The effect of type I tympanoplasty on the resonant frequency of the middle ear: comparison between chondrotympanoplasty and temporalis fascia grafting.

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Aim: To evaluate the effect of type I chondrotympanoplasty on the resonant frequency (RF) of the middle ear, and compare it to the respective outcomes of type I tympanoplasty utilizing temporalis fascia grafting (TFG). Hearing results and respective graft integration rates were also assessed.
Materials/Methods: Retrospective comparative study of patients who had undergone type I tympanoplasty at a tertiary University Hospital. Selection criteria included TM perforation following chronic otitis media/trauma/grommet insertion, intact ossicular chain, dry ear for at least 3 months, and normal middle ear mucosa. Patients with ossicular discontinuity/ossiculoplasty/cholesteatoma/previous ear surgery, syndromes affecting the middle ear, or younger than 16 years old were excluded.
Results: Sixty-nine patients met the inclusion criteria; chondrotympanoplasty was performed in 39, and TFG in 30. Three patients showed incomplete TM closure at follow-up. Graft integration rate was 97.4% in the chondrotympanoplasty group and 93.3% in the TFG group. An air-bone gap closure within 10 dB was achieved in 73.7% of chondrotympanoplasty versus 67.9% of TFG patients. Hearing gain of 21-30 dB in air-conduction thresholds was obtained in 65.8% of chondrotympanoplasty patients and 60.7% of their TFG counterparts. RF in the chondrotympanoplasty group was 808 ± 458Hz, and in the TFG group 628 ± 256Hz. The RF remained within the normal range in 73.7% of chontrotympanoplasty, versus 42.9% of TFG patients.
Conclusions: Chondrotympanoplasty has comparable hearing results to TFG myringoplasty. The cartilage can be used without concerns regarding its impact on the middle ear mechanics, as the sound-conducive properties of the tympanic membrane remain unchanged.

Key-words: Cartilage, tympanoplasty, chondrotympanoplasty, fascia, hearing, resonant frequency.

Introduction

The tympanoplasty is a procedure which primarily aims to eradicate the chronic inflammatory process and create a well-aerated and healthy middle ear, and additionally attempts to restore the mechanism of sound conduction to the inner ear.

Since the introduction of the 5 different types of tympanoplasty by Zoellner[1] and Wullstein[2] in 1952, numerous surgical techniques were developed for performing a myringoplasty (type I tympanoplasty). Indeed, skin, fascia, vein, perichondrium, and dura mater have all been used for the reconstruction of tympanic membrane (TM) [3-9]; however, temporalis fascia and cartilage comprise the most commonly accepted grafting materials. Recently, the term chondrotympanoplasty (CTP) was introduced to

describe modified techniques of cartilage graft tympanoplasty with very promising results[10, 11].

The respective success rate in myringoplasties is largely defined by the integration of the graft and the hearing results. However, there have been concerns regarding a potentially suboptimal sound conduction (and hearing results) using cartilage in type I tympanoplasty, due to its increased thickness, stiffness and mass[12].

Resonant frequency is a variable that can reflect changes in the mechanical properties (i.e. mass, resistance) of the sound-conduction system in the middle ear, and can be measured using multi-frequency tympanometry (MFT)[13-16]. Indeed, compared to standard 226 Hz tympanometry, MFT seems to be more sensitive in detecting such changes, and assessing the status of the middle ear[17-20].

The aim of the present study was to evaluate the effect of type I CTP on the resonant frequency of the middle ear using MFT and compare it with the respective outcomes of type I tympanoplasty utilizing temporalis fascia grafting (TFG). The hearing results and graft integration rates of each grafting material were also assessed.

Materials & Methods

A retrospective comparative study was performed in all patients who had undergone type I tympanoplasty at a tertiary University Hospital during a time-period of one year. Selection criteria included tympanic membrane perforation following chronic otitis media, trauma, or grommet insertion, with intact ossicular chain, dry ear for a period of at least 3 months and normal middle ear mucosa. Patients with history of ossicular discontinuity, ossiculoplasty, cholesteatoma, previous ear surgery, or syndromes affecting the status of the middle ear were excluded. Patients younger than 16 years of age were also excluded.

Sixty-nine patients met the inclusion criteria; a CTP was used in 39 and TFG in 30 cases. Patient notes were reviewed for graft integration, pure-tone average (PTA), difference between pre- and postoperative air-bone gap (ABG) and resonant frequency. Three patients showed incomplete TM closure at follow-up. These patients were excluded from further analysis of the audiometric and resonant frequency data. Hence, the corresponding results in the CTP, and TFG groups refer to 38 and 28 patients, respectively.

Pure-tone audiometry was performed using an *Amplaid 309* audiometer. The air- and bone-conduction hearing thresholds were calculated at the frequencies of 500, 1000, 2000, and 4000Hz. Standard 226 Hz and MFT were performed using a *Grason-Stadler GSI 33 Version 2* otoadmittance-meter.

The surgical technique of chondrotympanoplasty has been described elsewhere[10, 11]. In brief, tragal cartilage is harvested with its perichondrium. The cartilage strips are placed under the tympanic membrane after freshening the edges of the perforation from the inside, and in cases of subtotal or total perforations under the bony annulus both inferiorly and posteriorly touching the scarified middle ear mucosa, in contrast to the Heermann technique[21], where only the most anterior palisade is placed under the

bony annulus. The perichondrium is covering the cartilage strips both as an anterior on-lay graft and a posterior underlay graft (Fig. 1).

Fascia tympanoplasty was performed in a similar way as described in the literature. Fascia from the ipsilateral temporalis muscle is harvested, and the graft is placed using an underlay technique.

Results

The mean age in the CTP group was 48 years (range 16-73y). Twenty two patients were males and 17 females. Indications for surgery included chronic otitis media in 34 patients (87.2%), traumatic perforation in 2 (5.1%), perforation following grommet insertion in 2 (5.1%), and no specific cause of the TM perforation in one case (2.6%). In all cases tragal cartilage was used for reconstruction.

The mean age in the TFG group was 43 years (range 16- 65y). Twenty three patients were males and seven females. Indications for surgery was chronic otitis media in 22 patients (73.33%), traumatic perforation in 4 (13.33%) and perforation following grommet insertion in 4 (13.33%).

The graft integration rate was 97.4% in the chondrotympanoplasty group and 93.3% in the TFG group. One patient in the CTP group and two in the TFG group did not have successful closure of the perforation site at the 12 month follow up. None of these results was due to postoperative middle ear infection. The observed difference was not statistically significant ($p > 0.05$) (Table 1). Retraction, resorption or lateralization of the graft was not observed in the remaining cases (n= 66).

The mean preoperative PTA in the CTP and TFG groups was 35.3 ± 4.1 dB and 31.3 ± 7.9dB, respectively. The mean postoperative PTA in the CTP group was 20.8 ± 7.3 dB, versus 18.5 ± 5.4dB in the TFG group (Fig. 2). These results were statistically significant ($p<0.05$). No difference was found in the pre- or postoperative hearing thresholds between the two groups.

The mean ABG at each of the four tested frequencies improved in both groups. (Figs.3-4). The mean preoperative ABG for the CTP group was 27.2 ± 6.6 dB and the respective postoperative ABG was 9.1± 3.6. The mean preoperative ABG for the TFG group was 26.6 ± 7.4 dB and and the respective postoperative ABG was 8.8± 4.5 dB (Fig. 5). There was no statistically significant difference between the two groups for the pre- and postoperative ABGs. An ABG closure within 10 dB was achieved in 28 (73.7%) patients following a CTP, and in 19 (67.9%) patients after TFG myringoplasty (Table 2). In addition, a hearing gain of 21-30 dB in the air conduction thresholds was obtained in 25 (65.8%) patients in the CTP group, and in 17 (60.7%) patients in the TFG group. (Table 3).

The resonant frequency measured after three months was found to be 808 ± 458 Hz in the CTP group, whereas in the TFG group it was 628 ± 256 Hz. Furthermore, six months later the resonant frequency remained within the normal range in 73.7% of

patients in the CTP group, whereas 42.9% of patients in the TFG group had normal resonant frequency, and 57.1% were found to have low resonant frequency (Table 4).

Data were analyzed using the statistical package SPSS 16.0. Chi-square, paired t test and t test for independent samples were used for statistical comparisons. Statistical significance was accepted at the level of 0.05.

Discussion

The use of cartilage in tympanic membrane repair is not a new concept, but goes back to the 1960s, when Utech first described the interposition of cartilage in ossiculoplasty[22]. However, the surgeon who established the use of cartilage in tympanoplasty and introduced the cartilage palisade technique was Heermann.[21, 23]. Numerous variations of the technique for harvesting, and preparing the cartilage graft have since been proposed, and among them CTP was introduced in 1997 as a modification of the cartilage palisade technique[10, 11, 24, 25]

Reports in the literature suggest good anatomic reconstruction, and low graft failure rate after the use of cartilage to repair TM perforations[26-30]. This was indeed confirmed by the results of the present study, with the graft integration rate exceeding 97%. A key-point in the CTP technique is to freshen the edges of the perforation from the inside, leaving the external surface of the TM untouched. It is also very important not to cause scars to the ear canal skin at the antero-inferior angle between the TM and the ear canal wall, and to place the cartilage strips under the bony annulus after scarifying the middle ear mucosa in cases of subtotal perforations.

Cartilage seems to perform better than temporalis fascia[31-33] in cases of suspected suboptimal healing (i.e. Eustachian tube dysfunction, adhesive otitis, tympanic fibrosis), and also in total perforations, and bilateral disease[34]. Indeed, temporalis fascia may demonstrate radical and unpredictable changes in shape, because of uneven shrinking and thickening[35]. By contrast, cartilage demonstrates higher mechanical stability[36], considerable stiffness and slower metabolism, and can therefore be considered a reliable graft material for tympanoplasties[36-38]. Furthermore cartilage seems to be resistant to infection, perhaps due to its high concentration of the highly resistant protein elastin[24].

However, even though the rigid nature of the cartilage has proved effective in preventing retraction, it may theoretically impede with the sound-conducive properties of the tympanic membrane. These properties can be evaluated by determining the resonant frequency of the mechanical system in the middle ear.

The resonant frequency determines the balance between the elements of mass and stiffness. At the resonant frequency, the mass and stiffness acoustic reactance are equal, and cancel each other. Acoustic admittance is only represented by the friction of the middle ear. The resonant frequency is directly proportional to the stiffness of the middle ear and inversely proportional to the mass. Therefore, it increases in conditions of increased stiffness, such as otosclerosis, and decreases when stiffness decreases (i.e. in cases of ossicular discontinuity)[39, 40].

The present study not only demonstrated an overall hearing improvement after type I CTP, which was at least comparable to that after fascia grafting, but had also taken into account a specific audiologic parameter not previously mentioned in the literature; that of the resonant frequency. Indeed, the resonant frequency remained within the normal range in 73.7% of the CTP group, compared to 42.9% in the TFG group. In addition, 57.1% of patients in the latter group were found to have low resonant frequency, versus a respective 21% in the CTP group. This is consistent with Zahnert's findings on the acoustic properties of fascia and cartilage[41].

According to our MFT measurements, cartilage was found to be an excellent grafting material for the tympanic membrane, with acceptable transfer characteristics of the sound. Cartilage seems to improve the compliance of the repaired tympanic membrane-ossicular chain system, resulting in smaller impedance, as it eliminates the increased stiffness, by increasing the mass of the system. This factor may contribute to better results regarding the acoustic quality of sound. Admittedly, the latter is a psycho-acoustic rather than a physical property, and requires further investigation of the respective parameters after performing a chondrotympanoplasty.

However, we believe that objective acoustical measurements such as the ones obtained by MFT should be used to gain useful insight to the effect of cartilage repair of the hearing mechanism.

Conclusion

Chondrotympanoplasty has comparable hearing results to temporalis fascia myringoplasty. The tragal cartilage is not only a reliable grafting material for tympanoplasties, due to the higher mechanical stability, considerable stiffness, and resistance to infections, but can also be used without any concern regarding its impact on the middle ear mechanics, as the sound-conducive properties of the tympanic membrane remain unchanged.

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Tables

Table 1
Chi-square analysis of success rates in chondrotympanoplasty and temporalis fascia myringoplasty

tympanic membrane repair	chondrotympanoplasty	temporalis fascia grafting	total
yes	38	28	66
no	1	2	3
total	39	30	69

Table 2
Air-bone gap closure at 12 months follow up

ABG closure (dB)	chondrotympanoplasty group	temporalis fascia group
0-10	28 (73.7%)	19 (67.9%)
11-20	8 (21 %)	8 (28.6%)
>20	2 (5.3 %)	1 (3.5%)

Table 3
Air conduction hearing gain at 12 months follow up

hearing gain (dB)	chondrotympanoplasty group	temporalis fascia group
21-30	25 (65.8%)	17 (60.7%)
11-20	12 (31.6%)	10 (35.7%)
0-10	1 (2.6%)	1 (3.6%)

Table 4
Effect of type I tympanoplasty on the middle ear resonant frequency by grafting material at 6 months follow up

Resonant frequency (Hz)	Chondrotympanoplasty group n (%)	temporalis fascia group n (%)
650-1500 Hz	28 (73.7%)	12 (42.9%)
>1500 Hz	2 (5.3%)	0
<650 Hz	8 (21%)	16 (57.1%)