Determination of variations in temporal bone anatomical distances in CSOM and non-CSOM patients using computed tomography and intraoperative patient analysis

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Abstract. Tympanomastoidectomy surgery for chronic suppurative otitis media (CSOM) requires an understanding of the 3-dimensional anatomic structures of the middle ear. Although these structures can be evaluated radiologically, differences between CSOM and non-CSOM patients have not yet been determined, and the agreement between preoperative and intraoperative measurements has not been evaluated. This cross-sectional study was conducted at Cipto Mangunkusumo Hospital, Jakarta, Indonesia. The aim of this study was to evaluate differences in the temporal bone distances between CSOM and non-CSOM patients using computed tomography (CT) data from 30 consecutive cases and to evaluate the agreement between temporal bone distances measured using CT and intraoperative microscopy in 5 consecutive CSOM patients within a 9-month period. CSOM patients had smaller distances from the superior wall of the ear canal to two points on the tegmen, as well as a more acute sinodural angle and narrower aditus ad antrum. There was a good agreement between the temporal bone CT and intraoperative measurements of the distance from the posterior wall of the ear canal to the sigmoid sinus.

1. Introduction
Chronic suppurative otitis media (CSOM) is a chronic infection of the middle ear characterized by purulent secretion for more than 8 weeks, which may be continuous and can be exacerbated by perforation of the tympanic membrane [1,2]. Patients with this condition are generally subjected to computed tomography (CT) or magnetic resonance imaging (MRI) of the mastoid via Schuller's view to evaluate the temporal bone disorder. However, this modality is considered poorly sensitive (35%) and is complicated by the overlapping structures in this area, which makes it difficult to identify important elements. CT of the temporal bone provides high-resolution images in which specific temporal bone structures can be determined more easily, compared with plain radiography images. Accordingly, CT provides better image data corresponding to bony and soft tissues and air. In patients with CSOM, preoperative CT is particularly useful for identifying anatomic variations or pathologic
anomalies that might endanger the patient, as well as for surgical planning to avoid iatrogenic injury [3-10].

Currently, CSOM can be treated by tympanomastoidectomy, a surgical procedure requiring deep knowledge about the 3-dimensional anatomy surrounding the surgical target. Several parameters and features must be determined, including the distance between the ear canal superior wall and tegmen, distance between the ear canal posterior wall and sigmoid sinus (SS), the sinodural angle, and the aditus ad antrum. Notably, patency of the latter a requirement for successful tympanomastoidectomy. These structures may be affected by infection; for example, in adolescent patients, middle ear infection blocks the mastoid air cell which in turn affects the mastoid pneumatization and mastoid bone sizes [6,11-14]. According to Swartz et al. [12], the effect of otitis media on mastoid air cell growth depends on the duration of exposure to the infection. Regarding additional structures, Sirikci et al. reported that the distance from Henle's spine to the SS was significantly shorter in the mastoid of a CSOM patient, compared with a mastoid from a healthy control [15].

Intraoperative microscopic measurements require the use of tools such as the digital microscope Dino-lite®, which is set on the operating microscope and linked to a computer. Accordingly, intraoperative images can be saved and processed using software to determine measurements and perform calibration. This tool has several advantages, including the ability to obtain highly precise measurements (sizes <1 mm) and to measure angles, diameters, and even irregular surface areas [16]. These benefits have led to the wide use of this tool. For example, Rodriguez et al. measured the middle ear structure during cochlear implant surgery, while and Shinohara et al. measured the diameter of the Vesalius foramen (on the lateral side from the sphenoid bone) [17,18].

To date, no reports have discussed variations in the anatomic structures of the temporal bone between CSOM and non-CSOM patients using CT measurements. Similarly, no studies have evaluated agreement between the measurements obtained between preoperative CT and intraoperative imaging in CSOM patients at the Dr. Cipto Mangunkusumo National Central General Hospital. Therefore, this study aimed to determine differences in the measurements of several temporal bone structures via computed tomography (CT) between CSOM and non-CSOM patients and compared the preoperative CT and intraoperative measurements in CSOM patients. This study also included an analysis of the characteristic clinical symptoms exhibited by CSOM patients, including the otore duration history and frequency.

2. Methods
This cross-sectional study comprised 2 research projects, which had been approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Indonesia-Cipto Mangunkusumo Hospital. The first project aimed to determine differences in the CT-determined temporal bone anatomic structure between CSOM and non-CSOM patients. The second project aimed to assess the agreement between preoperative CT and intraoperative measurements of the temporal bone structure in a sample of CSOM patients. The research was conducted in the Department of Otolaryngology, Faculty of Medicine, Universitas Indonesia and Cipto Mangunkusumo Hospital, Jakarta, Indonesia in collaboration with the Radiology Department of the same institution. The research was conducted from July 2012 until the target number of research samples was met (April 2013).

For CSOM and non-CSOM patients, the inclusion criterion was high-resolution non-contrast CT of the temporal bone using the bone setting and a 1-mm slice thickness. The exclusion criteria included previous tympanomastoidectomy, destruction of the superior or posterior wall of the ear canal visible on imaging, or an anomaly (e.g., congenital, tumor, or trauma). CT data were collected consecutively until 30 CSOM and 30 non-CSOM patients had been included. Data of CSOM patients included in the project to determine the agreement between CT and intraoperative measurements were collected consecutively for 9 months.
As shown in Figure 1, the distance from the posterior wall of the ear canal was measured at 3 tegmens: the first appearance of the facial bridge (scutum) (i.e., 1st tegmen), the most lateral part of the external acusticus canalis the parallel to intracranial section and Henle's spine (i.e., 2nd tegmen), and the midpoint between the 1st and 2nd tegmens (i.e., 3rd tegmen, the larger measurement in non-CSOM samples). The distance between the posterior wall of the ear canal to the sigmoid sinus, the sinodural angle, and the area of the aditus ad antrum were also measured (Figure 1).

### 3. Results

During the study period, 60 samples (30 CSOM and 30 non-CSOM) were obtained from 37 patients for the first part of the study, while preoperative CT and intraoperative measurements were obtained from 5 CSOM patients who met the inclusion criteria. The CSOM sample and non-CSOM samples exhibited similar sex distributions (17 and 13 samples from men and women, respectively). The mean patient age was 38.67 ± 13.11 years, and the largest number of patients were 41–71 years age group. The non-CSOM sample included 15 right ears and 15 left ears, while the CSOM sample included 16 right ears and 14 left ears. In the latter group, 21 cases had been diagnosed with safe CSOM, while 9 samples had been diagnosed with dangerous CSOM. The longest otore duration was >60 months, and the greatest frequency was >6 per years.

Table 1 compares the CSOM and non-CSOM samples with respect to the distance from the superior wall of the ear canal to the tegmen. Notably, the groups differed significantly (p <0.05) in terms of the distances of the superior wall of the ear canal to the 2nd and 3rd tegmens, the sinodural angle, and the area of aditus ad antrum. By contrast, the distances of the superior wall of the ear canal to the 1st tegmen and of the posterior wall to the SS did not differ significantly between the groups (p >0.05).

| Variable | Non-CSOM (n = 30) | CSOM (n = 30) | p     |
|----------|-------------------|---------------|-------|
| Distance of superior wall of the ear canal to 1st tegmen (mm) | 5.51 ± 0.84 | 5.06 ± 0.89 | 0.052 |
| Distance of superior wall of the ear canal to 2nd tegmen (mm) | 8.89 ± 2.75 | 5.76  \(\sim (3.07–11.75)\) | 0.001 |
Table 1. Continue

| Variable | Non-CSOM (n = 30) | CSOM (n = 30) | p |
|----------|-------------------|---------------|---|
| Distance of superior wall of the ear canal to 3rd tegmen (mm) | 6.23 ± 1.45 | 5.13 ± 1.63 | **0.008** |
| Distance of superior wall of the ear canal to the sigmoid sinus (mm) | 14.35 ± 3.38 | 12.63 ± 4.42 | 0.096 |
| Sinodural angle (°) | 76.54 ± 21.6 | 66.4 ± 14.92 | **0.039** |
| Area of aditus ad antrum (mm²) | 39.34 ± 15.2 | 30.24 ± 10.65 | **0.009** |

Furthermore, a tendency toward a reduction in the temporal bone distances among samples from patients with an otore duration >60 months was observed, compared with those with an otore duration <12 months; however, this tendency was not observed for the distance from the posterior wall of the ear canal to the SS. Samples associated with an otore duration of 12–60 months had larger distances of the superior wall of the ear canal to the 2nd tegmen and of the posterior wall of the ear canal to the SS. Furthermore, we observed a tendency toward a reduction in the temporal bone distances among samples from patients with an otore frequency >6x/year, compared with those with a frequency of 1–3x/year; however, this tendency was not observed for the distance of the superior wall of the ear canal to the 1st tegmen. Samples associated with an otore frequency of 4–6x/year had greater distances of the superior wall of the ear canal to the tegmen, the posterior wall of the ear canal to the SS, and a greater sinodural angle, compared with those with an otore frequency of 1–3x/year.

In an analysis by sex, we observed insignificant differences (p >0.05) between men and women in terms of the distances of the superior wall of the ear canal to the 1st and 3rd tegmen points, distance of the posterior wall of the ear canal to the SS, the sinodural angle, and the area of the aditus ad antrum. However, the distance of the superior wall of the ear canal to the 2nd tegmen point differed significantly between men and women (p = 0.007) (Table 2). An analysis stratified by ear side found no significant differences in these measurements (Table 3).

Table 2. Comparison of temporal bone structural differences by sex among non-CSOM samples.

| Variable          | Distance to 1st tegmen (mm) | Distance to 2nd tegmen (mm) | Distance to 3rd tegmen (mm) | Distance to sigmoid sinus (mm) | Sinodural angle (°) | Area of aditus ad antrum (mm²) |
|-------------------|-----------------------------|------------------------------|-----------------------------|-------------------------------|---------------------|-------------------------------|
| **Men** (n = 17)  | 5.56 ± 0.77                 | 10.03 ± 2.19                | 6.23 ± 1.45                 | 14.76 ± 3.15                  | 77.57 ± 14.96       | 41.99 ± 17.37                 |
| **Woman** (n = 13)| 5.09 ± 4.41 (4.41–7.23)     | 7.4 ± 2.76                  | 6.22 ± 1.49                 | 13.82 ± 3.72                  | 75.18 ± 28.74       | 35.87 ± 11.54                 |
| p                 | 0.451                       | **0.007**                   | 0.99                        | 0.458                         | 0.788               | 0.282                         |

^ Median Score
Table 3. Comparison of temporal bone structural differences by ear side among non-CSOM samples.

| Variable                                      | Distance to 1st tegmen (mm) | Distance to 2nd tegmen (mm) | Distance to 3rd tegmen (mm) | Distance to sigmoid sinus (mm) | Sinodural angle (º) | Area of aditus ad antrum (mm²) |
|-----------------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------|-------------------------------|
| Right Ear (n = 15)                            | 5.5 ± 0.88                  | 8.75 ± 2.67                 | 6.45 ± 1.24                 | 14.15 ± 3.33               | 77.88 ± 23.38       | 37.03 ± 13.48                |
| Left Ear (n = 15)                             | 5.52 ± 0.82                 | 9.02 ± 2.91                 | 6.0 ± 1.64                  | 14.55 ± 3.52               | 75.19 ± 20.4        | 41.65 ± 16.9                 |
| Sinodural angle (º)                           | 55.18 ± 54.46 – 72.01       | 87.31 ± 45.34 – 94.82       |                            |                            |                     |                               |

In the second part of the study, we initially validated the Dino-lite® digital microscope, which was used as the intraoperative measurement tool. The initial validation test was performed by measuring 30 distances at increments of 0.5 mm; the distances ranged from 0.45 mm to 14.83 mm. The total measurement error was 3.33% and never exceeded 10%. In the second validation test, 18 angles were measured at increments of 5º; the angle depths ranged from 4.5º to 90º. The total measurement error was 6.11% and never exceeded 10%.

The 5 patients included in this analysis included 2 men and 3 women with a mean age of 38.8 ± 8.47 years old. Here, 4 right ears and 1 left ear were investigated, and 4 and 1 patient had been diagnosed with safe and dangerous CSOM, respectively. The longest otore duration was >60 months, and most had a frequency of >6x/year.

Table 4 presents the results of a Pearson correlation analysis of the distances from the superior wall of the ear canal to the 1st tegmen point measured via preoperative temporal bone CT and intraoperative imaging. This correlation was found to be weak (correlation strength = 0.207) and insignificant (p = 0.739). Although the preoperatively and intraoperatively measured distances of the superior wall of the ear canal to 2nd and 3rd tegmen points exhibited strong correlations (correlation strength = 0.72 and 0.774, respectively), both were insignificant (p = 0.17 and 0.125, respectively). By contrast, the preoperatively and intraoperatively measured distances of the posterior wall of the ear canal to the SS exhibited a very strong and significant correlation (correlation strength = 0.957, p = 0.01). The preoperative and intraoperative measurements of the sinodural angle exhibited an average and insignificant correlation strength (Spearman non-parametric correlation test, r = 0.5, p = 0.391).

Table 4. Analysis of agreement between preoperative CT and intraoperative imaging measurements of temporal bone distances in CSOM samples (n = 5).

| Variable                                      | CT              | Intraoperative | r   | p    |
|-----------------------------------------------|-----------------|----------------|-----|------|
| Distance from the superior wall of the ear canal to the 1st tegmen (mm) | 5.21 ± 0.90     | 4.28 ± 0.81    | 0.207 | 0.739 |
| Distance from the superior wall of the ear canal to the 2nd tegmen (mm) | 5.44 ± 1.26     | 4.08 ± 1.12    | 0.72  | 0.17  |
| Distance from the superior wall of the ear canal to the 3rd tegmen (mm) | 5.36 ± 1.25     | 4.47 ± 0.96    | 0.774 | 0.125 |
| Distance from the posterior wall of the ear canal to the sigmoid sinus (mm) | 8.07 ± 4.62     | 5.78 ± 4.04    | 0.957 | 0.01  |
| Sinodural angle (º)                           | 55.18 ± 54.46 – 72.01 | 87.31 ± 45.34 – 94.82 | 0.5 | 0.391 |

*Median score
4. Discussion
As noted previously, tympanomastoidectomy requires a deep understanding of the 3-dimensional anatomy of the middle ear. In this context, the tegmen is considered particularly important. Here, it serves as a risky border because all mastoidectomy procedures involve opening the antrum, which is topped by the tegmen. Accordingly, injury to this area can cause cerebrospinal fluid leakage, pneumocephalus, brain herniation, or cerebral abscess [9,10]. In our study a significant difference in the distances of the superior wall of the ear canal to the 2nd and 3rd tegmen points between CSOM and non-CSOM samples was observed. By contrast, the distance from the superior wall of the ear canal to the 1st tegmen did not differ significantly between the groups, which was likely due to the origin of embryonic development of the mastoid bones in the area adjacent to the middle ear cavity and mastoid antrum. This development would not have been susceptible to post-natal infection. However, the exact cause of these findings remains unknown [20].

This study further observed no significant difference in the distance from the posterior wall of the ear canal to the SS when we compared CSOM with non-CSOM samples. Whether the location of the SS in the mastoid cavum can be affected by pathologic processes (e.g., CSOM) remains controversial, and several researchers have reported that mastoid pneumatization does not affect this parameter. The sigmoid sinus is a constant structure in the mastoid because it cannot be affected by pathologic process. Shatz and Sade (1990), as quoted by Sarmiento et al. reported a shorter distance of the SS to the ear canal in a patient with sclerotic mastoid pneumatization, and Sirikci et al. reported a significant difference in the distance between the posterior wall of the ear canal to SS in a comparison of non-CSOM samples with safe and dangerous CSOM samples [8-13].

The sinodural angle differed significantly between CSOM and non-CSOM samples. It is noted that no published literature has addressed the sinodural angle. Han et al. [20] reported that the mastoid air cell grows continuously from birth to adulthood and begins in the posterolateral direction from the antrum. Therefore, a middle ear infection in a young person could prevent mastoid air cells, which could affect the mastoid pneumatization, including the mastoid air cells located on the border of the superior fossa media dura mater and the posterior SS (i.e., sinodural angle). This information can be used during tympanomastoidectomy to cleanly remove the pathologic tissue and prevent injury [6,13,21].

The aditus ad antrum is a canal connecting the mastoid cavity with the tympanic cavum. In children and adolescents, this canal can become obstructed by cholesteatoma, thus preventing mastoid cell growth. In the present study, the area of the aditus ad antrum was found to differ significantly between CSOM and non-CSOM samples. Few references in the recent literature have addressed the area of the aditus ad antrum. Long et al. (2012) reported the average width and height of the aditus ad antrum in a sample of 90 non-CSOM patients [22]. That CT-based research indicated that the aditus ad antrum serves as a door-like canal connecting the middle ear and irregular side of the mastoid cavity. Therefore, measurement of the area of the aditus ad antrum would provide a more correct answer [10,12,15,23,24].

In the middle ear, the mastoid air cells serve as an air reservoir, thus preventing negative pressure via air absorption by the middle ear mucosa upon the disruption of Eustachian tube function. This function plays an enormous role in preventing otitis media, given the importance of the aditus ad antrum as a link between the mastoid and middle ear cavities. Our observation of a significant area of the aditus ad antrum in CSOM samples relative to non-CSOM samples is consistent with these functional purposes. A narrow aditus ad antrum could cause the mastoid regio work less optimal as a reservoir, likely due to CSOM [20,25]. Specifically, the reduced area of the aditus ad antrum in CSOM samples might be attributable to irreversible mucosal changes and also the septa thickened mastoid bone that can decrease the air cell lumen. Ruedy, as quoted by Proctor stated that in an infant, otitis media could inhibit pneumatization and cause destruction of the mucosa, which would then be replaced with connective tissue and sclerotic bone [26]. The bony tissue would then target previous areas of osteoblastic activity to form new lamellar bone. Sade, as quoted by Swarts et al. stated that it
remains unknown whether the small mastoid size may cause a genetic predisposition to ear disease or whether otologic disease can disrupt mastoid development [27].

The second part of our analysis investigated the agreement between preoperative CT and intraoperative measurements of the temporal bone in CSOM patients. Notably, the distances from the superior wall of the ear canal to all tegmen points exhibited insignificant correlations, although the distances to the 2nd and 3rd tegmens exhibited high levels of agreement. The weak agreement at the 1st tegmen was likely attributable to the 3-dimensional curvature of this structure. Makki et al. reported that the low lateral position of the tegmen position led to a false assumption of a similar position on the medial side, causing the operator to drill the medial side at the same or a lower height relative to the lateral position [6].

By contrast, the analysis of agreement between the preoperative and intraoperative measurements of the distance from the posterior wall of the ear canal to the SS yielded a very strong level of agreement and a significant result. Although the values differed between the methods, the distances remained consistent. Han et al. reported that the SS in the posterolateral position could be consistently detected via temporal bone CT [20]. In contrast to the narrower and deeper 1st tegmen area, the relatively large, detectable SS allows the operator to confidently perform an optimal bone decimation procedure [8]. We note that in 1 case, the SS was located very near to the posterior wall of the ear canal. Such information is very useful with respect to surgical planning and injury prevention.

Finally, the agreement between the preoperative and intraoperative sinodural angle measurements was evaluated. This analysis yielded an average level of agreement and an insignificant result, consistent with the observation that the intraoperative measurement yielded larger values than the preoperative evaluation. During the process of intraoperative drilling, it can be difficult to identify the true sinodural angle if it is acute or irregular. Accordingly, this could lead to iatrogenic complications, and the intraoperatively determined angle should not be considered the true angle. In a CSOM patient, the 3-dimensional curvature of the dura and imperfect mastoid pneumatization may lead to the formation of a narrow angle [6,20].

This study used intraoperative tools, Dino-lite® and DinoXcope software, to assist with digital microscopy and thus facilitate the measurement process. It is noted that the narrow intraoperative area would limit the area of manipulation for measurement if a ruler or caliper is used. However, the tool provides the necessary calibration for each measurement. Future studies will likely use such tools to assist with high-precision measurements in narrow spaces [16,28].

5. Conclusion
In this comparison of the CT measurements of the temporal bones between 30 samples from CSOM and Non-CSOM ears, only the mean scores of the distance from the superior wall of the ear canal to the 2nd and 3rd tegmens, the sinodural angle, and the area of the aditus ad antrum differed significantly, which may explain the previous lack of detection of the reduced distances in CSOM samples. Notably, both a longer otore duration and increased otore frequency were found to decrease the temporal bone distances measured by CT. Furthermore, the preoperative and intraoperative measurements obtained from 5 CSOM patients exhibited a significantly high level of agreement only for the distance from the posterior wall of the ear canal to the SS.

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