Evaluating Intracochlear Trauma after Cochlear Implant Electrode Insertion through Middle Fossa Approach in Temporal Bones

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Abstract

Objective. To evaluate cochlear trauma after cochlear implant insertion through a middle fossa approach by means of histologic and imaging studies in temporal bones.

Study Design. Prospective cadaveric study.

Setting. University-based temporal bone laboratory.

Subjects and Methods. Twenty fresh-frozen temporal bones were implanted through a middle cranial fossa basal turn cochleostomy. Ten received a straight electrode and 10 a perimodiolar electrode. Samples were fixed in epoxy resin. Computed tomography (CT) scans determined direction, depth of insertion, and the cochleostomy to round window distance. The samples were polished by a microgrinding technique and microscopically visualized to evaluate intracochlear trauma. Descriptive and analytic statistics were performed to compare both groups.

Results. The CT scan showed intracochlear insertions in every bone, 10 directed to the middle/apical turn and 10 to the basal turn. In the straight electrode group, the average number of inserted electrodes was 12.3 vs 15.1 for the perimodiolar group (U = 78, P = .0001). The median insertion depth was larger for the perimodiolar group (14.4 mm vs 12.5 mm, U = 66, P = .021). Only 1 nontraumatic insertion was achieved and 14 samples (70%) had important trauma (Eshraghi grades 3 and 4). No differences were identified comparing position or trauma grades for the 2 electrode models or when comparing trauma depending on the direction of insertion.

Conclusion. The surgical technique allows a proper intracochlear insertion, but it does not guarantee a correct scala tympani position and carries the risk of important trauma to cochlear microstructures.

Keywords
cochlear implants, sensorineural hearing loss, middle fossa approach, temporal bone, histopathology

Different surgical approaches have been suggested to perform safer, less traumatic cochlear implant (CI) insertions, which vary from the traditional posterior tympanotomy/round window approach to less common techniques such as the suprameatal and transcanal approaches or the endoscopic combined transatival/transcanal approach.¹,² A middle cranial fossa approach (MFA) has also been described and proved to be useful for selected cases with chronic suppurative otitis media, mastoid cavities with recurrent otorrhea, partially ossified cochlea, and inner ear dysplasia.³-⁶ Considering chronic otitis media, the classic route might be contraindicated unless a 2-stage surgery is performed. Until now, only 2 surgical groups have reported cochlear implantation through the MFA with a total of 15 implanted patients. Recently, we published a review of the results obtained in this small number of patients. One group entered the cochlea in the most upper part of the basal turn, inserting the implant

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in the direction of the middle and apical turns in 11 patients, and the other group inserted the implant in the apical turn directed in a retrograde fashion to the middle and basal turns in 4 patients. Results obtained for both groups were similar.5

Residual hearing preservation has been shown to significantly improve cochlear implant performance. Thus, many studies aim to study trauma to the inner ear’s osseous and membranous microstructures with different CI electrode designs and surgical approaches. Nontraumatic insertions prevent damage to the basilar membrane (BM), osseous spiral lamina (OSL), spiral ligament (SL), and modiolar wall, as well as loss of residual hair cells. All of these may lead to cochlear fibrosis or ossification, which deteriorate hearing outcomes.7-9 The evaluation of new surgical techniques and CI designs to avoid traumatic insertions is not an easy task. Multislice computed tomography (CT), rotational tomography, and cone-beam or flat-panel CT scans may give important information about the electrode’s scalar position and its proximity to the modiolus, but there are some problems in interpretation because of the interference produced by the metallic electrodes. Besides, none of these can accurately describe if preservation of the fine microanatomy inside the cochlea was attained.10-15 The microgrinding technique described by Plenk16 in 1986, to study implanted temporal bones, aids in this problem.17 Since his description, refinement has been done to make it less expensive and time-consuming. Recently, our group published a detailed description of the technique as it is currently performed.18

An important number of temporal bone studies related to the anatomical basis for cochlear implantation through the MFA have been produced. Most of these focus on the identification of anatomic landmarks in the middle fossa (MF) floor to pinpoint a proper location for a cochleostomy, rather than to evaluate the effects that the CI insertion through this route produces in cochlear microanatomy. The objective of this study is to evaluate positioning and inner cochlear trauma with imaging studies and the microgrinding technique, when the CI is inserted through a MFA in fresh-frozen temporal bones.

Materials and Methods

The Research Ethics Committee of the University of São Paulo Department of Medicine approved this study. Three technicians randomly retrieved 20 human temporal bones within 24 hours after death, which were immediately frozen at −20°C. Temporal bones demonstrating signs of trauma, malformation, otological disease, or previous surgical treatment were excluded. Age, sex, and race were not taken into account; only the cause of death was determined, but the clinical history was unknown. The bones were randomly assigned to the perimodiolar electrode array (PMEA) group, which would receive a HiFocus Mid-Scala (Advanced Bionics, Valencia, California), or to a straight electrode array (SEA) group for a HiFocus 1J straight electrode (Advanced Bionics).

On the day of dissection, the bones were thawed at room temperature, placed in surgical position for an MFA, and operated under a surgical microscope replicating a real MFA cochlear implantation. A single surgeon performed all the procedures and cochlear implant insertions. A 4 × 3 MF craniotomy was performed, centered on top of the zygomatic root (Figure 1A). The dura was retracted until the anatomical landmarks of the MF were identified. The superior semicircular canal was blue-lined and the dura of the internal auditory canal (IAC) was exposed from the geniculate ganglion to the internal auditory meatus (IAM) to properly identify the location of the cochlea (Figure 1B). A special instrument with an “F” form was developed to identify the correct place for the cochleostomy in the basal turn. This “F” stylet takes in account measures taken from 50 temporal bones described in a study by de Brito et al.5 It
considers the minor and major distances where the cochleostomy should be opened, guided by the long axis of the meatal plane from its most proximal portion. This instrument, its placement, and measures are shown in Figure 2A, C, D. A 1-mm cochleostomy was performed and the endosteum and membranous labyrinth were opened with a stylet as normally performed for a round window cochleostomy. The electrode array was then introduced, trying to direct the insertion toward the middle/apical turns by orienting the array toward the arcuate eminence (Figure 2B). The insertion tool recommended by the manufacturer to facilitate insertion was used in all cases. Insertions stopped at the moment the surgeon felt resistance. The implant was fixed to the petrous apex bone with ethylcyanoacrylate glue. The bone size was reduced, preserving only the inner ear structures. The stapes was removed and the round window membrane opened to allow the flow of compounds used for histological preparation throughout the cochlea.

After the surgical procedures, the temporal bones were relayed to fixation, dehydration, and embedding. Next, CT scans were performed to determine the direction of insertion (middle/apical turns or basal turn as seen in Figure 3), the number of electrodes inserted, depth of insertion, and the distance between the cochleostomy and round window. A radiologist and a neuro-otologist evaluated the images together. Finally, the epoxy blocks were transferred to a microgrinding machine, polished, and stained with toluidine blue before microscopic analysis. This procedure was repeated every 500 μm until the entire cochlea was visualized. A detailed description of the microgrinding process as performed in our center, concerning its safety for the study of cochlear trauma, was published recently.18 Two individuals experienced with cochlear histology performed the analysis of CI position and trauma. Trauma was graded according to the classification proposed by Eshraghi et al9 in 2003. Examples of the 4 grades of trauma are shown in Figure 4.

A descriptive analysis of all measurements was performed. The number of electrodes inserted and the depth of insertion were compared between groups using Mann-Whitney U tests. The direction of insertion and proper scala positioning (described in Figure 5) was compared between groups using χ² tests. The trauma grades observed at the cochleostomy site were compared between groups with a Mann-Whitney U test. The highest trauma grade observed in each bone, excluding trauma produced by the cochleostomy, was also compared between groups and considering the direction of insertion, both with Mann-Whitney U tests. All tests considered a 95% confidence interval.

**Results**

The CT scans showed that the surgical technique permitted an adequate intracochlear implantation in all the temporal bones. In 10 samples (6 from the PMAG group and 4 from the SEA group), a middle/apical turn direction was obtained. None of the implants oriented to the basal turn entered the vestibule, stopping at the level of the round window. In 2 bones, both randomly allocated to the SEA group, partial ossification was observed on CT scans, close to the level of the cochleostomy, which made the electrode array enter in an undesired fashion in the direction of the basal turn. Still, they both attained good intracochlear electrode insertions up to the level of the round window. Even though there were more
implants from the PMEA group oriented to the middle/apical turns, as intended, there was no statistical difference between groups when comparing the direction in which the electrode was inserted ($\chi^2 = 0.8, P = .37$).

The distance measurements between the cochleostomy and round window for all samples ranged from 11.5 to 14.3 mm (average and median, 13.1 mm; standard deviation [SD], 0.8) with no statistical differences between groups.

Figure 3. The possible directions of insertion are represented in illustrations and observed with computed tomography scans. (A) Middle/apical turn insertion. (B) Basal turn insertion.

Figure 4. Trauma grades. (A) Grade 1: electrode in contact with the OSL and basilar membrane displacement. (B) Grade 2: basilar membrane rupture. (C) Grade 3: Vestibular insertion, Reissner’s membrane rupture. (D) Grade 4: OSL fracture. OSL, osseous spiral lamina; SL, spiral ligament; SM, scala media; ST, scala tympani; SV, scala vestibuli. Arrowheads: Reissner’s membrane; long arrows: basilar membrane; short arrows: OSL.
In the SEA group, the mean number of inserted electrode contacts was 12.3 (10-14; median, 12; SD, 1.3) vs 15.1 for the PMAG group (14-16; median, 15.1; SD, 0.7). There was a statistically significant difference in the number of inserted electrode contacts between groups ($U = 78, P = .0001$).

When observing insertion depth, we noticed an important difference between the medians, 12.5 mm for the SEA group (10.4-14.7 mm; mean [SD], 12.9 [1.4] mm) and 14.4 mm for the PMEA group (13.5-15.5 mm; mean [SD], 14.6 [0.7] mm). This difference was also statistically significant ($U = 66, P = .021$). In 3 of the middle/apical turn insertions with the PMEA, the full active length of the implant was inserted.

Regarding the intracochlear position immediately after entrance through the cochleostomy, in the SEA group, 5 implants entered the scala tympani (50%) and 4 the scala vestibuli. One entered in an interscalar position. In the PMEA group, 4 implants entered the scala tympani (40%), 4 in an interscalar position, and 2 through the scala vestibuli. The position was also analyzed in a mid-modiolar section to notice if the initial insertion position was preserved throughout the cochlea. In the SEA group, 4 implants maintained scala tympani positions (40%), 4 attained an interscalar position (1 previously seen in the scala tympani and 2 that entered in the scala vestibuli), and 2 ended in the scala vestibuli. Meanwhile, in the PMEA group, 3 implants maintained a correct scala tympani position (30%) and 7 had incorrect positioning, with 5 implants in the scala vestibuli (1 of which migrated from a previously correct insertion) and 2 in an interscalar position. There were no statistical differences between groups, considering either the immediate postcochleostomy position or the mid-modiolar intracochlear position ($\chi^2 = 0.2, P = .65$ and $\chi^2 = 0.22, P = .23$, respectively).

Only 1 nontraumatic insertion was achieved, with a PMEA inserted into the scala tympani in the direction of the basal turn. All other samples presented trauma, and in 14 (70%), high grades of trauma were observed (Eshraghi grades 3 and 4). The most common observation was electrode migration into the scala media and scala vestibuli, which in some cases was accompanied by a fracture of the OSL if the electrode was closer to the modiolus or detachment of the SL when the electrode was closer to the lateral wall. Even though we noticed a tendency for higher trauma grades with the SEA, when analyzing the data, no statistical difference was identified between the 2 models ($U = 43, P = .63$). Examples of electrodes inserted in a middle/apical direction and in the direction of the basal turn may be appreciated in Figure 6.

Finally, we wanted to observe if there were differences in trauma grades when the CIs were directed to the middle/apical or basal turns. We grouped all the samples together and noticed that even if there appeared to be a tendency for lower trauma grades when the CIs were directed to the basal turn, no statistically significant differences were observed between the 2 directions of insertion ($U = 58, P = .12$). All measurements and observations are summarized in Table 1.

**Discussion**

Different temporal bone studies have shown that it is possible to perform a CI insertion through the MF. In 2007, Todd$^{19}$ reported a study with 82 temporal bones in which an MF cochleostomy was performed using split electrode...
arrays. Electrode placement and depth of insertion were assessed, with achievement of a proper insertion in every bone, both toward the round window and the cochlear apex. He noticed that 75% of the electrode arrays inserted toward the round window extended into the vestibule, whereas insertions toward the cochlear apex had a median insertion depth of 12 mm, allowing the full length of the cochlea to be in contact with the electrodes. In contrast with that study, none of our basal turn directed insertions reached the vestibule. In 2013, de Brito et al. published a study with 50 temporal bones describing an approach to open the basal turn of the cochlea through the middle cranial fossa for cochlear implantation. They used the superior petrosal sinus, the anterior-lateral surface of the meatal plane, and the greater superficial petrosal nerve (GSPN) as landmarks to perform a 1.5- to 2-mm cochleostomy in the basal turn of the cochlea, which allowed visualization of the OSL and the scalas. They performed cochlear implantation through the scala tympani, directing the insertion to the arcuate eminence to obtain middle/apical turn insertions, and then performed CT scans to document if this direction was obtained. The current study used a similar technique, and an instrument was designed to aid in finding the correct spot for the cochleostomy in the basal turn based on their measurements, the so-called “F” stylet (Figure 2A). The present study attempted to perform atraumatic insertion, and therefore a 1-mm cochleostomy was created between the 2 branches of the “F,” and the endolymph/membranous labyrinth was opened with a stylet in the same fashion as performed during a round window cochleostomy. Doing so did not permit the observation of the OSL, and we did not know in which scala was our implant being inserted. The “F” stylet was reliable to open the basal turn of the cochlea since we obtained intracochlear insertions in the 20 temporal bones, but considering it is designed with maximal and minimal distances, it is not reliable to obtain scala tympani insertions. In the aforementioned work by de Brito et al., the average variation in distance of the place to correctly open the cochleostomy from one bone to the other was 1.66 mm. The possibilities of entering the cochlea in the correct scala improve when the cochleostomy is performed between the minimal and maximal distances observed in that research, but if we consider that the average diameter of the basal turn of the cochlea at 360°, more or less the place for our cochleostomy, is 1.21 ± 0.32 mm, then a 1.66-mm variation between samples is considerably large.

Controlling the direction of insertion and trying to orient it toward the arcuate eminence was also troublesome, mainly because of the small cochleostomy and the use of the insertion tools, which are large for this access route and always push the dura back to achieve a good insertion position. As shown in Figure 3, once the implant passes the cochleostomy, there is little to be done to control its direction, and it may go either to the middle/apical turns or to the basal turn. We found that the stylet in the PMEA gives rigidity, which is helpful to control insertion direction, but in a real clinical scenario, practicing a 2-handed off-stylet insertion technique or using the automatic insertion tool in the small space between the temporal lobe dura and the MF floor, even with a well-placed retractor, seems troublesome. An issue in regard to insertion direction is its implications in CI programing. As mentioned in previous studies, with a retrograde insertion toward the round window, audiologists face the problem of considering reversed frequency allocation of the electrodes to stimulate according to normal cochlear tonotopicity. Still, results obtained in real cases where the CI was inserted in the “reversed” fashion

Figure 6. (A, B) Middle/apical turn insertions in perimodiolar sections from a right- and left-sided temporal bone, respectively, showing electrode displacement. (C) Nontraumatic, scala tympani insertion with a perimodiolar electrode array observed in sequence.
through the MF starting at the apex of the cochlea were comparable to those obtained with a basal- to apical-oriented insertion or with a double array. This diminishes the relevance of considering the middle/apical direction as a better, more physiological direction of insertion.

According to our measurements, the average distance between the cochleostomy and round window was 13.1 mm, different from that by de Brito et al of 8.8 mm, suggesting a cochleostomy closer to the ascending part of the basal turn of the cochlea, or that encountered by Todd of 16 mm, which corresponds to an insertion practically in the transition between the basal and middle turns.

Concerning trauma, the MFA cochlear implantation, as it was performed, carries a high risk for damage to the delicate cochlear microanatomy. We observed Eshraghi grades 3 and 4 in the location of the cochleostomy in 50% of the samples and in up to 70% throughout the rest of the cochlea. If a small cochleostomy is performed, correct scala tympani insertion is not guaranteed, so perhaps it is better to do a 1.5- to 2-mm cochleostomy as suggested by de Brito et al, to properly observe the OSL and introduce the array in the correct scala. Furthermore, even in samples where we achieved proper scalar placement, we noticed severe intracochlear trauma and migration of the array from one scala to the other, and we did not see differences between the very different types of electrodes, perfectly developed for round window insertions. On the other hand, we believe that the most important factor to prevent trauma with this access, besides proper scala tympani visualization, would be the development of an electrode array with characteristics suitable for this insertion route. Considering our measurements, a proper electrode array for this access could include some of the following characteristics: an approximate length of 14 mm to be prepared for either direction of insertion; a fine diameter, which could start at 0.6 mm in the base and end at 0.4 mm to be compatible with the diameters of scala tympani in the middle and apical turns; and slight rigidity to help when orienting the insertion. Considering the PMEA showed a tendency to be less traumatic, it may be contemplated as a desirable characteristic, but none of our comparisons between electrode types were statistically significant, and removing the stylet in the PMEA is of concern.

The limitations of this study include the absence of information about the clinical history of the cadavers, since we

<table>
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<th>TB No. (Side)</th>
<th>CI</th>
<th>Direction of Insertion</th>
<th>No. of Inserted Electrodes/Insertion Depth, mm</th>
<th>Cochleostomy Position at the RW Distance, mm</th>
<th>Trauma Grade at Insertion Site</th>
<th>Position at Mid-Modiolar Section</th>
<th>Highest Trauma Grade Observed</th>
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<td>1 (R) HiFocus J straight Basal—RW</td>
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<td>SV</td>
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<td>4</td>
<td>IS</td>
<td>4</td>
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</tr>
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<td>4 (R) Mid/apical, folded and went basal</td>
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<td>13.1</td>
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<td>1</td>
<td>SV</td>
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<td>IS</td>
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<td>13.1</td>
<td>SV</td>
<td>3</td>
<td>SV</td>
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</table>

Abbreviations: CI, cochlear implant model; IS, interscala; L, left; NM, not measurable; R, right; RW, round window; ST, scala tympani; SV, scala vestibuli; TB, temporal bone.

The trauma grades are according to the classification by Eshraghi et al.
found 2 bones with evident cochlear ossification that were randomly allocated to the same group and altered the insertion pattern of the electrodes. These bones could have been excluded by knowing previous otologic disease or by performing CT scans before implantation. Another limitation was the small sample of temporal bones to work with, considered a sample by convenience, which may reduce the external validity of our research. Further larger studies with different types of electrodes (eg, shorter electrodes used for hearing preservation) are required to clarify our findings.

Conclusions
The surgical technique used is effective, allowing intracochlear insertions in every temporal bone. The use of the “F” stylet helped to obtain an accurate basal turn cochleostomy in every sample, but it did not guarantee proper scala tympani insertions. Cochlear implantation through the middle cranial fossa is possible, but it carries a high risk of trauma to the delicate intracochlear microstructures and thus should not be considered in cases where hearing preservation is desired. It is our opinion that only experienced surgeons should perform this surgical technique, and it must not be considered the first choice for patients who can be managed with a transmastoid-facial recess approach.

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Author Contributions
Juan Carlos Cisneros Lesser, conception and design; acquisition, analysis, and interpretation of data; drafting; final approval; and accountability for the work; Rubens de Brito, conception and design, critical revision, final approval, and accountability for the work; Graziela de Souza Queiroz Martins, data analysis, drafting, final approval, and accountability for the work; Eloisa Maria Mello Santiago Gebrim, acquisition and interpretation of data, final approval, and accountability for the work; Ricardo Ferreira Bento, conception and design, critical revision, final approval, and accountability for the work.

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References