

# Revision Cochlear Implant Surgery

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## Abstract

Cochlear Implantation (CI) is now widely accepted as a safe and effective treatment for children and adults with profound deafness. As with all electronic devices, a (CI) is susceptible to breakdown or failure. Although the (CI) reliability rate is now very high, the continually increasing population of implant recipients will result in the continued occurrence of revision surgeries. The first report of a CI revision surgery occurred in 1985, by Hochmair-Desoyer and Burian. Since then, several reports have addressed the safety of this procedure.

**Keywords:** sertraline, cisplatin, ototoxicity, otoacoustic emissions, hearing loss.

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## INTRODUCTION

Revision (CI) surgery, a relatively uncommon procedure, will likely continue to increase in frequency. Revision rates ranges are estimated to be from 4% to 11%, with children more likely than adults to require re-implantation<sup>1</sup>. As the numbers of patients with CIs for extended periods grow, older devices will increasingly fail or require upgrading. The need for revision surgery and re-implantation has become and will continue to be of great importance, both as the cohort of patients implanted as children age and with the continued expansion of indications for CI candidacy. Although results of revision surgery are typically favorable, thoughtful planning by the CI team is essential for a positive outcome.

This paper reviews the indications for revision implantation, comprehensive evaluation of patients suspected of requiring revision surgery, proper surgical techniques, and the appropriate patient counseling regarding expected outcome.

## METHODS

Our article focuses on reviewing of previous studies and papers on cochlear re-implantations surgery regarding causes of failure, how to deal with failed cases, surgical finding and outcomes together with our experiences in dealing with such cases.

### Indications of cochlear implant revisions

There are two main categories for indications for revisions: non-device related indications and device related indications<sup>2</sup>. Device related indications have been claimed to be the most common cause of re-implantation representing ~75% of cases. They include those patients where there is facial nerve stimulation, confirmed or suspected device failure and the need for device upgrading<sup>3</sup>. Non-device related indications represent 25% of cases and includes patients who require revision surgery because of scalp flap infections, allergic reactions, misplacement of the electrode array and electrode extrusions<sup>4</sup>.

### Device relate indications

#### *Device failure*

There is perhaps no more frustrating complication of cochlear implantation than device failure from the standpoint of both the patient and the implant team. Device failures are categorized as "hard" or "soft" among which the former are more common and account for most revision surgeries. A hard failure occurs when there significantly diminished or complete a lack of auditory perception resulting from a confirmed malfunction of a component of the CI device. This might result from head trauma especially in children preventing communication between the internal and external components. Hard failures may be heralded by a sudden change in device function or perception, an abnormal sound or an inability

to link the external processor to internal processor. Soft failures are typically more challenging to recognize because the recipient has improved hearing compared to pre-implantation and many factors are known to affect growth of auditory skills. Among all CI recipients, improvements in speech perception and localization varies widely across individuals Tyler et al.<sup>5</sup> Soft failures may present when performance unexpectedly plateaus or deteriorates over time, or is poorer than one would expect based on patient history. Unlike hard failures, manufacturer testing often fails to provide conclusive confirmation of device malfunction.

Identification of a soft failure is often challenging because of other non-device-related variables that may impact performance and rate of progress. Prior to recommending explanation with re-implantation of a new CI in suspected cases, it is important to evaluate, and where possible ameliorate, other factors that may be contributing to poorer than expected outcomes including electrode problems and need for external component upgrading. Symptoms of soft failure can be subtle and include decreased performance and speech perception, poor performance relative to expectations based on pre-implantation characteristics, aversive stimuli causing subjective discomfort or pain especially at low stimulation levels, and hearing static while the device is off. A frequent need for reprogramming or difficulty programming often mis-attributed to complicated patients may be related to the device. A strong index of suspicion may be needed to detect accompanying signs<sup>6</sup>.

Diagnosis of malfunction of the surgically implanted portion of the CI system typically begins with clinical documentation of signs that may be indicative of device malfunction such as changes in electrode impedances and inability to maintain consistent connection with the internal receiver, as well as reduced clinical benefit. When a device failure is suspected, the manufacturer is contacted and *in vivo* integrity testing is performed. Objective measures that may be performed include impedance telemetry, electrically evoked stapedial reflexes, electrically evoked auditory brainstem response, and electrically Evoked Compound Action Potentials (ECAP). Performing such tests provides objective information that can be compared to baseline measurements when concerns about performance or device function arise. A Computed tomography or even a plain radiograph to document the position of the electrode array within the cochlea is quite valuable. These types of imaging are associated with low radiation dosage. The imaging provides information regarding electrode placement and may identify problems such as a kink, a tip fold-over, misplacement, over insertion, or partial insertion of the electrode array<sup>7</sup>. If the results of the integrity testing are inconclusive, definitive evidence of device malfunction may be possible only after the device has been explanted and a detailed analysis has been performed by the manufacturer. However,

prior to recommending explanation for suspected soft failure, clinicians must also consider the possibility that reduced performance may be due to factors other than device malfunction, and that re implantation may result in no change or even a decline in performance. In rare cases, analysis of an explanted device from a patient with clinical improvement subsequent to re implantation may not identify a cause of malfunction. In children, additional factors need to be taken into consideration, because they cannot always verbalize that a device is not functioning as expected. A suggested checklist to evaluate for soft failures that was compiled by several implant centers is shown in Table 1.

To help ensure that implant failures and the reasons behind them can be tracked in the future, a European consensus statement on CI failures and explanations

was put forward in 2005<sup>8</sup>. A summary statement by the leading European implant centers put forth the following recommendations for the times when a device failure is suspected.

**Principles of reporting on device failure**

- All device failures must be reported to the competent authority (i.e., usually the implant manufacturer), with a calculated cumulative survival rate.
- The manufacturer’s reports of device failure should indicate the source data, sample size, and the time period over which the failure rate is being cited.
- Reports of survival rates should provide historic data about a given device and list any technical modifications.
- The complete data set of the manufacturer’s

**Table 1.** A checklist to evaluate soft failure in both children and adults.

Young children	A-Behavioural	Increase in bad behaviour Aggressiveness Un willing to wear device Inattentiveness Regression in speech/language Intermittent responsiveness
	B-Teacher/therapist concern	Frequent appearance of being off task Detoriarion of school performance Plateau in performance Failure to meet appropriate expectations Educational placement
	C-Other factors	Type and amount of therapy Familial involvement Puberty Atypical tinnitus Buzzing
	A-Auditory	Roaring Engine like noise Static Popping
	B-Non auditory	Pain over implant site Pain down neck Shocking Itching Fascial stimulations
	Adults/older children	C-Performance
D-Apping		Loss of channels Type and amount of therapy Change in impedance Short/open circuits
E-Hard ware		Replacements of all externals Surface potential testing
F-Objective assessment		Neural response measures Evoked potentials Stimulus artifact

product should be supplied when presenting data about subsequent device modifications.

- A new device category is assigned when there has been a change in the case, the electrodes, or the electronics that has been labeled with its own CE mark. CE mark is a certification mark that indicates conformity with health, safety, and environmental protection standards for products sold within the European Economic Area (EEA). The CE marking is also found on products sold outside the EEA that are manufactured in, or designed to be sold in the EEA. (A valid CE marking affixed to a product indicates that it complies with the relevant European product safety Directives).
- Cumulative survival rates should be separated for adults and children, with 95% confidence intervals reported.
- Device survival time should start being tracked at the closure of the CI incision.

### **Device upgrading**

In addition to when the implanted device fails to function, replacement of a CI is indicated when there is need to upgrade the internal component of the device. Revision for upgrade purposes remains a controversial issue, since the surgery bears risks of damage to the surviving auditory nerves, and the outcome cannot be accurately predicted preoperatively<sup>9</sup>. Due to recent advances in CI technology, a high level of speech recognition has been achieved by multichannel processing devices. Removal of a functioning implant in order to upgrade to a more advanced device is a critical issue, since we have no means to accurately predict the postoperative results. Gantz et al.<sup>9</sup> reported a case in which an upgrade from a single-channel to multichannel implant did not substantially improve the patient's speech recognition. In cases of unilateral CI, Implantation of a new device in the unused ear is another option. This could also provide better speech recognition by taking advantage of binaural hearing. Some patients, however, refuse a new implant in the contralateral ear for the sake of saving it for the future implantation of a still more-advanced device<sup>10</sup>.

According to animal experiments, damage of the cochlea may occur when replacing an intracochlear electrode. Greenberg et al.<sup>11</sup> Reported a study of guinea pigs in which re implantation induced degeneration of the spiral ganglion cells in some animals Using cats, Jackler et al.<sup>12</sup> demonstrated that the incidence of insertion trauma increased significantly when there was proliferation of granulation tissue in the round window area and scala tympani Clinical data are more favorable concerning safety of re-implantation. Hochmair-Desoyer and Burian successfully re- implanted a scala tympani electrode of their own design in two patients<sup>13</sup>. Lindeman et al.<sup>14</sup>, Chute et al.<sup>15</sup> and Economou et al.<sup>16</sup> reported

replacement of a single-channel House/3M implant with a Nucleus 22-channel implant. Gantz et al.<sup>17</sup> Reported on five patients who underwent successful revisions of CIs of various designs these authors all agreed that replacement of the implants did not cause deterioration of hearing, and enabled restoration of a similar or better auditory experience than the previous devices allowed. The audiological performance of patients was also comparable with those obtaining new devices.

### **Facial nerve stimulation**

Facial nerve electric stimulation is a possible consequence after CI with rates between 1% and 15%<sup>18</sup>. Possible explanations of this adverse effect are leakage of currents caused by a change in the electric properties of the bone or close proximity of the facial nerve to the outer wall of the cochlea, together with the need for high electric current to stimulate the auditory nerve (i.e., malformations or ossified cochleae). Patients with otosclerosis involving the otic capsule bone are particularly at high risk of facial nerve stimulation Burmeister et al.<sup>19</sup> in these scenarios, electrical discharge from CI electrodes through normal use causes twitching of the face; this symptom can range from mild irritation to an inability to use the implant entirely as a result of excessive facial pain. Kelsal et al.<sup>20</sup> reported a study consisted of 14 patients with facial nerve stimulation after placement of the Nucleus 22-channel CI. Records were reviewed retrospectively, and patients were studied with three-dimensional computed tomographic scanning techniques. Electrical testing was performed, and various CI programming strategies were evaluated. Important clinical features were reviewed. The radiographic and anatomical relationships of the facial nerve to the cochlea were evaluated, and the programming strategies used to effectively control facial nerve stimulation were reviewed. Prevalence of facial nerve stimulation in population was 7%. The most common cause was otosclerosis. Anatomical data confirmed the close proximity of the basal turn of the cochlea and the labyrinthine segment of the facial nerve. There was a high correlation between the electrodes causing symptoms and those found radiographically to be closest to the labyrinthine segment of the facial nerve. They were able to control facial nerve stimulation in all patients through programming mode changes. Familiarity with more elaborate programming techniques is critical to managing patients with this complication.

### **Non-device related indications**

#### **Scalp flap infections**

Skin-flap complications are some of the most common and challenging treatment dilemmas faced by CI surgeons. During the placement of the receiver–stimulator under the temporoparietal scalp, the surgeon is challenged by both the need to keep the flap thin enough to allow magnet retention for implant power and by the requirement of

leaving the skin thick enough to allow adequate perfusion to maintain flap viability<sup>21</sup>. There are many factors that can influence skin flap viability, including the surgical technique used, the underlying health of the patient, comorbidities such as the concomitant use of tobacco, associated dermatologic conditions, and the strength of the magnet used postoperatively, all of which must be taken into consideration both during and after surgery<sup>22</sup>. Postoperative infection rates from CIs range between 2%-8%. The incidence of infection has decreased, likely owing to a number of factors including the nature of incisions and the availability of perioperative antibiotics. Infection may be minor, necessitating only conservative treatment, or major requires revision surgery for persistent symptoms or device extrusion.

In cases of persistence or recurrent infections, the authors often proceed with wound debridement, wash out, and cultured-guided antibiotics in an attempt to maintain the implant integrity. This practice, however, represents a real challenge because of the potential formation of biofilms. Bacterial biofilms are composed of communities of bacteria enclosed in a self-produced polymeric matrix of mainly exopolysaccharides with a propensity to attach and persist on the surface of biomaterials. The biofilm may develop defense mechanisms against both a host immune system and antimicrobial agents preventing them from treating the infection. In this circumstance, the removal of implanted devices is often inevitable to eradicate the disease. In cases whereby IV antibiotics and local wound care fail to resolve infection, cutting the electrode lead at the facial recess or cochleostomy and the device should be removed leaving the electrode array within the cochlea. The patients are treated with antibiotics, followed by revision CI, generally after ~6 weeks.

According to Cohen<sup>23</sup>, minor scalp flap complications are those that require minimal treatment or no treatment. Jackson and Luetje<sup>24</sup> labeled these the “nonsurgical” complications when they concerned the scalp flap. They are less frequently reported than major complications. Signs of flap infection should be immediately recognized and treated. Local symptoms and signs include erythema, warmth, and drainage and crusting at the incision site. These may be treated with topical and/or oral antibiotics. In adults, oral cephalosporin or fluoroquinolones are used. In the pediatric population, oral cephalosporins are favored over fluoroquinolone. More persistent cases of infection should be treated with intravenous antibiotics with consultation from infectious disease specialists. Aggressive therapy should be maintained to prevent wound necrosis, which would then constitute a major complication requiring surgical intervention.

Major scalp complications, include flap necrosis is often the result of poorly planned/executed incisions or flap designs. For example, patients with previous face-lift incisions generally should not be implanted using an

anteriorly based, C-shaped flap, as the blood supply to the flap may be inadequate. A “lazy S,” straight, or inverted U- or J-flap will allow survival of the flap. Infection and/or underlying inflammatory conditions (vasculitis, etc.) may also predispose to flap necrosis and problems with wound healing. There have been case reports describing the use of hyperbaric oxygen to speed recovery/healing and even to “prepare” the bed for rotational flap<sup>25</sup>. Extrusion of the device can result from local flap pressure necrosis and infection transmitted from the mastoid. Paying particular attention to minimizing comorbid conditions prior to surgery, optimizing flap thickness, device location, and magnet strength, as well as aggressive and early treatment of infection are effective preventative strategies. In cases where adequately mobile, vascularized soft tissue in the post auricular area is unavailable, a rotation of the device or coverage with an extended flap, usually to a more superior location, may prevent the need to explant the device. Other situations may require a rotational pericranial flap to fill the defect and enhance implant coverage.

#### **Extra cochlear electrode extrusion**

Extra cochlear electrode extrusion is also an indication for revision surgery and may be suggested by a decline in speech perception for which there is no alternative explanation. After device-related indications, it is the most common cause of re implantation in children<sup>26</sup>. The exact etiology is unknown, but it may be related to initial misplacement, known cochlear ossification, or physical forces placed on the cochlea that pull the electrode out of position. This latter circumstance might manifest with a progressive decline in performance over time. Despite the intuitiveness of this theory as it relates to skull growth in patients implanted when they were young children, studies have not documented electrode migration in the developing pediatric population. The slow decline in speech perception found in these patients before revision CI suggests that extrusion may be a dynamic process that can progress. Some theorize that the use of perimodiolar electrodes which are stable by hugging the modiolus may decrease the likelihood of electrode extrusion. Additionally, tightly packing the cochleostomy site may aid in keeping the electrode in place<sup>27</sup>.

In other cases, although a full insertion may be achieved, manipulation of the electrodes while closing the incision may lead to accidental electrode extrusion. In some cases, intraoperative confirmatory imaging enables immediate recognition of insufficiently inserted or even extruded electrodes thereby preventing the need for revision surgery and all the attendant risks of an additional period of anesthesia by detecting the error before closing the incision.

#### **Cochlear implant electrode misplacement**

The standard location for insertion of the CI electrode array is into the scala tympani of the cochlea. Failure

to insert the electrode array into the scala tympani has been documented in the literature<sup>28</sup>. This can range from misplacement of the electrode array into the vestibule or internal auditory canal, placement into scala vestibuli or scala media or, more commonly, translocation of an array that is initially placed in scala tympani into the scala media or vestibuli as the electrode array advances apically. Fortunately, misplacement of the electrode array into extra cochlear locations (e.g. vestibule), considered to be a major complication is rare.

The true incidence of electrode array misplacement into extra cochlear sites is unknown. Furthermore, available manufacturer and FDA-maintained databases such as the Manufacturer User Facility and Distributor Experience (MAUDE) do not capture these cases routinely. There are significant limitations to the utility of the current MAUDE database for analyzing CI device complications, including electrode array misplacement, as expressed by other groups. Upon review of available published case series on CI complications that include data specifically on any electrode array displacement, the published literature reports an incidence rate ranging from 0.2% to 5.8%, with an average of 1.02%<sup>29</sup>.

Jain and Mukherji<sup>30</sup> reported that the electrode array may be misplaced into the middle ear cavity, mastoid bowl, cochlear aqueduct, petrous carotid canal, Eustachian tube, or may be only partially inserted into the cochlea. The electrode may also be inserted into the vestibular system, most commonly the superior or lateral semicircular canal. Therefore, vestibular symptoms that are associated with cochlear implantation should arouse suspicion of electrode array misplacement. In addition, electrode array malposition should be considered in all cases when no benefit is achieved, and should be evaluated both by device-integrity testing and CT imaging, even in the setting of late presentation weeks after implant surgery. Another potential cause for extra cochlear placement of the electrode array is an inadvertent attempt to place the implant in a infra cochlear air cell; this is more likely to occur if the round window niche is not clearly identified and may occur even in experienced hands if there is fibrous or bony obliteration of the niche. Therefore, reliance on other landmarks (i.e., oval window position) after opening the facial recess is important. The surgeon must be able to identify the round window niche and promontory, and not be misled by infra cochlear air cells<sup>31</sup>. Finally, inner ear malformations increase the likelihood of electrode array misplacement. Preoperative radiographic examination should help to avoid such complications. Yet, a normal preoperative CT scan does not exclude inner ear malformation that could lead to misplacement of the electrode array, such as malformation of the osseous spiral lamina. In addition, incomplete ossification of the tympano meningeal fissure (Hyrtl's fissure) that usually occurs by the 24<sup>th</sup> week in utero can result in permanent patency and provide another potential route

for extra cochlear misplacement of the electrode array. Beyond extra cochlear misplacement; electrode array misplacement within the cochlea can also reduce overall performance. since clinical functional outcome would be expected to be quite different. Regarding mal insertion of cochlear electrode within the cochlea, various patterns have been recognized<sup>32</sup>.

- **Tip Rollover:** It has been suggested that tip rollover can be detected by intraoperative spread of excitation measurements as it provides information regarding the selectivity of neural excitation fields around each electrode. Some newer, perimodilar electrode arrays are particularly prone to a tip rollover and in these cases intraoperative imaging is helpful to confirm appropriate placement<sup>33</sup>.
- **Over insertion of array:** placing it deeper into the cochlea than desired, resulting in absence of electrodes in the proximal basal turn of the cochlea where high-frequency information is typically delivered.
- A twist in the electrode so that, the electrode bends or twists over on itself.
- Partial electrode insertion
- **Translocation of the electrode array into scala media or vestibuli:** This complication is relatively common, especially for electrode arrays placed deep in the cochlear apex. It is associated with increased scarring/fibrosis, neural degeneration, and diminished performance<sup>34</sup>.

### **Magnet displacement**

A potentially problematic complication after cochlear implantation is the migration or displacement of the internal magnet. For older implant models in which there was a ceramic case that houses the internal receiver, this is not an issue. The advantage of having a removable magnet stems largely from the possibility of obtaining postoperative Magnetic Resonance Imaging (MRI) scans. In a simple outpatient procedure, the internal magnet can be removed, scan obtained, and the magnet replaced. As compared with MRI-compatible implants without a removable magnet, the quality of a head MRI in a patient with an implant with the magnet removed is far superior<sup>35</sup>. To facilitate MRIs, most new model implants contain removable magnets; however, it is possible that these removable magnets are more prone to dislodgement. In the most common scenario, a child sustains some trauma to the skull overlying the receiver, thereby causing the magnet to literally pop out of its bed within the housing. Children are likely at greater risk for this than adults as a result of their developing motor skills and associated play activities, thinner scalps in such a scenario, the patient may notice a lack of function of the implant or a hard lump just underneath the skin adjacent to the scalp. When a displaced magnet is encountered, the patient or

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family should be counseled to not wear the device until the magnet can be replaced as a result of the risk for injuring the skin flap. Fortunately the repair of the problem is relatively straightforward. In rare cases, if the magnet becomes dislodged on multiple occasions and there is a tear in the Silastic ring holding the magnet in place, the entire implant may have to be replaced<sup>36</sup>.

### **Evaluation protocol**

#### **Preoperative and audiological considerations**

- The surgeon and audiologist should collaborate to clearly define the cause or causes of impaired performance. In cases of suspected device failure, physical examination, radiographic imaging, reprogramming, external hardware replacement, electrical auditory brainstem response audiometry, and psychological and/or behavioral evaluations typically precede formal manufacturer integrity testing<sup>37</sup>. A preoperative Computed Tomographic (CT) scan is helpful to confirm the electrode location, insertion depth, and to evaluate the morphology of the cochlea and modiolus for congenital malformations or postsurgical changes. The implant team should counsel the patient and/or family regarding the risk of a decline in performance after revision. However, most patients can expect stable, or possibly improved, performance.
- The implant team should develop a surgical contingency plan if reinsertion is not possible. For example, intervening ossification and/or intracochlear granulation tissue may prohibit reinsertion of the new electrode. The surgeon should not first propose the question, "Can we implant the other ear?" in the operating room. Rather, the implant team should evaluate the suitability of the contralateral ear before revision surgery and counsel the patient accordingly. In cases of soft failure not associated with adverse stimuli, implantation of the contralateral ear may obviate removal of a functional device. In some circumstances, Promontory stimulation testing of the contralateral ear may be useful to ensure it is capable of responding to electrical stimulation.
- The surgeon must familiarize him/herself with the physical characteristics of the current CI device. Knowledge of electrode and ground lead locations and orientations will minimize the chance of inadvertent damage to a functioning implant. In this regard, preoperative imaging can provide a useful guide, particularly if the device was placed at a different center. This same care should be applied when removing a nonfunctioning device, to facilitate an accurate post explanation device analysis by the manufacturer.
- Electrode length and diameter are essential information, for the new intra cochlear electrode array dimensions typically should not exceed those of the explanted one. The surgeon should review both the initial surgery operative note and any primary imaging study, if available.

- The team should notify the manufacturer about the planned revision procedure and may have to order a split or double array device if complete insertion with a standard array is not probable. After explantation, the implant team should send the device to the manufacturer for bench testing and device analysis<sup>38</sup>.

#### **Surgical planning**

- Revision surgery can be categorized into the following two types: those that maintain a functioning device, and those that re implant a new electrode array into the cochlea, the surgeon should avoid monopolar cautery anytime a CI, or its components, are *in situ*. Perioperative antibiotics are recommended.
- The possibility of an intraoperative transition to the contralateral side should be considered during surgical preparation and draping of the patient.
- The surgeon must determine the appropriate procedure staging. In cases of soft tissue infection or device exposure, an extended course of intravenous antibiotics often warranted. If medical therapy does not resolve the infection, and then the implant team should stage the surgery, with a second stage re-implantation performed several weeks or a few after the first stage explanation. For all cases, the implant team should prepare the patient for the possibility of a need to stage the revision. Staging may be necessary in cases of unexpected soft tissue, middle ear, device infection, or if reinsertion is not possible<sup>39</sup>.
- In revisions associated with chronic otitis media, a canal wall-down procedure with Eustachian tube occlusion and external auditory canal closure may be indicated.
- In some cases, Intraoperative electrophysiological testing scan assist in confirming electrode position and function. Current electrically elicited neural response software may not be compatible with older devices; thus, preoperative coordination with the manufacturer may be necessary. These electrophysiological tests may be performed with or without intraoperative plain film x-rays or fluoroscopy the surgeon can compare the scout film from the preoperative CT scan with the intraoperative plain film to more confidently assess an intracochlear electrode location.
- Selection of the appropriate and potential back up devices should be considered. In most cases, a device from the same manufacturer as the original implant will be used. As an intra-cochlear fibrous tract develops around the electrode array, it is usually possible to re-insert a similar device using this tract as a conduit for the electrode array. Even in cases where a device has failed and the patient has retained, serviceable low-frequency acoustic hearing it is possible to replace the implant and maintain functional acoustic hearing Gantz et al. However, sometimes it may be prove difficult to insert a flexible device and having a backup device with a sty let can

facilitate full insertion. Likewise, if significant fibrosis or ossification is suspected, it may be helpful to have a split or double array electrode available as a backup device in case the intra cochlear scarring cannot be adequately cleared to accommodate a standard array<sup>40</sup>.

### Surgical techniques

Various incisions have been advocated for cochlear implantation. In most cases the use of the same incision from the first operation is usually preferred and similar flaps are developed. Classically, the anteriorly based, C-shaped flap has the advantage of providing complete coverage of the internal receiver/stimulator with borders that do not cross the implant. Inverted U- and J-shaped flaps take advantage of the posterior arterial supply from the occipital artery. Because these flaps have the disadvantage of the incision crossing the electrode lead as it enters the mastoid cavity, it is necessary to create an anteriorly based musculofascial flap (i.e., Palva flap) under the scalp to bolster electrode coverage. The patient may experience postoperative numbness of an area of scalp superior to the horizontal arm. The current approach to flap development has been influenced by the goal of the “minimal incision.” O’Donoghue and Nikolopoulos’ minimal access is accomplished *via* a 3 cm oblique incision<sup>41</sup>.

Flap thickness must be incorporated in surgical planning. As Cohen and Hoffman<sup>42</sup> warn, flaps that are too thick will impede the transmission of electrical signals, whereas a flap that is too thin may erode under magnetic pressure. In general, the flap should be no thicker than 8 mm over the device and no thinner than 3 mm. In younger children with a thin scalp, elevation of the post auricular and periosteal tissue in continuity with the skin flap may protect the flap from necrosis secondary to magnet pressure. Flap thinning is unnecessary in this population.

Mono polar cautery should be avoided to prevent current spread through the electrode lead to the neural elements of the cochlea as well as direct damage to the device itself. Using mono polar cautery with CI components in place poses a risk of getting in direct contact with the device and perhaps rendering an ear unsuitable for re implantation. The Bipolar cautery is preferred by the authors for revision CI surgery and has allowed adequate hemostasis without adverse effects on the patients. Roland et al.<sup>43</sup> Advocated the use of the Shaw heated scalpel (Hemostatix Medical Devices, Cherry Hill, NJ, USA), which is effective in controlling bleeding without affecting wound healing or flap viability. Others use the Ultracision harmonic scalpel (Ethicon, Cincinnati, OH, USA) that is capable of cutting tissue and establishes complete hemostasis with minimal thermal lesion by using mechanical vibrations to cause denaturation of proteins<sup>44</sup>.

During explantation, mechanical trauma to the device must be avoided. The ground or main electrode lead may have integrated with soft tissue, and inadvertent drill contact

with adherent soft tissue may damage these components and violate the device’s seal. The electrode lead might be encased in soft tissue and the use of a scalpel has been proven useful to cut the adhesions and follow the wire down to the facial recess at which point the array is removed if it is a single stage procedure or, if the procedure will be staged, the array is cut and maintained within the cochlea as an intra-cochlear stent until the second stage. Leaving the electrode array within the cochlea allows for a fibrous tract to remain to eventually accommodate the new electrode array during the second stage<sup>45</sup>.

In rare circumstances where the electrode lead itself is infected, a soft flexible stent of equal size should be inserted into the intra cochlear electrode tract as a temporizing measure. The intra cochlear electrode is left in place until the new electrode, of similar or smaller size and diameter, is ready for reinsertion.

Whether done primarily or as a staged procedure, removal of the electrode array should be done under direct visualization just before insertion of a new lead through the same intra cochlear tract. Improper technique may contribute to incomplete or traumatic electrode insertions, which may result in fewer active electrodes and declined performance<sup>46</sup>.

The electrode array is gently removed, and the new one inserted to appropriate depth. If the new device does not easily advance, perhaps there is obstruction from intra cochlear osteo neogenesis or fibrosis. Preoperative imaging might alert the surgeon to an obstructed basal turn and cochleostomy, but the obstructing tissue may elude imaging and is only being appreciated at the time of revision. Often this obstruction can be gently removed with micro instruments. Rivas et al.<sup>47</sup> described the use of laser to ablate the intra scalar fibrous tissue that obstructs the cochleostomy tract, which provides accessibility for easy insertion of a new array. Without these measures, the intra cochlear capsular tract can be lost which may lead to intra cochlear dissection, decreased insertion depth, and even cerebrospinal fluid leak. If the fibrosis or ossification cannot be removed to accommodate insertion of the electrode array, an attempt to place the electrode in scala vestibuli should be attempted. If this is not possible a circumodiolar drill out procedure may be required. In a double cochleostomy technique using a split electrode, the basal turn is drilled out for the lower electrode, and an apical cochleostomy is created for the upper array<sup>48</sup>.

After successful reinsertion of the electrode array, the cochleostomy is then packed in the usual manner with muscle, fascia, or periosteum to secure the electrode lead in place. Once a CI has been explanted, the internal CI device must be sent to the manufacturer for testing and reliability reporting. For the past 10 years, the reliability of CI has been similar between the 3 major manufacturers. In the future, manufacturers should follow the 2010



international classification of reliability for implanted CI receiver stimulators to report device failures in a manner that is fair and consistent to all manufacturers.

## CONCLUSION

Revision CI surgery is an essential tool in the armamentarium of CI programs. Early recognition of complications of primary surgery is an important issue in management of failed cases. Although CI surgery has been proven as a safe and effective method in rehabilitation of post lingual deaf adult and pre lingual deaf children, these devices are subjected to damage, breakdown, need to upgrade and failure. In such cases, re-implantation is necessary. Although surgical problems leading to revision surgery and re implantation are expected to diminish by experience, every center has to deal with device failures. Both revision surgery and re implantation require extra care and it should be better carried out by experienced surgeons. Implant performances are expected to be comparable with primary implantations and a lot of studies showed improve audio logical outcome after re implantation. The potential benefit of revision CI surgery must be reviewed with patients and parents, and they should be aware that.

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