Introduction

Mastoidectomy has been an essential procedure for the surgery of otitis media with cholesteatoma or discharging ears [1]. There are mainly two options in mastoidectomy, canal wall up or canal wall down techniques [2]. In canal wall up mastoidectomy (CWUM), postoperative wound heals relatively faster than canal wall down mastoidectomy (CWDM) with preserved normal anatomic contours of the posterior wall of external auditory canal (EAC). However, CWUM limits the exposure of the lesions due to posterior canal wall resulting in recidivism [3]. In CWDM, it would be much easier to identify and remove pathologic tissues with superior surgical view compared to CWUM, especially in revision surgeries [4]. As a result of posterior EAC wall removal in CWDM, there would be large cavities causing recurrent infections, stasis of secretion, or vertigo by caloric stimuli [5].

To avoid the above-mentioned problems, cavities after mastoidectomy have been obliterated with various materials, procedure so called mastoid obliteration (MO), combined with meatoplasty [4,6]. Autologous materials are usually used due to their excellent biocompatibility. Unfortunately, they show natural shrinkage with time and limited availability in amount [7], which have promoted the use of synthetic materials like silicone, hydroxyapatite, titanium, or bioactive glass [8,9]. Due to artificial properties of them, they show natural shrinkage with time and limited availability in amount [7], which have promoted the use of synthetic materials like silicone, hydroxyapatite, titanium, or bioactive glass [8,9]. Due to artificial properties of them, there has naturally caused rejection, extrusion, persistent otorrhea and so on [10]. Also, the choice of the filler materials has mainly been dependent on personal friendliness of the surgeons rather than scientific reasons [11,12].

Accordingly, we introduced bone allografts for MO after mastoidectomy and evaluated the surgical results to judge
their safety and effectiveness.

**Subjects and Methods**

**Patients**

In this study, we included only patients who underwent mastoidectomy with MO and followed more than 12 months between January 2013 and January 2021 at a tertiary referral center. Preoperatively, all of the mastoid cavities showed relatively large volume without sufficient autologous mastoid cortical bone. All subjects received CWUM or CWDM. We used autologous conchal cartilage as obliteration material at epitympanum and along tympanic membrane (TM). In MO group, bone allografts were additionally used to fill the remaining mastoid cavities. In the canal wall down (CWD) group, all subjects received CWDM, and inferiorly-based mucoperiosteal flaps were additionally used to fill the remaining cavities. Pre- and postoperative demographic and clinical data were obtained from patient medical records. Written informed consent was obtained from all the patients who participated in this study. SPSS version 11 (SPSS Inc., Chicago, IL, USA) for Windows was used for the statistical analyses. Mann-Whitney test was used to compare postoperative complications between the MO group and CWD group. This study was approved by the Institutional Review Board of Inje University Busan Paik Hospital (IRB No.: 2021-02-039-004).

**Surgical procedure**

After general anesthesia with orotracheal intubation, CWUM or CWDM with removal of pathologic tissues in mastoid cavities was done via postauricular incision. Then, tympanomeatal flap was elevated and middle ear pathology was removed, and the status of ossicular chain was checked if needed. In CWD, posterior EAC wall was removed to make sure of the control of diseases such as cholesteatoma or cavity problem due to high facial ridge. Autologous conchal cartilage was harvested and trimmed with blades. The prepared cartilages primarily filled epitympanum and mastoid antrum lining along imaginary border of projected laterally from facial nerve starting at 2nd genu.

In MO group, bone allograft product (coarse cancellous; Maxxeus®, Kettering, OH, USA) is crushed into particles about 3 mm of diameter (Fig. 1A-D). After then, the remaining spaces after cartilage insertion were filled with the crushed bone allografts (Fig. 1E and F). Also, epitympanoplasty with mastoid obliteration (EMO) was performed as described in pre-
vious reports [2,13]. In CWD group, the remaining spaces after cartilage insertion were filled with inferiorly-based mucoperiosteal flap.

Tymanoplasty with or without ossicular reconstruction using titanium prosthesis was followed, and temporalis fascia covered the neo-EAC wall not to expose placed cartilage or bone allograft. Operation ended with EAC packing with nylon gauzes and external dressing in compressive mode.

Review of medical records

We retrospectively investigated the records of all subjects including findings of operation, pure tone and speech audiograms, recidivism of cholesteatoma, state of TM and EAC, cavity problems, otorrhea, and postoperative complications. Grade 2 or 3 otorrhea is considered to be present during outpatient department visit according to a previous report [14]. Audiologic results were reported according to the guidelines suggested by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology-Head and Neck Surgery [15].

Results

Patient characteristics

The patient characteristics are shown in Table 1. A single surgeon (K.W.H.) performed all operations for the same indications except for cases with labyrinthine fistula. The patients who received surgery between July 2016 and January 2021 were MO group, and the patients who received surgery between January 2013 and June 2016 were CWD group. During the study period, there were 21 patients with 23 ears (9 males with 10 ears and 12 females with 13 ears) in MO group and 52 patients with 53 ears (24 males with 24 ears and 28 females with 29 ears) in CWD group (Table 2). There was no significant difference in demographics between the two groups including sex and age (p>0.1).

In MO group, 9 of the 23 ears received primary surgery and the rest did revision surgery. The mean postoperative follow-up duration was 38.9 months (range: 13–65 months). Preoperatively, posterior EAC wall was preserved in 18 of 23 ears, and 11 of them had history of past mastoidectomy. They received revisional mastoidectomy with MO using additional bone allografts, 5 of them did CWDM and the rest 13 did CWUM. CWDM and MO using additional bone allografts were performed for 5 of 18 ears with preoperative intact EAC wall and the rest 13 ears sustained the EAC wall after the surgery. There were 16 ears with cholesteatoma and 7 with chronic otitis media (COM) or adhesive otitis media (adhOM).

In CWD group, 25 of the 53 ears received primary surgery and the rest did revision surgery. The mean postoperative follow-up duration was 39.2 months (range: 12–80 months). Preoperatively, posterior EAC wall was preserved in 21 of 53 ears, and 9 of them had history of past mastoidectomy. There were 32 ears with cholesteatoma and 21 with COM or adhOM.

Case 4

A 61-year-old female patient visited our department with complaints of recurrent discharge and hearing disturbance for 5 months in right ear and had history of receiving simple mastoidectomy with type I tympanoplasty at another institute 11 years ago (Fig. 2). Her right TM showed central large perforation and there were mucoid discharge and fungal material at EAC. Preoperative pure tone audiogram revealed mixed hearing loss with 100% of speech discrimination score (SDS) and temporal bone CT did previous mastoidectomy-mized state. After oral medication and topical otic drops for 2 weeks to control active infection, the patient underwent revisional EMO using autologous cartilage and bone allografts. Twenty-four months later, postoperative findings showed well-reconstructed superior wall of EAC and intact TM, improved hearing, and stable obliterated site with bone allograft.

Comparison of preoperative and postoperative hearing between groups

In MO group, preoperative pure tone audiograms (mean±SD) showed that air conduction threshold (ACT), air-bone gap (ABG), and SDS were 66.0±22.2 dB, 32.4±13.7 dB, and 93.1%±14.0%, respectively. Postoperative results were 58.4±

<table>
<thead>
<tr>
<th>Table 1. Patient demographics according to group</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO group</td>
</tr>
<tr>
<td>Number of patients (male:female)/ears</td>
</tr>
<tr>
<td>Age (yr), mean (range)</td>
</tr>
<tr>
<td>Follow-up duration (month), mean (range)</td>
</tr>
<tr>
<td>Primary surgery : revision surgery</td>
</tr>
<tr>
<td>Preop, EAC wall, preserved : defective (ears with history of mastoidectomy)</td>
</tr>
<tr>
<td>Diagnosis (cholesteatoma : non-cholesteatoma)</td>
</tr>
</tbody>
</table>

MO, mastoid obliteration; CWD, canal wall down; Preop, preoperative; EAC, external auditory canal.
Bone Allografts for Mastoid Obliteration

25.5 dB of ACT, 25.3±12 dB of ABG, and 92.3±16.3% of SDS. There was decreasing tendency of postoperative ABG compared to preoperative ABG without statistical significance (p=0.0682), and there were no statistical difference between pre- and postoperative ACT and SDS (p>0.1).

In CWD group, preoperative pure tone audiograms as the mean±SD showed that ACT, ABG, and SDS were 69.3±25.8 dB, 35.6±15.2 dB, and 85.5±16.1%, respectively. Postoperative results were 60.7±27.1 dB of ACT, 29.1±14.6 dB of ABG, and 85.1%±14.0 % of SDS. There was statistically significant difference between pre- and postoperative ABG (p=0.0269), and there were no statistical difference between pre- and postoperative ACT and SDS (p>0.1).

Comparison of preoperative and postoperative complications between groups

There was no case of cholesteatoma recurrence in both groups. In MO group, TM perforation, TM adhesion, and retraction pocket occurred in 1, 1, and 2 case for each (Table 3). There was no case showing otorrhea from cavity problem or extrusion of bone allografts. The total complication rate was 17.4% (4 of 23 ears). In CWD group, the most common postoperative complication was otorrhea including cavity problem which were found in 5 cases. Retraction pocket occurred in 3 cases. Also, TM perforation, TM adhesion, and prosthesis extrusion occurred in 2 cases for each. There was 1 case with postauricular infection. The total complication rate was 28.3% (15 of 53 ears). The total complication rate in MO group

Table 2. Medical and perioperative findings in MO group

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Sex</th>
<th>Age (yr)</th>
<th>Diagnosis</th>
<th>Chief complaint</th>
<th>Revision</th>
<th>Preop complication</th>
<th>Operation name</th>
<th>Postop FU DR (mo)</th>
<th>Preop complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>19</td>
<td>Lt. EAC Chole Mastoiditis</td>
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<td>Yes</td>
<td>bEAC partial loss</td>
<td>EMO T3, meatoctomy</td>
<td>67</td>
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<td>2</td>
<td>F</td>
<td>60</td>
<td>Lt. rec Chole</td>
<td>Otorrhea, HD</td>
<td>Yes</td>
<td>bEAC loss E-C fis</td>
<td>EMO T3</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>3L</td>
<td>F</td>
<td>49</td>
<td>Lt. COM</td>
<td>Otorrhea, HD</td>
<td>No</td>
<td>bEAC loss E-C fis, LSCC fis</td>
<td>CWDM T3</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>61</td>
<td>Rt. rec COM</td>
<td>Otorrhea, HD</td>
<td>Yes</td>
<td>Eustachian tube fracture</td>
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<td>59</td>
<td>TM perforation</td>
</tr>
<tr>
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<td>F</td>
<td>59</td>
<td>Rt. Chole</td>
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<td>Yes</td>
<td>bEAC loss</td>
<td>EMO T4</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>37</td>
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<td>HD</td>
<td>Yes</td>
<td>-</td>
<td>EMO T3</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>26</td>
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<td>-</td>
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<td>52</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>53</td>
<td>Lt. rec COM</td>
<td>Otorrhea, Tinnitus</td>
<td>Yes</td>
<td>bEAC loss</td>
<td>CWDM T4</td>
<td>47</td>
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<tr>
<td>9</td>
<td>F</td>
<td>25</td>
<td>Rt. rec Chole</td>
<td>Otalgia, HD</td>
<td>Yes</td>
<td>-</td>
<td>EMO T3</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>60</td>
<td>Lt. rec Chole</td>
<td>Otorrhea, HD</td>
<td>Yes</td>
<td>bEAC loss</td>
<td>Radical M</td>
<td>43</td>
<td></td>
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<tr>
<td>11L</td>
<td>M</td>
<td>59</td>
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<td>Otorrhea, HD</td>
<td>No</td>
<td>LSCC fis</td>
<td>CWDM T4</td>
<td>34</td>
<td>Adhesion</td>
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<tr>
<td>11R</td>
<td>M</td>
<td>59</td>
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<td>Otorrhea, HD</td>
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<td>-</td>
<td>EMO T3</td>
<td>31</td>
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</tr>
<tr>
<td>12</td>
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<td>Otorrhea, HD</td>
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<td>-</td>
<td>Radical M</td>
<td>34</td>
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<tr>
<td>13</td>
<td>F</td>
<td>76</td>
<td>Rt. Chole</td>
<td>Otalgia, HD</td>
<td>No</td>
<td>-</td>
<td>Radical M</td>
<td>33</td>
<td></td>
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<tr>
<td>14</td>
<td>F</td>
<td>54</td>
<td>Rt. Chole</td>
<td>HD</td>
<td>No</td>
<td>Skull base defect</td>
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<td>M</td>
<td>10</td>
<td>Lt. rec Chole</td>
<td>HD</td>
<td>Yes</td>
<td>-</td>
<td>CWDM T4</td>
<td>32</td>
<td></td>
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<tr>
<td>16</td>
<td>M</td>
<td>45</td>
<td>Rt. rec Chole</td>
<td>HD, dizziness</td>
<td>Yes</td>
<td>Stapes loss</td>
<td>EMO T0</td>
<td>28</td>
<td></td>
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<tr>
<td>17</td>
<td>F</td>
<td>57</td>
<td>Lt. Chole</td>
<td>Otorrhea, HD</td>
<td>Yes</td>
<td>E-C fis</td>
<td>EMO T4</td>
<td>23</td>
<td></td>
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<tr>
<td>18</td>
<td>F</td>
<td>72</td>
<td>Lt. rec COM</td>
<td>HD, dizziness</td>
<td>Yes</td>
<td>-</td>
<td>CWUM T1</td>
<td>18</td>
<td></td>
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<tr>
<td>19</td>
<td>M</td>
<td>54</td>
<td>Rt. rec COM</td>
<td>Otalgia, HD</td>
<td>Yes</td>
<td>bEAC loss</td>
<td>CWDM T4</td>
<td>18</td>
<td></td>
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<tr>
<td>20</td>
<td>M</td>
<td>35</td>
<td>Rt. rec Chole</td>
<td>HD</td>
<td>Yes</td>
<td>-</td>
<td>EMO T3</td>
<td>15</td>
<td></td>
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<tr>
<td>21</td>
<td>M</td>
<td>22</td>
<td>Lt. rec Chole</td>
<td>HD</td>
<td>Yes</td>
<td>-</td>
<td>EMO T3</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

MO, mastoid obliteration; Preop, preoperative; Postop, postoperative; FU, follow-up; DR, duration; EAC, external auditory canal; Chole, cholesteatoma; COM, chronic otitis media; HD, hearing disturbance; bEAC, posterior wall of bony EAC; E-C fis, fistula between EAC and postauricular skin; LSCC fis, labyrinthine fistula at lateral semicircular canal; EMO, epitympanoplasty with mastoid obliteration; CWDM, canal wall down mastoidectomy; CWUM, canal wall up mastoidectomy; itch, itching; rec, recurrent or residual; T3, type III tympanoplasty; T4, type IV tympanoplasty; T1, type I tympanoplasty; T0, tympanization; M, mastoidectomy; TM, tympanic membrane.
showed decreasing tendency compared to CWD group ($p = 0.0658$).

### Discussion

Poor pneumatization of mastoid cavities, which could be correlated with decreased function of Eustachian tube, is known to be related to recurrence of middle ear pathology [16,17]. Also, reduction of air-containing space by exclusion of mastoid cavities, usually achieved by CWUM or CWDM accompanied by MO, seems to minimize this problem and enhance successful result of middle ear surgery [18,19].

After operation for chronic ear lesions, otorrhea would happen due to abnormal TM structure like perforation or atelectasis, reinfection of middle ear, recurrent or residual cholesteatoma, or cavity problems after a CWD procedure [20,21]. CWDM could occasionally result in intermittent debridement, water intolerance, calorically induced vertigo, and the inability to wear a hearing device due to the large mastoid cavity. It would be additionally infected by continuous moisture and bacterial growth [2,21]. To overcome these problems, MO using various materials has been attempted since the early 20th century [22].

To be an outstanding filler material for MO, it should be sustained in volume with time, resistant to infection, and effortless to use in cases of primary or revision surgery [11]. Since 1911, surgeons had tried to use pedicle flaps containing muscles, subcutaneous tissue, and periosteum for MO resulting in disappointments mainly by progressive reduction of their volume [23-27]. Cartilage for MO has shown its shape and volume for considerable period even if only covered by free soft tissue grafts owing to lower metabolic demands [2,12,13]. On the other hand, there is a crucial limitation about available volume for cartilage to be used for MO [11,12,23]. In this study, we used conchal cartilages to obliterate crucial area including epitympanum and spaces along facial nerve maximally to prevent postoperative problems in spite of volume issue.

Recently, several alloplastic materials, including bioactive glass, nanobone, titanium, polymethyl methacrylate, hydroxyapatite, and polyether ether ketone have been utilized for reconstruction of part of skull, which are free from contamina-
tion by the infection, possible seeding of cholesteatoma, and resorption through life [12,27]. Also, they have bone-bonding capacity, timesaving easiness in handling during surgery, and unlimited supply in amount [12,28,29]. Even with them, possible rejection reaction, protrusion from covering tissues, and additional costs would raise doubts about being used widely with recent reports [11,12,28,30].

Autologous bone has been used for MO in the form of bone chips or bone paste taken from temporal bone under surgery for more than 60 years [25,26]. Usually, bone chips produce the main bulk, and bone paste results in smooth surface covering rough materials with progressive shrinkage as a fatal weakness [11,24,25,31,32]. In MO group of this study, 14 of the 23 ears previously received mastoidectomy and there were scarcely remnant autologous bony tissues around mastoid cavity. To overcome shortage of amount of autologous bone near the temporal bone, iliac crest was used for a while surely causing prolonged operation time and donor site morbidity [31,32].

Homogenous cancellous bone has been harvested from orthopedic surgery for trauma or prosthetic replacement, which was adopted for ear surgery from late 1960s. Shea, et al. [23] reported the use of homogenous bone chips and autogenous bone paste for MO since 1972. They picked out cancellous bone as in this study because mastoid cavity is normally filled with cancellous bone which has superiority for osteogenesis and resistance to infection over cortical bone [12,23]. Also, the homogenous cancellous bone shows similar property in osteoconductivity and osteoinductivity union and fragmented form of them create greater chance to get blood supply and contact with osteocytes [27,33]. Also, commercially available human allogenic graft materials are harvested from bony tissues of cadaveric donor secured by consents and elimination of possible source of infective diseases especially in recent days [34]. Even in the case that grafted homogenous bone fragments for MO are extruded to EAC, the majority of them would keep in position with only a few of them lost [27]. Although they have successfully been used for sinus augmentation and dental surgeries, there are few reports to be applied for ear surgery [27,35].

In this study, we have successfully used bone allografts for MO after mastoidectomy owing to their excellent properties. In MO group, there was no case of otorrhea caused by cavity problem which would often happen after CWDM. There was only tendency of lower complications in MO group in this study. We believe that the small number of enrolled patients would limit statistical power in spite of excellence of bone allografts as MO material. Additionally, there could be selection bias that all subjects in MO group should always have demanded MO maximally because of large volume in targeted mastoid cavity and some subjects in CWD group would have been contrary owing to small mastoid cavity with less necessity to be obliterated.

In conclusion, we performed a retrospective study on the usage of bone allografts for MO after mastoidectomy. There was no case showing shrinking of the grafted bone allograft nor otorrhea after MO, which showed safety and effectiveness of bone allograft as a filler material after mastoidectomy. Further study with larger group would prove the above-mentioned advantage of bone allograft for MO.

Conflicts of Interest
The authors have no financial conflicts of interest.

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