



Radiological evaluation of inner ear trauma after cochlear implant surgery by cone beam CT(CBCT)

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Abstract

Purpose Cochlear implantation (CI) has been extended to involve younger age group with higher incidence of residual hearing which increases the need of minimizing surgical inner ear trauma. Radiological evaluation for electrode position has been studied yet without assessment of inner ear trauma, our objective is radiological evaluation of post cochlear implantation inner ear trauma

Material and methods 20 patients with CI for pre lingual SNHL were included in this study. Cone beam CT (CBCT) was used for evaluation of electrode position and assessment of inner ear trauma. A Neuroradiologist and an implant surgeon analyzed the relation of inserted electrode to the intra-cochlear structures, with introduction of novel radiological grading for inner ear trauma.

Results The mean major cochlear diameter was 8.9 mm, the mean angular depth of insertion was 406.9944 (SD = 165.0559). Ten patients were with no cochlear trauma (grade 0), three patients were grade 1, two patients were grade 2 and five patients were grade 3 inner ear trauma.

Conclusion Radiological evaluation for electrode position should extend to involve assessment of inner ear trauma using relation of the implant to cochlear internal structures which could be performed by CBCT with high resolution and least metallic artifacts.

Keywords Inner ear trauma · Cochlear implant · Cone beam CT

Introduction

Cochlear implants (CI) are increasingly available for treatment of pediatric and adult patients with profound hearing loss [1]. The indications of CI were extended to involve patients with different degrees of residual hearing. This mandates the importance of an atraumatic surgery to preserve delicate intracochlear structures [2].

Scalar electrode location and the proper intra-cochlear positioning of the electrode array in proximity to the modiolus are crucial for an optimal neural activity [1, 3]. Scala tympani (ST) placement is generally preferred as it has the least damaging effects to the intracochlear structures,

making it the optimal position for electrode introduction [2]. Alternative placement of the electrode in scala vestibuli (SV) may result in damage of the organ of Corti, Reissner's membrane and the basilar membrane [2].

Several factors can contribute in intracochlear damage during placement of CI electrodes. Electrode model and positioning can be crucial, with the lateral wall electrodes less traumatic than perimodiolar electrodes [4, 5]. Surgical pathway has also an impact on scalar location. Round window (RW) and extended round window (ERW) placements proved to be associated with less incidence of SV insertion in comparison to cochleostomy insertion. Variations in cochlear size and depth of insertion may affect the electrode location inside the cochlea. Lower cochlear volume and/or higher depth of electrode placement may lead to inter-scalar electrode position shift [6].

The relation between the frequency organization of the spiral ganglion and the electrode location in each patient can be demonstrated by imaging modalities [7, 8]. Placement of the electrode array at a depth of about 1.5 cochlear turns

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or 540° measured from the round window (RW) enables the auditory stimulation in lower frequencies corresponding with the human speech range (200–1200 Hz). Current reports have demonstrated that the placement of electrodes to a depth lower than 400° is preferred as further advancement can lead to higher incidence of intra-cochlear trauma and displaced electrodes between the scalae [9, 10].

Radiological imaging, as plain X-ray and CT scan can give a general idea about the intra-cochlear location and the electrode position and depth [11]. It also offers baseline data for possible electrode migration or movement on future follow-up [12].

Recently developed cone beam computed tomography (CBCT) offers a low radiation exposure, short scanning time and high-resolution images [13]. It has the potential of offering a satisfactory image quality depicting the accurate location of the electrode array [11, 14]. It is also considered as a very safe modality to be preferred, especially in this group of children who need repeated examinations due to lower radiation dose.

The aim of this study is to evaluate specific localization of the electrode in the inner ear following cochlear implantation, in relation to the osseous spiral lamina and with calculation of the angular depth of insertion. We also evaluated the presence of intracochlear trauma and introduced a novel radiological grading system based on degree of injury of the osseous spiral lamina.

Materials and methods

Patients

This prospective study was conducted in the period from April 2016 to January 2017. It was approved by the ethical committee of our institution.

The patients sample consisted of 20 prelingually deafened children who underwent CI surgery (6 males and 14 females) and their age ranged from 3 to 10 years. A written consent was signed by their guardians. The inclusion criterion was bilateral profound sensorineural hearing loss. Exclusion criteria included post-traumatic, post-meningitis sensorineural hearing loss and abnormal cochlear morphology visualized during preoperative CT imaging. Operative data were collected regarding the approach, the site of cochleostomy, type of electrode used, complete or incomplete insertion of the electrode array, and any encountered difficulties during introduction were noted.

CBCT

No special preparation was required. Imaging was performed using CBCT scanner, i-CAT Next Generation (Imaging Sciences International® USA) and was done 3 months after implantation.

The following protocol was used: 120 kvp, 5 mAs, voxel 0.2, matrix = 0.2 × 0.2 × 0.2 mm. FOV 12 × 7.5 cm. Exposure time was 7 s and scanning time was 14.7 s in every case. Acquisition of the basic axial images was first performed, and then multiplanar coronal and sagittal reconstructions were obtained. Cochlear view was perpendicular to the modiolus and parallel to the basal turn of the cochlea. The images were processed using the 3D Synapse® radiology visualization Software, FUJI FILM Medical Systems USA Inc. The largest cochlear diameter (distance A) was acquired in cochlear view from the middle of the RW to the opposing lateral wall [15] (Fig. 1a). The window width and level were adjusted manually until the individual electrode contacts and surrounding bony labyrinthine structures were clearly visualized.

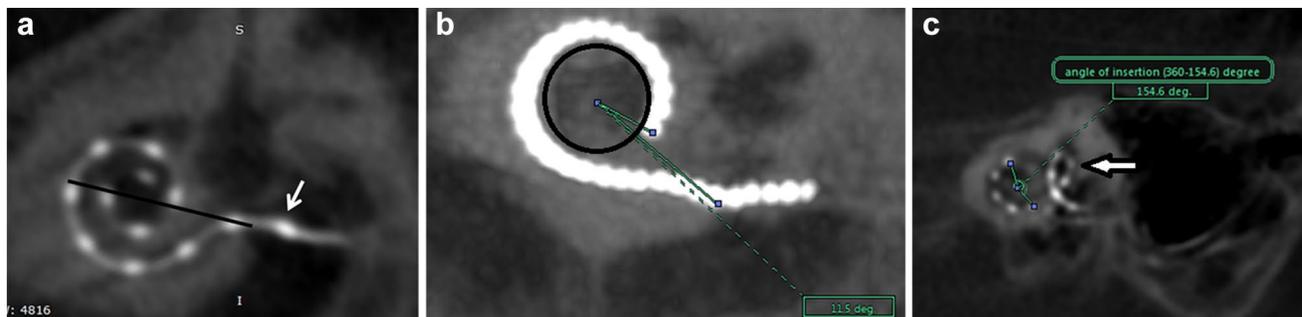


Fig. 1 Scalar position and angular depth of insertion of CI cochlear view **a** incomplete ST insertion of the electrode arrays (arrow). Black line represents the longest cochlear diameter. **b** Partial insertion of the electrodes, the angular depth of insertion is (360–11.5) degree. **c**

Malposition of the electrode array where the extra cochlear electrodes form a loop in the vestibule (arrow) with shallow angular depth of insertion measuring (360–154.6) degree

Image interpretation

Image quality was evaluated for each case according to the identification of the lateral bony wall, the contour of inserted electrodes, modiolus structure and either osseous spiral lamina (OSL) or its expected plane (in case of failure of its identification due to adjacent metal artifacts). Images of poor quality or not leading to clear identification of the structures of interest were excluded. An experienced neuroradiologist with 15 years' experience in head and neck imaging and an implant surgeon selected and analyzed scans with good and acceptable image quality.

Scalar electrode location and angular depth of insertion

Partial placement was defined as one or more contacts outside the cochlear lumen (Fig. 1a–c). All electrode contacts within the ST were considered as ST insertion (Fig. 2a). One of the electrode contacts in the SV was interpreted as SV insertion which is either complete (Fig. 2c) or partial (Fig. 2d, e).

Angular depth of insertion was calculated according to Pearl et al. [16] (Fig. 1b, c).

Inner ear trauma grading system (Table 1)

Our grading system was based on the scalar position and location of the electrode array in relation to the OSL (Tougan's radiological grading) in axial images as illustrated in Fig. 3: Grade 0: ST insertion with direct visualization of the intact OSL or normal electrode contour and alignment (indirect sign of intact OSL). Grade 1: direct visualization of elevated OSL or bowed contour of the inserted implant (mild inner ear trauma) Grade 2: complete SV insertion (moderate inner ear trauma). Grade 3: scalar translocation between ST and SV indicating fracture of the OSL (severe inner ear trauma).

Statistical analysis

Statistical package and Statistical analysis: The collected data were revised, coded, tabulated and entered to a PC using Statistical package for Social Science (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY, USA: IBM Corp). Quantitative variables are presented as mean and SD values or as median and interquartile range according to the distribution of data. Categorical results are presented as numbers of cases and percentages.

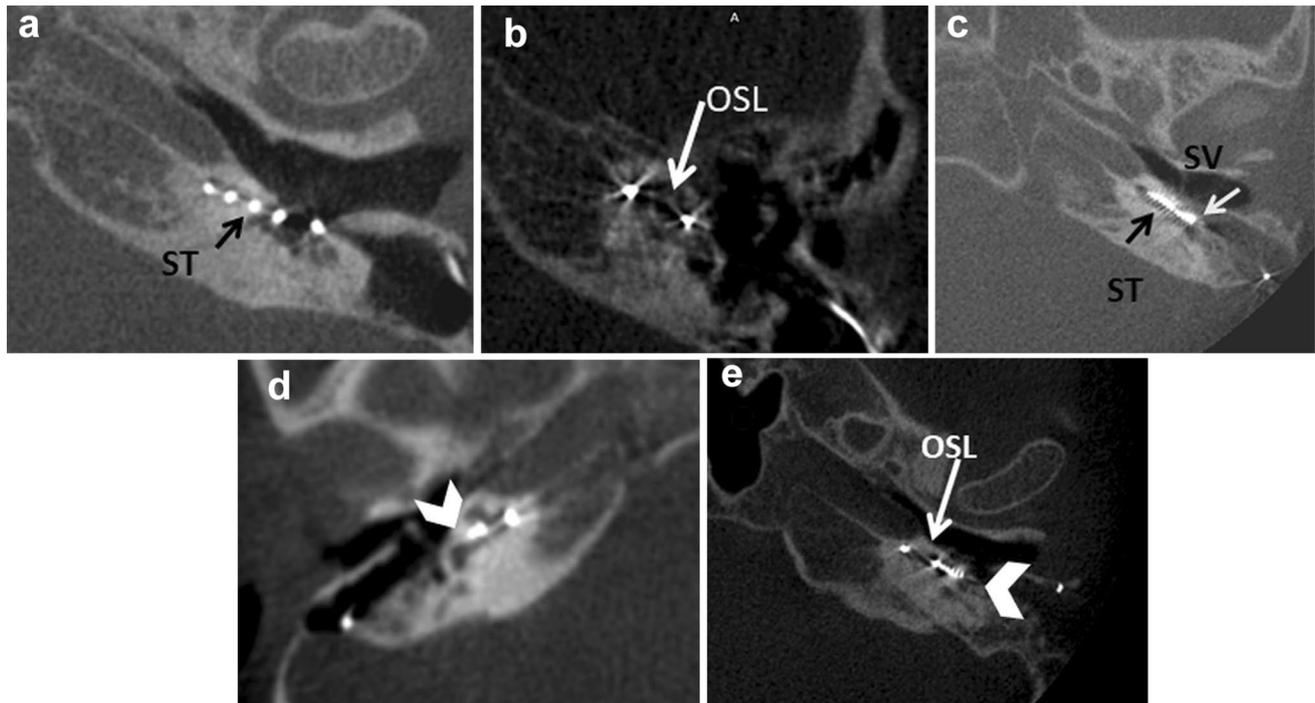


Fig. 2 Radiological grading of inner ear trauma. Axial images **a** ST insertion. Grade 0 All electrodes contacts are seen in ST (black arrow). **b** Grade 1 ST insertion with elevation of the OSL (long white arrow). **c** Grade 2 SV insertion (short white arrow) the ST of basal

turn of cochlea showed no electrode contact inside (black arrow). **d, e** Grade 3 showed translocation of electrode between ST and SV (arrowhead) and discontinuity of the OSL (long white arrow)

Table 1 Statistics of cochlear measurements

Variable	Number of cases	Mean	Median	Minimum	Maximum	SD
Depth of insertion	20	406.9944°	380°	196°	714°	165.0559°
Major cochlear diameter in mm	20	8.9		8	10	

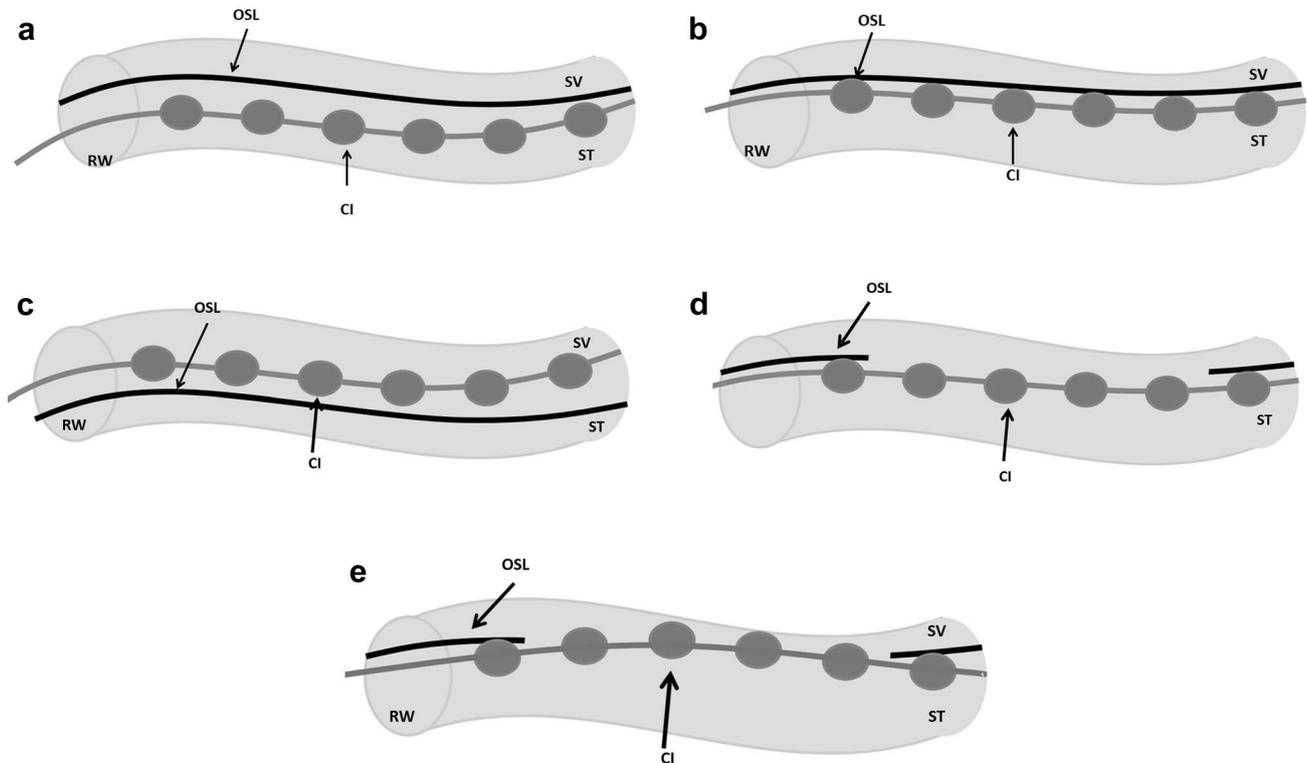


Fig. 3 Illustrative diagram for the Tougan's radiological grading of post CI inner ear trauma. **a** Grade 0: no inner ear trauma with ST insertion, intact and normal contour of OSL. **b** Grade 1 ST insertion yet with elevated OSL by the cochlear implant array. **c** Grade 2 SV insertion. **d** Grade 3 fractured OSL and increased risk of injured basi-

lar membrane (basilar membrane is not shown as it is not detectable radiologically). **e** Grade 3 scalar translocation between ST and SV as indirect sign of fractured OSL with high risk of basilar membrane injury and loss of residual hearing. *BT* basal turn of the cochlea, *CI* cochlear implant, *OSL* osseous spiral lamina, *RW* round window

Results

Surgical data

A postauricular incision was used in 13 patients, while 7 patients were approached by an extended endaural incision. All patients underwent classical posterior tympanotomy approach for cochlear implantation. Three patients had a round window membrane insertion and 17 patients had an extended round window approach. We used five types of electrodes from four different manufacturers. The following electrodes were used: Medel® 31-mm standard electrode in 5 patients, Medel® Flex 28 electrodes in 3 patients, AB® 1J electrode in 3 patients, Cochlear®

Nucleus CI24RE in 5 patients and Oticon® EVO electrode in 4 patients. The surgical data stated by the surgeons were full insertion in 12 cases, incomplete insertion in 5 cases and inconclusive data in 3 cases. There was some resistance during insertion in five cases.

CBCT data

The mean major cochlear diameter was 8.9 mm. The mean angular depth of insertion was 406.9944° (SD = 165.0559°) (Table 2). ST insertion was found in 16 cases, SV insertion in 4 cases and incomplete insertion was found in 7 cases.

According to Tougan's classification, no intracochlear trauma was found in 10 cases = Grade 0 (Fig. 2a). There were 10 cases (50%) with intracochlear trauma. Grade 1 or

Table 2 Radiological grading of inner ear trauma

Inner ear trauma	Scalar position of CI	Relation of CI to OSL
Grade 0	ST	Intact OSL with normal contour
Grade 1	ST	Elevated OSL/bowed contour of the implant
Grade 2	SV	OSL is posterior to the inserted electrode in axial plane
Grade 3	Scalar translocation between ST and SV	OSL fracture

mild trauma was found in 3 cases (15%) as evidenced by elevation of OSL (Fig. 2b), Grade 2 was found in 2 cases (10%) as evidenced by SV insertion (Fig. 2c) and Grade 3 was found in 5 cases (25%) as evidenced by fracture of OSL or scalar translocation (Fig. 2d, e).

Discussion

Diminishing damage to cochlear structures should be pursued in all CI recipients through soft surgery. This provides an optimal CI performance and allows preservation of delicate cochlear structures for any future therapeutic options [17]. Recently, cochlear implantation has proved to be of value in patients with residual low-frequency hearing allowing electroacoustic stimulation. This necessitates a hearing preservation surgery in which all attempts are made for prevention of inner ear trauma during the surgery, with an average of 20% or less hearing loss measured audiologically in comparison to the preoperative levels.

Over the years, there were several attempts to classify the inner ear trauma caused by the electrode insertion during cochlear implantation surgery. One of the most commonly used systems is the one described by Eshraghi et al. who graded the degree of cochlear trauma, using the histological assessment of the basilar membrane, spiral ligament and OSL [18]. However, most of the classifications were based on temporal bone studies or post-mortem examination. A reliable method to evaluate the effect of surgery on the inner ear structures in vivo is needed where the outcome is correlated.

Insertion trauma, inflammatory reactions, fibrosis development, excitotoxicity and endolymphatic hydrops are some of the conditions blamed for post-operative hearing loss and inner ear trauma following surgery [19].

The fine bony structures of the inner ear, such as modiolus and OSL as well as scalar position, can be readily apparent in the higher resolution examination by CBCT. In this work, we introduced a radiological scoring system for inner ear trauma through accurate assessment of the scalar position of the electrode array and the relation of the electrode to the OSL and modiolus structures. We assessed the severity of injury from minimal to maximum. The ST insertion with intact modiolus and normal contour of OSL were considered

as negative for inner ear trauma. Localized cochlear trauma seen as elevation of the OSL was considered as Grade 1 injury as it does not impede the intra-cochlear fluid hemodynamics [18]. The normal ionic gradient and cochlear hemodynamics are disturbed leading to destruction of both neural and hair cells as a result of post-traumatic merge of the endolymph and perilymph [19, 20]. So, trans-scalar displacement of electrode contacts was considered as a more advanced degree of inner ear trauma. Dalbert et al. evaluated the inner ear injury using the pure tone audiogram and characterized the traumatic hearing loss preceded by cochlear implantation procedure as discrepancy between pre- and post-surgical pure tone average. They suggested that scalar dislocation from ST to SV was combined with decrease of low-frequency ECoG (electrocochleography) responses and a total loss of residual hearing [17]. In addition, any overlap of the array between these two chambers will injure the intra-cochlear structures and have an unfavorable effect on speech recognition capability [21]. This was in concordance with our study grading the trans-scalar dislocation as grade 3 inner ear trauma.

Dalbert et al. also proposed that acute cochlear injury during implantation procedure is an essential prognostic factor for hearing loss after implantation procedure, despite that in some subjects, postoperative methods are also involved regardless the severity of surgical injury [17]. For this reason, a long-term follow-up is required after the implantation for accurate evaluation of functional inner ear trauma. Those electrophysiologic measures could not be performed to our subjects with profound hearing loss. In this study, the anatomical position of the electrode and its relation to intra-cochlear structures were documented on post-operative evaluation. However, the functional impact can only be assessed with long-term performance.

Radiology has been the mainstay of visual evaluation of the electrode position after cochlear implantation. Compared to CT, CBCT offers a better assessment due to less artifacts and higher-resolution images making the delineation of intra-cochlear structures possible [22, 23]. At the same time, lower radiation dose is preferred in repeated examinations especially for children [23]. Accurate depiction of cochlear location of individual electrode using CBCT may help in adjusting the setting up of acoustic frequencies resulting in better speech perception [21]. Ruivo et al. tailored a special

protocol to accurately depict the CI electrode location [24]. The CBCT protocol used in our study yielded images with good resolution and diagnostic quality in which anatomic features were clearly depicted. This is in line with another study on CBCT conducted by Güldner et al. who showed that CBCT was a valuable technique for the assessment of the anatomical structures of the temporal bone. Moreover, it offers a dependable post-operative control of electrode insertion, mainly in the cochlear basal part [25]. One of the controversies of the CBCT is the ACR practice guideline for CT of the head and neck which recommends that all imaging studies should be evaluated with soft tissue and bone algorithms; because of low radiation dose, CBCT can only provide bone details [26].

We were not able to correlate the trauma subjects with functional audiological measurements, as we used different types of electrodes from different manufacturers. Using different brands of electrodes by different surgical approaches is not addressed in our study as a variable of inner ear trauma, as the main aim was not to highlight the causes of inner ear trauma but the imaging features of the different degrees of trauma. This actually prevented bias towards certain electrode or technique.

Limitations of this study are lack of short- and long-term audiological correlation, low number of patients and various grades of hearing loss.

Conclusion

In this study, we introduced a new radiological scoring system for detailed evaluation of intra-cochlear electrode position, with proper assessment of inner ear trauma and visualization of delicate cochlear anatomical landmarks. The high image quality and the minor radiation exposure make CBCT an optimal and a secure imaging tool for the assessment of the precise CI electrode localization.

Compliance with ethical standards

Conflict of interest The authors declared no conflicts of interest.

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