hypothesis:** In pediatric patients with congenital malformations of the inner ear, anomalies within the anatomy may facilitate unintentional insertion of the cochlear implant electrode into the internal auditory canal. Revision procedures for removal and replacement of cochlear implant electrodes following internal auditory canal insertion are fraught with potential danger, including the theoretical risk of injury to vasculature within the internal auditory canal, repeat insertion within the internal auditory canal, and cerebrospinal fluid leak. The objective of this presentation is to describe a technique for revision cochlear implantation following internal auditory canal insertion to minimize the potential associated risks.

**Study Design:** Case series.

**Methods:** A retrospective chart review was performed on all patients at a tertiary care facility who underwent revision cochlear implantation for internal auditory canal insertion between January 1999 and July 2011.

**Results:** A total of four patients referred from outside institutions have undergone revision cochlear implantation for internal auditory canal insertion. The records from these patients were reviewed. Electrodes were safely removed in all cases without injury to the anterior inferior cerebellar artery or its branches (i.e., labyrinthine artery). Complete insertion was accomplished on reimplantation. Neural response telemetry was performed in all cases, and responses were noted. Fluoroscopy was utilized to visualize electrode progression during insertion. A detailed description of the operative technique is provided.

**Conclusions:** This case series describes a technique for revision cochlear implantation that appears to be safe and effective in preventing potential associated complications.

**Key Words:** Cochlear implant, implants, pediatric otology, congenital anomalies, revision, internal auditory canal insertion, congenital cochlear anomalies, X-linked deafness.

**Level of Evidence:** 4

**INTRODUCTION**

Cochlear implantation has gained increasing popularity in the aural rehabilitation of pediatric and adult patients with severe to profound sensorineural hearing loss of various etiologies. In the vast majority of cases, cochlear implantation may be performed safely and effectively without significant complication or malposition of electrodes. However, in approximately 0.5% of patients, revision cochlear implantation is required for correction of malpositioned cochlear implant electrodes. Anomalies and malformations of the inner ear anomalies complicate the cochlear implantation procedure and are more commonly associated with malposition of electrodes during implantation. Incomplete and vestibular insertions are the most commonly encountered forms of electrode malposition. However, internal auditory canal (IAC) insertion has been documented in cochlear implant electrode malposition. Common cavity malformation and cochlear hypoplasia pose a challenge in accurate cochlear implant electrode placement, given the lack of normal cochlear architecture. In most previously reported cases of IAC insertion, common cavity malformation and cochlear hypoplasia were noted as mitigating factors in electrode malposition. In addition to common cavity and cochlear hypoplasia, anatomic anomalies associated with X-linked deafness also predispose patients to IAC insertion. Cochlear implantation in patients with X-linked deafness is a relatively new phenomenon. Patients with X-linked deafness have characteristic findings on computed tomography examination, including a shortened cochlea, absent lamina cribosa (the bony partition between the basal turn of the cochlea and the IAC), and bulbous fundus.

IAC insertion may be managed simply by deactivating the associated electrodes; however, in most cases, this appears to merely be a temporizing solution.
Patients often complain of discomfort in association with IAC insertion, ultimately resulting in the patient’s inability to use the cochlear implant device, necessitating reimplantation.\textsuperscript{5,7} The procedure of revision cochlear implantation following IAC electrode insertion is somewhat more involved than the traditional revision cochlear implant procedure.

Revision cochlear implantation following IAC insertion has multiple theoretical complications. Given the direct communication between cochleostomy and IAC, the risk of cerebrospinal fluid leak may be increased.\textsuperscript{5} In addition, there is likely a higher than normal probability of repeat IAC insertion on revision cochlear implantation following IAC insertion.\textsuperscript{6} Finally, given the integral relationship of the anterior inferior cerebellar artery with the nervous complex of the IAC (seventh and eight nerve complex), there is a theoretical risk of injury to this vital vascular structure with manipulation of electrodes inserted into the IAC.

The objective of this article is to describe a modified technique for revision cochlear implantation following IAC insertion to minimize the potential associated risks. The cochlear implant procedure will be detailed as well as procedural outcomes and cochlear implant performance. This technique can also be used on initial implantation in patients with X-linked deafness cochlear anomalies to prevent IAC insertion.

**MATERIALS AND METHODS**

**Patient Selection**

Upon obtaining approval from the institutional internal review board, charts from all patients who underwent cochlear implantation at the tertiary care medical center between January 1999 and July 2011 were identified and included. Charts were screened for history of revision cochlear implantation. Patients who underwent revision cochlear implantation for reasons other than IAC insertion were excluded from this study. Preoperative and postoperative implant performance, preoperative temporal bone imaging, operative reports, intraoperative photodocumentation, and intraoperative fluoroscopic images were reviewed.

**Intraoperative Fluoroscopic Technique and Safety**

Intraoperative fluoroscopy was performed utilizing the standard C-arm. Preoperatively, the C-arm fluoroscopic equipment was tested for proper function and placement. The patient was then brought into the operating theater. Upon induction of general anesthesia, the patient was placed in the supine position, and the bed was positioned at a right angle in relation to the anesthesia team. The C-arm was placed with the beam generator below the head of the table directed in an anti-Stenvers view. The beam was then narrowed and centered to ensure sufficient magnification of the image of the petrous ridge. Care was taken to avoid placing radiodense equipment (i.e., facial nerve monitoring electrodes, electrocardiogram leads, bispectral index monitor cable) directly in the path of fluoroscopy. During the procedures, still frame and video imaging were utilized as needed.

Fluoroscopic assisted cochlear implantation has previously been reported to be safe in assisting initial cochlear implantation in patients with cochlear malformations or anomalous anatomy.\textsuperscript{4,5} To ensure patient safety, fluoroscopy should be used only as necessary during the procedure. Additionally, the radiation safety officer should be consulted to obtain device-specific calibrated exposure levels. Most C-arm fluoroscopy units produce \(<10\) rad/min. The lens is within the penumbra of radiation exposure during fluoroscopy for visualization of the petrous ridge. To minimize the risk of radiation cataracts, the recommended total exposure to the lens should not exceed 100 to 200 rad.\textsuperscript{16,17} The average exposure during cochlear implantation was \(<2\) minutes of total exposure time. The estimated percentage dose to the lens is approximately 20%.\textsuperscript{5,6} Therefore, the total radiation exposure to the lens

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*Fig. 1. Intraoperative fluoroscopy configuration. With the patient in the supine position and the right ear in the operative position, the bed was positioned at a right angle with relation to the anesthesia team, and the C-arm was placed with the beam generator below the head of the table directed in an anti-Stenvers view. The beam was narrowed and centered to ensure sufficient magnification of the image of the petrous ridge. (Reprinted with permission from Coelho DH, Waltzman SB, Roland JT Jr. Implanting common cavity malformations using intraoperative fluoroscopy. Otol Neurotol 2008;29:914–919.)*
during the procedure is approximately 4 rad (2 minutes × 10 rad/min × 0.2). Lead aprons and thyroid shields should be placed under the patient preoperatively and should be worn by all staff in attendance.

**Revision Cochlear Implantation Surgical Technique in IAC Insertion With Common Cavity Malformation**

After induction of anesthesia and positioning as described above with the fluoroscopic C-arm apparatus, the patient was prepped and draped in the normal sterile fashion. The C-arm was also draped to maintain the sterility of the operative field. Prior to initiation of the procedure, a single still fluoroscopic image was obtained to ensure appropriate positioning of the C-arm, allowing for full visualization of the petrous ridge and adequate magnification of the fluoroscopic field. This also allowed for confirmation of the current positioning of the cochlear implant electrode prior to the procedure.

The traditional transmastoid facial recess approach was utilized for revision cochlear implantation in all cases. The previous incision was utilized for revision cochlear implantation. The proposed incision was infiltrated with 1:200,000 to 1:100,000 epinephrine. The incision was made utilizing the Shaw hemostatic scalp (Hemostatix Medical Devices, Cherry Hill, NJ). The device was identified early in the procedure, and the electrode lead (and ground if present) was severed just distal to the receiver/stimulator upon its encounter. This allowed for safe removal of the device without concern for incidental removal of the electrode from the cochlea. Adhesions within the mastoid were lysed, and soft tissue was removed to identify the entry of the cochlear implant electrode into the facial recess. The implant electrode was then severed at the level of the facial recess. Depending upon the latency to revision cochlear implantation, osteoneogenesis may have occurred within the mastoid and facial recess. Therefore, the mastoidectomy and facial recess were revised as needed to allow for adequate visualization of the cochleostomy, with care taken to maintain the integrity of the cochlear implant electrode within the cochleostomy during drilling. The well and trough were revised to ensure proper seating of the revision device and to minimize the risk of soft tissue complications as well as unsightly contouring of the scalp by the device. Once the mastoidectomy, facial recess, well, and trough had been revised, the field was copiously irrigated with normal saline.

The revision device was then introduced onto the field and secured within the well and trough. Under fluoroscopic video image guidance, the electrode was then carefully removed from the cochleostomy. The new device electrode was then placed at the cochleostomy site, and a still fluoroscopic image was obtained. The tip of the implant was angled superiorly. One third of the new cochlear implant electrode was then inserted into the cochleostomy, and a second still fluoroscopic image was obtained. The second third of the implant was inserted with a subsequent still fluoroscopic image to visualize the trajectory of the electrode within the common cavity. If the electrode advanced along the curvatures of the common cavity, the entire length of the electrode was inserted, and a final still image was obtained. If the electrode appeared to be advancing in a linear fashion toward the IAC, the electrode was partially withdrawn, the angle of insertion was adjusted, and advancement was continued as above. Alternatively, video fluoroscopy may be performed during the entire insertion process to assess the trajectory of the implant electrode, but total fluoroscopy time should be limited to <2 minutes. In most cases, a total fluoroscopy time of only 15 to 45 seconds is required. Intraoperative assessment of device impedance and neural response evaluation (known as NRT with Cochlear devices, NRI with the Advanced Bionics devices, and ART with the MED EL devices) were performed to ensure the device function and neural response. The cochleostomy was then occluded with strips of peristeum to prevent cerebrospinal fluid (CSF) leak. The peritonal flap and soft tissue incisions were closed. A mastoid dressing was then applied, and the patient was awakened from general anesthesia.

**Revision Cochlear Implantation Surgical Technique in IAC Insertion With X-Linked Cochlear Malformation**

The techniques for revision cochlear implantation following IAC insertion in patients with X-linked cochlear malformation are similar to that involving common cavity malformation. The critical difference in operative technique is in the design and dimensions of the cochleostomy. In X-linked cochleae, there is an absence of bony separation between the basal turn of the cochlea and the IAC, and the fundus of the IAC is enlarged (Fig. 2). Therefore, the membranous labyrinth alone forms the separation between these structures. In IAC insertion with X-linked cochlea, the electrode is likely inserted through this membrane instead of along the normal contours of the cochlea. Enlargement of the cochleostomy allows for visualization of these two distinct compartments, facilitating insertion of the electrode within the basal turn of the cochlea (Fig. 3). One must see the cochlear outer modiolar wall and the IAC entrance. The electrode is positioned along the cochlear outer wall during insertion.

In cases with X-linked deafness, the procedure was initiated as described above, including induction of anesthesia, positioning of fluoroscopic C-arm apparatus, prepping, and draping. The position and magnification of the fluoroscopic image was confirmed prior to initiation of the procedure. The position of the cochlear implant electrode was confirmed.

As in the common cavity revision cases, the traditional transmastoid facial recess approach was utilized. The previous incision was infiltrated with 1:200,000 to 1:100,000 epinephrine, and the incision was made with the Shaw scalp. The device to be explanted was identified, and the cochlear implant electrode (and ground) was sharply divided distal to the receiver/stimulator upon its encounter. Upon safe removal of the device without concern for incidental removal of the electrode from the cochlea, adhesions within the mastoid were lysed, and soft tissue was removed to identify the entry of the cochlear implant electrode into the facial recess. The implant electrode was then severed at
The periosteal flap and soft tissue incisions were closed. A mastoid occluded with strips of periosteum to prevent CSF leak. To ensure proper functioning of the device, the cochleostomy was blocked and neural response evaluation were performed to demonstrate its patency. During insertion, the electrode should be inserted along the outer wall of the cochlear basal turn to avoid intrameatal placement. A still fluoroscopic image was obtained. The middle third of the implant was inserted with a subcerebral still fluorescent image to visualize the trajectory of the electrode within the common cavity. If the electrode advanced along the curvatures of the common cavity, the entire length of the electrode was inserted, and a final still image was obtained. Alternatively, video fluoroscopy may be performed during the entire insertion process to assess the trajectory of the implant electrode. Intraoperative assessment of device impedance and neural response evaluation were performed to ensure proper functioning of the device. The cochleostomy was then occluded with strips of periosteum to prevent CSF leak. The periosteal flap and soft tissue incisions were closed.

RESULTS

A total of 1,737 pediatric and adult cochlear implant procedures were performed during the study period. Of these procedures, 126 revision cochlear implant procedures were performed. Four patients were identified who underwent revision cochlear implantation for IAC insertion. Two patients had an associated common cavity deformity, and two patients had X-linked deafness cochlear malformation. All revisions for IAC insertion occurred in pediatric patients with a history of congenital deafness.

Two patients were initially implanted at an outside institution, and two patients were implanted at the study institution. At the initial cochlear implantation procedure, all patients underwent the traditional transmastoid facial recess approach for cochlear implantation. Intraoperative fluoroscopy was not utilized at the time of initial cochlear implantation in any of the cases of IAC insertion. At the time of the initial procedure, one patient had a significant CSF leak, requiring lumbar drain placement. Each of the four patients is presented below with a description of each case.

![Figure 3](https://example.com/figure3.png)

**Fig. 3.** Cochleostomy in a patient with X-linked deafness. This figure depicts intraoperative imaging of the left ear from patient 3, who had a history of X-linked deafness. On revision cochlear implantation, the cochleostomy has been widened to facilitate visualization of the basal turn of the cochlea (black arrow) and the membranous septation separating it from the internal auditory canal. The white arrow identifies the opening into the internal auditory canal, from whence the cochlear implant electrode was removed. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

![Figure 4](https://example.com/figure4.png)

**Fig. 4.** Dissection of the cochleostomy in a patient with X-linked deafness. (A) View of basal turn of the cochlea through the widened cochleostomy in a patient with X-linked deafness. After widening of the cochleostomy, the visualization and patency of the basal turn of the cochlea is expanded. The basal turn of the cochlea is highlighted by the white arrow. (B) Rosen needle within the basal turn of the cochlea through the widened cochleostomy in a patient with X-linked deafness. A Rosen needle (black arrow head) was placed into the basal turn of the cochlea (white arrow) to demonstrate its patency. During insertion, the electrode should be inserted along the outer wall of the cochlear basal turn to avoid intrameatal placement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
Case 1

The patient in case 1 was 2 years old at the time of initial cochlear implantation at the study institution. During insertion of the cochlear implant electrode, the first 17 electrodes advanced without difficulty, with resistance noted during the insertion of the following four electrodes. Spontaneous and significant egress of CSF was noted following insertion, requiring lumbar drain placement for control. The patient was noted to have partial intrameatal insertion at the time of the initial cochlear implant procedure based upon intraoperative plain film skull roentgenogram (x-ray; Fig. 5). Because a substantial number of electrodes were noted to be within the common cavity, revision insertion was not performed at that time. This was early in the institution cochlear implant experience. Postoperatively, the four electrodes within the IAC were inactivated, and the patient utilized the remaining electrodes. Open-set speech recognition was not achieved in this patient. Three years following initial implantation, the patient was noted to have declining performance and increasing channel interaction. This patient, therefore, underwent revision cochlear implantation at that time. The revision technique described above was utilized. The patient experienced improved performance, with an increase of active electrodes from eight electrodes following the first procedure to 17 electrodes following revision cochlear implantation. Upon revision cochlear implantation, pure tone audiometry thresholds at 250 to 8000 Hz were <40 dB. This patient attained speech perception category 3 on Early Speech Perception (ESP) testing.

Case 2

The second patient with common cavity malformation underwent initial cochlear implantation at the study institution at 14 years of age, with partial intrameatal cochlear implant electrode insertion identified at the time of the initial procedure (Fig. 6). Patient 2 had a total of eight active electrode. Although she never achieved open-set speech recognition, the implant helped this patient with lip reading and assisted with her communication ability. Three and a half years following the initial procedure, this patient experienced sudden onset of severe pain in association with her device, for which the offending electrodes were inactivated. She was later noted to have a decline in the benefit provided to her from the implant. Therefore, she underwent revision cochlear implantation to improve implant performance. The techniques described above for revision following IAC insertion in patients with common cavity malformation was utilized for the revision cochlear implant procedure. Following the revision implant procedure, the patient was noted to have substantial improvement in cochlear implant performance, although open-set speech perception was not attained. On pure tone audiometry, thresholds of <40 dB were noted at 250 to 4,000 Hz, with a threshold of 45 dB at 6,000 Hz. This patient maintained speech perception category 1 on ESP testing. Although the patient continued not to have open-set speech recognition, she now continues to wear the implant at all times and finds it to be beneficial in enhancing her ability to communicate.

Case 3

The patient in case 3 underwent initial cochlear implantation at an outside facility. No complications were reported in association with the initial cochlear implant procedure. The patient was noted to have poor cochlear implant performance, without acquisition of open-set...
speech recognition. He also experienced facial nerve stimulation managed by programmed deactivation of multiple cochlear implant electrodes. The care of this patient was transferred 2 years following the initial procedure. On transfer, plain film skull x-ray was obtained to evaluate cochlear implant electrode position (Fig. 7). Intrameatal insertion was detected. Two years following the initial cochlear implant procedure, the patient subsequently underwent revision cochlear implantation utilizing the techniques described above. Figures 3 and 4 depict intraoperative photodocumentation obtained from the revision implant procedure. A complete insertion was accomplished. The patient subsequently experience significant improvement in cochlear implant performance, with attainment of open-set speech multisyllabic word scores, which increased from 5% to 60% following revision implantation.

Case 4

The fourth patient also underwent initial cochlear implantation at an outside facility. Patient 4 was noted to have a CSF gusher at the time of the initial procedure following cochleostomy, which was controlled by packing around the cochlear implant electrode within the cochleostomy. There was no subsequent report of CSF leakage. Patient 4 experienced progressive decline in cochlear implant function. In evaluation of functional decline and in preoperative evaluation for contralateral implantation, computed tomography scan of the temporal bones was obtained, which revealed intrameatal insertion of the cochlear implant electrode (Fig. 8). The patient underwent contralateral cochlear implantation 2 years following the initial implant procedure. She subsequently experienced implant failure in the intrameatally implanted ear. The care of the patient was transferred in contemplation of revision cochlear implantation. Seven years following the initial procedure, revision implantation using the techniques described above was performed. Complete insertion of the cochlear implant electrode was accomplished. The patient experienced significant improvement in performance, from 0% to 100% correct on the disyllabic testing and from 0% to 50% correct on monosyllabic testing.

Complication

In each of the above described cases, revision cochlear implantation following IAC insertion was undertaken without complication (Table I). Within this

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<thead>
<tr>
<th>Complication</th>
<th>Initial Procedure</th>
<th>Revision Procedure</th>
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<tbody>
<tr>
<td>CSF leak requiring lumbar drain</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Facial paralysis</td>
<td>0</td>
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<td>Intracranial hemorrhage</td>
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<td>Dysmetria</td>
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CSF = cerebrospinal fluid.
series, there were no cases of facial paresis or paralysis. None of the patients within this series experienced CSF leak or meningitis following revision cochlear implantation. No patients required lumbar drain placement following revision cochlear implantation, including the patient who required lumbar drain placement at the time of initial implantation. There were no reported cases of intracranial hemorrhage and no evidence of injury to the anterior inferior cerebellar artery. All patients were maintained overnight postoperatively for observation. No patients experienced an extended hospital stay. All patients with a history of IAC insertion experienced varying degrees of improvement in cochlear implant performance following revision cochlear implant.

DISCUSSION

Cochlear implantation has become an acceptable means by which individuals with severe to profound sensorineural hearing loss are able to obtain aural rehabilitation and successfully attain open-set speech recognition. Although cochlear implantation has been demonstrated to be an extremely safe procedure, approximately 5% of patients require revision cochlear implantation for a variety of reasons (i.e., device failure, infection, soft tissue complications, trauma, cholesteatoma, electrode extrusion).1–3 Among the patients requiring revision cochlear implantation, approximately 10% of revision cochlear implant procedures are performed for electrode malposition.1–3 IAC insertion is an exceedingly rare complication of cochlear implantation. As such, IAC insertion represents the indication for revision cochlear implantation in an extremely small proportion of cochlear implant patients. However, cochlear malformations including common cavity deformity and X-linked deafness cochlea are most commonly associated with IAC insertion in cochlear implantation. All patients previously reported in the literature and those included within this review who presented with IAC insertion had associated cochlear malformation.4–9

In previous reports of patients with IAC insertion, maintenance of the initial implant with deactivation of electrodes within the IAC was advocated.7 However, complaints of pain and discomfort with IAC insertion, sometimes with temporal delay, is often encountered in these patients.4,7 Additionally, all patients in whom immediate revision surgery was not undertaken, within this series and in previous reports within the literature, ultimately experienced cochlear implant failure in association with IAC insertion.4–7

Within this series, results from four patients with revision cochlear implantation following IAC insertion were presented. Two patients had associated common cavity malformation, and two patients had X-linked deafness cochlea. All patients underwent revision cochlear implantation utilizing the technique described above with fluoroscopic assistance. Complete insertion was accomplished in all cases, and no patients experienced complications in association with revision cochlear implantation. Implant performance was also found to be improved in all cases.

CONCLUSION

IAC insertion is a rare complication of cochlear implantation that most commonly accompanies cochlear malformations (i.e., common cavity deformity and X-linked deafness cochlea). In cases of IAC insertion, revision cochlear implantation can be undertaken safely, with the expectation of good cochlear implant performance. Intraoperative imaging including intraoperative fluoroscopy is recommended to assist in safe explantation and accurate placement of the electrode within the cochlea or common cavity.

BIBLIOGRAPHY