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OTOLOGY

Healing acceleration of mastoidectomy through the external auditory canal incisionless approach

Jun Ho Lee[1,2,3]

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Abstract

Purpose To evaluate a surgical procedure of canal wall-up mastoidectomy without incision of the canal which enables accelerated healing and enhances hearing outcome.

Methods A total of 79 patients were enrolled. A canal-incisionless technique was used in 37 patients undergoing canal wall-up/down mastoidectomy (CWU/DM), explo-mastoidectomy, and cochlea implantation as staged operation after obliteration of the mastoid, and canal incision was used in the remaining 42 patients as comparison group.

Results Preoperative and postoperative pure tone audiometry/word recognition score and postoperative status including the healing time and complications were analyzed. Healing time of the canal-incisionless procedure (2.7 weeks) was shorter than that of conventional mastoidectomy with canal incision (5.7 weeks). Complication rate of the canal-incisionless procedure was lower than that of canal incision approach, even though statistical meaningless.

Conclusion Despite the small sample size of our study, in patients undergoing CWDM, explo-mastoidectomy, and cochlea implantation, more acceptable healing was achieved using the canal-incisionless technique than with the canal incision technique. CWU/DM without canal incision is useful to achieve optimal surgical view, eliminate pathology of the middle ear, and accelerate healing time.

Keywords Middle ear · Mastoid · Surgical wound · Wound healing

Introduction

Canal wall-up mastoidectomy (CWUM) is a basic procedure for case management of chronic otitis media (COM) with pathology of the mastoid [1]. It is an excellent procedure to manage and eradicate the pathologic tissues in the mastoid cavity and requires two skin incisions including postauricular incision and transcanal incision.

Ties Sr. first described the approach of transcanal incision for mastoidectomy in 1907, and Heermann and Lempert reported a modification of the method in the 1930s [2, 3]. Since then, Lempert I, II, and III incision are considered as standard approach for surgical field of the mesotympanum. The outer skin of the external auditory canal (EAC) through Lempert incision is retracted anteriorly with various self-retractors.

However, transcanal incision has several associated problems. First, swelling of the EAC skin or bony stenosis due to chronic inflammation can impede the procedure [4]. Second, the elevated skin could be injured by surgical manipulations or drilling. Finally, incision of the EAC naturally induces skin dehiscence and bony exposure of the EAC due to onset of separating tension, which is followed by pathologic formation of granulation tissue at the incisional area [5]. To address these problems, postoperative dressing should be performed frequently; some patients develop postoperative infection and the possibility of immediate postoperative infection is higher especially, if the cultured microorganisms are methicillin-resistant *Staphylococcus aureus* or

✉ Jun Ho Lee
zoonox@nate.com

1 Department of Otorhinolaryngology and Head and Neck Surgery, Chucheon Sacred Heart Hospital, Hallym University College of Medicine, 77, Sakju-ro, Chuncheon, Gangwon-do 200-704, Republic of Korea

2 Department of Otorhinolaryngology and Head and Neck Surgery, Hangang Sacred Heart Hospital, Hallym University Medical Center, Seoul, Republic of Korea

3 Institute of New Frontier Research, Hallym University College of Medicine, Chuncheon, Republic of Korea

quinolone-resistant *Pseudomonas aeruginosa*, due to inavailability of adequate oral medications [6, 7].

To reduce immediate healing problems, such as local infection, granulation, discharge, and swelling of the EAC, and expand the surgery field, some surgeons tried and used modified technique, which is mastoidectomy without canal incision. Gersdorff and Gérard introduced a canal incisionless technique in case of tympanoplasty alone, through the retroauricular approach [8, 9]. In this study, we modified a basic surgical procedure of mastoidectomy performed without incision of the canal called the Canal Incisionless Approach (CIA). We performed CIA in total 36 patients with COM, of which, 1 patient with cochlear implant (CI) had previously received canal reconstruction and mastoid obliteration using floating cartilages as treatment for COM [10]. Based on our experience, we recommend this CIA technique in patients following mastoidectomy with adequate indications.

Methods

Participants

A retrospective chart review of patients who underwent CIA technique between May 2018 and January 2019 at the Department of Otolaryngology-Head and Neck surgery, Hallym University, Chuncheon Sacred Heart Hospital, Chuncheon, Republic of Korea was performed. The CIA technique was consecutively performed in all patients and during these periods. To compare with the canal incision approach as the historical control group, all patients who underwent mastoidectomy with canal incision and between August 2017 and April 2018 were enrolled as the comparator cohort. A total of 79 patients with COM with or without cholesteatoma were treated. Canal incision approach was used in 42 patients, and CIA procedure in 37 patients. In the CIA group, the technique was used as part of initial procedure in 31 patients, surgical revision for recurrent cholesteatoma in three patients, and surgical treatment for congenital cholesteatoma in one patient, hearing problem due to tympanosclerosis was present in one patient, and CI following previous canal wall down mastoidectomy (CWDM) and mastoid obliteration in one patient (Table 1).

A database of patient age and preoperative and postoperative pure tone audiometry (PTA)/word recognition score (WRS) score was created. Hearing gain was determined by the absolute value of change in the average hearing level at different frequencies of 500, 1000, 2000, and 3000 Hertz, as recommended by the Committee on Hearing and Equilibrium [11]. In all patients, postoperative audiologic tests were performed at postoperative 3 months to determine the immediate hearing-gain status. Air–bone gap measurements, postoperative healing time, postoperative healing patterns, and complications were analyzed. The study protocol was approved by the Institutional Review Board of Chuncheon Sacred Heart Hospital.

Surgical technique

Trimming of the tympanic membrane perforation or retracted portion was performed before posterior-auricular skin incision. In some cases of cholesteatoma, trimming was not performed as initial procedure (Fig. 1a). After elevating the skin of the EAC up to the level of the fibrous annulus (Fig. 1b), a portion of the cholesteatoma opening was

Table 1 Patient demographics, healing time, and complications

Characteristic	Canal incision approach (42 patients)	CIA procedure (37 patients)	*p* values
Age, years (±SD)	60.7 (±13.7)	56.1 (±17.1)	0.193
Male/female	20/22	17/20	0.882
Right/left	16/26	22/15	0.058
Suppurative otitis media/acquired cholesteatoma/congenital cholesteatoma	30/12/0	26/10/1	0.561
Primary surgery for COM/revision surgery for COM/CI	37/5/0	33/3/1	0.577
CWUM/CWDM	35/7	35/2	0.162
Combined ossiculoplasty, tympanoplasy/PORP/TORP/tympanization	29/4/2/7	26/1/2/7	0.680
Pre-operative PTA level, air, dBs (±SD)	58.1 (±23.3)	54.9 (±27.5)	0.666
Pre-operative air–bone gap, dBs (±SD)	22.2 (±8.4)	20.9 (±13.7)	0.392
Pre-operative WRS, % (±SD)	83.3 (±23.2)	78.7 (±29.9)	0.646
Complications, %	14/42 (33.3%)	6/37 (16.2%)	0.081
Healing times, weeks	5.7±3.1	2.7±1.3	<0.001

CI cochlea implantation, *CIA* canal incisionless approach, *COM* chronic otitis media, *CWDM* canal wall down mastoidectomy, *CWUM* canal wall up mastoidectomy, *dBs* decibels, *PORP* partial ossicular replacement prosthesis, *PTA* pure tone audiometry, *TORP* total ossicular replacement prosthesis, *WRS* word recognition score

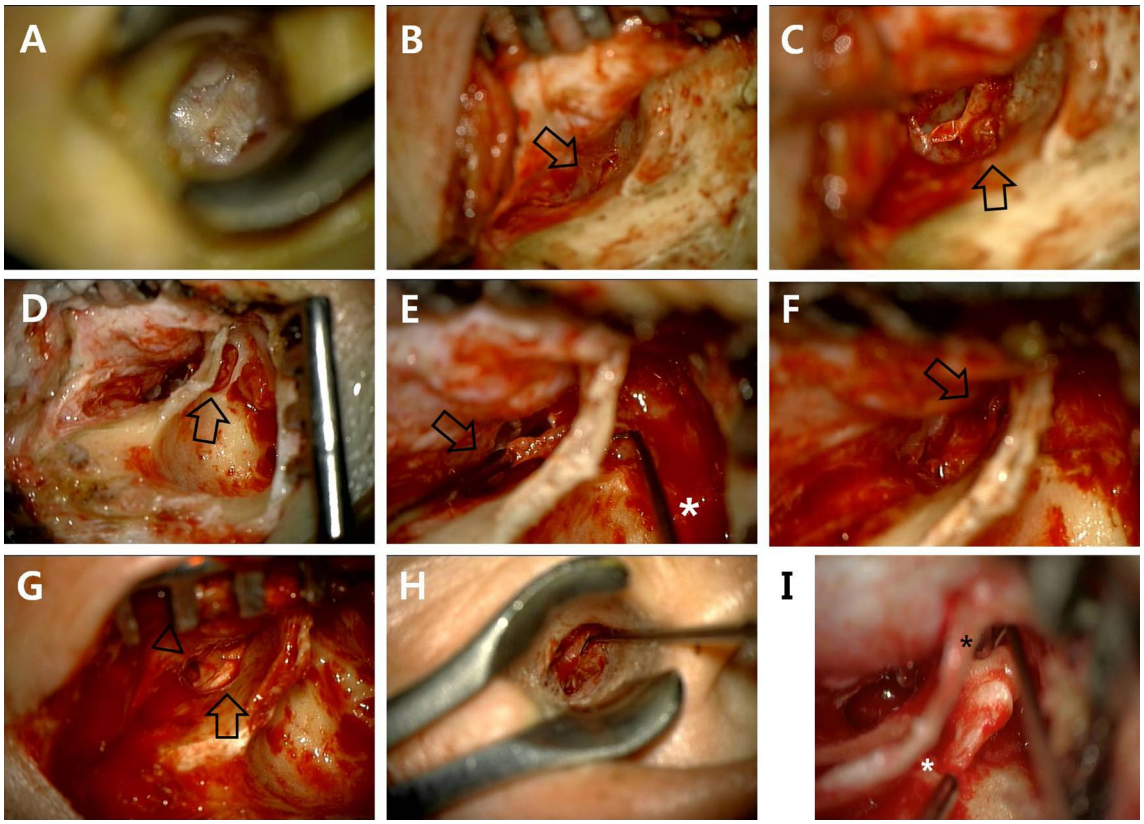

Fig. 1 Surgical photographs of CIA procedure. Figure 1a–h explained surgical technique in case of cholesteatomous COM. Figure 1i shown surgical view in case of suppurative COM. **a** Trimming was not performed in some cases. **b** Detachment of the posterior portion of the retracted tympanic membrane due to tension from the elevated skin at the EAC (black arrow in **b**). **c** The inlet of the cholesteatoma sac identified after performing the skin elevation (black arrow in **c**). **d** The cortical portion at the surface of the epitympanum was drilled out (black arrow in **d**). **e** Tracing (black arrow in **e**) and pulling (white asterisk in **e**) were performed to remove the cholesteatoma sac. **f** Preserved status of the chorda tympani nerve (black arrow in **f**). **g** Temporalis fascia (black arrowhead in **h**) and reinforcement with the sliced cartilage (black arrow in **g**). **h** Repositioning of the fascia graft and tympanic membrane were performed. **i** Surgical photograph of CIA in case of suppurative COM. Ossicles integrity were maintained during the manipulation of the supratubal recess (black asterisk in **i**) and stapes portion (white asterisk in **i**)

automatically trimmed by continuing to elevate the skin up to the level of the tympanic membrane (black arrows in Fig. 1b, c). Subsequently, the posterior-superior portion of the skin of the EAC and detached tympanic membrane from the malleus were simultaneously retracted anteriorly. After drilling the cortical bone of the epitympanum (extended epitympanotomy, that means the anterior portion of the epitympanum and the posterior buttress were drilled out extensively to allow easy access of the supratubal recess and a portion of the stapes, black arrow in Fig. 1d) and removing the malleus head and incus, the cholesteatoma was removed with suction under tracing of the target portion of the EAC (black arrow in Fig. 1e), and the mastoid portion (white asterisk in Fig. 1e) was pulled concomitantly to remove the cholesteatoma sac through the EAC at transmastoid surgical view. In extended epitympanotomy, the chorda tympani nerve could be easily saved, which is considered as an advantage (black arrow in Fig. 1f). The fascia graft was attached to the elevated tympanic membrane (black arrowhead in Fig. 1g). As a prevention measure, the cartilage was positioned at the posterior portion of the malleus handle (black arrow in Fig. 1g). The fluctuating posterior aspect of the EAC skin was repositioned in alignment with the natural contour using a right-angle pick (Fig. 1h). Gelfoam and Merocel were filled inside the EAC.

In the case of intact ossicles, pathologic tissues around ossicles were easily removed and the ossicle integrity was preserved though extended epitympanotomy (Fig. 1i). Posterior tympanotomy was not performed in all the enrolled patients.

Statistical analysis

Normal distribution of all audiometric data except that of WRS was demonstrated. Chi-square test was used to analyze demographic variables. Student's *t* test and Mann–Whitney

test were used to compare age, healing time, and audiologic parameters between each cohort. Paired *t* test or Wilcoxon signed rank test was used to compare audiologic data between pre-treatment and post-treatment time points. Statistical analyses were carried out using Statistical Package for the Social Sciences version 24 (SPSS IBM, New York, USA) for Windows. p value of < 0.05 was considered to be statistically significant.

Results

Patient and surgical factors

The patient age in CIA cohort was between 8 and 91 years (mean age, 56.1 ± 17.1 years), the male:female ratio was 17:20, and the right:left ratio was 22:15. Among the individuals undergoing primary surgery, 25 patients were diagnosed with COM with perforation, 9 patients were diagnosed with acquired cholesteatoma; 1 patient each was diagnosed with congenital cholesteatoma at the mastoid portion and tympanosclerosis with the intact tympanic membrane and fixed ossicles at the epitympanum. Main symptoms of hearing loss and persistent ear drainage were experienced by patients.

Except in one patient with CI, combined ossiculoplasty was performed as part of the procedure. Partial ossicular replacement prosthesis (PORP) was used in one patient, and total ossicular replacement prosthesis (TORP) was performed in two patients. In seven cases, ossiculoplasty was not performed simultaneously due to severe pathologic change of tympanization of the middle-ear mucosa. In the remaining 24 patients, tympanoplasty was performed (Table 1).

In contrast to the CIA group, the age of patients in the canal incision approach group was between 26 and 89 years (mean age, 60.7 ± 13.7 years). The male:female ratio was 20:22, and the right:left ratio was 16:26. Other demographic data are shown in Table 1. In the comparison between cohorts, no statistical differences were obtained.

Audiometric results

In the audiologic analysis, one case with CI, seven cases with tympanization and seven cases with follow-up loss in CIA cohort, and seven cases with tympanization and six cases with follow-up loss in canal incision approach cohort were excluded. In the remaining 22 patients in CIA cohort and 29 patients in canal incision approach cohort, no significant differences of preoperative/postoperative air conduction thresholds/air–bone gap and WRS were obtained (Table 2). There were no improvements in the postoperative air conduction thresholds (CIA: $p = 0.144$; canal incision approach: 0.522) and air–bone gaps (CIA: $p = 0.394$; canal incision approach: $p = 0.700$) (Table 2). Consistent WRS was achieved postoperatively in the CIA group ($p = 0.924$), whereas decrease in WRS in the canal incision approach cohort ($p = 0.002$) (Table 2). Even though statistical meaningless due to small case number, success rate of hearing gain with 10 dBs-cut-off of 40.9% (9/22 patients) was attained in CIA cohort, and that of 31.0% (9/29 patients) in canal incision cohort ($p = 0.465$, Table 2).

Minor complications

The incidence of minor complications was 16.2% (6/37 patients) in CIA cohort and 33.3% (14/42 patients) in canal incision cohort (Table 1). Among the six patients in CIA cohort, keloid formation at post-auricular incision was observed in one patient, and benign paroxysmal positional vertigo in one patient; persistent denudation of the tympanic membrane graft was present in one patient, for which subsequent skin graft was performed. Infection

Table 2 Audiologic outcomes

Audiologic outcomes	Canal incision approach (29 patients)	CIA procedure (22 patients)	*p* values
Pre-treatment PTA level, dBs	52.0 ± 18.0	46.6 ± 16.5	0.276
Post-treatment PTA level, dBs	50.4 ± 20.8	42.2 ± 21.5	0.172
Hearing gain, dBs	$p = 0.522$	$p = 0.144$	
Pre-treatment air–bone gap, dBs	21.4 ± 8.1	23.7 ± 10.8	0.386
Post-treatment air–bone gap, dBs	20.7 ± 11.0	21.5 ± 11.7	0.804
Reduced air–bone gap, dBs	$p = 0.700$	$p = 0.394$	
Pre-treatment WRS, %	90.9 ± 12.1	89.3 ± 17.7	0.836
Post-treatment WRS, %	81.7 ± 21.5	85.7 ± 21.8	0.396
Speech gain, %	$p = 0.002$	$p = 0.924$	
Hearing gain rate, % (cut off range ≥ 10 dBs)	9/29 (31.0%)	9/22 (40.9%)	0.465

CIA canal incisionless approach, *dBs* decibels, *PTA* pure tone audiometry, *WRS* word recognition score
$p < 0.050$ was considered statistically significant

of the graft material was observed and re-operation was performed as treatment in one case. Re-perforations of the tympanic membrane were observed in two patients. Of 14 cases in canal incision cohort, taste change was present in three patients, and continuous dizziness for a period of several weeks in one patient; focal abscess formation at the post-auricular incision site was reported in one patient; persistent denudation of the tympanic membrane graft was present in six patients, for which subsequent skin graft or continuous dressing was performed; infection of the graft material was observed and re-operation was performed as treatment in one case; re-perforations of the tympanic membrane were observed in two patients. No statistical significance in findings between the two cohorts was obtained ($p = 0.081$) (Table 1).

Healing times

The level of completion of epithelialization of the tympanic membrane was checked periodically. Average of healing time to epithelialization of 2.7 ± 1.3 weeks was obtained in CIA cohort, whereas that of 5.7 ± 3.1 weeks in canal incision approach cohort. Significant statistical differences between the two cohorts were obtained ($p < 0.001$) (Table 1, Fig. 2).

Among the 37 patients in CIA cohort, healing within 2 weeks was attained in 20 patients (54.1%); congenital cholesteatoma was present in one case, tympanosclerosis in one case, and healing of suppurative COM within 1 week in two cases (Fig. 2).

Discussion

Surgical techniques have been developed for several purposes, including minimal invasive approach. Recently, in the field of otorhinolaryngology, robotic surgery at the Head and Neck department, and close rhinoplasty in the field of rhinology are good examples of technique with minimal skin invasion [12, 13]. In the field of otology, endoscopic middle-ear surgery is a novel technique for widening of surgical field without trans-mastoid approach [14]. However, in case of pathologic change of the mastoid, minimizing of the skin incision was limited, because conventional post-auricular skin incision is considered as basic procedure in patients undergoing mastoidectomy.

Nevertheless, operators considered reducing the skin incision as an alternate approach. In case post-auricular incision is necessary for mastoidectomy procedures, operators can omit canal incision from mastoidectomy procedures. Over the last decade, canal incision described by Lempert [2] is essential since it is a necessary approach to the mesotympanum. However, there were several associated problems and controversies. For example, use of retractor with elevated skin at the canal incision site may interrupt the surgical field, and incidence of delayed healing may increase postoperatively; most importantly, prolonged retraction of the incised canal skin causes high separation tension and could damage the feeding blood vessels of the elevated canal skin [15]. Overall, these phenomena may compromise function of the canal skin including migration of keratin debris to the outer ear at post-operative period [16]. To reduce these problems,

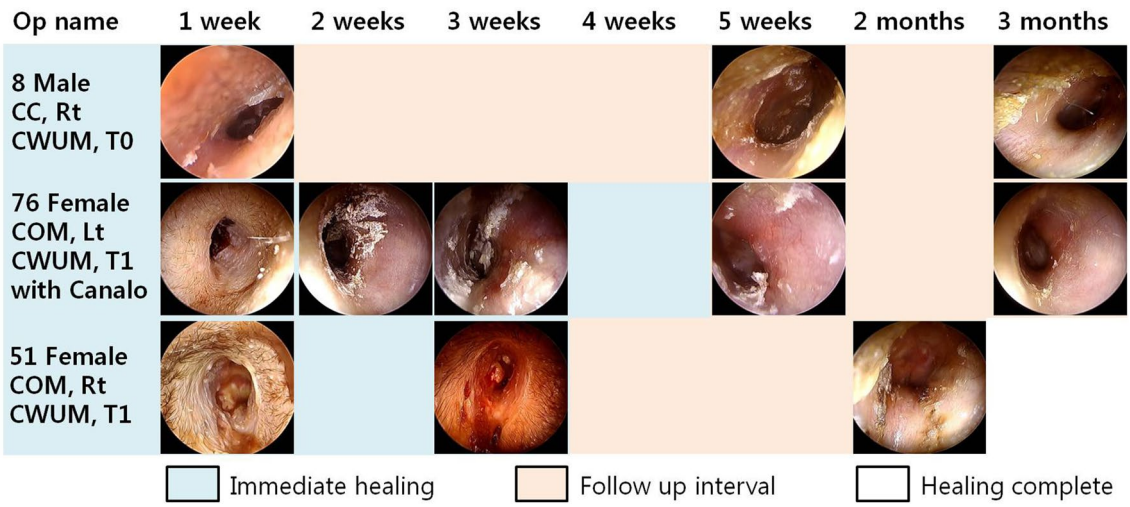

Fig. 2 Follow-up photo-images. Blue background area represents healing period to near completion of epithelialization at the EAC and tympanic membrane. Yellow background area represents interval between epithelialization time and last follow-up. *Canalo* canaloplasty, *CC* congenital cholesteatoma, *COM* chronic otitis media, *CWUM* canal wall-up mastoidectomy, *Op* operation, *T0* tympanization, *T1* tympanoplasty

some investigators developed novel methods of approach such as the canal incisionless technique [8, 9]. In our study, we evaluated CIA procedure under assumption that a larger tissue volume is generated by raising the total posterior EAC skin than using canal skin incision; however, the CIA method revealed better surgical fields in approaching the hypotympanum or eustachian orifice as compared to canal incision approach, due to attachment of the elevated tympanic membrane to the elevated posterior canal skin and natural positioning in relation to the anterior portion of the EAC.

Healing processes occur in both the mesotympanum and mastoid cavity, and healing time is important to patients' well-being. If healing of the EAC condition is delayed, it may lead to infection of the granulation tissues or swelling of the graft material at the level of the tympanic membrane and mastoid cavity [17]. Conventionally, healing time of mastoidectomy is approximately 2 months; for example, healing time of CWDM with obliteration was 10–11 weeks [18].

Previous methods included repositioning of the EAC skin, trimming of the tympanic membrane, and fascia graft with compression with Gelfoam, layon, cotton, ointment, or Merocel. With regard to prevention of iatrogenic infection at the EAC, frequent EAC dressing may be limited until 1–2 weeks postoperatively, and discharge from the tissues undergoing healing or granulations at the incision area may be mistaken for postoperative infection at the operation site. In CIA procedure, discharge or granulation limited to the tympanic membrane graft allowed simplified postoperative management.

The proposed CIA technique combined with extended epitympanotomy has many advantages. It allows wide surgical field at the mesotympanum as well as less surgery time for opening of the facial recess. Moreover, the natural epitympanic pathway previously blocked by the pathologic tissues is restored, and there is reduced risk of damage to the chorda tympani nerve since posterior tympanotomy is omitted; the rate of ossicle removal may be reduced because manipulation of the anterior-medial portion of the malleus head was easily accessed.

In this study, we performed CIA procedure in one patient with CWDM. Our group previously reported a novel technique of mastoid obliteration with free floating cartilages [10]. In this technique, canal incision at the EAC is performed mainly to prevent widening of the canal skin in CWDM due to stenotic effect of the fibroblasts. Although the effect of CIA procedure cannot be confirmed because only one case was included, the healing process was reasonable and the healing time was minimized (Fig. 3a, b); additionally, during the procedure, the intact skin of the EAC provided a good template for the attachment of the sliced cartilage on the dermis [10]. Further study including a large number of cases is needed to evaluate the effect of CIA in CWDM.

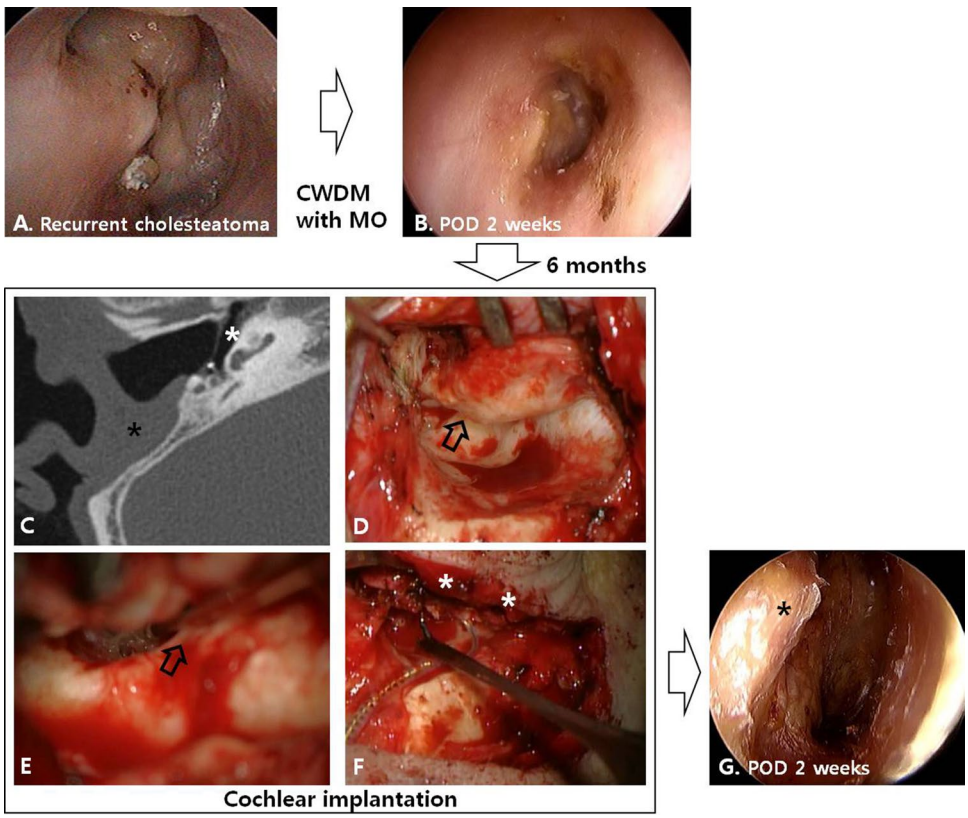

Fig. 3 Application of CIA to CWDM with mastoid obliteration and/or CI in COM. **a** Recurrent cholesteatoma after previous CWUM treated with CWDM and mastoid obliteration according to the method of Lee et al. 2017. **b** Almost complete healing was achieved at postoperative 2 weeks. After 6 months, CI was performed. **c** Aerated mesotympanum (white asterisk in **c**) and thickness at previous mastoid-obliteration site (black asterisk in **c**). **d** Elevation of the soft tissue at the mastoid obliteration site (black arrow in **d**). **e** Round windows through drilling (black arrow in **e**). **f** Cartilage reinforcement at the round-window areas, and positioning of the electrodes (white asterisks in **f**). **g** The conditions of the EAC at postoperative 2 weeks (black asterisk in **g**). The figures in **a/b** and **c/d/e/f/g** were by two different patients. *CWDM* canal wall-down mastoidectomy, *MO* mastoid obliteration, *POD* postoperative days

Subtotal petrosectomy is considered as the gold standard for CI in patients with COM [19, 20]. Staged CI after subtotal petrosectomy has an advantage of eliminating pathologic organisms in the middle ear. However, closure of the EAC and blocking of the Eustachian tube induced permanent fullness of the ear, and the operation time was prolonged. To avoid these problems, we performed mastoid obliteration instead of subtotal petrosectomy (Fig. 3b) [10]. After confirming the presence of mesotympanum (white asterisk in Fig. 3c) and thickness of the mastoid obliteration (black asterisk in Fig. 3c), we applied the concept of CIA in staged CI and achieved similar surgical view and postoperative management as those for CI in CWUM (Fig. 3d–g).

Theoretically, the technique also reduces associated taste problems. Permanent taste change after middle ear surgery is rare [21], but patients may complain of transient taste change, which can cause uncomfortable patient–clinician relationship. Extended epitympanotomy has minimal risk of manipulation of or damage to the chorda tympani nerve. This technique did not require drilling of the facial recess. After opening the posterior portion in extended epitympanotomy, natural positioning of the chorda tympani nerve in the air and surrounding inflammatory tissues could be viewed. The granulation tissue around the chorda tympani nerve could be easily and meticulously removed.

Finally, we maintained an operation-site drain for longer period in situ (additional 1 day), and we used a drain of larger width than those in canal incision approach. Some cases may show swelling of the surgical area. In canal incision cohorts, there may be exudation from the surgical field at incisional area of the EAC; this effect can be managed by maintaining an operation-site drain of large diameter for a long period.

Conclusion

CIA in mastoidectomy was useful to achieve optimal surgical view, reduce healing time, and prevent development of complications. It showed good performance to treat pathology of the middle ear, and in combination with extended epitympanotomy, to reduce the surgical time and risk of damage of the facial nerve, and maintain physiological attic aeration pathway. Despite absence of significance of hearing gain due to small cohorts and short follow-up in the present study, the proposed technique may be considered as preferred approach in patients with COM indicated for CWUM or CWDM.

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Compliance with ethical standards

Conflict of interest No known or potential conflicts of interest exist.

References

1. Zhang L (2016) Therapeutic outcomes of canal wall up mastoidectomy in combination with Type I tympanoplasty in otitis media. Pak J Med Sci 32(3):565–569. https://doi.org/10.12669/pjms.323.9780
2. Lempert J (1949) Lempert endaural subcortical mastoidotympanectomy for the cure of chronic persistent suppurative otitis media. Arch Otolaryngol 49(1):20–35
3. Paparella MM, Shumrick DA, Gluckman JL, Meyerhoff WL (1991) Otolaryngology, vol 2, Otology and neuro-otolgy. Third edn. Saunders, Philadelphia, pp 1422–1423
4. Schwarz D, Luers JC, Huttenbrink KB, Stuermer KJ (2018) Acquired stenosis of the external auditory canal—long-term results and patient satisfaction. Acta Otolaryngol 138(9):790–794. https://doi.org/10.1080/00016489.2018.1476779
5. Wiatr M, Skladzien J, Strek P, Przeklasa-Muszynska A, Wiatr A (2019) Chronic otitis media with granulation is a poor prognostic factor for hearing improvement and development of intracranial complications. J Int Adv Otol 15(1):12–17. https://doi.org/10.5152/iao.2019.4786
6. Mutoh T, Adachi O, Tsuji K, Okunaka M, Sakagami M (2007) Efficacy of mastoidectomy on MRSA-infected chronic otitis media with tympanic membrane perforation. Auris Nasus Larynx 34(1):9–13. https://doi.org/10.1016/j.anl.2006.05.017
7. Youn CK, Jun Y, Jo ER, Jang SJ, Song H, Cho SI (2018) Comparative efficacies of topical antiseptic eardrops against biofilms from methicillin-resistant *Staphylococcus aureus* and quinolone-resistant *Pseudomonas aeruginosa*. J Laryngol Otol 132(6):519–522. https://doi.org/10.1017/S0022215118000932
8. Gérard JM, el Makhloufi K, Gersdorff M (2003) Tympanoplasty without skin incision of the external auditory canal: preliminary results. Acta Otorhinolaryngol Belg 57(3):183–185
9. Gersdorff MC, Gérard JM (2002) Tympanoplasty without skin incision of the external auditory canal. Laryngoscope 112(8 Pt 1):1507–1508. https://doi.org/10.1097/00005537-200208000-00032
10. Lee HJ, Chao JR, Yeon YK, Kumar V, Park CH, Kim HJ, Lee JH (2017) Canal reconstruction and mastoid obliteration using floating cartilages and musculoperiosteal flaps. Laryngoscope 127(5):1153–1160. https://doi.org/10.1002/lary.26235
11. Committee on Hearing and Equilibrium guidelines for the evaluation of results of treatment of conductive hearing loss (1995) American academy of otolaryngology-head and neck surgery foundation, Inc. Otolaryngol Head Neck Surg 113(3):186–187. https://doi.org/10.1016/S0194-5998(95)70103-6
12. Poon H, Li C, Gao W, Ren H, Lim CM (2018) Evolution of robotic systems for transoral head and neck surgery. Oral Oncol 87:82–88. https://doi.org/10.1016/j.oraloncology.2018.10.020
13. Cafferty A, Becker DG (2016) Open and closed rhinoplasty. Clin Plast Surg 43(1):17–27. https://doi.org/10.1016/j.cps.2015.09.002
14. Tseng CC, Lai MT, Wu CC, Yuan SP, Ding YF (2017) Comparison of the efficacy of endoscopic tympanoplasty and microscopic tympanoplasty: a systematic review and meta-analysis. Laryngoscope 127(8):1890–1896. https://doi.org/10.1002/lary.26379
15. Leung IP, Fleming LT, Walton K, Barrans SM, Ousey K (2019) Finite element analysis to model ischemia experienced in the development of device related pressure ulcers. Proc Inst Mech

Eng H 23:954411919851387. https://doi.org/10.1177/0954411919851387
16. Cronin SJ, El-Kashlan HK, Telian SA (2014) Iatrogenic cholesteatoma arising at the bony-cartilaginous junction of the external auditory canal: a late sequela of intact canal wall mastoidectomy. Otol Neurotol 35(8):e215–e221. https://doi.org/10.1097/MAO.0000000000000481
17. Scalise A, Calamita R, Tartaglione C, Pierangeli M, Bolletta E, Gioacchini M, Gesuita R, Di Benedetto G (2016) Improving wound healing and preventing surgical site complications of closed surgical incisions: a possible role of incisional negative pressure wound therapy. A systematic review of the literature. Int Wound J 13(6):1260–1281. https://doi.org/10.1111/iwj.12492
18. Faramarzi M, Kaboodkhani R, Roosta S, Azarpira N, Shishegar M, Bahranifard H (2019) Application of amniotic membrane for covering mastoid cavity in canal wall down mastoidectomy. Laryngoscope 129(6):1453–1457. https://doi.org/10.1002/lary.27638
19. Casserly P, Friedland PL, Atlas MD (2016) The role of subtotal petrosectomy in cochlear implantation. J Laryngol Otol 130(Suppl 4):S35–40. https://doi.org/10.1017/S0022215116000979
20. Szymański M, Ataide A, Linder T (2016) The use of subtotal petrosectomy in cochlear implant candidates with chronic otitis media. Eur Arch Otorhinolaryngol 273(2):363–370. https://doi.org/10.1007/s00405-015-3573-1
21. Kim CW, Lee JS, Park CH, Kwon SY, Kim DK, Lee JH (2015) Comparison of sequential same-day middle ear surgeries: bilateral mastoidectomy, unilateral mastoidectomy with contralateral tympanoplasty, and bilateral tympanoplasty. Eur Arch Otorhinolaryngol 272(6):1395–1402. https://doi.org/10.1007/s00405-014-2931-8