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Relation of Preoperative Audiometric Data with Middle Ear Risks in Chronic Otitis Media

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ABSTRACT

Background: To investigate the relationship of preoperative audiometric data with middle ear risk index (MERI) and its subcategories related to ossicular head fixation (OHF) and stapes foot plate fixation (SFPF) for determining the outcome risks before tympanoplasty in chronic otitis media (COM).

Methods: Preoperative air conduction thresholds (ACTs) and bone conduction thresholds (BCTs) in 185 COM patients who underwent surgery were compared to their risk index for tympanoplasty outcomes (MERI) and its components comprising OHF and SFPF. Preoperative BCTs were analyzed for their effect in predicting the presence of OHF and SFPF intraoperatively.

Results: Preoperative ACTs and BCTs from 500 to 4000 Hz were all significantly correlated with MERI scores. Worse preoperative ACTs at 500, 1000, and 2000 Hz were significantly related to OHF.Worse preoperative BCTs at 1000 and 2000 Hz were significantly linked to OHF. From 500 to 4000 Hz, preoperative ACTs were significantly worse, while and BCTs were significantly worse, in ears with, compared to without, SFPF. Combined preoperative BCT cut-off values of ≥20 dB at 1000 Hz and ≥25 dB at 2000 Hz were better predictors than that of 500 Hz and 4000 Hz at 20 dB, and it had a 13.5-fold greater association with SFPF.

Conclusion: Preoperative ACTs and BCTs at 500-4000 Hz are related to MERI and its risk factors OHF and SFPF. The best predictors of SFPF in COM were in the combination of the BCT ≥20 dB at 1000 Hz and ≥25 dB at 2000 Hz.

Keywords: Chronic otitis media, middle ear, middle ear risk index, ossicular head fixation, stapes foot plate fixation

Introduction

The main surgical principles for chronic otitis media (COM) are based on the eradication of the pathology from the tympanic and mastoid cavity, restoration of middle ear (ME) and mastoid ventilation, and gain of hearing levels (HLs) with an air-bone gap (ABG) of 20 dB or less with no coexisting sensorineural hearing loss.[1] Patients sometimes have high expectations for hearing gain after tympanoplasty. Although promising information may be given by the surgeon in the context of otorrhea cessation and mucosal healing, hearing results may not be predicted accurately before the procedure. Several factors, particularly ossicular chain issues, interfere with hearing restoration. Former publications report that stapes foot plate fixation (SFPF) may negatively affect hearing outcomes.[2-4] Over manipulating the stapes in the case of severe SFPF is almost never advised by the experts because of the increased probability of deafness that the surgeon and patient will have to address after surgery.[5,6] Thus, SFPF remains an obstacle for successful ossicular reconstruction after surgery.[7] Usually, otologists need to anticipate problems in the ME cavity with which they will deal when giving more accurate answers to their patients' questions about hearing recovery. Many techniques have been developed for this purpose. However, they have some limitations that restrict their use in defining ossicle mobility.

In the late 2000s, new methods enhanced for analyzing the motion biomechanics of the ME ossicles displayed the varying motion of the ossicles under air conduction (AC) and bone conduction (BC) stimulations at different frequencies. With a further understanding of different effects of AC and BC stimulations on ME ossicles' vibration, the role of BC was verified recently in the sound transmission mechanism to the inner ear when these ossicles were fixed.[8] Having all these in mind, we aimed to investigate the role of AC and BC separately in

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analyzing the relationship between pre-operative audiologic data and tympanoplasty outcome risk index (MERI) and to analyze the role of BC in predicting the items of this index related to ossicular head fixation (OHF) and SFPF for better informing the surgeon and the patient about hearing outcome before undertaking tympanoplasty in COM.

Methods

Patients

This study is a retrospective chart review of patients with COM who underwent tympanoplasty with or without mastoidectomy in the otorhinolaryngology clinic of a tertiary referral center. All patients had hearing loss with or without otorrhea as a pre-operative symptom. Normal ACTs and BCTs were included according to HLs that were revised by American National Standard Specification for Audiometers in 1996 (ANSI S3.6-1996).[9]

Haydarpaşa Numune Education And Research Hospital Clinical Research Ethics Committee approved the study protocol. (HNEAH-KAEK,2012/62,Date:01.10.2012), and the study was conducted in accordance with the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from participants to participate in the study.

Study Design

Study data included the patients' ACTs and BCTs at 500-4000 Hz (Interacoustics, AC33, Middelfart, Denmark), preoperative and surgical findings that were scored according to the 2001 version of MERI.[10] Middle ear risk index is based on a 3-grade scoring system (0-3 points, mild disease; 4-6 points, moderate disease; and 7-12 points, severe disease), which was developed previously as a marker of preoperative ME disease severity and outcome risk scoring. It was revised by adding 2 points for smoking to the previous scores (Supplementary Table 1). Patients' preoperative ACTs and BCTs were further analyzed according to their MERI and OHF and SFPF items of this system.

Surgery Records

Postauricular or endaural approaches were used to perform tympanoplasty in conjunction with or without mastoidectomy. Total or partial titanium prostheses were used to replace missing ossicles. Ossicular mobility was ensured by removing any fibrotic band between the ossicles. Severe SFPF was accepted as no reflex gain at the round window despite mobilization attempts.

Statistical Analysis

Number Cruncher Statistical System (NCSS) 2007 and the Power Analysis and Sample Size (PASS) 2008 Statistical Software (Kaysville, Utah, USA) program were used for statistical analysis. Descriptive statistics and quantitative and qualitative (Pearson's, Chi-square) statistical methods were used. A Student's *t*-test was used to compare normally distributed parameters in the 2 groups. The Mann–Whitney *U*-test was used to compare non-normally distributed data. An intragroup comparison of normally distributed parameters was performed using the repeated-measures analysis of variance (ANOVA) followed by paired comparisons using a post hoc test (Bonferroni correction). The relationship between parameters was analyzed using Pearson's and Spearman's correlation tests. A receiver operating characteristic (ROC) curve analysis with a 95% CI and diagnostic tests were performed to determine the frequency-specific cut-off values for BCTs in ears with severe SFPF. Additionally, $P < .01$ and <.05 were considered to be statistically significant.

Main Points

- Preoperative air conduction thresholds (ACTs) and bone conduction thresholds (BCTs) are significantly correlated with Middle ear risk scores in chronic otits media.
- Worse preoperative ACTs and BCTs at all frequencies are significantly linked to stapes foot plate fixation (SFPF).
- Combined preoperative BCTs cut-off values of ≥20 dB at 1000 Hz and ≥25 dB at 2000 Hz have a 13.5-fold greater association with SFPF in chronic otitis media.

Results

One hundred eighty-five ears from 113 (61.1%) women and 72 (38.9%) men were included in the study. The mean patient age was 30.96 ± 10.98 years (age range, 19-57 years). Mean preoperative ACTs and BCTs were 52.54 ± 15.60 and 17.56 ± 10.81dB at 500 Hz, 45.49 ± 16.28 and 14.23 ± 9.94dB at 1000 Hz, 40.59 ± 16.66 and 14.83 ± 11.75 dB at 2000 Hz, and 45.03 ± 19.47 and 17.50 ± 14.92 dB at 4000 Hz. Pre-operative ACTs and BCTs were compared using a frequency-specific analysis, and the overall worst ACTs were found at 500 Hz while the worst BCTs were found at 500 and 4000 Hz (4.,1 > 2,3 post-hoc, [a]Repeated-measures ANOVA, $^{**}P < .001$; [b]Bonferroni test, $^{**}P < .01$; Table 1).

Details of Surgical Data, Mucosal Edema, Intraoperative Ossicular Findings, and Distribution of Middle Ear Risk Index Scores are Presented in Supplementary Table 2

Mean ACTs and BCTs over the 500-4000 Hz range were compared to MERI to analyze the relationship between pre-operative HLs and tympanoplasty outcome risk scores. A positive correlation was found between pre-operative ACTs from 500 to 4000 Hz and MERI scores ($r = 0.341$, $r = 0.399$, $r = 0.366$, $r = 0.354$, and $r = 0.349$, at 500, 1000, 2000, and 4000 Hz

Table 1. Distribution of Air and Bone Conduction Thresholds Displaying Worst ACTs (500 Hz), Worst BCTs (500, 4000 Hz)

ACTs	Min-Max	[a]Mean ± SD (dB)	[b]Post-Hoc
[1]500 Hz	15-100	52.54 ± 15.60	**1 > 2,3,4**
[2]1000 Hz	10-90	45.49 ± 16.28	**3 < 2,4**
[3]2000 Hz	5-90	40.59 ± 16.66	
[4]4000 Hz	5-120	45.03 ± 19.47	
BCTs			
[1]500 Hz	0-50	17.56 ± 10.81	**4,1 > 2,3**
[2]1000 Hz	0-55	14.23 ± 9.94	
[3]2000 Hz	0-60	14.83 ± 11.75	
[4]4000 Hz	0-80	17.50 ± 14.92	

[a]Repeated measures ANOVA, $P < .001$.
[b]Bonferroni test, $P < .01$.
[1,2,3,4]These numbers are for analyzing the worst mean hearing loss levels among the frequencies.

Table 2. Correlation of Air and Bone Conduction Thresholds with MERI Scores

	MERI Scores	
	r	*P*
ACTs 500 Hz	0.341	[a].001**
ACTs 1000 Hz	0.399	[a].001**
ACTs 2000 Hz	0.366	[a].001**
ACTs 4000 Hz	0.354	[a].001**
BCTs 500 Hz	0.349	[b].001**
BCTs 1000 Hz	0.383	[b].001**
BCTs 2000 Hz	0.345	[b].001**
BCTs 4000 Hz	0.282	[b].001**

r, correlation coefficient.
[a]Pearson correlation analysis. [b]Spearman correlation analysis. **$P < .01$.

respectively; $P < .01$, Pearson's correlation analysis). Worse pre-operative ACTs correlated with higher outcome risk scores. Similarly, there was a positive correlation between BCTs at 500-4000 Hz and MERI scores ($r = 0.383$, $r = 0.345$, $r = 0.282$, and at 500, 1000, 20 000, and 4000 Hz respectively; Spearman correlation analysis; $P < .01$; Table 2). Correlation between MERI scores and either ACTs or BCTs at 1000 Hz was higher (39.9% or 38.3%, respectively) than the corresponding correlation at 500 Hz (34.1% or 34.9%, respectively), 2000 Hz (36.6% or 34.5%, respectively), and 4000 Hz (35.4% or 28.2%, respectively; Table 2). Middle ear risk index scores were worsening related to worse ACTs and BCTs at 1000 Hz. Comparison of pre-operative ACTs with MERI subcategory scores that included OHF revealed a significant statistical relationship between worse preoperative ACTs at 500, 1000, and 2000 Hz and OHF. Air conduction thresholds at these frequencies were significantly worse in ears with OHF (59.12 ± 9.72 dB, 56.18 ± 11.25 dB, and 51.47 ± 17.21 dB, respectively) than in those without OHF (51.88 ± 15.95 dB, 44.40 ± 16.34 dB, and 39.49 ± 16.26 dB, respectively). However, there was no statistical significance between groups at 4000 Hz (Student's *t*-test; *$P < .05$; **$P < .01$; Table 3). Further analysis of BCTs compared to OHF demonstrated a significant relationship between BCTs at 1000 and 2000 Hz and OHF. Bone conduction thresholds at 1000 and 2000 Hz were significantly worse in ears with OHF (17.35 ± 7.93 dB and 20.59 ± 13.10 dB, respectively) than in those without OHF (13.92 ± 10.08 dB and 14.24 ± 11.49 dB, respectively). However, there was no significant relationship between BCTs and OHF at 500 and 4000 Hz (Mann–Whitney *U*-test, *$P < .05$; Table 3). Pre-operative ACTs and BCTs were also compared to SFPF item scores. For pre-operative SFPF, ACTs in the 500, 1000, 2000 to 4000 Hz range were significantly worse in ears with SFPF (64.21 ± 11.70 dB, 63.42 ± 11.67 dB, 57.37 ± 15.22 dB, 54.47 ± 15.36 dB, respectively) than those without SFPF (51.20 ± 15.46 dB, 43.43 ± 15.47 dB, 38.67 ± 15.75 dB, 43.95 ± 19.64 dB, respectively) (Student's *t*-test; *$P < .05$, **$P < .01$; Table 4). According to the presence of SFPF, BCTs from 500 to 4000 Hz were significantly worse in ears with SFPF (22.63 ± 9.77 dB, 23.95 ± 12.54 dB, 25.26 ± 11.48 dB, 27.11 ± 13.67 dB, respectively) than in those without SFPF (16.98 ± 10.79 dB, 13.12 ± 8.99 dB, 13.63 ±11.21 dB, 16.40 ± 14.69 dB, at 500, 1000, 2000 and 4000 Hz respectively) (Mann–Whitney

Table 3. Analysis of Air and Bone Conduction Thresholds According to the Presence or Absence of Ossicular Head Fixation

Air Conduction Thresholds		Ossicular Head Fixation		*P*
		Present	Absent	
500 Hz	Mean ± SD	59.12 ± 9.72	51.88 ± 15.95	.011*
	Min-Max	45-80	15-100	
1000 Hz	Mean ± SD	56.18 ± 11.25	44.40 ± 16.34	.001**
	Min-Max	35-75	10-90	
2000 Hz	Mean ± SD	51.47 ± 17.21	39.49 ± 16.26	.004**
	Min-Max	30-85	5-90	
4000 Hz	Mean ± SD	49.41 ± 20.83	44.58 ± 19.34	.331
	Min-Max	20-100	5-120	
Bone Conduction Thresholds				
500 Hz	Mean ± SD	19.71 ± 7.80	17.34 ± 11.06	.195
	Min-Max	5-35	0-50	
1000 Hz	Mean ± SD	17.35 ± 7.93	13.92 ± 10.08	.042*
	Min-Max	5-35	0-55	
2000 Hz	Mean ± SD	20.59 ± 13.10	14.24 ± 11.49	.018*
	Min-Max	5-50	0-60	
4000 Hz	Mean ± SD	20.29 ± 18.50	17.22 ± 14.54	.500
	Min-Max	5-70	0-80	

Student *t*-test with *$P < .05$, $P < .01$ and ** is used for air conduction thresholds. Mann–Whitney *U*-test with *$P < .05$ is used for bone conduction thresholds.

U-test; *$P < .05$, **$P < .01$; Table 4). In addition to the significant difference between the groups with or without SFPF, we analyzed the cut-off value for preoperative BCTs that may determine the presence of SFPF. The ROC analysis and diagnostic tests revealed that ≥20 dB and ≥25 dB were cut-off values for determining SFPF (Table 5). If ≥20 dB for 500, 1000, and 4000 Hz and ≥25 dB for 2000 Hz as an optimal cut-off values, analysis of the sensitivity, specificity, and positive and negative predictive values for BCTs would yield several sets of results, which are described below. The highest sensitivity (78.95%) was at 500 Hz and the highest specificity (81.33%) was at 2000 Hz. The highest positive predictive values (25.00% and 29.55%) occurred at 1000 and 2000 Hz, respectively, and the highest negative predictive values (96.12% and 95.74%) were at 1000 and 2000 Hz, respectively (Table 5). Bone conduction thresholds that were not worse than 20 dB at 1000 Hz and 2000 Hz were predictors of mobile stapes foot plate. The analysis of the association between SFPF and the 20 dB cut-off value for BCT at 500 Hz showed a 4.130-fold increase in SFPF frequency when preoperative BCT exceeded 20 dB at 500 Hz (Odds ratio [OR] 4.130, 95% CI 1.315-12.967; Table 6). The OR for the 20 dB BCT at 1000 Hz was 8.267 (95% CI 2.809-24.328). However, SFPF was 9.435 times more frequently present when BCT was >25 dB at 2000 Hz (OR 9.435, 95% CI 3.325-26.779; Table 6). The OR for the 20 dB BCT at 4000 Hz was 5.807 (CI 1.989-16.956; Table 6). The diagnostic tests were further evaluated to detect the frequency of SFPF when the BCT cut-off values at 1000 and 2000 Hz were combined. Bone conduction thresholds over 20 dB at 1000 and 2000 Hz

Table 4. Air and Bone Conduction Thresholds According to Stapes Foot Plate Fixation

Air Conduction Thresholds		Stapes Footplate Fixation		
		Present	Absent	*P*
500 Hz	Mean ± SD	64.21 ± 11.70	51.20 ± 15.46	**.001****
	Min-Max	45-90	15-100	
1000 Hz	Mean ± SD	63.42 ± 11.67	43.43 ± 15.47	**.001****
	Min-Max	45-90	10-90	
2000 Hz	Mean ± SD	57.37 ± 15.22	38.67 ± 15.75	**.001****
	Min-Max	30-90	5-85	
4000 Hz	Mean ± SD	54.47 ± 15.36	43.95 ± 19.64	**.025***
	Min-Max	25-90	5-120	
Bone Conduction Thresholds				***P***
500 Hz	Mean ± SD	22.63 ± 9.77	16.98 ± 10.79	**.013***
	Min-Max	5-40	0-50	
1000 Hz	Mean ± SD	23.95 ± 12.54	13.12 ± 8.99	**.001****
	Min-Max	5-55	0-50	
2000 Hz	Mean ± SD	25.26 ± 11.48	13.63 ± 11.21	**.001****
	Min-Max	5-40	0-60	
4000 Hz	Mean ± SD	27.11 ± 13.67	16.40 ± 14.69	**.001****
	Min-Max	5-55	0-80	

Student t-test with *P < .05, **P < .01 is used for analyzing Air conduction thresholds according to stapes foot plate fixation.
Mann–Whitney U-test with a *P < .05, **P < .01. *for analyzing the Bone conduction thresholds according to stapes foot plate fixation.

Table 5. Diagnostic Tests for determining the Cut-off Levels for BCTs over the 500-4000 Hz in Ears with Stapes Foot Plate Fixation

BCTs	Sensitivity	Specifity	Positive Predictive Value	Negative Predictive Value
500 Hz				
≥10	89.47	26.51	12.23	95.65
≥15	78.95	40.96	1.27	94.44
≥20	**78.95**	**52.41**	**15.96**	**95.60**
≥25	57.89	72.29	19.30	93.75
≥30	26.32	85.54	17.24	91.03
1000 Hz				
≥10	94.74	33.73	14.06	98.25
≥15	78.95	56.02	17.05	95.88
≥20	**73.68**	**74.70**	**25.00**	**96.12**
≥25	42.11	85.54	25.00	92.81
≥30	31.58	92.77	33.33	92.22
2000 Hz				
≥10	94.74	40.36	15.38	98.53
≥15	73.68	59.64	17.28	95.19
≥20	**68.42**	**71.08**	**21.31**	**95.16**
≥25	**68.42**	**81.33**	**29.55**	**95.74**
≥30	52,.63	90.36	38.46	94.34
4000 Hz				
≥10	94.74	34.34	14.17	98.28
≥15	73.68	53.61	15.38	94.68
≥20	**73.68**	**67.47**	**20.59**	**95.73**
≥25	68.42	75.30	24.07	95.42
≥30	52.63	81.93	25.00	93.79

displayed a 9.822-fold increase in SFPF presence (OR 9.822, 95% CI 3.454-27.929; Table 6). Moreover, when combined, BCTs >20 dB at 1000 Hz and >25 dB at 2000 Hz were 13.471 times more frequently associated with SFPF (OR 13.471, 95% CI, 4.654-38.993; Table 6). Analysis of the predictive value of BCTs using the ROC curve area method with a 95% CI demonstrated that BCTs exceeding the 20 dB cut-off level at 1000 Hz and 20 or 25 dB at 2000 Hz were better at predicting the presence of SFPF in COM (Figure 1).

Discussion

Tympanoplasty outcomes are still a concern for otologic surgeons. In addition to many factors such as the ME mucosa, presence of cholesteatoma, etc. the status of ME ossicles is known to play the principal role in this outcome. Based on these risk factors, several outcome methods have been developed in the literature.[10-13] Although they are useful for pre-operative counseling, these methods cannot be used pre-operatively without exploratory tympanotomy.[14] These limits led us to analyze the relationship of pre-operative ACTs and BCTs with MERI and the prognostic indicators of this system that include intra-operative ME ossicles' fixation status for having more accurate pre-operative instructions about surgery outcomes and ME ossicle status.[10-12] Former studies on the acoustic energy transmission mechanism to the cochlea revealed that the ME resonance frequency for AC differs from that of BC.[15,16]

Later on, a temporal bone ME structural system model demonstrated that there were two mechanisms for ossicle vibration, as follows: hinging at 1.2 kHz under AC and pivoting at 1.7 kHz under BC.[17] Based on this difference in ME structure resonance between BC and AC stimulation, we focused on ACTs and BCTs rather than on ABG to estimate the disease severity and ossicle fixation using these data. The correlation analysis between ACTs, BCTs over the range of 500 to 4000 Hz, and MERI scores demonstrated that ACTs and BCTs were all positively correlated with these risk scores, and the highest correlation between ACTs, BCTs, and MERI was at 1000 Hz. The result that the worsening of ACTs and BCTs at 1000 Hz were indicators of worse MERI may probably be attributable to the resonance frequency of the ME structures which is around 1000 Hz. Furthermore, ACTs and BCTs were also found to be related to OHF, and this was observed in 9.2% of the ears. Worse ACTs over 500 to 2000 Hz and worse BCTs at 1000 and 2000 Hz were significantly related to intraoperative OHF. Ossicular head fixation was reported to be 23% in the literature when matched with fixation of the incudomalleolar

Table 6. Relation of the Cut-off Levels of BCTs over the 500-4000 Hz with the Presence of Stapes Foot Plate Fixation

		SFPF Absent		SFPF Present		
		n	%	n	%	*P*
500 Hz BCT	**<20**	87	52.4	4	21.1	**.010***
	≥20	79	47,6	15	78.9	
1000 Hz BCT	**<20**	124	74.7	5	26.3	**.001****
	≥20	42	25.3	14	73.7	
2000 Hz BCT	**<25**	135	81.3	6	31.6	**.001****
	≥25	31	18.7	13	68.4	
4000 Hz BCT	**<20**	112	67.5	5	26.3	**.001****
	≥20	54	32.5	14	73.7	
1000 Hz + 2000 Hz BCT	**<20**	136	81.9	6	31.6	**.001****
	≥20	30	18.1	13	68.4	
1000 Hz (≥20) + 2000 Hz (≥25) BCT	**<20 + <25**	143	86.1	6	31.6	**.001****
	≥20 + ≥25	23	13.9	13	68.4	

Pearson chi-square test.
**P* < .05.
***P* < .01.

complex or the stapes or both. Similar to our findings, hearing loss at 500-2000 Hz was significantly higher in ears with, compared to without, OHF.[18] Worsening of BCTs between 1 and 4 kHz was reported to occur among patients with COM.[19] Furthermore, the impairment of BCTs at these frequencies was described in various conditions that affect the ME conduction mechanism.[20] However, the correlation between OHF and hearing attenuation at these frequencies was demonstrated by Nakajima who observed a higher velocity magnitude up to 2 kHz and only small changes in the velocity magnitude at frequencies above 2 kHz after experimental fixation of the

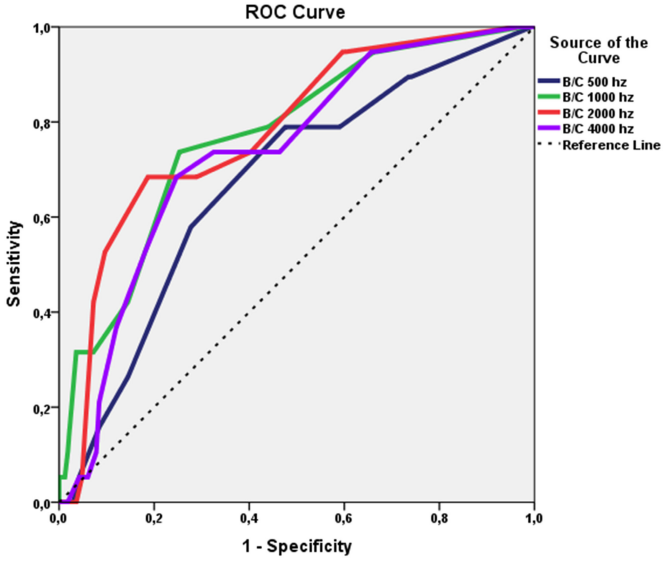

Figure 1. ROC curve of bone conduction thresholds over the 500-4000 Hz related to the presence of stapes foot plate fixation.

malleus head. Increasing stiffness of ME the structural elements was determined to affect hearing over frequencies of 500-2000 Hz.[21] Taken together OHF may be estimated preoperatively for worse ACTs and BCTs at 500-2000 Hz. Stapes foot plate fixation, another subcategory of MERI, is a critical obstacle to the success of reconstructing the sound conduction mechanism.[22] Stapes foot plate fixation was significantly related to worse pre-operative ACTs and BCTs in the 500-4000 Hz range in our cohort. Carhart was the first to reveal the deterioration of bone conduction in SFPF.[23] Worse BCTs over the range of 500-4000 Hz in ears with SFPF are also reported in ears with SFPF, malleus, or incus fixation.[20] Diverse studies that display significantly worse BCTs at 500, 1000, and 2000 Hz and a level close to significance at 4000 Hz in ears with an immobile ossicular chain were published in subsequent years.[24] Opinions that suggest that an alteration in BCTs may also be generated by several other factors that involve sound conduction to the inner ear are seen in published articles.[25] However, Stenfelt observed an artificially fixed stapes on human cadaveric temporal bones and showed that middle-ear inertia affects BC perception at frequencies between 1 and 3 kHz.[26] These observations are further supported by Nakajima et al[27] and Chhan et al[28] who showed a decrease in umbo and stapes velocities under BC stimulus between 1000 and 3000 Hz after experimental fixation of the stapes. Our findings of a worse ACT and BCT in ears with immobile stapes were in accordance with these studies. Few discrepancies that exist over 4000 Hz may be, in our opinion, linked to the small sample size in the experimental studies. Transmission of sound to the cochlear fluid occurs via skull vibrations, such as through BC in ears with an immobile stapes. Because BC plays a main role in sound conduction in the presence of SFPF and because of the significant difference between BCTs in ears with or without SFPF, we investigated the cut-off level, the predictive value, and odds ratios of BCTs in this situation. The cut-off value for preoperative BCTs at 500, 1000, and 4000 Hz was determined to be ≥20 dB and ≥25 dB at 2000 Hz.These cut-off values were significantly related to SFPF. Additionally, the OR analysis of the ≥20 dB cut-off value for BCTs at 1000 Hz increased 8.267-fold with the association of SFPF, whereas the presence of SFPF was 9.435-times more commonly seen when the BCT was >25 dB at 2000 Hz. This association was 13.471 times higher when the BCT cut-off level at 1000 Hz (≥20 dB) and at 2000 Hz (≥25) were both present in preoperative BCTs. These findings are also supported by ROC curve analysis, which demonstrated that preoperative BCTs that exceeded 20 dB at 1000 and 2000 Hz showed a tendency to be better predictors of intraoperative SFPF. Our findings were consistent with those of previous authors who indicated that BC resonance frequencies were apparent in the 1-2 kHz range.[16] The present findings are further supported in a human cadaver study that stated the alteration of stapes-to-umbo ratio between 1000 and 2000 Hz when the stapes was fully fixed with glue.[29] Objections to and support of these statements are also encountered in the scientific literature. In a cohort comprising patients with SFPF, OHF, and incudostapedial discontinuity, Kashio showed that a preoperative bone depth of 2 kHz was specific to SFPF, and it may also be influenced by any ossicular chain deficiency. However, for HLs in the author's cohort, BCTs for patients with SFPF were worse than those of the other 2 groups.[20] The author would probably have obtained results that were similar

to ours if they had performed the analysis based on only ACTs and BCTs. In a study in 2007, Carhart's notch was found to be predictive for stapes mobility at 1000 Hz and for footplate fixation at 2000 Hz.[30] Our observations were not completely consistent with the above-mentioned study. The 1000 and 2000 Hz BCTs >20 dB better predicted SFPF in our data. The discordance between our results and those of the above-mentioned publication was likely because of differences between cohorts. We analyzed data from patients with COM. However, the authors collected their data from a complex group of patients with otosclerosis, tympanosclerosis, temporal bone trauma, and COM. Moreover, their data were presented as a percentage and they did not statistically analyze the predictive values and OR at these frequencies. Our findings that BCTs >20 dB at 1000 Hz in conjunction with BCTs >25 dB at 2000 Hz was 13.471-times more associated with SFPF has not been previously investigated. To the best of our knowledge, this was the first study on this topic. Methods for determining the status of ME ossicles, specifically the stapes, remain controversial in the scientific literature. Arguments against the value of audiological data rely upon the subjective test characteristics which was also a limitation of the present study. However, for the high OR (13.5) that was derived from combined cut-off levels of these frequencies, we may assert that preoperative cut-off levels of 1000 and 2000 Hz provide definitive information about the intraoperative stapes fixation status.

Higher ACTs and BCTs over 500-4000 Hz are significantly correlated with worse tympanoplasty outcome risk scores (MERI). Additionally, 1000 Hz (ACTs–BCTs) was the frequency that correlated most often with MERI. High preoperative ACTs are significantly related to OHF at 500, 1000, and 2000 Hz. High preoperative BCTs at 1000 and 2000 Hz are significantly linked to OHF. Air conduction thresholds and BCTs at 500-4000 Hz all increase significantly in patients with SFPF. The combined preoperative BCT cut-off values of ≥20 dB at 1000 Hz and ≥25 dB at 2000 Hz were better predictors than that of 500 Hz and 4000 Hz at 20 dB, and they had a 13.5-fold greater association with SFPF in COM.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethics approval was obtained from the Ethics Committee of Haydarpaşa E.R. Tertiary Referral Center (serial number HNEAH-KAEK,2012/62,Date:01.10.2012).

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Supplementary Table 1. Middle Ear Risk Index 2001

Risk factors	Risk Value
Otorrhea (Bellucci)	
I. Dry ear	0
II. Occasionally wet	1
III. Persistently wet	2
IV. Persistently wet with cleft palate	3
Perforation	
None	0
Present	1
Cholesteatoma	
None	0
Present	2
Ossicular Status (Austin Kartush)	
0) M+I+S+	0
A) M+S+	1
B) M+S-	2
C) M-S+	3
D) M-S-	4
E) Ossicular head fixation	2
F) Stapes fixation	3
Middle ear: granulation or effusion	
No	0
Yes	2
Previous surgery	
No	0
Staged	1
Revision	2
Smoking	
No	0
Yes	2
	Total MER Index

Supplementary Table 2. Distribution of MERI scores among the patients

Risk Factors	n	%
Otorrhea (Bellucci)		
Dry Ear	89	48,1
Occasionally wet	45	24,3
Persistently wet	35	18,9
Persistently wet with cleft palate	-	-
Perforation	162	87,6
Cholesteatoma	3	1,6
Ossicular Status (Austin Kartush)		
M+I+S+	116	62,7
M+S+	23	12,4
M+S-	14	7,6
M-S+	6	3,2
M-S-	4	2,2
Ossicular head fixation	17	9,2
Stapes foot plate fixation	19	10,3
Middle ear: Granulation, Effusion	89	48,1
Previous surgery	8	4,3
Smoking	31	16,7