ORIGINAL ARTICLE

Feasibility of CBCT in Diagnosing Otosclerosis by Measuring CBCT Bone Density: A Preliminary Study

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Abstract The aim of this study was to measure cone beam computed tomography (CBCT) derived bone density of 6 anatomic points around the otic capsule in preoperative assessment of patients with clinically suspected otosclerosis, and to compare these densities with control group. CBCT images of 21 patients (34 ears, the otosclerosis group) with surgically confirmed otosclerosis and 26 patients (52 normal ears, the control group) were evaluated in this prospective study. Six regions of interest (ROI) were set manually around the otic capsule with the slice thickness of 0.3 mm. The mean CBCT bone density these regions were measured and compared in the case and control groups. In the case group, the mean CBCT bone density at the fissula ante fenestram (FAF) was significantly lower than the control group. Moreover, at the 4 points of the other ROIs (3–6) CBCT bone densities were significantly lower in the case group compared to the control group ($p < 0.01$). In this group, among 13 bilateral otosclerosis, 22 ears had conductive hearing loss (CHL), 4 ears had mixed hearing loss (MHL) and among 8 unilateral otosclerosis, 5 ears had CHL, 3 ears had MHL. Our study showed the mean CBCT bone density of ROIs 1 and 6 were correlated with the average air–bone gap in the bilateral and unilateral otosclerosis group, respectively. Quantitative evaluation of CBCT with a slice thickness of 0.3 mm can be used as a suitable tool for diagnosis and follow-up of otosclerosis in temporal bone.

Keywords Otosclerosis ·
Cone-beam computed tomography · Bone density

Introduction

Otosclerosis, the most common cause of conductive hearing loss in adult human beings, is an inflammatory bone disorder with unknown cause, particularly affecting otic capsule in temporal bone [1]. This disease is more prevalent in Caucasians with approximately 1% involvement [2]. It is frequently the disease of adult women in the age range of 15–55 years and usually starts at the age of 20 [1].

The most significant symptom of the disease is conductive hearing loss (CHL). However, sensory neural and mixed hearing loss (SNHL, and MHL) might also occur [2].

The disease mechanism is replacement of normal endochondral bone by spongy vascular bone, and it is also called 'otospongiosis' [3]. With disease progression in the final stages, the decalcified foci tend to become less vascular and sclerotic [4].

In patients, initially, anterior footplate of stapes also called Fissula Ante Fenestram (FAF), becomes demineralized and then the lesion extends to the vestibule and cochlea [5]. Consequently, based on the location and extent of demineralization, lesions are divided into fenestral and

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cochlear or retrofenestral otosclerosis, which are bilateral in 80% of cases [6].

Principally, otosclerosis diagnosis occurs as a result of patient's history of progressive hearing loss, positive family history, clinical, and audiometric examinations. Frequently, in otoscopy and clinical examination, tympanic membrane is normal. Air-bone-gap (ABG) more than 10 dB in audiometry implies the stapedial fixation, which is the cause of CHL [7, 8]. However, considering the positive and negative false results obtained from clinical and audiometric examinations in patients with vague symptoms, such as dizziness and hearing loss, the diagnosis of otosclerosis can potentially be a confusing and difficult process [3]. In recent years, pre-operative imaging has prevented blinded and unnecessary operations and increased patient's awareness regarding the treatment process.

High-resolution CT (HRCT) of the temporal bone is the modality of choice for the preoperative evaluation of otosclerosis due to its ability to accurately show anatomy and pathological changes in ossicular chain and tiny structures of middle and inner ear [9]. Numerous studies have confirmed high resolution computed tomography (HRCT) as an effective tool for determining the presence and extension of hypocalcified foci of bony labyrinthine in otosclerosis [2, 10].

Today, Cone beam computed tomography (CBCT), has an extensive application in producing three dimensional reconstructed images of the maxillofacial structures with high spatial resolution, and no magnification, superimposition or distortion [11–14]. Several studies have evaluated the practicality of CBCT in diagnosing temporal bone abnormalities [6, 8]. Previous studies demonstrated that gray density accuracy of CBCT is comparable with CT imaging systems and there is high correlation between the bone density value of CBCT and CT [16–20].

Findings show that CBCT might be a proper imaging method to define hypodense lesions of otic capsule otosclerosis in a manner similar to HRCT [1, 9].

To the best of our knowledge, there is no study that has quantitatively evaluated temporal bone density by CBCT in patients suspicious of otosclerosis. Therefore, this study was designed to measure CBCT bone density of six anatomic points around the otic capsule and its correlation with clinical and surgical findings.

Materials and Methods

This prospective case–control study was conducted 2017 to 2018 and the research was approved by the ethical board of institutional committee. The case group included 21 patients (10 men and 11 women, mean age of 32.51 ± 6.83 years) with otosclerosis in at least one ear. The control group consisted of 26 participants (12 men and 14 women, mean age of 34.76 ± 13.79 years), who had referred to imaging center for temporomandibular joint CBCT scanning due to various diagnostic tasks. All subjects underwent a complete clinical examination, including otoscopy, pure-tone and vocal audiometry and a CBCT scan. Preoperative CBCT scan in the case group was requested by the consultant otologist to rule out any other pathologic causes for hearing loss. Exclusion criteria were poor quality CBCT images for detecting ear structures, abnormal audiometric findings and history of hearing loss of any type amongst the control group. Patients with history of trauma and surgery in temporal bone, otitis media and other ear disorders were excluded from the control and case groups.

The Otologist (with more than 10 years' experience) reported the ABG and types of hearing loss including CHL, SNHL, and MHL according to the audiometric results. The average ABG was defined as the mean air conduction threshold minus the mean bone conduction threshold.

Clinical diagnosis of otosclerosis was based on normal tympanic membrane, CHL, SNHL, and MHL as well as ABG more than 10 db. Otosclerosis was confirmed in all case subjects during surgical procedure by stapedial fixation.

All CBCT images were captured by a NewTom VGi CBCT machine (QR- SRL, Verona, Italy) by the same clinician. Exposure factors were set at 110 KVP, 7.84 mAs and exposure time of 0.75 ms. A field of view (FOV) of 15×12 cm was selected to cover the entire temporal bones. Sectional images were reconstructed in axial, coronal and sagittal plans with slice thickness of 0.3 mm.

Around the oval window and cochlea, in axial views passing through the oval window six anatomic points were selected (Table 1). $1mm^2$ rectangular regions of interest (ROIs) were set manually in these points, and CBCT bone density was automatically measured in each ROI (Fig. 1, 2).

Qualitative and quantitative variables were compared between groups using chi-square and Mann–Whitney tests, respectively. The relationship between CBCT bone density in each ROI and hearing loss in otosclerosis cases was evaluated by Spearman Correlation Analysis. A p-value less than 0.05 was considered to be statistically significant.

Results

In this research, no significant statistical differences in terms of age, gender and side were detected between the otosclerosis and control subjects. (Table 2).

Table 1 Position of ROIs related to ear

Number	Position
1	Posterior to the oval window (posterior to the intersection of stapes posterior arch and stapes footplate)
2	Anterior to the oval window (anterior to the intersection of stapes anterior arch and stapes footplate)
3	Lateral to the middle turn of the cochlea
4	Lateral to the part between apex of the cochlea and the middle turn of the cochlea
5	Apex of the cochlea
6	Anteromedial to the basal turn of the cochlea

ROI indicates region of interest
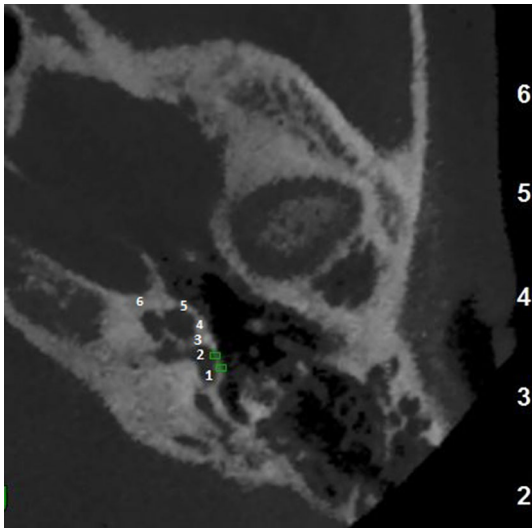
Fig. 1 Example of the ROI setting. In the axial view, six ROIs are manually placed. The area of each ROI is 1mm^2 and the mean CBCT bone density in each ROI can be measured automatically in this technique
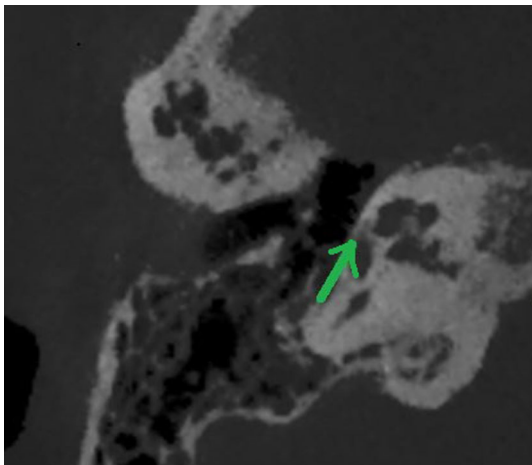
Fig. 2 The axial CBCT section demonstrates the hypodense area in FAF (arrow)

In otosclerosis group, among 21 cases, 13 had bilateral (26 ears) and 8 had unilateral otosclerosis.

Our study showed 11 patients (22 ears) had bilateral CHL with average ABG of 42.27 ± 9.72 dB, 2 (4 ears) had bilateral MHL with average ABG of 38.00 ± 13.03 dB, 5 ears had unilateral CHL and average ABG of 44.00 ± 8.94 dB, 3 ears had unilateral MHL and average ABG was 50 ± 0.00 dB in otosclerosis group. The average ABG in the otosclerosis group was 42.28 ± 9.72 dB.

In otosclerosis cases, ROI 2 had the lowest CBCT bone density and ROI 6 had a relatively the highest CBCT bone density compared to ROIs 1, 3, 4 and 5 (Fig. 3). The mean CBCT bone density was significantly lower in the case group in comparison with the control group at the ROIs 2, 3, 4, 5 and 6. However, at ROI 1, there was no statistically significant difference in CBCT bone density between the otosclerosis and control groups (Table 3).

In bilateral otosclerosis group, the CBCT bone density of ROIs 1 correlated with the average ABG in a negative trend (Spearman correlation, $n = 22$, $r = -0.636$, $p = 0.001$) (Fig. 4). Also, in patients with unilateral otosclerosis, there was a significant negative correlation between CBCT bone density of ROI 6 and average ABG (Spearman correlation, $n = 7$, $r = -0.802$, $p = 0.03$) (Fig. 5).

Discussion

Considering the higher spatial resolution, lower radiation dose, availability and ease of CBCT examination compared to CT, this research was conducted to evaluate the feasibility of CBCT in diagnosing otosclerosis by measuring CBCT bone density number or voxel value (VV) of six anatomic points adjacent to oval window and around the cochlea.

Several studies have revealed that gray density accuracy of CBCT is comparable with CT imaging systems [15, 16]. In Nomura et al. [17] study, they compared bone density

Table 2 The distribution of patients by age, side and gender

	Otosclerosis, n (%)	Control, n (%)	P value
Age	32.51(± 6.83)	34.76 (± 13.79)	0.374
Side			
Left	18(52.94)	26 (50.0)	0.929
Righ	16(47.05)	26 (50.0)	
Gender			
Male	10 (47.61)	12 (46.15)	0.846
Female	11 (52.38)	14 (53.84)	

Table 3 The mean CBCT bone density for each ROI (HU, mean ± SD)

ROI	Otosclerosis(n = 34)	Control(n = 52)	P value
1	531.29 ± 129.01	518.79 ± 203.42	0.359
2	310.26 ± 118.84	619.40 ± 144.60	< 0.001
3	937.00 ± 206 ± 04	1137.31 ± 219.16	< 0.001
4	1066.34 ± 199.68	1186.68 ± 196.05	0.004
5	1077.09 ± 170.97	1234.06 ± 162.88	< 0.001
6	1155.17 ± 206.97	1237.85 ± 13,283	0.031

ROI indicates the region of interest; *HU* Hounsfield unit; *SD* standard deviation

value in CT and CBCT and showed a high correlation between VV of CBCT and CT number in MSCT. On the other hand, many studies have shown that the obtained density values from CBCT are not absolute, but interestingly reported a positive high linear correlation between CBCT bone density and HU in MSCT [17, 19–21].

The results of present investigation show that the mean CBCT bone densities in ROI 2 to 6 for otosclerosis patients were significantly lower than the control group.

For the first time in 2012, Redfors et al. [9] used a visual grading system to detect fenestral and retrofenestral lesions of otosclerosis in multi-slice CT (MSCT) and CBCT images, which reported the preoperative CBCT to have a sensitivity of up to 85% with a slice thickness of 0.5 to 0.6 mm in patients with clinical otosclerosis. Their study

indicates that in many ways, CBCT is equivalent to MSCT for detecting hypodense foci in the temporal bone imaging. But they did not quantitatively evaluate in their study.

Therefore, in the present study, we used CBCT to evaluate bone density of some temporal bone anatomic points for diagnosing otosclerosis.

In another study, Haghanifar et al. [19] analyzed the relationship between gray density and VV of two CBCT imaging systems and CT. According to their results, there was a high correlation and linear relationship between the different studied imaging systems. Therefore, we can compare the results of the present study with previous studies that had used CT in their research.

Fig. 3 Compasion of the mean CBCT bone density numbers in each ROI between the otosclerosis group and the control group
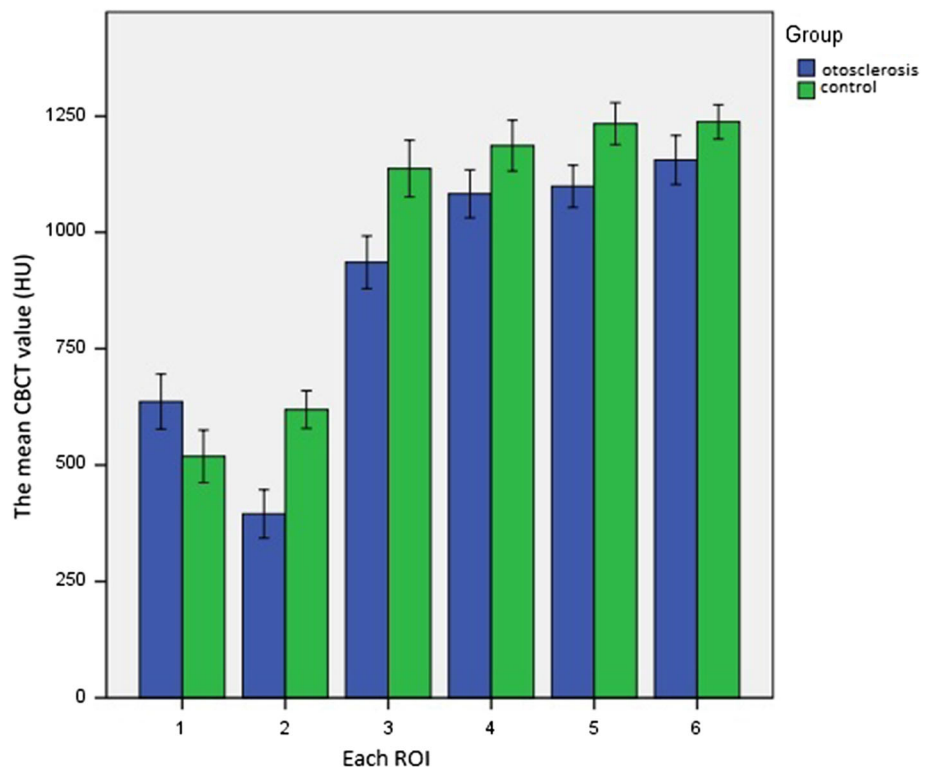
Fig. 4 The linear relationship between CBCT bone density of ROI 1 and the mean air–bone gap (dB HL) in bilateral otosclerosis, (Spearman correlation, n = 22, r = -0.636, p = 0.001)

R^2 Linear = 0.445

$y = 8.86E2 - 8.68 * x$
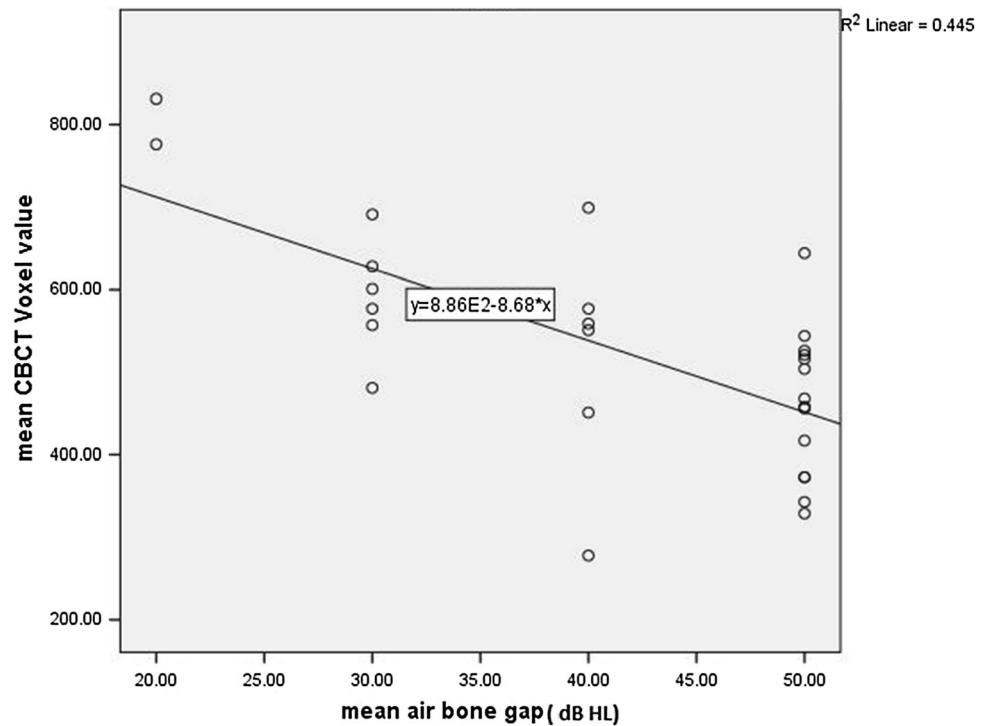
Fig. 5 The linear relationship between CBCT bone density of ROI 6 and the mean air–bone gap (dB HL) in unilateral otosclerosis, (Spearman correlation, n = 7, r = -0.802, p = 0.030)

R^2 Linear = 0.434

$y = 1.76E3 - 15.02 * x$
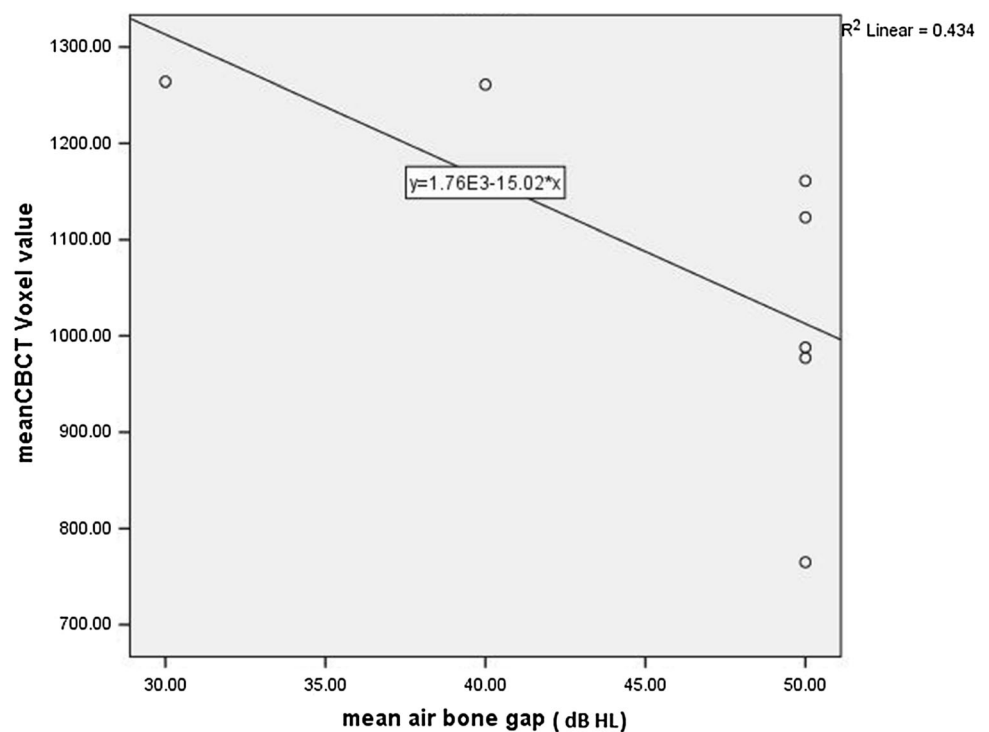
In a histological study by Schuknecht et al. [22] the foci of otosclerosis were mainly situated in the FAF, as shown in this study.

Grayeli et al. [5] reported the CT number only in the FAF (corresponding to ROI 2 in our study) and posterior semicircular canal (close to ROI 2) to be lesser in the otosclerosis group than the control group. While in the present study, the mean CBCT bone densities in other ROIs (2–6) in otosclerosis group were significantly lower than the control group. Also, Tringali et al. [23] stated that the mean CT value in the area anterior to the oval window (FAF) and the area anterior to the internal auditory canal

were significantly lower in the otosclerosis group than control group.

Mean CBCT bone density of the posterior to the oval window (ROI 1) was higher than the controls in this study; however, this difference was not significant. This finding was in contrast to the results of Zhu et al. [8] which reported significantly lower mean CT values in ROI 1 in otosclerotic ears comparing to the control group. Variations in the results of these studies can be contributed to the extent of sclerotic foci, different ethnicity, and difference in imaging method (less possibility).

Studies of Naumann et al. [24] found that the size of the ABG was determined by the extent and degree of pathological effects of otosclerosis at the posterior stapediovestibular joint area (corresponding to ROI 1). Kiyomizu et al. [25] stated that greater ABG associated with greater extent of sclerotic lesions might be due to progressive sclerotic lesions at the oval window. On the other hand, Min et al. [6] and Schuknecht et al. [22] did not find a significant relationship between the size of otosclerosis lesions in CT grading of sclerotic lesions and thresholds of bone conduction and ABG. In the present study, a significant negative correlation was observed between ABG and CBCT bone density for the ROIs 1 and 6 in bilateral and unilateral otosclerosis, respectively. This means that the more reduction in CBCT bone density, the more severe was the hearing loss.

Due to limited number of studies on CBCT imaging for diagnosing otosclerosis, further studies on CBCT evaluation of otosclerosis with more patients is recommended. future study using CBCT in diagnosing cochlear otosclerosis in cases with familial SNHL or MHL also is recommended.

Conclusion

Bone density measurements of temporal bone using CBCT with a slice thickness less than 0.5 mm indicated a significant lower value in otosclerosis lesions in comparison with the controls. Therefore, CBCT bone densitometry potentially appears to be a valuable and effective method for quantitatively determining the existence of otosclerosis in temporal bone.

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