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Comprehensive Evaluation of Cochlear and Vestibular Anatomy using CT and MRI: Insights into Development, Patency, and Associated Anomalies

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Abstract

To comprehensively evaluate cochlear and vestibular anatomy using computed tomography (CT) and magnetic resonance imaging (MRI) in patients undergoing preoperative workup for cochlear implantation. A total of 50 patients (27 males, 23 females; mean age 16 ± 9.1 years) with severe to profound sensorineural hearing loss underwent temporal bone CT and MRI at a tertiary care center. CT imaging was performed using a 16-detector scanner, and MRI was conducted on a 1.5T system with dedicated temporal bone protocols. Two experienced neuroradiologists independently reviewed the images, assessing cochlear development, patency, length, vestibular system integrity, cochlear nerve status, internal auditory canal characteristics, and other relevant findings. On CT and MRI, 22% of ears demonstrated cochlear underdevelopment, with vestibulocochlear cystic anomaly being the most common (40.9%). Non-patent cochleae were seen in 8.2% on CT and 9.2% on MRI, primarily due to ossification. The mean cochlear duct length on CT was 8.9 ± 0.78 mm. The vestibule was non-patent in 25% on CT and 29% on MRI, frequently associated with vestibulocochlear cystic anomaly involving the lateral semicircular canal (44-52%). Cochlear nerve aplasia/hypoplasia was detected in 17% on MRI, while internal auditory canal abnormalities were present in 7%. Preoperative CT and MRI provide complementary information crucial for comprehensive anatomical assessment in cochlear implant candidates. Delineation of cochlear development, patency, dimensions, vestibular abnormalities, neural integrity, and other relevant structures guides surgical planning and counseling regarding implantation feasibility and anticipated outcomes.

Keywords: Cochlear implant, Vestibule, Semicircular canal.

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1. Introduction

The intricate anatomy of the cochlea and vestibular system plays a crucial role in auditory and vestibular function, and accurate delineation of these structures is essential for the management of various otologic disorders [1]. Congenital anomalies, acquired pathologies, and anatomical variations can significantly impact the clinical presentation, treatment planning, and outcomes in patients with hearing loss or balance disorders [2]. Imaging modalities, such as computed tomography (CT) and magnetic resonance imaging (MRI), have emerged as invaluable tools for the evaluation of cochlear and vestibular anatomy. CT provides exquisite detail of bony structures, enabling the assessment of cochlear development, patency, and associated bony anomalies. Conversely, MRI offers superior soft tissue contrast, allowing for the visualization of membranous structures, fluid spaces, and neural elements, including the cochlear nerve [3]. This study aims to comprehensively investigate the cochlear and vestibular anatomy in a cohort of patients using both CT and MRI. By leveraging the complementary strengths of these imaging modalities, we seek to gain insights into the prevalence and patterns of various anomalies, as well as their potential implications for clinical management. The detailed characterization of cochlear development, patency, and associated anomalies, along with the evaluation of the vestibular system and cochlear nerve, can provide valuable information to guide therapeutic decisions, such as cochlear implantation, vestibular rehabilitation, or surgical interventions. Furthermore, this study may contribute to a better understanding of the complex interplay between anatomical variations and functional outcomes in patients with auditory or vestibular disorders [4].

By combining the power of CT and MRI, this research endeavors to advance our knowledge of cochlear and vestibular anatomy, ultimately paving the way for improved diagnostics, personalized treatment strategies, and enhanced patient care in the field of otology [5].

2. Patients and Methods

Study Design and Participants This retrospective study included 50 patients (27 males, 23 females) who underwent both computed tomography (CT) and magnetic resonance imaging (MRI) evaluation of the temporal bones at our tertiary care center between January 2020 and December 2023. The mean age of the participants was 16 ± 9.1 years, with an age range of 1 to 31 years. Patients were referred for imaging due to various otologic indications, including congenital hearing loss, acquired sensorineural hearing loss, vertigo, and tinnitus. Ethical approval was obtained from the institutional review board, and the study was conducted in accordance with the principles of the Declaration of Helsinki.

2.1. Imaging Protocols

CT imaging was performed using a GE Bright speed 16-detector CT scanner with the following parameters: slice thickness of 0.6 mm, pitch of 0.8, and a reconstruction kernel optimized for bone evaluation. Both axial and coronal reformatted images were generated. MRI examinations were conducted on a 1.5 Tesla Siemens Sempra system using a dedicated temporal bone coil. The imaging protocol included T2-weighted turbo spin-echo sequences in axial and coronal planes, as well as a three-dimensional T2-weighted fluid-attenuated inversion recovery (3D T2-FLAIR) sequence. Slice thickness ranged from 0.6 to 1.0 mm, with no interslice gap.

2.2. Image Analysis

All CT and MRI examinations were independently reviewed by two experienced neuroradiologists, blinded to the patients' clinical information. In cases of disagreement, a consensus was reached through discussion. The following anatomical structures were systematically evaluated:

- Cochlear development, patency, and associated anomalies.
- Cochlear length (measured on CT).
- Vestibule and semicircular canal morphology and patency.
- Cochlear nerve integrity.
- Internal auditory canal characteristics.
- Ancillary findings (e.g., middle ear status, cochlear/vestibular aqueduct morphology).
- Discrepancies between CT and MRI findings were noted and analyzed.

2.3. Statistical Analysis

Descriptive statistics were used to summarize the demographic data and imaging findings. Continuous variables were reported as means and standard deviations, while categorical variables were expressed as frequencies and percentages. Interobserver agreement between the two neuroradiologists was assessed using Cohen's kappa coefficient. Statistical analyses were performed using commercial software (SPSS Statistics, IBM Corp., Armonk, NY, USA), with a p-value < 0.05 considered statistically significant.

3. Results

3.1. Demographic data

The study included 50 patients, with 27 males (54%) and 23 females (46%). The mean age was 16 ± 9.1 years, ranging from 1 to 31 years old.

3.2. Cochlear Development and Anomalies

Cochlear development was assessed by both CT and MRI. The cochlea was well-developed in 78 ears (78%) and not well-developed in 22 ears (22%) by both modalities. The most common cochlear anomaly in ears with not well-developed cochleae was vestibulocochlear cystic anomaly, present in 9 ears.(%40.9)

3.3. Cochlear Patency and Anomalies

Cochlear patency was evaluated by CT and MRI. On CT, the cochlea was patent in 90 ears (91.8%) and not patent in 8 ears (8.2%). The main anomalies in not patent cochleae were partial ossification (50%) and complete ossification 37.5). On MRI, the cochlea was patent in 89 ears (90.8%) and not patent in 9 ears (9.2%). Partially ossified (44.4%) and completely ossified (33.3%) cochleae were the primary anomalies in not patent cochleae.

3.4. Cochlear Length

The mean cochlear length measured on CT was 8.9 ± 0.78 mm, ranging from 5.4 to 9.3 mm.

3.5. Vestibular System

The vestibule was patent in 75 ears (75%) on CT and 71 ears (71%) on MRI. Vestibulocochlear cystic anomaly was the most common vestibular anomaly, present in 11 ears (44%) on CT and 13 ears (44.8%) on MRI. The semicircular canals (SCCs) were patent in 78 ears (78%) on CT and 75 ears (75%) on MRI. Vestibulocochlear cystic anomaly involving the lateral SCC was the predominant anomaly, seen in 8 ears (36.4%) on CT and 13 ears (52%) on MRI.

3.6. Other Findings

Sigmoid location was type I in 88 ears (88%). The dural level was high in all ears (100%). Sentinel air cells were present in 92 ears (92%), and the facial nerve was normal in 92 ears (92%). Round window accessibility was easy in 90 ears (91.8%) on CT. The cochlear aqueduct was normal in 98 ears (98%) on both CT and MRI. The vestibular aqueduct was normal in 92 ears (92%) on CT and MRI, with enlargement seen in 6 ears (6%). The external auditory canal was normal in all ears (100%) on CT. The middle ear was infected in 7 ears (7%) on CT. On MRI, the internal auditory canal was normal in 92 ears (92%), atretic in 5 ears (5%), and absent in 2 ears (2%), with one ear (1%) showing a schwannoma. The cochlear nerve was intact in 82 ears (82%), aplastic in 12 ears (12%), and hypoplastic in 5 ears (5%), with one ear (1%) showing a mass. In summary, this study provides a comprehensive evaluation of cochlear and vestibular anatomy and associated anomalies in patients using CT and MRI, highlighting the prevalence of various structural abnormalities and their potential impact on treatment planning and outcomes.

Table 1 shows the description of Cochlear Development by CT/MRI. This table shows the crucial finding of whether the cochlea was well-developed or not, as well as the breakdown of different cochlear anomalies seen in cases of not well-developed cochleae. This is key information for assessing cochlear anatomy and suitability for interventions like cochlear implantation. Table 2 shows the description of Cochlear Patency by CT/MRI. Cochlear patency and the specific anomalies leading to non-patency (ossification, fibrosis, etc.) are highly relevant for determining cochlear functionality and potentially guiding management decisions. Table 3 shows the description of Vestibule/Semicircular Canals by CT/MRI. The vestibular system is closely linked to the cochlea, and anomalies in the vestibule and semicircular canals can have important implications for balance function and surgical approaches. This table provides a comprehensive overview of these structures. Table 4 shows the description of Cochlear Nerve by MRI. The integrity of the cochlear nerve is essential for effective auditory signal transmission, and anomalies like nerve aplasia or hypoplasia can significantly impact auditory function. This table highlights the prevalence of cochlear nerve abnormalities in your study population. These four tables encapsulate the core findings related to cochlear development, patency, the vestibular system, and the cochlear nerve – all of which are critical elements in understanding auditory anatomy and planning appropriate interventions or management strategies.

3.7. Case presentation

3.7.1. Case 1

- **Clinical data**: male patient 7 m, complaining from sensory neural hearing loss since birth.
- CT Findings are shown in Figure 1.
- MRI Findings are shown in Figure 2.

3.7.2. Case 2

- **Clinical data**: female pt 2 y complaining from sensory neural hearing loss since birth.
- CT Findings are shown in Figure 3.
- MRI Findings are shown in Figure 4.

3.7.3. Case 3

- **Clinical data**: male pt 2 y complaining from sensory neural hearing loss since birth.
- CT Findings are shown in Figure 5.
- MRI Findings are shown in Figure 6.

3.7.4. Case 4

- **Clinical data:** female pt 7 y, history of meningitis 2 months ago, now pt complaining from bilateral conductive and sensory neural hearing loss**.**
- CT Findings are shown in Figure 7.
- MRI Findings are shown in Figure 8.

4. Discussion

This study provides a comprehensive evaluation of cochlear and vestibular anatomy using both CT and MRI in patients undergoing workup for cochlear implantation. The systematic assessment of various structures yielded several important findings. A key finding was that 22% of ears demonstrated cochlear underdevelopment on both CT and MRI. The most common cochlear anomaly in these cases was vestibulocochlear cystic anomaly, seen in around 40% of underdeveloped cochleae. Accurate delineation of such anomalies is crucial for surgical planning and determining cochlear implant candidacy [6].

Table 1: Description of Cochlear development by CT in all studied patients.

		Studied ears (N = 100 ears)	
Cochlear development	**Well-developed**	78	78%
	Not well developed	22	22%
Cochlear anomalies	**Aplasia**	2	9.1%
	Hypoplasia	2	9.1%
	Incomplete partition type I	4	18.2%
	Incomplete partition type II	3	13.6%
	Vestibuleo-cochlear cystic anomaly	9	40.9%
	Common cavity malformation	2	9.1%

Table 2: Description of Cochlear patency by CT in all studied patients.

		Studied ears (N = 98 ears)	
Cochlear patency	**Patent**	90	91.8%
	Not patent	8	8.2%
Cochlear anomalies	**Partially ossified**	4	50%
	Completely ossified	3	37.5%
	Cochlear implanted device	1	12.5%

Table 3: Description of Vestibule / semicircular canals by CT in all studied patients.

		Studied ears (N = 100 ears)	
Vestibule	**Patent**	75	75%
	Not patent	25	25%
Vestibule anomalies	**Aplasia**	2	8%
	Vestibuleo-lateral SSC cystic anomaly	11	44%
	Dilated vestibule	6	24%
	Partially ossified	3	12%
	Completely ossified	3	12%
Semicircular canals	**Patent**	78	78%
	Not patent	22	22%
Semicircular canals anomalies	**Aplasia**	4	18.2%
	Hypo-plastic LSCC	2	9.1%
	Vestibuleo-lateral SSC cystic anomaly	8	36.4%
	Partially ossified	3	13.6%
	Completely ossified	5	22.7%

Table 4: Description of cochlear nerve by MRI in all studied patients.

		Studied ears (N = 100 ears)	
Cochlear nerve	**Aplasia**	12	12%
	Hypoplasia	5	5%
	Mass	1	1%
	Intact	82	82%

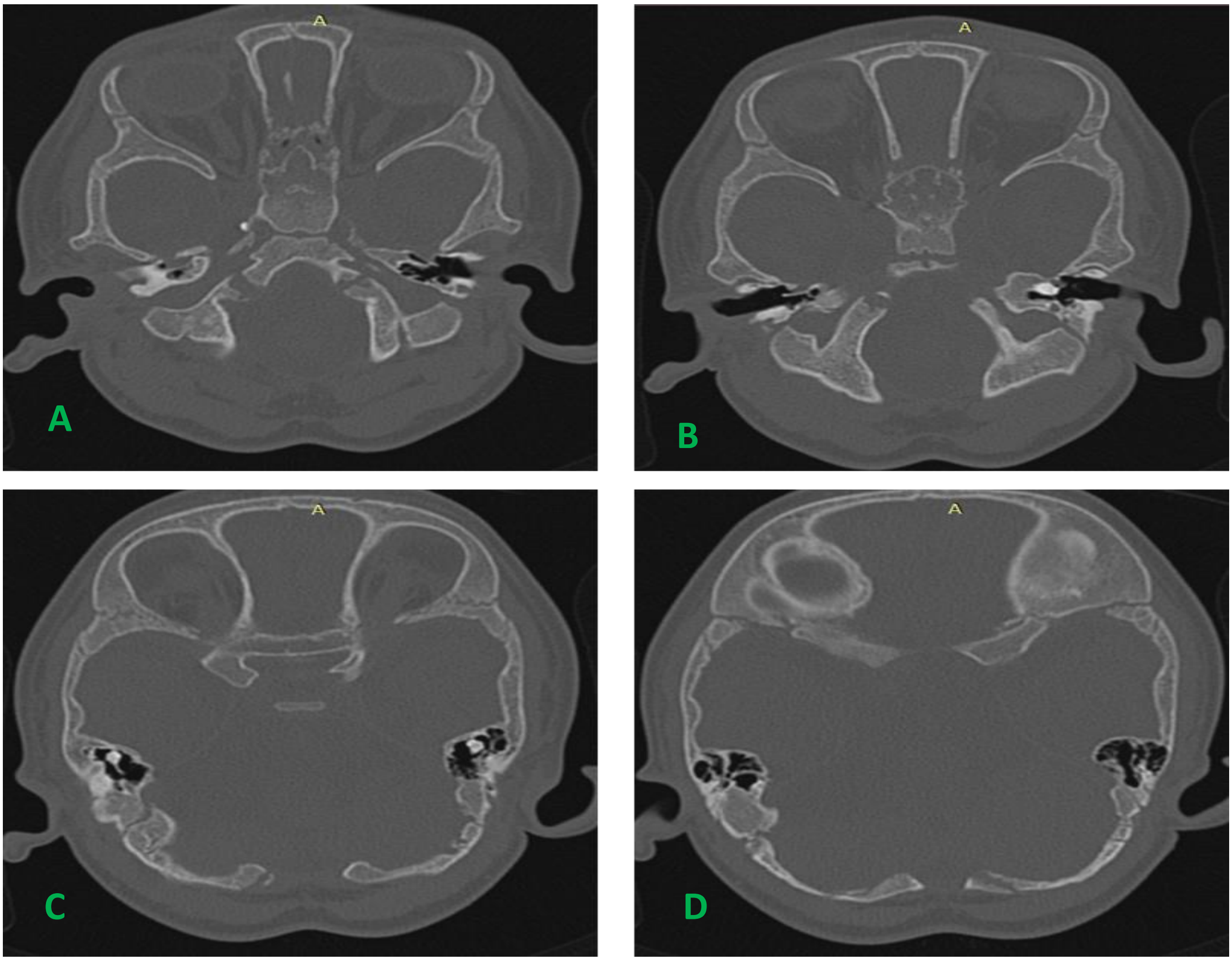

Figure 1: CT Findings:
(A) shows Totally absent Rt inner ear
(B) Shows Small dysplastic Lt bony labyrinth with absent other inner ear structures.
(A, B) Show Bilateral absent IACs.
(C, D) Show bilateral normal middle ear structures.

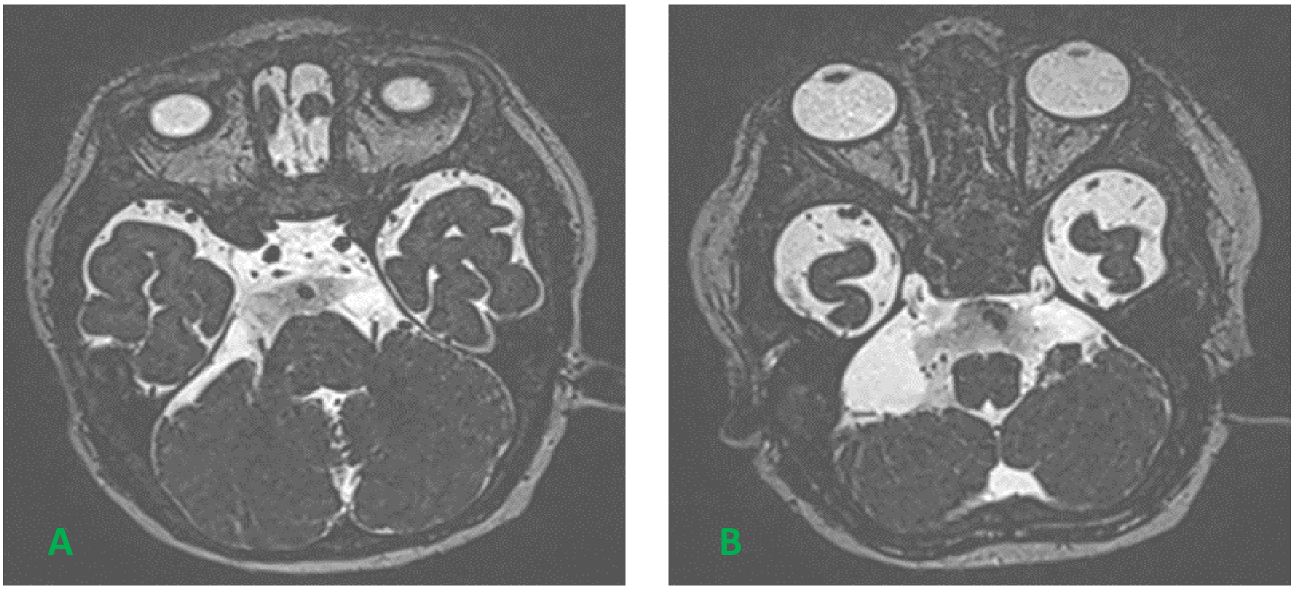

Figure 2: MRI Findings:
(A, B) show Absence of inner ear structures on both sides (Michel Aplasia), Bilaterally absent IACs, Absent 8th and 7th cranial nerves on both sides.

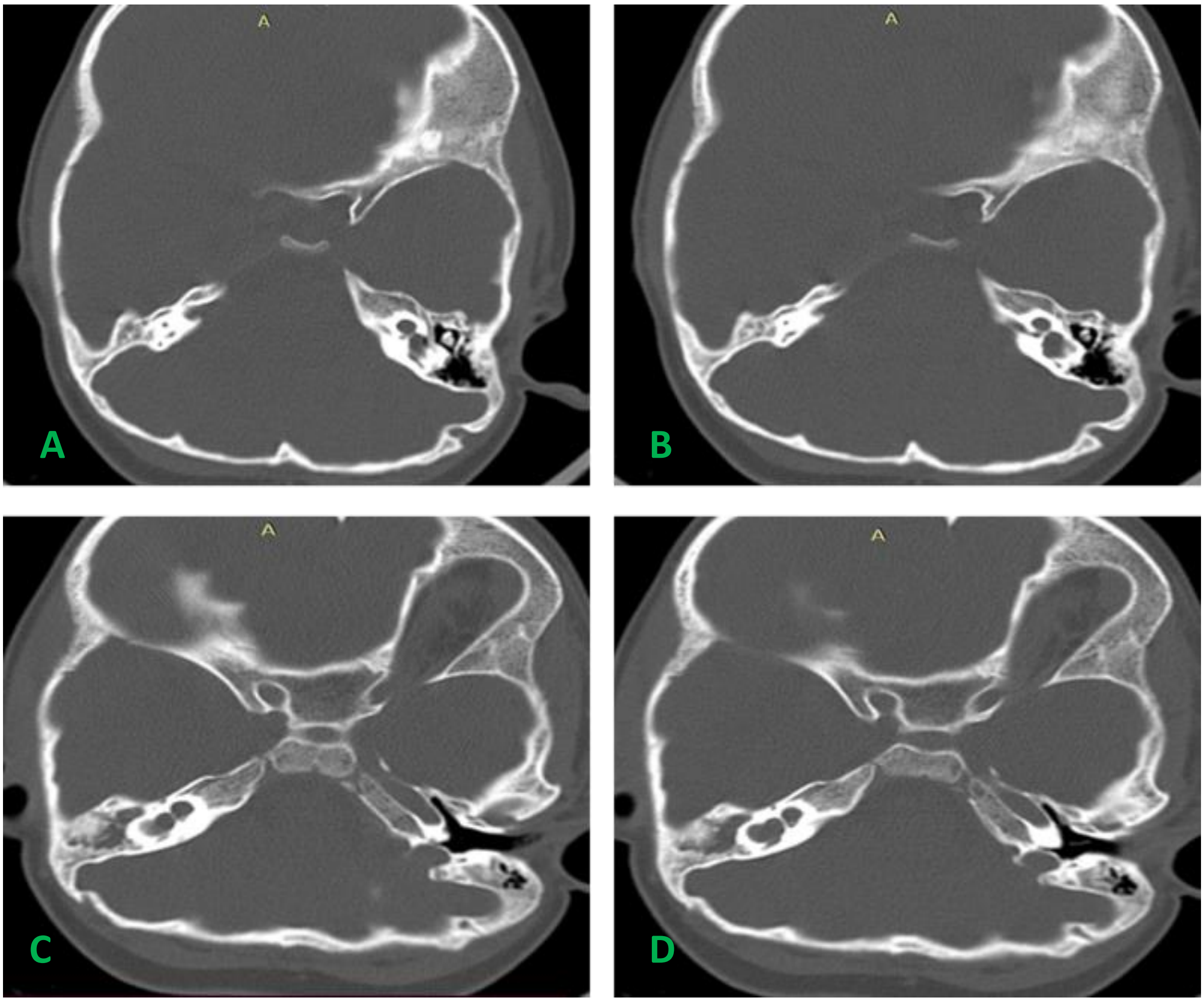

Figure 3: CT findings:
(B,C) show bilateral vestibule-cochlear cystic anomaly
(A,B) shows bilateral small sized IAC
(D) shows sigmoid sinus type I
(C,D) show sentinel air cell present

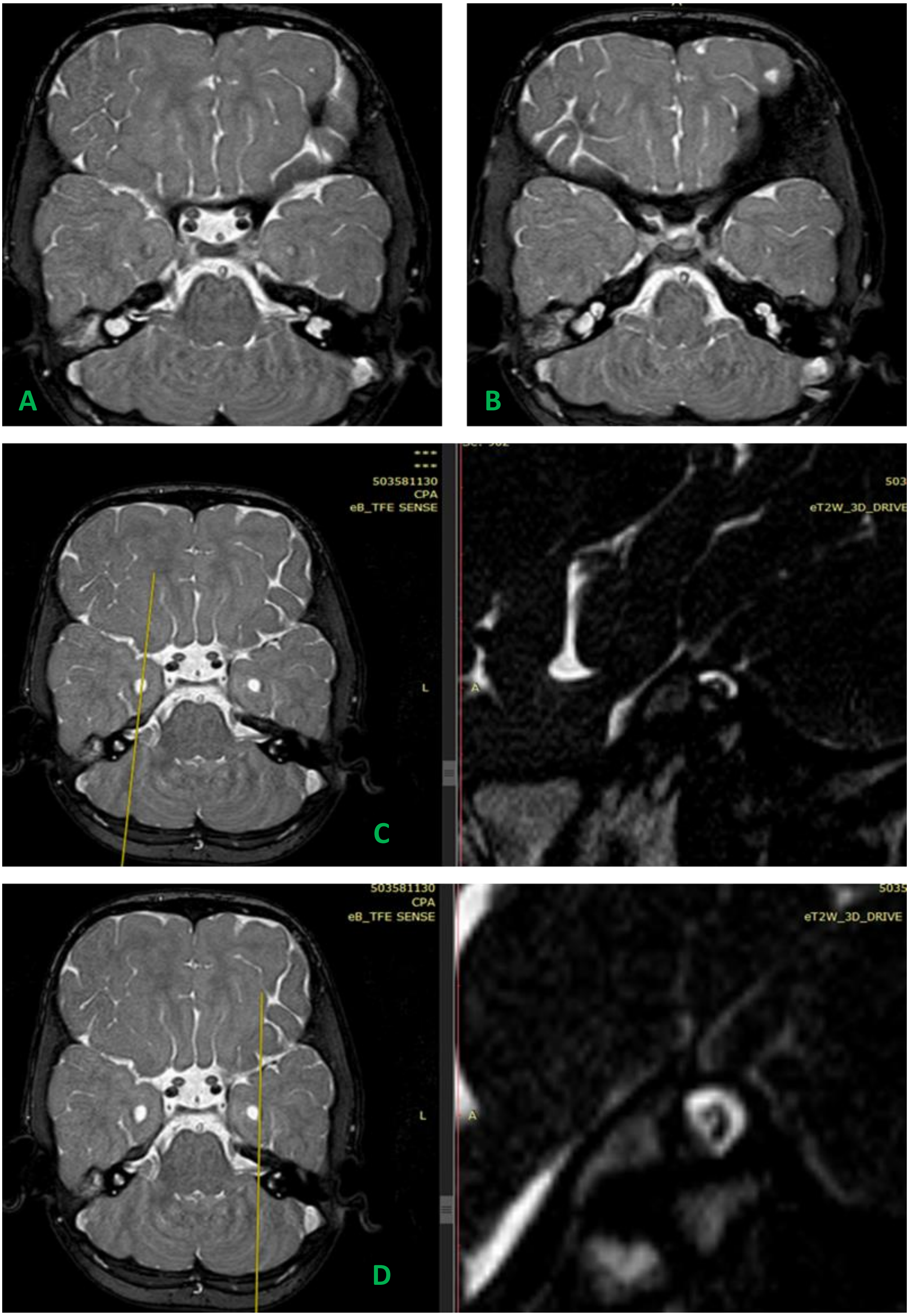

Figure 4: MRI Findings
(A, B) show Bilateral vestibule-cochlear cystic anomaly.
(C, D) show Bilaterally absent cochlear nerve.

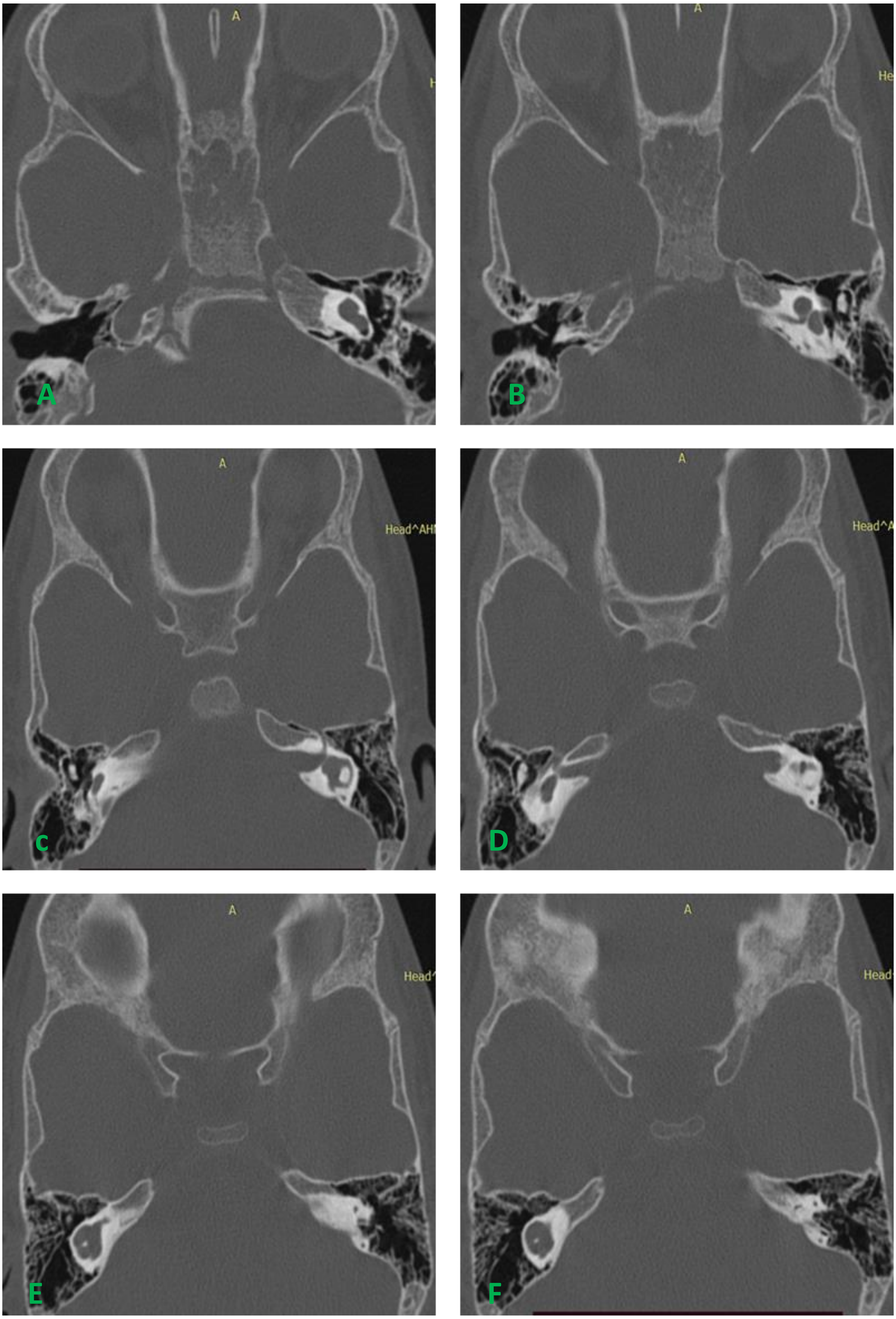

Figure 5: CT findings:
(A, B, D, E) show Bilateral cochlear incomplete partition type I
(D) shows Narrow right IAC, normal width of the left IAC.
(C,F) show bilaterally dilated vestibule , short lateral SSC.

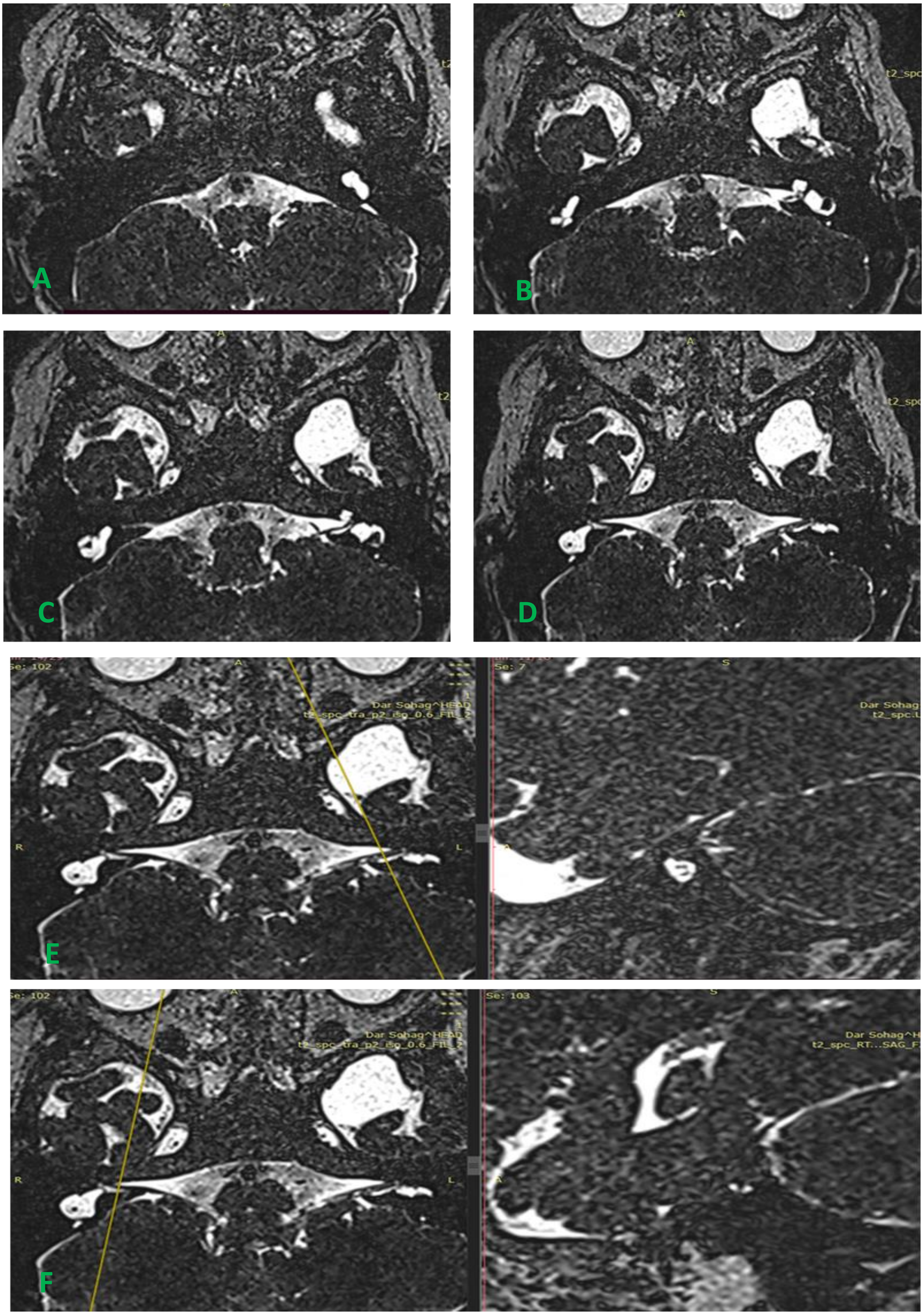

Figure 6: MRI findings:
(A, B, C, D) show Bilateral cochlear incomplete partition type I
(E, F) Show Narrow RT IAC containing single nerve (facial N), Normal width of the LT IAC, showing facial N, vestibular N, absent cochlear N.

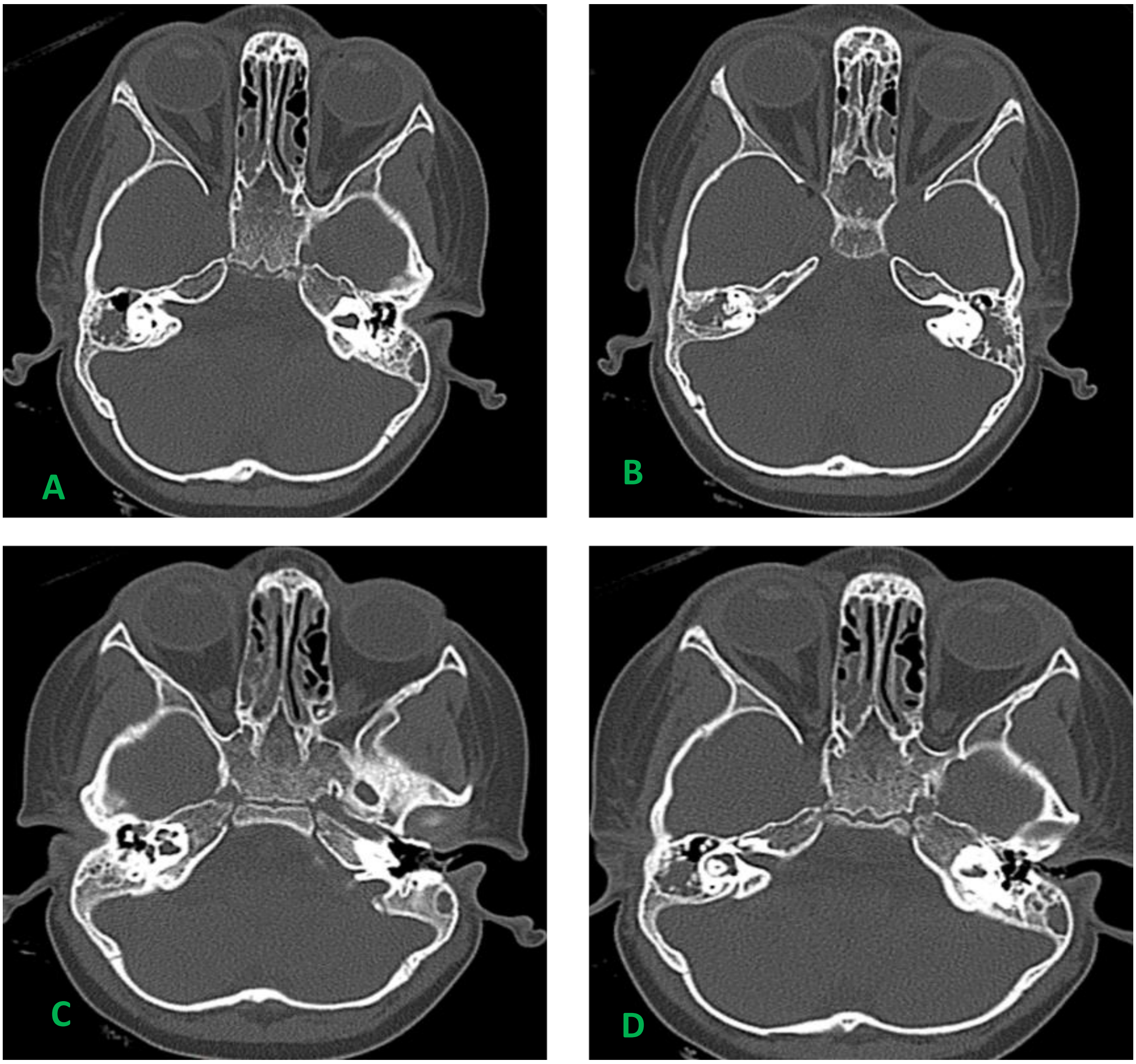

Figure 7: CTI findings:
(A,C) show partial ossification of the right cochlea, vestibule and semicircular canals.
(B,D) show complete ossification of the left cochlea (white cochlea), vestibule and semicircular canals.
(D) shows bilateral chronic oto-mastoiditis.
(A,B) show normal width of the IAC on both sides.

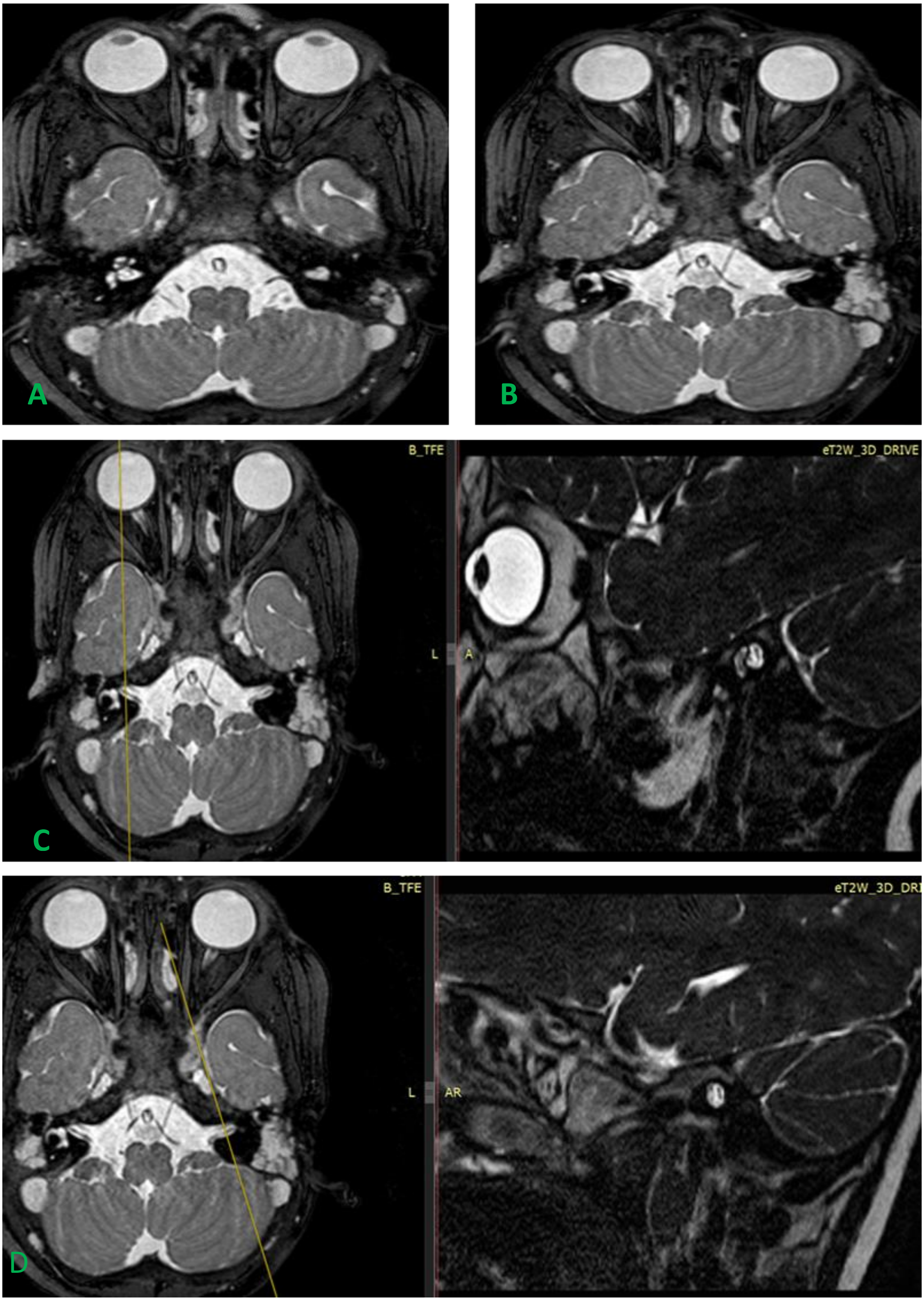

Figure 8: MRI Findings:
(A) shows Partial loss of T2 high signal of the right membranous labyrinth
(B) shows Complete loss of T2 high signal of the left membranous labyrinth (whipped out cochlea).
(C, D) show Intact cochlear nerve on both sides.

Cochlear patency was also thoroughly evaluated. On CT, 8.2% of ears showed non-patent cochleae, most frequently due to partial (50%) or complete (37.5%) ossification. MRI confirmed these findings, with 9.2% non-patent cochleae, primarily attributable to ossification (77.7% of non-patent cases). The presence of cochlear ossification can significantly impact the feasibility and approach to cochlear implantation [7]. Regarding cochlear dimensions, the mean cochlear duct length measured 8.9 ± 0.78 mm on CT, which is an important consideration for electrode array selection and insertion depth. Vestibular system abnormalities were relatively common, with the vestibule being non-patent in 25% of ears on CT and 29% on MRI. Vestibulocochlear cystic anomaly involving the lateral semicircular canal was the predominant vestibular anomaly, present in around 45% of non-patent vestibules on both CT and MRI [8]. MRI also enabled evaluation of the cochlear nerve, internal auditory canal, and other structures not well visualized on CT. Cochlear nerve aplasia or hypoplasia was detected in 17% of ears, while internal auditory canal abnormalities, such as atresia or absence, were seen in 7% of ears. These findings have important implications for auditory signal transmission and cochlear implant outcomes [9]. The complementary information provided by CT and MRI in this study highlights the value of a multimodal imaging approach in the preoperative evaluation of cochlear implant candidates. While CT excels in delineating bony anatomy, MRI offers superior soft tissue contrast and enables assessment of neural structures and potential fibro-osseous obliteration. By leveraging the strengths of both modalities, a more comprehensive understanding of the patient's anatomy can be achieved, facilitating individualized surgical planning and optimizing outcomes.

5. Conclusions

From the current study, it was concluded that:

- MSCT and MRI proved to be useful in preoperative assessment of pediatric and adult cochlear implant candidates.
- The 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 internal auditory canal affection. On the other hand, MSCT 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.

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