EXAMINATION AND COMPARISON OF THE PHYSIOLOGICAL RESULTS FROM COCHLEAR IMPLANT ELECTRODES THAT ARE DESIGNED TO ADJUST TO THE PROPERTIES OF THE HUMAN COCHLEA

PhD Thesis

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I. INTRODUCTION

466 million people worldwide have a varying severity of hearing loss, of which 34 million are children. Hearing loss may have a genetic background, but it can come from complications at birth, possible infectious diseases, chronic ear infection; a side effect of medicines (i.e. ototoxicity), noise and aging.

I.1. Cochlear Implant

In recent years, almost all severe types of hearing loss have been rehabilitated with an implantable hearing enhancement system. Cochlear implants (CI) have been providing functional rehabilitation for decades in children and adults with severe functional hearing loss due to cochlear damage of various backgrounds. The CI is a surgically, partially implanted, hearing aid. It stimulates the remaining working peripheral cells of the auditory nerve through a series of electrodes, directly in the lumen of the cochlea, acting as a hair cell prosthesis.

There are currently different trends in cochlear implant electrode design. The manufacturers provide a variety of implant configurations including different receiver-stimulators, electrode arrays (e.g. straight or pre-curved, full-length or short) and sound processors to choose from. This can facilitate decision making on an individual basis. Further important aspects of implant design such as: proximity to the modiolus, electrical current requirements, energy consumption, trauma to the cochlea, combined electro-acoustic stimulation, preservation of cochlear structures with low-trauma surgical technique and hearing preservation have become the focus of many discussions and studies.

I.2. Postoperative hearing preservation

Since the CI’s launch, they have undergone significant technical advancement, necessitating the adaptation of surgical techniques from time to time. From the outset, efforts have been made to preserve the patient's residual hearing after surgery. This concept was particularly prominent in all cases where the patient's low frequency hearing could be rehabilitated including cases with conventional hearing aids. However speech comprehension was accompanied by acoustic amplification, due to the simultaneous presence of severe mid- and high-tone loss representation, was almost impossible. This has led to the emergence of implant systems based on the principle of electro-acoustic stimulation (EAS), which use conventional acoustic amplification as well as implanted electrical stimulation.

Residual hearing sensitivity may deteriorate due to perioperative traumas or complications with delayed onset. The applied surgical approach (round window (RW), extended round window (ERW), and cochleostomy (CS)) and the implanted electrode profile mainly lead to immediate or short-term damage, while delayed alteration in cochlear function usually derives from the fibrous or bony remodelling of the endocochlear compartments.

Surgically important properties are: the physical attributes of the electrode configuration (perimodiolar vs. straight; rounded vs. smoothened tip; short vs. regular; with or without stylet, etc.), the type of cochlear fenestration (RW, ERW, CS), the method of electrode insertion (standard vs. soft surgery with advance-off-stylet), the use of lubricants or drugs in the cochlea (e.g. hyaluronic acid, intrascalar corticosteroids) and the intrascalar position of the electrode array (perimodiolar, mid-scala, or lateral wall).

However, the possible disproportion between the physical dimensions of the electrode profile and the endocochlear compartments (e.g. diameter, shape, length of scala tympani) also play a significant role in preserving inner ear structures and functions. Minimizing the damage in the inner ear enhances the possibility for hearing preservation, thus leads to better hearing performance.

I.3. Cochlear™ Nucleus® CI500 Profile™ Series

Competing companies provide different types of receiver-stimulators, implant electrodes and speech processors. One of the primary aims of cochlear implant system engineering is to promote atraumatic electrode insertion to maintain optimal postoperative hearing sensitivity by protecting and preserving the delicate inner ear structures.

A critical aspect of the design is the dimensions of devices. Decreasing the size (thickness of implant body, diameter of electrode array) facilitates minimally invasive surgical techniques, as thin implants can be implanted without a bony well. Most implantable hearing device manufacturers have aimed to decrease the thickness of their cochlear implants, the most ambitious change can be observed across the Cochlear™ Nucleus® Profile implant series.

The Nucleus Profile family is available with precurved electrode arrays (Contour Advance CI512, Slim Modiolar CI532) and a straight electrode array (Slim Straight CI522). The maximum thickness of the Nucleus Profile is 3.9 mm which makes it the thinnest cochlear implant body.

II. OBJECTIVES

1. To compare the influence of various electrode designs upon selected electrophysiological outcomes for cochlear implant recipients using the same model of receiver-stimulator, Cochlear™ Nucleus® Profile Series and sound processor in a retrospective study.
2. During cochlear implantation in the rehabilitation of hearing-impaired patients, postoperative preservation of residual hearing and the maximization of hearing performance depend on minimizing the trauma of implantation of the electrode array. To achieve this, minimal invasive methods and thinner, low-trauma electrode arrays were required. Our aim is to monitor the possibility of postoperative acoustic hearing preservation and demonstrate it in one special case and
3. to analyze statistical data of the registered long-term hearing preservation in a non-randomized, prospective clinical cohort with specialized slim, perimodiolar cochlear implant systems based on methods and results of above special case.

III. MATERIALS AND METHODS

4. **1. Electrophysiological measurements with Profile implant devices**

A total of 139 consecutive subjects who were implanted between 13 June 2014 and 4 May 2017 with a Profile CI532 (referred to as CI532), a Profile CI512 (referred to as CI512), and a Profile CI522 (referred to as CI522) device manufactured by Cochlear Ltd., Australia and gave their informed consent were enrolled into this retrospective study from two tertiary referral implant centers (referred to as Department of Otorhinolaryngology, Albert Szent-Györgyi Clinical Center, University of Szeged, Hungary (Clinic 1) and Department of

Otorhinolaryngology, Karl Landsteiner University Hospital of St. Pölten, Austria (Clinic 2)). Time periods of the study recruitment were from 13 June 2014 to 14 December 2015 for CI512, from 13 November 2015 to 4 May 2017 for CI532, and 11 March 2015 to 29 November 2016 for CI522. All subjects were examined with high resolution computed tomography (CT) and/or magnetic resonance imaging (MRI) before surgery. Exclusion criteria were cochlear malformations, cochlear otosclerosis, obliterative postmeningitis changes and electrode tip fold-over.

Subjects were consecutively treated as part of routine clinical practice that was comparable at each respective implant site. A total of 159 ears in 139 subjects were implanted with devices, including the same implant receiver stimulator electronics. CI532 had an array with 22 electrode endpoints which was perimodiolar and with a relatively smaller diameter (named Slim Modiolar), CI512 had a 22 electrode array which was perimodiolar with a relatively larger diameter (named Contour Advance), and CI522 had a 22 electrode array which was straight, also with a relatively small diameter (named Slim Straight).

A total of 54 ears were implanted with CI532 (all in Clinic 1), 54 ears with CI512 (51 in Clinic 1 and 3 in Clinic 2), and 51 ears with CI522 (47 in Clinic 2 and 4 in Clinic 1). Patients who were implanted with CI532 formed the test group. Two control groups were formed from patients who were implanted with 512 and 522.

III.1.1.Implantation technique

The electrode arrays were inserted into the cochlea according to the manufacturer's instructions provided in the physician's surgical guide. The method of electrode insertion was identical in both implant clinics [31]. Full insertion was achieved via the extended round window approach with CI532 and CI512 and via the round window approach with CI522 in all ears. The AOS (advance off-stylet) technique was used for CI512 and the freehand technique was used for CI522. Electrode choice was dependent on the type of implant availability for each center (regulated by the health authorities).

III.1.2.Electrophysiological testing

The three different types of electrode arrays were compared with regards to outcomes from intraoperative and 3-months postoperative electrophysiological testing performed as per routine clinical protocol. Intraoperative electrophysiological tests: Impedance was measured for each electrode, the electrical stapedial reflex threshold (ESRT) with 25 µs pulse width for every second electrode contact (No. 2, 4, 6 etc.) and neural response telemetry threshold (T-NRT) for 6 (No. 2, 6, 10, 14, 18 and 22) electrode contacts. ESRT values were compared in groups CI532 and CI512. T-NRT values in group CI532 were compared with those in both control groups.

The first fitting was performed 4 weeks after surgery in each case. In order to determine the electric threshold (T-levels), and comfort threshold (C-levels), the subjective fitting method was used in adults and the semi-objective NRT based fitting (based on the intraoperative T-NRT results) was applied in children. Default MAP parameters (25 µs pulse width, 900 Hz stimulation rate and 8 maxima) were used. Postoperative NRT was measured 2 months after the first fitting, i.e. 3-months follow up. C-levels at first fitting and 3-months follow-up fitting and T-NRT at 3-months follow-up were compared.

III.2. Possibility of postoperative preservation of residual hearing by CI532 with one case

Several studies have shown the positive properties, location and dimensions of CI532 Slim Perimodiolar electrode, which provide the possibility of preserving residual hearing after implantation. There are some surgical techniques of approaching the scala tympani (i.e., RW, ERW, CS) with varying risks of harming the fine structures of the cochlea with prompt or delayed onset. Such late complications, for example the appearance of endocochlear connective tissue or new bone formation, may lead to a gradual partial or complete loss of residual acoustic hearing. This is most likely to be seen when the RW is extendedly exposed, where endothelial lesions trigger new tissue proliferation. The tendency to harm the endocochlear structures is decreased when minimally invasive, soft surgery is applied. Physical attributes of the electrode profile may also interfere with postoperative cochlear function. Theoretically, the endocochlear hydrodynamics may also be altered, as the vibration of the basilar membrane is restricted due to the presence of an electrode array. At this point, as the travelling waves to the apical region are modified, the basilar membrane would react to sounds differently, which leads to an endocochlear "conductive" hearing loss.

III.2.1. Nucleus CI532 Slim Modiolar electrode profile

The studied cochlear implant system has a slim, full-length perimodiolar electrode. The electrode array is easy and smooth to insert through RW or CS with the guiding sheath that is the main handle assist tool and it is reloadable. The thin electrode array allows unobstructed access to the scala tympani that has a tip diameter of 0.35×0.4 mm and 0.45×0.5 mm at the base. At the last edge of the electrode array there are 3 white marker rings for controlling the insertion depth that are followed by 22 half banded platinum electrode contacts. These properties make this implant configuration easier to use with shorter incision and surgery time. The insertion assistant sheath platform and the physical attributes of the electrode array facilitate to approach the modiolus and thus prevent the electrode from dislocation into the scalae media or vestibuli.

Due to its special, flexible three-dimensional (3D) conformation allows to be located under the lamina spiralis ossea, ensuring that the stimulation points are near the spiral ganglion cells. Its atraumatic design ensures the preservation of endo-cochlear structures.

III.2.2. Minimally invasive surgical technique

Preserving the residual hearing requires minimally invasive techniques of (1) cochlear fenestration, (2) management of endocochlear fluid compartments and (3) atraumatic electrode insertion, known as soft surgery. Thinner and atraumatic electrode arrays are also designed to accomplish these aims, as postoperative hearing performance can be maximized by minimizing the insertion trauma.

Several important factors contribute to intracochlear damage during implantation: (1) direct physical trauma, (2) pressure wave propagation in the perilymphatic fluid, (3) vibration and/or heat trauma from drilling, (4) loss of perilymph, (5) changes in homeostasis/hydrodynamics of the endocochlear fluid compartments, (6) delayed fibrotic changes and new bone formation within the cochlear lumen.

III.2.3. Patient data

Our female patient was born in 1987. Due to her congenital loss of hearing, she has been wearing conventional air-conductive hearing aids on both ears since childhood. The implantation was performed when the patient turned 30, under general anesthesia. Since the patient had residual hearing on both ears prior to surgery, we decided to use a thin perimodiolar electrode profile (CI532 Slim Modiolar implant). The operation was performed on the patient's right ear using the minimally invasive surgical technique described above via the round window.

III.3. Long-term postoperative hearing preservation with CI532

In our previous series of case, we performed audiological measurements on a larger group of successes that could demonstrate the atraumatic effect of CI532.

Out of the total number of cochlear implantees with slim perimodiolar implant system (n=94) our study population was recruited on the basis of the following criteria: (1) patient with good compliance; (2) measurable preoperative hearing threshold; (3) slim perimodiolar electrode array implant system; (4) minimum one-year follow-up period.

30 consecutive subjects were enrolled into this prospective, non-randomized clinical study. 20 females and 10 males with mean age at implantation of 43.32 years, ranged between 10 years to 77 years. All subjects were implanted at the University of Szeged from 2015 until 2017.

IV. RESULTS

All subjects received Nucleus Profile implants. The only difference was the type of electrode. The patient groups were similar in subject numbers, etiology and duration of deafness, and indications.

IV.1. Electrophysiology testing

Firstly, intraoperative electrical stapedial reflex threshold (ESRT) and Neural Response Telemetry (T-NRT), results were compared across implant groups. The stapedial reflex was tested in all subjects in group CI532 and CI512 and could be elicited in 44 out of 54 cases in group CI532 and in 47 out of 54 cases in the control group (group CI512). The mean ESRTs were lower in group CI532 than in group CI512. This difference was significant (t probe: $p = 0.007$) for electrode contact 2. Grand average (all electrodes) statistic calculation (Grand $T_{532–512}$) showed significant differences between groups CI532 and CI512 ($p < 0.05$).

The neural response threshold was tested in all subjects and could be elicited in 50 out of 54 (group CI532), 47 out of 54 (group CI512), and 43 out of 51 (group CI522) cases. Repeated ANOVA analysis revealed significant difference ($p < 0.05$) between the three groups. On examining the significance in pairs, we found that the mean T-NRTs proved to be lower in each electrode in group CI532 when compared with each control group. The difference was significant in 5 measured electrode contacts when compared with CI522 and 3 measured electrode contacts when compared with CI512 (t-probe: $p < 0.05$). Grand average (all electrodes) statistic calculation (Grand $T_{532–512}$ and Grand $T_{532–522}$) showed significantly lower T-NRT values in group CI532 compared with the two control groups ($p < 0.05$).

The subjects were scheduled for the first fitting 4 postoperative weeks after surgery. C-levels during the first fitting were compared in patient groups with different implants. No significant difference in mean C-levels was seen on any electrodes between groups CI532 and CI512, but grand average (all electrodes) statistic calculation (Grand $T_{532–512}$) showed significant differences between the two groups ($p < 0.05$). C-levels were considerably higher on every electrode in group CI522 compared to groups CI532 and CI512, and the difference was significant for apical electrodes 2 to 12 ($p < 0.05$). Grand average (all electrodes) statistic calculation (Grand $T_{532–522}$) showed significant differences between the groups ($p < 0.05$). However, no significant difference was present on any electrodes in C-levels 2 months after the first fitting, only the grand average statistical analysis (Grand $T_{532–522}$) showed significant differences between groups CI532 and CI522.

In groups CI532 and CI512, T-NRT measurements were attempted in all subjects at the two-month follow up fitting and the measurements were successfully carried out in 32 subjects in group CI532 and 36 subjects in group CI512. The intraoperative electrophysiological measurements could be performed in all subjects under general anesthesia, whereas the postoperative measurements were performed in vigil subjects. In the latter case, some of the subjects complained about unpleasant sound volume before a neural response could have been measured, for this reason the electrophysiological testing could not be performed. The mean T-NRT results in the basal section were lower in group CI532 than in group CI512. The difference was significant ($p < 0.05$) on two electrodes (No 14 and No 16). Grand average (all electrodes) statistic calculation (Grand $T_{532–512}$) showed significant differences between the groups ($p < 0.05$).

IV.2. Hearing Preservation after Cochlear Implantation in one subject

Before Implantation the pure-tone threshold audiometry performed at speech frequencies (0.25 to 1.0 kHz) showed a hearing threshold of 85 dBHL, while speech understanding hearing test was not possible to perform due to the poor thresholds. The objective test result showed normal middle ear, no external hair cell activity was registered on either side and no retrocochlear lesion.

After the implantation the first control measurement, as pure-tone hearing threshold test, was in the 4th postoperative week. A 5-10 dBHL threshold decrease was registered in the range of speech frequencies, at 0.25-1.0 kHz. At 2.0 to 4.0 kHz, we experienced 20-25 dBHL loss.

With pure tone audiometry registered hearing threshold in the 6th postoperative month showed progression above 1 kHz, but in the postoperative 12th month, after improvement, hearing thresholds were the same as in the 4th month.

IV.3. Results of Hearing Preservation cohort

Pre- and postoperative pure tone hearing threshold measurements were completed for all of the 30 recruited subjects. The hearing threshold is the most stable within the 250 to 1000 Hz range, and the least is beyond 4 kHz. This statement is true either pre- or postoperatively.

The average preoperative thresholds of the hearing within the lower frequency range were 61.75 dBHL at 125 Hz (no response from 10 patients); 78.52 dBHL at 250 Hz (no response from 3 patients). At the middle frequency range, mean values were 88.67 dBHL at 500 Hz (response from all patients); 97.07 dBHL at 1 kHz (no response from 1 patient) and 100.50 dBHL at 2 kHz (no response from 10 patients). At the higher frequencies, the average values were 91.36 dBHL at 4 kHz (no response from 19 patients) and 84.00 dBHL at 8 kHz (no response from 25 patients).

One year postoperatively the average values of the hearing thresholds at the lower frequency range were: 93.89 dBHL at 125 Hz (no response from 17 patients); 87.86 dBHL at 250 Hz (no response from 10 patients). At the middle frequencies mean values were 102.86 dBHL at 500 Hz (no response from 10 patients); 111.61 dBHL at 1 kHz (no response from 14 patients) and 113.75 dBHL at 2 kHz (no response from 21 patients). At the higher frequencies, average values were 115.18 dBHL at 4 kHz (no response from 24 patients) and 99.29 dBHL at 8 kHz (no response from 29 patients).

Decrease was detected at each examined frequencie but the grade of it varied. The highest decrease was measured at 500 Hz with an average decrease of 14.19 dBHL and at 1000 Hz with an average decrease of 13.77 dBHL. At the lower frequency range, hearing remained substantially stable. At 125 Hz only 3.06 dBHL, while at 250 Hz only 7.19 dBHL loss was detected. At the high frequencies, from 2 to 8 kHz preoperative hearing sensitivity had been already proved to be rather poor, thus further loss had just little consequences.

Nine implantees (9/30=30%) showed up with total loss of residual hearing at every measured frequency following the surgery.

V. DISCUSSION

V.1. Electrophysiological measurements with different types of perimodiolar electrode array

A wide range of cochlear implants with different electrodes are available for rehabilitation of hearing-impaired patients with severe to profound sensorineural hearing loss. Hearing rehabilitation outcomes may be influenced by optimizing device and electrode choice for the individual. Several comparative studies have been conducted including electrophysiological (ESRT, NRT) test methods to evaluate the influence of straight and perimodiolar electrode designs and their in-situ characteristics on clinical outcomes. Our study is unique in that it measured the influence of various electrode designs combined with a common receiver-stimulator upon electrophysiological assessments for a relatively large routinely treated multicenter study cohort. As such, it is the first study to report on the influence of electrode design while using consistent implant receiver-stimulator electronics. The cooperation of Department of Otorhinolaryngology, University of Szeged, Hungary and Department of Otorhinolaryngology, Karl Landsteiner University Hospital of St. Pölten, Austria the was established in 2017 with the aim to compare the perimodiolar and the straight electrode arrays. The study clinics followed a standard protocol enabled by the manufacturer's software, thus a conclusion from their individual results can be made. The results of Hey et al. from their multicenter study on CI532 are in good correlation with our results which proves that our methodology and results are reliable.

The Slim Modiolar Electrode is designed for insertion with minimal cochlear trauma. It has the advantage of taking 60% less volume in the scala tympani compared to the Contour Advance Electrode and is therefore placed in a position close to the modiolus. Perimodiolar proximity is an important clinical consideration, observing that total insertion depth was not associated with better speech discrimination outcomes, however, the distance from the electrodes to the modiolus did indicate a significant influence. The Slim Modiolar electrode array takes a closer position to the modiolus than the Contour Advance electrode array as confirmed by a comparative radiological evaluation.

Results from the objective intraoperative measurements indicated that the electrode contacts of the CI532 array were located closer to the modiolus than those of CI512. A previous study found that withdrawal of the stylet in the Contour Advance Electrode resulted in better NRT and ESRT responses, than with the stylet in place. They concluded that this is most probably due to a more favorable position of the electrode array towards the modiolus within the scala tympani once the stylet is removed. In our study, although the mean ESRT was only slightly lower with CI532, the difference was statistically significant at the basal most electrodes tested. However, the mean T-NRT for CI532 was significantly lower than for CI512, especially in the apical-middle section, which is considered to be indicative of closer positioning towards the modiolus. An expected rate of scalar dislocations could be 26% with precurved electrode (i.e. CI512) and 3% with straight electrode (i.e.

CI522) with round window insertion technique and this dislocation should have a significant impact on the NRT threshold in the apical part of the electrode. In order to minimize scalar dislocation, the extended round window insertion technique was used. Although the regular institutional protocols did not include postoperative computed tomography, the results from T-NRT and ESRT, both being constantly higher for CI512 when compared with CI532 and T-NRT being constantly lower for CI512 when compared with CI522 are not indicative of significant dislocations between scalae tympani and vestibuli. The sizeable reduction in both T-NRT and ESRT observed in our study are considered sufficiently large to potentially influence differences in clinical outcomes as observed for subjective comfort level.

The surface area of an electrode is inversely proportional with the resistance, thus current is proportional with the surface area. If the electrode with a smaller surface is capable of eliciting the same response it means that it is closer to the stimulated structure. The lower objective electrophysiological thresholds of CI532 suggest that the electrodes are capable of eliciting reflex responses with lower stimulation intensity, resulting from closer proximity to the modiolus.

V.2. Hearing Preservation

Preservation of acoustic hearing associated with cochlear implantation improves the postoperatively achievable periodicity and spectral resolution, which improves the patient's speech comprehension and the localization of the tone in particularly difficult conditions.

The effects of cochlear implantation on residual hearing have been discussed in several studies in which a number of surgical and technical factors have been identified. There are some surgical techniques of approaching the scala tympani (i.e. RW, ERW, CS) with varying risks of harming the fine structures of the cochlea with prompt or delayed onset. Such late complications, like the appearance of endocochlear connective tissue or new bone formation, may lead to a gradual partial or complete loss of residual acoustic hearing. This is most likely to be seen when the round window is extendedly exposed, where endothelial lesions trigger new tissue proliferation. The slightest is the tendency to harm the endocochlear structures when minimally invasive, soft surgery is applied.

Physical attributes of the electrode profile may also interfere with postoperative cochlear function. Theoretically, the endocochlear hydrodynamics may also be altered, as the vibration of the basilar membrane is restricted due to the presence of an electrode array. At this point, as the traveling waves to the apical region are modified, the basilar membrane would react to sounds differently, leading to an endocochlear “conductive” hearing loss.

The new type of thin-diameter electrode arrays close to the modiolus are expected to have a lower hydrodynamic load, since the bony spiral lamina is attached from below, thus the basilar membrane vibrations remain unrestricted. However, the perimodiolar position of the electrode array allows the adjacent nerve elements of the spiral ganglion to be stimulated with a lower electrical intensity and through a smaller surface.

For the implementation of electro-acoustic (EAS) or hybrid speech processors the long-term preservation of residual acoustic hearing is inherently inevitable, thus application of atraumatic surgical techniques and electrode arrays is essential.

Our study cohort obviously demonstrates that by the application of appropriate soft surgery techniques and atraumatic electrodes are able to retain residual hearing on a long run. The positive experience gained with the new type of CI532 Slim Modiolar electrode predicts the possibility for the preservation of structural and functional integrity of all cochlear regions. Furthermore, a prompt, definitive solution could be provided for a possible late hearing loss progression, where only a psychophysical reprogramming of the implant would be enough.

On the basis of our results, if the acoustic hearing loss can be preserved with the assurance and efficacy of the initial experience, we will be able to provide sustained prominent hearing rehabilitation even in the indication of EAS that results in significant improvement in the life quality of many implantees.

In addition, long-term residual hearing preservation follow-up could be of crucial importance in the subsequent feasibility of regenerative procedures and medical treatments.

VI. CONCLUSION AND NEW RESULTS

Although the Slim Modiolar electrode is significantly thinner than the Contour Advance and similar sized as the Slim Straight electrode array, the Slim Modiolar electrode provides similar or better stimulation productivity compared to Contour Advance and Slim Straight electrodes. The manufacturer's thinnest electrode array, the Slim Modiolar Electrode takes the position that is closer to the modiolus compared to the Contour Advance Electrode and the Slim Straight Electrode. Our intraoperative and postoperative measurements confirmed this showing that more effective stimulation can be achieved through the use of the Slim Modiolar Electrode.

In cochlear implantation, the use of new electrode array could play a fundamental role in minimally invasive soft surgery, taking into individual needs, and providing long-term acoustic hearing preservation. Our study demonstrates the efficacy of the Nucleus CI532 Slim Modiolar electrode profile. It has the potential to preserve residual hearing, which predicts the possible use of this configuration as part of EAS systems, and it maintains the structures availability for future treatments, i.e. the regeneration-based new therapeutic approaches of intracochlear hair-cells.

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