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OTOLOGY

Are computed tomography and densitometric measurements useful in otosclerosis with mixed hearing loss? A retrospective clinical study

Gokhan Kutlar · Mehmet Koyuncu · Muzaffer Elmali · Figen Basar · Sinan Atmaca

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Abstract The objective of the study was to investigate the relationship between extent of otosclerotic foci and audiological findings in otosclerotic patients with mixed hearing loss using high-resolution computed tomography (HRCT) and also to measure the density of bony labyrinth in otosclerotic patients and compared with control group. This was a retrospective study. Twenty-five patients with clinical otosclerosis and mixed hearing loss were included in the study. The average threshold of air-bone conductions (AC, BC) within the 0.5–4 kHz frequency range, and average air bone gap (ABG) were calculated. Eleven patients with normal HRCT who received cochlear implant were included in the study as the control group. The lesions in HRCT were staged according to their extension. Eight different points of the otic capsule in each patient were measured using HRCT. Fifty ears total, from 25 patients, had bilateral otosclerosis. The mean AC of all the ears was 63 dB, mean BC was 35.2 dB, and mean ABG was 27.8 dB. HRCT staging indicated 22 ears had Grade 1, 21 ears had Grade 2, and 7 ears had Grade 3 lesions. There was a statistically significant difference between the mean AC, BC of ears with Grade 1 and Grade 2 when compared with the mean AC, BC of ears with Grade 3. When comparing the densitometric measurements of fissula ante fenestram localizations, a statistically significant difference was observed. HRCT examination and densitometric measurements in otosclerotic patients with mixed hearing loss presented significant results. We were unable to show a significant relationship between early stage and hearing thresholds, but there was a significant relationship in advanced stage. Densitometric measurements may provide significant results for otosclerosis, particularly for the FAF region when comparing with control group.

Keywords Otosclerosis · Hearing loss · Computed tomography · Densitometry

G. Kutlar (✉) · M. Koyuncu · F. Basar · S. Atmaca
Department of Otolaryngology, School of Medicine, Ondokuz Mayis University, Samsun, Turkey
e-mail: drkutlar@gmail.com

M. Elmali
Department of Radiology, School of Medicine, Ondokuz Mayis University, Samsun, Turkey

Introduction

Otosclerosis is a bony dyscrasia of the inner ear otic capsule presented only in humans [1]. It is most common in the fissula ante fenestram (FAF) just anterior to the oval window. If the disease extends into the annular ligamentum of the oval window, it results in stapes fixation and conductive hearing loss. If the disease extends into the endosteal layer of the cochlea, sensorineural hearing loss will be included in the symptoms. The disease may also manifest as cochlear otosclerosis by developing as sensorineural hearing loss alone [2].

High-resolution computed tomography (HRCT) has a significant role in imaging the labyrinthine and bony capsule of the temporal bone. The extent of otosclerosis into the cochlear capsule can be quantitatively evaluated using densitometric measurements [3].

Our purpose for this study was to investigate the extent of the otosclerotic foci in the temporal bone using HRTC and compare this measurement with audiological findings in adult patients with mixed hearing loss to determine a possible relationship. And also, we aim to determine the usefulness of CT densitometry in this patients by comparing to control group.

Materials and methods

The patients arriving at the Ear Nose Throat clinics between January 2007 and January 2012 with complaints of hearing loss were included in the retrospective study. A total of 25 patients with clinical otosclerosis who had a normal tympanic membrane, mixed hearing loss as determined by audiogram, progressive hearing loss as shown in the medical history, and previous stapes surgery and/or cochlear implant were included in the study.

Eleven adult patients with severe sensorineural hearing loss who had cochlear implantation surgery in our clinic and showed a completely normal middle ear and inner ear HRCT prior to the implantation were included in the study as a control group.

Audiological evaluation

Immitansmetric and audiometric findings from both ears of study group patients were obtained from clinical files. Preoperative audiological tests were also obtained for patients who had undergone stapedectomy or cochlear implantation. Patients with Type As or Type A tympanogram as shown by immitansmetric examination were included in the study, but those with Type B or Type C tympanogram were excluded from the study. When determining pure tone audiometry, each patient's average threshold for air conductions (AC) within the 0.5–4 kHz frequency range, mean bone conduction (BC), and mean air bone gap (ABG) were calculated.

Radiological evaluation

A neuroradiologist examined the 0.5 mm thin-slice axial HRCT scans of the 36 patients included in this study. Neuroradiologist was blinded to the results of the audiogram when evaluating the HRCT. The lesions shown on HRCT were evaluated by their appearance (hypodensity, thickening in the footplate of stapes, sclerosis, etc.), localization, and additional pathologies. Rotteveel et al.'s [4] grading system was used by modifying and the staging was separated on three grades based on the extent of the lesions. The staging is presented in Table 1.

Table 1 Lesion staging on CT

Grade 1	Lesion is fenestral only
Grade 2	Focal involvement (basal, medium or apical cochlear turns)
Grade 3	Diffuse involvement

Densitometric measurements were taken using HRCT at eight different points of the otic capsule in both ears for each patient and displayed as mean Hounsfield unit (HU). The eight points were located on the round window niche, posterior wall of the basal cochlear turn, FAF area, lateral wall of cochlear apex in mid-modiolar section, cochlear anterior wall in mid-modiolar section, lateral semicircular canal (LSCC) cruralis, and anterior and posterior walls of the internal acoustic canal (IAC). Densitometric measurements were performed using the Osirix® program.

Statistics

The relationship between HRCT staging of the otosclerotic foci and the mean AC and BC of patients with otosclerosis, and the relationship between densitometric measurements of patients with otosclerosis and the control group were performed using the SPSS 15.0 program. A p value of < 0.05 was considered to be statistically significant.

Results

The 25 patients with otosclerosis in this study included 7 males (28 %) and 18 females (72 %). The youngest was 31 years old and the oldest was 68 years old. The average age was 46.4 years. The control group included 4 males (36.4 %) and 7 females (63.6 %). The youngest was 33 years old and the oldest was 55 years old. The average age was 44.8 years. There was no statistically significant difference between the otosclerotic group and the control group in terms of age and gender ($p > 0.05$). Of the 25 patients in the study group with bilateral otosclerosis (50 ears), 11 had a positive family history (44 %).

The ears of all patients with otosclerosis had Type A or As tympanograms. The AC, BC, and ABG values of the patients, as determined using pure tone audiometry, are presented in Table 2. Appearances of otosclerotic foci on HRCT are shown in Fig. 1.

Table 2 Pure tone audiometry of patients with otosclerosis

	AC (dB)			BC (dB)			ABG (dB)		
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD
Right	45	103	68.9 ± 17.6	17.5	63.75	37.3 ± 13.4	15	46.25	31.6 ± 8.9
Left	40	102.5	64.2 ± 15.7	13.75	63.25	33.1 ± 12.2	6.25	38.75	23.9 ± 9.7

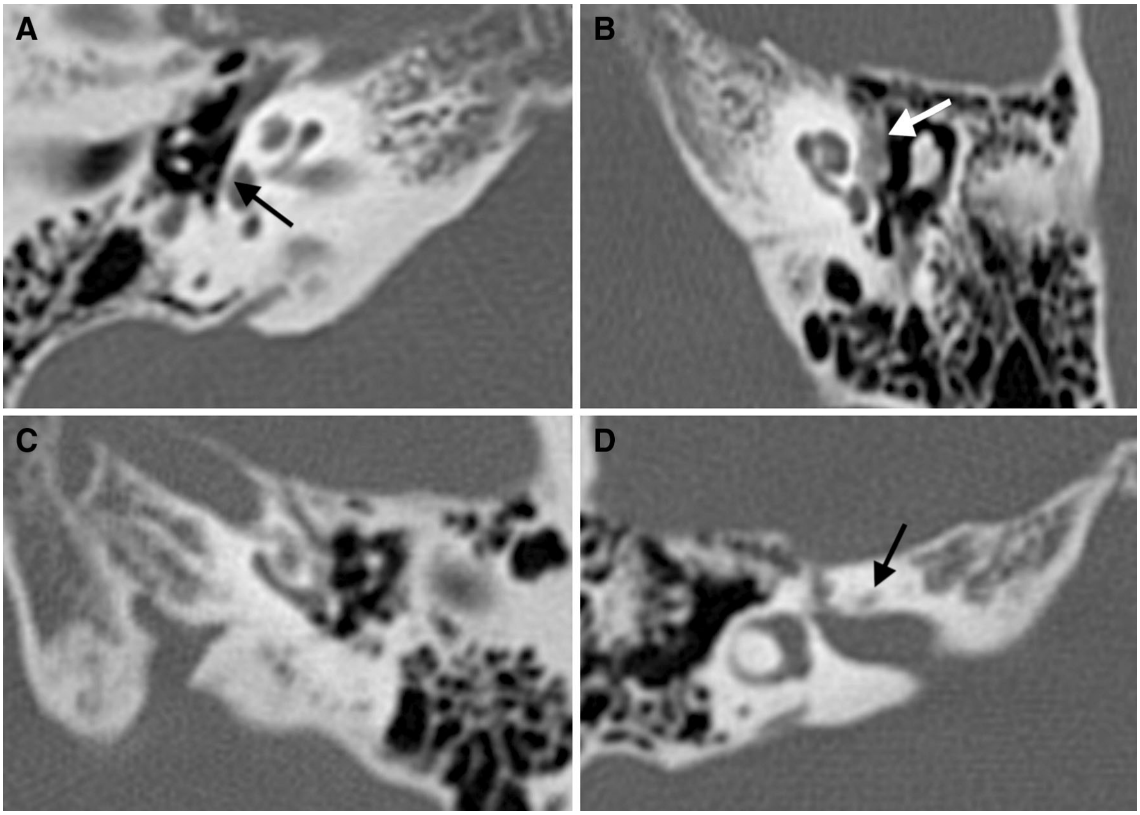

Fig. 1 Axial CT images of temporal bone and otosclerotic foci. **a** Otosclerotic foci caused sclerosis and thickening of the oval window (Grade 1). **b** Hypodense otosclerotic foci in FAF and lesion expanding to the cochlear anterior wall (Grade 2). **c** Otosclerotic foci with diffuse cochlear involvement (Grade 3). **d** A hypodense lesion on anterior wall of IAC

Table 3 The number of ears and the mean air conduction by lesion grade

	No. of ears	Mean AC (dB)	Mean BC (dB)
Grade 1	22	61.4	33.3
Grade 2	21	68.2	35.8
Grade 3	7	86.0	50.0

The distribution of ears with otosclerosis as determined using the staging system is shown in Table 3, and the comparison of mean AC and BCs by lesion grade as presented in Fig. 2 was used for evaluating the lesions in BT. There was no statistically significant difference when the mean AC, BC values of Grade 1 and Grade 2 ears ($p > 0.05$) were compared, while there was a statistically significant difference when comparing the mean AC, BCs of Grade 3 ears with Grade 1 and Grade 2 ears ($p < 0.05$).

Table 4 shows the mean HU values of patients with otosclerosis and the control group as determined by densitometric measurements obtained at eight different points. When comparing the densitometric measurements of patients with otosclerosis with those of the control group, there was a statistically significant difference in FAF localization ($p < 0.05$). However, there was no statistically significant difference at the seven other points of the otic capsule ($p > 0.05$).

Discussion

Although the diagnosis of otosclerosis is generally based on clinical history, physical examination, and audiological findings, it is more difficult to diagnose advanced otosclerosis or cochlear otosclerosis. Otosclerosis manifests mostly as conductive hearing loss when the otosclerotic foci extend into the footplate of the stapes and involve the annular ligamentum in the fissula ante fenestram just anterior to the oval window. The disease sometimes involves only the cochlear endosteum and can manifest with sensorineural hearing loss. This condition is called cochlear otosclerosis and accounts for 1 % of patients with otosclerosis [5]. The otosclerotic foci are known to worsen sensorineural hearing loss by inducing biochemical changes that include the release of enzymes such as trypsin, α-1, antitrypsin, and collagenase. In this theory, the proteolytic enzymes are released into the cochlear fluid by the active otosclerotic foci and damage the inner ear [6].

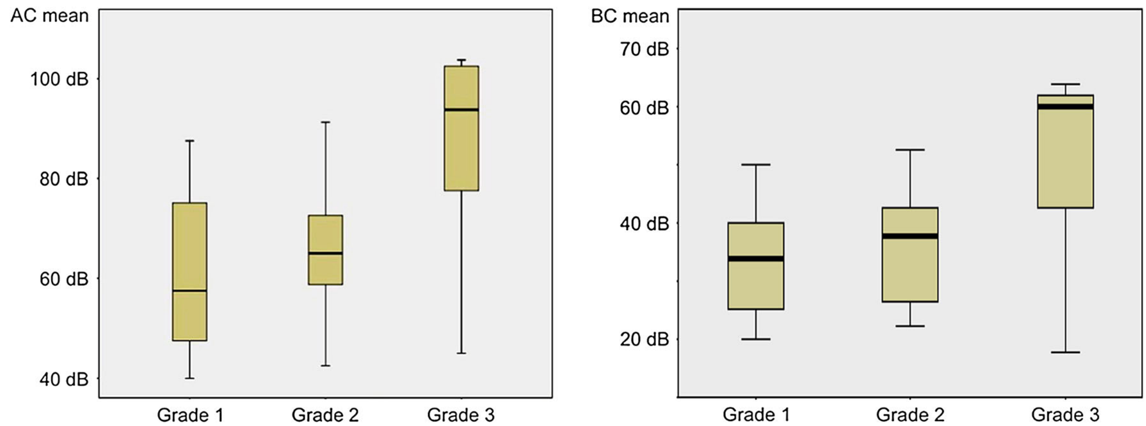

Fig. 2 The relationship between the grade of the lesions and the mean AC, BC. While there was no statistically significant difference between the mean AC, BC of Grade 1 and Grade 2 ears, there was a statistically significant difference between mean AC, BC when comparing Grade 3 ears with Grade 1 and Grade 2 ears

Table 4 Densitometric measurements and mean HU values

	Right ear			Left ear		
	Otosclerosis (mean HU)	Control (mean HU)	*p* value	Otosclerosis (mean HU)	Control (mean HU)	*p* value
FAF	1,131	2,091	<0.05	1,210	1,983	<0.05
Cochlear apex	1,848	1,822	>0.05	1,913	1,861	>0.05
Cochlear anterior	1,968	2,082	>0.05	1,941	2,087	>0.05
Anterior IAC	1,986	1,982	>0.05	1,957	1,941	>0.05
Posterior IAC	1,925	1,938	>0.05	1,931	1,944	>0.05
LSCC	1,901	1,893	>0.05	1,929	1,856	>0.05
Posterior CBT	2,046	2,118	>0.05	2,063	2,054	>0.05
RWN	1,827	1,534	>0.05	1,896	1,648	>0.05

IAC Internal Acoustic Canal, *LSCC* Lateral Semicircular Canal, *CBT* Cochlear Basal Turn, *RWN* Round Window Niche

The identification of otosclerotic foci using 0.5 mm thin-slice HRCT in this study contributes greatly to diagnosis. Furthermore, we were able to perform a detailed anatomical examination of the temporal bone with HRCT. The footplate of the stapes, the round window membrane, and the oval window could be identified. HRCT provided an advantage to showing any otosclerosis involvement of the otic capsule, such as the internal periphery of the auditory canal or the cochlear apex.

Lagleyre et al. [5] found preoperative computed tomography (CT) to be 95.1 % sensitive for identifying otosclerotic lesion. Lee et al. [7] showed 84 % of otosclerotic foci on CT were positive for clinical otosclerosis. In 1993, although Valvassori stated that an otosclerotic lesion had to be greater than 1 mm to be visible on a CT, new CT developments have allowed for the visualization of smaller lesions [3].

Many authors used different CT staging systems in their otosclerosis studies. Valvassori classified otosclerosis as fenestral or cochlear otosclerosis depending on the location and the extent of the disease [3]. Shin et al. [8] classified it as fenestral and pericochlear, and subdivided pericochlear as extending or non-extending into the cochlear endosteum. Kiyomizu et al. [9] graded fenestral disease as group A, FAF as group B1, demineralization extending toward the cochleariform process from the anterior region of the oval window as group B2, extensive demineralization surrounding the cochlea as group B3, and thick anterior and posterior calcified plaques as group C. However, none of the grading systems have been widely approved and consistently applied. We included only patients with mixed hearing loss in our study. Therefore, we aimed to evaluate concomitant sensorineural hearing loss. We also used Rotteveel et al.'s [4] grading system by modifying that was based on the extent of the lesion. Hence, we propose to present a relationship between the extent of otosclerosis and hearing loss.

Although previous studies showed that there was no significant difference between the extent, location, and cellular activity of an otosclerotic lesion and the grade of sensorineural hearing loss, there are some studies that reported a relationship between those factors. Because of this, the enzymes released from otosclerotic foci have been considered to have a role in pathophysiology of sensorineural hearing loss [5, 6, 8, 10, 11]. We found 22 ears with Grade 1, 21 ears with Grade 2, and 7 ears with Grade 3 lesions. There was no statistical difference between the mean AC, BC of the lesions in Grade 1 (fenestral) and Grade 2 (in cochlear foci). However, the mean AC, BC of diffuse disease in Grade 3 were significantly worse ($p < 0.05$). This suggests that the sensorineural component was less affected at the early stages of otosclerosis or circumscribed lesions, but sensorineural hearing loss increases during the late stages of the disease.

The quantitative evaluation of otosclerotic lesion is made possible by CT densitometry. Densitometry can also provide information about the otospongiotic or sclerotic stage of the otosclerotic foci. Kawase et al. evaluated 24 ears with otosclerosis in 17 patients using 0.5 mm thin-slice CT and compared the density of the otic capsule at eight different points with data from 19 normal ears. They found a statistical difference in HU values of FAF localization and anterior wall compared with normal ears [12]. Grayeli et al. used a 0.5 mm thin-slice CT to measure the density of the otic capsule at seven different points in 10 patients with otosclerosis and prospectively compare with patients presenting vestibular schwannoma. They found the densities of the FAF alone and the posterior semicircular canal to be statistically different [13]. In our study performed on otosclerotic ears, the density measurements of FAF area alone were found to be statistically lower than that of the control group. No statistical difference was observed between the mean density measurements of the other seven areas and those of the control group. Kawase et al. and Grayeli et al. [12, 13] also found the density measurements of the FAF area to be lower, as in our study. The FAF is the most common location of otosclerosis and lower density in this region often appears in otosclerosis. However, our results should be supported with additional densitometric studies using a larger number of otosclerosis patients.

Conclusion

We attempted to show the relationship between lesion extension on a CT and the degree of hearing loss in patients with mixed hearing loss. We were unable to show a significant relationship between early stage (fenestral, focal) and hearing thresholds, but there was a significant relationship in advanced (diffuse) stage. Densitometric measurements may provide significant results for otosclerosis, particularly for the FAF region when comparing with control group.

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Conflict of interest No conflicts of interest are present.

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