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Main Article

Half canal wall down tympanomastoidectomy

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Abstract

Objective. The purpose of this study is to analyse the effect of half canal wall down tympanomastoidectomy in the treatment of chronic otitis media or cholesteatoma.
Method. In this retrospective study, the half canal wall down tympanomastoidectomy technique was used at our hospital for chronic otitis media or cholesteatoma removal in 265 adult patients, representing 271 operated ears, with an average follow-up time of 8.4 years.
Results. The post-operative cavities were slightly wider and straighter in 91.9 per cent of the ears. Fifteen per cent of the patients needed cavity cleaning every six months, 25 per cent of them needed cavity cleaning every year and 60 per cent of the patients had a self-cleaning cavity. Only one patient with a cleft palate experienced cholesteatoma recurrence in the mesotympanum.
Conclusion. The half canal wall down tympanomastoidectomy technique showed a low-recurrence rate and satisfying operative cavities. The half canal wall down tympanomastoidectomy technique is a good choice for middle ear surgery.

Introduction

From the beginning, the initial purpose of otitis media surgery was to control the acute mastoiditis. Four centuries ago, Ambrose Pare, a French physician, first contemplated surgical drainage for acute otologic suppuration. However, the operation was not widely carried out because of the surgical techniques required and risk of post-operative infection.[1] Herman Schwartze first described simple mastoidectomy using a chisel and mallet in 1873.[1] Since then, mastoidectomy has been widely accepted because of its good efficacy.

After solving the problem of acute suppurative otitis media infection, medical predecessors began to explore the surgical methods for the treatment of chronic suppurative otitis media and cholesteatoma. The initial operation was to remove the lesion, and in 1889 von Bergmann performed such operation, known as radical mastoidectomy.[1] To solve the problem of hearing loss after radical mastoidectomy, Jansen and Heath proposed a conservative radical procedure with preservation of ossicles and the eardrum in 1893 and 1904,[1] respectively. In 1910, Bondy proposed the modified radical mastoidectomy for the attic cholesteatoma.[1]

With the introduction of antibiotics, operating microscopes and dental drills in middle-ear surgery, tympanic membrane repair and hearing reconstruction surgeries developed rapidly. Zöllner and Wullstein described the surgical methods of reconstructing the sound-pressure transformation between two windows to preserve hearing in 1951 and 1952.[1] In 1956, Wullstein classified tympanoplasties into five types, which were generally accepted and are still used today.[2] As a result, canal wall down tympanomastoidectomy has been widely used and has successfully solved the problems of removing lesions and reconstructing hearing.

The inevitable disadvantage of canal wall down tympanomastoidectomy is creation of a large mastoidectomy cavity. To solve the cavity problem after canal wall down tympanomastoidectomy, Claus Jansen first described transmeatal–transmastoid tympanoplasty in 1958.[1] This technique is also known as canal wall up tympanomastoidectomy with preservation of the posterior bony canal wall. The main advantage of this technique is the normal external auditory canal after operation. But the disadvantage of this technique is the potential for residual and recurrent cholesteatoma.

Of course, the ideal surgical method is a technique which can combine the advantages of both techniques (canal wall down tympanomastoidectomy and canal wall up tympanomastoidectomy). Mastoid obliteration was the initial attempt to remedy the canal wall down tympanomastoidectomy cavity. Many materials have been used in mastoid obliteration. Kisch first described the use of pedicled temporalis muscle flap and periosteal flap to remedy the canal wall down tympanomastoidectomy cavity in 1932.[3] After that, various autogenous materials including bone grafts, bone pâté, cartilage, fat and other soft-tissue flaps, and artificial materials including hydroxyapatite, silicone, artificial ceramics, methylate and proplast were used to assist the healing of the mastoid.[4–15] However, all kinds of materials have their inevitable disadvantages. The main problems of autologous tissue are atrophy and donor site lesions, and the main problems of artificial materials are rejection and infection.

In 1983, Paparella described intact-bridge mastoitympanoplasty.[16] The intact-bridge mastoitympanoplasty technique maintains the bony bridge and obliterates the mastoid cavity by blocking the aditus with bone pâté or cartilage. Although the intact-bridge mastoitympanoplasty technique has good exposure as in open cavity tympanomastoidectomy and obtains a wider middle-ear space, there is still an obvious post-operative cavity remaining, and there is still the potential for residual cholesteatoma under the bone bridge.

Retrograde mastoidectomy is also widely recommended. It is performed by drilling the attic until the posterior border of the cholesteatoma is visible. The resected posterior canal wall is reconstructed with conchal cartilage during the same surgery.[17] It has been reported that the recurrence rate of cholesteatoma in retrograde mastoidectomy is 16 per cent. The recurrence sites of cholesteatoma were in the mesotympanum and the cartilage reconstruction of the attic.[18,19]

At present, autogenous bone or cartilage is the first choice for external auditory canal reconstruction. We also have been trying to improve the operation of otitis media. We performed a different modified surgical technique, which is called partial canal wall preserved tympanomastoidectomy. The partial canal wall preserved tympanomastoidectomy technique performs mastoidectomy, atticotomy and drills part of the posterior and inferior bony external auditory canal to remove all the cholesteatoma while maintaining the posterior bony external auditory canal and a cortical bone bridge over the aditus ad antrum. Then the canal wall defect is reconstructed with conchal cartilage under the bone bridge, combined with obliteration of the mastoid and attic with bone chips and pâté in an attempt to prevent the attic retraction pocket.[20] We found that the partial canal wall preserved tympanomastoidectomy technique can easily expose and remove the cholesteatoma and left patients with a normal or slightly enlarged post-operative external auditory canal and self-cleansing function. However, the recurrence rate of cholesteatoma was still 5 per cent in epitympanum at 5 years, while nobody experienced recurrence in the mesotympanum. Cholesteatoma is easy to recur at the site of cartilage reconstruction in the epitympanum, which is a common problem in all surgical techniques of reconstructing the canal wall. Therefore, we have made some improvements on the basis of partial canal wall preserved tympanomastoidectomy, called half canal wall down tympanomastoidectomy, with the goal of solving this problem.

Materials and methods

Patients

The patients included in this study (265 patients; 271 ears) had undergone surgery for cholesteatoma or chronic suppurative otitis media with granulation using the half canal wall down tympanomastoidectomy technique between 2012 and 2015 in a university hospital centre. Operations were performed by two senior otologists. All patients were operated on for the first time. All patients underwent a temporal bone computed tomography (CT) scan to confirm that there was abnormal soft-tissue or bone erosion in the antrum and attic before operation. Patients having any of the following conditions were excluded from the study: (1) congenital cholesteatoma or petrositis, (2) external auditory canal cholesteatoma, (3) cholesteatoma otitis media only located in posterior tympanum, (4) severe sensorineural hearing loss, (5) combined with otogenic complications such as facial paralysis, intracranial infection etc., (6) the posterior inferior wall of the bony external auditory canal was destroyed, or (7) acute mastoiditis. This study was performed retrospectively and was approved by the ethics committee of Peking University Third Hospital.

Surgical steps

Step 1: Incision

A large C-shaped postauricular incision is made as shown in Figure 1a. The incision extends along the hairline and turns to the posterior sulcus when it is close to the tip of the mastoid process. Then make out the retroauricular skin flap and retain as much of the subcutaneous tissue and more retroauricular muscle tissue on the myoperiosteal flap as possible.

Step 2: Myoperiosteal flap

A myoperiosteal flap pedicled on the temporal muscle is made, as shown in Figure 1a. Fascia is harvested.

Step 3: Canaloplasty

The skin of the posterior wall of the external auditory canal is cut and the skin flap pedicled on the inferior wall is made to expose the superior wall, posterior wall and most parts of inferior wall of the bony external auditory canal. Then an abundant canaloplasty is done by drilling the bony external auditory canal wall maximally (including superior wall, posterior wall and inferior wall).

Step 4: Atticoantrotomy

The antrum and its surrounding large cells are opened. Those small cells without lesions can be preserved. If the incudostapedial joint is intact, the joint should be disarticulated to protect hearing. Then the bone of the superior external auditory canal is removed, and the attic is opened, so that the tympanic cavity, attic and antrum are connected into a surgical cavity. The incus and the head of the malleus are removed, as shown in Figure 1b.

Step 5: Posterior tympanotomy

The posterior tympanum is opened from the inside toward the mastoid until the posterior border of the cholesteatoma sac in the posterior tympanum is visualised. If the lesion invades the tympanic sinus, the stapedius can be sacrificed to thoroughly expose the tympanic sinus to remove the lesion. In this step, the posterior bony canal wall needs to be thinned, opening a few small mastoid cells is not a problem, as shown in Figure 1b.

Step 6: Eustachian tube exploration (optional)

If the patient fails to pass the Eustachian tube examination before operation, the Eustachian tube needs to be explored. If the exploration passes, proceed to the next step, otherwise, artificial ossicles are not used in tympanoplasty, and tympanic membrane catheterisation is required in the last step.

Step 7: Tympanoplasty

The tensor tympani tendon should be kept intact to prevent external displacement of the tympanic membrane after operation. Temporalis fascia is used to repair the tympanic membrane and cover part of the posterior canal wall and attic. The artificial titanium partial or total ossicular replacement prosthesis is placed between the stapes head or footplate and the fascia, and surrounded by Gelfoam® (Pharmacia & Upjohn, Kalamazoo, Michigan, USA).

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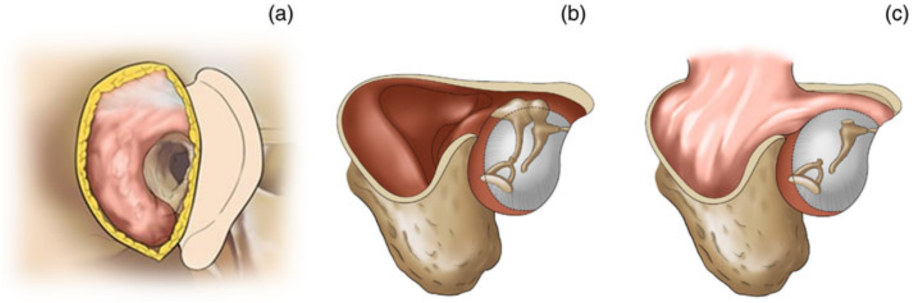

Figure 1. Schematic diagram of half canal wall down tympanomastoidectomy. (a) Big C-shaped postauricular incision and myoperiosteal flap pedicled on the temporal muscle is made. (b) The brown area shows the extent of bone removal in tympanomastoidectomy. (c) The mastoid and attic are obliterated with the pedicled myoperiosteal flap.

Step 8: Mastoid and attic obliteration

The mastoid and attic are obliterated with the pedicled myoperiosteal flap to reconstruct the posterior superior external auditory canal wall, as shown in Figure 1c. If the myoperiosteal flap is not enough for the mastoid cavity, the pedicled temporal muscle flap can be used to fill the mastoid cavity.

Step 9: Meatoplasty

Conchal cartilage and canal cartilage are removed appropriately to match the cartilage canal with the enlarged bony external auditory canal. The canal is then packed with Gelfoam®, followed by iodoform gauze in the external auditory canal.

Follow up

After operation, the patient is asked to make return visits every week before the cavity epithelises completely. The iodoform gauze is removed after two weeks. The Gelfoam® filling the canal shall be removed in steps after three weeks. The Gelfoam® over the fascia shall be left in place until four weeks. If there is a tendency for infection, all Gelfoam® shall be removed immediately and treated with antibiotics. If there is granulation hyperplasia in the surgical cavity, it should be removed immediately. If the surgical cavity is narrow enough to affect the cleaning and observation of the deep surgical cavity, triamcinolone acetonide should be injected locally in time to control scar hyperplasia.

All patients are checked regularly three months, six months and one year after operation. Patients with crusts accumulated in the whole cavity are required to attend checkups after three months, patients with crusts partially accumulated in the cavity are required to come in for a checkup after six months, and patients with a clean cavity are to get a checkup after one year. In the case of aural fullness, hearing loss, otorrhea, earache, vertigo and other ear-related symptoms, the patient needs to come in before the situation may progress. Pure tone audiometry, tympanometry and endoscopic examination are performed three months after surgery. In case of tympanic effusion, auripuncture is adopted, then a ventilation tube is placed if tympanic effusion does not disappear after three months. Computed tomography examination of the temporal bone is performed one year and five years after operation, and non-echo-planar imaging, diffusion-weighted imaging, magnetic resonance imaging are recommended for the early detection of any residual or recurrent diseases. The evaluation criteria of operative cavity are the same as those in our previously published article.[20] To evaluate the hearing outcomes, the pure-tone average (PTA) bone-conduction thresholds and PTA air–bone gap (ABG) pre-operatively and post-operatively are analysed. The average PTA bone conduction and PTA–ABG are calculated as the mean value of the threshold for 500, 1000, 2000 and 4000 Hz. Post-operative hearing improvement is indicated if bone-conduction rise after operation is less than10 dB and ABG decrease is greater than or equal to 10 dB.

Results

Patients in the medical trial included 140 males (52.8 per cent) and 125 females (47.2 per cent). The average age was 42 years old, with a range of 16–70 years old. During the operation, 249

Table 1. The pre-operative conditions of 265 patients (271 ears)

		n	%
Gender	male	140	52.8%
	female	125	41.2%
Side	left	137	51.7%
	right	122	46.0%
	bilateral	6	2.3%
Pre-operative Eustachian tube function	patency	233	86.0%
	obstruction	38	14.0%
Vertigo before operation	yes	14	5.3%
	no	251	94.7%
Hearing loss	conductive	129	47.6%
	mixed	142	52.4%
Mastoid pneumatisation	pneumatic	25	9.2%
	diploic	46	17.0%
	sclerotic	200	73.8%

Table 2. Intra-operative findings according to the extent of cholesteatoma invasion and bone destruction

Intra-operative findings	*n*	%
Malleus	210	77.5%
Incus	238	87.8%
Stapes suprastructure	84	31.0%
Stapes footplate	2	0.7%
Facial recess	154	56.8%
Sinus tympani	13	4.8%
Horizontal segment of facial nerve canal	67	24.7%
Lateral semicircular canal	12	4.4%
Attic	259	95.6%
Antrum	198	73.0%
Other mastoid cell	13	4.8%

ears of cholesteatoma and 22 ears of otitis media with granulation were determined. The average follow-up time was 8.4 years, with a range of 5.5–10 years. Pre-operative conditions of the 265 patients (271 ears) are shown in Table 1. Pre-operative examination showed that the Eustachian tube was unobstructed in 233 ears (86.0 per cent) and blocked in 38 ears (14.0 per cent). During the operation, membranous closure was found in 14 ears. Combined with a pre-operative CT, there was an aeration cavity in the Eustachian tube, so the Eustachian tube was judged to be unobstructed without Eustachian tube catheter exploration. The Eustachian tube was explored by catheter in the other 24 ears, of which 13 ears were still blocked.

The intra-operative findings with regard to the extent of cholesteatoma invasion and bone destruction are shown in Table 2. Cholesteatoma was found to invade the sinus tympani in 13 ears. In these patients, we opened the sinus tympani to remove the lesions in it by cutting the stapes tendon and grinding off the bone of the vertebral eminence and, when necessary, even removing the stapes muscle. Type III tympanoplasty-ossicular reconstruction was performed in 251 ears: 167 ears with artificial titanium partial ossicular replacement prosthesis, 79 ears with total ossicular replacement prosthesis, and 5 ears underwent classic type III tympanoplasty and ventilation tube without artificial ossicles because the Eustachian tube was obstructed. Tympanic membrane reconstruction only was performed in 12 ears, and the ossicular chain reconstruction was proposed at the time of the second stage operation. The 12 ears included 10 patients with extensive loss of tympanic mucosa and 2 patients with stapes foot plate erosion. Among the 13 patients whose Eustachian tube failed to pass the exploration, 5 patients with good hearing underwent classic type III tympanoplasty and a ventilation tube was placed at the same time. Modified radical mastoidectomy was performed in eight patients without practical hearing.

Pre-operative CT examination confirmed that there were 200 ears (73.8 per cent) of sclerotic mastoid, 46 ears (17.0 per cent) of diploid mastoid and 25 ears (9.2 per cent) of gasified mastoid. In 200 cases of sclerotic mastoid and 40 cases of diploic mastoid, the lesions of cholesteatoma and granulation did not exceed the scope of mastoid antrum. The pedicled myoperiosteal flap was enough to obliterate the opened cavity of the attic and antrum. In the cases of 6 diploic mastoids and 18 pneumatic mastoids, not only the attic and antrum but also the other mastoid cells were opened because of the lesion or good pneumatolysis of the mastoid, and the small cells without lesions at the tip of the mastoid were preserved. In these cases, the pedicled myoperiosteal flap was not enough to fill the larger surgical cavity. The pedicled temporalis muscle and myoperiosteal flap were taken to fill the surgical cavity together.

Among the 14 cases with vertigo symptoms before operation, 12 cases were found to have lateral semicircular canal fistula. In these cases, the cholesteatoma on the fistula was removed totally and carefully before tympanoplasty, and the labyrinthine fistula was repaired with temporalis fascia and a cartilage slice, then the following steps were carried out normally. The 12 patients with labyrinthine fistula had varying degrees of post-operative vertigo, and the nystagmus disappeared 1–7 days after operation, without any resulting sensorineural hearing loss.

One patient had a subcutaneous hematoma in the temporal region on the third day after operation. The local suture was removed, the hematoma was evacuated, then pressure dressings were used for 3 days. After 5 days, the wound healed, and the healing process of the ear cavity was not disturbed. One patient developed post-operative cavity infection on the fifth day after operation. The packing was taken out immediately, and the dressing in the surgical cavity was changed every day and treated with sensitive antibiotics. After one week, the infection was controlled, there was no necrosis of fascia and the pedicled myoperiosteal flap, and the post-operative healing and hearing were not affected by the infection. The other patients had no intra-operative cavity infection during the peri-operative period. The patients who used the temporalis muscle flap had a certain degree of limitation of mouth opening and pain in the donor area during chewing after operation. These symptoms gradually disappeared after one week to two months. There were no other intra-operative or post-operative complications.

The mean time of cavity drying was 5.2 weeks (4–7 weeks). In the three-month follow-up after the operation, it was found that 91.9 per cent of the operation cavities (249 ears) were slightly wider and flatter than the normal ear canal, and 7 per cent of the operation cavities (19 ears) were similar to the contralateral normal ear canal. At 4–5 weeks after operation, 3 patients had scar hyperplasia in the middle of the operation cavity. Local injection of triamcinolone acetonide was given immediately to inhibit scar growth, and administered once a week, 3–4 times according to the situation. After treatment, the scar hyperplasia in the surgical cavity was effectively controlled, and the stenosis of the operative cavity was slightly wider. Finally, the middle of the surgical cavity was slightly narrower than the normal ear canal, but it did not hinder the observation and cleaning of the deep surgical cavity. After operation, because of the placement of the ossicular replacement prosthesis and cartilage slices, the posterior superior of the pars tensa of the tympanic membrane was thicker than the normal tympanic membrane and slightly expanded laterally. Forty-three per cent of the tympanic membranes were similar to the normal tympanic membrane. In 57 per cent of the tympanic membranes, the pars flaccida was significantly larger than the normal tympanic membrane. The typical shape of the ear canal and tympanic membrane is shown in Figure 2. There was no obvious depression at the donor area after operation.

In the ear inspection follow up one year after operation, it was found that the Eustachian tube was still blocked in the five patients who underwent classic type III tympanoplasty and ventilation tube. In 31 cases, 11.4 per cent of the ears were obviously invaginated at the attic, but there was no epithelial accumulation or cholesteatoma retraction pockets. In 12 of the ears, the tympanic membrane adhered to the promontory, and no air-containing cavity was formed in the tympanum, accounting for 4.7 per cent of 258 ears with pre-operative and intra-operative judgment of Eustachian tube patency. Three patients had a middle-ear infection again after operation and caused pars tensa perforation. Among them, a small perforation in one patient healed itself, and the other two patients left the perforation. The prosthesis did not fall out due to infection.

At least one temporal bone CT examination within one year after operation was performed in 91.9 per cent of the patients, including 235 ears with ossicular replacement prosthesis. In those 235 ears, 31.1 per cent (73 ears) had soft-tissue proliferation in the posterior tympanum surrounding the prosthesis, 8.5 per cent (20 ears) had soft tissue filling the tympanum without the air-containing cavity, and in the remaining 60.4

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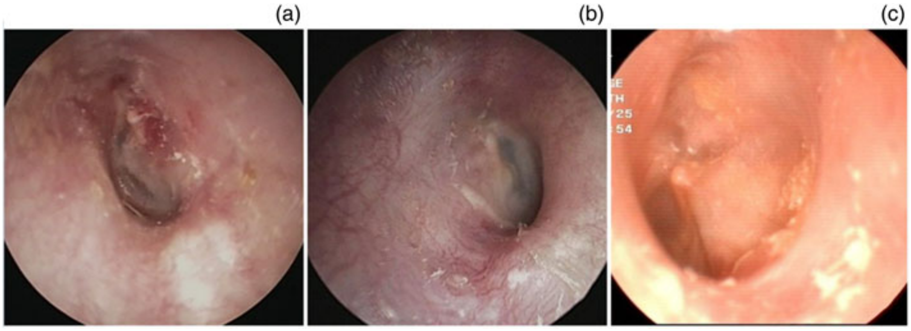

Figure 2. The typical postoperative endoscopic pictures after half canal wall down tympanomastoidectomy. The operation cavity (postoperative external ear canal) was slightly wider and flatter than the normal external ear canal. The posterior superior of the pars tensa of tympanic membrane was thicker than the normal tympanic membrane and slightly expanded laterally. (a) Endoscopic picture of a left ear at 3 months after operation; (b) endoscopic picture of a left ear at 1 year after operation; (c) endoscopic picture of a right ear at 1 year after operation. (a) and (b) show that the tympanic membrane were similar to the normal tympanic membrane. (c) shows that the pars flaccida was obviously larger than the normal tympanic membrane. The enlarged pars flaccida was smooth, slightly invaginated and without accumulation.

per cent (142 ears) the surgical cavity recovered well, as shown in Figures 3 and 4. Typical CT scans after operation showed that the external auditory meatus was slightly wider and flatter than normal, the superior and posterior wall were composed of soft tissue, the tympanum was an air-containing cavity, the antrum and the unresected small cells were filled with soft tissue, and there was no cyst and bone destruction in the unresected mastoid area compared with the pre-operative CT scan. Ten per cent of the patients underwent an MRI scan one year after operation, and no residual cholesteatoma was found, as shown in Figure 5.

After the regular follow-up period of one year after operation, the average return visit time was 11 months (6–18 months). Fifteen per cent of the patients needed cavity cleaning, which showed yellow crusts in the whole canal cavity except the eardrum, every half year. Twenty-five per cent of the patients required cavity cleaning, which showed regional crusts in the canal cavity, once a year. Sixty per cent of the patients had a canal cavity with a self-cleaning function.

Two patients gradually formed an air-containing cavity under the skin of the posterior wall of the canal cavity one year after operation, as shown in Figure 6. Both patients underwent revision surgery because of ear leakage caused by rupture of the air-containing cavity 1.5 years and 3 years after surgery. These two cases were cholesteatoma with pneumatic mastoid. Due to the large operation cavity, the pedicled postauricular myoperiosteal flap and pedicled temporal muscle flap were used for joint packing in the primary operative. It was confirmed that the air-containing cavity was covered with mucosal epithelium in the revision surgery. The site of tissue liquefaction was in the middle of the mastoid, which is the temporal muscle flap area. The rate of temporal muscle liquefaction was 6.5 per cent in all cases using combined tissue flaps after surgery. One patient (0.4 per cent) who presented with cholesteatoma of the mesotympanum in front of the malleus handle five years after surgery, underwent revision operation. This patient had a congenital cleft palate, and the Eustachian tube was unobstructed. The primary operative diagnosis was cholesteatoma with pars flaccida perforation. In the revision operation, the thin auricular cartilage with perichondrium was used to repair the tympanic membrane. After revision surgery, the tympanic membrane was followed up for two years without invagination.

In three patients, the pedicled myoperiosteal flaps in the antrum and attic gradually atrophied and were absorbed, with significant invagination at the antrum. These three cases were cholesteatoma with sclerotic mastoid. The pedicled postauricular myoperiosteal flap alone was used to fill the cavity in the primary operative. The necrosis rate of the tissue flap was 1.3 per cent when the pedicled postauricular myoperiosteal flap was used alone. The average follow-up time of all patients was 8.4 years (5.5–10 years). There was no recurrence of cholesteatoma in the rest of the cases until the latest follow up.

The average pre-operative PTA–ABG and PTA bone conduction was 31.7 ± 12.5 dB and 24.5 ± 9.2 dB hearing loss, respectively, compared with15.2 ± 7.9 dB and 23.8 ± 8.4 dB hearing loss post-operative (0.5–1 year post-operatively). There were significant differences between the pre-operative and post-operative PTA–ABG values ($p < 0.5$), and there was no significant difference between the pre-operative and post-operative PTA bone conduction. The PTA–ABG improved in 69 per cent of patients, of which 46 per cent had PTA–ABG improvement greater than or equal to 20 dB, and 23 per cent had PTA–ABG improvement greater than or equal to 10 dB and less than 20 dB. After operation, 31 per cent of the patients reached an ideal hearing level (PTA–ABG $\leq$ 10 dB), 46 per cent of the patients had PTA–ABG greater than 10 dB and less than or equal to 20 dB, and 23 per cent of the patients had PTA–ABG greater than 20 dB. Within two years after operation, eight patients had secretory otitis media, of which three patients had recurrent secretory otitis media twice. They all recovered after auripuncture and medication. Because of new conductive hearing loss, two patients underwent revision surgery at 14 months and 24 months after operation. During the operation, it was found that the prostheses were separated from the tympanic membrane, and the hearing of the two patients was improved after the appropriate prostheses were implanted. Other patients had no significant changes in post-operative hearing during the follow up one year after operation.

Discussion

Canal wall down tympanomastoid and canal wall up tympanomastoidectomy are the most classic techniques of middle-ear surgery. The two techniques have their own distinct advantages and disadvantages. To achieve better results, many modified middle-ear surgical techniques have been proposed. The ideal middle-ear surgery should have the following characteristics: (1) sufficient visualisation of the lesions and easily removable lesions, (2) maintaining normal structure and function as much as possible, (3) the post-operative cavity is similar to the normal external auditory canal in both appearance and self-cleansing function, (4) the rate of recurrence is lower, and (5) patients can obtain better hearing after operation. The external auditory canal reconstruction technique has the advantages of most ideal middle-ear surgeries, including good visualisation, preservation of normal structure, and

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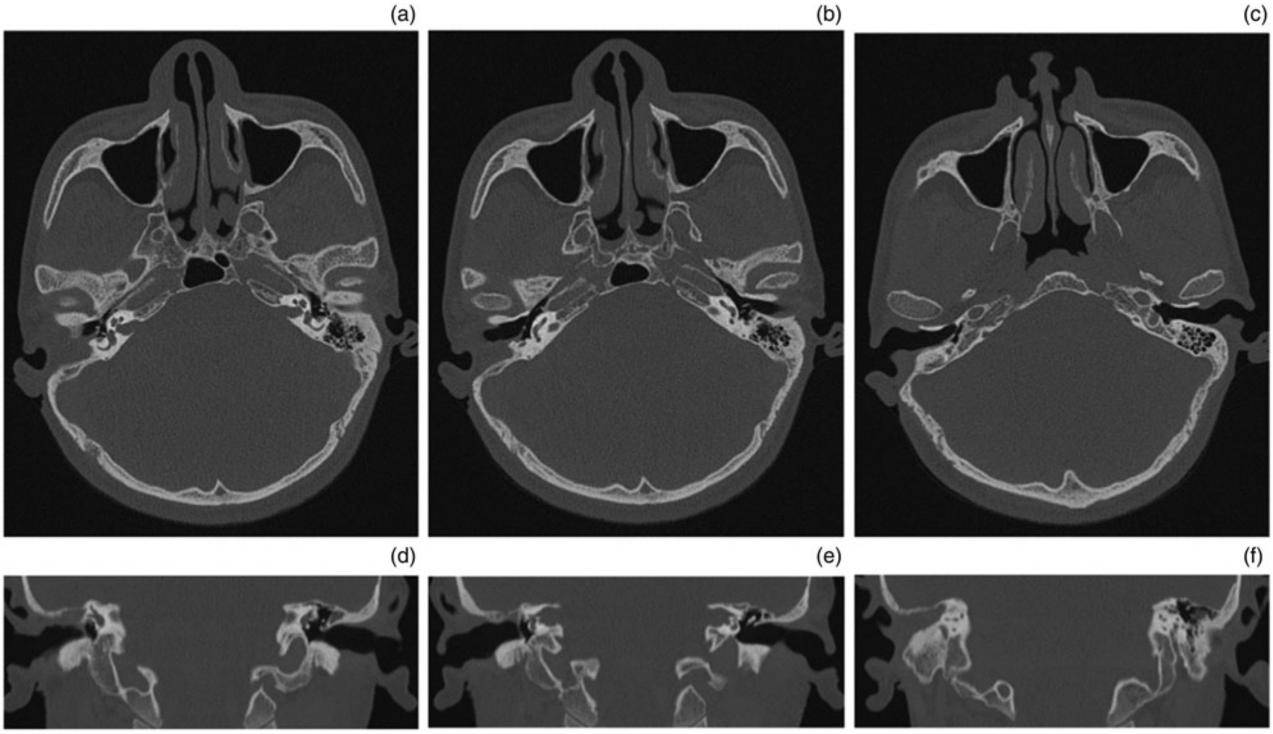

Figure 3. Typical postoperative CT image of a patient with PORP for hearing reconstruction. The postoperative external auditory canal was slightly wider and flatter than normal, the superior and posterior wall were composed of soft tissue, the tympanum was an air containing cavity, the mastoid cavity and the unresected small cells were filled with soft tissue density, and there was no cyst and bone destruction in the unresected mastoid area.

better post-operative cavity and hearing.[13,15,21,22] However, the disadvantage of this technique is the formation of retraction pockets in the epitympanum and mesotympanum.[22]

We also have been working to improve the surgical technique for nearly 20 years. We initially adopted the modified surgical technique of partial canal wall preserved tympanomastoidectomy.[20] In the partial canal wall preserved tympanomastoidectomy operation, the posterior bone canal and cortical bone bridge over the aditus ad antrum were kept to facilitate reconstruction, and a piece of cymba cartilage was used to reconstruct the superior wall of the bony external auditory canal so that the post-operative cavity is similar

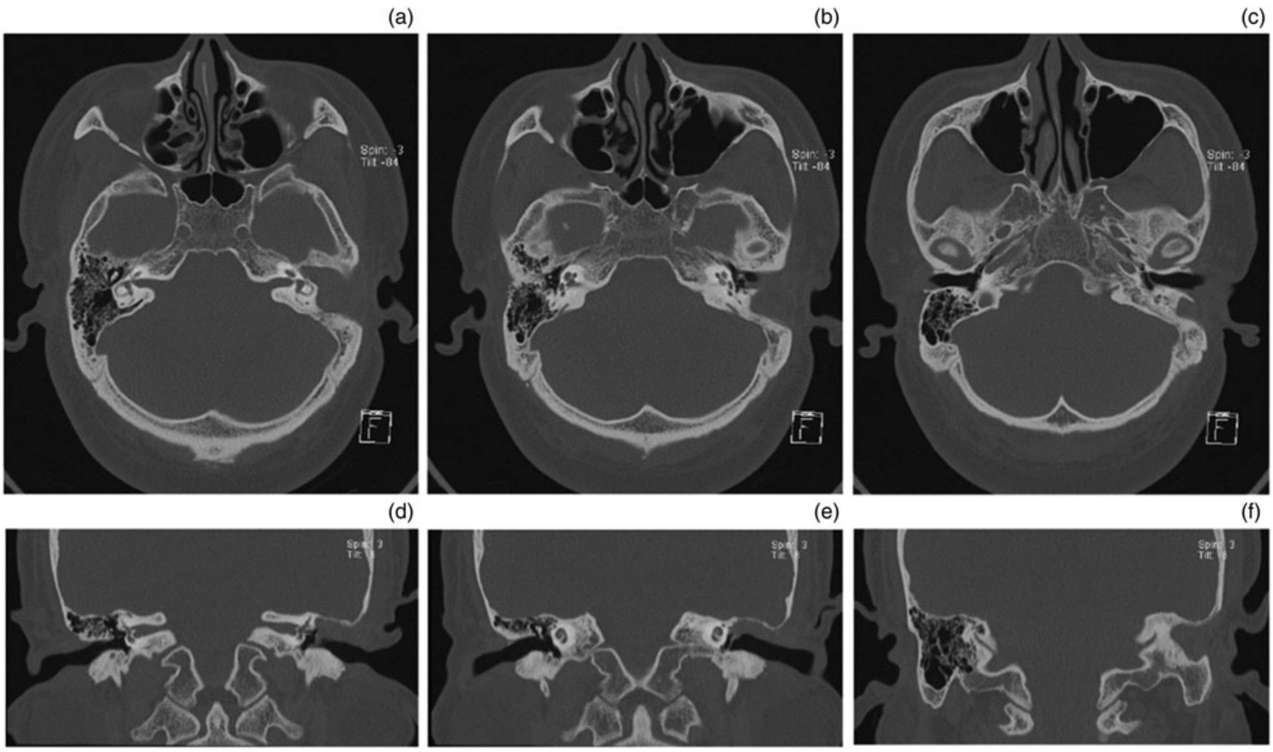

Figure 4. Typical postoperative CT image of a patient with TORP for hearing reconstruction.

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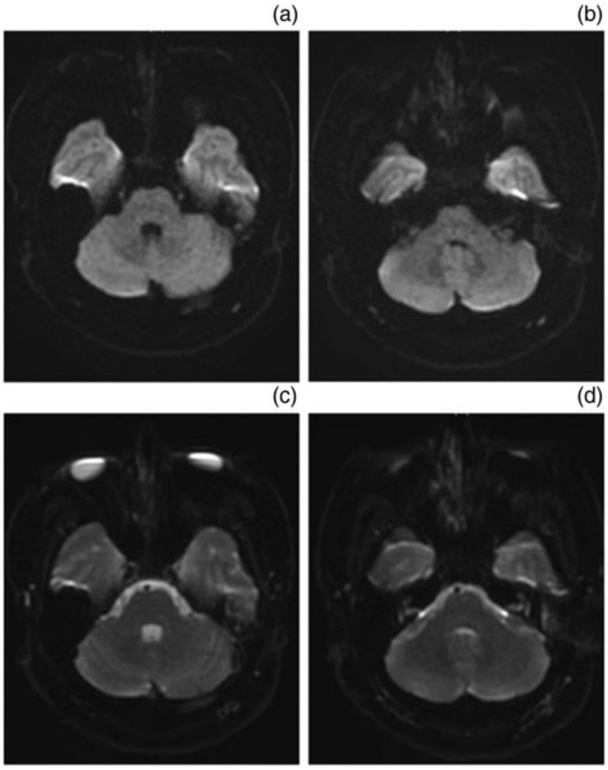

Figure 5. Typical postoperative diffusion-weighted magnetic resonance imaging of the temporal bone. Magnetic resonance imaging was performed on a 1.5 T superconductive unit using a standard head matrix coil. (a) and (b) show the T1-weighted images. (c) and (d) show the T2-weighted images. No cholesteatoma was found.

compared to the normal external auditory canal. The posterior tympanum is opened from the inside by thinning the posterior bony external auditory canal, thereby avoiding the posterior tympanic retraction and recurrence. The mastoid spaces and epitympanum were obliterated with autologous bone chips and pâté, with the goal of preventing formation of the retraction pocket at the reconstructed superior wall of the external auditory canal. However, post-operative long-term follow-up found the epitympanic cholesteatoma retraction was still inevitable. To solve this problem, we modified the surgical method based on the partial canal wall preserved tympanomastoidectomy technique, which was named half canal wall down tympanomastoidectomy.

Epitympanum has always been the most important position of the cholesteatoma recurrence in all surgical techniques of reconstructing the canal wall. The main reason for the recurrence of epitympanum may be the mastoid antrum negative pressure induced by the stenosis of reconstructed tympanic isthmus or insufficient Eustachian tube function resulted in the formation of attic retraction pockets, or the collapse of the reconstructed canal wall. Therefore, some surgeons used the modified technique of epitympanoplasty combined with mastoid obliteration with bone or cartilage, and reported that the modified technique can resist the formation of epitympanic retraction pocket, but the follow-up time is not long enough.[23,24] In partial canal wall preserved tympanomastoidectomy technology, we reconstructed the superior wall of the external auditory canal with cartilage and obliterated the mastoid and attic with bone chips and pâté, with the goal of eliminating the mastoid aeration cavity and reducing the risk of collapse of the reconstructed cartilage.

After these procedures, the epitympanic recurrence rate of cholesteatoma was 5 per cent at five years, which was lower than 16 per cent of the retrograde technique without obliterating and only reconstructing the external auditory canal.[25] It shows that although external auditory canal reconstruction and mastoid obliteration cannot eliminate the recurrence of epitympanic cholesteatoma, it can reduce the retraction pocket formation of epitympanum. The reason for the epitympanic retraction pocket in the reconstruction and obliteration technique may be attributable to the autologous bone chips and pâté absorbed, and the absorption cavity being ultimately relined with nitrogen-absorbing cuboidal mucosal epithelium, resulting in the formation of negative mastoid pressures, followed by retraction pocket formation or collapse of reconstruction cartilage, eventually leading to the recurrence of cholesteatoma.

In the process of trying to solve this problem, the technique of mastoid obliteration with a pedicled temporalis muscle flap has given us good inspiration. The cavity of the canal wall down tympanomastoidectomy technique combined with temporalis muscle flap obliteration is smooth. The temporalis muscle flap will atrophy in varying degrees after operation, and the cavity of the temporalis muscle flap will atrophy smoothly without local retraction pockets. Therefore, we inferred that if the attic and mastoid cavity were filled with soft-tissue flap instead of cartilage and bone, it was possible to solve the problem of post-operative retraction pocket formation. The temporalis muscle flap has the advantages of being easily harvested, strongly resisting infection and having less necrosis; however, atrophy and the effect on occlusion function are inevitable. Therefore, we adopted the postauricular myoperiosteal tissue flap pedicled on the superior temporal muscle. This pedicled flap is composed of some structures of the following tissues, including subcutaneous connective tissue, posterior auricular muscle, periosteum and sternocleidomastoid tendon. Therefore, this flap requires less blood supply, and strongly resists atrophy, infection and necrosis. The operation procedure is easy. Moreover, it has little effect on the function and appearance of the donor area. The postauricular myoperiosteal tissue flap can obliterate the attic, antrum and the opened mastoid as a whole. We speculate that even if the flap were atrophied after operation, it may atrophy smoothly without local retraction pockets. Our results support this conjecture that the epitympanic recurrence of cholesteatoma has not occurred in all our follow-up patients.

To distinguish from the partial canal wall preserved tympanomastoidectomy technique, we named this improved technique based on the partial canal wall preserved tympanomastoidectomy technique as half canal wall down tympanomastoidectomy. The half canal wall down technique does not need to preserve the cortical bone bridge over the aditus ad antrum, so that the tympanic cavity, attic, antrum and mastoid cells around the antrum form a smooth surgical cavity, which is filled with the pedicled postauricular myoperiosteal flap. The half canal wall down technique is simpler, easier to perform, and has shorter operative time than the partial canal wall preserved tympanomastoidectomy technique.

When the mastoid process is a sclerotic type or diploic type, the cavity formed by the half canal wall down technique is smaller. Because the sclerotic type or diploic type only needs to open the attic, antrum and its surrounding large cells, the postauricular myoperiosteal flap is enough to fill the cavity. A sclerotic type mastoid is the most common type of mastoid in cholesteatoma otitis media. In our group, sclerotic type

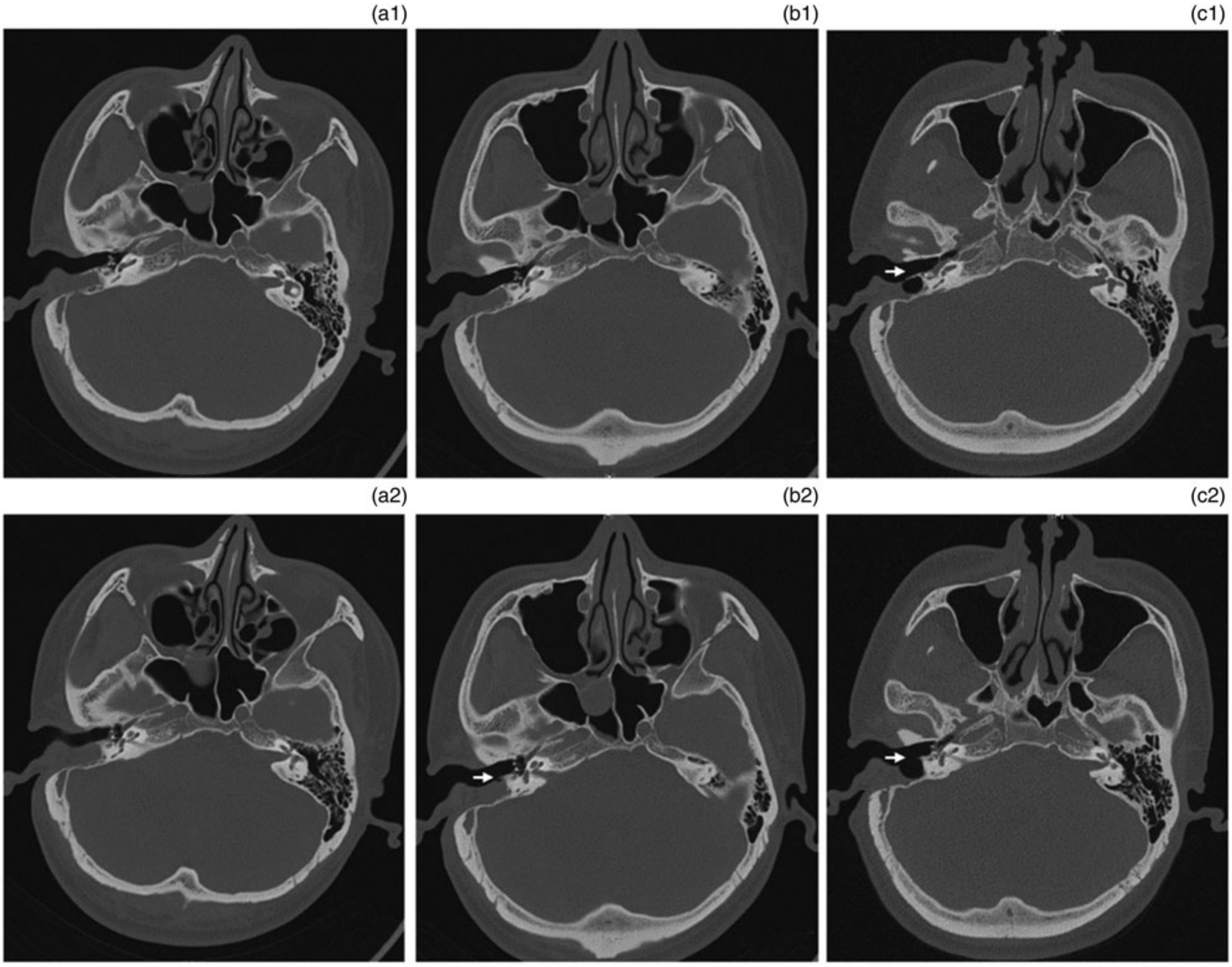

Figure 6. Typical postoperative CT image of a patient with liquefaction and absorption of tissue flap after operation. (a1) and (a2) show CT images half a year after operation. The mastoid cavity was filled with soft tissue density. The posterior wall was composed of soft tissue. (b1) and (b2) show CT images a year after operation. (b2) shows that there is a small air containing cavity in the soft tissue density of the posterior wall of the external auditory canal. (c1) and (c2) show CT images three years after operation. The air containing cavity in the posterior wall of the external auditory canal was significantly enlarged. (c2) shows the local skin was broken.

mastoids account for 73.8 per cent and diploic type mastoids account for 17.0 per cent. Therefore, for most cholesteatoma cases, the pedicled postauricular myoperiosteal flap is sufficient in the half canal wall down technique.

When the mastoid process is a pneumatic type, the half canal wall down technique needs to open the attic, antrum and mastoid larger cells, resulting in a larger cavity, which is not enough to be filled only with the pedicled postauricular myoperiosteal flap. If the operation cavity is only slightly larger, free cartilage and the pedicled postauricular myoperiosteal flap can be used as fillers. If this is still not enough to fill the cavity, then the pedicled temporal muscular flap and the postauricular myoperiosteal flap can be used together.

In the one-year follow ups after operation, it was found that 14.3 per cent of the ears were obviously invaginated at the attic, but there was no epithelial accumulation or cholesteatoma retraction pockets. The reason may be related to poor blood supply at the distal end of the pedicled myoperiosteal flap. There were also three patients who were treated with the pedicled myoperiosteal flap alone and experienced gradual atrophy and absorption after surgery. The reason for post-operative atrophy and absorption of the whole pedicled myoperiosteal flap may be related to poor blood supply caused by the narrow pedicle of the flap. Although these three patients did not undergo revision surgery, their antrum had significant invagination, with accumulated crusts that needed frequent cleaning, and there was risk of recurrent cholesteatoma.

Whether the pedicle tissue flap undergoes necrosis and atrophy largely determines the shape of the surgical cavity. Overall necrosis of the tissue flap may lead to recurrence of cholesteatoma. Therefore, the blood supply of the pedicled myoperiosteal flap is crucial. Two patients underwent revision surgery due to liquefaction and absorption of the tissue flap in the middle of the mastoid about one year after the primary surgery, in which the pedicled myoperiosteal flap and the pedicled temporal muscle flap were used together due to the pneumatic mastoid. We found that although the shape of the patient's ear canal was close to the normal ear canal one year after operation, there was an air-containing cavity under the skin of the posterior wall of the ear canal. The air-containing cavity was then infected, the local skin was broken, and the ear canal exudate in appearance. It was confirmed that the air-containing cavity was covered with mucosal epithelium in the revision surgery. The main reasons for this situation may be: (1) the internal temporal artery, a branch of the superficial temporal artery, was damaged during removal of the temporal muscle or temporal muscle fascia, resulting in poor distal blood supply of the muscle flap; (2) the mucous membrane in the gasified mastoid chamber was not removed completely; or (3) there is chronic mild infection in the surgical cavity.

- The half canal wall down tympanomastoidectomy technique needs to open the attic, antrum and mastoid larger cells, resulting in a smooth surgical cavity, which is filled with the pedicled postauricular myoperiosteal flap
- The half canal wall down tympanomastoidectomy technique combines the advantages of the canal wall down and canal wall UP tympanomastoidectomy techniques, providing a low recurrence rate of cholesteatoma, good postoperative hearing recovery, and good postoperative shape of the ear canal with a self-cleaning function
- The half canal wall down tympanomastoidectomy technique has proven to be a safe procedure for cholesteatoma removal with good intraoperative visualization

In both cases, liquefaction necrosis occurred at the site of the temporal muscle flap. When the tissue flap in the mastoid cavity undergoes atrophy and necrosis, if there is mucosal epithelium around it, the cavity is easily turned into an air cavity covered with mucosal epithelium, and this air cavity is prone to infection due to poor drainage. Survival of the tissue flap and removal of mucosa around the tissue flap are key factors in preventing surgical infection. We found that in both cases, liquefaction necrosis occurred at the site of the temporal muscle flap. The liquefaction rate of the temporal muscle flap was 6.5 per cent, while the necrosis rate of the pedicled myoperiosteal flap was 1.3 per cent. Therefore, it is necessary to ensure the blood supply of the temporalis muscle flap when using the combined flap. The half canal wall down technique is more suitable for patients with sclerotic or diploic mastoids. When using the half canal wall down technique for patients with pneumatic mastoids, it is necessary to comprehensively consider the size of the surgical cavity, the volume of the tissue flap, and the blood supply of the tissue flap.

The mastoid cavity problem will seriously affect the quality of life of the patients in middle-ear surgery. The mastoid cavity problem is closely related to the shape and function of the ear surgical cavity. Therefore, creation of a dry, self-cleansing cavity shape close to the external auditory canal can significantly improve the quality of life of the patients. Although the canal wall down tympanomastoidectomy technique has the advantages of convenient operation and low recurrence rate, the cavity problem is still an inevitable defect of canal wall down tympanomastoidectomy. This is also an important reason why the canal wall up technique is still used despite its high recurrence rate.

To solve the cavity problem, various materials have been used to remedy the canal wall down tympanomastoidectomy cavity, including autologous materials and biological materials. Although biological materials are readily available with no resorption, there is potential risk of infection and rejection, so biological materials are not widely used in clinics.[10–12] Autologous materials are widely used in clinics because of their strong anti-infection ability and no risk of rejection, but there are still restrictions on the amount of materials, the complex operation, atrophy and donor-site morbidity.[4,6,8,15] To solve this problem, we initially tried the partial canal wall preserved tympanomastoidectomy technique and found that preserving the posterior bone canal and reconstructing the superior canal wall with cartilage can obtain a post-operative cavity close to the normal external auditory canal. However, in the follow-up, we found that there was still a 5 per cent recurrence rate of epitympanic cholesteatoma with cartilage reconstruction in the epitympanum and mastoid obliteration by bone chips and pâté.[20]

In order to further reduce the recurrence rate of epitympanic cholesteatoma and obtain the ideal ear canal, we adopted the pedicle postauricular myoperiosteal tissue flap to obliterate the mastoid and reconstruct the epitympanic canal wall. It was found that 98.9 per cent of the patients obtained an ideal operation cavity, which was slightly wider and flatter than the normal external auditory canal or similar to the normal external auditory canal. In our early cases, three patients developed varying degrees of stenosis in the middle of the operation cavity at 4–5 weeks after surgery. The scar hyperplasia in the cavity began to appear about one month after operation and reached its peak at about two months after operation. Local injection of triamcinolone acetonide can control the hyperplasia of the scarring effectively. The cavities of these three patients were slightly narrower than the contralateral normal external auditory canals. Reviewing the patients' medical histories and intra-operative conditions, we found that this may be related to the excessive skin defects of the external auditory canal and or the scar physique. Therefore, in order to reduce the occurrence of post-operative cavity stenosis, we operated in strict accordance with the following requirements: (1) make the skin flap pedicled on the inferior wall of the external auditory canal and place it in the middle of the osseous canal after operation; (2) enlarge the bony external auditory canal as much as possible, especially when a skin defect is present in the external auditory canal; (3) do not fill too much tissue in the attic; and (4) appropriate skin grafting when there are too many skin defects in the external auditory canal. We have not experienced any cases of ear canal stenosis since strictly complying with the above requirements.

There was no significant change in the average bone conduction hearing threshold after operation, indicating that the operation did not cause sensorineural hearing loss. After operation, the PTA–ABG improved in 69 per cent of patients and 31 per cent of the patients reached an ideal hearing level, that is, PTA–ABG was less than or equal to 10 dB, which was not significantly different from previous literature reports.[19,26] It showed that the use of the pedicle postauricular myoperiosteal tissue flap to obliterate the mastoid and attic did not affect the post-operative hearing recovery of the patients. Two patients experienced conductive hearing loss due to lateral displacement of the posterior tympanic membrane 1–2 years after surgery, and their hearing was restored after the second surgical re-implantation of the appropriate prostheses. It shows that most patients have improved their hearing through a one-stage operation.

In post-operative CT scans, we also found soft tissue around the ossicles in 31.1 per cent of patients, which adversely affected the hearing recovery of patients. The reason for the appearance of soft tissue in the posterior tympanum is considered to be related to the loss of normal mucosa in the posterior tympanum. Therefore, in order to obtain better hearing and reduce the occurrence of posterior tympanic scar adhesion, the normal mucosa of posterior tympanum and horizontal facial nerve should be preserved as much as possible. Post-operative CT examination also found that in 235 ears with tympanoplasty and artificial ossicular implantation, 8.5 per cent (20 ears) did not form aerated middle-ear space, which is much higher than the 4.7 per cent incidence of ear inspection. These patients who did not form an aerated cavity had no improvement in their post-operative hearing. No improvement in post-operative hearing strongly suggests the absence of an aerated tympanic cavity after surgery.

Our only case of recurrent cholesteatoma after surgery is a patient with a congenital cleft palate. In patients with a cleft palate, the Eustachian tube is unobstructed, but its function is poor. The cause of recurrence of cholesteatoma in this patient is closely related to Eustachian tube function. It is suggested that the function of the Eustachian tube, but not the patency, is closely related to good post-operative recovery. The patency of the Eustachian tube and the function of the Eustachian tube cannot be regarded as the same.

Conclusion

The half canal wall down tympanomastoidectomy technique combines the advantages of both the canal wall down and canal wall up techniques, providing a low recurrence rate of cholesteatoma, good post-operative hearing recovery, and good post-operative shape of the ear canal with a self-cleaning function. Overall, the half canal wall down tympanomastoidectomy technique has proven to be a safe procedure for cholesteatoma removal with good intra-operative visualisation. This single-stage technique provides a new choice for the surgical treatment of middle-ear cholesteatoma.

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Competing interests. The authors declare that there are no competing interests.

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