Int J Clin Exp Med 2021;14(8):2164-2172
www.ijcem.com /ISSN:1940-5901/IJCEM0124462

Original Article

Preoperative imaging assessment of cochlear implant candidates: the integrative role of MDCT and MRI

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Received October 19, 2020; Accepted June 22, 2021; Epub August 15, 2021; Published August 30, 2021

Abstract: Background: We explored the strength and weaknesses of Multi-detector computed tomography (MDCT) and Magnetic resonance imaging (MRI) in the preoperative evaluation of cochlear implant candidates. Methods: A retrospective study including 13 adults and 38 pediatric patients who suffered from bilateral profound sensory neural hearing loss (SNHL) and underwent MDCT and MRI examination as a preoperative assessment for cochlear implant procedures. All patients underwent high-resolution spiral MDCT (128-slice) and 1.5 T MRI examination. Records of health history and physical ear examination, audiometry results, and operative data were collected and compared with imaging findings. Results: MDCT was superior in the demonstration of middle ear disease while MRI was more useful in the delineation of the cochlear nerve and cochlear patency as well as the detection of central causes of SNHL. Only 15% of adult patients had a positive clinical concern and showed positive imaging findings. All adult patients that had no clinical concern showed no significant imaging findings. About 36.8% of pediatric patients had a positive clinical concern and showed positive imaging findings. About 33.3% of pediatric patients who had no clinical concern showed positive imaging findings. The surgical plan was changed based on combined imaging findings in 15.4% of adult patients and 39.4% of pediatric patients. Conclusion: Multi-detector computed tomography and Magnetic resonance imaging are useful in the evaluation of congenital anomalies of the inner ear. MRI is superior in the evaluation of the cochlear nerve, early detection of labyrinthine fibrosis and detection of intrauterine causes of SNHL. MDCT is helpful in evaluation of middle ear pathology and also enables a detailed evaluation of the osseous anatomy. Integrative employment of both modalities in preoperative assessment of cochlear implant candidates is recommended.

Keywords: Multi-detector computed tomography, magnetic resonance imaging, sensory neural hearing loss, cochlear implantation, preoperative assessment

Introduction

Cochlear implantation is an advanced and broadly acknowledged treatment alternative for patients experiencing significant sensorineural hearing loss (SNHL) when they cannot get adequate benefit with hearing aids [1].

Numerous candidates for cochlear implantation have normal findings at imaging of the temporal bone; however, anatomic abnormalities and cochleovestibular anomalies can be seen in about 40% of these cases as per a few past reports [2, 3]. Patients with severe cochlear aplasia, absent cochlea, deformed vestibule and semicircular canals are not amenable to cochlear implantation on the influenced side [4]. A missing or insufficient cochlear nerve was an absolute contraindication for cochlear implantation. More recently the technique can be performed in patients with lower expected outcomes, and some young children may have good word recognition and spoken language skills [5].

Other congenital anomalies like common cavity malformation render the procedure more technically challenging and enhance the risk of cerebrospinal fluid (CSF) leakage and recurrent meningitis [6].

Anatomical variations may also be found in cochlear implant candidates. Roughly 15% may have an aberrant facial nerve course, which may increase the risk for facial nerve injury. Large occipital trans-osseous veins may affect the placement of the post-auricular incision and rarely a high-riding or dehiscent jugular bulb may influence cochleostomy placement [7].

Preoperative information about anatomical variations and cochleovestibular abnormalities is important for making the best decision and modifying the surgical approach in cochlear implantation. Computed tomography (CT) has been acknowledged as an initial imaging workup for cochlear implant candidates [8]. It enables a detailed assessment of the osseous anatomy of middle and inner ear cavities, detection of congenital anomalies and evaluation of patients with associated middle ear disease [9]. Modern multichannel scanners can provide dedicated high-resolution techniques with fine collimation and adequate coronal reformations that are required to achieve accurate anatomical details [10]. On the other hand, CT exposes patients to ionizing radiation, which is of specific concern, especially in the pediatric population. In addition, it lacks sensitivity in the assessment of cochlear patency and vestibulecochlear nerve [11].

Magnetic resonance imaging (MRI) provides better soft-tissue contrast. It is the modality of choice for imaging of the cochlear nerve and assessment of cochlear patency. The lack of ionizing radiation is a major advantage particularly in children [12]. Besides, the MRI assessment may be extended to include the brain together with the temporal bone to exclude associated brain anomalies and central cause of SNHL [1]. On the other hand, MRI usually requires sedation in children and is relatively time-consuming.

Many cochlear implant centers like to have both CT and MRI in preoperative assessment of their patients, taking into account the advantages and disadvantages of the two modalities. In this current study, we aimed to evaluate the role of MDCT and MRI in the preoperative assessment of cochlear implant patients.

Ethical approval

Study approval was provided by the College of Medicine Research Ethics Committee (Cm-REC) under Taibah University with IRB number 00010413.

Patients

A retrospective study was done for all adult and pediatric patients of both genders with profound SNHL upon those who came in for preoperative assessment of cochlear implantation to our institution withing the period from May 2016 to May 2018. We included only patients with available images for both MDCT and MRI of temporal bone in their records. The studied group of patients excluded patients with previous ear surgeries or those having contraindications for CT and MRI. The final total number of patients included in our study was 51 patients with a total of 102 diseased ears. Detailed history, physical ear examination, audiometry, tympanometry and imaging findings were collected using the hospital information system and picture archiving and communication system (PACS).

Methods

MDCT examination

All patients underwent MDCT (128-slice, spiral, Philips) high resolution with the following parameters: 0.75-mm collimation, 130 kvp, 20 mA, topogram length 265. The initial data sets were reconstructed at 0.6 mm slice thickness. Scan time was 8 Sec. with a delay of 3 sec. No contrast was used in our study. Patients were scanned in the supine position with craniocaudal direction. Scanning commenced parallel to the orbito-meatal line from the lower margin of the external auditory meatus and extended upward to the arcuate eminence of the superior semicircular canal, as seen on the lateral topogram. Reconstruction into coronal images was done to decrease radiation dose and time of examination compared to direct coronal images.

MRI examination

All patients underwent MRI examination (1.5 general electric Healthcare) with 8 channel head coils. Examination of the internal auditory canal and inner ear structures was done using Axial 3D FIESTA (Fast Imaging Employing Steady-state Acquisition). For better evaluation of the nerves, an oblique parasagittal view (FIE-

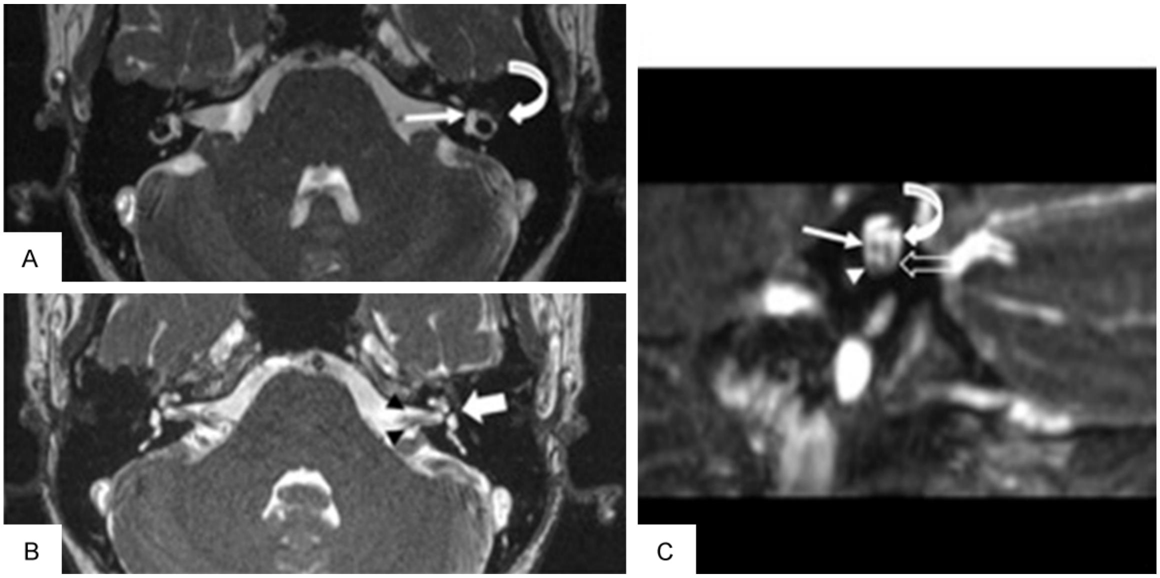

Figure 1. (A-C) Normal MRI examination; (A, B) Axial 3D FIESTA; (A) Vestibule (white arrow), Lateral Semicircular canals (curved arrow); (B) Cochlear (white arrow), internal auditory canal with vestibule-cochlear nerve (black arrowheads) and (C) Sagittal 3D FIESTA; Facial N. (Straight arrow), Cochlear division of VIII cranial nerve (white arrowhead), Superior (curved arrow), inferior (open arrow) of vestibular division of VIII cranial nerve.

Table 1. Parameters of MRI sequences

	TR (ms)	TE (ms)	NEx	Frequency. FOV	Phase. FOV	slice thickness (mm)	Whole-time (mins)
Axial 3D FIESTA	6.2	Minimum	2	18	1	0.8	5:50
Oblique sagittal 3D FIESTA	6.2	Minimum	2	18	1	0.8	5:50
T1 FS Inner ear	434	Minimum	4.00	288	20	3.0	3:56
Post-contrast T1 FS inner ear	434	Minimum	4.00	288	20	3.0	3:56
Axial T2 propeller	5379	77	2	24	0.8	5.5	3.56
Axial T2 FLAIR	9000	125	2	24	0.8	5.0	4:57
Axial DWI	4540	Minimum	2	24	1.0	5.0	1:58

DWI: Diffusion-weighted imaging. FIESTA: Fast Imaging Employing Steady-state Acquisition. FLAIR: Fluid-attenuated inversion recovery. FOV: Field of view. FS: Fat suppression. MRI: Magnetic resonance imaging. NEx: Number of excitations. TE: Echo time. TR: Repetition time.

STA) which is perpendicular to the plane of the Internal Auditory Canal (IAC) was done on both sides (**Figure 1**). Pre- and post-contrast axial T1 FS were done in cases with suspicion of tumors or inflammatory processes. For examination of the central auditory pathway and detection of any associated brain parenchymal abnormalities Additional axial T2 propeller, axial Fluid attenuation inversion recovery (FLAIR) and axial diffusion weighted images (DWI) brain cuts were performed (parameters are shown in **Table 1**).

Sedation

Young and uncooperative patients underwent general anesthesia while a conscious sedation protocol was used in adults and cooperative patients.

Data interpretation

Two consultant radiologists with 5 years of experience in head and neck imaging evaluated all cases separately. Both readers were blinded to the available operative and follow up data.

In MDCT images, superficial and deep structures were evaluated keeping in mind anatomical variations that may influence the surgical approach. The width of the internal auditory canal and osseous vestibular aqueduct were also measured in the axial images with less

Table 2. Causes of sensory neural hearing loss (SNHL) detected by imaging (in adult and pediatric patients)

Cause of SNHL	Adults (No (%))	Pediatrics (No (%))
No defined cause of SNHL*	11 (21.6%)	16 (31.3%)
Congenital	0 (0%)	6 (11.8)
Labyrinthitis	0 (0%)	2 (3.9%)
Post traumatic	0 (0%)	1 (1.9%)
Central brain	0 (0%)	5 (9.9%)
Associated Middle ear and mastoid affection	2 (3.9%)	8 (15.7%)
Total	13 (25.5%)	38 (74.5%)

*SNHL: Sensory neural hearing loss.

Table 3. Imaging findings

	Adults No (%)	Pediatrics No (%)	Total No (%)
MDCT Findings			
Dysplastic cochlea, vestibule, v. aqueduct	0 (0%)	6 (11.7%)	6 (11.7%)
Hypoplastic IAC	0 (0%)	1 (1.9%)	1 (1.9%)
Restricted cochlear patency	0 (0%)	1 (1.9%)	1 (1.9%)
Chronic middle ear disease	2 (3.9%)	8 (15.6%)	10 (19.6%)
MRI Findings			
Dysplastic cochlea, vestibule	0 (0%)	6 (11.7%)	6 (11.7%)
Restricted cochlear patency	0 (0%)	3 (5.8%)	3 (5.8%)
aplastic cochlear nerve	0 (0%)	1 (1.9%)	1 (1.9%)
Brain abnormalities	0 (0%)	5 (9.8%)	5 (9.8%)

MDCT: Multi-detector computed tomography. MRI: Magnetic resonance imaging. (%): percentage within whole study group (51 patients).

than 2 mm and more than 1.5 mm being considered abnormal respectively. In MRI images, the cochlear nerve is considered normal in diameter when equal to or greater than the facial nerve.

All previous data was recorded by both readers and correlated with the available operative and follow up data.

Statistical analysis

Data were gathered and analyzed using IBM SPSS software (release 25), SPSS Inc. Statistical methods included descriptive analysis, such as number and percentage, frequencies. Inter-rater agreement for each modality was calculated using Cohen's kappa coefficient.

Results

A total of 51 patients with 102 diseased ears were included in this study. Thirty patients were males and 21 were females with a male to female ratio of 1.4:1. Thirteen patients were adults with a mean age of 29 years old and 38 patients were children with a mean age of 5 years old. Based on radiological findings, no defined cause of SNHL could be detected in 27/51 (53%) patients. The detected cause of SNHL was congenital malformation in 6/51 (11.7%) cases; central cause of hearing loss in 5/51 (9.8%) cases, unilateral labyrinthitis in 2/51 (3.9%) cases, post-traumatic unilateral labyrinthitis ossificans in one case (1.9%) and combined middle ear cavity and mastoid abnormalities were detected in 10 (19.6%) cases (**Table 2**).

Out of the 13 adult patients, only 2 (15%) patients had positive clinical concern for associated conductive hearing loss. All other adult cases had no significant clinical concern. Among the 38 pediatric patients, only 14 (36.8%) patients had a positive history and clinical examination (one with a history of trauma, 8 cases with associated conductive hearing loss and 5 cases of asymmetrical SNHL).

Concerning the interrater variability in this study, there was a substantial agreement in reading MDCT exams (0.79) and almost perfect agreement (0.9) in reading MRI exams between the two readers.

MDCT revealed bilateral severe cochlear dysplasia with a deformed vestibule and semicircular canals associated with bilateral attenuated internal auditory canal in 1 case, unilateral mild cochlear hypoplasia in 3 cases, and bilateral enlarged osseous vestibular aqueduct in 2 cases. MDCT also best revealed unilateral labyrinthine ossification in one case with a history of trauma. Concerning mastoid and middle ear cavity aeration, MDCT revealed unilateral opa-

Table 4. Surgical plans changed by imaging findings

	Adults group (13)	Pediatrics group (38)	Total (51)
Surgical plans changed by findings read best on MDCT, n (%)	2/13 (15.4%)	8/38 (21%)	10/51 (19.6%)
Surgical plans changed by findings read best on MRI, n (%)	0/13 (0%)	7/38 (18.4%)	7/51 (13.7%)
Total	2/13 (15.4%)	15/38 (39.4%)	17/51 (33.3%)

MDCT: Multi-detector computed tomography. MRI: Magnetic resonance imaging. (%): percentage within the group.

cification of the mastoid antrum in 3 cases, bilateral opacification of mastoid antrum in 2 cases, unilateral otitis media in 2 cases and bilateral otitis media in 3 cases. MDCT showed a normal facial nerve course in all examined cases.

MRI revealed unilateral labyrinthitis in 2 cases, (both cases showed loss of normal fluid signal in the affected side with post-contrast enhancement). There was unilateral loss of a normal fluid signal in a case of posttraumatic labyrinthitis ossificans. For congenital abnormalities, MRI showed severe cochlear dysplasia in 1 case associated with an absent vestibulocochlear nerve at both sides, unilateral mild cochlear dysplasia in 3 cases and bilateral enlarged vestibular aqueduct in 2 cases. Extended brain images showed abnormal periventricular high T2WI and FLAIR signal intensity in 5 pediatric cases that were diagnosed as intrauterine brain infection. Detailed imaging findings with percentage are shown in (**Table 3**).

The cochlear implantation procedure was canceled based on findings provided by both MDCT and MRI in one case showing bilateral cochlear aplasia and an absent cochlear nerve on both sides. The surgical decision procedure was modified based on findings obtained by both MDCT and MRI in 3 cases with unilateral mild cochlear dysplasia with a selection of non-dysplastic side for the implantation and one case of post-traumatic labyrinthitis ossificans. The surgical decision was also modified based on findings observed in MDCT images in 3 cases with unilateral mastoiditis and 2 cases of differential mastoid opacification with the selection of normal or better-aerated sides respectively. The decision was also modified, based on MDCT findings, by a selection of normal sides in 2 cases of chronic otitis media. The procedure was postponed after medical treatment for 3 cases of bilateral otitis media. MRI findings helped in better selection of the amenable side for implantation in 2 cases of labyrinthitis (**Table 4**).

Discussion

Previous studies have reported that 20% of congenital SNHL is usually caused by inner ear malformations [13-15]. In this study, both CT and MRI reported inner ear malformations in 6 cases (15.7%). In one case there was bilateral cochlear aplasia, and both CT and MRI successfully revealed a bilateral absence of the cochlea with a deformed vestibule on both sides and a deformed posterior semicircular canal on the right side (**Figure 2**). Although CT couldn't detect the absence of the cochlear nerve in this case, it showed a diminutive internal auditory canal (less than 1.4 mm) at both sides. MRI images were helpful in this case which showed bilateral cochlear nerve absence. Gross malformations such as cochlear aplasia and cochlear nerve deficiency are considered contraindications for cochlear implantation. Patients in whom the cochlear nerve is not seen on MRI images may not show the expected outcome of the procedure and should undergo evaluation by an experienced audiologist before the decision is made [16, 17]. In this discussed case the patient was excluded from the procedure.

MDCT also successfully revealed unilateral mild cochlear hypoplasia in three cases that showed a diminutive cochlea with dysplastic vestibule and semicircular canals with a normal caliber of the internal auditory canal. MRI revealed a normal cochlear nerve on both sides in the mentioned cases. Cochlear Hypoplasia is not an absolute contraindication for implantation, although the auditory benefit varies depending on the severity of the abnormality as well as the degree of cochlear nerve deficiency [10]. In the current study, all three cases of

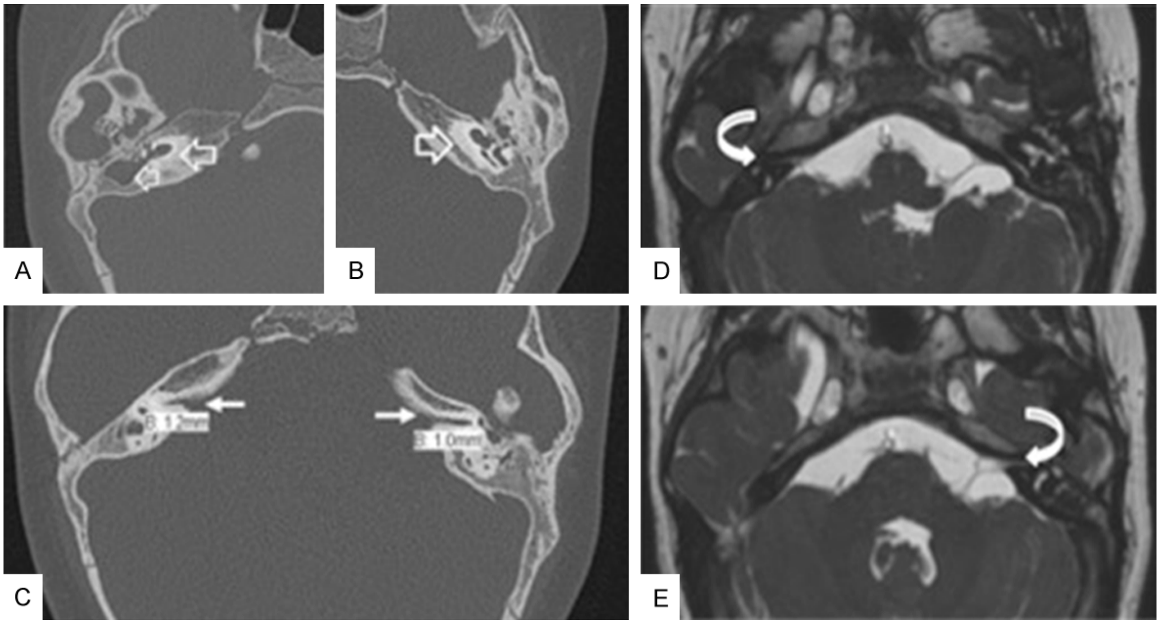

Figure 2. A-E. A case of cochlear aplasia; A-C. (Axial CT); A. Right cochlear aplasia with deformed vestibule and posterior semicircular canal; B. Left cochlear aplasia with deformed vestibule (Open white arrows); C. Diminuend right and left IAC (white arrows); D, E. Axial 3D FIESTA; right and left diminutive IAC with absent cochlear nerve (Curved White arrows).

cochlear hypoplasia showed unilateral affection that allowed the selection of non-dysplastic side for the cochlear implant procedure.

An enlarged vestibular aqueduct with or without mild cystic cochlear dysplasia has been accounted for being the most widely recognized inner-ear malformation associated with SNHL [18]. According to previous studies, 90% of cases showed bilateral affection [10, 12, 19]. In this study, two cases of bilateral enlargement of the vestibular aqueduct were detected by both modalities. In the two cases, CT showed bilateral enlargement of the osseous vestibular aqueduct (midway between the common crus and the external aperture) greater than 1.5 mm with no associated cochlear dysplasia. MRI also revealed bilateral enlarged endolymphatic duct and sac (greater than the diameter of the adjacent ascending part of the posterior semicircular canal) in both cases. Although there is an increased risk for CSF leakage in patients with an enlarged vestibular aqueduct, it is likely minor in the absence of associated cochlear malformations [20]. In this study, the two cases who underwent cochlear implant procedure with no further complications have been reported.

Imaging assessment of labyrinthitis ossificans is fundamental for surgical planning as those patients will benefit from urgent interference before obstruction of the cochlea occurs. Early implantation before the obstruction is necessary to optimize electrode insertion and avoid the need for complex approaches [21]. Steady-state T2-weighted MR imaging is the first-line modality for early detection of fibrosis in patients with suspected development of labyrinthitis ossificans. However, both fibrosis and ossification result in loss of signal intensity at T2-weighted MR imaging. Although MDCT is much less sensitive for the detection of fibrosis, it can be used to differentiate fibrosis from ossification when absent normal T2 signal intensity is detected [22]. This study had two cases of unilateral labyrinthitis. Both cases showed absent normal T2-weighted signal intensity of the cochlea and post-contrast enhancement of the affected side (**Figure 3**). MDCT scan for both cases were normal implying early affection. Another case of bilateral temporal bone fracture showed unilateral loss of signal intensity of the cochlea at T2-weighted MR images with cochlear ossification at MDCT scan implying the development of labyrinthitis ossificans in the affected side (**Figure 4**). The cochlear implant procedure was done on the normal-looking side in the mentioned cases.

Sclerotic or hypopneumatized mastoid air cells and middle ear opacification may limit expo-

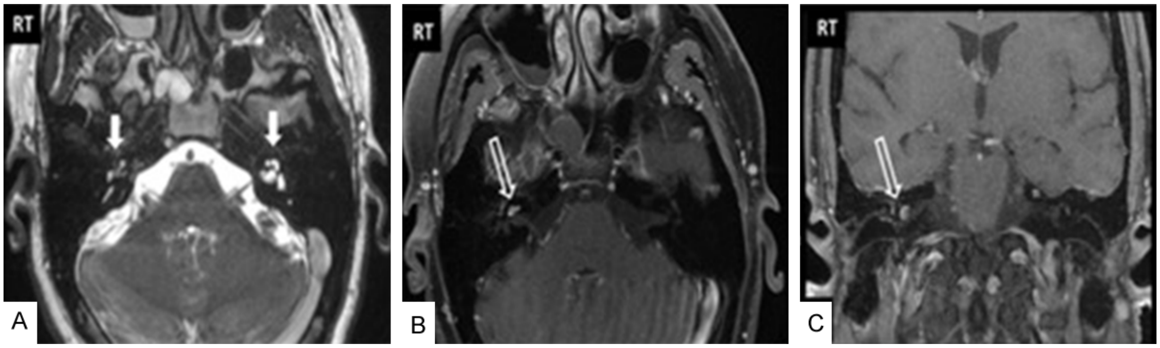

Figure 3. A-C. A case of Labyrinthitis; A. Axial 3D FIESTA, Loss of normal signal in the right cochlea compared to the left side (Closed white arrows); B. C. Post Contrast Axial and Coronal VIBE; B. Axial; C. Coronal shows abnormal enhancement of the Right Cochlea (open white arrows).

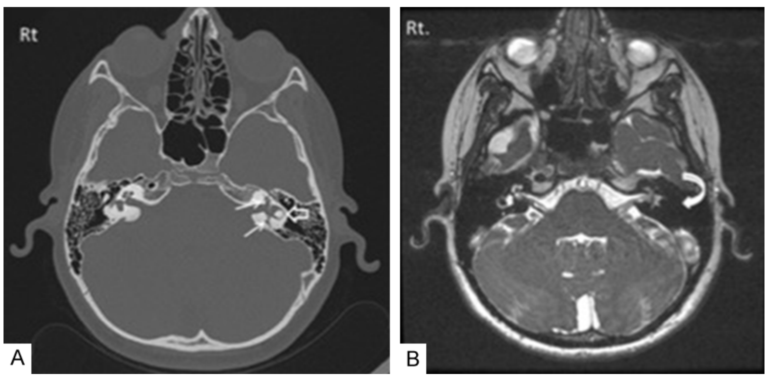

Figure 4. A, B. A case of Trauma; A. Axial CT, left transverse fracture of petrous bone (white arrows) with increased density of left lateral semicircular canal suggesting labyrinthitis ossificans (open white arrow). B. Axial 3D FIESTA shows absent of normal signal of left membranous labyrinth (curved white arrow).

sure and visualization during surgery. Acute otomastoiditis needs medical treatment before implantation to minimize the risk of infection and meningitis [10]. MDCT in this study revealed unilateral opacification of mastoid antrum in 3 cases, bilateral opacification of mastoid antrum in 2 cases, unilateral otitis media in 2 cases and bilateral otitis media in 3 cases. MDCT findings in these cases helped in the selection of better-aerated side in the cases with unilateral affection and we were able to postpone of the procedure after medical treatment in the bilateral affection case.

Intrauterine infection contributes to sensorineural hearing loss in many infant populations. The abnormal white matter foci of increased T2 signal intensity that are seen on MRI obtained in children with sensorineural hearing loss have been attributed to cytomegalovirus infection [23]. Extended MRI brain images of 5 pediatric patients in this study showed abnormal periventricular high T2 and FLAIR signal intensity. Although this finding suggests intrauterine insult, it didn't affect the decision for cochlear implantation in these cases.

Workup for cochlear implantation differs among institutions. CT has traditionally been utilized as the favored preoperative imaging workup for cochlear implantation candidates [24]. Recently the role of MR imaging in the preoperative assessment is increasingly perceived [14].

In this study both techniques proved to be useful in preoperative assessment of pediatric and adult cochlear implant candidates. Both imaging modalities in our study could identify congenital anomalies of the inner ear. MRI was superior in the assessment of soft tissue abnormities and evaluation of a cochlear nerve. MRI was also useful in the early detection of labyrinthine fibrosis and additional brain cuts were helpful for the detection of possible intrauterine causes. On the other hand, MDCT was helpful when associated conductive hearing loss is considered and also enables a detailed evaluation of the osseous anatomy of the inner and middle ear. The surgical plan in the current study has been changed based on findings in both imaging modalities in 39.4% of pediatric patients and 15.4% of adult patients. The combination of both techniques is recommended for preoperative assessment of cochlear implant candidates. However, the risk-benefit ratio of each imaging study should be also considered especially in pediatric patients. MRI often requires sedation in pediatric patients and there are potential long-term effects of radiation exposure in MDCT examination [14, 25].

Conclusion

Both MDCT and MRI are useful in the evaluation of congenital anomalies of the inner ear. MRI is superior in the evaluation of the cochlear nerve, early detection of labyrinthine fibrosis and detection of intrauterine causes of SNHL. MDCT is helpful in evaluation of middle ear pathology and enables detailed evaluation of the osseous anatomy. Integrative employment of both modalities in preoperative assessment of cochlear implant candidates is recommended.

Acknowledgements

The author is very thankful to all the associated personnel in any reference that contributed to the purpose of this research, this includes Mr. Emad Alnagdi a technician in Uhod General Hospital, Madinah, Saudi Arabia.

Disclosure of conflict of interest

None.

Abbreviations

MDCT, Multi-detector computed tomography; MRI, Magnetic resonance imaging; SNHL, Sensory neural hearing loss; 3D, 3-dimensional; CSF, Cerebrospinal fluid; CT, Computed tomography; T2WI, T2 weighted image; FIESTA, Fast Imaging Employing Steady-state Acquisition; IAC, Internal Auditory Canal; FLAIR, Fluid attenuation inversion recovery.

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