The osseous external auditory canal
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Shape of the osseous external auditory canal and its relationship to troublesome cavities

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ABSTRACT

Background
On the basis of clinical observations, the shape of the osseous external auditory canal (OEAC) has often been seen as an aetiological factor in troublesome cavities after modified radical mastoidectomy.

Methods
To assess the role of the shape of the OEAC in troublesome modified radical cavities using computed tomography (CT) scans of three groups of patients (without pathology and with or without draining cavities), we determined the depth of the pretypanic recess (DPTR) and its anterior curvature (ACPTR). In addition to looking at the shape of the OEAC, we also studied the role of any remaining mastoid air cells in relation to troublesome radical cavities, as well as the consultation frequency.

Results
The DPTR was significantly deeper in draining cavities than in ears without pathology and dry cavities. No difference in the ACPTR was observed. The presence of remaining mastoid air cells is significantly associated with the presence of a troublesome radical cavity.

Conclusion
The shape of the OEAC – in other words, the depth of the pretypanic recess (DPTR) – is a contributory factor to the drainage of modified radical cavities.

Level of evidence: 4

Keywords
Ear canal, Ear disease, Radical Cavity, tomography X-ray computed
INTRODUCTION

Open-cavity mastoidectomy is a common procedure for chronic otitis media (COM) with or without cholesteatoma. However, the resulting radical cavities can be troublesome (1). Self-cleansing mechanisms of the osseous external auditory canal (OEAC) are disrupted, leading to frequent consultations with otorhinolaryngologists (2,3). A multifactorial aetiology has been proposed and revision surgery has proven to be very effective (4-7). Well-known aetiologies of troublesome cavities include a high facial ridge, inadequate meatoplasty, a deep mastoid tip, persistent mastoid air cell tracts and inadequate canalplasty (6), the latter being the focus of this manuscript.

In some series, up to 67% of troublesome cavities are linked to inadequate canalplasty (6). Certain OEAC shapes seem to be involved more frequently than others in the development of chronically inflamed radical cavities. In our opinion and on the basis of clinical observations, it is the variation in the anterior and inferior curvature of the most medial part of the OEAC that explains why some radical cavities develop into troublesome radical cavities [Figure 1]. In the literature, the nomenclature for this area varies from pretympanic sulcus and recess, to tympanic sulcus, pretympanic sinus and inferior tympanic recess. The aim of this study was to examine the role of various pretympanic recess (PTR) dimensions in the development of troublesome radical cavities.

MATERIAL AND METHODS

Participants

We retrospectively identified 107 patients with draining modified radical cavities that were eligible for revision surgery (draining cavity group). Of these 107 patients, 70 were included in the study after the exclusion of patients with bilateral disease (which would have precluded any comparison with the contra-lateral 'normal' side), children (patients < 18 years of age) and patients without adequate CT scans (CT scans performed with the wrong protocol). CT scans were performed as part of regular pre-operative work-up as all patients were scheduled for revision surgery in our tertiary otology referral centre.

Our first control group consisted of CT images of the OEACs of 38 adult patients without a draining modified radical cavity (non-draining cavity group). We identified 76 patients with non-draining modified radical cavities in regular outpatient clinical care over a period of one year. Twenty-four of these 76 patients did not undergo a post-surgery CT scan and, in 9 cases, the CT scan available was not performed using our hospital protocol. Another 5 patients suffered from bilateral disease, leaving us with 38 eligible subjects. All our participants with a cavity had undergone a prior surgery in which the middle ear space was present and the tympanic membrane was reconstructed (modified radical cavity).

The second control group consisted of CT images of the OEACs of 100 randomly selected adult patients (200 ears) scheduled for cochlear implantation ('normal' group). None of
Figure 1. Dimensions of the pretymppanic recess (PTR) in different planes (top row). CT images show two series (A and B) illustrating difficult ACPTTR measurements in radical cavities (all in coronal view). First slide: When the bony anterior wall is complete (series A) or when the anterior bone is level with the umbo (series B; dotted line). Second slide: when the bony annulus is not present (arrow)(not zygomatic (#), epitympanal(*) or hypotympanal/tubal (+) cell tracts).
the patients in the cochlear implantation group had a history of prior ear disease except for their sensorineural hearing loss.

Imaging of the osseous external auditory canal
All CT scans were obtained using 125 mAs and 120 kV with multi-detector row CT scanners (Philips Mx8000 and Philips Brilliance 64). Images were taken parallel to the orbitomeatal line and slide thickness varied slightly between 0.5 mm and 0.6 mm. The thickness interval was 0 mm. The window level was 600 HU and the window width was 3200 HU.

Measurement of the PTR dimensions
The dimensions of the pretypanic recess (PTR) in both ears were assessed as described earlier by our group (8) in all three patient groups. The depth of the PTR (DPTR) was measured in the axial plane. The slide was identified where the inferior part of the OEAC was first entirely visible. The number of slides were counted inferiorly until the PTR was not visible anymore, i.e. complete closure of the area in front of the tympanic membrane. The anterior curvature of the PTR (ACPTR) was measured in the coronal plane and was performed almost similar to the measurement of the depth of the PTR. Using the first slide where the anterior part of the OEAC was completely visible as starting point. The number of slides was counted until the most anterior point next to the drum was reached. Both the depth (DPTR) and anterior curvature (ACPTR) of the PTR of all radical cavity patients were determined ‘blind’. Cavity patients were randomly presented to an observer who did not know whether the cavity was either draining or dry. In radical cavity patients with zygomatic (epitympanic) cell tracts extending a long way in the anterior direction, the starting point of the ACPTR was marked by the first slide, in which the osseous canal extended in a more superior direction than the presumed umbo. In all cases, the bony annulus was used to define the location of the tympanic membrane [Figure 1].

Classification of clinical status and remaining air cell tracts
The frequency of clinical consultation in each year was retrospectively determined for all cavity patients by reviewing the last three years and taking the average number of visits per year. Cavities were classified using the Merchant classification (9). [Table 1] shows this classification. All patients in the draining radical cavity group were Merchant types 2 or 3; all patients in the non-draining radical cavity group were Merchant types 0 or 1. In addition to the Merchant classification, the remaining air cell tracts were scored in all radical cavity patients using CT images. Three areas were defined for the remaining air cell tracts: (1) mastoid air cell tracts (2) supralabyrinthine air cell tracts and (3) the sinodural angle. All areas were scored separately.

Statistical analysis
Statistical analysis was carried out using SPSS 16.0.2 (Chicago, IL, USA). The data were expressed as numbers (%) and means (SD). Normality was checked using the Shapiro-Wilk test. One-way
ANOV A and independent T-tests were performed to check for significant changes between DPTR, the ACPTR of the OEAC, age and clinical visits per year of the participants in the three different groups. Affected and non-affected sides were analysed independently. The left ear in the cochlear implantation group was used as the control group for the affected side and the right ear in the cochlear implantation group was used as the control group for the non-affected side. Chi-square analyses were used to identify differences in the distribution of remaining air cell tracts (location and number) by comparison with the Merchant classification and cavity type (non-draining and draining cavity). In addition, gender distribution between the three groups was evaluated using chi-square testing. Additionally we assessed the difference in ACPTR and DPTR between the condition groups correcting for differences in presence of remaining air cell tracts by multivariable logistic regression. $P$ values of less than 0.05 were considered statistically significant.

### RESULTS

#### Study population

Patient characteristics are listed in [Table 2]. The mean age of the participants was 60 years of age in the control (cochlear implantation) group (range 25 – 88 years, female percentage 41%), 55 years of age in the non-draining cavity group (range 29 – 95 years, female percentage 47%) and 48 years of age in the draining cavity group (range 22 – 80 years). A slight female predominance was observed in the control group (59% females). By contrast, a slight male predominance was observed in both radical cavity groups (53% males in the non-draining cavity group and 63% males in the draining cavity group). This observed difference was statistically significant ($p = 0.02$). A significant difference in age was seen between patients in the ‘normal’ group and patients in the draining radical cavity group ($p < 0.01$) but all other differences in age were non-significant ($p > 0.05$).

Table 1. Merchant classification (9)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>No episode of otorrhea, AND no pus or granulation tissue on otologic exam.</td>
</tr>
<tr>
<td>Grade 1</td>
<td>One episode of otorrhea of &lt;2 weeks’ duration in 3-month period OR no otorrhea but a subjective feeling of wetness in the ear.</td>
</tr>
<tr>
<td>Grade 2</td>
<td>More than one episode of otorrhea in 3 month period, OR an episode of otorrhea lasting more than 2 weeks, OR otologic exam showing localized granulation tissue/pus that was promptly cured with antibiotic drops, curettage, or silver nitrate cautery.</td>
</tr>
<tr>
<td>Grade 3</td>
<td>Constant purulent otorrhea on a daily basis, OR otologic exam showing extensive granulation tissue, OR need for a revision procedure to control infection.</td>
</tr>
</tbody>
</table>
The non-draining cavity group included 31 patients with a Merchant type 0 cavity and 7 patients with a Merchant type 1 cavity. The draining cavity group included 21 patients with a Merchant type 2 cavity and 49 patients with a Merchant type 3 cavity.

As for the frequency of clinical consultation, an additional 26 patients in the draining radical cavity group and 3 patients in the non-draining radical cavity group were excluded from analysis because of insufficient data about follow-up and/or insufficient time prior to operation (because of direct referral for surgery). In the draining cavity group, an average of 4 (median 3) visits per year (range 1 to 12 visits per year) was observed. In the non-draining cavity group, an average of 1 (median 2) visit per year (range 1 to 5 visits per year) was observed. This difference was statistically significant (p < 0.001).

### Table 2. Patient characteristics

<table>
<thead>
<tr>
<th></th>
<th>Normal N (%)</th>
<th>Wet cavity N (%)</th>
<th>Dry cavity N (%)</th>
<th>P-value t-test or chi-square (Anova)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N =</td>
<td>100</td>
<td>70</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Median age (y)</td>
<td>60</td>
<td>48</td>
<td>55</td>
<td>&lt;0.01 (&lt;0.001)</td>
</tr>
<tr>
<td>Male:female</td>
<td>41 : 59</td>
<td>44 : 26</td>
<td>20 : 18</td>
<td>0.02 (0.01)</td>
</tr>
<tr>
<td>Number of clinical visits/year</td>
<td>N/A</td>
<td>3</td>
<td>2</td>
<td>&lt;0.001 (N/A)</td>
</tr>
<tr>
<td>Remaining air cell tracts</td>
<td>N/A</td>
<td>65</td>
<td>15</td>
<td>&lt;0.001 (N/A)</td>
</tr>
</tbody>
</table>

**Regions affected**

- **Sinodural angle**
  - N/A 40 6
  - P-value: 0.54 (N/A)
- **Mastoid tip**
  - N/A 61 9
  - P-value: 0.54 (N/A)
- **Supralabyrinthine area**
  - N/A 46 11
  - P-value: 0.54 (N/A)

**Regions involved**

- **0**
  - N/A 5 23
  - P-value: <0.001 (N/A)
- **1**
  - N/A 18 7
  - P-value: <0.001 (N/A)
- **2**
  - N/A 12 5
  - P-value: <0.001 (N/A)
- **3**
  - N/A 35 3
  - P-value: <0.001 (N/A)
Differences in DPTR and ACPTR between the groups

As for the dimensions of the pretympanic recess, the DPTR was found to range between 0 and 6 mm in the control (cochlear implantation – ‘normal’) group. In the non-draining and draining radical cavity groups the DPTR ranged from 0 to 6 mm and 0 to 8.3 mm respectively. The average DPTR in the control group was 2.2 ± 1.4 mm. In the non-draining radical cavity group it was 2.1 ± 1.8 mm. A DPTR of 2.9 ± 1.7 mm was observed in the draining radical cavity group [Figure 2]. The difference in DPTR between draining radical cavities and non-draining radical cavities was statistically significant (p = 0.04). The same holds true for the comparison between draining radical cavities and the ‘normal’ control ears (p = 0.005). The significant difference between the DPTR of patients with draining and non-draining radical cavity groups disappeared when the comparison was made with the non-affected side (p = 0.18). When comparing the non-affected side of patients with a draining radical cavity with ‘normal’ control ears, however, we still observed a significant difference in DPTR (p = 0.03).

In the ‘normal’ control ears, the average ACPTR was 2.2 ± 0.9 mm (range 0 to 5.0 mm). In non-draining radical cavities, the ACPTR was 2.4 ± 1.1 mm (range 0 to 4.2 mm). In draining radical cavities, on the other hand, the ACPTR was 2.2 ± 0.9 mm (range 0 to 4.4 mm) [Figure 2]. No significant difference in the ACPTR was observed when the affected ears were compared (all p > 0.3). Nevertheless, a significant difference was seen in the non-affected ears of the two radical cavity groups. In these groups, the ACPTR in non-affected ears was significantly more pronounced than in ‘normal’ controls (p = 0.03 and p < 0.01 respectively). No significant difference was observed when these two groups were compared (p = 0.53).

Differences in remaining air cell tracts between the groups

We observed remaining air cell tracts in 15/38 patients (39.5%) in the non-draining radical cavity group. Remaining air cell tracts were observed in one area in 7 of these 15 patients (47%), in two regions in 5/15 cases (33%) and in all three areas in 3/15 patients (20%). Eleven of these 15 patients (73%) had remaining air cell tracts in the supralabyrinthine area, 9/15 (60%) in the mastoid tip area and 6/15 (40%) in the sinodural angle.

In the draining radical cavity group, remaining air cells tracts were found in 65/70 patients (93%). Eighteen of these 65 patients had remaining air cell tracts located in one area (28%), 12/65 in two areas (18%) and 35/65 in all three areas (54%). The difference between the two radical cavity groups in terms of remaining air cell tracts was statistically significant (p<0.001). Sixty-one of 70 patients (94%) in the draining radical cavity group had remaining air cell tracts in the sinodural angle area. There was involvement of the supralabyrinthine air cell tracts in 46/70 patients (71%) and involvement of cells in the sinodural angle area in 40/70 patients (62%). The difference in the affected remaining air cell tracts between the two radical cavity groups was not statistically significant (p = 0.54). Similar results were observed when the Merchant classification was compared with the presence or absence of remaining air cell tracts in the two groups.

The multivariable logistic regression showed no significant association between ACPTR and the cavity condition corrected for the presence of remaining air cell tracts (OR 0.75; 95
CI 0.46 to 1.23; p=0.26 ). The association between DPTR and the cavity condition corrected for the presence of remaining air cell tracts was statistically significant (OR 1.47; 95% CI 1.08 to 2.02; p=0.02). This result implicates that with each 1 mm increase in DPTR, the odds that a cavity will become a draining cavity instead of a dry cavity is about 1.5 times higher.

Figure 2. Averages and 95% confidence interval of DPTR and ACPtr compared between normal, dry cavity and draining cavity groups are depicted. Both affected and contralateral ear are shown separately. (*: significant difference, p<0.05; NS: no significant difference)
DISCUSSION

This study demonstrates that the shape of the osseous external auditory canal (OEAC) is a contributory factor to a draining radical cavity. Our hypothesis that the PTR is an important area of the OEAC and is therefore involved in the development of a draining radical cavity is strengthened. This result suggests that the pathophysiology of the chronically draining cavity may resemble the pathophysiology of chronic OE in some patients since a previous study by our group demonstrated that an increased DPTR is also correlated with therapy-resistant otitis externa (OE) (8). We postulate that regular clinical cleaning and the self-cleansing ability of the cavity is hampered by a deep PTR. Another possibility could be that intertriginous eczema can arise as sharper angles enable skin-to-skin contact when inflamed, thus perpetuating the inflammation and leading to chronic disease. As the 95% confidence intervals for the DPTR in all three groups (control group of cochlear implant patients, non-draining radical cavity patients and draining radical cavity patients) overlap, we cannot state with certainty that a certain depth of the DPTR is predictive for the development of a draining radical cavity, but a depth exceeding 2.7 mm is certainly not beneficial (this number exceeds the 95% confidence interval for non-draining radical cavities). The fact that no significant difference in ACPTR was observed concurred with the results of the above OE study (8).

In addition to the shape of the pre tympanic recess, this study confirms that the presence of remaining air cell tracts is another important contributory factor in the development of a draining cavity. Other well-known contributory factors - an inadequate meatoplasty and/or high facial ridge, for example - were not studied since there are no objective and adequate measurement techniques. Although our multivariable logistic regression showed that the DPTR is a contributing factor regardless of the remaining air cell tracts these other etiologies should be considered as well.

Patients with draining cavities need more frequent clinical consultations (in other words, several appointments every year) than patients with non-draining cavities. This result is in line with the patient perception of the burden associated with a draining cavity. Nevertheless, no hard conclusions can be drawn about these results given the inclusion bias resulting from the selection of draining cavities for operation and the short follow-up period. In addition, gaps in the data undermine these results.

This study included only patients with a unilateral cavity. As a result, we were able to use the contra-lateral non-affected ear as the possible 'pre-operative' condition since individual’s ears are intra-individually correlated (8). Unexpectedly, a significantly different ACPTR was observed in the contra-lateral non-affected ear in the two cavity groups and in the control (cochlear implantation) group. One could speculate that the presence of a more pronounced ACPTR is associated with the development of pathology (cholesteatoma) or that a cavity was drilled because of limited visibility in the anterior direction (in other words, a canal wall up procedure may suffice in patients with cholesteatoma with smaller ACPTR).
The inclusion of unilateral cases only in this study was intended to simplify the evaluation of our data since including both ears would have precluded a non-paired analysis given the fact that including both ears of single individuals results in paired observations.

Due to the limited number of participants in some groups, meaningful sub-analyses of cavities with and without remaining air cell tracts in both non-draining and draining cavity groups was not feasible. An analysis of this kind would be desirable in order to show whether the localisation of the remaining air cell tracts play a role at all.

As the analysis of data based on the groups defined as wet and dry cavities on the one hand, and the individual grades of Merchant groups on the other, did not produce different results, we feel confident in stating that combining types 0 and 1 and types 2 and 3 is reasonable and that a combination approach of this kind could be adopted in future research.

Our study was retrospective in nature and so conclusions will always be subject to bias. To exclude bias as much as possible, CT scans were blinded before the dimensions of the PTR were assessed.

One could argue that we should have included children in our study as the presence of cavities is not limited to the adult population. However, because it is still not known how PTRs develop during childhood, we decided to exclude all children from the present study. Future studies should look to study the development of PTRs during childhood and to determine whether the shape of the PTR is involved in draining cavities in children as well.

Studies in the future should focus on the clinical implications of our current findings. A better clinical outcome could be possible in patients with deep PTRs and draining cavities after OEAC shape has been adjusted with a canalplasty. In that case, the OEAC should be reduced to an extent that is adequate to offset the deep DPTR (that is to say, to less than 2.7 mm). If correcting the depth of the DPTR leads to better results, this would further support our hypothesis, and also justify the conclusion that the treatment (revision surgery, for example) of troublesome cavities should take both the depth of the pretymppanic recess and remaining air cell tracts into account.

CONCLUSION

To our knowledge, this is the first paper to supply evidence that the shape of the osseous external auditory canal is significantly associated with the presence of a draining modified radical cavity. PTR depth is particularly important. Although it is more pronounced in the non-affected ears of all radical cavity patients, the ACPTR seems not to be involved in the development of draining modified radical cavities. Remaining air cell tracts were present significantly more often in draining modified radical cavities than in non-draining radical cavities. Further research to determine the importance of this association in the multi-aetiological problem of the troublesome cavity is warranted.
REFERENCE LIST