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Wideband Tympanmetry Results of Bone Cement Ossiculoplasty

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A B S T R A C T

Objective: We aim to investigate hearing sensitivity and wideband tympanometry results in bone cement ossiculoplasty cases in present study.
Study design: A prospective study.
Setting: Ossiculoplasty patients were grouped according to the anatomical location of bone cement application by surgery note. Ossiculoplasty and tympanoplasty patients were retrospectively invited to the clinic and evaluated. 30 bone cement ossiculoplasty cases as well as 30 Type I tympanoplasty cases (intact ossicular chain) and 30 healthy controls were included in the study and Wideband Tympanometry was performed. Tympanometric peak pressure, equivalent middle ear volume, static admittance, tympanogram width, resonance frequency, average wideband tympanometry and absorbance measurements were analyzed.
Results: A statistically significant improvement was observed in the hearing levels of all ossiculoplasty and type I tympanoplasty patients ($p < 0.05$). Bone cement ossiculoplasty groups demonstrated the remarkable differences than the type I tympanoplasty and control group in Wideband Tympanometry test parameters. In some parameters, malleus-stapes and manubriostapedioplasty groups demonstrated similarities to Type I tympanoplasty and control groups.
Conclusion: Bone cement is an effective application for ossiculoplasty. Wideband tympanometry is a promising method for the evaluation of the middle ear dynamics.

1. Introduction

The objective of tympanoplasty is the eradication of the pathology existing in the middle ear and restoration of the hearing [1]. The sound transfer mechanism should ensure a link between the vibrating tympanic membrane and cochlea in the middle ear [1,2]. The most frequent ossicular chain defect is encountered between incus and stapes during tympanoplasty [3]. The ideal ossiculoplasty technique should be easy to apply and the material used in operation should be affordable and biocompatible. The application of bone cement is a biologically well-tolerated method which creates ossicular chain integrity, also it has a low risk of extrusion high stability [4,5].

Wideband Tympanometry (WBT) is an immittancemetric method in which the click stimulus is used at a wide frequency range (226–8000 Hz) applied through the external ear canal [6]. The WBT having a similar working principle with that of conventional immittancemetry asses the sound transfer function of the middle ear [6,7].

The purpose of this study is to analyze the effect of the bone cement ossicular reconstruction on the middle ear by using WBT and to evaluate whether the bone cement creates a stiffness or mass effect which diminishes middle ear resonance.

2. Material and methods

2.1. Participants

This study was conducted from January 2015 to December 2016 in Audiology and Speech Pathology Unit of Hacettepe University. The study was approved by Hacettepe University Faculty of Medicine Non-interventional Clinical Research Ethics Comietee.

Participants of our study were 18–65 years of age. The control group participants (n = 30) were healthy individuals visited the hospital for a medical check-up with no otological complaint and normal otoscopic examination. The study group consisted of 2 groups were made ossiculoplasty (n:30) and Tip I tympanoplasty (n:30). Ossiculoplasty group was performed by using bone cement and divided into 3 subgroups according to the location of bone cement application; incus-stapes group (n:10), malleus-stapes group (n:10) and manubriostapedioplasty group (n:10). The Tympanic membrane was repaired with cartilage graft in all ossiculoplasty groups. Type I tympanoplasty group was created to control the effect of the membrane in individuals applied bone cement. The Ossicular chain was intact in Type I tympanoplasty group for whom cartilage grafts were applied.

The ossicular chain defect was repaired using glass ionomer cement (Ketac-Cem, Espe Dental AG, Seefeld, Germany). This type of bone cement is composed of a sterile powder and a liquid. Two components

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were mixed on a metal surface in sterilized conditions before the establishment of the bone bridge during surgery. The mixture was placed by a thin pick and 5-minute waiting period was necessary to enable stabilization of the bridge. Absorbable materials were used to support the graft in the middle ear.

2.2. Audiometric measurements

The pure tone air conduction (125–8000 Hz), bone conduction (500–4000 Hz) thresholds and pure tone average (PTA) at 500, 1000, 2000 and 4000 Hz were recorded before and after the surgery as well as during the routine follow-ups of the patients. An Audiological evaluation was performed at least 3 months for a subject after the surgery by an audiologist if the subject had an intact graft membrane with the normal external ear canal. Pure tone thresholds were conducted in the Industrial Acoustics Company's (IAC) soundproof rooms with stereo audiometers (GrasonStadler GSI 60 with Telephonics TDH-50P earphone, B17 vibrator).

2.3. Wideband tympanometry (WBT) measurements

WBT (Tympanometric Peak Pressure-TPP, equivalent ear canal volume-V_{eq}, compensated static acoustic admittance-Y_{tm}, the tympanometric width-TW and resonance frequency-RF) measurements were performed using Interacoustics Titan Suite software (version 3.1.024, Middelfart, Denmark) with wideband click stimulus for the frequency range of 226–8000 Hz with 2.5 s duration time [6,7]. Average wideband tympanometry (A-WBT) measurement and absorbance measurements (at tympanometric peak pressure and ambient pressure) were conducted progressively in the same session with a wideband click stimulus.

2.4. Statistical analysis

The recorded data was transferred into a special MS Office Excel (Microsoft Corp., Redmond, WA, USA) file labeled as “WBT” created by the company, namely Interacoustics, for analysis, and a numerical breakdown and a graphics display were generated. TPP, V_{eq}, Y_{tm}, TW, RF, A-WBT findings were further transferred into SPSS 22 (Armonk, NY: IBM Corp.) computer software and analyzed. The arithmetic means, standard deviations, minimum, and maximum values, were provided as the descriptive statistics. The comparison of preoperative and postoperative hearing test results of the groups with ossiculoplasty and tympanoplasty was performed with the Wilcoxon Signed Rank Test. The comparison of the results of between groups WBT parameters was performed with Tukey HSD Test. The comparison of in-groups findings of WBT parameters was performed with the Wilcoxon Signed Rank Test.

3. Results

3.1. Demographic findings

Ninety (n = 90) individuals enrolled in the study. The study and control groups showed no difference in terms of age and gender distribution. Otoscopic examination was performed before the tests. For all individuals in the study group, the tympanic membrane healed without any perforation.

3.2. Audiometric results

Hearing outcomes of all study groups were shown in Table 1. The mean preoperative PTA (38.45 dB) and postoperative PTA (24.12 dB) difference was statistically significant in Type I tympanoplasty group ($p < 0.05$). Among the ossiculoplasty groups; PTA was declined from 52.87 dB to 33.75 dB in the incus-stapes group, from 38 dB to 25.25 dB in the malleus-stapes group and from 47.25 dB to 18.20 dB in the manubriostapedioplasty group. These differences were also significant ($p < 0.05$). Fig. 1 illustrates the preoperative and postoperative hearing sensitivity of the study groups.

Table 1
Hearing Outcomes of study groups.

Groups		Mean PTA (dB)	Mean ABG (dB)
Incus-stapes	Pre-operative	52.87	34.62
	Post-operative	33.75	15.50
Malleus-stapes	Pre-operative	38.00	39.50
	Post-operative	25.25	12.00
Manubriostapedioplasty	Pre-operative	47.25	40.25
	Post-operative	18.20	12.62
Type 1 Tympanoplasty	Pre-operative	38.45	28.16
	Post-operative	24.12	12.12

Mean PTA and ABG values were evaluated taking into account 500, 1000, 2000 and 4000 Hz thresholds (PTA: pure tone average, ABG: air-bone gap).

The success of the surgery was evaluated in terms of the air-bone gap closure. In Type I tympanoplasty group; preoperative and postoperative air-bone gap values were 28.16 dB and 12.12 dB, respectively and this difference was statistically significant ($p < 0.05$). Among the ossiculoplasty groups; the preoperative air-bone gap was declined from 34.62 dB to 15.50 dB in the incus-stapes group, from 39.50 dB to 12 dB in the malleus-stapes group and from 40.25 dB to 12.62 dB in the manubriostapedioplasty group (see Fig. 2). These differences were also significant ($p < 0.05$).

3.3. Wideband tympanometry results

The descriptive values of WBT results obtained in the range of 226–8000 Hz (at the frequency point of 107) are shown in Table 2.

Tympanometric Peak Pressure (TPP) differences among groups were observed statistically significant and outstanding ($p > 0.05$), but in the normal range. The TPP values of two study groups (incus-stapes and Type I tympanoplasty) were found on the more negative side than the others, respectively −66.40 and − 65.16 daPa.

Equivalent ear-canal volume (V_{eq}) parameters exhibit similarities among the results of the malleus-stapes, the manubriostapedioplasty and control groups, and the contrast between the incus-stapes and the Type I tympanoplasty groups. The largest V_{eq} (1.96 ± 0.46 ml) was obtained for the incus-stapes group, and the difference between the incus-stapes group and all other groups was statistically significant ($p < 0.05$).

Compensated static acoustic admittance (Y_{tm}) demonstrated a difference among groups with the lowest value (0.36 ± 0.31 ml) in Type I tympanoplasty group. The difference between Type I tympanoplasty group and the control group was statistically significant ($p < 0.05$).

The tympanometric width (TW) indicates the sharpness of the tympanogram peak. The values of TW obtained from incus-stapes group and Type I tympanoplasty groups turned out to be close to each other, but wider compared to other groups. The amount of the narrowest TW (78 ± 26.27 daPa) was obtained from the control group. The difference between the control and incus-stapes groups was statistically significant as between the control and Type I tympanoplasty groups ($p < 0.05$).

Resonance frequency (RF) values were closely correlating in malleus-stapes, manubriostapedioplasty and Type I tympanoplasty groups. The difference among these three groups was not statistically significant ($p > 0.05$). The highest RF value (1103 ± 111.34 Hz) was obtained from the control group and so there was a statistically significant difference between the control and other groups ($p < 0.05$). The lowest RF value (441.3 ± 90.71 Hz) was obtained from the incus-stapes ossiculoplasty group. The difference between incus-stapes group and other groups was also statistically significant ($p < 0.05$).

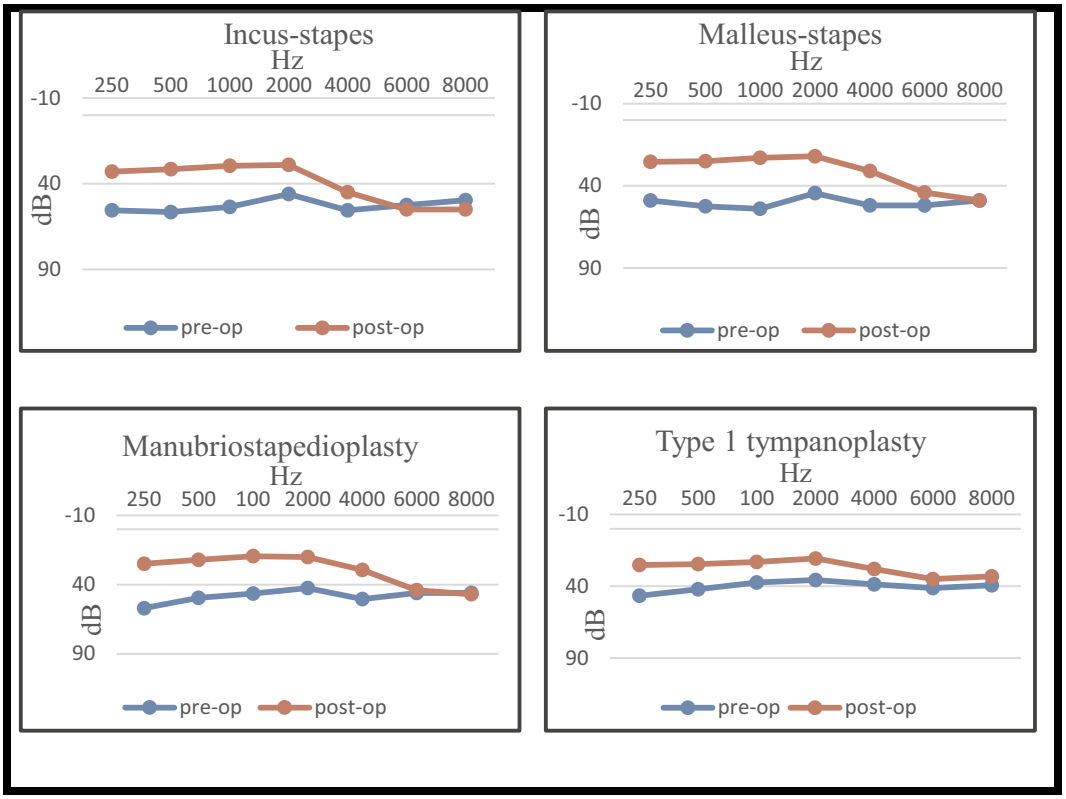

Fig. 1. Preoperative and postoperative hearing sensitivity of the study groups.

3.4. Absorbance at tympanometric peak pressure and ambient pressure

The absorbance values of all individuals were analyzed at 107 frequency points under the tympanometric peak and ambient pressure in the range of 226–8000 Hz. There were statistically significant difference between absorbance values under the tympanometric peak and the ambient pressure for the incus-stapes group between 226 and 1887 Hz, for the malleus-stapes group between 324 and 686 Hz, for the manubriostapedioplasty group between 385 and 771 Hz and for the Type I tympanoplasty group between 458 and 840 Hz ($p < 0.05$). No difference was observed between the absorbance values under the tympanometric peak pressure and ambient pressure for the control group.

Under the ambient pressure, for the incus-stapes group; the lowest absorbance value was 0.04 in the frequency range of 4000–8000 Hz, whereas the highest absorbance value was 0.87 at 727 Hz. For the malleus-stapes group; the lowest absorbance value was 0.05 at 297 Hz and the highest value was 0.95 at 2911 Hz. For the manubriostapedioplasty group; the lowest absorbance value was 0.03 at 324 Hz, whereas the highest value was 0.93 at 1414 Hz. For Type I tympanoplasty group; the lowest absorbance value was 0.02 at 324 Hz with the highest value of 0.96 at 1000 Hz. For the control group; the lowest absorbance value was 0.06 at 297 Hz while the highest value was 0.99 at 2911 Hz.

3.4.1. Absorbance values of groups at ambient pressure

The absorbance values of all groups under ambient pressure were shown in Fig. 3. The comparison of the ossiculoplasty groups and Type I tympanoplasty group reveals that the difference in the range of 226–8000 Hz was not statistically significant ($p > 0.005$). There were no statistically significant difference between the malleus-stapes and

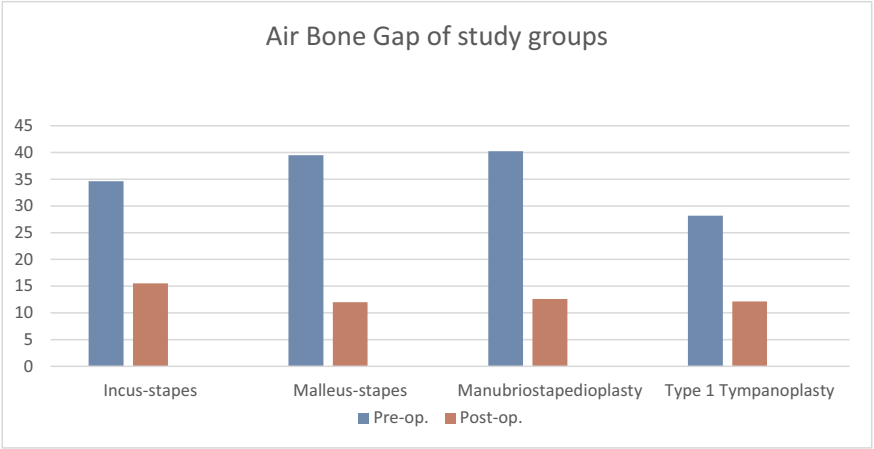

Fig. 2. Preoperative and postoperative Air Bone Gap of study groups (in dB).

Table 2
Wideband Tympanometry measurement results of the study and control groups.

	TTP Mean ± SD	V_{eq} Mean ± SD	Y_{tm} Mean ± SD	TW Mean ± SD	RF Mean ± SD
Incus-stapes	−66.40 ± 82.08	1.96 ± 0.46	0.76 ± 0.73	167.70 ± 107.39	441.3 ± 90.71
Malleus-stapes	−46.50 ± 78	1.40 ± 0.32	0.45 ± 0.54	134 ± 78	711.2 ± 111.6
Manubriostapedioplasty	−28.80 ± 78.28	1.40 ± 0.24	0.57 ± 0.58	98 ± 86.13	725.70 ± 68.61
Type1 tympanoplasty	−65.16 ± 99.46	1.50 ± 0.34	0.36 ± 0.31	161 ± 93.94	722.63 ± 107.29
Control	−4 ± 14.32	1.40 ± 0.35	0.85 ± 0.50	78 ± 26.27	1103 ± 111.34

(TTP: Tympanometric Peak Pressure (daPa), V_{eq}: Equivalent Ear-Canal Volume (ml), Y_{tm}: Static Acoustic Admittance (ml), TW: Tympanogram Width (daPa), RF: Resonance Frequency (Hz))

manubriostapedioplasty groups ($p > 0.005$). There was a statistically significant difference between incus-stapes and malleus-stapes groups at 2310–3363 Hz range and between incus-stapes and manubriostapedioplasty groups at 2310–2593 Hz range ($p < 0.05$).

3.4.2. Absorbance values of groups at tympanometric peak pressure

The absorbance values of all groups under tympanometric peak pressure were shown in Fig. 4. The comparison of ossiculoplasty groups and Type I tympanoplasty group revealed no statistically significant difference in the range of 226–8000 Hz ($p > 0.005$). There were no statistically significant difference between malleus-stapes and manubriostapedioplasty groups ($p > 0.005$) but there was a statistically significant difference between incus-stapes and malleus-stapes groups in the range of 2118–3267 Hz and between incus-stapes and manubriostapedioplasty groups in the range of 2244–2593 Hz ($p < 0.05$).

3.5. Wideband averaged tympanometry (A-WBT) results

The peak pressure amplitudes of all study groups display more kurtosis in comparison to the control group (see Fig. 5). Upon the review of A-WBT graphics, greater kurtosis was observed in the incus stapes group compared to other groups. Similar results (same kurtosis) were obtained in the malleus-stapes group and in the manubriostapedioplasty group. A-WBT values turned out to be −22 daPa in the incus-stapes group, −8 daPa in the malleus-stapes group, −5 daPa in the manubriostapedioplasty group, −11 daPa in Type I tympanoplasty group and − 2 daPa in the control group.

4. Discussion

The bone cement is preferred and applied in our clinic in ossicular reconstruction given the ossicular chain integrity, low extrusion risk, high stability in proper application and due to the fact that it is a biocompatible, cheap and easily applicable method [4,8]. A review conducted on the literature discloses that the bone cement as published in numerous articles does not lag behind in terms of hearing recovery compared to partial ossicular replacement prosthesis (PORP) or incus transposition [4,9,10].

Gungor et al. (2016) advised in their study that the average of the preoperative hearing thresholds of air conduction of incus-stapes

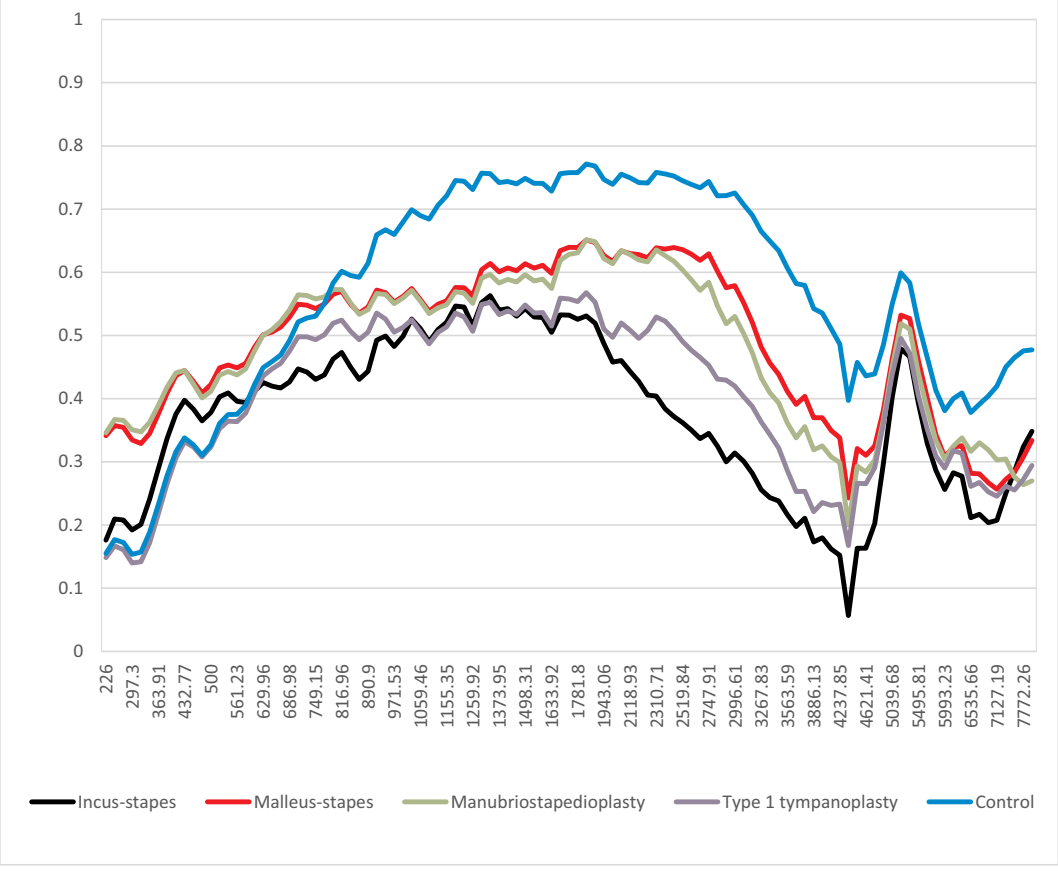

Fig. 3. Results of absorbance curves under ambient pressure.

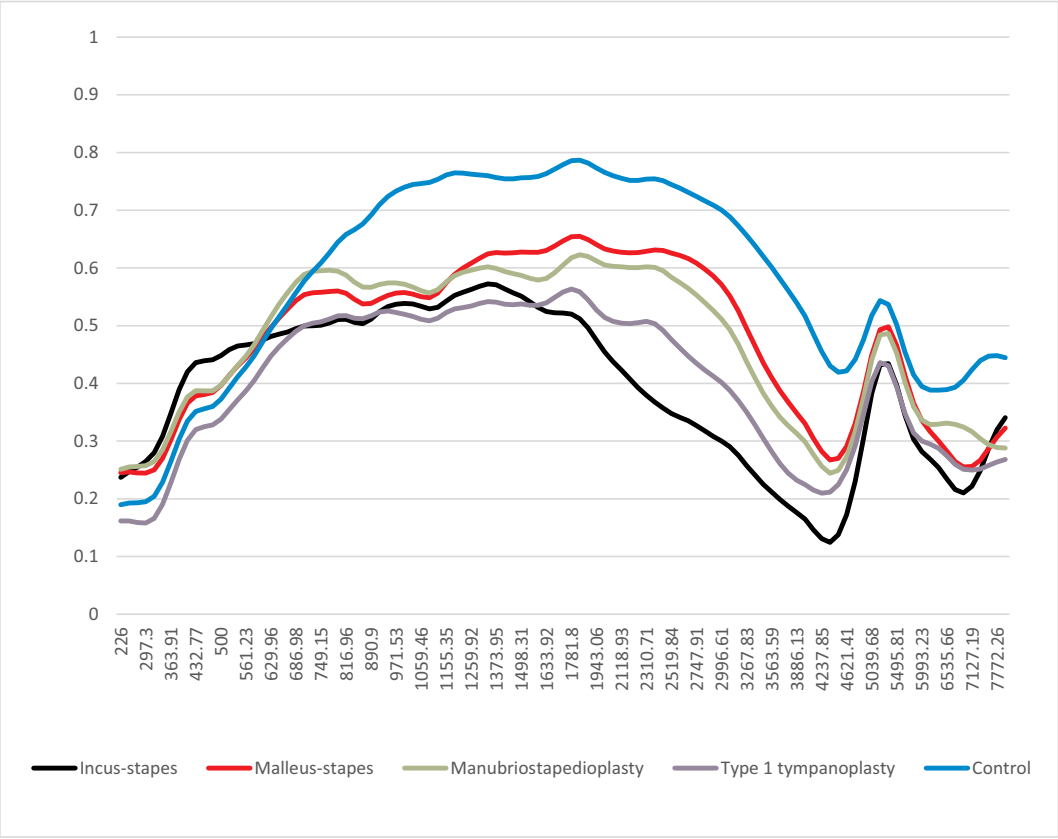

Fig. 4. Results of absorbance curves under tympanometric peak pressure.

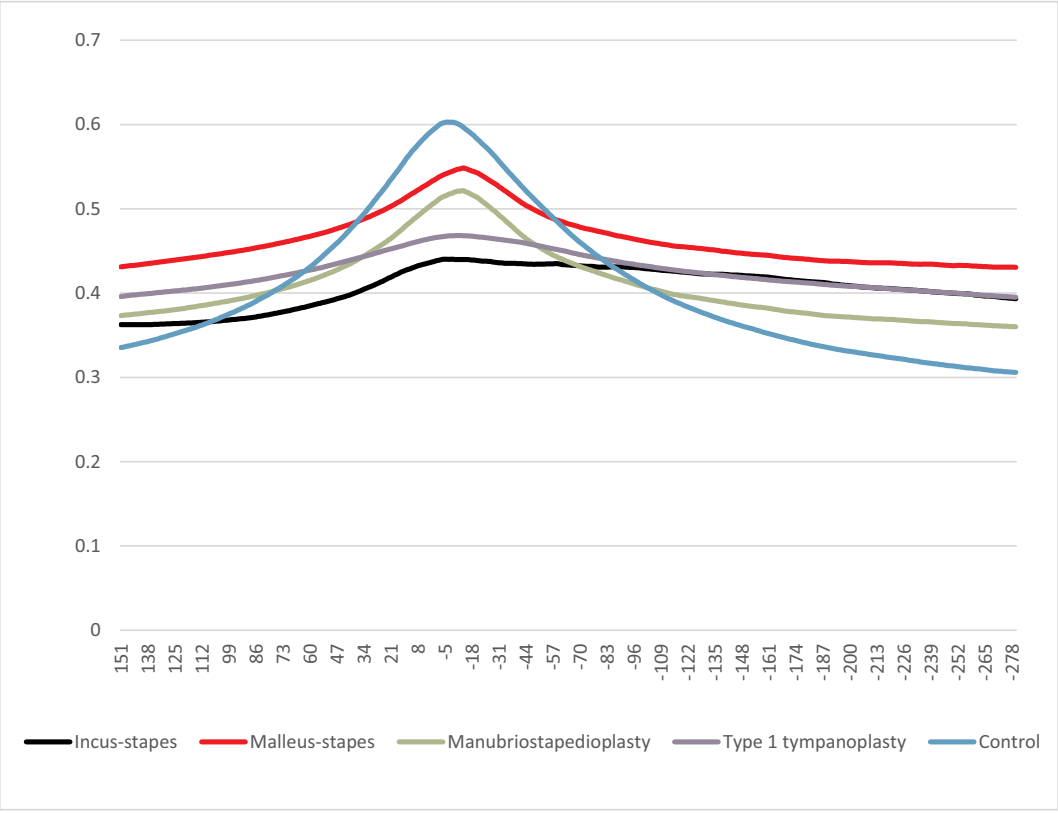

Fig. 5. Wideband Averaged Tympanometry graphics of groups.

ossiculoplasty group who underwent bone cement application was 49.6 dB and changed to 35.5 dB [4]. Air-bone gap was less than 20 dB in 70% of the patients while the gap was less than 10 dB in 43% of the patients [4]. Baylancicek et al. (2014) compared the bone cement and PORP results on incudostapedial joint and reported that the difference between the hearing recoveries obtained from both groups was not statistically significant [9].

In our study, we examined the results of preoperative and postoperative air conduction thresholds and air-bone gaps. A significant improvement was observed in the air conduction thresholds within the range of 250–4000 Hz in the incus-stapes ossiculoplasty group after the surgery. The air-bone gap average was 34.62 dB preoperatively and observed as 15.62 dB postoperatively. It was observed that the air conduction thresholds within the frequency range of 250–6000 Hz significantly improved after the operation since the pre-operational air-bone gap average was 39.50 dB and changed to 12 dB after the operation. By considering the relevant literature, it can be said that the levels of hearing recovery obtained by this study are consistent with similar studies.

The literature provides various studies in which the success of the bone cement in the incudostapedial joint reconstruction is assessed [8,10,11]; however, there exists no study focused on a comparison with respect to the incus-stapes or malleus-incus reconstruction. The most important aspect of our study is the assessment of the middle ear dynamics of ossiculoplasty groups through wideband tympanometry (WBT) and no study has ever been encountered in the literature to this effect.

The air-bone gap average of 5 individuals who underwent manubriostapedioplasty, defined as a new method by Sennaroglu et al., was 42.75 dB before the surgery and 6 dB after the surgery and the method was inferred to be a promising method [12,13]. In present study, for patients with manubriostapedioplasty, positive results were obtained in terms of the air-bone gap and hearing recovery. The application of bone cement manubriostapedioplasty comes out as a cost-effective alternative in comparison to the use of PORP. In this study, we used endaural and endomeatal approaches, and found similar results as found in the relevant literature accepting the bone cement as an effective material in hearing reconstruction [4,9,10]. The contribution made by our study to the body of the literature is the assessment of the application of ossiculoplasty with regards to middle ear dynamics. The research on the effect of the bone cement ossiculoplasty upon the middle ear dynamics by means of conventional audiological test battery as well as WBT is a brand new perspective.

WBT provides plenty of easily attained, reliable and swift information in a single session with respect to the functions of the middle ear. For such reason, it is considered to be employed as a part of the audiological test battery. In order to extend and popularize the clinic use of the WBT, a new and smart software, interpreting the measurement results and analysis easily, is needed.

The Tympanogram Peak Pressure (TPP) values in Polat's study with adult patients are consistent with the TPP values of the healthy individuals in this study [14]. TPP values obtained at normal limits indicate normal tympanic membrane and a normally ventilated tympanum. Ozdamar et al. state in a study performed with cartilage graft that tympanum pressure average was −14.73 daPa [15] and Zhang et al. further specified the existence of tympanogram with kurtosis peak in normal pressure range in all individuals involved in tympanoplasty group [16]. Although the TPP results for each of the ossiculoplasty groups and Type I tympanoplasty group are within normal limits in our study, their skewness toward the negative direction is remarkable. The fact that both ossiculoplasty groups and Type I tympanoplasty group underwent the application of cartilage graft through the same method gives rise to the thought that the trend of negative pressure does not arise out of the effect of the graft.

V_{eq} (equivalent ear-canal volume), another parameter assessed in this study, is an important parameter since it provides information about the external ear volume and integrity of the membrane. In our study, there was no statistically significant difference among the malleus-stapes, the manubriostapedioplasty, Type I tympanoplasty and the control groups for the V_{eq} values ($p > 0.05$). However, there were statistically significant differences between the incus-stapes group with the highest numerical value and other groups ($p < 0.05$).

The compensated static acoustic admittance (Y_{tm}) is the admittance value of the tympanum [17]. An increase indicate in the flexibility in the middle ear is caused by a decrease of Y_{tm}, and a decrease in the flexibility in the middle ear is caused by an increase in Y_{tm}, and this provides critical information in the diagnosis of pathologies in the middle ear [18,19]. In a study conducted in our country on WBT normalization, Y_{tm} value was as 0.68 mmho [20]. In our study, the differences among Y_{tm} values for the ossiculoplasty groups and other groups were not statistically significant ($p > 0.05$).

The tympanogram width (TW) provides information as a slope of tympanogram and is known to be an effective parameter in assessing the middle ear pathologies [18,21,22]. The value of TW in the manubriostapedioplasty group was 98 ± 86.13 daPa when it was 78 ± 26.27 daPa in the control group. TW value obtained from the control group seems to be in accord with the literature [20,23]. TW values of other ossiculoplasty groups and Type I tympanoplasty group were within normal limits but wider, and this difference was not significant ($p > 0.05$).

The resonance frequency (RF) is the frequency value at which the sum of mass and stiffness units equal to zero. Given the fact that RF is the frequency point where the middle ear system operates at maximum, it readily reflects the changes occurred in the system [17]. According to Shahnaz et al. RF increases in any pathology such as otosclerosis, ossicular chain adhesion or negative tympanum pressure; and decreases in any pathology which reduces the stiffness of the middle ear such as tympanic membrane pathology and ossicular chain discontinuity [6]. Upon the review of the RF values of the groups included in our study, RF values of malleus-stapes ossiculoplasty, manubriostapedioplasty and Type I tympanoplasty groups were observed closed to each other with a difference that was not statistically significant ($p > 0.05$). It is suggested that RF values were not varied in Type I tympanoplasty group because of an intact ossicular chain and a tympanoplasty surgery performed with an only cartilage graft. In the malleus-stapes ossiculaplasty group and the manubriostapedioplasty group, the application of bone cement was considered to cause no variation on the RF values.

Iacovou et al. reported that the RF values was 808 ± 458 Hz for individuals were applied with cartilage graft and 628 ± 256 Hz for individuals were administered with fascia graft, thus the cartilage graft could be used without any concerns of any impact on the middle ear mechanics [24]. Furthermore, they further advised that the application of tympanoplasty with a cartilage graft enhances the accord between the tympanic membrane and ossicular system and causes lower impedance through the reducing of the effect of stiffness and increases the effect of the mass [24]. The lowest RF value (441.30 ± 90.71) in our study was obtained in the incus-stapes ossiculoplasty group. It is noteworthy that the RF value of incus-stapes ossiculoplasty group was obtained significantly lower than that of other bone cement ossiculoplasty groups. The RF result in this group was thought to be linked to another fixation between malleus and incus that accompanies the bone cement application between incus and stapes as a secondary to tympanum pathologies like tympanosclerosis or fixation to malleus attic due to fibrotic tapes developed depending on the lengthy inflammation. Incudostapedial joint and incudomalleolar joint are two different anatomic regions that should be assessed independently and our study suggests that such two joints may have different mechanic features.

Wideband absorbance represents the sound absorbed by the middle ear as a function of the frequency in case sound energy is assumed to be not absorbed by the external auditory canal [17]. In the relevant literature, it is reported that the absorbance measurements under the tympanometric peak pressure are more sensitive for middle ear

pathologies that the absorbance measurements under ambient pressure [20,25,26]. In our study, no difference were found between the pressurized and unpressurized absorbance measurement results in the control group consisting of healthy individuals, and the result is similar to the results of the studies of Sahin (2015), Keefe et al. (2012), and Kaya (2015) [20,25,27].

Our review of the absorbance data of the bone cement ossiculoplasty group and Type I tympanoplasty group discloses certain differences between the absorbance values at ambient pressure and tympanometric peak pressure. The absorbance values of the malleus-stapes ossiculoplasty group and the manubriostapedioplasty group similarly vary from around 324 Hz to 771 Hz. The absorbance values obtained at ambient pressure in such range were observed to be less than those obtained at tympanometric peak pressure, but not statistically significant ($p > 0.05$). Although a similar difference exists in the absorbance values under the ambient and tympanometric peak pressure in the range of 458–840 Hz in Type I tympanoplasty group, the difference was not statistically significant ($p > 0.05$). The absorbance values in the incus-stapes ossiculoplasty group were quite different than other ossiculoplasty groups. The absorbance values obtained at the ambient pressure in the range of 226–1887 Hz were lower than those absorbance values under the tympanometric peak pressure ($p < 0.05$). Liu et al. (2008) argued that the reason for absorbance values at lower frequencies under the ambient pressure obtained lower than those absorbance values at the tympanometric peak pressure could be the positive pressure affecting the flexibility of the membrane depending upon the air entrainment in the external auditory canal occurred while placing the probe [28]. On the contrary, another researcher suggested that a negative tympanum pressure is required for such positive pressure to affect the flexibility of the tympanic membrane [20]. In our study, such finding as absorbance values obtained under the ambient and tympanometric peak pressure in the range of 226–1887 Hz in incus-stapes group did not exist in other ossiculoplasty groups and the negative tympanum pressures of incus-stapes and Type I tympanoplasty groups being close to each other was considered as a distinctive feature for the incus-stapes group.

A further review on the studies pertaining to the flexibility of the middle ear structures discloses the advice was given by Voss, Moonshiram, and Horton (2008) that increase in flexibility leads to reflectance reduction at lower frequencies (increase in absorbance) [29]. Feeney, Grant, and Marryott (2003) also advised that negative tympanum pressure increases the reflectance values at lower frequencies, causing a reduction in the flexibility [30]. Nakajima et al. (2013) and Allen et al. (2005) argued that otosclerosis reduces the absorbance values at lower frequencies, decreasing flexibility [31,32].

In a study conducted on a cadaver, Voss, Merchant, & Horton (2012) examined the reflectance varies depending upon the positive and negative pressure created in the external ear and changes on the flexibility of the tympanic membrane [33]. They stated that there was no reflectance variation at higher frequencies under pressure and reflectance values only vary under negative pressure. Feeney et al. (2003) and Shaznaz et al. (2009) further stated that absorbance values was increased at lower frequencies and decreased at higher frequencies depending on the increase in the flexibility of the membrane in the ossicular chain discontinuities [7,30].

We offer that to investigate WBT measurements obtained pre and postoperative middle ear surgeries could provide significantly valuable information about the subject. Based on the WBT measurements obtained in our study, this study would lead future research on the reconstruction of ossicular chain pathologies and contribute significantly to the relevant literature.

Significant differences were detected during the comparison of the control group with the bone cement group and Type I tympanoplasty group. When the bone cement groups were compared each other, hearing recovery results and WBT results were different for each group. The largest difference among the bone cement groups was in the incus-stapes group.

In incus-stapes ossiculoplasty group, it is a distinctive characteristic for this group have differences between results of under pressurized and unpressurized absorbance measurements in the frequency range of 226–1887 Hz. It is suggested that further studies should be performed with more subjects. Some parameters (such as V_{eq}, RF, TW) in the malleus-stapes and the manubriostapedioplasty groups exhibited similarity to Type I tympanoplasty group and control group. In light of such results, the effect of bone cement application on middle ear dynamics was inferred to be not negative in terms of hearing recovery and WBT. During researching the effect of bone cement on the middle ear dynamics, it was considered that comparison studies were necessary in which other materials and prostheses (such as TORP, PORP) were employed for ossicular chain discontinuity.

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