

Functional Results of Surgery for Otosclerosis

Otoskleroz Cerrahisi Fonksiyonel Sonuçları

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ABSTRACT

Introduction: To evaluate the audiological variables and to investigate the factors affecting hearing improvement in patients who underwent stapedotomy with the diagnosis of otosclerosis.

Methods: The data of 114 patients who had middle ear exploration were retrospectively reviewed. Air conduction thresholds between 250-6000 Hz and bone conduction thresholds between 500-4000 Hz were examined in pure tone audiometry. Postoperative air-bone gap (ABG), change in ABG, and change in bone conduction threshold at high frequency were primarily examined. The results of different piston diameters were compared.

Results: Eighty-three patients with stapedial footplate fixation were included in the study. While post-operative air conduction thresholds decreased significantly at all frequencies, bone conduction thresholds decreased significantly only at 2000 Hz ($p=0.001$). The most notable gain in ABG was obtained at 500 Hz. The post-operative air conduction pure tone average was significantly higher in patients with 0.6 mm diameter prosthesis. Postoperative mean ABG and ABG values at 2000 and 4000 Hz were found to be significantly lower in patients with 0.8 mm diameter prosthesis ($p<0.05$). The change in ABG at 2000 Hz was significantly lower in patients with 0.6 mm diameter prosthesis ($p=0.029$). The mean change in bone conduction thresholds at high frequencies was positive in 58 patients (70%) and negative in 25 patients (30%). There was no difference between different piston diameters regarding bone thresholds at high frequencies.

Conclusion: Improvement was achieved at all frequencies in air conduction thresholds following stapedotomy. In our study, it was found that the lower the pre-operative bone conduction thresholds were, the more the improvement in ABG. A significant advantage was achieved at 2000 and 4000 Hz frequencies in patients with 0.8 mm piston diameter compared to 0.6 mm piston diameter.

Keywords: Air-bone gap, otosclerosis, stapedotomy

ÖZ

Amaç: Otoskleroz tanısıyla stapedotomi yapılmış olan olgularda odyolojik değişkenleri değerlendirmek ve işitme kazancını etkileyen faktörleri incelemektir.

Yöntemler: Orta kulak eksplorasyonu yapılmış 114 hastanın retrospektif taraması yapıldı. Saf ses odyometrik incelemede hava iletim eşikleri 250-6000 Hz arası, kemik iletim eşikleri ise 500-4000 Hz arasında incelendi. Postoperatif hava-kemik aralığı (HKA), HKA değerindeki değişim ve yüksek frekans kemik iletimindeki değişim primer olarak incelendi. Farklı çapta piston kullanılan hastaların sonuçları kıyaslandı.

Bulgular: Stapes taban fiksasyonu tespit edilen 83 hasta çalışmaya dahil edildi. Postoperatif hava yolu eşiklerinde tüm frekanslarda anlamlı azalma tespit edilirken, kemik yolu eşiklerinde sadece 2000 Hz'te anlamlı bir azalma tespit edildi ($p=0,001$). HKA'da en yüksek kazanç 500 Hz'te elde edildi. Postoperatif hava yolu saf ses ortalaması 0,6 mm çaplı protez kullanılan hastalarda anlamlı olarak daha yüksek tespit edildi. Postoperatif HKA ortalaması ile 2000 ve 4000 Hz'teki değerleri, 0,8 mm piston çapı kullanılan hastalarda anlamlı olarak daha düşük bulundu ($p<0,05$). HKA değişimi 2000 Hz'te 0,6 mm çaplı piston kullanılan hastalarda anlamlı olarak daha düşük idi ($p=0,029$). Yüksek frekans kemik eşikleri ortalamasındaki değişim 58 hastada (%70) pozitif iken, 25 hastada (%30) negatif değerdedi. Farklı piston çapları arasında yüksek frekans kemik eşikleri açısından fark saptanmadı.

Sonuç: Stapedotomi sonrasında hava yolu eşiklerinde tüm frekanslarda kazanç sağlanmıştır. Çalışmamızda, preoperatif kemik yolu eşikleri ne kadar düşükse, HKA kazancının o kadar fazla olduğu tespit edilmiştir. 0,8 mm çaplı piston kullanılanlarda, 0,6 mm çaplı piston kullanılan hastalara göre 2000 ve 4000 Hz'te anlamlı avantaj elde edilmiştir.

Anahtar Kelimeler: Hava-kemik aralığı, otoskleroz, stapedotomi



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Introduction

Otosclerosis is an otic capsule disease characterized by bone resorption and replacement that causes fixation in the stapes footplate (1). Otosclerosis, which is one of the common causes of conductive hearing loss in adults, is seen more frequently in women and between the ages of 30-40 years (2). Two-thirds of otosclerosis cases have a family history of hearing loss (3).

Three different treatment modalities have been defined for otosclerosis: wait - see, hearing aid, and stapes surgery. The effect of stapes surgery on conductive hearing loss due to otosclerosis is well known. Stapedectomy, defined by John Shea, has been replaced by stapedotomy over time. The risk of sensorineural hearing loss with stapedotomy is reported to be less (4-7).

Although some prognostic factors have been emphasized in the pre-operative evaluation of otosclerosis, these factors are not clear as in tympanoplasty (5,6). Surgical experience, patient characteristics and intra-operative findings have an important place among prognostic factors (8-10).

In our study, the functional results of patients who underwent stapedotomy with the diagnosis of otosclerosis were evaluated through an audiological perspective and a prognostic point of view. The effect of stapedotomy surgery on bone and air conduction hearing thresholds, and change in frequency-specific air-bone gap (ABG) were investigated.

Methods

Patient Selection and Evaluation

A retrospective analysis of 114 patients who underwent middle ear exploration with a preliminary diagnosis of otosclerosis between 2007 and 2013 was performed. Patients with tympanic membrane perforation or retraction and patients without intra-operative stapedial footplate fixation were excluded from the study. Stapedotomy was performed in all patients. Patients who had undergone revision surgery, ear surgery for another reason, and had juvenile otosclerosis were not included in the study. Age, gender, pre-operative and post-operative audiogram data, diameter of the prosthesis used during surgery, and hearing status of the other ear were recorded. The study was approved by the Local Ethics Committee of İstanbul Training and Research Hospital (513-25/07/2014).

The audiometric examinations (AC 40; Interacoustics A / S, Assens, Denmark), which were performed before the surgery and at least 1 year after surgery, were evaluated. In the pure tone audiometric examination, air conduction thresholds were examined at 250, 500, 1000, 2000, 4000 and 6000 Hz frequencies, and bone conduction thresholds at 500, 1000, 2000 and 4000 Hz frequencies. The pure tone average (PTA) values were calculated by taking the arithmetic average of both air and bone conduction thresholds at 500, 1000, 2000 and 4000 Hz. ABG at 500, 1000, 2000 and 4000 Hz was calculated by subtracting the bone conduction threshold value from the air conduction threshold value at these frequencies. The mean ABG (mean ABG) value was calculated by taking the arithmetic average of the ABG values at four frequencies. The change in postoperative ABG (gain) was determined by subtracting the postoperative ABG value from preoperative ABG

value, and it was calculated separately for meanABG and for the four frequencies examined. The difference between pre-operative and post-operative bone conduction thresholds at 1000, 2000 and 4000 Hz were determined and the effect of surgery on bone conduction was evaluated. Positive value indicated improvement in bone conduction and negative value indicated damage in inner ear (11).

Speech reception threshold (SRT) and speech discrimination score (SDS) values in the speech audiometry were recorded. The post-operative changes in SRT and SDS values were determined.

The primary aim was to investigate post-operative ABG, the change in ABG and changes in mean of bone conduction thresholds at 1000, 2000 and 4000 Hz. The secondary aim was to investigate the frequency-specific changes in bone and air conduction thresholds, and changes in speech audiometry (SRT and SDS) values. The differences between the patients with 0.6 and 0.8 mm stapes prosthesis diameter were evaluated.

Statistical Analysis

SPSS 15.0 for Windows (IBM Corporation, Chicago, IL, USA) was used for statistical analysis. Descriptive statistics were expressed as number and percentage for categorical variables and mean \pm standard deviation (minimum-maximum) for numerical variables. The comparisons of non-normal distributed numerical variables between two independent groups were performed by using Mann-Whitney U test. Dependent group comparisons were evaluated using the dependent sample t-test for normal distribution and Wilcoxon test for non-normal distribution. The relationships between the numerical variables were examined by Spearman's correlation analysis because of the non-parametric test condition. Statistical significance was accepted as $p < 0.05$.

Results

Eighty-three patients (49 men and 34 women) who underwent stapes surgery were included in the study. Surgeries were performed by three different surgeons. The mean age of the patients was 41.3 ± 11.11 (minimum-maximum: 20-68) years. Hearing loss was accompanied by tinnitus in 49.4% of the patients, dizziness in 6% and pain in 2.4%. The operated ear was on the left side in 47% and on the right side in 53%. Hearing loss was detected in the other ear in 73.2% of the patients. 0.6 mm stapes prosthesis was used in 48 patients (58%) and 0.8 mm stapes prosthesis was used in 35 patients (42%). The main factor determining the diameter of the prosthesis was the size of the fenestration created at the base of the stapes.

The mean air conduction value was 56.1 ± 9.9 dB hearing level (HL) in the preoperative period, and 34.1 ± 17.5 dB HL in the postoperative period. The difference was statistically significant ($p < 0.001$). The reduction in air conduction thresholds at 250, 500, 1000, 2000, 4000 and 6000 Hz were similarly significant ($p < 0.05$) (Table 1). The difference between the frequency-specific air conduction thresholds of different stapes prosthesis diameters was not significant. However, the PTA value of postoperative air conduction was significantly higher in patients with a 0.6 mm diameter stapes prosthesis ($p = 0.042$).

The mean bone conduction value was 18.1 ± 7.3 dB HL in the preoperative period, and 16.7 ± 12.9 dB HL in the postoperative period.

Table 1. Preoperative and postoperative air conduction hearing thresholds

| AC threshold | Preoperative | | | Postoperative | | |
|--------------|--------------|-----------|-----------|---------------|-----------|-----------|
| | Total | 0.6 mm | 0.8 mm | Total | 0.6 mm | 0.8 mm |
| 250 Hz | 64.5±13.1 | 64.8±11.8 | 64.5±14.8 | 37.8±17.6 | 42.2±19.7 | 36.9±16.3 |
| 500 Hz | 62.2±10.7 | 62.9±10.0 | 61.7±11.1 | 35.2±17.0 | 38.2±19.0 | 32.0±16.5 |
| 1000 Hz | 58.5±10.2 | 59.4±11.3 | 57.4±7.8 | 32.5±17.6 | 35.0±19.2 | 29.9±17.3 |
| 2000 Hz | 51.5±12.6 | 52.1±14.4 | 50.6±11.7 | 32.0±18.2 | 35.1±19.4 | 30.5±19.0 |
| 4000 Hz | 52.0±16.7 | 53.5±17.8 | 47.7±15.1 | 36.6±22.6 | 42.8±24.9 | 34.0±23.2 |
| 6000 Hz | 55.4±19.3 | 58.4±22.6 | 49.9±16.9 | 47.2±23.4 | 55.1±27.8 | 43.9±15.9 |
| PTA | 56.1±9.9 | 57.8±11.0 | 54.3±8.6 | 34.1±17.5 | 29.1±23.2 | 19.9±20.6 |
| SRT | 54.6±10.5 | 57.7±10.5 | 52.3±10.2 | 33.5±18.1 | 35.5±19.6 | 29.2±18.3 |
| SDS | 91.7±7.9 | 90.8±9.2 | 93.4±6.3 | 90.5±8.6 | 90.9±8.6 | 92.7±9.9 |

AC: air conduction, PTA: pure tone average, SRT: speech reception threshold, SDS: speech discrimination score

Table 2. Preoperative and post-operative bone conduction hearing thresholds

| BC threshold | Preoperative | | | Postoperative | | |
|--------------|--------------|-----------|-----------|---------------|-----------|-----------|
| | Total | 0.6 mm | 0.8 mm | Total | 0.6 mm | 0.8 mm |
| 500 Hz | 16.5±8.0 | 17.9±9.8 | 15.4±5.4 | 14.9±12.9 | 15.6±15.7 | 11.7±10.1 |
| 1000 Hz | 17.1±8.3 | 18.7±8.9 | 15.3±6.7 | 15.6±13.7 | 16.4±16.3 | 13.2±12.2 |
| 2000 Hz | 21.5±10.4 | 22.5±11.4 | 19.3±8.4 | 17.2±13.9 | 17.6±17.3 | 17.0±13.2 |
| 4000 Hz | 17.2±12.4 | 18.0±13.4 | 15.1±12.1 | 19.1±15.7 | 20.5±18.1 | 17.0±17.0 |
| PTA | 18.1±7.3 | 19.3±8.2 | 16.3±5.7 | 16.7±12.9 | 13.5±15.5 | 9.3±11.8 |

BC: bone conduction, PTA: pure tone average

Table 3. Air-bone gap values before and after otosclerosis surgery

| ABG | Preoperative | | | Postoperative | | |
|----------|--------------|-----------|-----------|---------------|-----------|-----------|
| | Total | 0.6 mm | 0.8 mm | Total | 0.6 mm | 0.8 mm |
| 500 Hz | 45.8±11.3 | 45.1±12.5 | 46.5±11.3 | 20.2±11.6 | 17.4±14.4 | 11.7±12.5 |
| 1000 Hz | 41.3±9.0 | 40.8±8.9 | 42.2±8.0 | 16.9±9.6 | 14.4±11.6 | 9.9±10.1 |
| 2000 Hz | 30.1±8.7 | 29.7±10.0 | 31.0±8.2 | 14.8±9.9 | 13.5±11.1 | 7.6±8.5 |
| 4000 Hz | 34.8±11.9 | 35.3±13.1 | 32.5±11.1 | 17.4±12.3 | 17.3±13.9 | 9.7±11.0 |
| Mean ABG | 38.0±7.6 | 38.1±8.3 | 38.1±6.5 | 17.3±9.2 | 15.6±11.6 | 9.7±9.6 |

ABG: air-bone gap, mean ABG: mean air-bone gap

Table 4. Distribution of air-bone gap according to different frequencies

| ABG change | Total | 0.6 mm | 0.8 mm |
|------------|-----------|-----------|-----------|
| 500 Hz | 25.5±15.4 | 27.9±18.3 | 34.9±16.2 |
| 1000 Hz | 24.5±13.6 | 26.8±14.9 | 32.4±13.6 |
| 2000 Hz | 15.3±13.6 | 16.2±15.2 | 23.3±13.1 |
| 4000 Hz | 17.3±14.9 | 18.3±18.3 | 22.8±14.0 |
| Mean ABG | 20.7±11.4 | 22.7±13.7 | 28.3±11.6 |

ABG: air-bone gap, mean ABG: mean air-bone gap

The difference was not statistically significant ($p=0.07$). While the change in bone conduction thresholds at 500 Hz, 1000 Hz and 4000 Hz were not statistically significant, the change at 2000 Hz was statistically significant ($p=0.001$). Bone conduction thresholds were not significantly different between patients with different stapes prosthesis diameters ($p>0.05$) (Table 2).

The mean ABG value was 38 ± 7.6 dB HL in the preoperative period, and 17.3 ± 9.2 dB HL in the postoperative period ($p<0.001$). Mean ABG and ABG values at all frequencies showed a statistically significant decrease (Table 3). The ABG values at 2000 and 4000 Hz in the postoperative period and mean ABG values were significantly higher in patients with a 0.6 mm stapes prosthesis diameter compared to patients with a 0.8 mm prosthesis diameter ($p<0.05$).

The mean ABG change was 20.7 ± 11.4 . The highest ABG change was found at 500 Hz and the lowest value was at 2000 Hz. The change at 2000 Hz was found to be significantly lower in patients with a 0.6 mm stapes prosthesis diameter compared to patients with a 0.8 mm prosthesis diameter ($p=0.029$). Regarding ABG, there was no significant difference between the patients with different stapes prosthesis diameters, except at 2000 Hz. The change in ABG is given in Table 4.

There was no statistically significant relationship between age, gender, and change in ABG ($p>0.05$). Preoperative bone conduction threshold

values were significantly ($p < 0.05$) negatively correlated with ABG change at all frequencies, except 2000 Hz ($p = 0.092$).

There was no statistically significant relationship between bone conduction at high frequency and age ($p = 0.597$) and gender ($p = 0.985$). This value was positive in 58 patients (70%) and negative in 25 patients (30%). Two patients with negative values were diagnosed with total hearing loss after surgery. This variable was positively correlated with bone conduction hearing thresholds and mean bone conduction threshold values at 500 Hz and 1000 Hz ($p = 0.011$, $p = 0.004$, $p = 0.010$, respectively). On the other hand, no significant relationship was found with bone conduction hearing thresholds at 2000 and 4000 Hz ($p = 0.098$ and $p = 0.259$, respectively). The mean of bone conduction threshold change at high frequency was found to be 5.8 dB HL in the 0.6 mm prosthesis diameter group, and 7.2 dB HL in the 0.8 mm prosthesis diameter group ($p = 0.64$).

While the postoperative change in SRT was statistically significant ($p < 0.001$), there was no significant change in SDS ($p = 0.43$) (Table 1). There was a negative correlation between the change in SRT and bone conduction hearing threshold level at 4000 Hz ($p = 0.046$), and positive correlation with air conduction hearing threshold levels at 500 and 1000 Hz ($p = 0.024$ and $p = 0.005$, respectively). There was also a positive correlation between this change and ABG at 1000 Hz ($p = 0.005$). There was no statistically significant relationship between the change in SDS and the other parameters. There was also no statistically significant difference between SRT ($p = 0.682$) and SDS ($p = 0.648$) change in gender groups.

Discussion

Stapedotomy is known to cause gains in air conduction hearing thresholds in patients with otosclerosis. In our study, gain is obtained at all frequencies in the postoperative air conduction hearing threshold values compared to the preoperative values, while gain was achieved only at 2000 Hz in bone conduction. Both the significant gain in the bone conduction at 2000 Hz and the lower gain in the ABG at 2000 Hz compared to other frequencies are consistent with the principle of formation of the Carhart's notch. When the Carhart's notch was first described by Carhart (12) in 1950, it was reported as a worsening at the pure tone threshold of bone conduction at maximum 2000 Hz (500 to 4000 Hz). Although the Carhart's notch formation mechanism, which was reviewed after that period, has not been fully elucidated, some studies have been reported to support the association with the resonance frequency of the ossicular chain (13-15). After a successful otosclerosis surgery, Carhart's notch disappears. Therefore, this is thought that bone conduction thresholds at 2000 Hz do not reflect the cochlear reserve.

In our study, a significant negative correlation was found between ABG gain and preoperative bone conduction hearing thresholds at all frequencies, except 2000 Hz. In other words, preoperative bone conduction thresholds were determined as a prognostic factor affecting the gain in ABG. The data we have obtained suggest that the individuals who have better bone conduction thresholds will be more likely to have ABG gain.

The highest gain in ABG was detected at 500 Hz and 1000 Hz. When the preoperative ABG values were examined, the highest values were

found at 500 and 1000 Hz similarly. These data are interpreted as being compatible with the fact that otosclerosis causes more hearing loss at lower frequencies. Otosclerosis acts on the rigidity of middle ear and affects especially low frequencies. However, high frequencies are also affected in the presence of progressive disease (16). In the studies examining the relationship between ABG gain and age, Marchese et al. (3) reported low functional results at age 50 and older and Bittermann et al. (8) stated that ABG gain was advantageous in patients over 40 years of age. In our study, there was no relationship between ABG gain and age.

There was a statistically significant change between pre- and postoperative ABG values at all frequencies (500, 1000, 2000 and 4000 Hz). The highest gain was achieved at 500 Hz, while the lowest gain was at 2000 Hz. In our study, a significant improvement was observed at all frequencies in postoperative air conduction hearing thresholds. Gerard et al. (5) and Meyer (17) reported that there might be no significant improvement at high frequencies due to the effect of cochlear otosclerosis. On the other hand, Ueda et al. (18) reported a significant ABG gain at 2000 and 4000 Hz, and poor gain at higher frequencies and below 1000 Hz.

Postoperative changes in the ossicular chain after a successful stapes surgery are known as overclosure (11). In case of a worsening in this value, which is calculated as the change in mean bone conduction threshold at 1000, 2000 and 4000 Hz, a surgical damage to the cochlea can be interpreted (11). This change, calculated as negative in 30.1% (25 patients) in our patient group, gives the rate of internal ear damage that occurred during or after surgery.

Conflicting findings have been obtained in studies on the effect of stapes prosthesis diameter on hearing gain in otosclerosis surgery. There are studies reporting that the prosthetic diameter does not have an effect on hearing gain, and there are studies reporting that large-scale prostheses provide more gains at lower frequencies and small-diameter prostheses at higher frequencies (19-23). In cases where small fenestration is made at the stapes base, the risk of internal ear damage and prosthesis migration is reported to be less (24). In our study, no significant difference was found between the bone conduction thresholds of groups with a 0.6 or 0.8 mm stapes prosthesis diameter. When the frequency-specific air conduction thresholds were examined, there was no significant difference between the two groups, while the mean air conduction was significantly higher in the patient group with 0.6 mm diameter prosthesis. The change in ABG was found to be significantly higher at only 2000 Hz in the 0.8 mm prosthesis diameter group. Postoperative ABG values were found to be significantly lower in the 0.8 mm prosthetic diameter group at 2000 and 4000 Hz. The change in mean bone conduction at high frequency that is used to detect inner ear damage did not show a significant difference between the groups. These findings can be interpreted as partially better results with 0.8 mm stapes piston diameter.

Conclusion

In our study, gain was obtained at all frequencies in air conduction thresholds after stapedotomy. The significant gain in the bone conduction thresholds at 2000 Hz reflects the Carhart's phenomenon. Otosclerosis is associated with conductive hearing loss at low frequencies, especially

at the beginning. Observing the highest change at 500 Hz is consistent with this fact. In our study, it was found that ABG gain increased with decreasing preoperative bone conduction threshold. It was determined that the postoperative ABG was less with 0.8 mm stapes prosthesis diameter, especially at 2000 and 4000 Hz. There was no significant difference in hearing gain between patients with 0.6 and 0.8 mm stapes prosthesis diameter.

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