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OTOLOGY

Osteoplastic atticoantrotomy with autologous bone chips and a bony attic strut in cholesteatoma surgery

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Abstract The objectives of this study were to determine whether autologous bone chips are suitable materials for canal wall reconstruction after cholesteatoma removal and to evaluate the effectiveness of a separate attic bone graft for the prevention or recurrent cholesteatomas using prospective study of two consecutive patient series (29/31 unselected patients with an average follow-up of 36.3 ± 11.1/21.5 ± 6.3 months) and retrograde resection of the posterior-superior canal wall followed by reconstruction of the canal defect using one or more temporal squama bone chips. In the second series, lateral attic wall reconstruction and pars flaccida reinforcement was established by a notched bony attic strut attached onto the neck and short process of the malleus for structural support. In the first series, the rate of recurrent cholesteatomas (17.3%), in particular of attic retraction pockets (31%), was significantly high. The average postoperative air–bone gap was 6.4 ± 6.3 dB in type-I tympanoplasty (TP), 8.7 ± 3.4 dB in type-III TP with intact stapes suprastructure, and 16.4 ± 9.3 dB in type-III TP with TORP, respectively. In the second series, recurrent cholesteatoma and retraction pocket rate could be decreased to 9.7 and 6.5%, respectively. The postoperative air–bone gap was 7.5 ± 5.1 dB HL in type-I tympanoplasty (TP), 11.6 ± 4.9 dB HL in type-III (PORP) TP, and 17.9 ± 12.2 dB HL in type-III (TORP) TP. Connecting the attic strut to the malleus neck did not affect the malleus mobility and hearing outcome. Osteoplastic atticoantrotomy with autologous bone chip reconstruction enables a tailor-made anatomical and physiological reconstitution of the auditory ear canal, thus enhancing the acoustic properties. Precise reconstruction of the lateral attic wall and reinforcement of the superior part of the tympanic membrane seems to be important for the prevention of retraction pockets and subsequent recurrent cholesteatoma development.

Keywords Cholesteatoma · Middle ear surgery · Canal wall up surgery · Tympanoplasty · Retraction pockets · Attic strut graft

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Introduction

The surgical management of cholesteatomas remains a controversial issue. The canal wall down (CWD) mastoidectomy with the resection of the posterior-superior canal wall and flattening of the tympanic cavity represents the classic procedure for the removal of cholesteatoma formations from the epi- and retrotympanal spaces. With this single-stage open technique, the incidence of residual and recurrent cholesteatomas can be effectively prevented. The main disadvantages of the open cavity are the necessity for periodic cleansing and the susceptibility for infections, which causes significant restrictions in lifestyle, especially for children (e.g., swimming) [1, 2]. Moreover, the widening of the auditory canal [3, 4] and the reduced intratympanic air volume [5] result in a deterioration of the acoustic conditions with impaired hearing results [6]. To avoid these problems, there has been a trend to maintain the normal anatomy of the ear canal either partially by preserving a bony bridge between the meso- and hypotympanon [7] or completely through a combined posterior–anterior approach with a posterior tympanotomy [8] ("canal wall up" , CWU-technique). Unfortunately these techniques have resulted in a high rate of residual cholesteatoma because the surgical exposure and access to all tympanic and retrotympanic spaces is greatly limited and impeded [9, 10]. The advantages of both techniques—optimal exposure of all middle ear spaces and preservation of the normal anatomy—is offered by procedures that involve the temporary removal and reinsertion [11, 12] or reconstruction of the canal wall [13]. The most popular material for reconstitution of canal wall defects is autologous ear cartilage [14, 15], since it is easy to harvest and easy to shape with reliable graft survival. However, resorption, distortion, and retraction of the implanted cartilage into the mastoid and attic as well as gaps between the cartilage grafts sometimes can be observed in the long-run [16, 17], which increases the risk for recurrent cholesteatoma. Although posing the risk for acute resorption or necrosis [12, 16], bone grafts perhaps might offer more stability compared to cartilage grafts in the long term. The purpose of this study was to evaluate the outcome of bone grafts from the temporal squama for the reconstruction of the canal wall after closed cholesteatoma surgery based on two patients' series.

Materials and methods

1. In the first series, 29 consecutive and unselected patients (29 ears) between 2002 and 2007 had undergone canal wall defect reconstruction with autologous bone chips after cholesteatoma removal (osteoplastic atticoantrotomy). Preliminary results of this technique were published in a previous study [18].
2. Since 2006 we have modified our reconstructive technique in reaction to the results of the previous series. In the second series of 31 consecutive and unselected patients (31 ears), canal wall reconstitution was again performed by autologous bone chips, but in addition the lateral attic wall and the pars flaccida was reconstructed and reinforced by a separate autologous notched bony attic strut graft. Among these were 12 patients from the first cohort of this study, which exhibited recurrent cholesteatomas (four patients) or postoperative epitympanic retraction pockets (eight patients).

All surgery and follow-up examinations were performed by the author.

The following data were obtained and analyzed in both series: age at the time of surgery; sex; site of cholesteatoma; duration of current follow-up after surgery; type of tympanoplasty and ossicular reconstruction; pre- and postoperative audiogram; otologic results in regard to retraction pockets, residual and recurrent cholesteatoma formations; bone graft viability and integrity. The audiometric data were presented as a pure-tone average air–bone gap (PTA-ABG) calculated for 500, 1,000, 2,000, and 3.000 Hz.

Follow-up after initial postoperative treatment was scheduled every 3 months in the first year, every 6 months in the second year, and once in the following years. Pre- and postoperative examinations were performed by microotoscopy and endootoscopy with digital photographic and videographic documentation ("AIDA", Karl Storz GmbH & Co KG, Tuttlingen, Germany). Audiometric data were obtained with clinical audiometers ("Phillips HP 8745/4091" and "Interacoustics AC 30").

Residual cholesteatoma formation and quality of bone graft integration was assessed at staged second-look tympanoscopy or in case of revision surgery. Since the CWU-technique carries a higher risk of residual cholesteatoma, a staged second-look tympanoscopy was broadly indicated, especially (a) cholesteatomas in children, and (b) cholesteatomas with intraoperative matrix disruption or when complete removal was doubtful.

Surgical technique

An endaural approach was chosen in most of the patients. After identification of the cholesteatoma sac, the lateral attic wall was resected by drilling and the malleus and incus were visualized in the epitympanum. Further surgical steps were dependent on the localization and extent of the cholesteatoma. If the cholesteatoma matrix could be easily dissected from the ossicular chain with no extent into the anterior epitympanum, the ossicular chain was preserved. Otherwise the incustapedial joint was disarticulated, the incus removed, and the head of the malleus was cut. The cholesteatoma sac then was tracked backwards as posteriorly as necessary by stepwise drilling of the posterior and superior canal wall (retrograde atticoantrotomy) until the cholesteatoma and its branches were completely exposed. In some cases, a complete retrograde mastoidectomy was necessary. The cholesteatoma then was dissected out of the mastoid cavity in a posterior-to-anterior direction without violation of the cholesteatoma matrix as far as possible. After resection an anterior tympanotomy was performed. The anterior attic bony plate of the anterior epitympanic recess, the cog, existing in front of the malleus head was removed, thus creating a wider route between the attic and the epitympanic sinus and supratubal recess [19, 20].

The first step of reconstruction was the restoration of the tympanic membrane (*type-I tympanoplasty*) by underlaying fascia and, if necessary, the restoration of the sound transformation (*type-III tympanoplasty*). In the first cohort, ossiculoplasty with intact stapes suprastructure was performed by autologous transplantats (autologous incus, head of malleus, and cartilage) and alloplastic implants [titanium partial ossicular replacement prosthesis (PORP), type "Düsseldorf Bell", Fa. Kurz, Dusslingen, Germany]. In cases of absent stapes suprastructure, a titanium total ossicular replacement prosthesis (TORP, type "Düsseldorf Aerial", Fa. Kurz, Dusslingen, Germany) was inserted. In the second cohort, alloplastic titanium prostheses were used in all cases of ossiculoplasty. In some second-look tympanoscopies, when the preoperative audiogram revealed a proper sound conduction, the previously reconstructed ossicular chain was not touched or altered, whenever possible. In general, all middle ear prostheses were covered with thinned cartilage slices from the tragus.

For reconstruction of the canal wall temporal fascia was harvested, the temporal muscle was incised and the temporal squama exposed; then by using plain or curved chisels, it was possible to obtain flat or bended bone chips from the tabula externa of the squamous temporal bone (Fig. 1a). Grooves were drilled into the zygomatic root and attic wall superiorly and the facial ridge inferiorly for a good fit of the bone chips. A hockey-stick-shaped bone chip was placed medially between the grooves at the level of the antrum in a manner that the tail of the bone chip fit into the defect of the lateral attic wall and abutted the posterior edge of the malleus head (Fig. 1b, c). This allowed for an adequate aeration pathway to the antrum to be maintained. The lateral aspect of the posterior-superior canal wall was then restored with further bone chips, sometimes using gelfoam in the mastoid cavity to stabilize the graft. Any bone gaps and all chip-to-groove-junctions were filled with the previously collected bone dust (Fig. 1d). In addition, the reconstructed area was covered, the posterior-superior part of the tympanic membrane was underlayed with temporal fascia (Fig. 1e), and the tympano-meatal and lateral skin flap was repositioned. The procedure was finished by splinting the ear drum and the canal wall with silastic sheaths and gelfoam.

In the second series, the crucial and decisive part of reconstruction, the assembly of the tympanic frame of reconstruction, was modified: The anterior part of the tympanic membrane was dissected, and the anterior lateral attic wall was partially resected to give space for the attic strut. The attachment of the mallear ligaments to the anterior attic buttress was respected to avoid any luxation. A small bone chip was shaped and trimmed to the length of the lateral attic wall. At the inferior edge, a notch was drilled so that the bone graft could be precisely attached onto the short process and neck of the malleus using them as an inferior support for the strut. Any bone gap was filled with bone dust. Resection of the incus or the malleus head did not interfere with this kind of reconstruction, since the tensor tympani tendon was left attached. This technique enabled a stable fit of the attic strut and a strong support of the posterior as well as the anterior part of the lateral attic wall and the pars flaccida. Sometimes, in limited defects (atticotomy) a single attic strut was appropriate (Fig. 2a–f), but in most of the cases the posterior-superior canal wall had also to be reconstructed by additional bone chips as described above (Fig. 3a–e). In the last series, long-term ventilation tube insertion was performed, if feasible, primarily when an effusion was evident preoperatively or secondarily, when effusion or tympanic membrane retraction occurred in the postoperative period.

Results

Patient population

1. Among the 29 patients of the first cohort 16 were males and 13 were females, six of them were children under 15 years of age. The average age at the time of surgery was 36.6 ± 19.1 years with a range of 7–76 years. 19 cholesteatomas (65.5%) originated from the pars flaccida (epitympanic), four of them were recurrences. Ten cholesteatomas (34.5%) were mesotympanic (pars tensa and tympanic sinus) including three recurrences. The average time of follow-up after surgery was 36.3 ± 11.1 months (range 18–69 months; median 35 months).
2. Among the 31 patients of the second cohort 16 were males and 15 were females, six of them were children under 15 years of age. The average age at the time of surgery was 37.2 ± 18.0 years with a range of 8–76 years (median 39 years). Sixteen patients presented with epitympanic cholesteatomas (50.0%), 11 of them were recurrences (68.7%). Among these were four patients from the first cohort of this study. Three patients exhibited a sinus cholesteatoma. Twelve patients showed deep epitympanic retraction pockets (37.5%). All of these patients had undergone previous cholesteatoma surgery, eight of these patients originated from the first cohort. The average time of follow-up after surgery was 21.5 ± 6.3 months (range 12–33 months; median 21 months).

Audiological findings

1. The pre- and postoperative hearing results (air–bone gap) in relation to the kind of tympanoplasty in the first series are shown in Table 1. Three out of four patients in type-I tympanoplasty had an excellent hearing outcome, one patient developed chronic middle ear effusion and received a ventilation tube later on, but still revealed a 16-dB conductive hearing loss. Of the patients with ossicular reconstruction, the best hearing results were obtained in type-III tympanoplasties with intact stapes suprastructure. These patients showed an

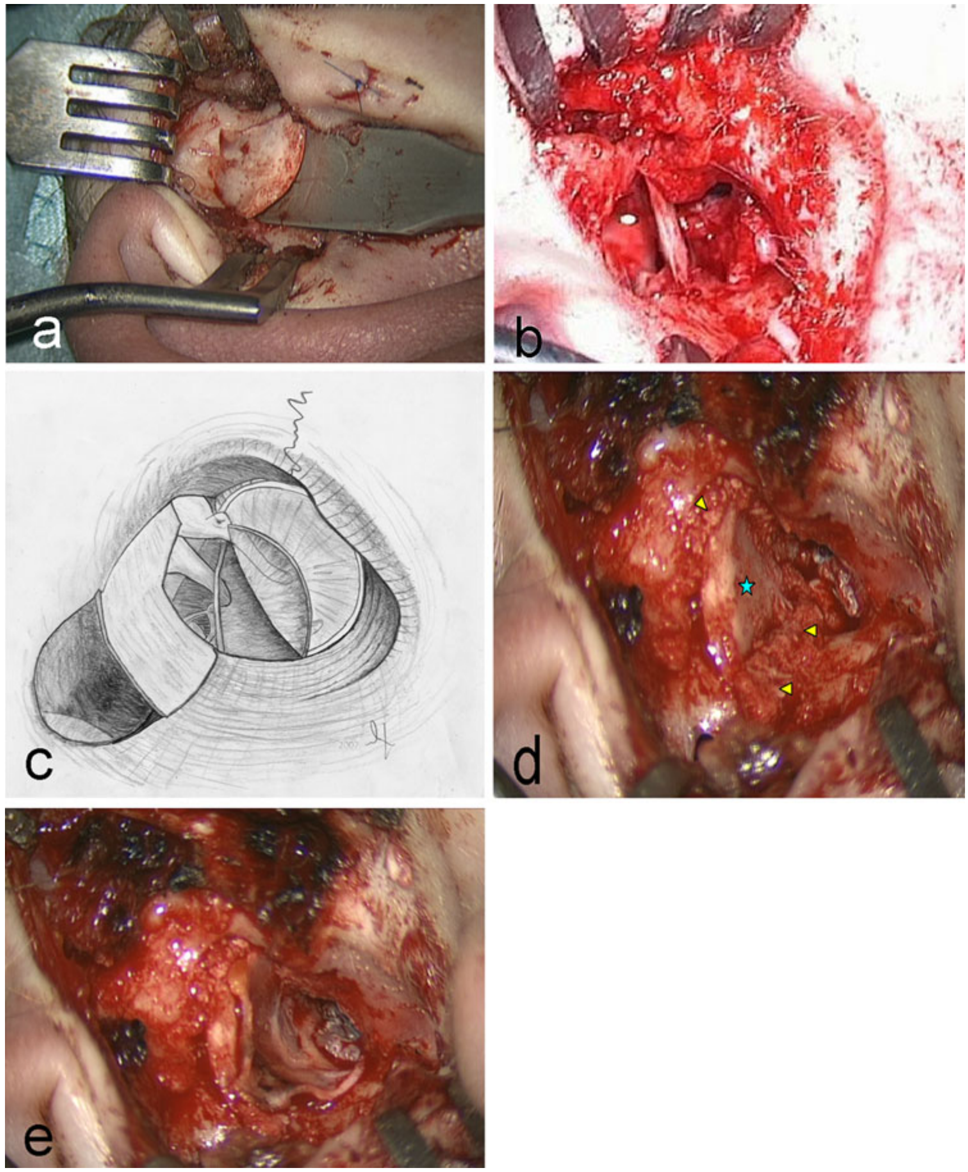

Fig. 1 Autologous bone chip harvesting from the temporal squama via an endaural approach with a curved chisel (**a**) and insertion between the anterior and posterior canal wall (**b**, **c**). After subsequent reconstruction of the lateral posterior-superior canal wall with other bone chips (*blue star*) the grooves and any bone gaps are filled with bone dust (*yellow arrows*) (**d**). The reconstructed area is covered with temporal fascia (**e**) and the meatal skin flap (right ear)

average postoperative PTA-ABG of 8.7 ± 3.4 dB HL. All of these patients had a PTA-ABG equal or less than 20 dB HL with 84.6% of them having excellent sound conduction through the middle ear of 10 dB HL or less. Hearing results in type-III tympanoplasties with absent stapes superstructure were likewise heterogeneous. Postoperative PTA-ABG had a mean value of 16.4 ± 9.3 dB HL. Most of the patients (54.5%) had a good sound conduction (11–20 dB), but only three patients achieved an excellent PTA-ABG (≤10 dB). One patient had a fair sound conduction (21–30 dB) and one was poor (>30 dB).

2. In the second series again three out of four patients in type-I tympanoplasty (75%) had an excellent hearing outcome (Table 2). PTA-ABG in type-III tympanoplasty (PORP) was 11.6 ± 4.9 dB HL postoperatively. Compared to the previous series, only 36.4% received an excellent hearing outcome; however, all of the patients evinced a PTA-ABG equal or less than 20 dB HL (good hearing). Hearing results after type-III tympanoplasty (TORP) in this group were comparable to the results of our first series. In seven patients with staged second-look tympanoscopy, re-ossiculoplasty was considered not to be indicated. The hearing outcome of these patients (11.8 ± 6.3 dB HL vs. 8.7 ± 4.4 dB HL) did not differ significantly after the procedure.

Bone graft viability and integrity, cholesteatoma recurrences, attic retraction pockets, and malleus mobility

1. In the first series, all but one of the 29 patients exhibited a well-healed external ear canal at the otoscopic follow-up examinations (Fig. 4a; Table 3). Attic retraction pockets were observed in nine patients (31%), and

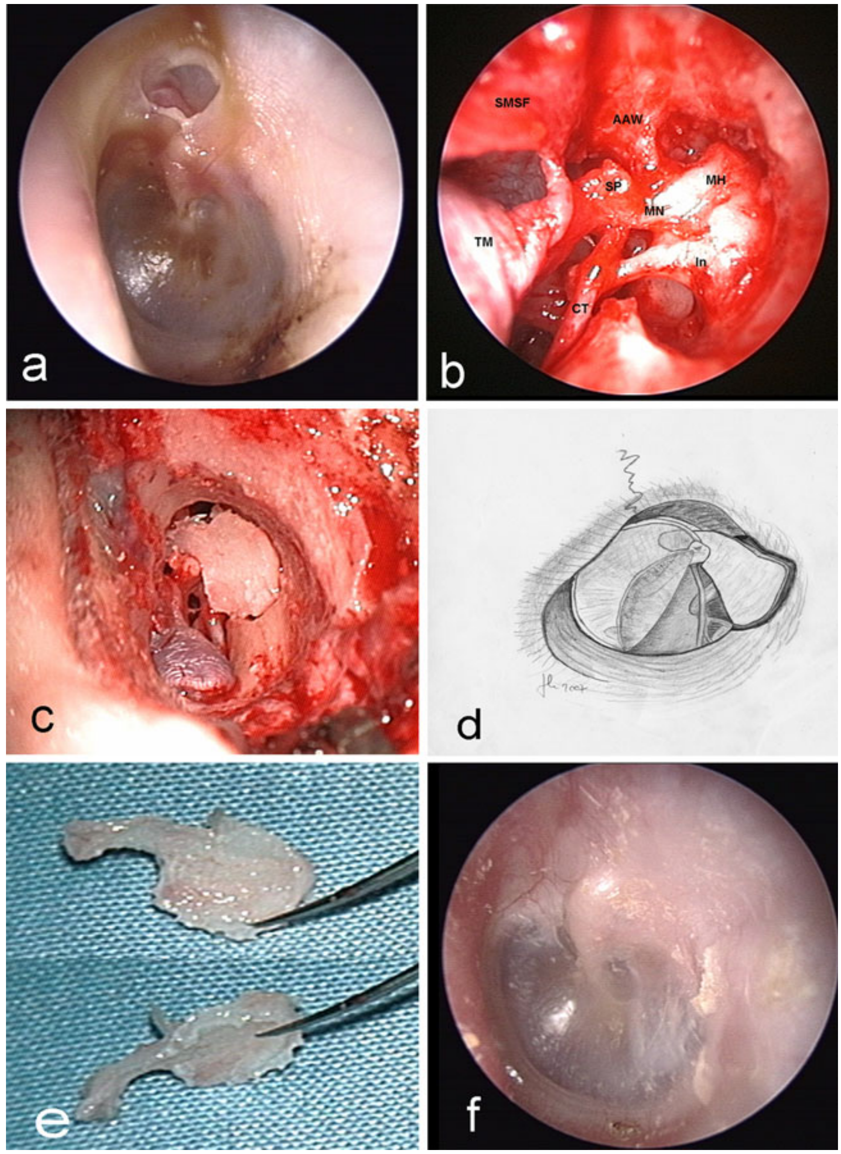

Fig. 2 Typical epitympanic cholesteatoma of the left ear after removal of debris showing a defect of the lateral attic wall (**a**). After atticotomy and cholesteatoma resection (**b**) the lateral attic wall (scutum) and the medial part of the posterior-superior canal wall is reconstructed and the superior part of the tympanic membrane (pars flaccida) is reinforced in one piece by a single autologous notched bony attic strut, which is placed onto the neck and short process of the malleus (**c**–**e**). Otoendoscopic follow-up 10 months after surgery (**f**). *TM* tympanic membrane; *SMSF* superior meatal skin flap; *CT* chorda tympani; *SP* short process of the malleus; *MN* malleus neck; *MH* malleus head; *In* incus; *AAW* anterior attic wall

manifest recurrent cholesteatomas were seen in five cases (17.3%), four of them were epitympanic and one mesotympanic. Revision surgery or staged second-look tympanoscopy was performed in 20 out of 29 patients (69%). One patient with an epitympanic retraction pocket formation refused second-look surgery. Second-look or revision surgery enabled the assessment of the previously transplanted bone chips. In one case, a defect of the posterior-superior canal wall due to a complete necrosis of the bone grafts was already detected at otoscopy. Another graft failure (vital, but not ingrown bone chip in the posterior canal wall) was detected only during second-look tympanoscopy. Both defects were reconstructed with another bone chips. In all other 18 patients the bone chips were found to be unimpaired and completely integrated into the circumjacent bone with a normal contoured ear canal (Fig. 4b), accounting for a graft failure of 10 or 6.9% for all patients. Residual cholesteatoma was detected in two cases (10%, i.e., 6.9% in total) during second-look or revision surgery, one in the attic and one in the middle ear cavity, which could be easily resected.

2. Twenty-nine out of 31 patients (93.5%) of the second cohort showed an intact canal wall postoperatively at otoscopy (Table 4; Figs. 2f, 3e, 5). Recurrent cholesteatomas were seen in three patients (9.7%); in two cases the cholesteatomas now originated from the posterior-superior quadrant of the tympanic membrane and invaginated the attic and antrum space underneath the reconstructed and reinforced bony tympanic frame and attic wall. One young patient has developed a meatal skin necrosis with subsequent malnutrition of one of the

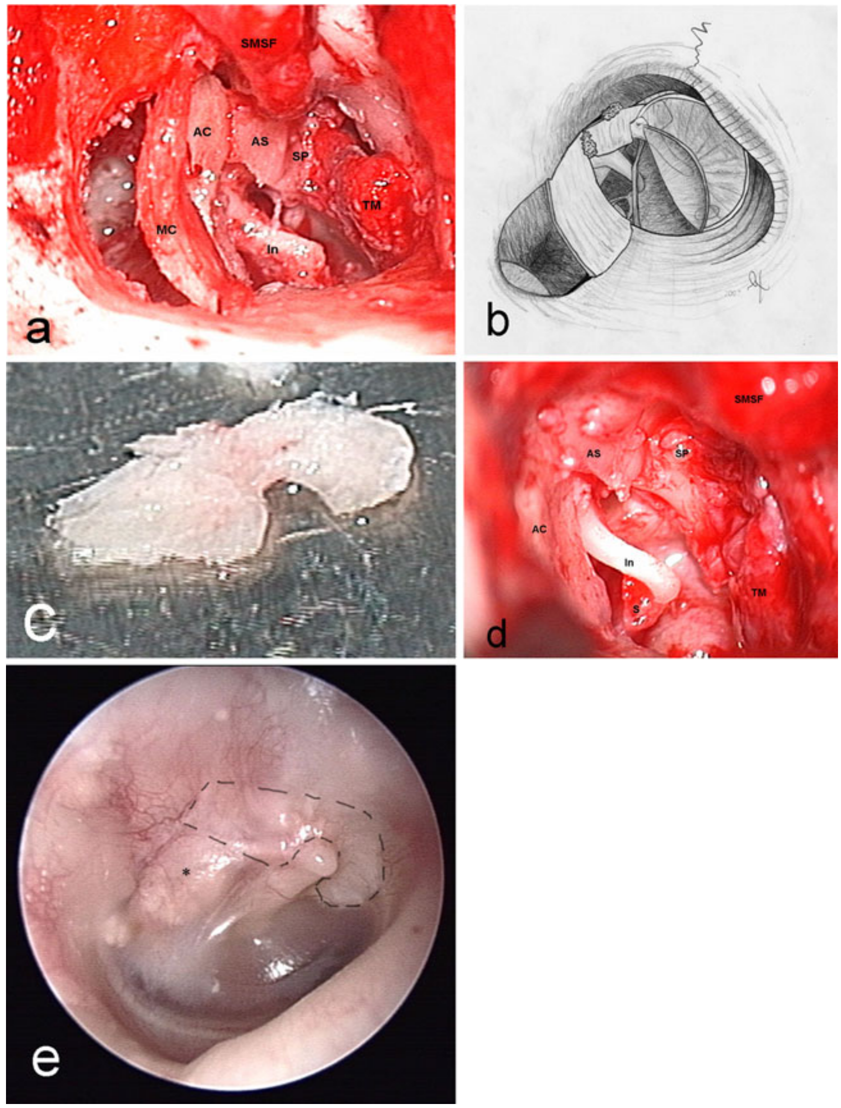

Fig. 3 Canal wall and lateral attic wall reconstruction of the right ear after atticoantrotomy and cholesteatoma removal with an autologous notched bony attic strut and additional bone chips (**a**–**c**). Any remaining bone gaps are then filled with bone dust. Second-look tympanoscopy 6 months after surgery reveals a well-integrated attic strut and a mobile malleus (**d**). Otoendoscopic follow-up 6 months after surgery (**e**). The extensions of the attic strut are marked (*deposit of bone dust). *TM* tympanic membrane; *SMSF* superior meatal skin flap; *SP* short process of malleus; *In* incus; *AS* attic strut; *AC* antrum chip; *MC* mastoid chip; *S* stapes)

Table 1 Audiological results of 28 patients after tympanoplasty and osteoplastic atticoantrotomy

PTA-ABG (dB HL)	TP I	TP III PORP	TP III TORP
Preoperative	21.6 ± 13.3	20.5 ± 9.9	34.8 ± 13.4
Postoperative	6.4 ± 6.3	8.7 ± 3.4	16.4 ± 9.3
≤10 dB HL (excellent) (%)	3 (75)	11 (84.6)	3 (27.3)
11–20 dB HL (good) (%)	1 (25)	2 (15.4)	6 (54.5)
21–30 dB HL (fair) (%)	–	–	1 (9.1)
>30 dB HL (poor) (%)	–	–	1 (9.1)

Classification of PTA-ABG according to Dornhoffer [15]

Ossicular reconstruction in one patient was suspended to a later second-look operation, which was not performed yet

PTA-ABG pure tone average air–bone gap; *TP I* type-I tympanoplasty; *TP III PORP* type-III tympanoplasty with intact stapes suprastructure; *TP III TORP* type-III tympanoplasty with absent stapes suprastructure

implanted bone chips, which later resulted in an ear canal cholesteatoma invading the mastoid. At revision surgery the attic strut graft was found to be intact and stable and no epitympanic cholesteatoma or retraction pocket developed since the initial attic strut reconstruction.

The attic strut seemed to be intact in 29 patients (93.5%) at otoscopy; accordingly two attic retraction pockets (6.5%) were observed, probably due to (partial) attic strut necrosis or displacement. All these retraction pockets were currently shallow and clean without any signs of cholesteatomatous transformation until last follow-up, so no further surgery was indicated.

Sixteen patients received a staged second-(or third-)look tympanoscopy or revision surgery (8.7 ± 3.1/10.2 ± 4.7 months later). In all these patients, survival of the bony attic strut could be proven during surgery (100%). In all but two cases (87.5%), the previously inserted bone chips were

Table 2 Audiological results of 31 patients following osteoplastic atticoantrotomy and a notched bony attic strut

PTA-ABG (dB HL)	TP I	TP III PORP	TP III TORP	No Re-OR
Preoperative	20.6 ± 15.1	22.8 ± 13.4	33.2 ± 7.0	11.8 ± 6.3
Postoperative	7.5 ± 5.1	11.6 ± 4.9	17.9 ± 12.2	8.7 ± 4.4
≤10 dB HL (excellent) (%)	3 (75.0)	4 (36.4)	3 (33.3)	4 (57.2)
11–20 dB HL (good) (%)	1 (25.0)	7 (63.6)	4 (44.5)	3 (42.8)
21–30 dB HL (fair) (%)	–	–	1 (11.1)	
>30 dB HL (poor) (%)	–	–	1 (11.1)	

Classification of PTA-ABG according to Dornhoffer [15]

PTA-ABG pure tone average air–bone gap; *TP I* type-I tympanoplasty; *TP III PORP* type-III tympanoplasty with partial ossicular replacement prosthesis; *TP III TORP* type-III tympanoplasty with total ossicular replacement prosthesis; *no Re-OR* prior ossicular reconstruction was left untouched)

seen to be well integrated into the posterior-superior bony canal wall.

A particular attention in the surgical assessment of the implanted attic strut was paid to its relationship to the malleus as it was suspected that the mobility of the malleus handle could be impaired by an adhesive interaction of these two bony components during the phase of wound healing. In fact, in 15 out of 16 patients (93.7%) the intraoperative palpation of malleus was normal. One patient developed a severe conduction loss after type-I tympanoplasty, but not resulting from a bony fixation of the mallear handle by the attic strut as presumed, but rather from a bony fixation of the mallear head to the tympanic tegmen, which was probably caused by displacement of bone dust into the epitympanum. However, it could be proved that the adjustment of an attic strut onto the mallear neck did not affect the malleus mobility. It can be assumed that the mallear movements prevent a bony union to the attic strut and facilitate the development of a pseudarthrosis similar to the inadequate healing of bone fractures.

Four residual cholesteatomas (25.0%, i.e., 12.9% in total) were detected at surgery in the posterior epitympanum (2), the mesotympanum (1), and the antrum and mastoid (1).

Twelve patients from the previous cohort after osteoplastic atticoantrotomy were involved in this consecutive study. Eight of these patients showed enlarging attic retractions pockets after the first procedure during the ongoing follow-up and finally received a resection of the invaginated epithelium and attic strut reconstruction at second-look tympanoscopy. Seven of these patients (87.5%) were free of retraction formations at the time of the last follow-up 25.2 ± 4.7 months after surgery. Four patients, who had recurrent epitympanic cholesteatomas and underwent cholesteatoma resection with subsequent attic strut and canal wall reconstruction, were still disease-free after 22.2 ± 5.5 months.

Discussion

The main goal of surgery in acquired middle ear cholesteatomas is the complete eradication of the disease with an ear free of discharge and inflammation. This can be performed either by open or closed techniques with their inherent benefits and drawbacks, but there is still an ongoing debate about the best choice. However, many otosurgeons prefer the physiological canal wall up option, delivered by either the preservation (combined approach) [8, 21, 22], reposition [11, 12, 20], or reconstruction of the canal wall [13, 15], with or without partial obliteration of the epitympanum, antrum or mastoid [23], overcoming the inconveniences derived from the open mastoid cavity making superior hearing outcomes more likely. Preserving the canal wall resulted in limited exposure of the epitympanum and the posterior middle ear cavity preventing entire cholesteatoma identification and removal, thus leading to high rates of residual cholesteatomas [9, 10]. Several techniques to remove and reinsert the lateral attic wall and/or the posterior canal wall have been developed not only to provide adequate radical exposure but also to maintain function [11, 12, 16]. The temporary removal of the canal wall is a challenging procedure and requires a well-pneumatized mastoid, and a posterior–anterior approach for mastoidectomy and cholesteatoma resection, necessitating the vast resection of much regular mastoid cells [13]. Transcanal atticoantrotomy followed by reconstruction of the lateral attic and posterior-superior canal wall has the advantage that the cholesteatoma sac at its site of origin in the epi- or mesotympanum can be exposed and followed to its extent in a retrograde fashion. The bony defect of the posterior-superior canal wall can be limited to that necessary for complete exposure and removal of the cholesteatoma [24, 25].

Various autologous or alloplastic materials have been applied in the past for canal wall reconstruction: fascia, muscle, cartilage [15], bone dust (mainly for attic reconstruction/scutumplasty) [17, 26–28], bioactive glass

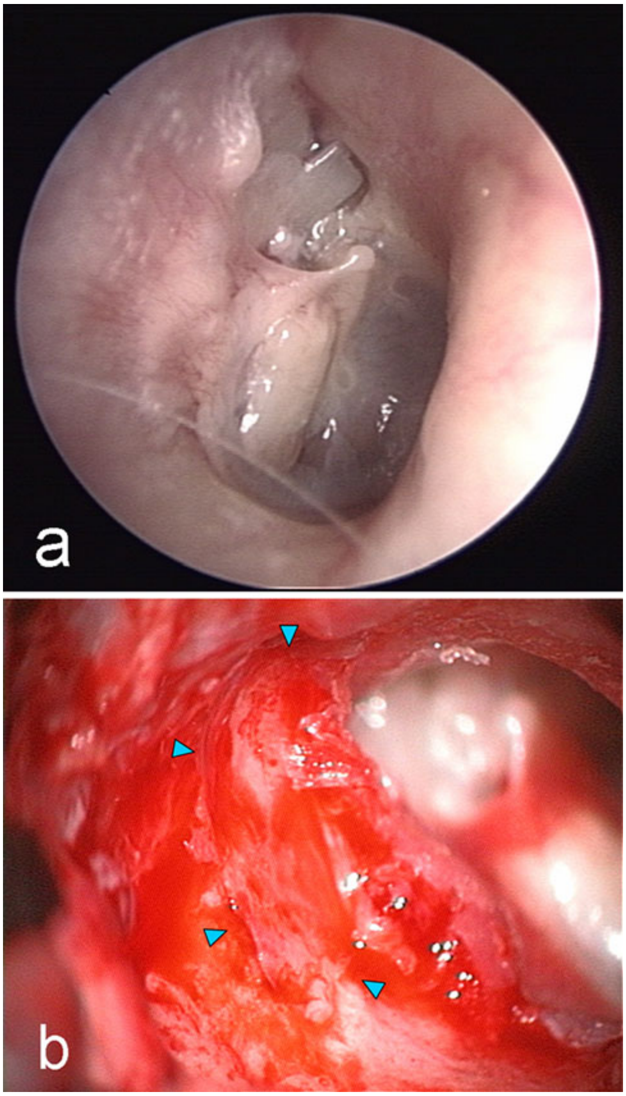

Fig. 4 **a** Otoscopy 16 months after osteoplastic atticoantrotomy on the right side showing the reconstructed posterior lateral attic wall. Note the beginning of an attic retraction pocket between the restored attic wall and the malleus and mallear folds. **b** Second-look tympanoscopy of the same patient with demonstration of the reconstructed medial posterior canal; the bone graft was completely integrated into the bony canal wall and could only be delineated through small fissures (*arrows*) (from [18])

Table 3 Morphological findings after osteoplastic atticoantrotomy (see text for details)

	Otoscopy $n = 29$ (%)	Second-look tympanoscopy/ revision surgery $n = 20$ (%)	Total $n = 29$ (%)
Intact canal wall	28 (96.0)	18 (90.0)	27 (93.1)
Intact tympanic membrane and lateral attic wall	15 (51.7)	6 (30.0)	15 (51.7)
Attic retraction pocket	9 (31.0)	8 (40.0)	9 (31.0)
Recurrent cholesteatoma	5[a] (17.3)	5[a] (25.0)	5[a] (17.3)
Residual cholesteatoma	–	2 (10.0)	2 (6.9)

[a] Epitympanic = 4, mesotympanic = 1

Table 4 Morphological findings after osteoplastic atticoantrotomy with attic strut (see text for details)

	Otoscopy $n = 31$ (%)	Second-look tympanoscopy/ revision surgery $n = 16$ (%)	Total $n = 31$ (%)
Intact canal wall	29 (93.5)	14 (87.5)	29 (93.5)
Intact attic strut	29 (93.5)	16 (100.0)	29 (93.5)
Attic retraction pocket	2[a] (6.5)	0[a] (0)	2[a] (6.5)
Recurrent cholesteatoma	3[b] (9.7)	3[b] (18.7)	3[b] (9.7)
Residual cholesteatoma	–	4 (25.0)	4 (12.9)
Malleus mobility	–	15 (93.7)	15 (93.7)

[a] Retraction pockets were stable and did not receive second-look tympanoscopy/revision surgery

[b] Two mesotympanic and one external ear canal cholesteatoma due to a posterior canal wall defect

ceramics (Ceravital), hydroxyapatite or titanium [29–32]. Autologous bone grafts from the cortical mastoid have also been used with good success [33–36]. However, until today, this technique has not gained much popularity. TOS criticized the need to harvest sufficiently large bone plates from the mastoid cortex to be shaped into a canal wall and the time-consuming technique [32]. Wullstein stated that immediate bone healing without interposition of connective tissue is achieved only by immediate firm contact of the bony lid in the surrounding bone, if it is in a correct and orthotopic position as in osteoplastic epitympanotomy. Autologous, but nonorthotopic bone grafts ought to have deficient contact points in the reconstructed wall, resulting in a fibrous and unstable union [16]. However, the described technique of canal wall reconstruction with nonorthotopic bone chips and bone dust demonstrates a well and reliable bone graft survival with intraoperatively proven excellent osseointegration in most cases. In combination with bone dust any gaps between the bone grafts and the bony environment can be closed, so that any access for epithelium retractions is avoided. This is also a disadvantage, when a second-look tympanoscopy is necessary, as is often the case in closed cholesteatoma surgery. For control of the antrum and mastoid, the former bone incisions must sometimes be reopened with a burr, or a new hole must be drilled into the posterior canal wall. The harvesting technique is quite easy, if sharp chisels are provided, and not coupled with a major donor site defect. Unlike cartilage there is abundant material to be obtained even in revision cases. Since we use the endaural approach in the majority of cases, we collected the bone grafts from the temporal squama. It must be considered that the cortical bone of the temporal squama sometimes can be

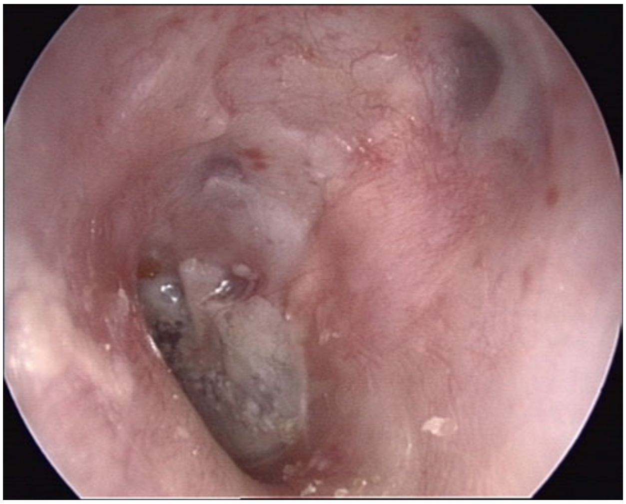

Fig. 5 Otoendoscopic follow-up 26 months after osteoplastic atticoantrotomy with implementation of a notched bony attic strut demonstrating an orthotopic tympanic membrane reinforced superiorly and a normal and solid auditory ear canal. The borders of the former bony defect of the lateral attic and posterior-superior canal wall are clearly to be seen (left ear)

very thin, so the surgeon must be careful to avoid any dural injury. The chisels should be applied in a sharp angle to avoid any deep intrusion.

Bone grafts offer the opportunity to be shaped very thin without losing stability, which is fundamental for the attic strut design and for precise placement. Depending on the resulting defect of the canal wall, several adequate-sized bone chips in series can be inserted and fixed by the application of bone dust serving as a compound. Therefore, bone resection and cholesteatoma removal, as well as canal wall reconstitution can be adapted to any existing intraoperative situation as far as to the extent of a complete mastoidectomy and entire posterior ear canal reconstruction. The bone chips must be covered with temporal fascia and the meatal skin flap in order to gain vascular supply. A coverage with pedicled muscle or periosteal flaps as described by Gerlach [37] is not necessary.

The external auditory canal, the mobility of the ossicular chain, and the middle ear pressure balance are important factors in the physiology of the middle ear and sound conductive mechanisms [20]. The firm restoration of the tympanic frame and the posterior-superior bony canal wall with bone chips is based on these principles and allows the preservation of the audiological function and resonance of the auditory canal, as well as the depth of the middle ear cleft with a deep and (re-)aerated middle ear and a vibrating tympanic membrane. Therefore, the bony reconstruction of the ear canal must be considered to be an important precondition, which enables excellent postoperative hearing results, especially in type-I tympanoplasty and type-III tympanoplasty with intact stapes suprastructures.

Despite the undisputable benefits of restoring the auditory ear canal by canal wall-up (CWU) techniques in cholesteatoma surgery, this surgical principle mainly has the disadvantage of possessing a high long-term incidence of recurrences of up to 60–70% [38, 39]. While the incidence of residual cholesteatomas in the first cohort was insignificant, the rate of recurrent cholesteatomas and particularly attic retraction pockets was disappointing. Retraction pocket formations (“precholesteatomas”) play a significant role in the development of both primary acquired and recurrent cholesteatomas [17, 38, 39], when internal or external inflammatory stimuli (otitis media or externa, inflammation of accumulated debris and crusts) initiate papillary ingrowth through the floor of the retraction pocket. For this reason, deeper postoperative epithelium invaginations must be watched and controlled vigilantly and be treated in time—for instance during second-look tympanoscopy—before they change into a cholesteatomatous formation.

Although the exact pathogenesis is still unknown, Eustachian tube dysfunction, negative middle ear pressure as produced from the air filled spaces of the epitympanum and the mastoid cavity after CWU surgery, and middle ear inflammation are proposed to be the main factors for this entity [26, 28, 40, 41]. Epitympanic retractions in particular are discussed to be strongly related to defects of the lateral attic wall (scutum), either due to the surgical procedure or due to the disease itself. Hence, the repair and reconstruction of the lateral attic wall defect (scutumplasty) is considered to be the fundamental step for the prevention of postoperative retraction pockets when performing a CWU-technique [26].

In the first series, the site of recurrences and retraction pocket formations was typically in the epitympanic region, around the lateral attic wall reconstruction and above the short mallear process and the posterior and anterior mallear folds (Fig. 4a). It could not be definitely clarified whether these recurrences have developed through the reconstructed area, which would have been mainly related to the absorption of the graft material, or underneath or beside it. This area was identified by Dornhoffer [15] as a high-risk site for recurrences after closed cholesteatoma surgery. Particularly, the anterior lateral attic wall was recognized by Duckert et al. [42] to be very prone to residual cholesteatomas as well as recurrent cholesteatomas. To improve structural support to this area and to prevent any retractions, here we refined our technique by applying a separate autologous bone chip for subtle reconstruction of both the posterior and anterior lateral attic wall defect, as well as reinforcement of the pars flaccida of the tympanic membrane. This “attic strut” was notched at its caudal edge, in order to closely adapt to the neck and short process of the malleus and for strut stability.

The integration of this notched bony attic strut into our surgical concept of tympanic frame and canal wall reconstruction by autologous bone chips has lowered the rate of attic retraction pockets from 31% in the first cohort to 6.5% in the second cohort. The rate of recurrent cholesteatomas now was 9.7% compared to 17.3% in the previous cohort, but it has to be noted that now none of these recurrences arised from the epitympanum, the initial affected site, but mostly from the posterior-superior mesotympanum. Stability and integrity of the attic strut could be verified during second-look or revision surgery in all cases. Seven of eight patients (87.5%) from the first cohort showing attic retraction pockets after initial surgery and four patients with recurrent epitympanic cholesteatomas were free of disease after more than 2 years, indicating the effectiveness of this method in the prevention of recurrent cholesteatomas and their precursors, attic retraction pockets. The described technique of lateral attic wall reconstruction differs from others by two features: (1) Stability of the lateral attic wall replacement is not only determined by the graft material itself but also by the support provided by the short process and neck of the malleus. This principle was originally described by Luetje ("saddle blanket graft tympanoplasty"), but he used free autologous tragal cartilage [43]. We adopted this principle and modified this technique by applying a notch into a bony strut graft, allowing the strut to snap into place, thus enhancing the structural support of the reconstruction. (2) In addition, the notch enables the attic strut to slip inferiorly. In this way, it is possible not only to cover the existing attic defect but also to support the posterior and particularly the anterior pars flaccida.

Dornhoffer [15] used a similar technique for reconstruction of the posterior canal and attic wall as we described in the first cohort except that he used cymba cartilage instead with additional reconstruction of the posterior tympanic membrane by cartilage palisades. Later he also reinforced the high-risk area between the malleus handle, canal wall and tympanic membrane reconstruction, which he found to be critical for recurrences, with chips of cartilage after finishing the framework at the end of the operation. Nevertheless, we found it helpful to start the canal wall reconstruction with the keypoint of reconstruction, the sculpturing and insertion of the attic strut, since at this time of the operation the overview of the posterior attic area, the mallear neck and particularly the anterior attic wall was unimpeded, which facilitated the precise adjustment of the graft. Since two of the three observed recurrent cholesteatomas arised from the posterior-superior quadrant of the tympanic membrane, we now also reinforce the posterior tympanic membrane in accordance with Dornhoffer with cartilage palisades that are resting on the bony attic strut.

The hearing results in concern of a remaining conductive hearing loss (air–bone gap) in the second group have shown to be comparable to those of the previous cohort, except for type-III tympanoplasties with a PORP, which were gradually worse with less individual outcomes being excellent. This might be contributed to the fact that revision cases and cholesteatoma recurrences with comparatively poor preconditions were overrepresented in the current study. However, the overall audiological outcome was encouraging. The hearing results imply that the coupling of the notched bony attic strut to the malleus does not affect the malleus mobility, and therefore is not associated with impaired hearing. This was also proven intraoperatively by palpating the malleus handle and inspecting the attic graft-malleus junction, which demonstrated a fibrous tissue connection, thus acting like a pseudarthrosis joint.

Residual cholesteatoma arises from the failure to remove all of the original disease from the middle ear cleft and the paratympanic spaces. The high-risk areas are in the middle ear, the tympanic sinus and oval niche, and the attic, especially the anterior epitympanic recess [42, 44]. However, the rate of residual cholesteatoma in the second series found at second-look or revision surgery (25.0%, i.e., 12.9% in total) was apparently high compared to our the first cohort (10% at surgery, i.e., 6.9% in total), although the kind of the surgical exposure of the middle ear and the paratympanic spaces and the technique of cholesteatoma removal were identical in both series. The reason for this is unclear—it might be a statistical effect because of the small number of patients in both cohorts—but these findings underline the necessity for a staged second-look tympanoscopy when closed techniques are performed.

The average follow-up time (21.2 $\pm$ 6.6 months) in the second cohort was rather short, and it is recommended that validation of any approach or technique in cholesteatoma surgery should only come with a minimum follow-up of 5 years, or preferably 10 years [15]. However, Pfleiderer et al. [17] have shown that the mean time for the development of retraction pockets was 21.0 months with a median of 12 months. They found that most of the patients (13 of 19, i.e., 68%) had their recurrences already detected 12 months after initial surgery and 80% after 20 months, which indicates that most of the potential recurrences in our current study are already included at present, but further long-term evaluation of the osteoplastic atticoantrotomy technique with implementation of a notched bony attic strut as reported here will be needed.

Conclusion

Osteoplastic atticoantrotomy with posterior-superior canal wall reconstruction employed by autologous bone chips after cholesteatoma excision, as described in this paper, enables a tailor-made anatomical and physiological reconstitution of the auditory ear canal and the tympanic cavity, even in extensive or revision cases, and facilitates excellent postoperative hearing results. Precise reconstruction of the lateral attic wall and reinforcement of the superior part of the tympanic membrane (pars flaccida) by a separate notched bone graft (attic strut), as well as reinforcement of the posterior-superior quadrant of the tympanic membrane by cartilage palisades with close contact to the attic strut seems to be important for the prevention of retraction pockets and subsequent recurrent cholesteatoma development.

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