Experimental and clinical aspects of otosclerosis and stapes surgery

DOCTORAL (Ph.D.) THESIS

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1 Introduction

1.1 The history of discovering stapes fixation

The stapes was first described by Giovanni Filippo Ingrassia (1510-1580), who characterized the inner ear during cadaver studies (1546). It was Antonio Valsalva (1666-1723), who recognized the so called otosclerosis accompanied by stapes fixation. In the book, titled *De aure humana tractatus* he associated deafness with ossified and fixated stapes. The otosclerotic focus affecting the fooootplate of the stapes was first described by Adam Politzer (1835-1920) in 1862.

1.2 The early conservative and surgical attempts to treat otosclerosis

The classical conservative treatments tended to mobilize the ossicular chain. To achieve a mobile stapes, air inflation was applied with the Politzer balloon. Ernst Mach (1838-1916) was the first, who attempted to mobilize the stapes in 1875. Miot reported 126 cases with stapes mobilisation in 1896. Among these cases he diagnosed otosclerosis in 24 cases, and demonstrated good results in 18 out of 24 cases. However, the surgical methods were unsuccessful due to recurrent infections and the risk of developing intracranial abscess. At the beginning of the 20th century stapes surgeries were abandoned for almost 2 decades, and pharmaceutical approaches emerged due to poor surgical results and the statements of experts.

1.3 Fenestration methods

Róbert Bárány (1876-1936) obtained good results with the fenestration of the posterior semicircular canal in 1910. Sourdille (1885-1961) developed a novel technique called „tympanolabyrinthopexy" performed in 2 or 3 stages during aseptic conditions. Lempert introduced one-stage approach for the fenestration of the lateral semicircular canal in 1938. Shaumbaugh reported the 10 year postoperative results of 2100 cases of fenestration in 1949. The majority (70%) of these cases maintained the hearing level measured 1 year postoperatively.

1.4 Attempts to mobilize the stapes and stapediolysis

Samuel Rosen (1897-1981) was a succesful specialist applying the Lempert fenestration method. Rosen realized, that mobilizing the fixed stapes prior to fenestration may yield better hearing result as compared with fenestration. Holmgren, later on Fowler applied a method in which the stapes footplate was intentionally fractured in the middle. The posterior part of the footplate was mobilized, the anterior part was removed, and the posterior crus was pushed cranially to achieve a mobile one-crus stapes attaining „stapediolysis”.

1.5 Stapedectomy

In the 1950s Howard House (1908-2003) was one of the first otologists to incorporate the stapes mobilization technique popularized by Rosen in their practice besides the fenestration surgery. John Shea (1924-2015) participated in one of the courses organized by Rosen in 1953. During a discussion about the surgeries performed the day Shea suggested House to remove the stapes and replace it with a prosthesis. Shea was impressed by Frederick L. Jack who reported good results in a case of a double stapedectomy with a 10 year follow up in 1902. Shea performed the first stapedectomy in 1955 with the interposition of a rod-like homograft cortical bone, placed between the incus and the oval window covered with a thin connective tissue. The hearing gain was remarkable, however the graft was rejected later on. Stapedectomy with teflon prosthesis was first performed on may 1, 1956. During the operation performed under local anaesthesia, the oval window was covered with a piece of vein and the prosthesis was placed between the incus and the vein. This novel surgical method revolutionized the surgery of otosclerosis and other stapes fixations.

1.6 Stapedotomy

Shea reported good results after creating a small hole in the footplate and placing a teflon prosthesis without a vein graft. This technique was modified by Jean Marquet (1928-1991) from Antwerp in 1963, and named it as platinotomy which was later renamed stapedotomy. He achieved excellent results with his technique, while the rate of postoperative sensorineural hearing loss remained low.

1.7 Laser stapedotomy

A new chapter began in middle ear surgery with the introduction of lasers. Owing to the basic features of the laser beam (coherence, collimation, high energy), cutting, coagulating and vaporising may also be possible with laser. According to different authors excellent hearing results are achievable with laser, while the postoperative vertigo is milder and the period of hospitalization is shorter as compared with the conventional stapedotomy technique.

1.8 Stapes prostheses

Several other pistons from different materials were introduced following the development of the teflon prosthesis by Shea. Knox introduced the SMart piston made from nitinol in 2005. The hook made of nitinol is available in an open condition, and becomes closed with the application of heat. A few years later NiTiBOND piston was introduced which has heat memory as well as the SMart nitinol piston but differs in shape.

2 Objectives

1. Demonstrating the features and the short-term hearing results achieved with the NiTiBOND piston, the latest heat-memory prosthesis
2. Comparison of hearing results following the use of NiTiBOND versus Nitinol prostheses in stapes surgery
3. Surgical management of particular cases as persistent stapedial artery, obliterative otosclerosis, bilateral stapes fixation, otosclerosis leading to mixed hearing loss, ptotic facial nerve, loose wire syndrome are demonstrated, and the required conditions are discussed
4. The diagnostic role of temporal bone CBCT is discussed in otosclerosis
5. The diagnostic role of the HRCT and it's ability in determining the extent of disease regarding different types of stapes fixations are discussed

3 Comparison of hearing results following the use of NiTiBOND versus Nitinol prostheses in stapes surgery: a retrospective controlled study reporting short-term postoperative results

3.1 Introduction

With the introduction of the heat-memory nitinol (nickel-titanium alloy) pistons the manual crimping has become avoidable. Owing to the heat-memory of the piston it adopts the predefined shape when heat is applied. The applied SMart Nitinol and NiTiBOND pistons differ from each other as regards the shape of their attachment loop. While the loop of the shape-memory Nitinol piston has the shape of a shepherd's crook, the loop of the NiTiBOND piston forms a daisy shape when heated, which results in different extents of coverage of the surface of the long process of the incus. According to our semi-quantitative calculations, NiTiBOND covers only 25-30 % of the total perimeter of the long process of the incus, while the SMart Nitinol covers two-third when closed.

3.2 Patienst and methods

Thirty-one patients underwent stapedotomy with use of the NiTiBOND prosthesis between September 2012 and September 2014, and 39 patients received the Nitinol piston between March 2006 and December 2012. The mean age was 43.8 years (range 22-61) and 46.9 years (range 28-83) in the NiTiBOND and the Nitinol group, respectively. The inclusion criteria were a normal-appearing tympanic membrane, a type A tympanogram, the absence of a stapedial reflex and a substantial air-bone gap (ABG), resulting in a louder bone conduction (BC) than air conduction (AC) with the 1024 Hz tuning fork and the absence of a vestibular evoked myogenic potential on the affected side.

3.3 Results

Postoperative ABG closure within 10 dB was achieved in 77% of the cases in NiTiBOND and in 59% in the Nitinol group ($p = 0.10$) at the 3-months follow up, the difference was not statistically significant. The ABG closure was < 20 dB in all patients in both groups. The mean preoperative ABG before NiTiBOND was 24.6 dB (SD 7.2), which declined to 7.6 dB (SD 4.7) postoperatively ($p < 0.001$, Table 1, fig. 1). The mean ABG before Nitinol was 28.2 dB (SD: 10.1) preoperatively, which improved to 9.3 (SD 4.1, $p < 0.001$) following surgery (Table 1, Fig. 1). The mean postoperative AC threshold at 4 kHz was 43.8 dB as compared with 51.6 dB preoperatively for NiTiBOND ($p = 0.007$), and 36.4 dB as compared with 49.1 dB for Nitinol ($p < 0.001$, Table 1). Neither the preoperative ($p = 0.60$), nor the postoperative ($p= 0.13$) 4-frequency AC thresholds of the two groups were significantly different. The difference between the mean preoperative ($p = 0.33$) and postoperative ($p = 0.18$) AC threshold at 4 kHz of the two groups was not significant (Table 2). The measure overclosure was 1.4 dB for NiTiBOND ($p = 0.12$) and 6 dB for the Nitinol group ($p < 0.001$). The mean 3-frequency (1, 2 and 4 kHz) BC threshold postoperatively was 26.3 dB (SD 13.2), as compared with 27.1 dB (SD 8.8) preoperatively for NiTiBOND ($p = 0.20$), and 18.5 dB (SD 7.4) as compared with 22.9 dB (SD 8.5) for Nitinol ($p < 0.001$, Fig. 2).

Table 1: Comparison of the preoperative and 3-month postoperative hearing results within the two surgical groups

Variables	NiTiBOND		p	Nitinol		p
	Preop.	Postop.		Preop.	Postop.	
Mean ABG, dB (SD)	24.6 (7.2)	7.6 (4.7)	p <0.001	28.2 (10.1)	9.3 (4.1)	p <0.001
Mean BC, dB (SD)	26.1 (7.2)	24.7 (12.7)	p=0.12	22.6 (7)	16.6 (5.8)	p <0.001
Mean AC, dB (SD)	50.7 (8.9)	32.3 (15.6)	p <0.001	50.9 (14.4)	25.9 (6.2)	p <0.001
Mean BC (1,2 and 4 kHz), dB (SD)	27.1 (8.8)	26.3 (13.2)	p=0.20	22.9 (8.5)	18.5 (7.4)	p <0.001
AC 4 kHz, dB (SD)	51.6 (18.5)	43.8 (22.1)	p=0.007	49.1 (21)	36.4 (15)	p <0.001

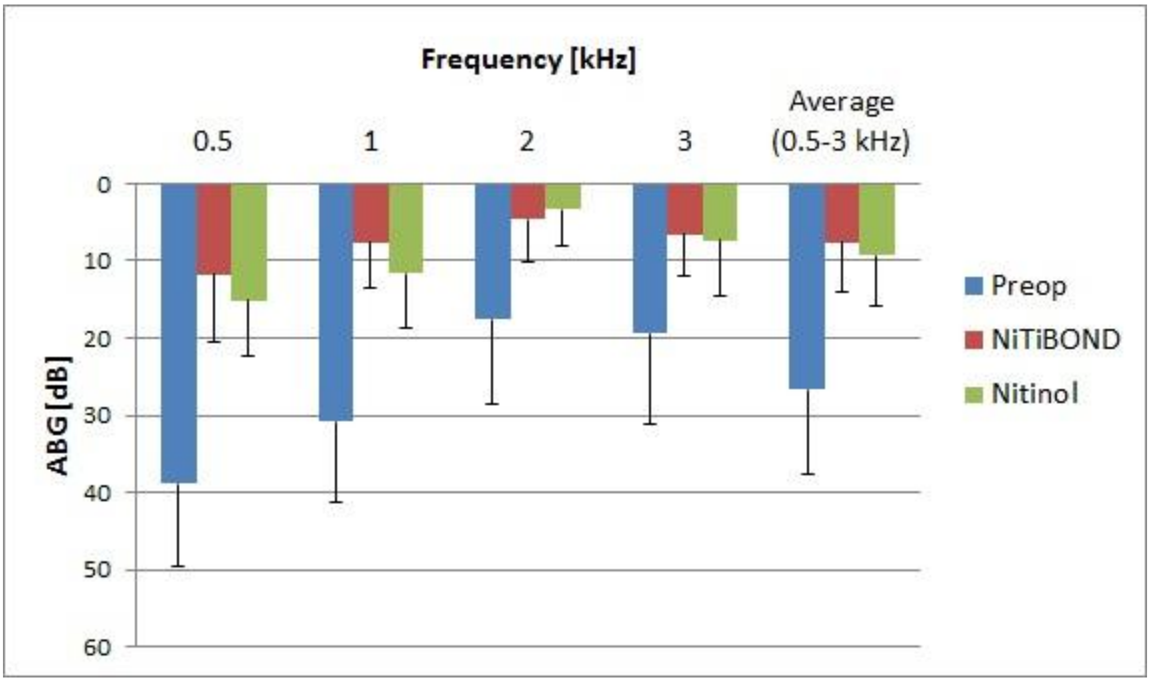

Fig. 1: Preoperative and 3-month postoperative mean air-bone gap (ABG) in the NiTiBOND and Nitinol groups. Bars indicate 1 SD

Neither intraoperative complications nor significant hearing deterioration occured in the groups (Table 2).

Table 2: Comparison of the preoperative and 3-month postoperative hearing results between the two surgical groups

Variables	Preop.		p	Postop.		p
	NiTiBOND	Nitinol		NiTiBOND	Nitinol	
Mean ABG, dB (SD)	24.6 (7.2)	28.2 (10.1)	p=0.17	7.6 (4.7)	9.3 (4.1)	p=0.059
Mean BC, dB (SD)	26.1 (7.2)	22.6 (7)	p=0.008	24.7 (12.7)	16.6 (5.8)	p=0.002
Mean AC, dB (SD)	50.7 (8.9)	50.9 (14.4)	p=0.60	32.3 (15.6)	25.9 (6.2)	p=0.13
Mean BC (1,2 and 4 kHz), dB (SD)	27.1 (8.8)	22.9 (8.5)	p=0.009	26.3 (13.2)	18.5 (7.4)	p=0.006
AC 4 kHz, dB (SD)	51.6 (18.5)	49.1 (21)	p=0.33	43.8 (22.1)	36.4 (15)	p=0.18

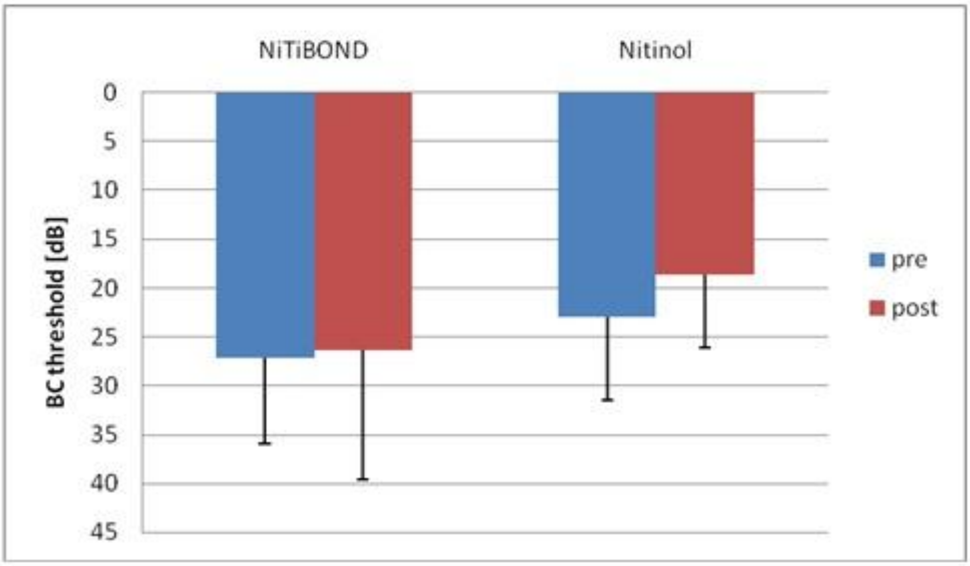

Fig. 2: Preoperative and 3-month postoperative means of the 3-frequency (1, 2 and 4 kHz) bone conduction (BC) threshold in the NiTiBOND and Nitinol groups. Bars indicate 1 SD

3.4 Discussion

We compared the 3-month postoperative hearing results of patients who underwent stapedotomy for stapes fixation with the application of either a NiTiBOND or a Nitinol stapes piston prosthesis. It has been hypothesized that lower incus coverage by the NiTiBOND piston as compared with Nitinol is therefore advantageous, leading to a decrease in the chance of incus necrosis, which can be the underlying pathology in up to 49% of revision surgeries. The application of the NiTiBOND piston results in easier manipulation as compared with the SMart Nitinol piston, with similar air-bone gap closure ratio. The daisy-shaped attachement loop of the NiTiBOND may decrease the chance of incus necrosis, as it covers less mucosal surface and the laser beam is aimed more distal to the core of the long process of the incus, as compared with Nitinol.

4 Special surgical interventions in stapes surgery

4.1 Introduction

With the introduction of laser stapedotomy the special cases of stapes surgery, such as obliterative otosclerosis, persistent stapedial artery causing mixed hearing loss and pulsatile tinnitus and the ptotic facial nerve associated with stapes fixation seemed manageable. In selected cases the bilateral simultaneous stapedotomy have also become manageable with good results. The advanced otosclerosis affecting the cochlea may result in mixed, moderately severe hearing loss. This condition can be managed recently by the combination of the Vibrant Soundbridge (VSB) placed on the incus and stapedotomy in one stage. Rarely the fixation of the piston may be unsuccessful leading to the loose wire syndrome, characterized by the fluctuation of auditory acuity and perception of distorted sounds.

4.2 Patients and methods

4.2.1 Case report 1: management of persistent stapedial artery causing vertigo and tinnitus

A 35-year-old female presented at our department in 2012 with left-sided progressive, severe mixed hearing loss, left-sided pulsatile tinnitus, headache and vertigo. Explorative tympanotomy was performed in June 2012 following examinations. During the surgical intervention a persistent stapedial artery was revealed running on the surface of the stapes footplate. Following repeated embolizations of the vessel and the KTP laser assisted partial stapedectomy, the pulsatile tinnitus and headache ceased, while the hearing improved. According to the angiography, the artery was proved to be the middle meningeal artery arising from the internal carotid artery.

4.2.2 Case report 2: obliterative otosclerosis

A 45 year-old-male presented at our department with a bilateral, progressive hearing loss since 2011. Explorative tympanotomy was performed in September 2013. During the surgical intervention an excessively thick and rigid stapes footplate was found. KTP laser vaporisation was carried out on the posterior surface of the footplate, then a 0.8 mm microdrill was applied alternatively. The stapedotomy was performed with the microdrill. The ossicular chain was reconstructed with a NiTiBOND piston measuring 4.75 x 0.6 mm. The right ear was managed surgically in the same manner in March 2014 due to the similar findings as compared with the contralateral ear. The 2-week postoperative audiogram revealed a 5 dB air-bone gap on the right side, as compared with 6.75 dB ont he left side. No significant bone-conduction threshold shift was recorded related to cochlear trauma.

4.2.3 Case report 3: bilateral stapedotomy

A 60-year-old female presented at our department with a progressive, bilateral conductive hearing developed in 2010. Bilateral explorative tympanotomy was performed simultaneously in May 2015. During the surgical intervention fixed stapes was found both sides and simultaneous bilateral KTP laser stapedotomy was performed. The ossicular chain was reconstructed with NiTiBOND piston both sides. Following uneventful surgery 5 dB air-bone gap was measured on the 1-month postoperative audiogram. On the left side 5 dB overclosure was recorded. No signs of cochlear damage occured.

4.2.4 Case report 4: „power stapes"

A 35-year-old female presented at our department with a progressive left-sided hearing loss in 2014. Following retroauricular incision, mastoidectomy and posterior tympanotomy was performed and fixed stapes was found. The floating mass transducer of the VSB was placed on the long process of the incus. Laser stapedotomy was performed and SMart Nitinol piston measuring 5.4 x 0.6 mm was implanted. Fifty-two dB functional gain was achieved with the VSB and 11.25 dB improvement was measured due to the stapedotomy. With the VSB turned on, the word reception score reached 85 % as compared with 0 % with the device turned off.

4.2.5 Case report 5: ptotic facial nerve

A 27-year-old male presented at our department with a right-sided hearing loss and tinnitus existing for 6 months. Explorative tympanotomy was performed in July 2015, while fixed stapes was found. The facial nerve revealed running over the posterior surface of the stapes footplate. The edge of the promontorium sorrounding the stapes footplate was drilled due to the narrow condition. Following the removal of the stapes suprastructure KTP laser vaporisation was performed on the posterior third of the stapes footplate, the stapedotomy was carried out with a microdrill and the ossicular chain was reconstructed with the latest Nitiflex piston. The hearing improved, and the facial nerve function remained intact.

4.2.6 Case report 6: „loose wire” syndrome

A 54-year-old female patient presented at our department with a progressive bilateral conductive hearing loss. KTP laser stapedotomy was carried out, whereby a self-crimping heat memory NitiBOND piston was implanted to reconstruct the ossicular chain. Following surgery however, the hearing did not improve and the patient complained about distorted sound perception and fluctuation of auditory acuity. Revision surgery was carried out due to settled complaints, whereby a loose connection was revealed between the head of the NiTBOND piston and the long process of the incus. The rod of the piston was found to be placed accurately in the stapedotomy whole. The connection between the head of the piston and the incus was reinforced with KTP laser and glass ionomer cement. Following the revision surgery the distorted sound perception disappeared and the hearing slightly improved.

4.3 Discussion

During the surgical managements of stapes fixations rare anatomic and pathologic conditions may be revealed such as persistenst stapedial artery, obliterative otosclerosis or ptotic facial nerve. Hearing rehabilitation in case of advanced otosclerosis leading to mixed moderate to severe hearing loss is a challenge. Besides the modern stapes prostheses available to close air-bone gap, the active middle ear implants facilitate the achievement of remarkable functional gain. In case of unchanged postoperative hearing, distorted sound perception and fluctution in audiotory acuity the loose wire syndrome should be taken into consideration. These unique and challenging situations in stapes surgery seem manageable recently with the support of modern instrumentation and adequate surgical experience. As long as the the majority of cases in stapes surgery can be managaed without laser and microdrill, we state that these situations require advanced surgical experience and the support of modern instrumentation including a laser with a hand-piece, a microdrill and a stapes prosthesis made of nitinol.

5 Diagnostic value of cone-beam CT in histologically confirmed otosclerosis

5.1 Introduction

Otosclerosis is a unique bone dyscrasia of the human otic capsule that is characterized by pathologically increased new bone formation. Modern imaging techniques introduced new insights into the preoperative evaluation of various osseous disorders of the human temporal bone, which have been confirmed by several studies in stapes fixation. Preoperative detection of otosclerosis-like hypodense foci has great clinical significance, since it might correspond to the severity and progression of hearing loss. Cone-beam computed tomography (CBCT) is a relatively new imaging method that is widely used in dentistry. The emitted X-ray dose by the CBCT is significantly less as compared with the high-resolution computed tomography (HRCT) and the scanning procedure (20–40 s) and the reconstruction time (2 min) are also significantly shorter than those in HRCT. Present study investigates the correlations between CBCT scans and postoperative histopathologic findings in patients with stapes ankylosis to assess the role of CBCT in the preoperative diagnosis of otosclerosis.

5.2 Patienst and methods

5.2.1 Patients

In this study 102 temporal bone CBCT scans were performed. Thirty-two patients (64 ears) with stapes ankylosis were included in the study, who underwent stapedectomy with postoperative histopathologic analysis of the removed stapes footplates. The study group consisted of 24 females and 8 males (female/male ratio 3:1). The mean age of patients was 32.57 years (range 26–53 years). The diagnosis of stapes fixation was based on clinical, audiometric, tympanometric and CBCT findings.

5.3 Cone-beam computed tomography (CBCT) scans and image review

Cone-beam computed tomography scans of the temporal bone were performed by a multi-slice CBCT scanner with 0.4 mm section thickness by axial, sagittal and coronal imaging. All examinations were performed without contrast material and imaging included the entire temporal bone. CBCT scans were evaluated by the grading system of Marshall et al.

5.4 Histopathologic analysis

A total of 32 ankylotic stapes footplates were fixed in 10 % (w/v) buffered formaldehyde and decalcified in 0.5 M Na-EDTA (sodium ethylene-diamino-tetraacetate, 72 h, 4 °C) containing 0.02 % (w/v) sodium azide. Specimens were embedded in 15 % (w/v) purified gelatin (24 h, 56 °C) and refixed in 4 % (w/v) paraformaldehyde (24 h, 20 °C). Gelatin blocks were cryoprotected in 20 % (w/v) sucrose solution (2 h, 4 °C) and sectioned into 10 µm slides at -25 °C (MNT-200, Slee, Mainz, Germany). Slides were stored in 0.1 M PBS (phosphate-buffered saline) containing 0.03 % (w/v) sodium azide at 4 °C. Sections were processed to conventional hematoxylin and eosin (H.E.) staining.

5.5 Results

Ankylotic stapes footplates (n = 32) removed by stapedectomy were analyzed through conventional H.E. staining, respectively. Histopathologic results were correlated to the preoperative CBCT scans and the audiometric findings. Histologic diagnosis of otosclerosis was established in all ankylotic stapes footplates. Otosclerotic stapes footplates were affected by single otosclerotic foci. Among these specimens, foci of otosclerosis were considered to be active in 21 stapes footplates and inactive in 11 cases (Table 3).

Table 3: Preoperative cone-beam computed tomography findings in otosclerosis correlated to audiologic data

Histology of the ankylotic stapes (n=32)	**Temporal bone CBCT[1](n=32)**				**Sensitivity[2] (%)**	**Speci-ficity[3] (%)**	**ABG[4] (0.5-1-2 kHz, dB)**	**BC[5] (0.5-1-2 kHz, dB)**
	Positive findings[6]			Negative findings[7]				
	Oval window niche	Round window	Pericochlear					
Otosclerosis (n=32, 100%)	21	0	0	11	65.62	100	22.4	7.3
Active (n=21, 65.6%)	21	0	0	0	100	100	17.9	6.8
Inactive (n=11, 34.4%)	0	0	0	11	0	0	36.1	8.5

[a]Cone-beam computed tomography
[b] Sensitivity of CBCT correlated to histopathologic confirmation of otosclerosis
[c] Specificity of CBCT correlated to histopathologic confirmation of otosclerosis
[d] Air-bone gap average at 0.5–1–2 kHz frequencies
[e] Bone conduction average at 0.5–1–2 kHz frequencies
[f] Hypodensity detected in the otic capsule
[g] No hypodensity detected in the otic capsule

During the further analysis, ears were divided into three groups: (1) active otosclerosis (n = 21); (2) inactive otosclerosis (n = 11); and (3) contralateral ears (n = 32) without histopathologic findings. According to our results, both histologically active and inactive cases of otosclerosis displayed pure conductive hearing loss. According to the audiometric findings, otosclerosis was bilateral in 15 patients (46.87 %). There was a statistically significant association between the histopathologic activity of otosclerosis and ABG averages at 0.5–1–2 kHz frequencies ($p < 0.05$, Mann–Whitney's U probe). In contrast, no statistically significant association was found with BC averages in the two histopathologic groups of otosclerosis. Among the ears with otosclerosis (n = 32), CBCT revealed 21 positive findings indicating a sensitivity for otosclerosis as 65.62 %. In the active otosclerosis group (n = 21), the sensitivity of CBCT for otosclerosis increased to 100 %, while in case of inactive otosclerosis (n = 11), sensitivity levels decreased to 0 %. According to CBCT findings, otosclerosis was bilateral in 18 patients (56.25 %), which was higher than those that revealed by preoperative audiometric estimation findings (46.87 %). We have found a statistically significant and inverse association between the CBCT grades and ABG averages in ears with active or inactive otosclerosis ($p < 0.001$, Mann–Whitney's U probe). However, it could not be confirmed in the contralateral ear group. On the contrary, CBCT grades did not present statistically significant association with BC averages in the group of ears with different histopathologic activities of otosclerosis.

6 Discussion

In the present study, we demonstrated associations between CBCT scans and audiometric findings in patients with histologically confirmed otosclerosis. In our series, however, CBCT seemed to be highly sensitive for non-symptomatic otosclerotic foci overestimate revealing bilateral otosclerosis as 56.25 %, in contrast to 46.87 % prevalence revealed by pure-tone audiometry. We have found statistically significant associations between the ABG averages and CBCT grades including the location of hypodense lesions in patients with histologically confirmed otosclerosis. This association followed an inverse function: histologically active otosclerosis with less ABG averages was characterized by positive CBCT findings; however, histologically inactive cases with larger ABG averages displayed negative CBCT scans. Temporal bone CBCT is a useful imaging method in the preoperative evaluation of histologically active fenestral otosclerosis. In the lack of histologic findings, inactive otosclerosis and non-otosclerotic stapes fixations may occur as differential diagnostic difficulties during imaging. Its overall sensitivity falls away from that of histologic analysis;

however, it is continuously evolving due to the introduction of higher resolution CT techniques and more powerful analyzer softwares. In critical interpretation, CBCT seems to be reliable tool in the preoperative diagnosis of otosclerosis; however, further studies are necessary to assess the precise diagnostic values of this imaging technique.

7 Comparative analysis of preoperative diagnostic values of HRCT and CBCT in patients with histologically diagnosed otosclerotic stapes footplates

7.1 Introduction

Nowadays, the most exact diagnosis of otosclerosis is still based on the postoperative histopathologic analysis of the removed ankylotic stapes footplates. However, there are several limitations: most ear surgeons prefer stapedotomy or partial stapedectomy by piston technique, which are not suitable methods to obtain whole stapes footplate specimens. Furthermore, in some cases of early otosclerosis, the stapes footplate is not affected by spongiotic lesions, which can lead to misdiagnosis. In the latest years, range of interest for preoperative imaging in different types of conductive hearing losses with normal tympanic membrane significantly increased. There are two main causes: (1) preoperative imaging helps to avoid 'blinded surgery' a.k.a. explorative tympanotomy; (2) most of the patients would like to know detailed informations regarding the problem in their middle ear cavities before they give their consent for surgery. Positivity of X-ray-based imaging has been reported as an important prognostic factor of surgical success rates according to the extension and location of radiologically hypodense bone lesions of the otic capsule. According to the previous studies, high-resolution computed tomography (HRCT) is the first imaging method of choice in the evaluation of structural disorders in the human temporal bone in cases of condutive hearing loss (CHL) and mixed hearing loss (MHL) with normal tympanic membranes. Present study investigates the correlations between CBCT and HRCT scans and postoperative histopathologic findings in patients with histologically confirmed otosclerosis to assess and compare the usefulness of CBCT and HRCT in the preoperative diagnosis of otosclerosis.

7.2 Patients and methods

7.2.1 Patients

A total of 131 temporal bone CBCT and HRCT scans were performed. Finally, 43 patients (86 ears) with stapes ankylosis were included in the study, who underwent stapedectomy with postoperative histopathologic analysis of the removed stapes footplates. The study group consisted of 29 females and 14 males (female/male ratio 2.07). The mean age of patients was 36.11 years (range 16–59 years). The diagnosis of stapes fixation was based on clinical, audiometric, tympanometric, CBCT and HRCT findings. This study was strictly focused on histologically confirmed otosclerosis to avoid statistical bias. Specificity data could be calculated, since we used age- and gender-matched patients without otological disorders, who underwent CBCT examinations due to various dental problems. In case of HRCT, we used another group of patients, who underwent HRCT examinations due to idiopathic sudden sensorineural hearing loss (ISSNHL).

7.3 CBCT and HRCT scans and image review

Cone-beam computed tomography scans of the temporal bone were performed by a multi-slice CBCT scanner with 0.4 mm section thickness by axial, sagittal and coronal imaging. All examinations were performed without contrast material, and imaging included the entire temporal bone. HRCT scans of the temporal bone were performed by a 16-section CT scanner with 0.625 mm section thickness and both axial and coronal imaging. The deviceoptimized and controller softwares and the devices themselves allow the above-mentioned resolutions. All examinations were performed without contrast material, and imaging included the entire temporal bone. CBCT and HRCT scans were evaluated by the modified grading system of Marshall et al. Our modification was the following: (1) grade 0 is a negative finding; (2) grade 1 is fenestral lesion and (3) grades 2a, b, c–3 are retrofenestral or fenestral–retrofenestral lesions.

7.3.1 Histopathologic analysis

A total of 32 ankylotic stapes footplates were fixed in 10 % (w/v) buffered formaldehyde and decalcified in 0.5 M Na-EDTA (sodium ethylene-diamino-tetraacetate, 72 h, 4 °C) containing 0.02 % (w/v) sodium azide. Specimens were embedded in 15 % (w/v) purified gelatin (24 h, 56 °C) and refixed in 4 % (w/v) paraformaldehyde (24 h, 20 °C). Gelatin blocks were cryoprotected in 20 % (w/v) sucrose solution (2 h, 4 °C) and sectioned into 10 µm slides at -25 °C (MNT-200, Slee, Mainz, Germany). Slides were stored in 0.1 M PBS (phosphate-buffered saline) containing 0.03 % (w/v) sodium azide at 4 °C. Sections were processed to conventional hematoxylin and eosin (H.E.) staining.

7.4 Results

Ankylotic stapes footplates (n = 43) removed by stapedectomy were analyzed through conventional H.E. staining. Histopathologic results were correlated with the preoperative CBCT and HRCT scans and to the audiometric findings, respectively. Histologic diagnosis of otosclerosis was established in all ankylotic stapes footplates. During further analysis, ears were divided into three groups: (1) active otosclerosis (n = 31); (2) inactive otosclerosis (n = 12); and (3) contralateral ears (n = 43) without histopathologic findings (Table 4).

Table 4: Preoperative cone-beam computed tomography (CBCT) findings in otosclerosis correlated to audiologic data

Histology of the ancylotic stapes (n=43)	**Temporal bone CBCT[1] (n=43)**				**Sensitivity[2] (%)**	**Speci-ficity[3] (%)**	**ABG[4] (0.5-1-2 kHz, dB)**	**BC[5] (0.5-1-2 kHz, dB)**
	Positive findings[6]			Negative findings[7]				
	Oval window niche	Round window	Retrofenestral					
Otosclerosis (n=43, 100 %)	31	0	0	12	61.37	100	21.2	6.8
Active (n=31, 72%)	31	0	0	0	100	100	16.2	5.3
Inactive (n=12, 28%)	0	0	0	12	0	100	35.3	9.7

[a]Cone-beam computed tomography
[b] Sensitivity of CBCT correlated to histopathologic confirmation of otosclerosis
[c] Specificity of CBCT correlated to CBCT results of patients with various dental disorders
[d] Air-bone gap average at 0.5–1–2 kHz frequencies
[e] Bone conduction average at 0.5–1–2 kHz frequencies
[f] Hypodensity detected in the otic capsule
[g] No hypodensity detected in the otic capsule

According to our results, histologically active otosclerosis displayed pure CHL, while histologically inactive otosclerosis represented MHL in eight cases. According to the audiometric findings, otosclerosis was bilateral in 25 patients (58.14 %). There was a statistically significant association between the histopathologic activity of otosclerosis and ABG averages at 0.5–1–2 kHz frequencies ($p < 0.05$, Mann–Whitney’s U probe). In contrast, no statistically significant association was found with BC averages in the two histopathologic group of otosclerosis. Among the ears with otosclerosis (n = 43), CBCT revealed 31 positive findings indicating a sensitivity for otosclerosis as 61.37 %. In the active otosclerosis group (n = 31), the sensitivity of CBCT for otosclerosis increased to 100 %; while in case of inactive otosclerosis (n = 12), sensitivity levels decreased to 0 %. According to CBCT findings, otosclerosis was bilateral in 21 patients (48.83 %), which was smaller than the preoperative audiometric estimation (58.14 %). However, this finding was not statistically significant. As replication of previously reported data, a statistically significant and inverse association was found between CBCT grades and ABG averages in ears with active or inactive otosclerosis ($p < 0.001$, Mann–Whitney's U probe). Among all otosclerosis cases (n = 43), HRCT revealed 40 positive findings indicating a sensitivity for otosclerosis as 76.29 %. In the active otosclerosis group (n = 31), the sensitivity of HRCT for otosclerosis increased to 100 %, while in case of inactive otosclerosis (n = 12), sensitivity levels decreased to 59.3 % (Table 5).

Table 5: Preoperative high-resolution computed tomography (HRCT) findings in otosclerosis correlated to audiologic data

Histology of the ancylotic staes (n=43)	**Temporal bone HRCT[1] (n=43)**				**Sensitivity[2] (%)**	**Speci-ficity[3] (%)**	**ABG[4] (0.5-1-2 kHz, dB)**	**BC[5] (0.5-1-2 kHz, dB)**
	Positive findings[6]			Negative findings[7]				
	Oval window niche	Round window	Retrofenestral					
Otosclerosis (n=43, 100 %)	31	2	13	3	76.29	100	21.2	6.8
Active (n=31, 72%)	31	1	9	0	100	100	16.2	5.3
Inactive (n=12, 28%)	7	1	4	3	59.3	100	35.3	9.7

a High-resolution computed tomography
b Sensitivity of HRCT correlated to histopathologic confirmation of otosclerosis
c Specificity of HRCT correlated to HRCT results of patients with idiopathic sudden sensorineural hearing loss
d Air-bone gap average at 0.5–1–2 kHz frequencies
e Bone conduction average at 0.5–1–2 kHz frequencies
f Hypodensity detected in the otic capsule
g No hypodensity detected in the otic capsule

We have found statistically significant association between HRCT grades (fenestral or retrofenestral) and ABG ($p < 0.05$) and BC averages ($p < 0.001$) in the contralateral ears. HRCT grades also showed statistically significant association with BC ($p < 0.001$) and ABG averages ($p < 0.001$) comparing the groups of active and inactive otosclerosis.

7.5 Discussion

In this study, various statistical associations were demonstrated between CBCT and HRCT scans and audiometric findings in patients with histologically confirmed otosclerosis. The weakness of our study is the relatively low number of subjects, however; is a comprehensive imaging and histologic study that is able to assess the sensitivity and specificity values of CBCT and HRCT scans in histologically confirmed otosclerosis. Sensitivity levels of HRCT scans have been reported as 70.5–84.5 % in patients with stapes fixation. In histologically confirmed cases, specificity levels were estimated as 100 %. According to our previous and present observations, in the group of histologically confirmed otosclerosis, CBCT showed 61.37–65.62 % overall sensitivity, which was lower than that of previous reports. According to our observations, in case of otosclerosis, HRCT showed 76.29 % overall sensitivity, which is more robust, compared to the sensitivity levels of CBCT. In our series, however; CBCT seemed to be less sensitive for non-symptomatic otosclerotic foci revealing bilateral otosclerosis as 48.83 %, in contrast to the 58.14 % prevalence revealed by pure tone audiometry. In contrast, HRCT showed a good correspondence (55.81 %) with audiological findings in the clinical assessment of bilateral cases. Histologically active otosclerosis with less ABG averages was characterized by positive CBCT findings; however, histologically inactive cases with larger ABG averages displayed negative CBCT scans. On the contrary, HRCT grades (fenestral or retrofenestral) showed a statistically significant association with ABG and BC averages in the contralateral ears and also in the histologically confirmed group of stapes footplates depending on the histologic activity of otosclerosis. Regarding to HRCT findings, in case of inactive otosclerosis, the sensorineural component of hearing impairment shows a strong correlation with the severity and extension of otosclerosis. However, it cannot be confirmed by CBCT. Preoperative evaluation of the extension of otosclerosis by combined application of HRCT and audiometry has a great clinical significance, since patients with far advanced cochlear otosclerosis may have benefit from cochlear, DACS or BAHA implantation depending on the bone conduction threshold rather than stapedectomy or stapedtotomy. In conclusion, temporal bone HRCT is a useful imaging method in the preoperative evaluation of different types of stapes fixations and may serve as a reliable tool in the assessment of disease extension. Its sensitivity is much higher for retrofenestral lesions and for inactive otosclerosis than that of CBCT. Therefore, it can be stated that HRCT must be the first choice of temporal bone imaging. As we have previously concluded, preoperative HRCT scan may serve as a valuable imaging method in the planning of stapes surgery. It helps to avoid serious complications and unnecessary stapes surgeries by the detection of several abnormalities in the middle or inner ear, such as large vestibular aqueduct, dehiscent facial canal, superior semicircular canal dehiscence, round window obliteration, persisting stapedial artery and malleus head fixation. Temporal bone CBCT is a reliable imaging method in the preoperative evaluation of histologically active fenestral otosclerosis. Other authors have reported that selected anatomic structures of the temporal bone (n = 16) were clearly reconstructed by CBCT and no discrepancies were found compared to HRCT findings. These results indicate that CBCT may also serve as a choice of temporal bone imaging in case of CHL. Nevertheless, CBCT is a cheap, easy and a rapid imaging method that is characterized by considerably lower radiation dose than HRCT with normal tympanic membranes. Its overall sensitivity falls away from that of HRCT and histologic analysis; however; it is continuously evolving due to the introduction of more powerful analyzer softwares.

8 Summary

1. Applying laser technique and the NiTiBOND piston together we newly developed a reliable method in stapes surgery which promise excellent short-term hearing results
2. We experienced easier manipulation with similar air-bone gap closure achieved with NiTiBOND piston as compared with the SMart Nitinol piston, while the risk of incus necrosis may continue to decrease
3. We introduced the surgical management of particular situations in stapes surgery, such as stapes fixation associated with persistent stapedial artery, obliterative otosclerosis, bilateral stapes fixation, otosclerosis leading to mixed hearing loss, ptotic facial nerve, loose wire syndrome initially in the hungarian literature
4. The temporal bone CBCT was demonstrated to be a reliable and useful imaging method in the preoperative evaluation of histologically active fenestral otosclerosis
5. We introduced HRCT as the imaging method of choice in temporal bone imaging to differentiate between the types of stapes fixations preoperatively and to serve as a reliable tool in the assessment of disease extension

9 Publications related to the thesis

1. Révész P, Harmat K, Háromi I, Ráth G, Karosi T, Molnár K, Gerlinger I. Különleges stapes sebészeti megoldások – esetismertetések és irodalmi áttekintés. Fül-Orr-Gégegyógyászat 2016; 62: 9-16.
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10 Further publications

1. Szabadi É, Török L, Révész P, Burián A, Gerlinger I, Lujber L. Dobhártyapótlás új lehetőségének bemutatása állatkísérletes modellen. Fül-Orr-Gégegyógyászat 2010; 56 (3): 182.
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