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OTOLOGY

Retrograde mastoidectomy with canal wall reconstruction versus intact canal wall tympanomastoidectomy for cholesteatoma with minimal mastoid extension

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Abstract

Purpose Appropriate reconstruction of the canal wall or maintenance of the middle ear pressure in cholesteatoma may help in preventing recurrence. Retrograde mastoidectomy with canal wall reconstruction (RMR) can overcome the challenge of a wider canal wall defect or temporal bone immaturity, which possibly increases the recurrence risk. This study compared the outcomes of RMR and intact canal wall tympanomastoidectomy (ICW) for cholesteatomas with minimal mastoid extension and quantitatively evaluate the relationship between anatomical features and recurrence.

Methods This single-center retrospective cohort study included patients who had undergone primary ICW or RMR for *pars flaccida* cholesteatoma with minimal mastoid extension from 2009 to 2019. The main outcome measures were anatomical measurements of the shortest distance between the cranial fossa and the upper canal wall (SCU), attic volume, and bony defect area of the canal wall (BDC) on computed tomography; recidivism; and postoperative air–bone gap (ABG).

Results There were no significant differences in the preoperative anatomical factors, recidivism incidence, and postoperative ABG between the RMR ($n=20$) and ICW ($n=60$) groups. However, the median BDC was significantly greater in the RMR group (58.3 vs. 37.0 mm^2). There was no significant difference in the SCU and attic volume between patients with and without recurrence.

Conclusion Selection of RMR or ICW may not affect recidivism and hearing outcomes in cholesteatoma with minimal mastoid extension. Bony defect size and attic narrowness were not associated with recurrence. Considering wider visualization and one-staged operation, RMR can be more adaptable than ICW for cholesteatoma with minimal mastoid extension.

Keywords Cholesteatoma · Canal wall reconstruction · Intact canal wall tympanomastoidectomy · Recurrence · Hearing outcome

Introduction

The optimal surgical method for cholesteatoma remains controversial, including the method of handling the posterior canal wall. Intact canal wall tympanomastoidectomy (ICW) conserves the normal anatomy of the external auditory canal, thus avoiding cavity-related problems and possibly improving hearing [1]. However, ICW often requires a planned second-stage operation because of a high residual disease rate [2, 3]. Alternatively, retrograde mastoidectomy with canal wall reconstruction (RMR) also preserves the canal wall configuration [4, 5]. It improves the accessibility to difficult-to-visualize regions, such as the lateral epitympanum [6], thereby permitting a single-stage surgery. Furthermore, its ICW-equivalent recurrence rate (16%) [7] allows for a comparison between the two procedures.

During long-term follow-up after any canal wall reconstruction, distortion and retraction of the implanted graft into the mastoid occurs [8, 9]. This could be attributed to difficulty in canal wall reconstruction depending on the width of the canal wall bony defect, possibly leading to a higher recurrence rate; however, the effect of preserving or reconstructing the canal wall (e.g., ICW vs. RMR) on recurrence

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has not been quantitatively investigated. Therefore, the effect of the bony defect size on recurrence is uncertain. Furthermore, temporal bone immaturity could increase the risk of recurrence, especially among pediatric population. Inside a narrow attic, cholesteatoma removal is challenging during epitympanectomy, particularly in ICW, as it can induce more mucosal damage. Moreover, mucosal destruction in the mastoid by mastoidectomy in ICW can lead to postoperative negative pressure, graft collapse, or a retraction pocket [10, 11], which may not occur in RMR as it entails minimal manipulation of the mastoid. Therefore, recurrence may also be related to a narrow attic space; however, reliable data on the aforementioned topics are limited.

The indications of exclusive endoscopic ear surgery are expanding. Advances in instruments and techniques have enabled access to the central mastoid without requiring an open mastoidectomy. Therefore, endoscopic retrograde mastoidectomy on demand can remove the cholesteatoma matrix extending to the antrum, and the canal wall can be reconstructed using tragal cartilage [12]. However, in limited extension to the nearby antrum, the optimal surgical method for preventing recurrence is controversial owing to the lack of comparative studies with subjects exhibiting such homogeneous extensions. Therefore, we planned to focus on cholesteatomas located within the antrum (defined as minimal mastoid extension) in this study.

In this endoscopic ear surgery era, the effectiveness of canal wall reconstruction in preventing recurrence must be evaluated. We hypothesized that wider pathological bony defects or excavation following the appropriate repair of the canal wall during RMR would not increase the risk of recidivism and that RMR would be more adaptable than ICW, even to ears with narrow attics. Therefore, we aimed to compare the outcomes of RMR and ICW in a homogeneous cohort of patients with cholesteatoma and minimal mastoid extension. Moreover, we intended to quantitatively investigate the effect of bony defect size of the canal wall or temporal bone immaturity on recurrence.

Materials and methods

Design and setting

In this single-center, retrospective cohort study, we reviewed the charts of consecutive patients who underwent primary surgery for cholesteatoma at a tertiary academic medical center from January 2009 to December 2019. This observational study was reported in accordance with the STROBE statement. The study protocol was approved by the appropriate institutional review board (approval number: 32-205[10286]), and the requirement for informed consent was waived due to the retrospective nature of the study. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Participants

We included patients who had undergone primary tympanoplasty for *pars flaccida* cholesteatoma. The exclusion criteria were as follows: (1) canal wall down tympanomastoidectomy or mastoid obliteration, (2) follow-up < 24 months, (3) requirement for staged operation strategy, (4) cholesteatoma invading the peripheral mastoid, (5) cholesteatoma confined within the attic, (6) no intraoperative findings in the charts suggestive of epithelial extension in the mastoid, and (7) no perioperative computed tomography (CT) or hearing assessment (Fig. 1). We also excluded patients exhibiting extension to the peripheral mastoid cells because a wider mastoidectomy is mandatory in such patients.

Cholesteatoma extension

Minimal mastoid extension of the *pars flaccida* cholesteatoma was defined as cholesteatoma within the epithelium in the posterior end of the lateral semicircular canal (Fig. 2a). This cholesteatoma extension was determined intraoperatively and confirmed by operation record or video. The disease extension, development of mastoid cells, and pathological status of the stapes were classified based on previous reports [13].

Surgical procedure

Retrograde mastoidectomy with canal wall reconstruction

Retrograde mastoidectomy involves the wide-range retrograde removal of the lateral or posterior wall (inside-outside technique), as well as tympanoplasty, followed by canal wall reconstruction. Depending on the localization and extent of the disease, step-wise drilling with the track a matrix

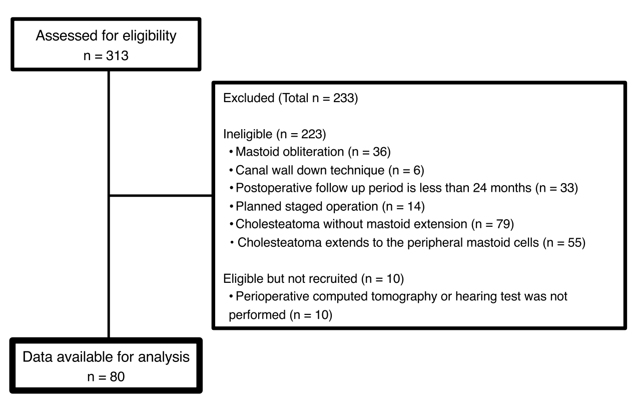

Fig. 1 Flow diagram of participant recruitment

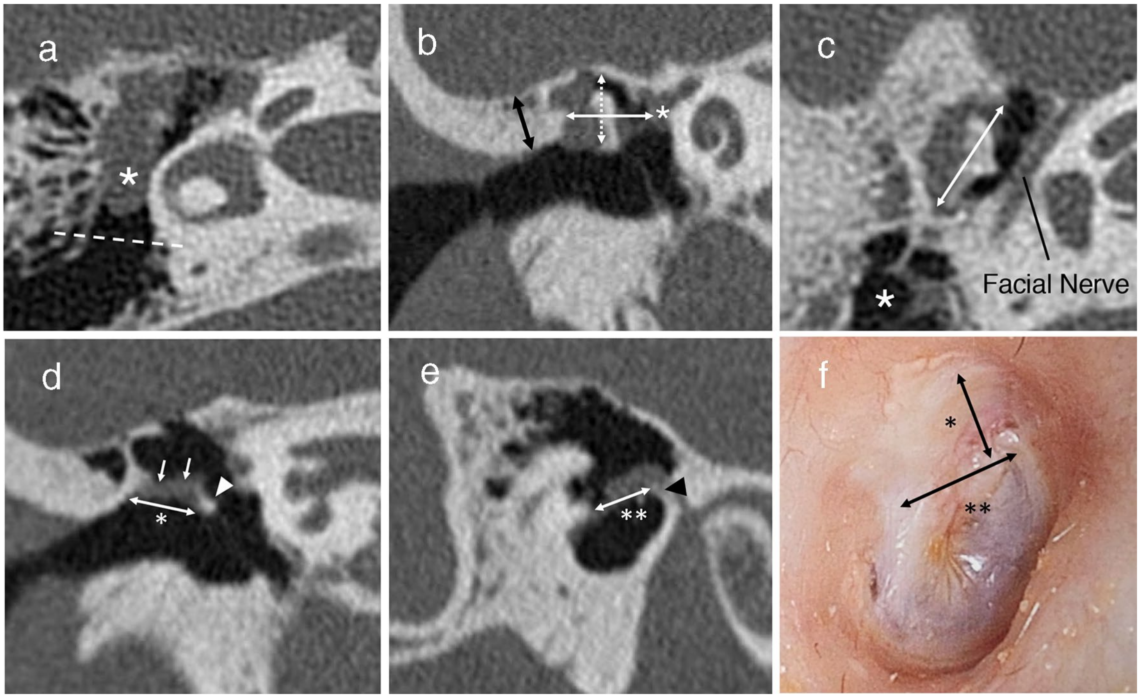

Fig. 2 Radiological evaluation of the middle ear using pre- and post-operative high-resolution computed tomography evaluation of the temporal bones with right-sided *pars flaccida* cholesteatomas. Images were selected from three patients; images in (**b**) and (**c**) belonged to the same patient, and those of (**d**), (**e**), and (**f**) are of the same patient. **a** Preoperative axial plane. An illustration of a *pars flaccida* cholesteatoma with minimal mastoid extension (asterisk). The matrix is retained within the posterior end of lateral semicircular canal. The definition of minimal mastoid extension needs to be confirmed intraoperatively. The dotted line defines the border between the *pars flaccida* cholesteatoma with minimum mastoid extension and that extending to the peripheral part of mastoid: the posterior end of the lateral semicircular canal. **b** Preoperative coronal plane. The shortest distance between the cranial fossa and the upper canal wall is indicated (black double-headed arrow). The craniocaudal length of the attic is defined as the length between the superior attic wall and the short process of malleus (white dotted double-headed arrow). The mediolateral length of the attic is defined as the length between the tympanic segment of the facial nerve and the lateral attic wall (white double-headed arrow). The asterisk indicates the facial nerve. **c** Preoperative axial plane. The anteroposterior length of the attic is defined as the length between the anterior attic wall and the fossa incudis (double-headed arrow). An area of air density within the peripheral mastoid cells is shown (asterisk); this ear is positive for "aeration in peripheral mastoid." **d** Postoperative coronal plane. The longitudinal length of bony defect area of the canal wall is defined as the length between the short process of the malleus and the medial margin of the upper bony defect (asterisk). The bony defect was reconstructed using a cartilage (arrows). The short process of the malleus (arrowhead). **e** Postoperative sagittal plane. The transverse length of the bony defect area of the canal wall is defined as the distance between the lesser tympanic spine and the posterior margin of the bony defect (double asterisk). Lesser tympanic spine (arrowhead). **f** An otoscopic view of the tympanic membrane post intact canal wall tympanomastoidectomy is shown. The defect of the canal wall was reconstructesd using a cartilage. The bony defect area of the canal wall is calculated by multiplying the "longitudinal length" (asterisk) by the "transverse length" (double asterisk)

backward was performed until the superior or posterior end was completely removed. Next, the bony defect canal wall was reconstructed using cartilage grafts. The major considerations were appropriate shaping of the cartilage graft to ensure tight approximation with the canal wall and formation of a robust and smooth surface adjacent to the remnant bone. The wall gap was filled with bone dust and fixed with fibrin glue, followed by tympanic membrane reconstruction. In contrast to the Dornhoffer's procedure [4], we performed cartilage reinforcement of the tympanic membrane only for selected cases, which have a retraction or adhesive status of the pars tensa of tympanic membrane. Meanwhile, when a good approximation between the tympanic membrane and the reconstructed canal wall is not achieved, small pieces of the cartilage can be applied to reinforce this gap. For cholesteatomas with minimal mastoid extension, the attic or mastoid was not obliterated.

Intact canal wall tympanomastoidectomy

Minimal transcanal atticotomy and mastoidectomy were performed by preserving the canal wall configuration with cartilage scutumplasty. The range of mastoidectomy depends on the extent of the epithelium. In addition, posterior tympanotomy was performed when necessary. For scutumplasty, cartilage grafts were placed medially on the lateral canal wall and fixed with fibrin glue, abutting the edge of the minimal bony defect. Eventually, the tympanic membrane was reconstructed using the fascia.

Each surgery was performed by expert neuro-otological surgeons with more than 7 years of experience. Selection criterion for the required surgical procedure was mastoid involvement based on preoperative CT evaluation. When the extension was predicted to be limited behind the antrum, RMR was adopted; however, when the cholesteatoma was predicted to extend beyond the antrum, ICW was performed. Extension determined intraoperatively was often less or greater than that predicted preoperatively. Preoperative magnetic resonance imaging (MRI) was not routinely performed; therefore, the surgical approach was fundamentally selected in the absence of a diffusion-weighted assessment of mastoid involvement. If necessary, the ossicular chain was reconstructed using an autograft. An anterior aeration route was created. In both techniques, once the cholesteatoma was removed, we carefully inspected the mastoid and tympanic cavities to identify epithelial remnants using an endoscope. We usually selected one-stage surgery; however, a staged operation was planned when complete matrix resection was not accomplished or when high residual disease was predicted because of severe infection. We neither performed routine intraoperative insertion of the ventilation tube.

Computed tomography

CT was performed in all patients using the 64-row (SOMATOM® Definition Flash [SDFlash], Siemens Medical Solutions, Forchheim, Germany) or 128-row (SOMATOM® Definition AS + [SD], SOMATOM® Perspective [SP], Siemens Medical Solutions, Forchheim, Germany) multidetector CT scanner. The scan parameters were as follows: slice collimation, $2 \times 64 \times 0.6$ mm (SDFlash and SD) or $2 \times 32 \times 0.6$ mm (SP); gantry rotation time, 500 ms (SDFlash and SD) or 600 ms (SP); pitch, 0.5; tube voltage, 120 kVp; field of view, 5 cm; and matrix size, 512×512. Axial CT images were reconstructed at a slice thickness of 0.6 mm. The display window width was 4000, and the window level was 70.

Main outcome measures

Recidivism

In our institute, postoperative follow-up visit was conducted every three months until 1 year following the operation, followed by every 6 months. CT was routinely performed at 1 year following the operation in all cases. Subsequently, serial CT or magnetic resonance imaging, including the diffusion sequence, was performed during the follow-up period.

We defined "recidivism" to comprise "recurrent cholesteatoma" and "residual cholesteatoma." Recurrent cholesteatoma was defined as reoccurring cholesteatoma requiring reoperation or tympanic membrane re-retraction, wherein the bottom was not observed and debris was accumulated, even when reoperation was not required. Residual cholesteatoma was defined as cholesteatoma pearls, which were confirmed at follow-up surgery.

Anatomical evaluation of the middle ear using CT

High-resolution CT images of the temporal bone were retrospectively analyzed by a single otorhinolaryngologist blinded to the prognosis. We defined the threshold level of the bone density as 250 Hounsfield units while analyzing the sectional areas of bone and tissues with differing densities.

The shortest distance between the cranial fossa and the upper canal wall was measured on preoperative coronal CT section (Fig. 2b).

The attic volume was calculated by multiplying the anteroposterior length by the craniocaudal length and mediolateral length on the preoperative CT image. The anteroposterior length was defined as the length between the anterior attic wall and fossa incudis on a line parallel to the facial nerve (FN) on the axial plane displaying the tympanic segment of the FN (Fig. 2c). The craniocaudal length was the distance between the superior attic wall and the short process of the malleus on a line perpendicular to the running FN's course (Fig. 2b). The mediolateral length was defined as the distance between the tympanic segment of the FN and the lateral attic wall on a horizontal line on the coronal plane displaying the short process of the malleus (Fig. 2b).

The bony defect area of the canal wall was calculated by multiplying the longitudinal length of the defect wall by the transverse length on the 1-year postoperative CT image. The longitudinal length was defined as the distance between the short process of the malleus and the medial margin of the upper bony defect of the canal on a coronal plane displaying the short process of the malleus (Fig. 2d, f). The transverse length was defined as the distance between the lesser tympanic spine and the posterior margin of the bony defect wall on a sagittal plane displaying the neck of the malleus (Fig. 2e, f).

On observing air density in the peripheral mastoid (from the posterior end of the lateral semicircular canal) preoperatively, the ear was deemed positive for "aeration in the peripheral mastoid" (Fig. 2c).

Hearing

Four-frequency averages of pure tone hearing levels were calculated using frequencies of 0.5 kHz, 1 kHz, 2 kHz, and 3 kHz preoperatively and at 1-year postoperatively. Clinically significant sensorineural hearing deterioration was defined as a reduction of ≥ 20 dB in bone conduction, based on the average of the four frequencies.

Statistical analyses

We performed statistical comparisons for findings in sex, cholesteatoma extension in the tympanic cavity, imaging evaluation for mastoid, surgical details, and recidivism rate using Fisher's exact test. The comparisons for age, measured values on CT, and hearing level were performed using the Mann–Whitney *U* test. All tests were two-sided; a *P* value < 0.05 was considered statistically significant. All analyses were conducted using JMP® 14 (SAS Institute Inc., Cary, NC, USA).

Results

Study participants and characteristics

We enrolled 80 patients, including 52 men and 28 women, with a median age of 44.0 years (Fig. 1). Table 1 summarizes the participant characteristics. Twenty patients underwent RMR and 60 underwent ICW. Concurrent stapes surgery and ventilation tube insertion were not required in any case. The

Table 1 Patient demographics

	Total (*N* = 80)	RMR (*N* = 20)	ICW (*N* = 60)	*P*
Age, years, median (IQR)	44.0 (22.0)	51.0 (20.0)	43.0 (23.8)	0.1277
Sex, *n* (%)				0.0892
Men	52 (65.0)	10 (50.0)	42 (30.0)	
Women	28 (35.0)	10 (50.0)	18 (70.0)	
Cholesteatoma extension in tympanic cavity, *n* (%)				
Extension to the protympanum[a]				0.6008
Present	9 (11.3)	2 (10.0)	7 (11.7)	
Absent	71 (88.7)	18 (90.0)	53 (88.3)	
Involvement of sinus tympani				0.6829
Present	8 (10.0)	2 (10.0)	6 (10.0)	
Absent	72 (90.0)	18 (90.0)	54 (90.0)	
Pathological status of the stapes[a]				
S 0–1	71 (88.7)	18 (90.0)	53 (88.3)	0.6008
S 2–3	9 (11.3)	2 (10.0)	7 (11.7)	
Imaging evaluation				
Shortest distance between the cranial fossa and the upper canal wall, mm, median (IQR)	4.94 (1.96)	4.89 (1.43)	5.03 (2.34)	0.1974
Attic volume, mm^3, median (IQR)	514.20 (246.00)	436.27 (242.01)	517.49 (249.35)	0.2689
Development of mastoid cells[a], *n* (%)				0.2953
MC 0–1	54 (67.5)	15 (75.0)	39 (65.0)	
MC 2–3	26 (32.5)	5 (25.0)	21 (35.0)	
Aeration in peripheral mastoid, *n* (%)				0.1100
Presence	18 (22.5)	7 (35.0)	11 (18.3)	
Absence	62 (77.5)	13 (65.0)	49 (81.7)	
Details of surgery, *n* (%)				
Type of ossicular reconstruction				0.1744
PORP	73 (91.3)	19 (95.0)	54 (90.0)	
TORP	5 (6.3)	1 (5.0)	4 (6.7)	
Not required	2 (2.5)	0 (0.0)	2 (3.3)	
Pure tone audiogram				
Average pre-operative ABG, dB, median (IQR)[b]	18.8 (16.2)	15.0 (19.08)	18.8 (15.0)	0.8923

RMR retrograde mastoidectomy with canal wall reconstruction, *ICW* intact canal wall tympanomastoidectomy, *IQR* interquartile range, *PORP* partial ossicular replacement prosthesis, *TORP* total ossicular replacement prosthesis, *ABG* air–bone gap

[a]According to the proposal of the Japanese Otological Society[12]

[b]The four-frequency average of hearing levels of pure tone was calculated using following frequencies: 0.5, 1, 2, and 3 Hz

mean (standard deviation) postoperative follow-up period was 55.4 (18.7) months. There were no significant differences in the clinical backgrounds between the RMR and ICW groups (Table 1). In terms of age distribution, significant difference was not found between the two groups, with median [interquartile range] of 51.0 [20.0] and 43.0 [23.8] years in the RMR and ICW groups, respectively ($P = 0.1277$, Mann–Whitney *U* test).

Bony defect area of the canal wall

The median [interquartile range] (mm^2) bony defect area of the canal wall was significantly greater in the RMR than in the ICW (58.3 [29.77] vs. 37.02 [14.91]; $P < 0.0001$) (Table 2) group.

Recidivism

Recurrence was observed in two and 13 cases in the RMR and ICW groups, respectively. In our cohort, all the residual diseases were capsulized and not connected to the tympanic membrane or the skin of the external ear meatus during reoperation, thereby we were able to define them as "residual disease." Only one patient in the RMR group had residual disease in the attic. In the ICW group, four and one patient had residual disease in the attic and protympanum, respectively. The recurrence rate and residual disease did not differ between the two groups (Table 2).

Hearing outcome

The postoperative air–bone gap (ABG) rate was not significantly different between the two groups (Table 2).

Attic variation and recurrence

Figure 3 illustrates the effect of attic anatomical features on cholesteatoma recurrence. We compared such features between the groups with and without recurrence. There was no significant difference between the groups in the shortest

Table 2 Comparison of outcomes in patients with *pars flaccida* cholesteatoma with minimal mastoid extension ($N = 80$)

Surgical procedure	Bony defect area of canal wall, mm^2		Recurrence		Residual disease		Postoperative air bone gap, dB	
	Median (IQR)	*P**	*n* (%)	*P***	*n* (%)	*P***	Median (IQR)	*P**
		< .0001		0.2082		0.5301		0.4427
RMR ($n = 20$)	58.3 (29.77)		2 (10.0)		1 (5.0)		10.7 (15.0)	
ICW ($n = 60$)	37.0 (14.91)		13 (21.7)		5 (8.3)		16.3 (13.7)	

The bony defect area of the canal wall is calculated by multiplying the "longitudinal length of the bony defect" by the "transverse length of the bony defect" on the 1-year postoperative computed tomography image (Fig. 2d–f)

RMR retrograde mastoidectomy with canal wall reconstruction, *ICW* intact canal wall tympanomastoidectomy, *IQR* interquartile range

*Mann–Whitney *U* test; **Fisher's exact test

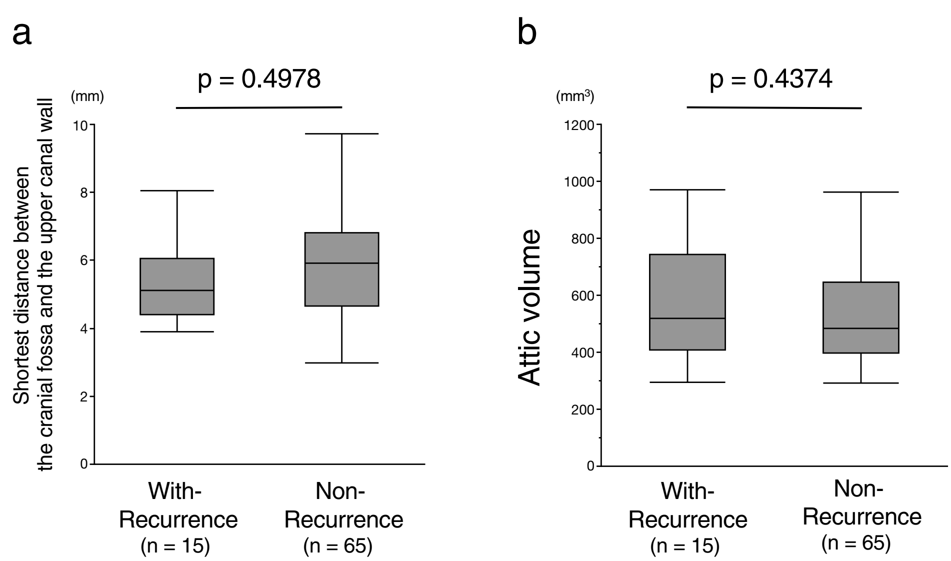

Fig. 3 A comparison of the attic anatomical features between the with-recurrence group ($n = 15$) and non-recurrence group ($n = 65$). The shortest distance between the cranial fossa and the upper canal wall (**a**) and attic volume (**b**) did not significantly differ between the two groups

distance between the cranial fossa and the upper canal wall (Fig. 3a) and attic volume (Fig. 3b) with respect to recurrence rate.

Complications

Perforation of the tympanic membrane was observed in three patients, one in the RMR group and two in the ICW group. Significant sensorineural hearing loss, permanent FN palsy, or vestibular dysfunction were not observed at the last follow-up in any group.

Discussion

The current study compared the surgical outcomes between RMR and ICW for *pars flaccida* cholesteatoma with minimal mastoid extension. Although a significantly larger bony defect of the canal wall was evident in the RMR group, there was no difference in recidivism incidence and postoperative ABG between the RMR and ICW groups. In terms of attic immaturity, the shortest distance between the cranial fossa and the upper canal wall and attic volume was not associated with recurrence.

This is the first study to quantitatively explore the relationship between the bony defect area of the canal wall and prognosis in cholesteatoma using CT. Few studies have reported the benefits of minimally invasive procedures in preventing recurrence [10, 14]. However, their results must be cautiously interpreted because subject heterogeneity in disease extension or anatomical variations in the temporal bone could impose selection biases. Considering disease extension was not systematically reported in these studies, the minimally invasive procedure group might have comprised patients with less extensive disease, which were perceived as having a lower recurrence rate. In clinical practice, preoperative imaging evaluation for cholesteatoma extension sometimes does not correspond with the intraoperative findings, especially on CT evaluation for mastoid cells filled with granulation tissue or effusion. Meanwhile, manipulation difficulty introduces selection bias in determining surgical indications. For instance, in cases with a tight sclerotic mastoid, otosurgeons struggle within the narrow attic while adopting ICW, but can switch to alternative methods, such as RMR. In the current study, the inclusion criteria and quantitative considerations for anatomical features could have minimized the bias, including the age distribution, the temporal bone immaturity, or the cholesteatoma extension, thereby delivering a more accurate comparison of outcomes between RMR and ICW.

We demonstrated that the adoption of ICW or RMR and the bony defect area did not correlate with cholesteatoma recurrence among cases with minimal mastoid extension. Considering the presence of negative pressure in the middle ear cavity as the primary mechanism of recurrence [15], difficulties in canal wall reconstruction can be associated with higher recurrence rates. In other words, wider reconstruction is technically more challenging with ease of gap formation between the autograft and remnant wall, which may not resist the negative pressure. In an observational study, retraction pockets and recurrence were significantly lower in the group with endoscopic minimal canal wall removal than those in groups with ICW performed under a microscope [10]. Key issues in reconstruction are resistance against negative pressure, including shape fitting, stabilization, or long-term survival of the graft; however, our RMR technique addressed these issues by using a flexible cartilage and robust fixation using fibrin glue and/or bone pate. Although we did not require routine cartilage reinforcement of the tympanic membrane to minimize the effect of the pars tensa elasticity on sound transmission, a good approximation between the tympanic membrane and the reconstructed canal wall is generally achieved, else small pieces of cartilage can be applied to reinforce this gap. Thus, our reconstruction technique may not increase the risk of recurrence, despite the need for wider excavation for eliminating cholesteatomas with minimal mastoid extension.

The current study illustrated that tegmen lowness and attic narrowness were unrelated to recurrence in epitympanum-origin and minimally mastoid-extended cholesteatomas. Perioperative anatomical features such as mastoid involvement [16], a small pneumatized mastoid [17], and non-improved mastoid aeration [18] are the negative prognostic factors of recurrence. The underlying rationale to prevent recurrence is the possible preservation of the mastoid mucosa and the re-establishment of physiologic ventilation that produces re-aeration in the middle ear, as supported by histopathological studies [19, 20]. In practice, an impairment of mucosal function can occur in a narrow attic space where the surgeon encounters manipulation difficulties. Contrary to this concern, our data did not reveal an association between recurrence and anatomical indicators of the attic narrowness (the shortest distance between the cranial fossa and the upper canal wall: a measure of attic volume). This may be clinically plausible because of the negligible mucosal impairment even postoperatively in cases of limited mastoid involvement behind the antrum. In another perspective, RMR has a technical disadvantage. Considering the size limitations in the graft, RMR should be avoided when there is a need for considerably wider excavations; however, RMR may be more technically adaptable than ICW when manipulating in the narrow attic or antrum owing to wider visualization. Therefore, for cases with a narrow attic and minimal mastoid extension, our RMR technique including mucosal preservation can reconstruct the canal wall configuration without affecting the recurrence rate.

Our study did not demonstrate any significant differences in residual disease between RMR and ICW. The residual rate was similar to that in previous reports, namely 1–10% and 3.3–36% following RMR [4, 5] and ICW [21, 22], respectively. Analogous to another article [23], the removal of the canal wall in RMR improved the visualization of the entire epitympanum and posterior tympanum. Nevertheless, our cautious surveillance with higher resolution image of the endoscope was also highly useful in not overlooking the epithelial remnants. In clinical practice, recent advances in small diameter enabled the addition of this routine surveillance even in narrow attics when the RMR was adopted. Therefore, the absence of a difference in the incidence of the residual disease between our two techniques could also be attributed to the use of the endoscope. Meanwhile, when the infection cannot be controlled until operation, single-stage surgery should be avoided because it can cause necrosis of the graft and is associated with a high incidence of residual disease. In our RMR technique, the stability of the canal wall configuration can be maintained for a long term by using cartilage, which can be resistant to infection. Coupled with the advent of modern diffusion-weighted MRI sequences that can help to determine the need for a two-staged operation [24–26], our institutional experience can recommend the single-stage strategy in RMR even for cholesteatoma with persistent infection owing to wider visualization and infection-resistant reconstruction.

The auditory outcomes with RMR were comparative to those with ICW in the present study. Researchers have achieved satisfactory auditory improvement following RMR [27]. Several variables influence the hearing results following cholesteatoma surgery, including the depth of the middle ear, condition of the mucosa, and ventilation of the tympanic cavity [28]. The preservation of the bony canal wall can restore both the vibrating tympanic membrane and a deep and well-aerated tympanic cavity, which contribute to hearing [29–31]. At our institution, we reconstructed a robust canal wall using RMR, resulting in sufficient tympanic cavity depth for appropriate ossiculoplasty even when not planning the stage strategy. Moreover, RMR involves mastoidectomy performed in a retrograde manner, producing a small cavity by avoiding the unnecessary of drilling of the healthy mucosa. Therefore, mucosal function preservation may positively affect the hearing outcome. Generally, RMR does not require a staged strategy; however, the appropriate reconstruction of the canal wall in RMR could optimize postoperative hearing in cholesteatomas with minimal mastoid extension.

Some important limitations should be considered when interpreting our findings. First, this retrospective study had a small sample size. The eligibility criteria ensured homogeneity among all patients and their eligibility to receive either type of treatment. However, the nature of the observational study might have introduced residual confounding. For instance, we might have overlooked unobserved anatomical or technical factors that could have influenced the surgical outcome. Second, the imaging results were restricted to 1 year post-surgery. Therefore, the measured bony defect area of the canal wall may have had errors related to the time course of the bony growth reaction. Third, we followed up with the patients for a minimum period of 24 months. A longer follow-up is required to detect long-term recurrence and confirm its association with surgical procedures or anatomical variation.

In summary, the recidivism incidence and hearing outcomes were equivalent in RMR and ICW for *pars flaccida* cholesteatomas with minimal mastoid extension. Moreover, the bony defect area of the canal wall or narrowness of attic were unrelated to recurrence. Our RMR technique was more adaptable than ICW, even in middle ears with narrow attics or antrum with comparative outcomes and does not require staged operation. Although endoscopic ear surgery was not evaluated exclusively, this limitation does not undermine our results, i.e., microscopic RMR has comparative outcomes to ICW in minimal mastoid extension. These findings should be substantiated by large-scale future studies, including the addition of attic obliteration to our RMR technique, which could reduce the recurrence.

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Author contributions Concept: MM, YY; design: MM, YY; supervision: HK; resource: YY, MT, YS; materials: TN, KY; data collection and/or processing: TN, SS, MT; analysis and/or interpretation: MM, YY, TA; literature search: MM; writing: MM, YY; critical reviews: YY, TU.

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Data availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available owing to privacy or ethical restrictions.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors alone are responsible for the content and writing of the manuscript.

Ethics approval Approval was obtained from the institutional review board of The Jikei University School of Medicine (approval number: 32-205[10286]). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

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