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Surgical Technique of Cochlear Implantation: An Update

Marroni GA[1], Luciani GO[1], Shibukawa DE[1], Leahy L[1], Mezzomo LM[1], da Silva AC[2], dos Santos Vieira CR[2] and Hamerschmidt R[1]

[1]Department of Ophthalmo-otorhinolaryngology, Federal University of Paraná, Curitiba (Paraná), Brazil

[2]Medical School, Federal University of Paraná, Curitiba (Paraná) Brazil

***Corresponding author:**

Rogério Hamerschmidt,
Department of Ophthalmo-otorhinolaryngology,
Federal University of Paraná, Curitiba (Paraná),
Brazil, E-mail: rogeriohamer@hotmail.com

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1. Abstract

Devices that amplify sound are essential for managing hearing impairment. Most hearing impairments can be treated with a modern hearing aid. Cochlear implants are surgically implanted devices that electronically stimulate the auditory nerve in the cochlea to provide hearing. Criteria for cochlear implant selection include moderate to severe sensorineural hearing loss and a patient who still struggles to hear and understand despite the hearing aids being properly adjusted. Advances in cochlear implants and the surgical technique of cochlear implants have a long history full of innovations that have resulted in better surgical technique approaches, fewer complications, and improved recovery. This review aims to make an update on the surgical technique of cochlear implants.

2. Introduction

The cochlear implant is a complex electronic device that can provide sound perception to people with profound or severe hearing loss who do not obtain adequate benefit from the personal sound amplification device [1].

The cochlear implant cannot provide normal hearing, but it benefits its user with extremely useful auditory information for communication and the individual's relationship with the environment [2].

It consists of an external and an internal part. The outside is made up of a microphone, a speech processor, and an antenna. They transform sound stimuli into electrical signals. The internal unit, which is surgically inserted, captures the electrical signals that are transmitted to electrodes implanted inside the cochlea that stimulate different parts of the auditory nerve [2]. The rudimentary function and components are virtually the same among cochlear implant manufacturers. However, each brand has its particular design, processing, and programming techniques, as well as auxiliary devices that match in different systems.

There are very old reports of cochlear implants, but it was only in 1957 that Djourno and Eyries described the effects of electrical stimulation of the auditory nerve [3]. In Brazil, the first cochlear implant surgery was performed at Hospital Israelita Albert Einstein, by Professor Pedro Luiz Mangabeira Albernaz, in 1977 [4]. The device was quite rudimentary compared to current ones.

The cochlear implant received Food and Drug Administration approval in 1984, and since then, the criteria for surgery have expanded to enable improved quality of life for younger-age individuals with some residual hearing.

Not every patient with hearing loss will benefit from cochlear implant surgery. A multidisciplinary team works together and dynamically in the selection of candidates for cochlear implant surgery, guided by indication protocols. The objective is to offer the best outcome to the patient, to obtain the greatest benefit and result with the existing devices, concerning the surgical risk. Generally speaking, the possibility of a cochlear implant is based on two criteria: severity of the hearing loss; poor speech recognition, with or without a hearing aid [2] (Figure1).

Cochlear implant results are dependent on a wide range of factors. Age at onset of hearing loss, pre-or post-lingual deafness, stimulation of the auditory pathway before surgery, residual hearing, cognitive skills, patient and family personality, and motivation, parental involvement and commitment, quality of device programming, and consistency in follow-up appointments are factors that change the outcome of the post-surgical process [5]. The more assistance and motivation of the patient and family, the better the results.

In Brazil, the referral protocols are based on the "Criteria for Indication of Cochlear Implants" of the Brazilian Association of Otorhinolaryngology and GM/MS Ordinance No. 2.776, of December 18, 2014 [6].

For implanted patients to obtain the optimal benefit from the device, pre-and postoperative follow-up with speech therapy is necessary. The follow-up of auditory rehabilitation has an individual duration, according to the development of each individual, considering the pre-existing factors already mentioned.

When well indicated and well assisted, patients with cochlear implants have a unique benefit for improving their quality of life, developing greater independence, and greater social interaction.

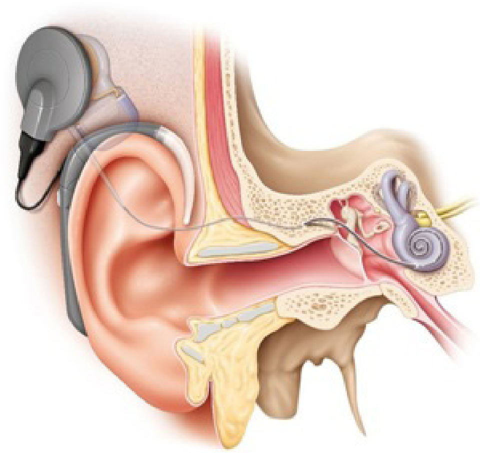


Figure 1: Representation of a cochlear implant, from the receptor, speech processor and the electrodes

3. Surgical Technique

After being properly followed up with speech therapy and strictly indicated by an otolaryngologist, through auditory and imaging tests, the internal portion of the cochlear implant can be surgically implanted.

4. Anesthesia

The integration of safe, high-quality surgical care with low-risk anesthesia in a clinically applicable approach is continually the ultimate goal of surgical innovations [7].

Anesthesia is a key point for surgery. The recovery of patients, in addition to the surgery itself, depends on the anesthetic technique, symptoms in the immediate postoperative period, and the patient's prompt recovery to return to normal activities.

We decided to start performing cochlear implant surgery in adults with local anesthesia and sedation for several reasons. The cost of general anesthesia is high, making the health insurance companies prefer local anesthesia, but the main factor is patient safety. With local anesthesia and sedation, there is less morbidity, the symptoms of vomiting and nausea in the immediate postoperative period are minimal, and the patient is discharged on the same day. In addition, many patients feel safer undergoing surgery with this type of anesthesia, as general anesthesia is a concern for most patients.

There is also an increase in the number of indications for cochlear implants in older patients, and many of these patients have limitations to general anesthesia, due to their comorbidities, they can already be candidates for cochlear implants under local anesthesia with sedation.

The anesthesiology service must also be prepared to deal with issues related to deafness, know how to approach the deaf patient, and explain clearly and objectively what will happen during surgery, especially any discomfort during intraoperative neural telemetry.

The effectiveness of this technique is well established for other ear surgeries, such as mastoidectomies, stapedotomy, and tympanoplasties. We also perform some of the inner ear surgeries with this type of anesthesia, such as decompression of the endolymphatic sac. But for cochlear implant surgery, many psychological and emotional aspects are involved. These aspects should be discussed by the medical team, the speech therapists, and especially the psychologists so that the patient feels safe with their decision to undergo surgery with local anesthesia and sedation, and the surgery can take place without any complications. Another point is the electrical stimulus of telemetry.

There was concern that, without general anesthesia, the patient could present minimal movements, which would interfere with the procedure, but with the deepening of sedation by the anesthesiologist, telemetry proceeds without problems. Monitoring of the facial nerve can be carried out easily under local anesthesia as well, it only needs the attention of the surgeon and the electrophysiologist regarding the natural facial movement of the sedated patient.

5. Sedation

At the time of surgery, the anesthesiologist explains to the patient, through gestures and lip-reading, what will happen, keeping the patient calm and prepared for the procedure. The patient is monitored with electrocardiogram and pulse oximetry. The drugs used for anesthetic induction are Fentanyl 1 ucg/kg, Meperidine 0.5 mg/kg, Midazolam 5 mg, and Clonidine 2 ucg/kg.

The patient receives an oxygen flow of 3 L/min through a nasal cannula. During surgery, opioids can be re-administered if any signs of pain or discomfort from the patient are noticed. Other drugs routinely used are: Ondansetron 4 mg, Metoclopramide 10 mg, Cefazolin 1g, Dexamethasone 1 mg/kg, Dipyrone 1 g, and Ketorolac 30 mg. Reversal of anesthesia, when necessary, can be achieved with the administration of 0.2 mg naloxone [8].

6. Local Anesthesia

After positioning the patient in the supine position, with the back slightly inclined and the head reclined, exposing the ear to be operated on, we infiltrate with 2% lidocaine and epinephrine at a concentration of 1:50,000 in the retroauricular region, introducing it to the point of making a bulging in the posterior wall of the conduit. We move up and down to the incision area in the retroauricular sulcus (Figure 2). Afterward, we infiltrate the external auditory canal in its four quadrants, first superficially and then more deeply. We progress to infiltrate the site of detachment and insertion of the internal component, at an angle of 45 degrees with a line that posteriorly touches the external auditory meatus (Figure 3). Usually, five milliliters of infiltration are sufficient for the entire area, using smaller amounts in children [9].

Infiltration is essential in surgeries with sedation, but we also do it in cases with general anesthesia, as it facilitates the procedure when it allows less bleeding in the surgical field and contributes to the necessary detachment of the periosteum.

Figures 2 and Figure3: Infiltration with 2% lidocaine and epinephrine at a concentration of 1:50.000.

7. Trichotomy

Retroauricular trichotomy facilitates the procedure, clearing the surgeon's vision and palpation, in addition to providing better control of surgical wound infections. We remove about 3 cm of the retroauricular hair and extend it to the region where the internal component is implanted.

8. Facial Nerve Monitoring

The facial nerve, the seventh pair of cranial nerves, is endowed with a motor root, responsible for the innervation of the facial mimic muscles, the stylohyoid muscle and the posterior belly of the digastric, and a sensory root – intermediary nerve –, afferent of the gustatory impulses of the anterior two-thirds of the tongue. The facial nerve penetrates the internal acoustic meatus of the temporal bone along with the vestibulocochlear nerve, travels through the facial canal, and emerges from the skull through the stylomastoid foramen. The course of the facial nerve inside the temporal bone measures about three centimeters in length and is formed by three segments: labyrinthine, tympanic, and mastoid. In ear surgeries, especially those that include mastoidectomy – as is the case with cochlear implant surgery – the anatomy and course of the facial nerve must always be constantly reviewed by the surgeon, to avoid unfortunate injuries.

Facial nerve damage can occur in different degrees, from simple momentary paresis – due to some dehiscence in its bone canal that provides contact with the infiltrated local anesthetic – to peripheral facial palsy, sometimes permanent on that side of the face, when complete rupture occurs during drilling of the mastoid. Anatomical variations of the facial nerve occur, for this reason, its status and location must be evaluated in complementary exams before surgery.

In some selected cases, it is prudent to use facial nerve monitoring during the surgical procedure, especially in children (facial nerve location in children under 2 years of age is more superficial at the tip of the mastoid) and in patients with middle ear malformations, in which anatomical variation is more likely to happen.

The electrodes are placed over the musculature innervated by the facial nerve on the side to be operated: frontal, orbicularis oculi, orbicularis oris, and mentalis muscles (Figure 4). Then, they are connected to the monitor. Discharges generated by stimulation or irritation of the facial nerve are translated into different alarm sounds that guide the surgeon about the position of the nerve. By the end of the procedure, the complete integrity of the nerve is verified [10].

Figure 4: The electrodes placed over the frontal, orbicularis oculi, orbicularis oris, and mentalis muscles

9. Skin Marking

After antisepsis and placement of sterile drapes, we mark the incision site behind the ear, the speech processor area, and the position of the indoor unit, using shapes that accompany the cochlear implant, with slightly different formats, according to each cochlear implant supplier company (Figure 5). This marking is relevant so that the indoor unit can be in a position far enough away from where the speech processor will be located, with the purpose that there is no overlap of the two cochlear implant components. The incision is usually 3 cm long, 0.5 cm away from the line of the retroauricular sulcus, slightly curvilinear, and following the sulcus. In children under 2 years of age, the incision of the inferior portion should be deviated posteriorly to avoid damage to the facial nerve.

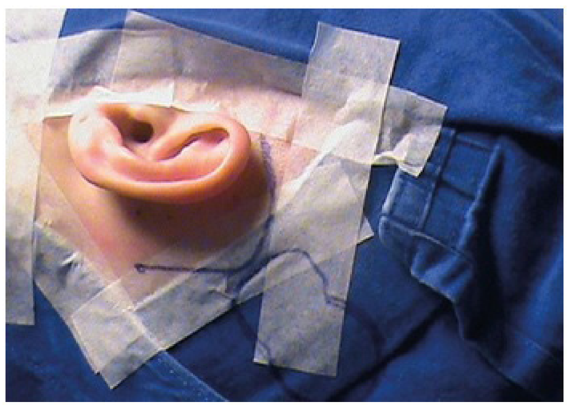


Figure 5: The incision site behind the ear, the speech processor area and the position of the indoor unit.

10. Retroauricular Incision

We use a small incision, approximately 3 cm, curved, just behind the retroarticular sulcus (Figure 6). It is performed on the skin and subcutaneously, exposing the temporal fascia, retroauricular muscles, and pericranial tissues. Plans are dissected until reaching the periosteum of the mastoid cortex, where a T-shaped incision is made to expose the mastoid cortex itself, which will be drilled.

With time and development along with the improvement of surgical techniques, the retroauricular incision has become smaller, following the evolution of cochlear implant devices [11]. Previously used augmented C incisions, endoaural incisions, U incisions, and inverted J incisions have already been abandoned for the unwanted results. The 3 cm curved incision behind the retroauricular sulcus is sufficient for the entrance of the internal unit, for its non-extrusion, to maintain arterial circulation, and for access to the middle ear without difficulties. The reduced size of the incision brings less morbidity to the patient, offering less postoperative pain and a lower risk of complications.

Figure 6: The C shaped incision behind the retroauricular sulcus.

11. Mastoidectomy

After exposing the cortical bone of the mastoid, the anatomical reference points for drilling are identified [12]:

1. Suprameatal spine of Henle: bony protuberance at the posterosuperior edge of the external auditory meatus; is the starting point of drilling.
2. MacEwen's Triangle (cribriform area): depression posterosuperior to the spine of Henle, with an irregular bone surface; corresponds to the projection of the antrum on the mastoid surface.
3. Temporal line: indicates the floor of the middle fossa; it is the upper limit, in the posteroinferior insertion of the temporal muscle up to the root of the zygoma. The dura mater can end up being exposed and bleeding in some access points, especially when the roof
4. for the middle fossa is low, which should already be observed in the preoperative tomography exam. This bleeding can be controlled by pressing the site with cotton wool soaked in solution (the same as the infiltration), with bone powder from the drill itself, or with bone wax applied to the site.
5. Tip of the mastoid: it is the lower limit of drilling. In children younger than 2 years of age, the bone at the tip of the mastoid is made up of medullary bone, which can cause more intraoperative bleeding. Controlling the bleeding with cotton soaked in solution is essential to follow the next steps.

A simple transcortical mastoidectomy is performed until the mastoid cortex is adequately exposed (Figure 7). The cavity must be continued posteriorly, identifying and skeletonizing the sigmoid sinus and the synodural angle – Citelli's. This step facilitates microscopic visualization of the round window niche through proper angulation. The antrum must be located 1,2 cm deep from the cribriform area and, when found, the prominence of the lateral semicircular canal can be seen. From then on, the posterior wall of the external auditory meatus is thinned, allowing the visualization of the short branch of the incus, which is an important repair point of the facial nerve and essential for the next surgical step – the posterior tympanotomy.

During the entire mastoidectomy, irrigation is important to remove residual bone, in addition to avoiding thermal damage to the facial nerve due to drilling. It is important to mention that there are other ways of accommodating the cochlear implant, performed mainly in cases of anatomical variations, such as too anterior sigmoid sinus or low dura mater:

1. The transcanal approach (Veria) was introduced by Kiratzidis in 1995: the electrode wire is housed in a small, superficial tunnel, made in the posterior wall of the external auditory canal, without contact with the skin. It has the advantages of preserving the mastoid and obtaining good access to the middle ear. However, the need for specialized material limits its use [13].
2. Suprameatal approach described by Kronenberg in 1999: access to the middle ear is through a tympanomeatal flap. The risk of facial nerve damage is minimal with the preservation of the mastoid. Its disadvantage is that the insertion of the electrodes through the round window is difficult, and if cochleostomy is performed, the electrodes will be stretched for insertion, which may damage them. There is also the risk of tympanic membrane perforation [14].
3. The combined technique described by Lavinsky in 2006: cochleostomy using a tympanomeatal flap requiring a smaller mastoidectomy and a smaller posterior tympanotomy [15].
4. Approach through the middle fossa: challenging procedure, even for experienced surgeons, due to the risk of cerebrovascular lesions and also of the facial nerve. It is indicated for cases with anatomical alterations in the middle ear, mainly [16].
5. Open cavity mastoidectomy: the posterior wall of the external auditory meatus is removed, prioritizing better visualization of the middle ear. Performed in cases where anatomical variations prevent the use of the traditional technique. Subsequently, the posterior wall of the meatus must be reconstructed with bone or cartilaginous grafts [17].
6. Petrosectomy: with obliteration of the Eustachian tube, and external auditory meatus, isolating the middle ear from the external environment. It can be used for cases of chronic otitis media [18].

Our service uses the traditional technique, simple mastoidectomy, most of the time. Exceptions occur when there are anatomical variations in the patient's ear. The traditional technique is satisfactory, already well standardized in our hospital, and congruent with local anesthesia [19].

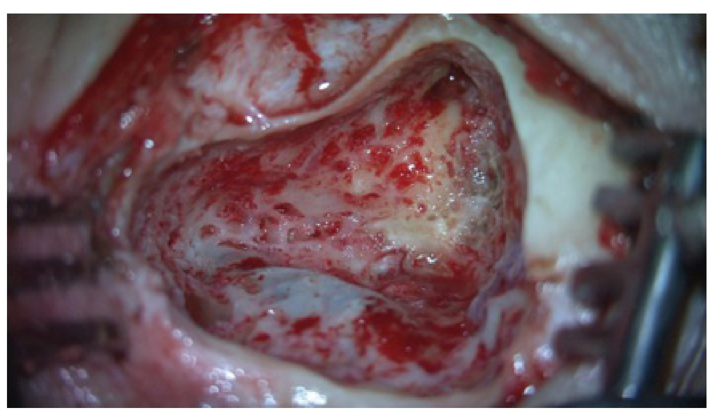
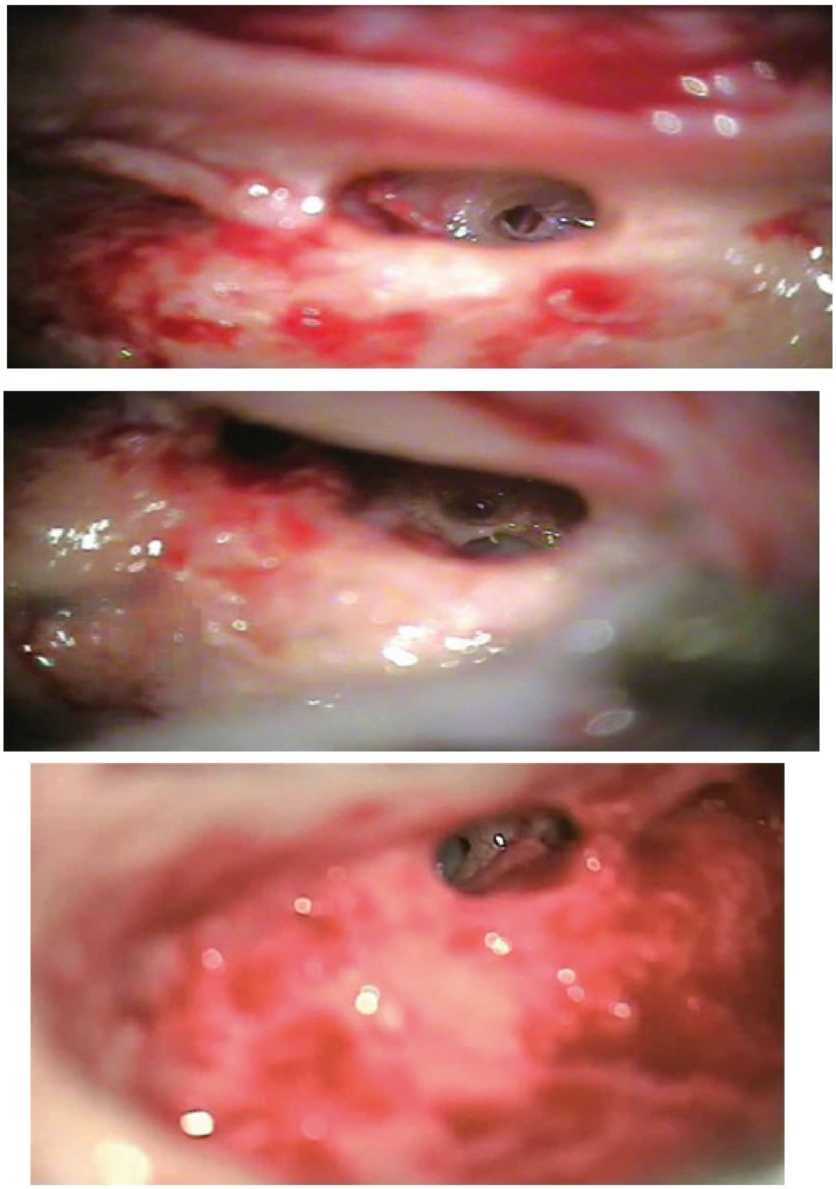


Figure 7: Transcortical mastoidectomy

12. Posterior Tympanotomy

Access to the middle ear, through simple mastoidectomy, is the posterior tympanotomy. Through anatomical landmarks, we can perform it successfully and without damage to immediate structures. The short branch of the incus points to the facial nerve canal in its mastoid portion, inferiorly to the lateral semicircular canal. The lower edge of the external auditory meatus maintains a close relationship with the chorda tympani nerve, a branch of the facial nerve, which travels in an opposite path to its originator. Among them, there is a bone triangle that is removed to access the space called "the facial recess" and that provides a view of the middle ear through the mastoid. One can then observe the promontory and the niche of the round window, where the electrodes of the cochlear implant will be introduced. The round window niche is located between 2-3 mm inferior to the tendon of the stapes muscle which can be visualized through the external auditory meatus, when a tympanomeatal flap is raised to facilitate the identification of structures (Figures 8,9, 10).



Figures 8, Figure9, Figure10: Posterior tympanotomy.

13. Round Window Niche Drilling

When the round window cannot be directly visualized through the posterior tympanotomy described above, the bone covering the membrane of this window can be drilled until its complete exposure. A small diamond bur is used to minimize thermal and sound damage to the nerve structures of the cochlea.

A delicate opening is made in the membrane of the round window, exposing access to the tympanic scale of the basal turn of the cochlea, where the electrode bundle will be inserted (Figure 11).

In young children, the cochlea has not yet performed its full rotation and lateralization, which makes it more difficult to locate the round window membrane, sometimes requiring inferior expansion of the posterior tympanotomy.

A variation of this surgical step is cochleostomy when the anteroinferior region of the round window is drilled, via the promontory, to access the scala tympani. An opening of approximately 1.5 mm in diameter is made in the most superficial portion of the basal turn, using a small-caliber diamond bur.

This technique is used when the round window niche is not easily visible, has difficult access, or in malformation situations. This technique can also be used in cases where the cochlea is ossified, such as a sequela of labyrinthitis or meningitis. In ossifying pathologies, the process starts near the round window and ascends to the apex, affecting the basal turn more frequently [20]. The preparation of the cochleostomy must be meticulous, taking care that the opening of the membranous portion of the tympanic scale is not performed with the drill, but by incision with tweezers, trying to preserve the reserve of hair cells [21].

With the advent of new electrodes and greater emphasis on preserving residual hearing, the interest is greater in the round window pathway for electrode insertion [22]. Compared with cochleostomy via the promontory, insertion via the round window significantly reduces the amount of perforation required, reduces the risk of trauma, loss of perilymph, and entry of bone dust into the tympanic scale [23]. Furthermore, both techniques stimulate the cochlear nerve in the same way [24].

Regarding the opening of the round window membrane, the smaller the opening, the lower the risk of perilymph loss and residual hearing loss, and the residual membrane itself assists in stabilizing the electrode bundle and occlusion of the round window, when their contacts are tight, avoiding their exteriorization and not requiring grease or other support to occlude the round window.

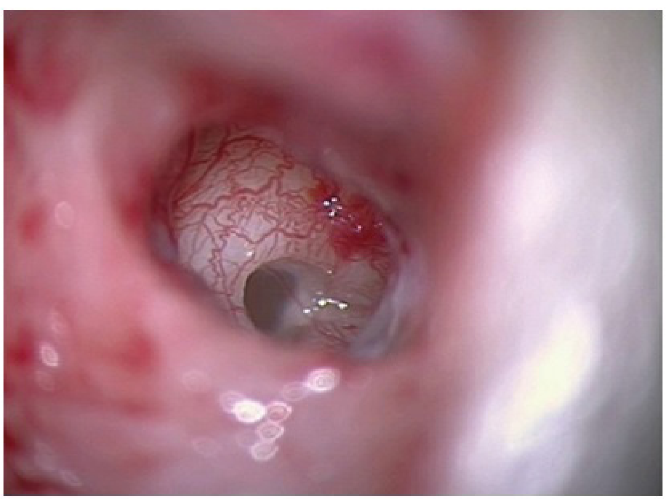


Figure 11: The round window

14. Placement of the Indoor Unit and Insertion of Electrodes

At the demarcated site on the skull, approximately 1 cm from the retroauricular incision, and at a 45-degree angle with the line that touches the external auditory meatus, we perform the detachment of the periosteum to place the internal unit.

The detachment must be close at the base, in horizontal movements, avoiding opening like a fan. After sufficient subperiosteal detachment in the skullcap, previously demarcated, the internal unit is carefully introduced, pulling the skin to the upper and posterior regions. There is no need to create a niche in the skull with a drill using this technique. Making the detachment small, but sufficient for the introduction of the indoor unit, it hardly moves out of position.

After the internal unit is fully inserted and positioned, the electrode bundle is then slowly and progressively introduced into the cochlear scala tympani, through posterior tympanotomy, using a delicate and specific instrument, until its complete insertion, always avoiding manipulating the electrodes (Figure 12). When there is resistance to its introduction, bends can occur in the bundle that can damage the electrodes, which can lead to worse audiological results [25]. Some cochlear implant bundles already have the introduction limit demarcated, which facilitates the occlusion of the round window, when there is a complete introduction. If placed up to the limit, the implant can stimulate the most apical portion of the cochlea, which provides better audiological performance in the postoperative period.

Cochlear implant brands usually have a standard electrode bundle model (standard) and models with different shapes (perimodiolar, for the side wall of the cochlea) and bundle sizes (shorter, more flexible, more robust) available for different cases and cochlear malformation or ossification.

The sizes and models are defined during the cochlear implant indication process and discussed with the patient and family about the best decision. When the implant model has a reference-ground electrode, this electrode is placed under the temporal muscle.

Over time, different approaches have been proposed to facilitate the visualization of anatomical structures, the insertion of electrodes and, more recently, the preservation of residual hearing [26], such as the electrode bundles, which are being manufactured thinner and more delicate. In cases where there is residual hearing, it is possible and beneficial to preserve it, through the non-traumatic insertion of the bundle, avoiding damage to inner ear structures and neural tissue degeneration. This method proved to be quite advantageous, as it allows combined electrical and acoustic stimulation [27]. There is emerging evidence from intraoperative testing to monitor hearing preservation and acoustic trauma during electrode array insertion. The use of electrocochleography during electrode set insertion can provide real-time information about cochlear function [28].

The growing technology offers the possibility of all drilling to be monitored and directed through 3D computed tomography coupled with neuronavigation. This instrument offers an assisted and controlled perforation from the surface of the mastoid, creating a tunnel that passes through the recess of the facial nerve, to the round window, in addition to cochleostomy by neuronavigation. The electrode bundle is inserted through the tunnel drilled into the cochlea. The instrument offers surgery with a reduced risk of injury to structures, such as the facial nerve and the chorda tympani nerve, in addition to a reduced surgical time [29].

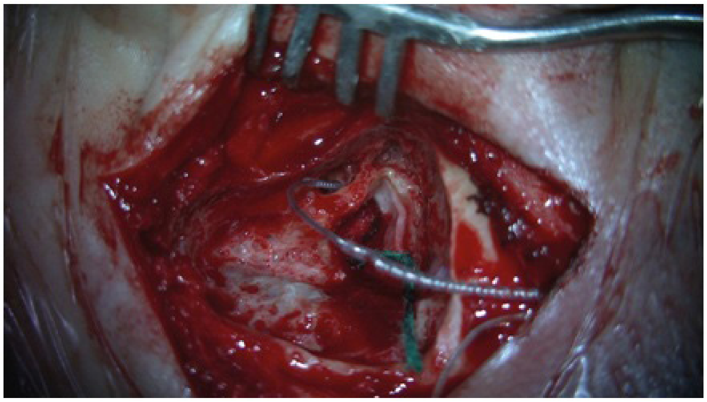


Figure 12: The insertion of the electrodes into the cochlear scala tympani.

15. Suture

The suture is made in layers – periosteum, muscle, fat, and skin – with absorbable suture material (Vicryl 3-0) (Figure 13). The skin is also sutured with the same material, without the need to remove stitches in the postoperative period, facilitating the immediate postoperative period, especially with younger children.

Bilateral implementation, even simultaneously (performed in our Service), has become a very plausible option. Its benefits include binaural hearing with better speech understanding in a noisy environment and sound source location, in addition to maximizing the potential of this technology [30]. We implant bilaterally, following the same steps described above on both sides. Neural tests are performed at the end of both sides.

Figure 13: Suture in layers with absorbable suture material.

16. Intraoperative Neural Tests

There are several issues surrounding the surgery that the audiologist needs to be aware of. This knowledge also guides the patient through the process to understand when it is necessary to raise concerns to the surgeon. Communication between the audiologist and the surgeon is essential throughout the cochlear implant process [31].

Intraoperative tests, performed in the operating room or remotely, provide valuable information to the audiologist, as well as the surgeon and family members about the integrity of the device. The integrity of the individual electrodes is tested, providing data on the device's basal impulse intensities, testing the central function and the auditory nerve against the first electrical stimuli, and can determine if there is a need for immediate reimplantation with the backup device (which always accompanies the devices), due to possible failure of the implanted device – avoiding the patient's hearing deprivation. Typically, a combination of electrode impedance measurements, other objective measurements (ECAP, for example), and images are used to determine if the use of a backup device is necessary. However, there is no clear agreement in the current literature on when a backup device should be used [31].

Electrode impedance telemetry is the first to be performed (Figure 14). It indicates whether the device is providing proper stimulation. A normal impedance does not imply a complete insertion of the electrode bundle; their information indicates that the electrodes are in contact with an electrically conductive medium. Impedance telemetry verifies the functionality of the internal device by measuring the voltage of the intracochlear electrodes. It also checks system integrity, internal and external communication, and ground electrode conditions. The fact that it is performed intraoperatively, under general anesthesia or sedation, allows the use of high-intensity currents, without causing discomfort to the patient. Short circuits are identified as abnormally low impedance values, and open circuits are identified as abnormally high impedance values, as designated by each manufacturer [31].

The examination with a portable intraoperative X-ray device is a way to assess the positioning of the internal structures of the cochlear implant when it demonstrates the wire of spiral electrodes positioned inside the cochlea and its integrity. It is a quick, practical, and available procedure in most hospitals, which provides, if necessary, immediate intervention. Neural response telemetry is an objective test that detects the action potential transmitted by auditory nerve fibers to the brain. The recording signal is called the "evoked auditory nerve action potential component" (ECAP or EAP) and has an amplitude between 0.01 and 2 microvolts, occurring approximately 1 millisecond after stimulation. Intraoperative ECAP thresholds are usually observed at higher stimulus levels compared to thresholds obtained postoperatively [32]. Failure to register ECAP does not necessarily mean implant malfunction or neural alteration and depends on several factors, such as the time of hearing deprivation – in many cases, this response is only visible after a period of stimulation and use of the cochlear implant device. This test does not depend on the patient's level of consciousness and can be performed with sedation or after surgery. Neural response telemetry also provides us with the auditory threshold and the discomfort threshold (maximum and minimum limits of stimulation current) that will greatly assist in mapping and activating the implant during the next steps [33].

The electrically Evoked Stapedial Reflex Threshold (ESRT) is another tool used to determine the function of the device and the function of the peripheral brainstem portion of the auditory pathway. The presence of the stapedial reflex indicates that the auditory nerve and the stapedial reflex are responding to electrical stimulation and that the device is therefore functioning. Its absence does not necessarily indicate that the device is defective or that the auditory nerve is not functioning. Its intraoperative measurements are seen at higher levels of stimulation compared to measurements obtained postoperatively. Furthermore, they can be affected by the dosage of anesthesia. Muscle contraction is a bilateral response and, therefore, it can be observed in the contralateral ear [34].

Some implant models offer the possibility of researching electrically evoked brainstem potentials (EABR), providing complete information about the integrity and functioning of the entire auditory system, from the inner ear to the brainstem. Especially for more complex cases, this research is of great importance.

In our service, the audiologist monitors the surgery remotely and starts the tests in the operating room with neural response telemetry and electrode impedance [35]. When the audiologist is not available, the surgeon himself can perform the electrode impedance telemetry with a device included in some brands of cochlear implants.

When possible and convenient, we also perform the activation of the cochlear implant in the immediate postoperative period, still in the operating room. The fact that most of our surgeries are performed under local anesthesia and sedation offers this advantage [36]. The device's health is registered and then inactivated. It takes a few days to use the external unit, due to the need to reduce local edema and heal stitches.

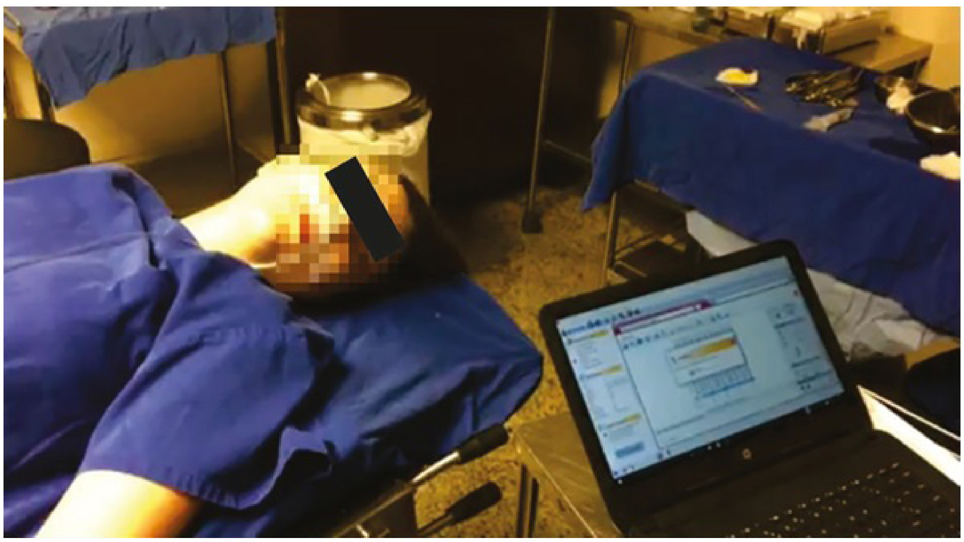


Figure 14: Intraoperative neural tests.

17. Bandage

A compressive dressing is applied to cover the operated ear, with gauze and bandage, to avoid bruises and mobilization of the internal unit, for a period that guarantees the stabilization of the implanted structures (Figure 15). This dressing stays on for 2 days, after which it is removed by the doctor.

18. Post-Operative Follow-Up

After complete post-surgical recovery, which takes an average of 40 days, the patient is ready to use the external unit and continue with speech therapy. In the subsequent speech therapy sessions, the implant will be fully activated and the stimulations will be continued, until the team and the patient are satisfied. For the maximum benefit of the cochlear implant, its users must be under constant speech therapy, the family must remain motivated so that the interventions and programming of the cochlear implant can take place without major difficulties.

Figure 15: Compressive dressing with gauze and bandage.

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