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Retrospective Study of 157 Patients with Otosclerosis to Evaluate Association Between Carhart Notch on the Preoperative Bone-Conduction Audiogram and Postoperative Hearing and Balance Evaluated by the Vestibular Disorders Activities of Daily Living Scale

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Background: A Carhart notch in the pure tone audiogram can be an indicator of stapes fixation in otosclerosis. This retrospective study of 157 patients with otosclerosis aimed to evaluate the association between the presence of a Carhart notch on the preoperative bone-conduction audiogram and postoperative hearing and balance evaluated by the Vestibular Disorders Activities of Daily Living scale.

Material/Methods: Patients with suspected otosclerosis based on medical history and audiometric tests were considered. The analysis included 157 consecutive patients who underwent surgery in the years 2016 to 2019, in whom the diagnosis of otosclerosis was confirmed during surgery. Carhart notch was defined as an impairment in the bone conduction threshold of ≥7.5 dB for 2000 Hz frequencies above the mean thresholds at higher and lower adjacent frequencies. The Vestibular Disorders Activities of Daily Living subjective scale was used in the preoperative period and 4 and 12 months after surgery.

Results: The preoperative presence of Carhart notch and progressive sensorineural hearing loss were statistically significantly correlated with more common onset of tinnitus and then dizziness (P=0.006). Preoperative vertigo was observed in patients who had Carhart notch observed in the preoperative audiometric test. This vertigo more commonly coexisted with profound sensorineural hearing loss and minor or no improvement in average values of bone conduction after surgery (P=0.002).

Conclusions: Preoperative Carhart notch on audiogram and the severity of sensorineural hearing loss were associated with tinnitus and vertigo. However, preoperative Carhart notch was not associated with persistent postoperative tinnitus in patients with cochlear otosclerosis.

Keywords: Hearing Loss • Otosclerosis • Tinnitus • Vertigo

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Background

Otosclerosis is characterized by an initial presentation of unilateral progressive hearing loss that can progress into bilateral hearing loss, tinnitus, and, in some cases, vertigo. Abnormal metabolism of bone tissue occurs, consisting of initial resorption and subsequent recalcification of the endochondral layer of the temporal bone. This leads to bone remodeling and consequently the immobilization of the stirrup in the oval window. In this way, the physiological oscillatory motion of the ossicle is hindered or suppressed, leading to the deterioration of sound conduction to the inner ear. The most common site of otosclerotic foci formation is the area in front of the niche of the oval window, also known as the fissula ante fenestram. However, otosclerotic changes are also observed in the structures of the inner ear, such as the semicircular canals, utricle, saccule, and even within the inner ear canal [1].

A clear cause responsible for the development of otosclerosis has not been proven. In the etiology of the disease, genetic, hereditary, and infectious factors, and hormonal disorders, ethnicity, and sex are considered [2].

In the diagnosis of otosclerosis, the following are used: a characteristic clinical interview, audiological diagnostics, including tuning fork tests, pure tone, and impedance audiometry, and, in selected cases, high resolution computer tomography of the temporal bones. To illustrate cases of otosclerosis involving the oval window, **Figure 1** shows conductive hearing loss in the absence of other hearing problems with a normal otoscope image. The presence of an air-bone gap in pure-tone audiometry and the absence of the stapedius muscle reflex in impedance audiometry with normal tympanometry are typical. Involvement of the inner ear with the disease process results in the clinical picture of sensorineural hearing loss, which requires differentiation from other diseases that disturb bone conduction. In the natural course of otosclerosis, initially disturbing air conduction, with the progression of the disease process, the sensorineural component of hearing loss is added, giving a clinical picture of mixed hearing loss [2,3].

According to the available literature, otosclerosis is the cause of 5% to 10% of all cases of hearing impairment and 18% to 22% of all cases of conductive hearing impairment [4]. Noticeable hearing loss impeding everyday activities is defined at the air conduction threshold of 25 to 30 dB. Another characteristic component of pure tone audiometry in otosclerosis is the Carhart notch, described in 1950 by Raymond Carhart. The Carhart notch is described as an impairment in the bone conduction threshold (BC) by 10 to 20 dB for 2000 Hz frequencies above the mean thresholds at higher and lower adjacent frequencies (**Figure 1**) [5].

The presence of Carhart notch results from the disappearance of the resonance properties of the ossicles at this frequency. The occurrence of Carhart notch in the literature is reported to be between 31% to 80% [6,7]. In cases in which otosclerotic lesions are limited to the inner ear, the observed hearing loss has a sensorineural character, clinically presenting as cochlear otosclerosis (observed in 15% of cases).

Treatment of otosclerosis consists of the use of a prosthesis suspended on the long process of the incus and placed in the

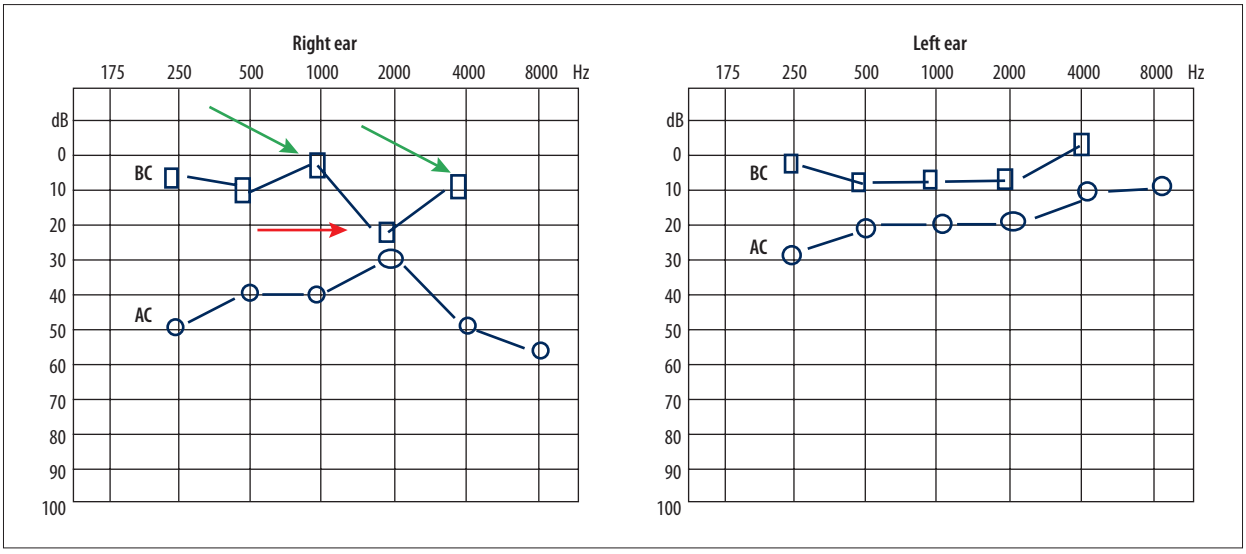

Figure 1. An example of an audiogram showing a Carhart notch (red arrow) in the right ear. Carhart notch as an impairment in the bone conduction threshold (BC) for 2 kHz frequency above the mean thresholds at higher and lower adjacent frequencies (green arrows). BC – bone conduction threshold; AC – air conduction threshold; Hz – hertz; dB – decibel. Prepared using CorelDraw9, Corel Corporation.

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orifice created in the stapes footplate immobilized by the disease process. In this way, air conduction is improved, restoring the mobility of the ossicular chain. There is no effective treatment for sensorineural hearing loss caused by the development of otosclerotic foci within the inner ear (cochlear otosclerosis) [8].

Tinnitus is the phenomenon of perceiving sound when the hearing organ is not stimulated by an external acoustic stimulus. Tinnitus can occur on one or both sides, constantly or periodically, and it is assumed that it arises as a consequence of disorders of the nervous system in various sections of the auditory pathway [9]. Almost 60% of patients with otosclerosis report persistent high- and low-frequency tinnitus, which significantly reduces their quality of life [10]. In otosclerosis, tinnitus is most often described as a high-frequency noise [11].

The etiopathogenesis of tinnitus in otosclerosis is not yet fully understood. Over the last few years, there have been a number of theories trying to explain the reasons for this pathogenesis. The etiology of tinnitus takes into account the disturbance of circulation and vibration of the inner ear fluids, pathological vascularization of the newly formed otosclerotic bone, and the toxic activity of metabolites released during the otosclerotic process. Reduction or complete remission of tinnitus is observed in approximately two-thirds of patients after surgical treatment of otosclerosis [12].

Other symptoms that significantly affect patient quality of life with otosclerosis include vestibular disorders such as vertigo and balance impairment. According to the available literature, a subjective feeling of imbalance occurs in approximately 32% of patients. Objective analysis, confirmed by a videonystagmography test, shows vertigo affecting approximately 26% of patients with otosclerosis. Vestibular disorders can result from, among other things, changes in the biochemical composition of the perilymph and an increase in the pressure of the inner ear fluid. The clinical manifestation of vestibular symptoms depends on the severity of the disease [13].

Among the available methods of assessing balance disorders, attention should be paid to subjective tests that can be performed after middle ear surgery and at the same time assess the quality of life of patients, such as the Vestibular Disorders Activities of Daily Living (VADL) scale. The VADL scale measures the ability to independently and safely perform 28 daily activities assessed according to a 10-point Likert scale. The assessed activities were divided into 3 categories: functional, ambulatory, and instrumental. Selecting 1 point on an activity means independent performance of the task, while 10 points indicate great difficulty in performing the activity independently [14,15]

Shifts in the BC curve (the Carhart effect) are observed in the course of various diseases of the middle ear. In otosclerosis, the Carhart effect (also known as the Carhart notch) is most often observed at 2000 Hz, which is associated with the immobilization of the stapes plate. According to Yasan, the presence of a 1000 Hz notch in the course of middle ear diseases indicates that the mobility of the stapes is preserved [16]. In the course of chronic or exudative otitis media, the Carhart effect is often observed at 4000 Hz. The prognostic value of the Carhart effect after surgical treatment of middle ear diseases in terms of air-bone gap closure and the effect of treatment on BC values is widely discussed [3].

The objective of this study is a postoperative analysis of audiometric test results in patients with otosclerosis in association with factors influencing quality of life, such as the occurrence and intensity of vertigo and tinnitus.

Therefore, this retrospective study of 157 patients with otosclerosis aimed to evaluate the association between the presence of a Carhart notch on the preoperative bone-conduction audiogram and postoperative hearing and balance evaluated by the VADL scale.

Material and Methods

Ethics Statement

The approval of the bioethics committee for the study was obtained (no. 122.6120.206.2016). All analyzed patients gave their written informed consent for treatment and participation in the study.

Material

A retrospective analysis was conducted involving 157 consecutive patients aged 18 to 50 years (average age 41.3 years) who underwent surgery for otosclerosis for the first time from 2016 to 2019. A total of 90 women and 67 men were qualified for the study. Patients up to 50 years of age were analyzed to eliminate the factors related to the ageing of hearing organs.

Inclusion and Exclusion Criteria

The inclusion criteria for this study were as follows: (1) age between 18 and 50 years; (2) informed consent for the treatment; (3) clinically diagnosed otosclerosis; (4) history of stapedotomy; and (5) exclusion of other factors causing vertigo and/or tinnitus.

The exclusion criteria for this study were as follows: (1) age below 18 years old and above 50 years old; (2) lack of informed consent for the treatment; (3) coexistence of other diseases affecting the ear; (4) other factors causing vertigo and/or

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tinnitus; (5) history of stapedectomy; and (6) patients with onset of vertigo/tinnitus directly after the surgical treatment persist over time, which can indicate a connection to the surgical treatment.

Groups of Patients

Depending on the presence of Carhart notch in the operated ear, which was determined by pure-tone audiometry before and after the surgery, 4 groups of patients were formed. Based on the observations of other authors, Carhart notch was defined as an impairment in the BC of ≥ 7.5 dB for 2000 Hz frequencies above the mean thresholds at higher and lower adjacent frequencies. It was assumed that the Carhart notch frequency threshold had to be higher than the adjacent frequency thresholds [3].

The analyzed group of patients was characterized by a large differentiation in the magnitude of the Carhart notch. Due to the necessity to distinguish a large number of statistically insignificant subgroups, the influence of the Carhart notch magnitude on the obtained results was not discussed.

Group 2 was divided into 2 subgroups (2a and 2b) with a criterion of average BC of <30.65 dB and >30.65 dB. At this value, a Carhart notch could be observed in preoperative audiometry in group 1.

The following groups of patients were created: group 1 (n=39), Carhart notch observed before and absent after surgery; group 2 (n=87), Carhart notch not observed before and after surgery; subgroup 2a (n=41), average BC <30.65 dB; subgroup 2b (n=46), average BC >30.65 dB; group 3 (n=10), Carhart notch absent before surgery and present after surgery; and group 4 (n = 21), Carhart notch observed before and after surgery.

Note that group 3 had few patients that could not be included in a meaningful statistical analysis. Therefore, group 3 was omitted from further statistical analysis of the data.

Material and Methods

Audiometric tests were performed before surgical treatment and at 4 and 12 months after surgery.

The tonal audiometry results were analyzed, with particular care given to the average values of BC in the operated ear before surgery, approximately 120 days after surgery and approximately 12 months after surgery.

Within the groups, the effectiveness of the otosurgery and its impact on the function of the inner ear were assessed by analyzing the average value of BC and the change in the average value of BC at fixed time intervals at the frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz, based on the current recommendations [17].

The tinnitus matching test, a subjective test measuring the level of tinnitus, was used to study the frequency and intensity of tinnitus. The Tinnitus Handicap Inventory scale was used to assess the severity of tinnitus and its impact on the daily functioning of the patient [18]. Determination of the loudness and frequency type of tinnitus was conducted using a clinical audiometer, performing the test first for octave and then at inter-octaval frequencies, by narrowing the tinnitus to half an octave [19,20]. Tinnitus was assessed before surgery and 12 months after ear surgery for otosclerosis.

The air and bone conduction values were measured by a Madsen MIDIMATE® 622 audiometer equipped with TDK 39 headphones. The audiometer met the ISO standards for both air (ISO0389-1985) and bone conduction (ISO7566-1987).

The understanding of speech test was carried out using the AAD80 type audiometer and the Technics amplifier and CD player.

The VADL subjective scale was used to evaluate vestibular disorders [21]. This questionnaire uses 28 basic daily activities to assess the patient's ability to independently, safely, and comfortably perform activities on a scale from 1 to 10. The choice of the subjective VALD scale was dictated by the inability to perform a safe objective assessment of vestibular disorders in electronystagmography in the early phase of postoperative otosclerosis treatment.

Statistical Analysis

Statistical analysis was carried out using the STATISTICA 13 suite (StatSoft Polska, Cracow, Poland). The following tests were used: chi-squared test, Pearson's linear correlation, *t* test, and one-way analysis of variance with small group adjustments. The Tukey's test was used to test post hoc statistically significant results of the analysis of variance.

Statistically significant results were considered when $P<0.05$.

Results

The evaluation of the average BC values for 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, in association with the occurrence of balance disorders and tinnitus, was carried out in the immediate preoperative period, as well as at 4 and 12 months after the surgical treatment.

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Table 1. Variance analysis of average bone conduction thresholds (as an average for 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz) and presence of the tinnitus and disturbance of balance before surgical treatment in group1 and group 4 considered together.

Groups 1+4 (considered together)		Preoperative BC (dB)					
Before surgery	n	Average	SD	Me	Min	Max	
Tinnitus	13	25.3	7.7	23.8	15.0	36.4	*P*<0.001
Disturbance of balance	35	32.6	8.4	33.8	16.3	45.0	
Tinnitus and disturbance of balance	11	44.0	2.5	43.8	42.5	51.3	

Symptoms/average BC (dB)	Tinnitus	Disturbance of balance	Tinnitus and disturbance of balance
	BC=25.3	BC=32.6	BC=44.0
Tinnitus/BC=25.3		0.044	<0.001
Disturbance of balance/BC=32.6	0.044		0.006
Tinnitus and disturbance of balance/BC=44.0	<0.001	0.006	

Preoperative BC – average bone conduction thresholds before surgery; BC – bone conduction threshold; dB – decibel; SD – standard deviation; Me – median; min – minimum; max – maximum; n – number of patients; Hz – hertz.

Preoperative Analysis

When analyzing the average preoperative BC value in an aggregation of groups with a preoperative Carhart notch (groups 1 and 4), a statistically significant correlation was found between the average BC values and the occurrence of tinnitus and vertigo. In the group of patients with preoperative Carhart's notch, tinnitus was the first symptom to occur, with the deterioration of sensory hearing loss (with an average BC of 25.3 dB). A greater degree of hearing loss coincided with vertigo (with an average BC of 32.6 dB). At an average BC value of 44.0 dB, tinnitus coexisted with vertigo *(P*<0.001; **Table 1**).

In cases of a preoperative lack of a Carhart notch (groups 2a and 2b), no statistically significant correlation was found between the average values of BC and the occurrence of tinnitus and vertigo *(P*=0.879).

The occurrence of Carhart notch was used as a divider for patient groups during the postoperative evaluation of the obtained results. Analyses of the results obtained from groups 1 and 4 were performed separately.

In the early postoperative evaluation, performed 4 months after surgery, the relationship between the occurrence of vertigo and the values of average postoperative BC was analyzed. In the later evaluation at 1 year after surgery, the relationship between average BC values and occurrence of both vertigo and tinnitus was analyzed.

Analysis 4 Months After Surgery

At the 4-month post-surgery follow-up, a statistically significant correlation was found with the occurrence of vertigo when analyzing the variance of the average BC value in the group of patients without the Carhart notch after surgery (group 1). During early observation, vertigo was observed with an average BC value of 37.8 dB. The observed correlation was statistically significant *(P*=0.002; **Table 2**).

Group 1 demonstrated vertigo coinciding with a deterioration in average BC values when compared with measurements performed before surgery. The change in average BC (ΔBC) was -5.69 dB. Group 1 patients without vertigo, assessed 4 months after surgery, displayed an improvement in average BC values (ΔBC 4.82 dB), as outlined in **Table 2**. Six patients in group 4 (with persistent Carhart notch) demonstrated vertigo (54.5% of the group) during early postoperative observation and an average BC of 29.4 dB in postoperative observation. However, this result was not statistically significant (*P*=0.445).

Analysis of the 4-month postoperative average BC values in the operated ears of patients in groups without preoperative Carhart notch yielded a statistically significant correlation in group 2a with the occurrence of vertigo. In this group, vertigo was observed in patients with an average BC threshold value of 24.1 dB, higher than in patients without early vertigo. Similar to in group 1, the presence of vertigo correlated with a lack of improvement in average BC values, as opposed to patients in whom vertigo was absent, in which average BC values improved by nearly 3.5 dB.

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Table 2. Variance analysis of average bone conduction threshold and presence of balance disturbance in early 4-month follow-up after surgical treatment in groups 1, 2a, and 2b.

Group	Disturbance of balance	n	Postoperative BC at 4 months (dB)					*P*	BC preop (dB)	ΔBC (dB)
			Average	SD	Me	Min	Max			
Group 1	Absent	29	26.3	8.8	25.0	10.0	46.3	*P*=0.002	31.12	4.82
	Present	10	37.8	10.4	36.9	21.3	53.8		32.11	-5.69
Group 2a	Absent	31	19.3	7.7	16.9	10.0	32.5	*P*<0.05	22.6	3.3
	Present	10	24.1	7.4	26.3	10.0	37.5		22.7	-1.4
Group 2b	Absent	32	30.7	10.5	31.3	16.3	63.8	*P*<0.05	38.5	7.8
	Present	14	38.8	8.8	40.0	26.3	51.3		40.3	1.5

Postoperative BC – average bone conduction thresholds after surgery; BC – bone conduction threshold; BC preop – average bone conduction threshold before surgery; ΔBC – change in bone conduction; dB – decibel; SD – standard deviation; Me – median; min – minimum; max – maximum; n – number of patients; Hz – hertz.

Table 3. Variance analysis of average bone conduction thresholds and presence of balance disturbance in late 1-year follow-up after surgical treatment in group 2a.

Disturbance of balance	n	Postoperative BC at 1 year (dB)					*P*	BC preop (dB)	ΔBC (dB)
		Average	SD	Me	Min	Max			
Absent	33	11.6	0.9	10.6	10.0	11.3	*P*<0.05	21.3	9.7
Present	2	23.5	7.4	23.8	10.0	37.5		22.8	-0.7

Postoperative BC – average bone conduction thresholds after surgery; BC – bone conduction threshold; BC preop – average bone conduction threshold before surgery; ΔBC – change in bone conduction; dB – decibel; SD – standard deviation; Me – median; min – minimum; max – maximum; n – number of patients.

In the 4-month postoperative follow-up of group 2b, vertigo was observed with an average BC value of 38.8 dB. This value was higher than that in the group without vertigo (the average BC value in this group of patients was 30.7 dB). The result was statistically significant at *P*<0.05. Additionally, postoperative vertigo was accompanied by a lack of improvement in average BC values.

Analysis 12 Months After Surgery

During the 12-month follow-up, in analyzing the postoperative average BC value in the operated ear in the groups without the Carhart notch, a statistically significant correlation was observed between the mean BC value and persistence of vertigo in group 2a. The average postoperative BC value in this group was 23.5 dB, and, similar to the observation of early vertigo up to 4 months after surgery, it was higher than the mean BC value in patients without vertigo (amounting to 11.6 dB). Compared with the assessment in the period immediately after the surgical treatment, the number of patients with dizziness was lower (**Table 3**).

It is worth noting that in group 2a, there were patients who had improvements in average BC values who did not experience vertigo, whereas other patients in this group had vertigo in conjunction with persistent sensorineural hearing loss.

In groups 1 and 2b, no statistically significant correlation was found between the average postoperative BC values and the persistence of vertigo in the long-term follow-up. In group 4, no patients experienced vertigo in the late 12-month postoperative follow-up. The average postoperative BC value in this group was 26.6 dB.

During the 12-month follow-up, when analyzing the postoperative variance of average BC values in the operated ear in group 4, a statistically significant correlation was found between the mean postoperative BC value and the persistence of tinnitus *(P*<0.05). The average value of the postoperative BC was 37.1 dB. Increased tinnitus coexisted with profound sensorineural hearing loss, with slight improvement in average BC values (**Table 4**). This correlation was not found in the group of patients without postoperative Carhart notch (group 1). Increased tinnitus coexisted with profound sensorineural hearing loss, with slight improvement in mean BC values.

During the 12-month follow-up, when analyzing the postoperative average BC in the groups without Carhart notch, a

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Table 4. Variance analysis of average bone conduction threshold and presence of tinnitus in late 1-year follow-up after surgical treatment in groups 4 and 2a.

Group	Tinnitus	n	Postoperative BC at 1 year (dB)					*P*	BC preop (dB)	ΔBC (dB)
			Average	SD	Me	Min	Max			
Group 4	Absent	7	23.0	4.6	22.5	13.8	27.5	*P*<0.05	27.5	4.5
	Quiet	4	17.5	12.5	11.3	11.3	36.3		35.0	17.5
	Loud	7	37.1	4.1	36.3	35.0	46.3		43.35	6.25
Group 2a	Absent	13	19.2	7.5	18.8	10.0	28.8	*P*<0.05	22.5	3.3
	Quiet	17	25.6	6.2	26.3	16.3	37.5		23.6	-2.0
	Loud	11	23.1	8.6	21.3	11.3	33.8		21.4	-1.7

Postoperative BC – average bone conduction thresholds after surgery; BC – bone conduction threshold; BC preop – average bone conduction threshold before surgery; ΔBC – change in bone conduction; dB – decibel; SD – standard deviation; Me – median; min – minimum; max – maximum; n – number of patients.

Table 5. Average bone conduction thresholds in the established groups 4 months and 12 months after surgery.

Follow-up	Group	n	Postoperative BC (dB)					*P*
			Mean	SD	Me	Min	Max	
12 months after surgery	1	39	29.2	10.4	26.3	10.0	53.8	*P*<0.001
	2a	41	22.9	7.6	23.8	10.0	37.5	
	2b	46	33.2	10.6	31.9	16.3	63.8	
	4	21	27.5	9.7	28.8	11.3	46.3	
4 months after surgery	1	39	29.5	10.3	26.0	11.0	54.5	*P*<0.001
	2a	40	23.4	7.5	24.1	10.0	38.5	
	2b	46	33.6	10.6	32.3	16.5	64.0	
	4	21	28.0	9.8	29.0	12.0	46.3	

Postoperative BC – average bone conduction thresholds after surgery; BC – bone conduction threshold; SD – standard deviation; Me – median; min – minimum; max – maximum; n – number of patients.

statistically significant correlation was found with the persistence of postoperative tinnitus in group 2a *(P*<0.05). The mean postoperative BC value was 25.6 dB. Tinnitus coexisted with no improvement in average BC values at the 1-year follow-up after surgery.

In groups 1 and 2b, no statistically significant correlation was found between the persistence of tinnitus at the 12-month follow-up after surgery and average BC values.

The conducted analysis showed that the mean BC value assessed 4 and 12 months after surgery was statistically significantly dependent on the group (*P*<0.01; **Table 5**).

Post hoc testing showed statistically significant differences in BC values in the control 12 months after surgery between groups 2a and 1 (*P*=0.018) and 2b and 2a (*P*<0.001). There were no significant differences between groups 1 and 2b, 1 and 4, 2a and 4, and 2b and 4.

The post hoc testing also indicated the presence of statistically significant differences in the BC values in the postoperative control after 4 months between groups 2a and 1 (*P*=0.023), as well as between groups 2b and 2a (*P*<0.001). There were no significant differences between groups 1 and 2b, 1 and 4, 2a and 4, and 2b and 4.

The values of postoperative BC in the established groups showed time consistency in the follow-up 4 and 12 months after surgery.

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At a later stage, the presence of tinnitus in the analyzed groups was assessed in the preoperative period, with particular attention to the maintenance of symptoms after 12 months of follow-up following surgery. In the preoperative period, no statistically significant differences were observed in the incidence of preoperative tinnitus between the established groups of patients. Most of the patients had high-frequency tinnitus of moderate intensity (grade 2 according to the Tinnitus Handicap Inventory).

Postoperative improvement in tinnitus incidence (complete resolution or significant reduction in intensity) observed in patients with tinnitus in the preoperative period was statistically significant (P=0.040) in the analyzed groups. In group 1 and in group 2b, there was a comparable percentage of patients with improvement (68%). The lowest percentage of patients with improvement (28.57%) was in group 4.

Discussion

This study showed a relationship between the depth of sensorineural hearing loss observed after surgery in patients with otosclerosis and its tendency to coexist with symptoms of inner ear damage.

In individuals with preoperative Carhart notch and progressive sensorineural hearing loss, there was a statistically significantly more common onset of tinnitus and then dizziness. In cases of profound bone conduction impairment, tinnitus and dizziness could be observed at the same time. This finding can be explained by the severity of the cochlear otosclerosis.

Despite the disappearance of Carhart notch after surgery, which is an audiometric manifestation of the restoration of vibrations for the resonant frequency of the ossicular chain, vertigo was observed during the early follow-up as a manifestation of deep sensorineural hearing loss. As the disease progressed in patients from this group, vertigo and tinnitus were less severe, depending on the depth of sensorineural hearing loss. This can be explained by the progressive degradation of the sensory cells of the inner ear in the course of otosclerosis and the ongoing process of compensation [22].

In our study, persistent Carhart notch predisposed for the persistence of tinnitus in patients with profound sensorineural hearing loss. This relationship was not observed in group 1 (individuals without Carhart notch after surgery). The lack of restoration of vibrations for the resonant frequency (as seen in group 4) begs consideration of the performed surgical treatment as a possible factor underlying the ailments. Persistent Carhart notch does not correlate with the tendency to experience vertigo in early and late follow-up.

In more than half of the analyzed patients (group 2), the clinical picture suggested a predominance of cochlear otosclerosis, with less immobilization of the stirrup in the course of the otosclerotic process and no Carhart notch in the preoperative evaluation. The obtained results showed that the progressive damage to the inner ear functions was a factor predisposing to dizziness and vertigo in the long-term observation, the presence of which correlated with the minor improvement of sensorineural hearing loss after performed surgical treatment.

In this study, preoperative vertigo was observed in patients in groups 1 and 4, those who had Carhart notch observed in the preoperative audiometric test. This vertigo more commonly coexisted with profound sensorineural hearing loss and minor or no improvement in average values of BC after surgery. The above observation indicates the preoperatively observed Carhart notch as a factor predisposing to the presence of preoperative vertigo in patients with accompanying profound sensorineural hearing loss. This group consisted of 60 patients, which constituted 38% of all patients included in the study.

Dizziness at the early 1-month follow-up occurred in groups 1, 2a, and 2b, which concerned patients without postoperative Carhart notch. In these patients, symptoms may have been associated with the opening of the inner ear space in the course of surgical treatment.

In a long-term follow-up, vertigo persisted only in group 2a. In this group, a statistically significant persistence of postoperative tinnitus was also observed in long-term follow-up. Over time in these patients, the symptoms of cochlear otosclerosis with deepening sensorineural hearing loss and a tendency for headaches and tinnitus were present in the foreground of the clinical picture [23].

Surgical treatment of otosclerosis is focused on reducing the air-bone gap, thus reducing hearing loss in the affected ear. Otosclerotic foci can occur in any part of the temporal bone and involve the niche of the round window, cochlear labyrinth, the base of the stirrup, posterior part of the oval window niche, internal auditory canal, the cochlear and vestibular aqueduct, or the semi-circular canals [2,8].

Apart from the typical clinical presentation with the presence of conductive hearing loss, the disease can remain asymptomatic or lead to dysfunction of the inner ear, which is responsible for the clinical presentation of cochlear otosclerosis with the presence of sensorineural hearing loss and vestibular symptoms. In addition to progressive hearing loss, the disease can cause tinnitus and balance disturbances that are troublesome for the patient.

Considering the natural progression of otosclerosis in patients whose symptoms in the first stage of the disease resulted only from the disturbance of the mobility of the stapes,

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other symptoms related to dysfunction of the inner ear were observed over the years.

In the final assessment of the results of surgical treatment, one should also consider the symptoms reported immediately after ear surgery and those resulting from the treatment. This is especially relevant in the early postoperative period and is a result of the surgical methodology during stapedectomy and placement of the prosthesis [24].

This study is consistent with the observations of other authors on the influence of the mechanics of the middle ear on the function of the inner ear. The level of bone conduction in otosclerosis is influenced by several factors: cochlear otosclerosis, the Carhart effect, possible damage in the operated ear to the inner ear during surgery, and the occurrence of complications after surgery [16].

Opinions are consistent regarding the improvement of bone conduction in the early period after uncomplicated stapes surgery. In the available studies, an improvement in bone conduction is noted after the surgical treatment of otosclerosis, even in 60% of those operated on up to 15 dB in the speech frequency range [25].

Based on the conducted research, Lamblin et al presented an improvement in the average values of BC in the operated ear in the early follow-up (4-12 months after surgery) [3]. However Szymański et al noticed hearing deterioration in the long-term period (average 10-year follow-up) [26]. This can be associated with the progression of cochlear otosclerosis, in the course of which the inner ear is damaged due to the formation of abnormal otosclerotic bone in the endosteum of the cochlea bony sheath many years after ear surgery due to otosclerosis [27,28].

According to reports by other authors, vertigo occurs in approximately 30% of patients with otosclerosis. Otosclerotic changes, typically located in the fissula ante fenestram, can also be observed in the structures of the inner ear. In the studies of Hizli et al, examination of the anatomical pathological structure of the temporal bones of deceased patients suffering from otosclerosis revealed a decrease in the density of type I and II atrial hair cells when compared with the image of bones unchanged by the otosclerotic process. Abnormalities were observed in the upper semicircular canal, lateral semicircular canal, utricle, saccule, and posterior semicircular canal [29].

A study by Saka et al of vestibular-evoked myogenic potentials in response to bone-conducted sound in patients with otosclerosis indicated that 20% to 37% of patients with otosclerosis develop tinnitus and vertigo over the course of the disease. The authors investigated the causes of dizziness in patients with otosclerosis using vestibular-evoked myogenic potential in response to bone-conducted sound (BC-VEMP). Patients with otosclerosis who had not been treated before were analyzed, comparing the data from their medical history with the results of BC-VEMP. Disturbed vestibular function was found in 90% of patients with a history of vertigo. Saccule dysfunction was indicated as the main cause of vertigo in patients with otosclerosis [30].

The presented observations justify the necessity of research on the variability of Carhart notch occurrence and its relationship with the postoperative improvement in the quality of life of patients in terms of the impact on the function of the hearing organ and balance system.

Conducting an objective assessment of the vestibular organ with the use of caloric tests is often contraindicated after surgery on the middle ear. The limitation of the conducted analysis was the use of subjective tests in the assessment of balance disorders without caloric tests.

Our intention was to indicate whether balance disorders appeared in patients after surgery for otosclerosis and whether they hinder everyday functioning. The collection of information about imbalances in the preoperative period indicates a relationship between the treatment performed and the change (severity/reduction) of these symptoms. The assessment of the impact of balance disorders on the quality of life was analyzed in terms of the subjective feeling of dizziness and its impact on the daily functioning of patients (VADL scale).

A further difficulty in conducting the research was the presence of transient dizziness in the immediate postoperative period, which resulted from the opening of the inner ear space at the stage of prosthesis insertion.

Considering the factors that can have a negative impact on the final result of otosclerosis treatment, we should also mention factors including the wrong length of the prosthesis, its defective attachment on the long process of the incus, and incorrect sealing of the hole in the stapes plate.

Conclusions

The findings from this retrospective study from a single center showed that the presence of a preoperative Carhart notch on audiogram and severity of sensorineural hearing loss were associated with tinnitus and vertigo. However, preoperative Carhart notch was not associated with persistent postoperative tinnitus in patients with cochlear otosclerosis.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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References:

1. Wiatr A, Składzien J, Swiezy K, Wiatr M. A biochemical analysis of the stapes. Med Sci Monit. 2019;25:2679-86
2. Zafar N, Jamal Z, Khan MAB. Otosclerosis. [Updated 2022 Jul 25]. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2022 Jan. Available at: https://www.ncbi.nlm.nih.gov/books/NBK560671/
3. Lamblin E, Karkas A, Jund J, Schmerber S. Is the Carhart notch a predictive factor of hearing results after stapedectomy? Acta Otorhinolaryngol Ital. 2021;41:84-90
4. Palacios-Garcia J, Ropero-Romero F, Aguilar-Vera F, Sanchez-Gomez S. Short-term audiological outcomes of stapedotomy: Microdrill at low revolutions versus manual perforator to perform a small footplate fenestra. A prospective observational study. Otolaryngol Pol. 2020;74(5):1-5
5. Carhart R. Clinical application of bone conduction audiometry. Arch Otolaryngol (1925). 1950;51(6):798-808
6. Dauman R. Bone conduction: An explanation for this phenomenon comprising complex mechanisms. Eur Ann Otorhinolaryngol Head Neck Dis. 2013;130:209-13
7. Stenfelt S. Inner ear contribution to bone conduction hearing in the human. Hear Res. 2015;329:41-51
8. Bajaj Y, Uppal S, Bhatti I, Coatesworth AP. Otosclerosis 3: The surgical management of otosclerosis. Int J Clin Pract. 2010;64(4):505-10
9. Ismi O, Erdogan O, Yesilova M, et al. Does stapes surgery improve tinnitus in patients with otosclerosis? Braz J Otorhinolaryngol. 2017;83:568-73
10. Cavalcante AMG, Silva IMC, Neves BJ, et al. Degree of tinnitus improvement with stapes surgery – a review. Braz J Otorhinolaryngol. 2018;84:514-18
11. Ayache D, Earally F, Elbaz P. Characteristics and postoperative course of tinnitus in otosclerosis. Otol Neurotol. 2003;24:48-51
12. Gersdorff M, Nouwen J, Gilain C, et al. Tinnitus and otosclerosis. Eur Arch Otorhinolaryngol. 2000;257:314-16
13. Job K, Wiatr A, Wiatr M. Association between postoperative vertigo and hearing outcomes after stapes surgery for otosclerosis. Ear Nose Throat J. 2021 [Online ahead of print]
14. Cohen HS. Use of the Vestibular Disorders Activities of Daily Living Scale to describe functional limitations in patients with vestibular disorders. J Vestib Res. 2014;24(1):33-38
15. Cohen HS, Kimball KT. Development of the vestibular disorders activities of daily living scale. Arch Otolaryngol Head Neck Surg. 2000;126(7):881-87
16. Yasan H. Predictive role of Carhart's notch in pre-operative assessment for middle-ear surgery. J Laryngol Otol. 2007;121(3):219-21
17. American Academy of Otolaryngology – Head and Neck Surgery. Committee on Hearing and Equilibrium guidelines for the evaluation of results of treatment of conductive hearing loss. Otolaryngol Head Neck Surg. 1995;113:186-87
18. Lima AF, Moreira FC, Costa IE, et al. Tinnitus and otosclerosis: An exploratory study about the prevalence, features and impact in daily life. Int Arch Otorhinolaryngol. 2021;26:e390-95
19. Danesh AA, Shahnaz N, Hall JW 3rd. The audiology of otosclerosis. Otolaryngol Clin North Am. 2018;51:327-42
20. Vernon JA, Meikle MB. Tinnitus: Clinical measurement. Otolaryngol Clin North Am. 2003;36:293-305
21. Yardley L, Luxon LM, Haacke NP. A longitudinal study of symptoms, anxiety and subjective well-being in patients with vertigo. Clin Otolaryngol Allied Sci. 1994;19:109-16
22. Wiatr A, Składzień J, Strek P, Wiatr M. Carhart notch – a prognostic factor in surgery for otosclerosis. Ear Nose Throat J. 2021,100:NP193-97
23. Cureoglu S, Baylan MY, Paparella MM. Cochlear otosclerosis. Curr Opin Otolaryngol Head Neck Surg. 2010;18:357-62
24. Hildebrandt M, Daugaard Larsen K, Glad H, Djurhuus B. Validity and test-retest reliability of the translated stapesplasty outcome test 25 for measurement of disease-specific quality of life in patients with otosclerosis. J Int Adv Otol. 2020;16:358-61
25. Vijayendra H, Parikh B. Bone conduction improvement after surgery for conductive hearing loss. Indian J Otolaryngol Head Neck Surg. 2011;63:201-4
26. Szymański M, Olejarz P, Zadrożniak M, et al. Wpływ operacji strzemiączka na próg przewodnictwa kostnego w odległym okresie obserwacji. Otorynolaryngologia. 2012,11:17-21 [in Polish]
27. Wycherly BJ, Berkowitz F, Noone AM, Kim HJ. Computed tomography and otosclerosis: A practical method to correlate the sites affected to hearing loss. Ann Otol Rhinol Laryngol. 2010;119(12):789-94
28. Shin YJ, Fraysse B, Deguine O, et al. Sensorineural hearing loss and otosclerosis: A clinical and radiologic survey of 437 cases. Acta Otolaryngol. 2001;121:200-4
29. Hızlı Ö, Kaya S, Schachern PA, et al. Quantitative assessment of vestibular otopathology in otosclerosis: A temporal bone study. Laryngoscope. 2016;126:E118-22
30. Saka N, Seo T, Fujimori K, et al. Vestibular-evoked myogenic potential in response to bone-conducted sound in patients with otosclerosis. Acta Otolaryngol. 2012;132:1155-59

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