Methods of Hearing Preservation during Cochlear Implantation

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Abstract

Introduction Recent advances in surgical techniques and electrode design have made residual hearing preservation during cochlear implantation (CI) possible, achievable, and desirable.

Objectives The objective of this study was to review the literature regarding methods used for hearing preservation during CI surgery.

Data Synthesis We performed a search in the LILACS, MEDLINE, SciELO, PubMed databases, and Cochrane Library, using the keywords CI, hearing preservation, CI electrode design, and CI soft surgery. We fully read about 15 studies that met the criteria described in “study selection”. The studies showed that several factors could contribute to possible cochlear damage during or after CI surgery and must be kept in mind; mechanical damage during electrode insertion, shock waves in the perilymph fluid due to implantation, acoustic trauma due to drilling, loss of perilymph and disruption of inner ear fluid homeostasis, potential bacterial infection, and secondary intracochlear fibrous tissue formation. The desire to preserve residual hearing has led to the development of the soft-surgery protocols with its various components; avoiding entry of blood into the cochlea and the use of hyaluronate seem to be reasonably supported, whereas the use of topical steroids is questionable. The site of entry into the cochlea, electrode design, and the depth of insertion are also important contributing factors.

Conclusion Hearing preservation would be useful for CI patients to benefit from the residual low frequency, as well as for the children who could be candidate for future regenerative hair cell therapy.

Keywords
- cochlear implantation
- ear
- hearing

Introduction

Cochlear implants (CIs) represent a well-established treatment for severe and profound bilateral hearing loss. The number of candidates with significant residual hearing who are eligible to receive CIs has increased, fostering studies on attempts of preservation of the residual hearing in these patients.[1] Hearing preservation is essential for all CI recipients for several reasons.[2,3] First, because it helps to ensure that some neural structures in the cochlea are left undamaged, which is critical in allowing CI recipients to benefit from future therapies and/or technologies. It is likely that any future interventions, either device, biological, or pharmaceutical in nature, will be more successful in attaining a cochlea with preserved neural structures. Second, many individuals with severe to profound hearing loss may still be able to hear some low frequency sounds. Preservation of the residual hearing during CI surgery is vitally important, as it enables the patients to use the natural hearing in combination with a CI, providing the user with the best possible listening experience.[1] Therefore, for all CI recipients, hearing

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preservation during a CI procedure is essential for their hearing both now and in the future. Considering the importance of a good understanding of the factors that assist to a higher rate of hearing preservation in patients who undergo CI, this study aimed to review the literature regarding methods used for hearing preservation during CI surgery.

Review of Literature

We searched several medical databases, including LILACS, MEDLINE, SciELO, PubMed, and the Cochrane Library to find out relevant articles. We focused our review on studies involving how to preserve residual hearing during CI. Following Miranda et al,[1] several factors could contribute to possible cochlear damage during or after CI surgery. Most of them related to the surgical technique. The desire to preserve residual hearing has led to the development of the soft-surgery. The site of entry into the cochlea, electrode design, and the depth of insertion are also important contributing factors. The authors fully read and analyzed the results of 15 studies that describe various approaches to preserve residual hearing during CI, highlighting their importance for hearing preservation both now and in the future to profit from any new regenerative hair cell therapy.

Discussion

Intracochlear trauma by electrode insertion and foreign body reaction to the implanted electrode within the scala tympani might be sufficient to cause hearing loss. Hearing preservation during CI is based on five items; minimally invasive surgery, suitable route for insertion, gentle insertion technique, control of the inflammatory response to electrode insertion, and use of atraumatic electrode.

Minimally Invasive Surgery

The technique is based on a commonsense approach to open and manipulate the cochlea. Some of the principles of the soft-surgery technique are also dependent on early otology surgery experience and subsequent experience with CI. The objectives of the soft-surgery technique include avoidance of mechanical trauma to the cochlea and reduction of the introduction of factors that may cause adverse intracochlear reactions.[4,5] Care is taken during the approach to the cochlea to minimize the potential for acoustic trauma such as from micro drill contact with the ossicular chain.[6] Bone dust and pate are thoroughly irrigated away to avoid their entry into the cochlea at the cochleostomy or by contact with the electrode array. Because blood is an inner-ear toxin, its entry into the cochlea should be also avoided by preparing the tympanic cavity to minimize bleeding and decrease the potential for blood to enter the cochlea.[7] Postulated mechanisms for the hearing loss as mentioned by Radeloff et al[8] included oxidative damage induced by hemoglobin or inflammatory reaction to blood and its breakdown products, as well as additional fluid introduction into the cochlea.

Loss of perilymph from the inner ear can have detrimental effects on cochlea-vestibular function. Gentle perilymph exposure may be quite safe.[9] However, the surgeon must take cautions against the suctioning of perilymph with additional concerns of the suction tip that can cause mechanical damage to the basilar membrane and osseous spiral lamina.[4] Moreover, the surgeon should make sure to permit the escape of excess perilymph out of the cochlea to prevent its effect on the endocochlear potential.

Suitable Electrode Insertion Route

CI arrays can be inserted through the round window (RW) or via cochleostomy. The RW insertion has been referred to as a less traumatic and more direct approach to the scala tympani than cochleostomy.[3]

►**Table 1** gathers results of clinical human studies comparing the RW versus the cochleostomy approach, showing that RW approach causes the same[10,11] or significantly less trauma to the cochlea.[12,13]

Table 1 Results of clinical studies compared round widow (RW) versus cochleostomy approach in CI

Results	Device used	Number of patients	Study
Greater significant damage occurred in cochleostomy and RWE groups than in RW	N/A	12; 3 groups of temporal bones: insertion through RW, after enlarging RW (RWE) and cochleostomy	Richard et al[12]
no statistically significant differences	N/A	20; 8 (40%) round window-related cochleostomy and 12 (60%) RW	Adunka et al[10]
no statistically significant difference	Cochlear Nucleus CI 422 slim straight electrode	41; 14 cochleostomy	
27 RW approach.	Hassepass et al[11]		
RW was less harmful to residual hearing particularly at 125 Hz ($p < 0.05$), than standard cochleostomy	Med-El +Flex (SOFT)	34; 17 RW-HP with full insertion	
-17 cochleostomy with shorter perimodiolar electrodes.	Nordfalk et al[13]		

Abbreviations: CI, cochlear implantation; RW, round window; RWE, enlarged round window.

Cochleostomy is the traditional and more commonly used approach to the scala tympani. Cochleostomy site and size have a role in hearing preservation and so avoiding damage to inner ear structures. Cochleostomy located anterior-inferior to the RW membrane is the preferred site because it is correlated with better residual hearing results than a strictly inferior or anterior entry.[14] This site avoids damage to the osseous spiral lamina and so inadvertent entry into the scala media or scala vestibuli.[15,16] A small cochleostomy enabled Sharzynski et al[17] to preserve some hearing in 21 of their 26 patients (80.8%) using the soft-surgery technique.

Lenarz et al[18] found that RW insertion may not be suitable for all electrode configurations. Longer, thicker and less flexible electrodes insertion through RW became difficult and required cochleostomy. Thinner and more flexible electrodes have enabled insertion through RW. When using a custom short array, RW produces little intracochlear damage. However, using a perimodiolar electrode showed significant damage to basal turn structures.

There is no accurate evidence determining the best method for hearing preservation CI. Initially, insertion through the RW was the standard technique for hearing preservation CI surgery. This technique consists of a minimal incision through the membrane, with no need for drilling the cochlea, thereby reducing acoustic trauma and the possibility of bone fragments entering the scala tympani.[3] However, a recently published study showed that the angle of insertion of the electrode is similar for both techniques (through the RW and by cochleostomy), and in both procedures, tissue damage will be minimal if an electrode designed for hearing protection is used.[19] In a systematic literature review in 2013 comparing the two approaches, we could not find a single study specifically comparing insertion techniques; the levels of hearing preservation were similar between the two approaches, being slightly higher in patients undergoing insertion through the RW.[3]

The cochleostomy approach is familiar to nearly all CI surgeons; nonetheless, it needs to be placed appropriately. Meanwhile, Adunka et al[10] reported that the RW approach demonstrates an advantage over cochleostomy in hearing preservation and explained this by known potential problems with cochleostomy, such as (a) perilymph loss and acoustic trauma caused by drilling; (b) formation of new bone within the cochlea, caused by the presence of bone dust; (c) the risk of osseous spiral lamina injury; and (d) damage due to infection, which may cause the formation of fibrous tissue. Temporal bone studies were used to address these issues and have demonstrated the supremacy of the RW approach over cochleostomy in preventing trauma to cochlear structures as mentioned by Adunka et al.[10]

Gentle Insertion Technique

The introduction of the electrode array into the cochlea certainly plays an important role in hearing preservation. To decrease insertion force, a drop of surgical lubricant such as hyaluronic acid could be applied into the opened endosteum. Every efforts should be done to avoid any forceful procedure and the insertion should be stopped at the first resistance point. Surgeons have to be aware of the electrode insertion force and speed, keeping it slow and steady as force equals trauma. The insertion is performed with as little pressure as possible. Resistance may indicate contact of the electrode tip with the basilar membrane, osseous spiral lamina, or vasculature along the lateral cochlea wall[20,21] (►**Table 2**).

The electrode array can be coated in steroid or Healon to provide lubrication and easier insertion. Healon® (sodium hyaluronate, a.k.a. hyaluronic acid or hyaluronan) is a normal constituent of the extracellular matrix. It is commonly used in implant surgery as a lubricant for electrode insertion.[22] Secondary to cytostatic properties of the hyaluronate, it can reduce friction and trauma during electrode placement, prevent perilymph leakage, and/or prevent cochlea contamination with blood and bone dust. Despite these favorable outcomes, there is some indication that gross introduction of hyaluronic acid into the cochlea may have cytotoxic effects and should be avoided in hearing preservation surgery.

Control Inflammatory Reaction after CI

Despite meticulous surgical technique, opening of the cochlea and placement of a foreign body within the scala tympani will elicit cellular and molecular responses. Cochlear implantation is always accompanied by surgical injury, which initiates an

Table 2 Results of studies investigating the CI insertion forces

Study	Results and recommendation
Kontorinis et al[20]	High insertion speeds significantly increase insertion; thus, during the insertion, CI surgeons should use low and stable speeds. On experimental models, insertion speed close to the average used value in the theaters should be utilized to approximate human CI conditions.
Radeloff et al[8]	
(Experimental)	Coating of the CI electrode carrier may decrease insertion forces leading to less surgical trauma. Coating may assist to transmit and deliver drugs to the apical parts of the cochlear, where there are hair cells reside in patients with residual hearing
Anagiotos et al[21]	During CI, the underwater technique provides a reliable non-traumatic method for insertion of the electrode array because it respects the cochlear physiology and minimizes the pressure changes during cochlear opening and implantation.

Abbreviations: CI, cochlear implantation; RW, round window.

acute inflammatory response to the electrode. The acute phase of inflammation may be replaced by a chronic phase due to a foreign body reaction induced by components of the electrode array. Seyyedi and Nadol[23] reported that the severity of the fibrotic reaction and new bone formation adjacent to the intracochlear part of the electrode was significantly more apparent at the cochleostomy compared with the middle and the tip of the electrode. Fibrosis along the basal turn is predicted to alter vibration of the apical basilar membrane and, thus, interfere with residual low-frequency acoustic hearing.[24]

There is the concept that applying steroids directly on the round window, cochleostomy site, and/or the electrode array can inhibit inflammatory and molecular responses to implantation and avoid the loss of residual hearing with strong evidence that steroids can protect the cochlea from adverse reaction to cochleostomy and electrode insertion. Freidland et al[25] reported that the protective effect, however, was only seen with intrascalar administration of the steroid. Furthermore, when a steroid is applied topically, it reaches peak concentration within an hour and lasts less than 24 hours.[26] Systemic steroid use, however, may provide the necessary dosage and duration of treatment to protect the cochlea. The aim of postoperative medication is to prevent against long term intracochlear cell death. Intravenous corticosteroids should be used to prevent or limit apoptosis of functional cells. Additionally, postoperative antibiotics should be used to avoid infection which could compromise residual cochlear function.

Atraumatic Electrodes

There are variety of CI electrodes; surgeons and audiologists can work together to select the perfect individualized electrode for a patient. There is no one electrode that is suitable to all candidates. Despite successful preservation of low frequency hearing in patients undergoing CI, there remains controversy over which devices should be used to maximize hearing preservation.[27] Although shorter electrodes may minimize trauma to the apical cochlea, they may fail to electrically stimulate the distal cochlear neurons in some with a longer duration of high-frequency hearing loss. This may result in poor performance.[28] Therefore, investigators are actively searching for an electrode that maximizes acoustic potential without compromising electric potential.

Looking at the cochlear duct length on the preoperative CT scan as well as preoperative audiological assessment can be valuable guide in electrode selection as can identifying how much hearing there is to preserve. Long, medium, and short electrodes are all options. Both standard and atraumatic electrodes are available. The standard electrode is what we would consider for the conventional cochlear implant recipient.

For an atraumatic insertion, electrodes with special characters should be used. The tip of the electrode plays an important role in hearing preservation as it can fit through a round window or a tiny cochleostomy. Flexibility of the electrode is another option. To increase flexibility of the electrode in one design, the five most apical contacts are not paired, through which the diameter at the tip is oval to provide better apical flexibility. Slim electrodes have been found to be less invasive. Half band electrodes are designed to ensure that the electrodes are as thin as possible. Realistically, a flexible electrode with thin tapering tip and very short diameter can easily fit through a round window or small cochleostomy.[29]

Final Comments

Although still not conclusively proven, most agree that minimizing trauma during CI electrode insertion will result in improved audiological performance.[30] Gantz et al[31] have shown that preserving acoustic hearing offers advantages in back-ground noise and music appreciation. Carlson et al[2] found that patients with hearing preservation had significantly better postoperative speech-perception performance in the CI-only condition compared with those who lost residual hearing. Gifford et al[30] showed that CI with hearing preservation yields significant benefit for speech recognition in complex listening environments. As such, extensive effort has been focused on minimizing the identified mechanisms of mechanical trauma during electrode insertion including fracture of the osseous spiral lamina, injury to the modiolus, compression or tearing of vasculature, and interscalar excursion from scala tympani to scala vestibule.[31,32]

In our opinion, experience of the surgeon with skilled hands, as well as type of the electrode implanted, play a major role in hearing preservation through atraumatic soft surgery procedure.

Conflict of Interest and Financial Support
The authors declare no conflict of interest or financial support or interest to this study.

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