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Stability of computed tomography densitometry in patients with otosclerosis:a two-year follow-up

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ABSTRACT

Objectives: To quantify the progression of otosclerosis in the unoperated ear between two stapedotomy procedures for patients with bilateral otosclerosis which can help to determine whether a HRCT scan should be re-performed before the second surgery for patients who already received HRCT imaging before the initial surgery.

Methods: 35 patients who underwent bilateral stapedotomy were included. Two rounds of HRCT examination and audiometry were performed at the time of the first surgery and second surgery on the ear that was not operated on during the initial surgery. The relationship between the changes in HRCT densitometry and audiometry over time was analyzed.

Results: The second round of HRCT did not add significant information about the changes to the otosclerosis lesions in either the imaging diagnosis or the HRCT density values except for small changes in the HRCT densitometry readings at the area anterior to the inner auditory ($P = 0.01$). While the changes in HRCT manifestation are small, changes near the fissula ante fenestram (FAF) were still positively correlated with the air bone gap (ABG) of patients ($p = 0.031$, $r = 0.388$).

Conclusions: The progression of lesions in otosclerosis is slow resulting in small and insignificant changes to the HRCT features. Therefore, a repeat HRCT evaluations prior to surgery is not necessary for patients who have had a previous HRCT evaluation within 2 years of the operation. The small changes in HRCT manifestation near the FAF were still correlated with negative effects on the ABG which could cause worsened hearing thresholds over this timeframe.

1. Introduction

Otosclerosis is a bony dyscrasia of the otic capsule and stapes footplate that is only known to affect humans (Rudic et al., 2015; CHOLE and MCKENNA, 2001). Otosclerosis causes conductive hearing loss due to a fixation of the stapes (CHOLE and MCKENNA, 2001) and accounts for up to 85% of the conductive hearing loss in the Caucasian population (Stewart, 2001). Stapedectomy and stapedotomy are the only treatments that have proven effective in reversing the symptoms of otosclerosis (Moscillo et al., 2006). These surgeries are often required in both ears since bilateral otosclerosis accounts for up to 87.5% of otosclerosis patients (Xie et al., 2019). Stapes surgeries on bilateral otosclerosis patients have been found to cause fewer complications if performed in two different surgeries, but no standardized time interval has been established. This is especially important given the prevalence of complications like dead ear that occur in 0.2%–2.9% of patients after a primary stapes surgery (Psillas et al., 2011).

High-resolution computed tomography (HRCT) scans of the

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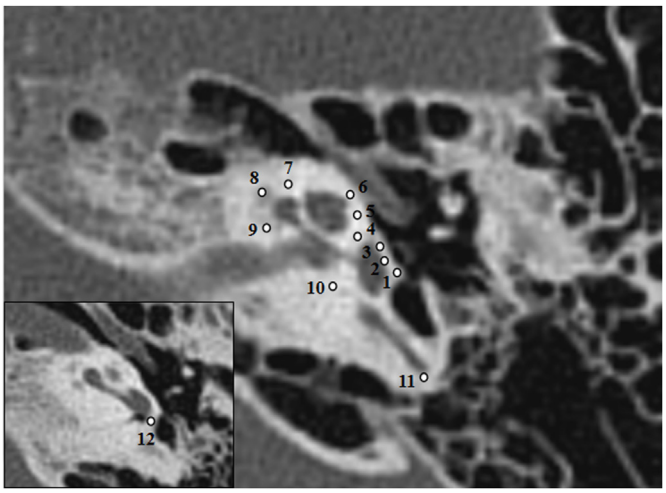

Fig. 1. Example of the ROI setting. In the low axial section, 11 ROIs are manually placed. ROI 12 was located on the layer in which the niche of the round window was best shown. Mean CT values in each ROI could be measured automatically using the tool in the CT working station after selecting a 1mm2 ROI area.

temporal bone help to understand the complex anatomy of the temporal bone and it is important in diagnosing otosclerosis with a sensitivity as high as 95% (Virk et al., 2013). HRCT is usually necessary for preoperative evaluation before a stapes operation to ensure the surgeon is aware of any abnormalities which could interfere with the operation. HRCT imaging does not come without its drawbacks which include the cost and radiation exposure which can be especially detrimental for patients undergoing repeated examinations as is seen in patients with bilateral otosclerosis (Agostini et al., 2020). As such, it would be beneficial to determine whether a patient with bilateral otosclerosis requires a repeated CT scan before the second stapes surgery or if the evaluation from the initial surgery is still representative.

Along with aiding in surgeries, previous studies have assessed the relationship between the HRCT images or HRCT density and the auditory outcomes in patients with otosclerosis using cross-sectional studies (Zhu et al., 2010; Kutlar et al., 2014; Wycherly et al., 2010; Kiyomizu et al., 2004; Min et al., 2009; Marx et al., 2011). There was no unanimous conclusion reached by these studies which could be because of differences between the patient groups used. One possible way to remove this variability is by taking data on the same group of patients at different intervals of time. By removing the variability of patients this method could provide more accurate results and significantly correlate CT density to auditory outcomes.

The aims of this paper are as follows: 1) To determine the difference in HRCT readings between two rounds of HRCT scans with a minimum interval of 1 year ears for patients with otosclerosis, and 2) to investigate the relationship between the changes of HRCT densitometry in these ears and the changes in their hearing thresholds.

2. Materials and methods

2.1. Patient enrollment

Inclusion criteria: patients with bilateral otosclerosis who underwent stapedotomy operations on both ears in stages; patients with CT scan performed before each operation separately; completed information including a pure-tone hearing test performed before each operation; a minimum interval of 1 year between the two rounds of HRCT.

Exclusion criteria: patients who received revision stapes surgeries, Children, or dissatisfactory HRCT imaging data which resulted from radiographic artifacts.

From January 2014 to July 2020, 35 patients were included and retrospectively analyzed in this study. The ear that was unaffected by the initial surgery was used for completed data because that ear underwent HRCT imaging before both stapes surgeries. The average interval time between HRCT scans was 23.2 months (SD:16.2, range 12–72 months). There were 25 women and 10 men: 19 left and 16 right ears with a mean age of 37.2 years. All patients were diagnosed with clinical otosclerosis which was supported by the history of the patients, the surgical finding, and the audiological examinations.

2.2. Surgical procedure

Procedures were performed by one senior surgeon under general anesthesia. Each surgery was performed using the transcanal approach and replaced the stapes with a titanium piston prosthesis. This standardized approach was performed as described in previous publications (Fang et al., 2021).

Table 1
Position of ROIs.

Numbered ROI	Abbreviation of each ROI	Position	Numbered ROI	Abbreviation of each ROI	Position
1	P-OW	Posterior to the oval window (posterior to the intersection of stapes posterior arch and stapes footplate)	7	A-M-Co	Anteromedial to the middle turn of the cochlea
2	M-SF	The mid-point of stapes footplate	8	A-B-Co	Anteromedial to the basal turn of the cochlea
3	A-OW	Anterior to the oval window (anterior to the intersection of stapes anterior arch and stapes footplate)	9	A-IAC	Anterior to the inner auditory canal
4	L-MB-Co	Lateral to the middle of the basal turn and middle turn of the cochlea	10	PPR	Petrouspyramid
5	L-AM-Co	Lateral to the part between apex of the cochlea and the middle turn of the cochlea	11	P-P-SC	Posterolateral to the posterior semicircular canal
6	Ap-Co	Apex of the cochlea	12	NRW	Niche of the round window

ROI: region of interest.
1. P-OW, indicating posterior to the oval window; 2. M-SF, indicating the mid-point of stapes footplate; 3.A-OW, indicating anterior to the oval window; 4.L-MB-Co, indicating lateral to the middle of the basal turn and middle turn of the cochlea; 5. L-AM-Co, indicating lateral to the part between apex of the cochlea and the middle turn of the cochlea; 6. Ap-Co, indicating apex of the cochlea; 7. A-M-Co, indicating anteromedial to the middle turn of the cochlea; 8. A-B-Co, indicating anteromedial to the basal turn of the cochlea; 9. A-IAC, indicating anterior to the inner auditory canal; 10. PPR, indicating petrouspyramid; 11. P-P-SC, indicating posterolateral to the posterior semicircular canal; 12.NRW, indicating niche of the round window.

Table 2
Changes in bone density at the for each ROI (HU) (n = 35).

Numbered ROI	1	2	3	4	5	6	7	8	9	10	11	12
Abbreviation of each ROI	P-OW	M-SF	A-OW	L-MB-Co	L-AM-Co	Ap-Co	A-M-Co	A-B-Co	A-IAC	PPR	P-P-SC	NRW
Initial measurement	1275.4 ± 393.9	781.4 ± 306.2	1055.3 ± 386.0	1808.5 ± 286.6	1838.6 ± 278.7	1851.7 ± 209.5	1932.6 ± 167.8	1872.3 ± 144.3	1849.0 ± 134.2	1602.8.2 ± 126.6	1597.4 ± 123.8	1792.1 ± 123.6
Final measurement	1343.7 ± 363.6	851.6 ± 334.4	987.3 ± 290.0	1821.2 ± 251.0	1864.4 ± 252.0	1801.5 ± 169.9	1885.8 ± 177.7	1829.6 ± 124.1	1764.1 ± 132.9	1582.91 ± 121.9	1569.3 ± 158.1	1765.7 ± 131.3
Changes in bone density	68.3 ± 417.2	68.1 ± 397.9	13.4 ± 309.1	25.7 ± 216.0	−50.2 ± 223.2	−46.8 ± 217.2	−27.8 ± 207.9	−42.7 ± 188.8	−84.9 ± 184.3	−20.6 ± 144.5	−27.6 ± 179.3	−26.4 ± 142.7
P	0.34	0.35	0.19	0.79	0.49	0.19	0.21	0.43	0.01	0.41	0.38	0.27

1. P-OW, indicating posterior to the oval window; 2. M-SF, indicating the mid-point of stapes footplate; 3.A-OW, indicating anterior to the oval window; 4.L-MB-Co, indicating lateral to the middle of the basal turn and middle turn of the cochlea; 5. L-AM-Co, indicating lateral to the part between apex of the cochlea and the middle turn of the cochlea; 6. Ap-Co, indicating apex of the cochlea; 7. A-M-Co, indicating anteromedial to the middle turn of the cochlea; 8. A-B-Co, indicating anteromedial to the basal turn of the cochlea; 9. A-IAC, indicating anterior to the inner auditory canal; 10. PPR, indicating petrouspyramid; 11. P-P-SC, indicating posterolateral to the posterior semicircular canal; 12.NRW, indicating niche of the round window.

2.3. HRCT evaluation

Two rounds of pre-operative HRCT and pre-operative audiometry were collected. HRCT (Siemens Sensation 10, Munich, Germany) was performed using an HR program with the following parameters: 140 kV, 100 mAS, 512 × 512 matrix, and a section 0.6 mm thick at intervals of 0.5 mm. The field of view was 22 cm. The area of each ROI was 1 mm^2 and the mean HRCT value at each ROI was measured automatically in the CT workstation. The window width was 4000 Hounsfield units (HU) and the window level was 700 HU. Multiplanar reconstruction (MPR) was used if necessary. In the workstation, the stapes, vestibule, cochlea, and internal auditory canal were depicted in the low axial section which was defined as the standard layer. 12 circular regions of interest (ROIs) were manually set around the otic capsule in the standard layer (Fig. 1, Table 1).

The numbered ROIs are as follows: 1. P-OW, indicating posterior to the oval window; 2. M-SF, indicating the mid-point of stapes footplate; 3. A-OW, indicating anterior to the oval window; 4. L-MB-Co, indicating lateral to the middle of the basal turn and middle turn of the cochlea; 5. L-AM-Co, indicating lateral to the part between the apex of the cochlea and the middle turn of the cochlea; 6. Ap-Co, indicating apex of the cochlea; 7. A-M-Co, indicating anteromedial to the middle turn of the cochlea; 8. A-B-Co, indicating anteromedial to the basal turn of the cochlea; 9. A-IAC, indicating anterior to the inner auditory canal; 10. PPR, indicating petrous pyramid; 11. P-P-SC, indicating posterolateral to the posterior semicircular canal; 12. NRW, indicating niche of the round window.

The standard layer was defined as the coronal layer with the superstructure of the stapes being clearly shown except for ROI 12(NRW) which was analyzed using a separate coronal layer that had a niche where the round window clearly shown. An experienced radiologist measured all ROIs. Measurements for ROI 1(P-OW) and ROI 3 (A-OW) were done in the bony areas posterior and anterior to the intersections of the stapes arch and stapes footplate to decrease the possibility of the partial volume effect. Each ROI was measured twice, and the mean value was used. A minimum of 20–30 min was needed to measure one set of HRCT data across all ROIs. Based on the final CT findings, the ears with otosclerosis were classified into one of three groups: Group A, i.e., the normal group, with no pathological CT findings; Group B, i.e., the FAF group, with low density near the FAF area; and Group C, i.e., the cochlea group with lesions involvement in the inner ear, including the cochlea vestibule and round window.

2.4. Auditory evaluation

Pure tone average (PTA) values for air conduction (AC), bone conduction (BC), and air-bone gap (ABG) were calculated as the average of the hearing thresholds in the 0.5–4 kHz range. ABG was calculated by using the appropriate AC and BC thresholds which were recorded at the same time. Threshold deterioration was calculated by finding the change in the measured hearing thresholds between the two tests. Similarly, changes in CT densitometry were measured by finding the difference between the two tests.

2.5. Statistical analysis

Paired t-tests were used to analyze the significance of the auditory and HRCT data of patients. Spearman analysis was used to determine the correlation between different parameters. Chi-squared tests were used to compare the success rates of subgroups. For these tests, Stata 10.0 software packages (StataCorp LP, College Station, TX, U.S.A.) were used with a statistical significance level of $\alpha = 0.05$.

Table 3
Changes of the hearing thresholds at two time points and the deteriorated threshold.

Mean (SD), dB	BC	AC	ABG
Initial time	28.6 (9.0)	50.9 (11.5)	22.3 (6.7)
Final time	32.3 (9.7)	58.5 (10.9)	26.2 (6.5)
Deterioration threshold, dB	3.7	7.6	3.9
P	0.0140	0.0002	0.0073

Table 4
Deterioration of the mean threshold at each frequency for AC, BC and ABG.

	Deterioration, dB	0.25 kHz	0.5 kHz	1 kHz	2 kHz	4 kHz
BC	Threshold	5.0	7.0	7.5	6.0	2.5
AC	Threshold	10.0	10.0	9.1	8.9	8.4
ABG	Threshold	5.5	3.3	1.7	3.6	6.1

3. Results

3.1. HRCT characteristics of patients with otosclerosis

The section with the superstructures of the stapes was usually the best layer for observing the density decrease near the FAF. There were only 2 cases where the standard layer of the stapes was not found which meant MPR technology was used. The diagnostic consistency between the two rounds of HRCT was 94.3% (n = 33). This is shown through the change in groupings between the initial HRCT which showed 4 (11.4%) cases of normal HRCT, 26 (74.3%) cases with only FAF affected and 5 (14.3%) cases with both the FAF and cochlea involved and the second round of HRCT which showed 4 (11.4%) cases of normal HRCT, 24 (68.6%) cases with only FAF affected and 7 (20.0%) cases with both the FAF and cochlea involved. Among the patients, only two had lesions that developed in another grouping which was not detected by the original HRCT measurement. These patients had lesions that only appeared at the FAF area on the initial HRCT scan and developed additional lesions around the cochlea which were shown on their second round of HRCT scans. In combination, the FAF area was the most affected area with 88.6% (n = 31) of the patients having some legions in the FAF area. Both the round window and semicircular canal were both involved in 1 case.

To find the consistency of the HRCT readings, an area around the inner ear with suspected low density is measured at two different time points. For each ROI, the outcomes of the two measurements were significantly correlated for all ROIs, with $p < 0.0001$ and $R > 0.9$ for ROI 1–11, and $p = 0.039$ and $r = 0.35$ for ROI 12 (NRW).

3.2. Change in the CT densitometry for different ROI areas

For ROI 1–5 except for ROI 3 (indicating P-OW, M-SF, L-MB-Co, and L-AM-Co, respectively), an increase in CT densitometry was observed whereas for ROI 6–12 (indicating Ap-Co, A-M-Co, A-B-Co, A-IAC, PPR, P-P-SC, and NRW, respectively) a decrease in CT densitometry was observed (Table 2). Only ROI 9 (A-IAC) showed a statistically significant difference between the two time points ($P = 0.01$). Both the CT densitometry of the stapes footplate (ROI 2, M-SF) and the FAF area (ROI 4, L-MB-Co) increased whereas those at the round window niche (ROI 12, NRW) decreased.

3.3. Changes of hearing threshold

The hearing threshold of patients deteriorated significantly by 7.6 dB ($p < 0.05$), 3.7 dB ($p < 0.05$) and 3.9 dB ($p < 0.01$) on average for AC, BC, and ABG respectively (Table 3). The thresholds deteriorate for each frequency is shown in Table 4. The maximal deterioration for BC was 7.5 dB at 1 kHz and for AC it was 10 dB at both 0.25 kHz and 0.5 kHz.

3.4. The relationship between changes in CT densitometry and auditory threshold

No statistically significant correlation was found between the changes of the AC and BC at the PTA level and the changes of the CT densitometry of all ROIs. However, the results showed a positive correlation ($P = 0.031$, $r = 0.388$) between the changes in the ABG-PTA and the changes of CT densitometry at ROI 4 (L-MB-Co), which represents the FAF area.

3.5. Results of sub-groups according to CT

Based on the CT findings, the ears with otosclerosis were classified into three groups (Methods Section). No significant difference was found between the epidemiological features and the deterioration of AB, BC, ABG among the three sub-groups. For the inner ear or cochlea group, there was a larger, statistically insignificant, deterioration of the previously stated auditory parameters than in the other groups. However, this group was older on average than the other groups which is a confounding variable for auditory degradation (Table 5) (Fig. 2 a, b, and c presented the initial and final hearing outcomes in the normal group, the FAF group, and the cochlea group, respectively.)

4. Discussion

The sensitivity of HRCT scans in the diagnosis of otosclerosis has increased substantially due to advances in HRCT technology. In this study, lesions from otosclerosis could be observed in 88.6% of patients which is close to the 87% detection rate in Vicente et al.'s study (Vicente Ade, 2006). The most common focal point for otosclerosis detection was near the FAF, with a high detection rate from 61.7% to 88.5%[11, 13, 17]. In this study, round window involvement was found in 2.9% of patients, which is around the

Table 5
Demographic and audiological deterioration of the three sub-groups according to CT.

		Group A: Normal group	Group B: FAF group	Group C: Cochlea group	p
Number of patients		4	24	7	–
Gender	Female	2	15	5	0.88
	Male	2	9	2	
Age		25.7 ± 6.0	28.1 ± 8.8	41.5 ± 11.1	0.42
Side	Left	2	13	4	1.00
	Right	2	11	3	
Deterioration of threshold, dB	BC	2.9 ± 1.9	5.0 ± 6.7	8.3 ± 4.6	0.22
	AC	2.9 ± 6.9	8.9 ± 10.9	12.9 ± 11.9	0.28
	ABG	0.0 ± 5.7	3.9 ± 7.5	4.6 ± 13.1	0.19

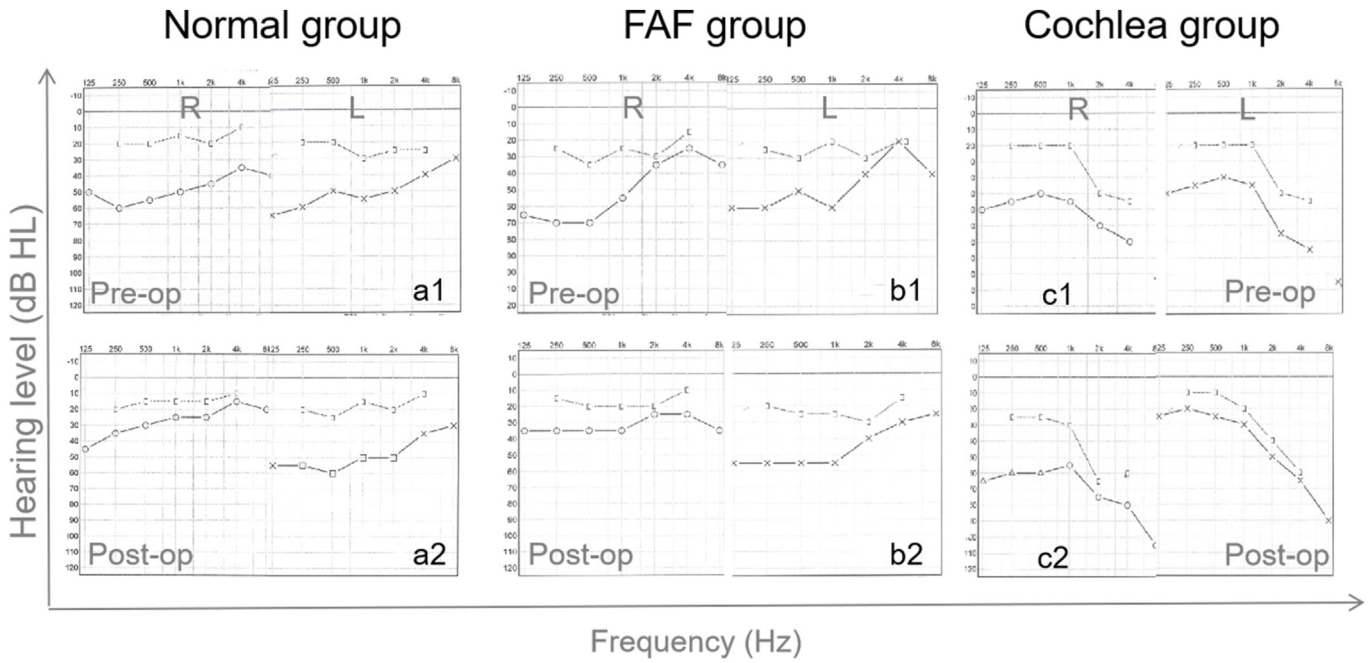

Fig. 2. Presents the initial and final hearing levels in the cases of the normal group, the FAF group, and the cochlea group, respectively. The pre- and postoperative pure tone audiograms of the ears that underwent the initial surgery for these same patients is also presented. In figure a1, a patient from the normal group had a decrease in the BC threshold of 7.5 dB while the AC threshold was unchanged over the 3 years between audiograms. In figure b1, a patient from the FAF group showed an increase of 2.5 dB in their AC threshold while their BC threshold remain the same over the same time period. Lastly, in Figure c1, a patient in the cochlea group had an increase of 3.75 dB in both AC and BC hearing thresholds over a slightly shorter period of 2 years.
L: left, R: right, pre-op: preoperative, post-op: postoperative.

detection rate of Lagleyre's study (Lagleyre et al., 2009). 20% of the inner ears were affected in this study which is similar to the 20.6% reported by Wycherly et al. (2010) and 17.7% from Lagleyre et al. (2009). Along with the improvements in technology, the reasons for the difference in detection rates between studies may be the use of different HRCT parameters, diagnostic experience, different lesion sizes within a small observation space, and different populations/ethnic groups. The false negative rate from this study was 11.4% (n = 4), which fit within the previous detection ranges from 7.2% up to 39% (Kiyomizu et al., 2004; Lagleyre et al., 2009). False-negative radiological findings may result from inactive otosclerosis foci having the same CT density readings as surrounding bony or hypodense lesions of otosclerosis with diameters < 1 mm.

HRCT is useful when determining the location/type of lesions since it can categorize them into categories including fenestral only (fenestral otosclerosis), additional focal involvement (including the cochlear, internal canal, round window or/and the vestibule), or even diffuse involvement (double-ring sign around the cochlea) (Lagleyre et al., 2009). Previously, postoperative hearing threshold have been positively correlated with the use of HRCT for the detection of abnormal features in patients with otosclerosis (Marx et al., 2011; Lagleyre et al., 2009) which indicates that HRCT has great value for the prognosis of surgery in patients with otosclerosis. Given the importance of preoperative HRCT evaluation for patient outcomes, it is important to understand the differences between the second and initial HRCT findings for patients with bilateral otosclerosis. For patients who are planning staged surgery on both ears, the preoperative CT scan before the second stapes operation is intended to ensure that there is no unexpected growth of legions in the time from the initial preoperative HRCT scan. From this study, with an average observation time of approximately 2 years, the diagnostic consistency between the two time points was as high as 94.3%. This indicates very slight changes to the legions in these patients. In the two cases where new low-density foci formed around the cochlea on their second HRCT, the foci were small and not obvious.

Among the patients, all but one section region of interest had changes in HRCT densitometry that were insignificant, and it was difficult to decern the changes based on the readings. In the area anterior to the inner auditory canal, the HRCT densitometry readings were significantly decreased in this study. This change was similar to previous studies including Kawase et al.'s study and indicates that surgeons should take extra care in this area if a second round of HRCT is not performed (Kawase et al., 2006). Over the two year observation time, there is little change in the HRCT images between the initial and second HRCT images which results in the second HRCT images not adding significant information about the lesions caused by otosclerosis. This lack of benefit is seen in both the imaging diagnosis as well as in the CT density values which suggest that a repeated CT evaluation within 2 years of the initial CT scan is not necessary. This conclusion has both economic and safety benefits for patients since they would be avoiding unnecessary CT imaging.

It is reported that the HRCT densitometry readings near the FAF are significantly lower in ears with otosclerosis than those without this condition. This is the result of new low-density bone growth in the area for patients with otosclerosis (Zhu et al., 2010; Kutlar et al., 2014; Tringali et al., 2007). It is well documented that this low-density bone growth occurs, however, there have been no studies that have explored the rate of growth since they were cross sectional in nature. This study found that with an average interval of 2 years the CT densitometry around the FAF area did not have large changes which indicate a slowly developing legion. While small, these changes in CT manifestation near the FAF were still correlated ABG of patients which indicate that small changes in the CT manifestation near the FAF could worsen the hearing threshold.

In this study, a positive correlation was found between the changes in the ABG-PTA and the changes in CT densitometry at the FAF area. This trend was also observed in Zhu et al.'s study where the mean CT values in the area posterior to the oval window, which was just adjacent to the FAF area, was positively correlated with the AC and ABG thresholds which confirms the close relationship between the FAF region and the change of hearing threshold (Zhu et al., 2010). One explanation for this could be that the changes in CT densitometry at the FAF area indicates changes in the function of the stapediovestibular joint which is associated with the middle ear transmission function.

In addition, there have been several studies that have tried to confirm the relationship between CT value and preoperative hearing thresholds using contemporaneous comparisons. One study was performed by Kutlar et al. and found that a significant relationship exists between hearing threshold (AC and BC) and HRCT manifestations in advanced stages of otosclerosis but not in early stages (Kutlar et al., 2014). Another performed by Lagleyre et al. reported that sensory neural hearing loss could occur if a disease invaded sensorineural structures of the inner ear (Lagleyre et al., 2009). This, however, was inconsistent with Min et al.'s results which were not able to see this correlation (Min et al., 2009). In our study, there was a deterioration of auditory parameters in all groups with a slightly larger deterioration of all auditory parameters in the sub-group who had legions in the cochlea, but this deterioration was not statistically significant. This difference is thought to be due to the larger mean age in this group which is a confounding variable for hearing loss. As such, more data must be collected on whether this reflects the clinical characteristics of cochlear otosclerosis.

The development of otosclerosis is a very slow process that may lead to a slow progression of hearing loss. In Marx et al.'s study, the AC and BC threshold increased with a mean aggravation of 4.4 dB and 6.6 dB respectively at a 3-year-followup in a natural course of otosclerosis. In Ishai et al.'s study based on a 10 year follow-up, when the expected age-related deafness was adjusted, the deterioration of BC threshold in patients with otosclerosis was 4.6 dB, 2.6 dB, 3.0 dB, and 2.7 dB for frequencies of 0.5, 1, 2 and 4 kHz, respectively (Ishai et al., 2016). The corresponding data in this study after a two 2 follow-up is 7.0 dB, 7.5 dB, 6.0 dB, and 2.5 dB, respectively. These differences could be accounted for by differences in the patients selected specifically regarding age and the specific audiometry tests that were conducted.

5. Conclusion

The progression of otosclerostic lesions is slow which results in there being little difference in the manifestation of these lesions on HRCT images taken within 2 years of each other. The diagnostic consistency between the two rounds of HRCT was as high as 94.3% with only two patients having any significant changes to the HRCT manifestations of the legions. In these two patients, the legion developments were small and not obvious. As such, a repeat HRCT evaluation before surgery is not necessary for patients who have had a previous HRCT evaluation within 2 years of the operation. The small changes in HRCT manifestation near the FAF were still correlated with negative effects on the ABG which could cause worsened hearing thresholds over this timeframe.

Statement of ethics

All subjects in this study have given their (or their parents or guardians) written informed consent. This research program was approved by Xingtao Zhou, who was the chairman of the Ethics Committee of EENT Hospital affiliated with Fudan University (No.2020035).

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Author contributions

Yanqing Fang designed, analyzed data and wrote the paper; Wei Chen measured all HRCT data; Liu-Jie Ren help analyze data; Sebastian Kiehn polished the paper; Bing Chen did surgery in this study and reviewed the paper; Yilai Shu reviewed and guided to write the paper. Yanqing Fang and Wei Chen contributed equally to this work. All authors discussed the results and implications and commented on the manuscript at all stages.

Declaration of competing interest

There is no conflict of interest.

References

Agostini, A., Borgheresi, A., Bruno, F., Natella, R., Floridi, C., Carotti, M., Giovagnoni, A., 2020. New advances in CT imaging of pancreas diseases: a narrative review. Gland Surg. 9 (6), 2283–2294.
Chole, R.A., Mckenna, M., 2001. Pathophysiology of otosclerosis. Otol. Neurotol. 22 (2), 249–257.
Fang, Y., Zhang, K., Ren, L., Lamb, J.J., Hong, R., Shu, Y., Chen, B., 2021. Changes of incudostapedial joint angle in stapedotomy: does it impact hearing outcomes? Eur. Arch. Oto-Rhino-Laryngol. 278 (3), 645–652.
Ishai, R., Halpin, C.F., Shin, J.J., McKenna, M.J., Quesnel, A.M., 2016. Long-term incidence and degree of sensorineural hearing loss in otosclerosis. Otol. Neurotol. 37 (10), 1489–1496.
Kawase, S., Naganawa, S., Sone, M., Ikeda, M., Ishigaki, T., 2006. Relationship between CT densitometry with a slice thickness of 0.5 mm and audiometry in otosclerosis. Eur. Radiol. 16 (6), 1367–1373.
Kiyomizu, K., Tono, T., Yang, D., Haruta, A., Kodama, T., Komune, S., 2004. Correlation of CT analysis and audiometry in Japanese otosclerosis. Auris Nasus Larynx 31 (2), 125–129.
Kutlar, G., Koyuncu, M., Elmali, M., Basar, F., Atmaca, S., 2014. Are computed tomography and densitometric measurements useful in otosclerosis with mixed hearing loss? A retrospective clinical study. Eur. Arch. Oto-Rhino-Laryngol. 271 (9), 2421–2425.
Lagleyre, S., Sorrentino, T., Calmels, M., Shin, Y., Escudé, B., Deguine, O., Fraysse, B., 2009. Reliability of high-resolution CT scan in diagnosis of otosclerosis. Otol. Neurotol. 30 (8), 1152–1159.
Marx, M., Lagleyre, S., Escudé, B., Demeslay, J., Elhadi, T., Deguine, O., Fraysse, B., 2011. Correlations between CT scan findings and hearing thresholds in otosclerosis. Acta Otolaryngol. 131 (4), 351–357.
Min, J., Chung, W., Lee, W.Y., Cho, Y.S., Hong, S.H., Kim, H.J., Lee, H., 2009. Otosclerosis: incidence of positive findings on temporal bone computed tomography (TBCT) and audiometric correlation in Korean patients. Auris Nasus Larynx 37 (1), 23–28.
Moscillo, L., Imperiali, M., Carra, P., Catapano, F., Motta, G., 2006. Bone conduction variation poststapedotomy. Am. J. Otolaryng. 27 (5), 330–333.
Psillas, G., Vital, I., Beretouli, E., Markou, K., Constantinidis, J., Vital, V., 2011. Dead ear following stapedotomy: case report and literature review. J. Int. Adv. Otol. 7 (3), 418.
Rudic, M., Keogh, I., Wagner, R., Wilkinson, E., Kiros, N., Ferrary, E., Sterkers, O., Bozorg Grayeli, A., Zarkovic, K., Zarkovic, N., 2015. The pathophysiology of

otosclerosis: review of current research. Hearing Res. 330, 51–56.
Stewart, M.G., 2001. Outcomes and patient-based hearing status in conductive hearing loss. Laryngoscope 111 (11 Pt 2 Suppl. 98), 1–21.
Tringali, S., Pouget, J., Bertholon, P., Dubreuil, C., Martin, C., 2007. Value of temporal bone density measurements in otosclerosis patients with normal-appearing computed tomographic scan. Ann. Otol. Rhinol. Laryngol. 116 (3), 195–198.
Vicente Ade, O.Y.H.A.P., 2006. Computed tomography in the diagnosis of otosclerosis. Otolaryngol. Head Neck Surg. 4 (134), 330–333.
Virk, J.S., Singh, A., Lingam, R.K., 2013. The role of imaging in the diagnosis and management of otosclerosis. Otol. Neurotol. 34 (7), e55–e60.
Wycherly, B.J., Berkowitz, F., Noone, A.M., Kim, H.J., 2010. Computed tomography and otosclerosis: a practical method to correlate the sites affected to hearing loss. Ann. Otol. Rhinol. Laryngol. 119 (12), 789–794.
Xie, J., Zhang, L., Zeng, N., Liu, Y., Gong, S., 2019. The clinical characteristics of otosclerosis and benefit from stapedotomy: our experience of 48 patients (58 ears). Acta Otolaryngol. 139 (10), 843–848.
Zhu, M.M., Sha, Y., Zhuang, P.Y., Olszewski, A.E., Jiang, J.Q., Xu, J.H., Xu, C.M., Chen, B., 2010. Relationship between high-resolution computed tomography densitometry and audiometry in otosclerosis. Auris Nasus Larynx 37 (6), 669–675.