Chapter

Advances in Surgical and Anesthetic Techniques for Cochlear Implantation

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Abstract

Cochlear implantation (CI) is usually performed under general anesthesia using the classic surgical approach, the mastoidectomy posterior tympanotomy approach (MPTA), which was originally described by William House in 1961. Many alternative surgical approaches have been described for CI. Robotic image-guided cochlear implantation has also been described as a new advance in CI. Also, in some situations, CI can be performed under conscious sedation with local anesthesia (CS-LA) instead of general anesthesia (GA). With the ongoing advance in CI devices and surgical techniques, CI surgery nowadays could preserve hearing in ears with preoperative residual hearing. This chapter describes different approaches and techniques in CI surgery, whether classic or alternative technique, with special attention to advantages and disadvantages of each approach or technique. Also this chapter describes, in surgical points of view, the anesthetic techniques in CI, whether GA or CS-LA, with focus on indications, advantages, and disadvantages of CS-LA in CI.

Keywords: cochlear implantation, mastoidectomy posterior tympanotomy approach, alternative approaches, round window, conscious sedation with local anesthesia, general anesthesia, receiver/stimulator

1. Introduction

Cochlear implantation (CI) is the surgical implantation of an electrical device that can directly stimulate the auditory nerve through bypassing a nonfunctional inner ear. Through this device, speech and other sounds can be heard by severe to profound deaf people [1].

The first "true" CI was performed by William House and John Doyle on January 9, 1961; the surgery was performed through postauricular incision using mastoidectomy posterior tympanotomy approach (MPTA) to the middle ear. The electrode array was inserted then, after exposure of the round window (RW) membrane, into the scala tympani [2].

Interestingly, the surgical approach used and described by William house in 1961 became the classic or the standard approach for CI; for more than half a century, there was no major advancement or change in the surgical approach. However, there were different alternative approaches and some technical advancements, each of them having relative advantages and disadvantages.

2. Surgical technique of "classic" cochlear implantation

The surgical technique of classic CI was described in detail by House [3]. The basic surgical steps are the following:

2.1 Skin incision

Postauricular incision is the originally described incision for CI, and also it is the most common used incision for CI [4] (**Figure 1**).

2.2 Elevation of periosteal flaps

A "U"-shaped anterior-based periosteal flap or Palva flap (**Figure 2**) is performed to expose both the mastoid bone and the planed site for drilling a well "seat or bed" for the receiver/stimulator (RS).

2.3 Mastoidectomy posterior tympanotomy approach

MPTA is performed using both the surgical microscope and otologic drill. Widening of the posterior tympanotomy in an inferior direction with removal of excess bone in front of the facial nerve is an essential step for good exposure of RW niche and membrane, taking care that RW membrane may be obscured by a false membrane (false RW membrane) that should be removed first by sharp instrument (**Figure 3**).

2.4 Drilling a bony well for the RS

In classic CI, fixation of the device is achieved mainly by drilling a custom-fit bony well "seat or bed" for accommodation of the thick part, the titanium case, of the RS of the selected implant. This well must be designed with the same configuration of the RS and should be deep enough so that the package rests in the well stably without the possibility of sliding or rocking and without protrusion outside the skull as a swelling [5].

Figure 1.
Minimal access postauricular incision.

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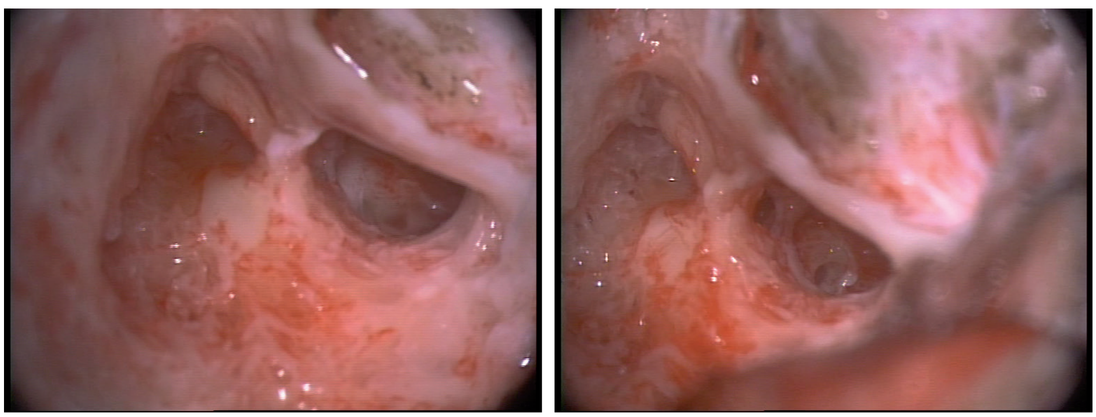
Figure 2.
Palva flap in CI.



(a) (b)

Figure 3.
(a) Classic MPTA showing good visualization of the RW niche and false membrane that cover true RW membrane. (b) After removal of the false membrane, RW membrane is now well visualized.

2.5 Cochleostomy

The RW niche is lowered down by drilling the tegmen and pillars of the RW till good exposure of the RW membrane is achieved, and then cochleostomy is performed. In classic CI, cochleostomy is drilled as a separate opening inferior and slightly anterior to the RW membrane [6].

2.6 Electrode insertion

The device is brought up to the surgical field, and then the electrode is inserted into the cochlea either by using the fine-tipped micro forceps or by using the specific instruments manufactured for insertion of the selected electrode type.

2.7 Confirm device fixation

The RS should be positioned in its drilled well "Seat or bed." Its stability in the well should be ensured. Sewing the periosteum together over the implant is also important for further stabilization [7].

The distal end of the electrode array should be secured and fixed. This is performed routinely by sealing off the cochleostomy site through harvesting a small piece of fascia or pericranium and then applying it around the electrode array at the cochleostomy site. This sealing also prevents transmission of infection from the middle ear into the cochlea [6]. Also the electrode array is further stabilized by placing a loop of electrode cable against the tegmen mastoideum [8].

2.8 Intraoperative monitoring

Intraoperative device monitoring is performed to confirm both electrical output of the device and electrical response of the patient at the same time. Intraoperative monitoring also provides objective data that can be used as a starting point for behavioral testing "psychophysics" [9].

First impedance telemetry, which confirms the integrity of the electrodes, is performed to all electrodes, and then the neural response of the patient can be tested by either measuring the electrical stapedial reflex thresholds (ESRT) or by measuring electrical compound action potential (ECAP), or neural response telemetry (NRT), which confirms stimulation of the auditory nerve. These electrical tests are essential to confirm the success of surgery; however, they are not a reliable predictor of postoperative performance [10].

2.9 Wound closure

The wound is closed in three layers: the periosteum, the subcutaneous layer, and the skin. Usually the dressing and pressure bandage are kept for 24 hours to reduce the possibility of a development of seroma or hematoma, then the wound is inspected, and another dressing is applied for another 5 days [5].

3. Advances of the surgical technique

Surgical technique of cochlear implantation was described in detail by House [3]; this description remains the classic or the standard surgical technique for cochlear implantation. Up till the time of writing of these words, there is no significant change in the basic surgical principles of the classic or standard CI. However, some surgical modifications and technical innovations were advanced and advocated by some surgeons. The most important surgical advances on the classic CI, according to our point of view, are listed in this section and sorted according to the consequence of surgical steps of CI.

3.1 Skin incision

The first described incision for CI was small postauricular C-shaped incision as the device has a single channel and is small in size, and then after inventing the multichannel devices, which had larger RS, larger postauricular C-shaped incisions or interior-based U-shaped incision were used. Due to the drawback of these large incisions on the blood supply with high incidence of flap necrosis, postauricular incision became the standard again and remained the most commonly used incision [4]. It was first long with an upward extension "inverted J-shaped incision" and then gradually become shortened by time. Nowadays many CI centers use the minimal access postauricular incision (**Figure 1**), which is 3–4 cm in length and 1 cm behind the postauricular crease [11].

An extended endaural incision has been described as an alternative incision [12]. This incision aimed at making the skin incision away from the tension that may be caused by the body of the implant and the RS; however, skin breakdown at the external auditory canal (EAC) and wound infection have been reported as complications of this incision [11, 13, 14].

The surgical technique of endaural incision in CI should differ from the standard technique used for other otologic surgeries; the standard endaural incision entails incising the skin and periosteum in the same incision line at the incisura and the bony cartilaginous junction of the EAC. Endaural incision for cochlear implantation should be modified. The skin only is incised at the incisura and at the intercartilaginous gap between the conchal cartilage and EAC cartilages (**Figure 4**), then the skin and the SC tissues are dissected from the underlying pericranium, and then the pericranium is incised away from the site of skin incision. We think that through this modification, endaural incision can be used in CI with lower risk of wound infection or skin breakdown.

3.2 Periosteal flap elevation

Few modifications of the standard anterior-based periosteal flap "Palva flap" in CI were described; the aim of these modifications is to ensure both good exposure of the drilling areas (mastoid bone and RS well) and tight periosteal covering of the device at the same time. One of these modifications was described by Fouad et al. [15] in which the periosteum is elevated through two flaps: the first flap is a short anteriorly based periosteal flap that aims at exposure of the mastoid bone, and the second flap is an inferiorly based flap that aims at exposure of the RS bony well (**Figure 5**). Through this modification, the periosteum can cover the device completely without tension, and mastoid emissary vein disruption could be avoided [15].

3.3 Mastoidectomy posterior tympanotomy approach

For more than half a century, the MPTA remains the gold standard approach for CI [16]. However, there is still need for "alternative" approach in certain situations. Also robotic CI is a new invention that can be used to reduce the need for excess bone drilling and to gain more rapid, safe, and direct access to the RW membrane.

3.3.1 Other "alternative" approaches

MPTA is the classic standard approach for CI [17]. Many alternative approaches were described for CI. The most common are the suprameatal approach [18], the pericanal approach [19], transcanal (Veria) approach [20], and transattic approach [21].

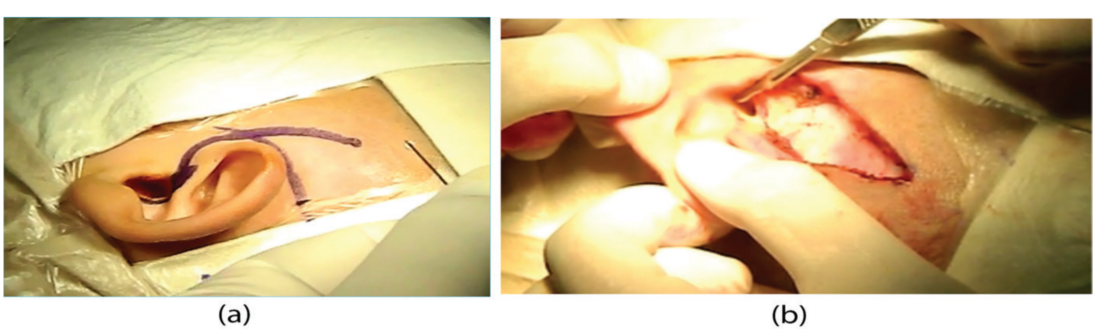


Figure 4.
Modified endaural incision for CI. (a) Incision marking on the skin (note the transverse part of the incision is at the junction between the conchal cartilage and EAC cartilage) and (b) cutting the transverse part of the incision with scalpel.

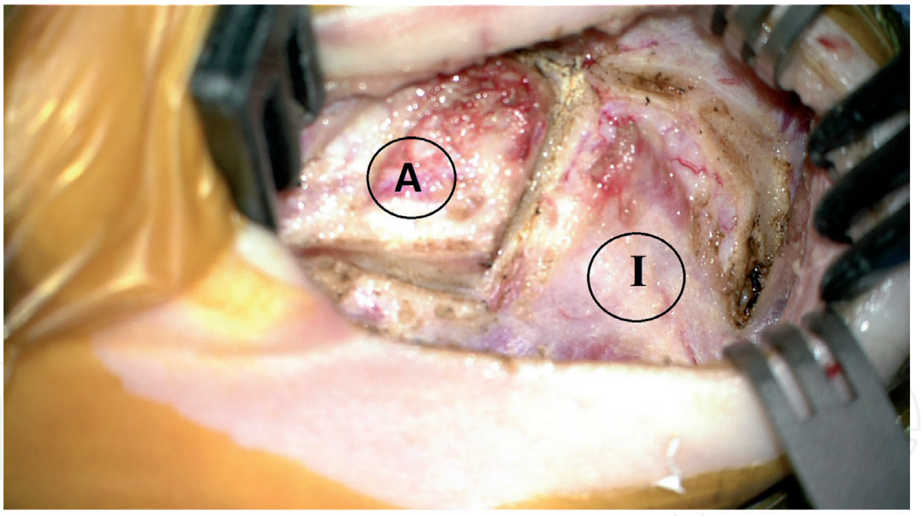


Figure 5.
Modified periosteal flap for CI. Two flaps are taken: (A) anteriorly based flap and (I) inferiorly based flap.

These alternative approaches aim at avoiding the risk of facial nerve injury and decreasing the duration of the surgical procedure. According to El-Anwar et al., there is no significant difference between the reported overall complications rate using either the classic or alternative approaches for CI [22]. However, many authors discourage the non-mastoidectomy approaches for cochlear implantation for the following reasons: First, the angle between the electrode array and the trajectory line of the cochlea is more than 30°; this makes electrode insertion difficult with increasing possibility of intracochlear kinking of the electrode or intracochlear trauma [23]. Second, fixation of the electrode array into a tunnel or groove in the EAC is not suitable for children due to continuous EAC growth [19]. Third, alternative approaches have higher rate of revision cases on the long-term follow-up [11].

Most of the surgeons nowadays use the standard MPTA for CI; the nontraditional approaches for CI are used in extremely rare cases with difficult anatomical situations [22].

3.3.2 Robotic surgery in cochlear implantation

The beginning of the idea of "robotic cochlear implantation" was by thinking in using the navigation system in cochlear implantation through a computer-assisted CI surgery using the same classic posterior tympanotomy approach. This idea was first introduced and tried first on cadaver dissection in 2004 [24]; then in 2009, Majdani et al. [25] performed a cadaveric study of using a combination of industrial robot system and navigation system for building a "closed-loop feedback" control system for CI. Through this system they could make real-time feedback to track any movement or changes in the bone based on a preoperative temporal bone CT scan. Vital structures, such as the facial nerve, were defined and protected. The robot was able to drill only the targeted bone without violation of any critical structures [25].

After extensive work and experimental trials for inventing accurate combined robotic and image-guided system for CI [26–28], the minimally invasive robotic percutaneous cochlear implantation (PCI) became real [29].

PCI can modify the classic MPTA into drilling a predesigned small single straight bony tunnel starting from the mastoid cortex and targeting into the RW without risk of injury of the facial nerve, chorda tympani, external auditory canal, and tympanic membrane annulus [30].

3.3.3 Technique of robotic PCI

According to the first reported case of robotic PCI [29], the procedure starts by preoperative imaging and accurate planning of the drilling pathway and identification of vital structures, before surgery. Then intraoperatively the drill path was assessed using imaging- and sensor-based data to confirm the proximity of the facial nerve. After making the bony tunnel with the robot, a small postauricular incision is made to elevate tympanomeatal flap to expose the RW membrane. The RW membrane is opened through anterior tympanotomy after elevation of the tympanomeatal flap, and then the electrode array, passing through the drilled tunnel, was inserted manually under microscope visualization [29].

3.3.4 Advantage of robotic PCI

1. It is a minimal invasive surgery with small wound, short duration, and minimal bone drilling which can cause noise and thermal effect on the cochlea.

2. It has high accuracy rates; the geometric accuracy was measured, in experimental studies, equal to 0.15 ± 0.08 mm at the depth of the cochlea.

3. It preserves the mastoid air cells, which has physiological role in middle ear ventilation.

3.3.5 Disadvantage of robotic PCI

1. Expensive.

2. Its safety and accuracy in vivo are still under clinical trials.

3.4 Drilling a bony well for the RS

The trends in manufacturing recent CI devices is toward making the RS as thin as possible, so that recent devices are thinner and need drilling a shallower bony well for RS. For example, the thickness of the RS of the CI532® (Cochlear Corp) is 3.9 mm, while the thickness of the RS of the older generation of the same company such as CI124RE® is 6.9 mm. Drilling a bony well with depth equal to 3 mm is usually enough to accommodate most of recent implants.

Some surgeons advocate the tight “temporalis pocket” technique in fixating the body of the implant; this technique entails elevation of small tight periosteal pocket that can just lodge the device tightly without the need of drilling a well for the RS [31]. Although slim devices can be fixed easier with tight temporalis pocket technique, still most of surgeons prefer drilling a well for stabilization of the RS [16].

Other methods for RS fixation:

- Tie-down sutures that were passed through monocortically drilled holes on each side of the R/S [32].

- Using polypropylene mesh over the R/S and securing the mesh with titanium screws [33].

- Cementing the R/S with ionomeric bone cement [34].

- Some CI devices, such as the Neuro Zti® (Oticon Corp), are manufactured with two titanium screws that can be fixed during surgery without the need for drilling a bony well.

3.5 Cochleostomy

Insertion of the electrode into the scala tympani is the goal of standard cochlear implantation. To achieve this goal, there are three possible approaches to the scala tympani, each one having advantage and disadvantage:

1. Traditional cochleostomy technique: in which there is a separate opening just inferior and slightly anterior to the RW membrane; it should be crated after good visualization of the RW membrane and lowering down the RW niche. The main advantages of this approach are avoiding the hook region of the basal turn, providing more effective sealing of both cochleostomy and RW by fibrous tissue, and providing appropriate angle of electrode insertion away from the osseous spiral lamina [5, 16], However, this approach entails more bone drilling on the cochlea that may expose the neuro-sensitive structures of the cochlea to traumatic and thermal effect of the drill [35].

2. RW approach: in which the RW membrane is opened, better by using a sharp needle. This approach is the least traumatic approach; however, electrode insertion may be difficult, and electrode may be hanged in the hook region by a projecting crista fenestra, which will need further drilling to allow electrode insertion.

3. Extended RW approach: in which the round window membrane is opened and then the anterior-inferior margin of the RW is drilled till good visualization of the scala tympani is achieved. Through this approach, the hook region is avoided, electrode array insertion will be in the same trajectory line of the scala tympani, and trauma to the osseous spiral lamina will be avoided.

The "best" type of cochleostomy is still a controversial issue; however, according to the meta-analysis conducted by Santa Maria et al., hearing preservation rates were higher in cochleostomy than in RW approach [36]. Whatever the surgical approach used for cochleostomy, the key point for successful scala tympani insertion with minimal trauma is good access and visualization of the whole round window membrane.

However, the RW visibility through the surgical microscope through MPTA is variable. St Thomas' Hospital introduced a classification for the visibility of the RW during CI as follows: type I, the RW membrane is entirely exposed; type IIa, more than 50% but less than 100% of the RW membrane is exposed; type IIb, the exposure of RW membrane is less than 50% but more than 0%; and type III, the RW membrane could not be identified. Most of the adult cases (76%) were type I, 17% was type IIa and IIb, while 7% was type III [37].

3.5.1 Endoscopic cochlear implantation

Otoendoscopy can be used, instead of surgical microscope, to solve the problem of "difficult RW." Marchioni et al. [38] has described the surgical technique of endoscopic CI. They used 3 mm rigid otoscope through the EAC, after elevation of an intact tympanomeatal flap, without incising the EAC skin, and then endoscopic cochleostomy is performed through the RW membrane. However, they did not use

MPTA for electrode insertion; instead of that, they used pericanal approach by drilling a bony grove in the posterior wall of EAC [38].

However, due to the advantages of the standard MPTA, the use of endoscope in CI became mainly limited to help the surgeons in accurate identification of the RW membrane and precise electrode placement; also this technique appears to be particularly useful for malformed or abnormal cochlea [39–41].

3.6 Electrode insertion

3.6.1 Types of CI electrode arrays

According to the method of insertion of the CI electrode array, there are three main types of CI electrode arrays that vary in the design and the method of the insertion:

1. The lateral wall (LW) electrode: Such as the K electrode of the Nucleus® (Cochlear Corp, Lane Cove, Australia), all MED-EL electrodes (MED-EL Corp, Innsbruck, Austria), and the HiFocus™ 1 J Electrode (Advanced Bionics Corp, Sylmar, CA). The lateral wall electrode, with exception of the 1 J electrode, is usually inserted by using micro forceps with or without the guide of claw instrument. The 1 J Electrode is better to be inserted with its specific pre-loaded metal tube connecting to its specific applicator.

2. The midscalar (MS) electrode: such as Mid-Scala Electrode of HiFocus™ (Advanced Bionics Corp,). This type of electrode is usually inserted through a specific applicator using the off-stylet technique (that was originally described for the Contour Advance electrode® (Cochlear Corp) [42].

3. The perimodiolar (PM) electrode: such as HiFocus Helix™ electrode (Advanced Bionics Corp) and the Contour® electrode (Cochlear Corp). Both of these electrodes have a stylet that is removed during insertion by the off-stylet technique. The recent CI532® (Cochlear Corp) is a PM slim electrode (0.7 mm); during insertion the electrode is loaded in its sheath, the stopper is kept at the cochleostomy opening, and then the electrode array is slowly advanced out of the electrode sheath. The electrode sheath was then removed, after seeing the three white markers at the cochleostomy site [43].

Each of the three types of electrode array has advantages and disadvantages. In general, the LW electrodes are usually slimmer and are assumed to have less traumatic effect on the cochlea during insertion, but they are usually rest away from the spiral ganglia which are the target of the electrodes' stimulatory impulses. The PM electrodes can hug the modiolus and became very close to the spiral ganglia; but because of the need of stylet, they are usually more stiff and thick, except the new PM electrode generations such as CI532® (Cochlear Corp), so that PM electrodes usually have more traumatic potentials on the cochlea during insertion. The MS electrodes are assumed to have the advantages of both LW and PM electrodes, but they can also have the disadvantages of both of them [44–46].

3.6.2 Depth of insertion of the CI electrode array

Proper electrode insertion is achieved by both making full insertion, which entails inserting all active electrodes into the scala tympani, and by making appropriate depth of insertion. Regarding the depth of insertion, Yukawa et al.

[47] reported that the better predictor of the outcome for the depth of electrode insertion is the angular depth rather than the intracochlear length of the electrode or even the number of active electrodes that is used in speech processing. It is expected that LW electrodes, especially the long types as FlexSoft™ (MED-EL Corp), can demonstrate greater angular insertion depth, more than 360°, while the PM or MS electrodes are usually designed to encircle the first basal turn making angular insertion depth nearly equal to 360° [48]. Insertion depth at 360°, or less than one cochlear turn, is usually associated with poor speech outcome; however, above 360°, there is no association between the depth of insertion and the speech outcome [49, 50]. Deep insertion is assumed to have the advantage of extending the electrical stimulation into the apical region that is responsible for low-frequency sounds; this provides better place pitch match which may improve the outcomes of CI especially in the music perception [51]. However, deep insertion is usually associated with increasing the risk of intracochlear trauma [45].

In conclusion, the best design for "ideal" CI electrode is a matter of debate; there is no "best" CI electrode for all CI cases.

3.7 Fixation of the implant and then testing the device function

Fixation of the implant entails both fixation of the RS, the main body of the implant, and fixation of the electrode array. Fixation of the RS was mentioned before, but whatever is the technique used, the periosteum should be tightened and sewed over the implant during this step [7].

Fixation of the electrode array should be in both its proximal and distal ends; the proximal end is fixed simply by either drilling a deep groove or trough starting from the RS bony well at the site of exit of the electrode to the mastoid cavity [52]. This trough could be drilled deeper. As it reaches the mastoid cavity at the sino-dural angle, the bone at this area is thick, so the trough can be modified in this area into incomplete tunnel with a bony ledge. The electrode could be secured in this tunnel even after electrode insertion (**Figure 6**).

The distal end of electrode array is fixed routinely by both inserting fascial plug around the electrode at the cochleostomy site and also by placing a loop of electrode

Figure 6.
The electrode is secured at the sino-dural angle before entering the mastoidectomy cavity, by an incomplete tunnel with a bony ledge.

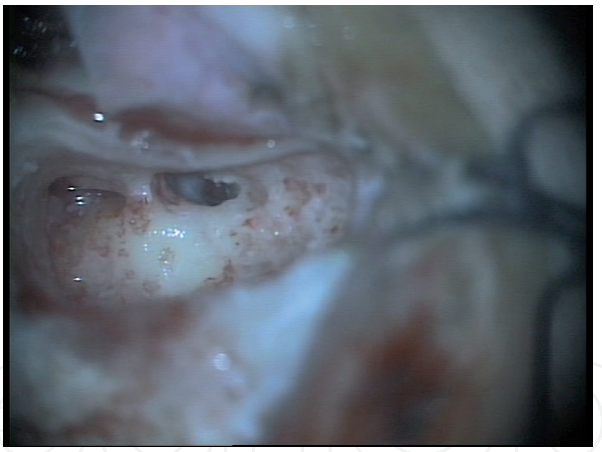


Figure 7.
A groove in the lower end of the posterior tympanotomy for accommodation and stabilization of the electrode after insertion.

cable against the tegmen mastoideum. Other surgical techniques that can be used, in addition, for electrode fixation at its distal end are:

1. Using a titanium clip to attach the electrode array to the incus bar [53].

2. The "split-bridge" technique [54], in which a channel is made through the incus bar and the lead wedged in it.

3. Making a small inferiorly based bone grove in the posterior tympanotomy into which the electrode array can be squeezed for fixation [55]. The groove is made with 1 mm diamond burr between the facial nerve and the chorda tympani nerve (**Figure 7**).

3.8 Intraoperative device monitoring

The use of the Internet for monitoring of CI devices from remote locations is a recent advance in CI programming. In a study by Shapiro et al. [56] remote intraoperative CI device monitoring was compared to in situ monitoring. The results showed that there is a significant reduction of the audiologist's time with remote testing than in situ testing. This represents a significant reduction in time required for testing and consequently the cost. This can be achieved by only Internet connection and a telephone [57].

4. Advances of the anesthetic techniques

4.1 CI under conscious sedation with local anesthesia (CS-LA)

Toner et al. [58] reported a case series of cochlear implantation under local anesthesia; however, using local anesthesia in CI was not widely used till the last 10 years [59–63], especially after the introduction and widespread usage of dexmedetomidine as a sedative drug for cases of CS-LA. Dexmedetomidine can make "cooperative sedation," in which the patient remains arousable and cooperative without causing delirium and unnecessary movements associated with delirium [63].

CI under CS-LA achieved comparable results with general anesthesia (GA) regarding perioperative comorbidities and achieved better results than GA regarding patient satisfaction in elderly patient [63].

4.2 Indications and advantages of CS-LA in CI

CS-LA is not only indicated in patients who are unfit for GA, but also it is generally preferred than GA in elderly patients. CI under CS-LA has the following advantages in elderly patients [63]:

1. CS-LA was associated with decreased drug costs, surgery time, and anesthesia time.

2. Length of stay was significantly shorter in patients undergoing CI under CS-LA.

3. Patient satisfaction was superior with CS-LA.

4. Perioperative morbidity was higher, but not significant, with GA than CS-LA.

5. GA in elderly patient carries the risk of unexpected cognitive consequences after surgery.

4.3 Technique

According to Shabashev et al. [63], the patient receives dexmedetomidine as the main sedative drug, in addition to fentanyl, midazolam, lidocaine, and propofol, depending on the necessary level of sedation and analgesia. In addition, 8–10 mL of 2% lidocaine with 1:100,000 epinephrine was used as a local infiltration anesthesia. In some instances, when patients experienced additional pain upon exposing the middle ear mucosa, gelfoam pledges soaked in the same local anesthetic solution were applied directly to the middle ear mucosa for 2 minutes before continuing the manipulation. Supplemental oxygen less than 29% was administered via nasal cannula or face mask. Surgical drape was applied around the operative site, but the face was left completely uncovered to facilitate direct communication with the patient during the procedure [63].

5. Hearing preservation during cochlear implantation

5.1 Surgical technique

All the previously described refinements and advances in both surgical techniques and electrode design aim at increasing the performance of the electrode within the cochlea and decreasing the traumatic effect of the electrode on the residual neuro-sensitive structures in the cochlea; this can preserve the residual function of these structures aiming at hearing preservation. Through these surgical refinements, nontraumatic “soft” CI surgery can achieve the target of hearing preservation.

In addition to the previously described technical refinements, there are many surgical considerations that should be respected during performing nontraumatic “soft” CI surgery. The most important surgical considerations are:

1. Minimal bone drilling during cochleostomy and avoidance of entrance of bone dusts into cochlear lumen [35].

2. Careful dealing with the endosteum during cochleostomy by incising it sharply using a sharp needle [64].

3. Scala tympani electrode insertion and avoidance of injury of the osseous spiral lamina and basilar membrane [65].

4. Preservation of the perilymph in scala tympani by avoiding suction of the perilymph during cochleostomy [16].

5. Smooth and slow electrode insertion [36].

6. In case of using long electrode, avoid excess pressure on electrode during insertion that may cause intracochlear trauma [45].

7. Electrode fixation and stabilization [7].

8. Sealing of the cochleostomy with soft tissue seal to avoid perilymph leakage [36].

5.2 Pharmacotherapy for hearing preservation during CI

Corticosteroid can be administrated during CI surgery aiming at hearing preservation [65]. Perioperative corticosteroids can be used either systemic, intratympanic, or intracochlear. Systemic steroid can be used either intravenously during the surgery or orally after the surgery [64]. Postoperative oral corticosteroid improved hearing preservation rates according to the systematic review conducted by Santa et al. [36].

Intratympanic steroid has been described through either applying a gelfoam soaked with methylprednisolone 125 mg/ml over RW membrane for 30 minutes before cochleostomy [66] or by filling the middle ear by dexamethasone 4 mg/ml before electrode insertion [67].

Intracochlear corticosteroid has been described through either using intracochlear injection of triamcinolone acetonide solution in addition to hyaluronic acid [68] or through silicone-based dexamethasone-eluted cochlear implant [69].

Experimental animal study on corticosteroid-eluted cochlear implant devices showed significant hearing preservation rates and histopathologic evidence of lower inflammatory response to the electrode [70–72]. However, until nowadays, many authors still discourage the use of intracochlear or intratympanic corticosteroids during CI surgery [16].

In addition to corticosteroid, other drugs can be administrated through drug-eluted CI device. There are many ongoing experimental trials on intracochlear application of neurotrophins and antiapoptotic drugs through drug-eluted CI device [72].

5.3 Effect of hearing preservation surgery on CI outcomes

CI surgery was introduced first as the only solution for hearing loss in profound deaf subjects. The US Food and Drug Administration first approved CI for adults with postlingual profound bilateral sensorineural hearing loss in 1985 and children in 1990. Nowadays, with the refinement of the surgical techniques and the advances of electrode design, CI candidacy guidelines have been expanded to include adults and children with residual hearing in the implanted ear [73].

This expansion in CI candidacy criteria was based on the strong evidence of two hypotheses: the first is the ability of CI surgery to preserve the residual hearing, and the second is the beneficial effect and the better speech outcomes of CI surgery in ears with residual hearing.

Systematic review studies were conducted on the effect of CI surgical techniques on hearing preservations [36, 65, 74]; all of these studies gathered that nontraumatic "soft" CI surgery can preserve hearing. Gantz et al. conducted a multicenter study on the outcome of CI surgery on 87 ears with residual hearing. At initial activation, 90% of the subjects maintained a functional low-frequency pure-tone average; this percentage was reduced to 80% after 12 months [75].

Regarding the benefit of CI in ears with residual hearing, a systematic review study was conducted on the outcome of CI in children with residual hearing; this study demonstrated that the better the preoperative residual hearing, the better the postoperative speech perception outcomes [76].

6. Conclusion

More than half a century passed since the first cochlear implantation surgery; throughout this long period, the main advances happened in cochlear implantation were the manufacture of the implant itself, surgical technique showing a lot of refinement rather than changes, and also the possibility of surgery nowadays to be performed under local anesthesia. The ongoing advances in cochlear implants and refinements of the surgical techniques have improved the outcomes of cochlear implantation and allowed for hearing preservation in case of preoperative residual hearing.

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Conflict of interest

The authors declare no conflict of interest.

Abbreviations

CI	cochlear implantation
MPTA	mastoidectomy posterior tympanotomy approach
RW	round window
CS-LA	conscious sedation with local anesthesia
GA	general anesthesia
RS	receiver/stimulator
ESRT	electrical stapedial reflex thresholds
ECAP	electrical compound action potential
NRT	neural response telemetry
PCI	percutaneous cochlear implantation
EAC	external auditory canal
LW	lateral wall
MS	midscalar
PM	perimodiolar

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