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Original Article

Stapedial Otosclerosis in Cone Beam CT (CBCT): a Prospective Study

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ABSTRACT

Background: The CB-CT imaging technique presents a novel approach that offers a notable reduction in radiation exposure compared to conventional MSCT.

Methods: A total of 40 patients with conductive hearing loss and normal anatomical inner ear structures, were selected from Audiovestibular Medicine Unit. CBCT equipment NEWTOM GiANO was utilized for all tests, which were conducted without the use of contrast material. The imaging included the entirety of the temporal bone. Throughout the procedure, the individual assumes a seated position on a seat that can be adjusted to accommodate their needs. To reduce the potential for motion artifacts, the head was affixed to a headband.

Results: Twenty-seven patients (67.5%) exhibited thickening of the stapes footplate on the right side, while 25patients (62.5%) demonstrated thickening of the stapes footplate on the left side. Regarding the enlarged stapes footplate side, bilateral involvement was observed in 25 patients (92.6%), while unilateral involvement was observed in 2 cases (7.5%). On the right side, mild symptoms were observed in 4 individuals, accounting for 10% of the sample, whereas moderate symptoms were reported in 36 patients, constituting 90% of the sample. On the left side, the observed condition was within the normal range in two patients (5%), slightly abnormal in two patients (5%), mildly abnormal in 26 patients (65%), and moderately abnormal in 10 patients (25%).

Conclusion: This study demonstrates the possibility of high-resolution cone-beam computed tomography (CB-CT) imaging in providing more definitive findings on the diagnostic capabilities of CB-CT for the middle ear.

Keywords: Otosclerosis, Cone beam CT, Imaging technique, MSCT.

INTRODUCTION

Otosclerosis is the most prevalent cause of conductive hearing losses (CHL) [1]. The prevalence of this condition exhibits a higher incidence among individuals of Caucasian descent, with approximately 1% of this population being affected [2]. The prevalence of this condition is usually observed among adult females between the ages of 15 and 55 years, with onset typically occurring around the age of 20 [1]. The predominant manifestation of the illness is chronic hearing loss (CHL). However, it is also possible for individuals to experience

sensory neural and mixed hearing losses, commonly referred to as SNHL and MHL, respectively [2].

In certain instances, namely, the frontal footplate of the stapes, also known as the Fissula Ante Fenestram (FAF), undergoes demineralization, leading to additional injury to the cochlea and vestibule [3]. Consequently, based on the location and extent of mineral loss, lesions are classified as fenestral and cochlear or retrofenestral otosclerosis, which exhibited bilateral occurrence in 80% of the subjects [4].

The identification of otosclerosis primarily occurs due to patients' history of significant hearing impairments, familial predisposition to the disease, as well as clinical and audiometric evaluations. In the context of otoscopy and clinical examinations, it is common for the tympanic membrane to exhibit normal characteristics. An air-bone gap (ABG) greater than 10 dB in audiology testing indicates the presence of stapedial fixations, which is the underlying cause of conductive hearing loss [5]. However, when examining individuals with ambiguous symptoms such as dizziness and hearing loss, clinical and audiometric tests have revealed both positive and negative false findings. As a result, the identification of otosclerosis can be a complex and challenging process [6]. In recent times, the utilization of preoperative scanning has effectively mitigated the occurrence of uninformed and unnecessary procedures, while enhancing patients' understanding and knowledge regarding the medical intervention.

At present, Cone Beam Computed Tomography (CB-CT) is extensively employed for the purpose of generating three-dimensional representations of the maxillofacial anatomy, exhibiting enhanced spatial resolution. The temporal bone is a complicated bony structure within the human body that encompasses complex anatomical formations. The auditory system include structures that play a crucial role in the processes of hearing and balance, and can be affected by many conditions such as fractures, developmental abnormalities, infections, and cancer **[7]**.

The objective of this study was to assess the utility of cone beam CT (CB-CT) in the diagnostic process of stapedial otosclerosis.

METHODS

This study was conducted with a prospective research design. A total of 40 participants, consisting of 18 males and 22 females, were selected from the Audio-vestibular Medicine Unit. The recruitment period spanned from January, 2022, to October, 2022. The patients in the sample have ages that vary between 20 and 50 years, with a mean age of 34.8 ± 9.7 years.

The inclusion criteria for this study encompassed individuals between the ages of 20 and 50, of both genders. All participants exhibited conductive hearing loss, with varying degrees and configurations of hearing loss. Additionally, all participants had normal anatomical characteristics of the external auditory canal and tympanic membrane, as well as normal middle ear function.

The exclusion criteria for this study included patients who have a history of previous aural discharge or abnormal otological examination, patients with an unhealthy tympanic membrane, patients with sensorineural hearing loss (SNHL) or mixed hearing loss, patients with a history of previous ear operation, and any patient who is found to have a pathology other than otosclerosis during exploration.

Every patient was subjected to the following:

Complete history taking as follow: History taking: personal medical history (name, age,

gender, place of residence, occupation, marital status (pregnancy, siblings), and special habits for medical reasons). Complaints and their duration (hearing loss, tinnitus). History of current illness: Analysis of complaints (side, onset, course, duration, aggravating and provoking factors), other ENT symptoms: (hearing disturbance, tinnitus, ear discharge, vertigo). Medical history: similar symptoms, medical conditions, surgical history, radiation and noise exposure, drugs (including ototoxic drugs). Family history: same disease, other diseases, consanguinity.

Examination: Otoscopy findings indicate a normal external auditory canal and undamaged tympanic membrane. The tuning fork tests were conducted using a 512 Hz tuning fork. The results of the Rinne test were negative, indicating a potential conductive hearing loss. Additionally, the Weber test revealed lateralization towards the ear with a greater degree of conductive hearing loss.

Investigations: Audiology is a branch of healthcare that focuses on the study and management of hearing and Pure tone audiometry (PTA) is a diagnostic test commonly used in audiology to assess an individual's hearing abilities. The audiometric bone gap (ABG), which represents the difference in decibels between the AC and BC thresholds, was assessed for each patient. This assessment involved measuring the 4-frequency pure tone average at frequencies of 0.5, 1, 2, and 4 kHz, as well as conducting tests for tympanometry, acoustic reflex, and speech discrimination.

Radiology technique: The analysis involved the examination of cone beam computed tomography (CB-CT) scans of the petrous bone in a cohort of 40 individuals. All investigations were conducted using the CB-CT device known as NEWTOM GiANO.

1- The data acquisition image technique: All examinations were conducted without the use of contrast material, and imaging encompassed the entirety of the temporal bone. The single scanner and the detector rotate around the patient's head acquiring from as little as 200 basis images and up 1,800 depending on the design of the unit. Slice thickness of CBCT varies from 0.075 to 0.5 mm. The digital data of the multi-angle projections are processed by algorithms that reconstruct the volume of the target voxels. Data analysis has been conducted using a dedicated software tool. The New-Tom NNT analysis package is widely regarded as a highly effective tool for both 2D and 3D imaging **[17]**. The utilization of neural network techniques (NNT) enables the generation of diverse categories of two-dimensional (2D) and three-dimensional (3D) visual representations. The images have undergone reconstruction using filtered back-projections, resulting in a data depth of 8 bits per pixel. The average radiation exposure of the scanned segment was determined to be 1.4 mGy. This measurement was obtained using a standard dosimetry CT setup, which involved utilizing a cylindrical head phantom with a 16 cm axial diameter. Therefore, the measured effective dose amounted to 13 mSv, which is similar to the effective dose resulting from half of a posterior-anterior thorax radiography.

2- The image analysis: Two experienced radiologists, with 10 years of expertise in the fields of imaging and otology, independently evaluated each anatomical landmark, placing particular emphasis on visualizations. The assessment of image quality was categorized into three distinct levels: note 1, indicating complete visibility; note 2, indicating partial visibility; and note 3, indicating no visibility.
The otosclerotic changes were classified into two types: Type 1, which involves fenestral

lesions characterized by a thickening footplate and/or a narrower or expanded window, and Type 2, which involves retrofenestral lesions with or without fenestral involvement. Type 2 can be further classified into two subcategories: dual ring impact narrowed basal turn, and dual ring and narrowed basal turn. Type 3 refers to a condition characterized by the presence of severe retrofenestral lesions, which involve the deformed otic capsule. These lesions may or may not involve the fenestrae.

***Statistical analysis*:** The acquired data underwent coding, inspection, and statistical analysis using IBM SPSS-20. (The study population was analyzed descriptively to define their characteristics. The diagnostic variability was evaluated and their P value). The Mann-Whitney U and kruskal wallis tests were used to compare between variables studied. Multivariate regression analysis was utilized to investigate the predictors of enlarged stapes. P value less than 0.05 was considered significant.

RESULTS

The current study was examined a cohort of 40 patients who diagnosed with conductive hearing loss and an intact tympanic membrane. Cone beam computed tomography (CT) was utilized to examine the temporal bone in all patients.

Regarding the reported complaints, it was observed that 28 patients (70%) experienced both impaired hearing and tinnitus, whereas six patients (15%) reported tinnitus alone, and another 6 patients (15%) reported diminished hearing alone. Regarding laterality, the side was found to be right-sided in six cases, accounting for 15% of the sample, while bilateral involvement was observed in 34 patients, including 85% of the cohort. Tinnitus was observed in a total of 34 patients, accounting for 85% of the sample population. Among these patients, tinnitus was reported to be present on the right side in six individuals, representing 17.6% of the affected patients, while bilateral tinnitus was reported by 28 patients, accounting for 82.4% of the cases. Eight patients (20%) experienced symptoms of vertigo. All patients included in the study (100%) had no history of prior ear surgery, as indicated in **Table (1).**

As regard tympanogram, it was type A in 22 patients (55%) and type AS in 18 patients (45%) in both right and left sides. As regard acoustic reflex, it was absent on both sides in all studied patients as shown in **Table (2)**

Regarding the degree of hearing loss in all the patients under study. On the right side, mild symptoms were observed in four individuals, accounting for 10% of the sample, whereas moderate symptoms were reported in 36 patients, constituting 90% of the sample. On the left side, the observed condition was within the normal range in two patients (5%), slightly abnormal in two patients (5%), mildly abnormal in 26 patients (65%), and moderately abnormal in 10 patients (25%), as indicated in **Table (3).**

A total of 27 patients (67.5%) exhibited thickening of the stapes footplate on the right side, while 25 patients (62.5%) had thickening of the stapes footplate on the left side. Regarding the enlarged stapes footplate side, it was observed to be bilateral in 25 patients (99.6%) and unilateral in 2 patients (7.5%), as depicted in **Table (4) and Figure (1 & 2).**

The analysis conducted in **Table (5)** reveals that there was no statistically significant difference between the length of the disease regarding the studied variables (p-value) and variables under investigation, namely CB-CT findings, side of CB-CT findings, and the degree of hearing loss in the right and left sides.

Table (6) presents the results of a multivariate regression analysis, indicating the predicted factors for enlarged stapes footplate in CB-CT. The results indicated that there was a statistically significant association between female sex and the outcome variable (B = 1.5, SE = 0.72, p = 0.038, odds = 4.5 & 95% CL = 1.08 – 18.6). The occupation of the individual under study was that of a farmer. The corresponding statistical values for this occupation are as follows: (B = 2.1, SE = 1.02, p = 0.032, odds = 9 & 95% CL = 1.2 – 67.4).

Table (1): Description of clinical data in all patients

		Studied patients (N = 40)	
Complain	Diminished hearing	6	15%
	Tinnitus	6	15%
	Diminished hearing+ Tinnitus	28	70%
Side	Right side	6	15%
	Left side	0	0%
	Bilateral	34	85%
Tinnitus	No	6	15%
	Yes	34	85%
Side of tinnitus	Unilateral	6	17.6%
	Bilateral	28	82.4%
Vertigo	No	32	80%
	Yes	8	20%
Ear surgery	No	40	100%
	Yes	0	0%

Table (2): Description of tympanogram and acoustic reflex in all studied patients

			Studied patients (N = 40)	
Tympanogram	Right side	Type A	22	55%
		Type AS	18	45%
	Left side	Type A	22	55%
		Type AS	18	45%
acoustic reflex	Right side	Present	0	0%
		Absent	40	100%
	Left side	Present	0	0%
		Absent	40	100%

Table (3): Description of degree of hearing loss in all studied patients

			Studied patients (N = 40)	
Degree of hearing loss	Right side	Mild	4	10%
		Moderate	36	90%
	Left side	Normal	2	5%
		Slight	2	5%
		Mild	26	65%
		Moderate	10	25%

Table (4): Description of CB-CT finding in all studied patients

			Studied patients (N = 40)	
CB-CT finding	Right side	No finding	13	32.5%
		thickened stapes footplate	27	67.5%
	Left side	No finding	15	37.5%
		thickened stapes footplate	25	62.5%
Thickened stapes footplate Side		Bilateral	25	92.6%
		Unilateral	2	7.5%

Table (5): Difference between duration of disease regarding studied variables

		N		Duration	Test	P-value
CB-CT finding	No	13	32.5%	4.3 ± 4.9	MW = 170	0.887 NS
	Yes	27	67.5%	4.7 ± 5.8		
Side of CB-CT finding	Bilateral	25	92.6%	5.06 ± 5.9	MW = 0.051	0.051 NS
	Unilateral	2	7.5%	0.5 ± 0.0		
Degree of HL on Rt. side	Mild	4	10%	1.5 ± 0.6	MW = 47	0.281 NS
	Moderate	36	90%	4.9 ± 5.6		
Degree of HL on left side	Normal	2	5%	1 ± 0.0	KW = 4.45	0.217 NS
	Mild	10	25%	5.6 ± 5.3		
	Slight	2	5%	1.2 ± 1.1		
	Moderate	26	65%	4.7 ± 5.8		

MW: Mann Whitney U test , KW: Kruskal Willis test NS: p> 0.05 result was nonsignificant.

Table (6): Multi-variate logistic regression analysis for parameters predictive of thickened stapes footplate in CB-CT

	B	SE	p-value	Odds	95% CL	
Age	0.028	0.036	0.439	1.02	0.95	1.1
Sex (female)	1.5	0.72	0.038	4.5	1.08	18.6
Occupation (Farmer)	2.1	1.02	0.032	9	1.2	67.4
Residence	0.45	0.89	0.614	1.57	0.27	9.1
Duration	0.014	0.064	0.821	1.01	0.89	1.15
Family history	1.13	0.76	0.138	3.09	0.69	13.8
Side	1.71	0.94	0.071	5.55	0.86	35.7
Tinnitus	1.71	0.94	0.071	5.55	0.86	35.7
Tinnitus side	1.71	0.94	0.071	5.55	0.86	35.7
Vertigo	1.43	1.13	0.204	4.2	0.45	38.4
Complain	0.044	0.94	0.962	1.04	0.166	6.6
Complain side	1.71	0.94	0.071	5.55	0.86	35.7
Tinnitus (clinical)	1.71	0.94	0.071	5.55	0.86	35.7
Tinnitus side (clinical)	1.71	0.94	0.071	5.55	0.86	35.7
Vertigo (clinical)	1.43	1.13	0.204	4.2	0.45	38.4
Rt. Tymp	- 0.06	0.67	0.919	0.93	0.24	3.5
Lt. Tymp	- 0.06	0.67	0.919	0.93	0.24	3.5

B: Regression coefficient, SE: Standard error, CI: Confidence interval.

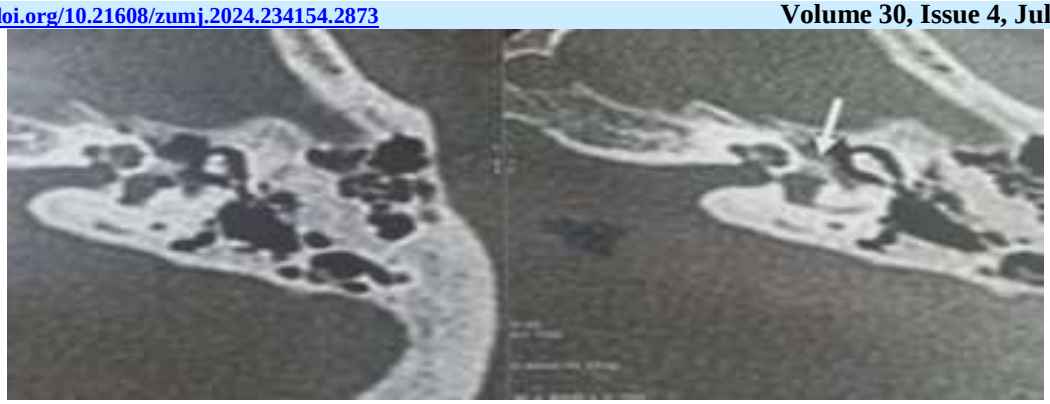

Figure (1): Axial CB-CT reconstruction images of the left petrous bone shows increase density at the footplate of the stapes at the region of oval window (white arrow).

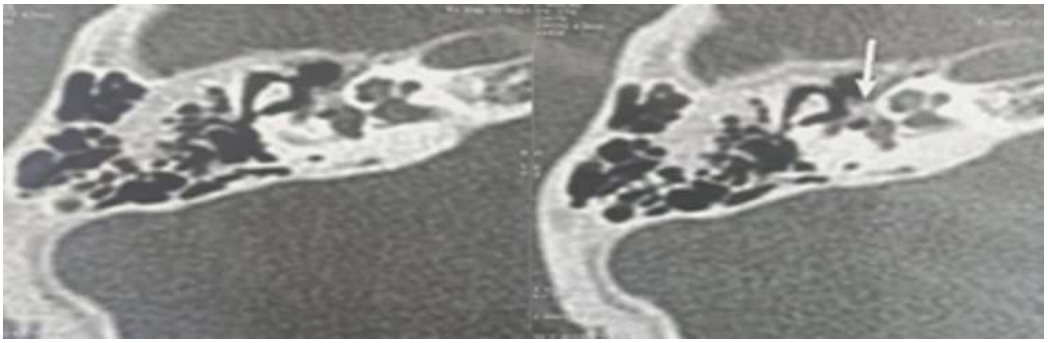

Figure (2): 33 year old female with high quality axial CB-CT reconstruction images of the right petrous bone shows increase density at the footplate of the stapes at the region of oval window (white arrow).

DISCUSSION

This study was conducted on a sample of 40 individuals diagnosed with conductive hearing loss (CHL) and who had an intact tympanic membrane.

In the present study, a total of 28 patients were observed to have both impaired hearing and tinnitus, accounting for 70% of the sample. Additionally, 6 patients exhibited diminished hearing without tinnitus, representing 15% of the sample, while another 6 patients experienced tinnitus without diminished hearing, also accounting for 15% of the sample. Among the observed cases, 34 patients were found to have bilateral symptoms, making up 85% of the sample, while the other 6 patients had unilateral symptoms, representing 15% of the sample. Among the cohort of 34 individuals diagnosed with tinnitus, a majority of 28 patients (82.4%) exhibited bilateral symptoms, whereas a minority of 6 patients (17.6%) presented with unilateral manifestations. A total of eight individuals experienced symptoms of vertigo, accounting for 20% of the patient population. In a study conducted by **Izadparast, Yalda et al. [8]**, it was shown that out of the total number of cases, 61.9% (13 cases) exhibited bilateral otosclerosis affecting both ears, whereas 38.1% (8 cases) presented with unilateral otosclerosis affecting only one ear. In a study conducted by **Lucas, Matthew [9]**, a total of 35 individuals diagnosed with otosclerosis were examined. Among these participants, 11 individuals (31.4%) exhibited unilateral hearing loss, with their unaffected ear demonstrating audiometric thresholds within the normal range often observed in clinical settings. The findings of this study are consistent with previous research conducted in Iran **(10)** and Hungary **(11)**, which reported that around 53% of otosclerosis patients in Iran experienced unilateral hearing loss, while about 21.0% of cases in Hungarian study were characterized by unilateral otosclerosis.

In a study conducted by **Skarżyński , Piotr Henryk, et al. [12]**, it was observed that out of the whole study group, 71 women and 36 males, accounting for 68.2% of the participants, experienced preoperative tinnitus. The prevalence of chronic tinnitus was found to be similar between women and men, with 67.0% of women and 70.6% of men reporting experiencing this condition. The average duration of tinnitus was found to be 6.80 years, with a range of 0.5 to 30 years. Out of the total number of cases, 56 were characterized by bilateral tinnitus, while 51 individuals exhibited unilateral tinnitus, wherein only one ear was eligible for surgical intervention. According to the findings of the questionnaire, a majority of cases (76.60%) exhibited a greater prevalence of hearing loss issues compared to tinnitus. In 13.10% of cases, tinnitus was found to be a more significant issue than hearing loss, whereas in 10.30% of cases, the adverse effects of hearing loss and tinnitus were comparable.

The diagnosis of stapes fixations was established based on clinical evaluations, audiometric assessments, tympanometric measurements, and results obtained from cone-beam computed tomography (CB-CT) scans. All participants underwent a standard audiological assessment. Regarding the tympanogram, it was observed that 22 patients (55%) exhibited a type A tympanogram, whereas 18 patients (45%) displayed a type AS tympanogram in both the right and left sides. Regarding the acoustic reflex, it was found to be absent bilaterally in all patients included in the study. In a study conducted by **Liktor Bala´zs, et al. [1]**, it was shown that 64.1% of the ears exhibited type-As tympanograms, while 35.9% of the ears had type-A tympanograms.

The clinical investigation of the middle ear involved the use of otoscopic and acoustic immittance examinations. A well-aerated ear exhibits no otoscopic evidence of middle ear condition, such as the presence of middle ear fluids. Additionally, the findings from the tympanogram and static compliance tests indicate normal results, suggesting that the middle ear is mobile and capable of conducting sounds. However, it has been suggested that the utilization of traditional tympanometric measurements of static compliances may not be appropriate in the differential diagnosis **[13]**. The reason for this phenomenon can be attributed to the lack of consistent adherence to static compliance among the general population. In cases of otosclerosis, the drop in static compliance may not be significant enough to counteract the variability observed within the population.

In our study, the findings of CB-CT revealed that 27 patients (67.5%) exhibited thickening of the stapes footplate on the right side, while 25 patients (62.5%) exhibited thickening of the stapes footplate on the left side. Bilateral involvement was observed in 25 patients, accounting for 92.6% of the cases, whereas unilateral involvement was observed in 2 patients, accounting for 7.4% of the cases.

In a study conducted by **Redfors et al. in 2012**, a visual scaling system was employed for the identification of fenestral and retrofenestral injuries associated with otosclerosis in MSCT and CB-CT imaging. The authors reported that pre-operative CB-CT imaging demonstrated a sensitivity of up to 85% in cases of clinical otosclerosis, using a slice thickness ranging from 0.05 to 0.06 cm [14]. The authors disclosed that CB-CT exhibits similar capabilities to MSCT in identifying hypodense foci during temporal bone scans. However, a quantitative assessment was not conducted in their study.

This study is consistent with the results reported by **Peltonen et al., [7]**, who observed that all CB-CT scans obtained from 13 dry temporal bone samples using the 3-D Accuitomo CB-CT device showed a clearly defined oval window. However, it is important to note that the acquisition parameters used in this study were not representative of clinical examinations, where image quality can be significantly affected by factors such as soft tissue attenuation, scattered radiation, and the presence of metal or dynamic artifacts.

Redfors et al. [14], examined a sample of 65 patients to reconstruct the anatomical structures (16) of the middle and inner ear

using CB-CT. The results of this reconstruction were found to be consistent with those obtained from HRCT, indicating no significant discrepancies between the two imaging techniques. The results of this study indicate that CB-CT can be considered as an alternative to temporal bone scanning as the primary diagnostic method for individuals with CHL and intact tympanic membranes. The use of MSCT has revealed a higher incidence of fenestral injuries compared to CB-CT. the first assessor saw Specifically, 60% and 30%, whereas Assessor 2 saw rates of 85% and 65%, respectively.

The study conducted by **Shin et al., [16]** found a similar occurrence of fenestral injuries compared to the findings published by Redfors. However, Shin et al. also discovered a substantially lower rate of fenestral injuries (39%) in their investigation on pre-cochlear implantations.

Some limitations of this study is the scan width and the field of view ae smaller to assess both temporal bones.

CONCLUSION

Cone beam computed tomography (CBCT) is a novel imaging technique that offers a notable reduction in radiation exposure compared to conventional multi-slice computed tomography (MSCT). This study demonstrates the potential of utilizing high-resolution cone-beam computed tomography (CBCT) imaging to obtain more definitive findings regarding the efficacy of multislice computed tomography (MSCT) as a diagnostic modality for the middle ear. The results indicate that CBCT offers superior picture quality and reduced radiation exposure compared to MSCT. Compared to CT scans, cone beam computed tomography (CBCT) offers advantages in terms of lower radiation exposure. Consequently, CBCT is considered more suitable for repeated examinations, post-operative follow-ups, pediatric explorations, and investigations of chronic otitis media with normal tympanic membranes. The findings of our study suggest that the use of cone beam computed tomography (CBCT) is suitable for the purpose of scanning temporal bones in cases with otosclerosis.

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