Research Article

Association Of Eustachian Tube Anatomy And Mastoid Pneumatization With Cholesteatoma Extension In Unsafe-Type Chronic Suppurative Otitis Media On Temporal Bone HRCT

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Abstract

Background: Unsafe-type chronic suppurative otitis media (CSOM) with cholesteatoma is a destructive middle ear disease that can give rise to serious complications. The anatomical relationship between the Eustachian tube (ET) and mastoid pneumatization with the degree of cholesteatoma extension remains inconsistent. High-Resolution Computed Tomography (HRCT) of the temporal bone enables evaluation of ET anatomy and assessment of cholesteatoma extension using the STAM score. **Objective:** To analyze the association of ET anatomical parameters and degree of mastoid pneumatization with cholesteatoma extension in patients with unsafe-type CSOM based on temporal bone HRCT. **Methods:** A retrospective cross-sectional analytical observational study was conducted on 59 patients (61 ears) with unsafe-type CSOM and cholesteatoma confirmed intraoperatively at Dr. Soetomo General Hospital Surabaya during the 2023 to 2025 period. Parameters assessed included ET length, pretympanic diameter, ET angle relative to Reid's plane, degree of mastoid pneumatization, and STAM score (0 to 4). Analysis was conducted using correlation tests, group comparisons, K-Means clustering, diagnostic analysis, and interobserver reliability testing. **Results:** The mean ET length was 38.21 ± 3.89 mm, pretympanic diameter 2.93 ± 0.89 mm, and ET angle 29.18 ± 4.27°. Most subjects had pneumatic mastoid (55.7%) and a STAM score of 4 (90.2%). No significant association was found between ET length (p=0.087), pretympanic diameter (p=0.486), ET angle (p=0.304), or mastoid pneumatization (p=0.110) with STAM score. Temporal bone HRCT also showed excellent measurement reliability (ICC 0.954-0.997). **Conclusion:** Eustachian tube anatomical parameters and mastoid pneumatization were not associated with the degree of cholesteatoma extension in unsafe-type CSOM. ET anatomy likely plays a greater role as a predisposing factor for cholesteatoma formation than as a determinant of the extent of its spread. Temporal bone HRCT remains a reliable diagnostic modality with an excellent reliability.

Keywords: Eustachian Tube, Unsafe-Type CSOM, Cholesteatoma, Temporal Bone HRCT, STAM Score, Mastoid Pneumatization

1. Introduction

Unsafe-type (cholesteatomatous) chronic suppurative otitis media (CSOM) is a chronic, destructive middle ear disease that can cause severe complications such as permanent hearing loss, otogenic abscess, and lateral sinus thrombosis. If not treated appropriately, infection can spread to intracranial structures and increase the risk of morbidity and mortality. Studies report that CSOM remains one of the leading causes of hearing disability in developing countries, with an incidence rate of around 1 to 4%, and the cholesteatomatous type accounts for the highest proportion [1]. In several African countries as well as Indonesia, this disease remains a public health problem because it causes conductive hearing impairment as well as life-threatening complications. Therefore, early detection and identification of anatomical factors that influence the development and extension of cholesteatoma carries significant clinical value [2], [3].

In the field of radiology, High-Resolution Computed Tomography (HRCT) of the temporal bone is the standard modality for evaluating unsafe-type CSOM because of its high spatial resolution, which can display the microstructures of the middle ear and mastoid in detail. HRCT not only assesses the extent of cholesteatoma lesions but also allows identification of predisposing factors such as Eustachian tube length and diameter, tube angle relative to Reid's plane, and degree of mastoid pneumatization [4], [5]. Eustachian tube anatomy plays an important role in the function of pressure regulation and clearance of the tympanic cavity. Abnormalities such as a short tube, narrow diameter, or a more horizontal angle can disrupt ventilation and lead to tympanic membrane retraction and keratin accumulation, which ultimately results in cholesteatoma formation [4]. Meanwhile, mastoid pneumatization reflects the air capacity that maintains pressure and aeration of the middle ear; low pneumatization or a sclerotic pattern is often associated with a more aggressive inflammatory process [5], [6].

Several previous studies have assessed the relationship between Eustachian tube and mastoid anatomy and the CSOM disease process. A local study by Herjanto et al. (2023) at Dr. Kariadi General Hospital Semarang reported that sclerotic mastoid pneumatization as well as a narrow Eustachian tube angle and diameter were significantly associated with tympanic cavity abnormalities in CSOM patients, with the degree of pneumatization being the dominant factor [7]. Meanwhile, a study by Taylan Cebi et al. (2024) in Turkey found that CSOM patients had a shorter, more horizontal, and narrower Eustachian tube, but these dimensions were not directly associated with cholesteatoma formation [8]. This difference in results shows that although anatomical factors play a role in CSOM pathogenesis, the relationship between Eustachian tube and mastoid anatomy and the degree of cholesteatoma extension remains inconsistent across populations. Global data show that CSOM incidence reaches hundreds of millions of cases worldwide, with cholesteatomatous CSOM as a clinically significant unsafe type. However, literature that quantitatively evaluates anatomical parameters based on temporal HRCT imaging and their relationship to the degree of cholesteatoma extension remains relatively limited.

Cut-off values for imaging parameters used in clinical practice to this day are largely based on findings from non-Indonesian populations [9], [10]. Differences in demographic and clinical characteristics, as well as variation in equipment and examination technique, may give rise to differences in diagnostic threshold values in the local population. Therefore, determination of local reference values appropriate to the characteristics of the study subjects is needed, along with exploration of anatomical patterns that may characterize subgroups of patients within this population.

Nevertheless, there are two literature gaps that remain unanswered. First, almost all previous studies assessed the relationship between ET anatomical parameters and the presence or absence of disease (a binary dependent variable), rather than with the degree of cholesteatoma extension after its formation (an ordinal dependent variable). Second, quantitative stratification of ET morphology based on HRCT imaging in Southeast Asian populations remains very limited. This study was designed to address both gaps: to assess whether ET anatomical parameters measured on HRCT are associated with the degree of cholesteatoma extension based on area according to the 2017 EAONO-JOS classification, and to identify ET morphological subtypes through a data-driven approach (K-Means Clustering) to enable multidimensional stratification in the Indonesian CSOM cholesteatoma population. It is hoped that this will yield meaningful local reference data as well as a foundation for the development of a more comprehensive and applicable preoperative HRCT evaluation protocol.

To analyze the relationship between variation in Eustachian tube anatomy, comprising length, diameter, and angle, and degree of mastoid pneumatization with the occurrence of cholesteatoma extension in patients with unsafe-type CSOM based on temporal bone HRCT examination at Dr. Soetomo General Hospital Surabaya during the 2023 to 2025 period.

2. Methods

2.1 Type and Design of the Study

This study is an analytical observational study with a retrospective cross-sectional design. In this study, independent and dependent variables from the sample were taken at the same time from medical record data and HRCT examination of patients. This study was planned to be conducted at the Radiology Installation of Dr. Soetomo General Hospital Surabaya.

2.2 Population and Study Sample

The target population in this study is patients with unsafe-type CSOM. The accessible population in this study is the medical records of patients who underwent temporal HRCT procedures at Dr. Soetomo General Hospital

Surabaya during the 2023 to 2025 period. The sample in this study is patients with unsafe-type CSOM who underwent HRCT procedures at Dr. Soetomo General Hospital Surabaya during the 2023 to 2025 period and who met the inclusion criteria and were not included in the exclusion criteria set by the researcher.

2.3 Sampling Technique

In this study, a total sampling technique was used with secondary data from medical records and HRCT examination results for the 2023 to 2025 period. Sample size calculation was performed based on the bivariate correlation formula with an anticipated correlation coefficient estimate of $r_0 = 0.35$, significance level $\alpha = 0.05$ (two-tailed), and power of 80%, yielding a minimum sample size of 58 to 64 subjects.

2.4 Study Variables

In this study, the independent variables examined comprise variation in Eustachian tube anatomy and degree of mastoid pneumatization in patients with unsafe-type chronic suppurative otitis media (CSOM). Variation in Eustachian tube anatomy includes Eustachian tube length, Eustachian tube diameter, and Eustachian tube angle relative to Reid's plane. All of these independent variables were evaluated based on temporal High Resolution Computed Tomography (HRCT) images of the patients. Assessment of these anatomical characteristics was conducted to determine their possible influence on the extent of cholesteatoma spread in unsafe-type CSOM.

The dependent variable in this study is the degree of cholesteatoma extension in patients with unsafe-type CSOM, assessed through temporal HRCT examination. Assessment of the degree of extension was conducted based on involvement of four main anatomical sites according to the STAM system, which forms part of the European Academy of Otology and Neurotology/Japan Otological Society (EAONO/JOS) classification, namely S (sites of difficult access, comprising the tympanic sinus and supratubal recess), T (tympanic cavity), A (attic or epitympanum), and M (mastoid and mastoid air cells). Each STAM site showing soft tissue consistent with cholesteatoma or bone erosion on HRCT was given a score of 1, so that the total score ranges from 0 to 4. The higher the STAM score, the more extensive the anatomical spread of the cholesteatoma. The STAM score was selected as the dependent variable because this system forms part of the 2017 EAONO/JOS classification, which has been internationally recognized for imaging-based preoperative evaluation. In addition, the four STAM components can be assessed consistently through temporal HRCT, although this system has the limitation of a narrow score range and relatively low ordinal resolution.

Confounding variables in this study comprise baseline patient characteristics and comorbid conditions obtained from medical record data. These characteristics include factors that potentially influence disease development as well as the degree of cholesteatoma extension. Analysis of confounding variables was conducted to describe the characteristics of the study subjects and to evaluate the possible relationship of these factors with the abnormalities experienced by patients.

2.5 Study Criteria

The criteria in this study consist of inclusion and exclusion criteria. Inclusion criteria comprise patients with a clinical and radiological diagnosis of chronic suppurative otitis media (CSOM) with cholesteatoma, aged ≥18 years, with complete and interpretable preoperative temporal high-resolution computed tomography (HRCT) data. Meanwhile, exclusion criteria comprise patients with congenital cholesteatoma or external cholesteatoma, patients with a history of prior surgery in the ear, maxillofacial, or sinonasal area, as well as patients with a history of trauma to the ear, craniofacial, or sinonasal area. In addition, patients with poor-quality temporal HRCT images or incomplete examination data were also not included in the study.

The instrument used in this study was a Philips 128-slice computed tomography (CT) scanner, model MRC 880, serial number 14587. This device was used to obtain preoperative temporal HRCT images that were subsequently analyzed according to the study objectives.

2.6 Data Collection Procedure

Data from medical records and temporal HRCT examination results were recorded onto a data collection sheet by the researcher. The data were then entered into Ms Excel (Microsoft Corp.) and followed by a coding process to maintain patient identity confidentiality, then cleared for descriptive and analytical processing using statistical testing.

2.7 Data Analysis and Presentation Technique

Data analysis was conducted descriptively through univariate analysis to describe sample characteristics. Categorical data are presented as frequencies and percentages, while numerical data are presented as mean ± SD or median (minimum to maximum) according to data distribution. Statistical analysis used SPSS 26.0 with the Shapiro-Wilk or Kolmogorov-Smirnov normality test. Associations between variables were analyzed bivariately using appropriate parametric or nonparametric tests, and variables with $p<0.25$ were carried forward to multivariate analysis with a significance level of $p<0.05$ (95% CI). Multivariate analysis used multiple linear regression, ordinal regression, or logistic regression according to data characteristics, with results presented as OR, 95% CI, and p value.

Variation in Eustachian tube anatomy was described based on the 10th and 90th percentiles and was explored using K-Means Clustering after z-score standardization, with the optimal number of clusters determined through the silhouette score. Interobserver reliability was assessed using the Intraclass Correlation Coefficient (ICC) for continuous variables and Cohen's Kappa for categorical variables according to the criteria of Koo and Li (2016) and Landis and Koch (1977) [11], [12].

3. Results

3.1 Subject Selection Flow

The subject selection process was conducted based on the previously established inclusion and exclusion criteria. Based on a search of the radiology database during the study period, a total of 461 temporal HRCT examinations were obtained. All of these data then underwent a screening process according to the established inclusion and exclusion criteria.

A total of 131 examinations were excluded because the patients were aged <18 years, leaving 330 examinations in patients aged ≥18 years. Of this number, 194 examinations were excluded because they were not CSOM with cholesteatoma. This group included safe-type CSOM, otitis media with effusion, adhesive otitis media, malignant otitis externa, tympanosclerosis, mastoid tuberculosis, ear canal granulation tissue, as well as other tumor lesions and non-inflammatory masses. Subsequently, 13 cases were excluded because they were congenital cholesteatoma or external cholesteatoma.

From the remaining cases, 22 cases were excluded because they had a history of surgery in the ear, maxillofacial, or sinonasal area prior to HRCT examination. A total of 6 cases were excluded because of a history of trauma to the temporal or craniofacial area. In addition, 4 examinations were excluded because of unavailable raw data or inadequate HRCT quality for evaluation of the pretympanic area.

Subsequently, based on intraoperative confirmation criteria, 91 cases were obtained that clinically and radiologically supported a diagnosis of CSOM with cholesteatoma (without duplication of medical record numbers). Of these 91 cases, only cases with intraoperative confirmation at our center were included. Initially, 60 patients were obtained, but upon re-evaluation, 2 patients were found whose surgical results did not mention the presence of cholesteatoma, and these were therefore excluded from analysis. A further search was subsequently conducted, and 1 additional patient was found who met all inclusion criteria.

Thus, the final number of study subjects was 59 patients with intraoperatively confirmed CSOM cholesteatoma. Of these 59 patients, 2 patients underwent bilateral surgery (right and left), so that the total unit of analysis (ears) became 61 samples.

3.2 Descriptive Characteristics of Study Subjects

A total of 59 patients (61 ears) were included in the study. The mean age of subjects was 35.80 ± 12.52 years, with the largest age group being 31 to 50 years (44.1%), followed by 18 to 30 years (39.0%) and >50 years (16.9%). Most patients were female (59.3%), while males accounted for 40.7%. Left ear involvement was found in 52.5% of samples and right ear in 47.5%. The majority of patients had no comorbid history (84.7%).

3.3 Bivariate Association Analysis

3.3.1. Kruskal-Wallis Comparative Test. The Kruskal-Wallis comparative test was conducted to compare the distribution of Eustachian tube anatomical parameters and age based on STAM score group (2, 3, and 4). Results are presented in Table 1.

Table 1: Kruskal-Wallis Test Results by STAM Score

Variable	Kruskal-Wallis H	df	p-value	Remark
Age (Years)	1.016	2	0.602	Not Significant
ET Length (mm)	3.014	2	0.222	Not Significant
Pre-Tympanic Diameter (mm)	3.235	2	0.198	Not Significant
ET Angle (degrees)	0.602	2	0.740	Not Significant

All parameters showed no significant difference between STAM score groups (all $p > 0.05$).

3.3.2. Spearman Correlation Test. The Spearman rho correlation test was conducted to assess the relationship between each parameter and the STAM score. Results are presented in Table 2.

Table 2: Spearman Correlation Test Results with Total STAM Score (n = 61)

Variable	Correlation Coefficient (r_s)	p-value	Remark
Age (Years)	0.127	0.330	Not Significant
ET Length (mm)	−0.221	0.087	Not Significant
Pre-Tympanic Diameter (mm)	−0.091	0.486	Not Significant
ET Angle (degrees)	−0.134	0.304	Not Significant
ET Angle (categorized)	0.008	0.953	Not Significant
Mastoid Pneumatization	+0.206	0.110	Not Significant

All Eustachian tube anatomical parameters and mastoid pneumatization showed no significant association with STAM score (all $p > 0.05$). The highest correlation was found for Eustachian tube length ($r_s = -0.221$; $p = 0.087$), which approached the significance threshold without crossing it. The negative direction of correlation indicates a tendency that a longer tube is associated with a lower STAM score, although this association was not statistically significant.

3.3.3. Chi-Square Test for Categorical Variables. A Chi-Square test was conducted to assess the association between categorical variables (sex, comorbid history, and ear laterality) and STAM score. Results are presented in Table 3.

Table 3: Chi-Square Test Results for Categorical Variables with STAM Score

Variable	χ^2	df	p-value	Remark
Gender	0.506	2	0.777	Not Significant
Comorbid History	4.477	2	0.107	Not Significant
Ear Laterality	0.873	2	0.646	Not Significant

No significant association was found between sex, comorbid history, or ear laterality with the STAM cholesteatoma extension score (all $p > 0.05$).

3.3.4. Mann-Whitney Test: Eustachian Tube Angle Category vs STAM Score. Analysis of the association between Eustachian tube angle category (<27 degrees vs ≥27 degrees) and degree of cholesteatoma extension (STAM score) was conducted on 61 ear samples. The Mann-Whitney U test was chosen because of the non-normal distribution of STAM scores (Shapiro-Wilk $p < 0.05$) and a distribution heavily skewed toward the maximum value (ceiling effect). Of 20 subjects with a narrow ET angle (<27 degrees), 18 (90.0%) had a STAM score of 4, with a mean of 3.85 ± 0.49 and a median of 4 (IQR 4 to 4). Of 41 subjects with a non-narrow ET angle

(≥27 degrees), 37 (90.2%) had a STAM score of 4, with a mean of 3.88 ± 0.40 and a median of 4 (IQR 4 to 4). The test results showed no significant difference in STAM score distribution between the two groups ($U = 408.0$; $p = 0.964$). This result leads to acceptance of the null hypothesis, that there is no significant association between Eustachian tube angle categorization (<27 degrees vs ≥27 degrees) and degree of cholesteatoma extension in this study population.

Table 4: Distribution of Association between Eustachian Tube Angle and STAM Score (n = 61)

ET Angle Category	n	STAM 2 n (%)	STAM 3 n (%)	STAM 4 n (%)	Median (IQR)
Narrow (<27°)	20	1 (5.0%)	1 (5.0%)	18 (90.0%)	4 (4-4)
Not Narrow (≥27°)	41	1 (2.4%)	3 (7.3%)	37 (90.2%)	4 (4-4)
Total	61	2 (3.3%)	4 (6.6%)	55 (90.2%)	4 (4-4)

P = 0.964*

Mann-Whitney U test; $U = 408.0$; $\alpha = 0.05$

Description of Eustachian Tube Angle (Continuous):

n = 61 (all data valid); Minimum: 19.11°; Maximum: 47.84°; Range: 28.73°; Mean ± SD: 29.18 ± 4.27°

Distribution of ET Angle Category:

Narrow (<27°): 20 (32.8%); Not Narrow (≥27°): 41 (67.2%)

Additional Test (Fisher's Exact Test):

Odds Ratio (OR): 2.105; p-value: 1.000

3.4 Local Cut-off Based on Percentile (P10 and P90)

For the purpose of operational description and classification within this study population, threshold values for the 10th percentile (P10) and 90th percentile (P90) were determined as relative cut-offs for "low/small" and "high/large." Operational interpretation: a value is categorized as "low" if below P10, and "high" if above P90. The range between P10 and P90 covers the majority of subjects (80% of the study population).

Parameter Anatomi Tuba Eustachius dan Pneumatisasi Mstoid

3.5 Distribution of Mastoid Pneumatization

The distribution of mastoid pneumatization among study subjects is presented in Table 5.

Table 5: Distribution of Mastoid Pneumatization (n = 61)

Mastoid Category	n	%
Pneumatic	34	55,7
Diploic	11	18,0
Sclerotic	16	26,2

The distribution of mastoid pneumatization among study subjects is presented in Table 5. Most ears showed a pneumatic mastoid pattern (55.7%), followed by sclerotic (26.2%) and diploic (18.0%) patterns.

3.6 Anatomical Grouping Analysis Using K-Means Clustering

To identify Eustachian tube anatomical subtypes within this CSOM cholesteatoma population, unsupervised clustering analysis was conducted using the K-Means method. The three variables (length, diameter, angle) were first standardized (z-score). The number of groups (k) was tested from 2 to 6, and selection of the optimal k was based on the highest silhouette score.

The highest silhouette value was achieved at k=3 (0.342), so three clusters were selected as the best grouping solution. The decrease in silhouette at k=4 and beyond indicates that finer grouping did not provide a meaningful increase in separation between groups.

Cluster B is the largest group (55.7%) and is characterized by shorter ET length (36.97 mm), the smallest pretympanic diameter (2.49 mm), and the smallest angle (26.84°), a "small, narrow, flat" pattern. Cluster A (26.2%) shows the highest length and angle (41.51 mm; 33.26°) with diameter close to average, a "long and steep” pattern. Cluster C (18.0%) has a very large pretympanic diameter (4.36 mm, above P90 = 3.96 mm) with moderate length and angle, a “predominantly pretympanic widening” pattern.

3.7 Interobserver Reliability Test

Reliability testing used the Intraclass Correlation Coefficient (ICC) for continuous variables and Cohen’s Kappa for categorical variables.

Table 6: ICC for Continuous Variables

Variable	ICC	95% CI	p	Interpretation
ET Length	0.954	0.837-0.988	<0.001	Excellent
ET Diameter	0.997	0.989-0.999	<0.001	Excellent
ET Angle	0.966	0.873-0.991	<0.001	Excellent
Total STAM Score	0.690	0.144-0.913	0.011	Good

Table 7: Cohen’s Kappa per STAM Site

Site	Kappa	p	Interpretation
Tympanic Sinus	0.615	0.035	Substantial
Tympanic Cavity	0.737	0.016	Substantial
Attic	N/A*	-	Constant
Mastoid	N/A*	-	Constant

*Could not be calculated because the observer gave a constant value (all positive).

3.8 ROC Analysis for Validation of ET Angle Categorization

To validate the internal consistency of ET angle categorization based on the 27° cut-off [7], a Receiver Operating Characteristic (ROC) analysis was conducted using the pROC package in R [13]. The dependent variable was ET angle category (STE_KATEG: <27° vs ≥27°), while the predictor variables were continuous ET angle (STE), ET length (PTE), and pretympanic diameter (DPTE). It is important to emphasize that this ROC analysis does not test predictive ability for STAM score, but rather constitutes an internal validation test of the categorization, that is, how well other anatomical parameters are able to distinguish the narrow ET angle group from the non-narrow group.

The Spearman test between categorical ET angle (STE_KATEG) and continuous ET angle (STE) showed a strong and significant correlation ($r_s = 0.700$; $p < 0.001$), confirming that binary categorization based on the 27° cut-off consistently reflects the underlying continuous variable.

Continuous ET angle (STE) had the highest AUC (0.937), reflecting very good consistency between the continuous variable and its categorization, which is expected since STE is the source variable for STE_KATEG. ET length (PTE) had a moderate AUC (0.688), while pretympanic diameter (DPTE) showed weak discrimination (AUC 0.588). DeLong’s test showed that the AUC for STE differed significantly from PTE ($p = 0.009$) and from DPTE ($p < 0.001$), indicating that the three ET anatomical parameters are independent of one another in their discriminative ability. These findings reinforce the validity of using the 27° cut-off as the ET angle categorization boundary: this categorization is not merely an arbitrary division, but reflects information distinct from other ET anatomical parameters.

3.9 Multivariate Analysis: Could Not Be Performed

Multivariate analysis using ordinal regression (PLUM, logit link, predictors: PTE, DPTE, STE, mastoid pneumatization; dependent variable: STAM score) was attempted but could not be performed and the results could not be interpreted. SPSS produced the following warnings: (1) there were 122 cells (66.7%) with zero frequency due to unique combinations of predictor values; (2) the log-likelihood was practically zero, indicating complete separation in the data; (3) maximum likelihood parameter estimates could not be validly computed (Nagelkerke $R^2 = 1.000$ is an artifact, not a genuine measure of model fit).

This multivariate failure was caused primarily by the extreme ceiling effect in the dependent variable (90.2% STAM score = 4), which created perfect separation in the predictor space. With such limited variability in the dependent variable, no regression model could produce stable and valid parameter estimates on this data. The raw PLUM output is included in the Appendix as documentation of methodological transparency.

4. Discussion

4.1 Demographic and Clinical Characteristics

This study involved 59 patients (61 ears) with unsafe-type CSOM with intraoperatively confirmed cholesteatoma at Dr. Soetomo General Hospital Surabaya during the 2023 to 2025 period. The mean age of subjects was 35.80 ± 12.52 years, consistent with literature stating that unsafe-type CSOM with cholesteatoma is most commonly found in the productive age group from young adulthood through adulthood [14], [15]. This predominance of the productive age group can be explained by the progressive accumulation of the chronic inflammatory process and tympanic membrane retraction, which requires years to develop into a clinically significant cholesteatoma.

The proportion of female subjects (59.3%) was more dominant compared to males (40.7%). This finding differs somewhat from several reports describing a relatively balanced sex distribution or slight male predominance in CSOM cases [16]. This difference may be caused by variation in healthcare-seeking behavior between populations, selection bias in the tertiary referral population, or differences in environmental risk factors in the Indonesian population.

Most subjects (84.7%) had no comorbid history, indicating that unsafe-type CSOM can occur in individuals without significant accompanying disease. Ear laterality distribution was relatively balanced (right 47.5%, left 52.5%), consistent with literature stating no particular side predilection in CSOM with cholesteatoma [17].

The predominance of canal wall down mastoidectomy procedures (80.3%) in this study reflects the high proportion of cases with extensive cholesteatoma requiring a radical surgical approach. This finding aligns with the high STAM score (90.2% with a score of 4), indicating that patients referred to a tertiary center generally have already reached an advanced disease stage. This is a characteristic feature of tertiary referral hospital populations in Indonesia, where delayed diagnosis and referral remain a significant challenge.

4.2 Variation in Eustachian Tube Anatomy and Mastoid Pneumatization

The mean Eustachian tube length (38.21 ± 3.89 mm) falls within the range reported by Takasaki et al. (2007) in a normal adult population (36 to 38 mm). The mean angle relative to Reid's plane (29.18 ± 4.27°) is also consistent with the report by Nemade et al. (2018), which reported a mean of 25 to 28° in a COM population [18]. The mean pretympanic diameter (2.93 ± 0.89 mm) is consistent with the study by Varghese et al. (2022). The substantial variability in ET length (22.52 to 46.18 mm) and diameter (1.71 to 7.01 mm) indicates significant anatomical heterogeneity [19].

Comparison across international studies provides richer context. Taylan Cebi et al. (2024), in an HRCT-based study in Turkey, found that CSOM patients had a shorter, more horizontal, and narrower Eustachian tube compared with healthy controls; however, these dimensions did not correlate with cholesteatoma formation specifically [8]. This finding aligns with the results of the present study and reinforces the conception that static ET anatomical parameters play a greater role in the initiation phase of tubal dysfunction (the development of disease) than as a predictor of disease severity once formed. In a similar vein, Ridwan et al. (2021), from an Indonesian population, reported significant differences in ET angle and length between safe-type and unsafe-type CSOM, but did not assess the degree of extension within the cholesteatoma group, so the present study goes a step further by assessing whether ET anatomical variation is also associated with how extensively the cholesteatoma develops once formed [3]. This question had not previously been answered in the Indonesian population.

Comparison with other studies provides an important perspective. Nemade et al. (2018) reported that COM patients had a lower Reid plane-ET angle (25.41 ± 2.57°) compared with normal ears (27.56 ± 3.62°; $p < 0.05$), as well as a narrower pretympanic diameter in COM [18]. Varghese et al. (2022) also found a significant difference in ET angle between COM and controls [19]. Herjanto et al. (2022), from an Indonesian population (Dr. Kariadi

General Hospital Semarang), showed an association between sclerotic mastoid pneumatization, narrow ET angle, and narrow ET diameter with tympanic cavity abnormalities [7]. These studies assessed the relationship of ET parameters with the presence or absence of COM, while the present study assesses the relationship with the degree of cholesteatoma extension (STAM score), which is a different variable with limited variability.

If the population mean values in this study are compared with the descriptive classification framework based on the literature outlined, the following picture emerges. The mean ET length of 38.21 mm falls within the “Normal” category (35 to 38 mm) according to Takasaki et al. (2007), although the wide data range (22.52 to 46.18 mm) spans the entire spectrum from “Short” to “Long.” [20] The mean ET angle of 29.18° falls within a liminal category between “Shallow” (<28°) and “Normal” (30 to 40°), consistent with the finding of Nemade et al. (2018) that COM patients had a mean angle of 25.41° [18]. The mean pretympanic diameter of 2.93 mm falls within the lower bound of the “Normal” category (2.5 to 4.5 mm), although the minimum value of 1.71 mm indicates the presence of a subgroup with a diameter within the “Narrow” category (<2.0 mm) that is theoretically at high risk of aeration disturbance. It should be emphasized that this comparison is descriptive in nature because all study subjects were CSOM cholesteatoma patients without a control group; mean values falling within the “normal” range reflect anatomical heterogeneity within this disease population, which is consistent with the finding that cholesteatoma is a multifactorial condition not determined solely by static ET anatomical dimensions.

K-Means Clustering analysis enriches this understanding by revealing that within the CSOM cholesteatoma population, there are three distinct anatomical subtypes in a multidimensional sense. Cluster B (55.7%), with a “small, narrow, flat” pattern, is most consistent with the “high-risk” profile according to the literature classification framework: length <P50, diameter close to the lower bound of normal, and angle within the “Shallow” range. Cluster A (26.2%), with a “long, steep” pattern, instead falls within the “Normal” to “Long” category and “Normal” for angle, suggesting that non-anatomical pathological factors (chronic inflammation, mucociliary dysfunction, or genetic factors) play a greater role in this group. Cluster C (18.0%), with a pretympanic diameter falling within the “Wide” category (>5 mm in some cases), is the most unusual finding and warrants special attention in surgical planning. This heterogeneity confirms that ET anatomical classification based on a single parameter alone is inadequate; a multidimensional approach such as K-Means is more appropriate for mapping anatomical variation in this complex clinical population.

From a clinical and risk stratification perspective, applying an HRCT-based ET classification framework has several practical implications. First, identification of patients with a combination of short ET length (<33 mm), shallow angle (<28°), and narrow pretympanic diameter (<2.0 mm) on preoperative HRCT represents an anatomical profile that may indicate more severe tubal dysfunction, which can be taken into consideration in patient selection for tubal function rehabilitation procedures (such as balloon tuboplasty) in addition to cholesteatoma eradication surgery. Second, patients with a wide pretympanic diameter (>5 mm, as in Cluster C) require special attention in planning exploration of the pretympanic area because of the potential for an expanded pathway of cholesteatoma dissemination toward the tube. Third, although in this study ET anatomical classification was not statistically significantly correlated with cholesteatoma extension score (STAM), this finding does not mean that ET anatomy is not clinically relevant; it is more likely that ET anatomy plays a greater role as a predisposing factor in early cholesteatoma formation than as a determinant of its extension, which is multifactorial in nature. Prospective longitudinal research with a broader disease spectrum, including early-stage cases, is needed to confirm the predictive role of this ET anatomical classification.

The pretympanic diameter (mean 2.93 ± 0.89 mm) falls within the normal range reported by Varghese et al. (2022), although the high variability (range 1.71 to 7.01 mm) indicates the presence of a subgroup with meaningful pretympanic widening [19]. There was no significant correlation between pretympanic diameter and STAM score (rs = −0.091; p = 0.486), consistent with the absence of a validated cut-off separating risk groups based on this parameter. The absence of a standard cut-off in the literature reflects that pretympanic diameter has large natural anatomical variability, and its influence on tubal function is more contextual than deterministic.

Regarding ET length, the negative correlation trend approaching significance (r_s = −0.221; p = 0.087) suggests a tendency for a shorter ET to be associated with more extensive cholesteatoma. This finding is consistent with reports by Liaqat et al. (2025) and Terisno et al. (2025), who also found no significant association between ET length and disease severity [21], [22], as well as with Taylan Cebi et al. (2024), who found a shorter ET length in CSOM but no direct correlation with cholesteatoma formation [8]. These three studies together support the position that ET length may be relevant as a predictor in a population with a broader disease spectrum, but its effect is not detected in an advanced-stage population due to the ceiling effect.

From a statistical perspective, the value of $r_s = -0.221$ for ET length indicates a small-to-moderate effect according to Cohen's convention ($r < 0.30$ = small). With $n = 61$ and a severe ceiling effect (90.2% with score 4), post-hoc power analysis shows that statistical power to detect a correlation of this magnitude is only about 54 to 60%, far below the recommended 80% threshold. This means there is a substantial possibility that a true association (Type II error) went undetected due to insufficient power. Rough estimation indicates that $n \approx 197$ would be required to detect $r = 0.20$ with 80% power, or $n \approx 85$ for $r = 0.30$, both larger than this study's sample. This negative trend needs confirmation in studies with a more heterogeneous population and a larger sample.

The distribution of mastoid pneumatization in this study shows the pneumatic pattern as the most common category (55.7%), followed by sclerotic (26.2%), and diploic (18.0%). The proportion of sclerotic mastoid of 26.2% carries important clinical meaning, as this condition reflects an involutive process due to repeated chronic inflammation that inhibits the development of mastoid air cells since childhood [23], [24]. Pathophysiologically, sclerotic mastoid is associated with reduced capacity as a pressure buffer, the mastoid's function in compensating for sudden pressure changes in the middle ear, so that any ventilation disturbance due to Eustachian tube dysfunction will directly create more severe and persistent negative pressure in the tympanic cavity, accelerating membrane retraction and cholesteatoma formation [25], [26].

Nevertheless, the Spearman correlation test showed no significant association between degree of mastoid pneumatization and STAM cholesteatoma extension score ($r_s = +0.206$; $p = 0.110$). The positive direction of correlation, in which better pneumatization tends to be associated with a higher STAM score, can be explained through the mechanism that a well-pneumatized mastoid provides a wider anatomical space for cholesteatoma to expand into various compartments, so that a higher STAM score is in fact more likely to occur in a pneumatic mastoid than in a sclerotic one [27], [28]. However, this interpretation must be made with caution, given that the extreme ceiling effect in the dependent variable, with 90.2% of subjects having a STAM score of 4, fundamentally limits the capacity to detect a meaningful statistical correlation. This finding is consistent with Singh et al. (2020), who concluded that mastoid pneumatization plays a greater role as a mediating variable between tubal function and disease severity than as a direct predictor of the degree of cholesteatoma extension [4].

The possibility of reverse causality should also be considered: at a very advanced cholesteatoma stage (STAM score 4), extensive bone destruction and invasion can in fact cause damage to mastoid air cells, making the mastoid appear more sclerotic on imaging, rather than the reverse. Thus, the observed positive correlation direction (better pneumatization leading to a higher STAM score) may reflect a temporal bias: patients with a pneumatic mastoid have more room for cholesteatoma expansion, allowing them to reach a STAM score of 4 before detection, while patients with a sclerotic mastoid may show symptoms earlier due to limited space. This hypothesis requires confirmation through a prospective longitudinal study measuring pneumatization prior to disease onset [23].

4.3 Distribution of Cholesteatoma Extension Based on STAM Score

The most prominent finding in this study is the distribution of STAM scores heavily skewed toward the maximum value, with 90.2% of subjects having a score of 4 (involvement of all four anatomical sites). This distribution carries important implications for statistical analysis and interpretation of results.

First, this heavily skewed distribution creates a ceiling effect that substantially limits the variability of the dependent variable. With more than 90% of subjects concentrated at a single value, statistical ability to detect a meaningful correlation becomes very limited, even though a biological association may indeed exist. Second, the high proportion of STAM score 4 reflects the characteristics of a study population consisting of tertiary referral patients with advanced-stage disease. In a population with a broader disease spectrum, including early and moderate cases, the STAM score distribution would be expected to be more heterogeneous.

Third, this finding is consistent with literature stating that cholesteatoma has a progressively destructive nature that tends to spread to all compartments of the middle ear and mastoid over time [29], [30]. By the time patients undergo surgery at a tertiary referral center, most cholesteatomas have reached an extensive degree of spread. This finding underscores the importance of early detection and timely referral to prevent more extensive cholesteatoma spread.

4.4 Association Analysis

The absence of a significant association between Eustachian tube anatomy, mastoid pneumatization, and degree of cholesteatoma extension in this study must be interpreted with caution. The very high proportion of advanced-stage cases (STAM score 4 in 90.2% of subjects) indicates a clear ceiling effect, which substantially limits the discriminative capacity of the dependent variable. This distribution most likely reflects the characteristics of a tertiary referral center, where patients referred for surgery generally already have advanced-stage disease. Thus, this study does not assess the progression or determinants of cholesteatoma extension across the full spectrum (score 0 to 4), but rather assesses anatomical patterns in end-stage disease. This finding leads to acceptance of H_0, although this is likely a false negative due to the low variability of the dependent variable, rather than simply the absence of a biological association. Several explanatory factors are outlined below.

4.4.1. The Influence of Ceiling Effect and Limited Variability. The heavily skewed distribution of STAM scores (90.2% with score 4) creates a ceiling effect that is the primary factor in the non-significant result. Correlation testing requires variability in both variables; with more than 90% of subjects concentrated at a single value, statistical power decreases substantially, increasing the risk of Type II error. Although ET length showed a negative trend ($r_s = -0.221$; $p = 0.087$) approaching significance, the homogeneous score distribution limits the ability to detect a meaningful correlation.

4.4.2. Sample Size and Statistical Power. The number of 61 samples is considered moderate. Post-hoc power analysis shows that to detect a weak-to-moderate correlation ($r = 0.30$) at $\alpha = 0.05$ with 80% power, a minimum of approximately 85 subjects is needed. This limitation is worsened by the ceiling effect, further reducing statistical effectiveness.

4.4.3. The Multifactorial Pathophysiology of Cholesteatoma. Cholesteatoma is a complex pathological entity with multifactorial pathogenesis. Cholesteatoma extension is not determined solely by Eustachian tube anatomical factors, but is also influenced by disease duration, microorganism virulence, local immune response, genetic factors, proinflammatory cytokines, proteolytic enzyme activity (matrix metalloproteinases), middle ear mucosal status, and environmental factors [29], [30]. The relative contribution of Eustachian tube anatomy may be too small to be statistically detectable amid the interaction of so many confounding variables.

This multifactorial argument is supported by internal findings of the study. Chi-Square analysis showed that clinical variables such as sex, comorbid history, and ear laterality were also not significantly associated with STAM score, consistent with the pattern that no single available variable is strong enough to predict the degree of cholesteatoma extension in this advanced-stage population. Likewise, age, as a proxy for disease duration, did not correlate significantly with STAM score ($rs = 0.127$; $p = 0.330$), even though theoretically a longer duration of inflammation should be associated with more extensive spread. The lack of significance across all available variables, both anatomical and clinical, reinforces the hypothesis that in advanced-stage disease (dominated by STAM score 4), the determining factors for extension are already biological-intrinsic in nature, namely matrix metalloproteinase enzyme activity, keratinocyte proliferation, and local immune response, none of which can be measured from HRCT and retrospective medical record data [30], [31].

Several studies show that Eustachian tube dysfunction plays a role in cholesteatoma initiation through a mechanism of chronic negative pressure that causes tympanic membrane retraction, but once the cholesteatoma has formed, its extension is determined more by the intrinsic biological nature of the cholesteatoma (epithelial proliferation, osteolytic activity) than by static anatomical factors [31]. Thus, this data is more consistent with the hypothesis that Eustachian tube anatomy plays a role as a predisposing factor for cholesteatoma initiation, though it must be emphasized that this cross-sectional study design does not allow for causal or temporal conclusions. The statement that ET "only plays a role in initiation" cannot be confirmed without longitudinal data measuring ET anatomy prior to disease onset and monitoring its progression. A more accurate conclusion is: in an advanced-stage CSOM population at a tertiary referral center, static ET anatomical parameters measured on HRCT are not sufficiently sensitive to distinguish the degree of cholesteatoma extension, regardless of the biological mechanism that may be present.

4.4.4. Eustachian Tube Angle Categorization and Cholesteatoma Extension. Categorical analysis of Eustachian tube angle using a threshold of 27 degrees [7] also showed no significant association with degree of cholesteatoma extension (Mann-Whitney U = 408.0; $p = 0.964$), consistent with the continuous analysis result ($r_s = -0.134$; $p = 0.304$). STAM score distribution in both groups was nearly identical: 90.0% of subjects in the narrow group and 90.2% in the non-narrow group had a STAM score of 4, with identical medians (4; IQR 4 to 4). The absence of a significant difference does not necessarily reflect an absence of biological association, but rather reflects an extreme ceiling effect that limits statistical power to detect differences between groups.

Theoretically, a smaller (more horizontal) ET angle is associated with disturbed ventilation and middle ear clearance through decreased efficiency of tube opening by the tensor veli palatini muscle, which triggers chronic negative pressure as a pathogenic mechanism for cholesteatoma [20], [26]. Herjanto et al. (2022), from an Indonesian population, demonstrated that a narrow ET angle (<27 degrees) was significantly associated with tympanic cavity abnormalities (OR = 5.29; $p = 0.001$), while Nemade et al. (2018) found a significant angle difference between COM patients and normal controls [18]. However, both of these studies assessed the association with the presence or absence of disease, not the degree of extension, so the variability of the dependent variable in those studies was far greater and more suitable for detecting a statistical correlation.

This finding aligns with the conception that ET angle anatomy plays a greater role as a predisposing factor in the initiation stage of cholesteatoma than as a primary determinant of its degree of extension, which is multifactorial and depends on disease duration, microorganism virulence, local immune response, and proteolytic enzyme activity [29], [30]. The study population, drawn from a tertiary referral center, inherently includes advanced-stage cases, so the variability in STAM score required for correlation analysis becomes very limited. Prospective research with a broader severity spectrum, including early-stage CSOM cases with STAM scores of 0 to 2, is needed to confirm the predictive role of this ET angle categorization.

The ROC analysis conducted as an internal validation test confirms that the 27° cut-off categorization is consistent and statistically significant. Continuous ET angle achieved AUC = 0.937 in predicting its own category ($r_s = 0.700$; $p < 0.001$), which is strong evidence of internal consistency. In contrast, ET length (AUC = 0.688) and pretympanic diameter (AUC = 0.588) were not able to predict ET angle category well (DeLong $p < 0.01$), confirming that the three ET anatomical parameters measure different aspects and are independent of one another. This reinforces the argument that the non-significant association findings are not due to a categorization error, but rather to the limited variability of the dependent variable.

4.4.5. Limitations of HRCT in Soft Tissue Evaluation. Temporal HRCT has the advantage of evaluating bony structures and pneumatization, but has inherent limitations in soft tissue contrast resolution. HRCT cannot reliably distinguish between cholesteatoma, granulation tissue, mucoid effusion, and fibrosis within the middle ear cavity and mastoid [32]. This limitation can lead to overestimation or underestimation of STAM score in some cases. Unlike Magnetic Resonance Imaging (MRI) with diffusion-weighted imaging (DWI) sequences, which has higher specificity for distinguishing cholesteatoma from other soft tissue, HRCT remains the primary modality for preoperative evaluation because of its superior capability for mapping bony anatomy and pneumatization.

4.4.6. Selection Bias and Tertiary Referral Population. This study was conducted at a tertiary referral center (Dr. Soetomo General Hospital Surabaya), which inherently receives cases with a higher level of severity. Selection of patients who underwent surgery also introduces selection bias, as it only includes cases considered to require surgical intervention, generally cases with a sufficiently large cholesteatoma. Patients with early-stage cholesteatoma who had not yet undergone surgery or who were managed conservatively were not included in the analysis. This selection bias contributes to the high homogeneity of STAM scores and limits generalization of the results.

4.4.7. Operator Variation and Measurement Standardization. Although the interobserver reliability test showed excellent agreement for Eustachian tube anatomical parameters (ICC 0.954 to 0.997), there remains potential variability in measurement technique that could influence the results. Measurement of Eustachian tube anatomy on HRCT requires precise multiplanar reconstruction, and variation in determining anatomical landmarks (tympanic orifice, pharyngeal opening, Reid's plane) can affect measurement reproducibility. Stricter measurement protocol standardization and the use of automated software may improve accuracy in the future.

4.5 Comparison with Previous Research

Literature that specifically correlates Eustachian tube anatomical parameters on HRCT with cholesteatoma extension scores such as STAM remains very limited. This study has methodological novelty as one of the first studies to assess this association in the Indonesian population. Nevertheless, a systematic comparison with the most relevant studies is needed to contextualize this non-significant result.

(1) The present study (Indonesia, 2026, n=61 ears): independent variables, length, pretympanic diameter, ET angle, and mastoid pneumatization; dependent variable, STAM score 0 to 4; result, not significant (all $p > 0.05$).

(2) Taylan Cebi et al. (2023, Turkey): independent variable, ET dimensions on HRCT; dependent variable, presence or absence of cholesteatoma (binary); result, ET dimensions differed between CSOM and healthy controls, but did not correlate with cholesteatoma formation specifically [8].

(3) Herjanto et al. (2022, Indonesia/Semarang): independent variables, angle, ET diameter, mastoid pneumatization; dependent variable, presence or absence of tympanic cavity abnormality (binary); result, significant, OR for narrow angle <27° = 5.29 ($p = 0.001$); mastoid pneumatization as the dominant factor [7].

(4) Ridwan et al. (2021, Indonesia): independent variables, angle and ET length; dependent variable, safe-type vs unsafe-type CSOM (binary); result, significant, unsafe-type CSOM had a smaller angle and shorter ET [3].

(5) Nemade et al. (2018, India): independent variable, ET angle; dependent variable, presence or absence of COM (binary); result, significant (25.41° in COM vs 27.56° in controls; $p < 0.05$) [18].

(6) Liaqat et al. (2025): independent variable, ET length; dependent variable, disease severity (ordinal); result, not significant ($p = 0.60$) [22].

(7) Terisno et al. (2025): independent variable, ET length; dependent variable, disease severity (ordinal); result, not significant ($p = 0.763$) [21].

The consistent pattern from the comparisons above reveals something important: studies using a binary dependent variable (presence or absence of disease, or presence or absence of abnormality) tend to find a significant association with ET anatomical parameters, while studies using an ordinal dependent variable to measure degree of severity, including the present study, Liaqat et al. (2025), and Terisno et al. (2025), consistently find no significant association [21], [22]. This indicates that ET anatomy acts as a threshold factor (a threshold determining whether a person is susceptible to disease initiation), but not as a gradient factor (a factor determining how severe the disease becomes once formed). This conceptual difference between "whether the disease exists" versus "how severe the disease is" explains the difference in results between the present study [7], [18], while also confirming the scientific validity of the present study even though H_0 was accepted.

This finding is also consistent with Khan et al. (2022), who assessed the correlation of ET anatomical parameters with mastoid pneumatization, rather than directly with cholesteatoma extension, as well as with Singh et al. (2020), who concluded that mastoid pneumatization acts as a mediating variable between tubal function and disease severity, rather than a direct predictor [4]. Taken together, these findings support a two-stage pathogenesis model: (1) ET anatomy and mastoid pneumatization play a role in CSOM predisposition and initiation; (2) cholesteatoma extension once formed is determined primarily by intrinsic biological factors, namely matrix metalloproteinase enzyme activity, keratinocyte proliferation, and local immune response, which cannot be measured from static HRCT parameters alone.

4.6 Interpretation of K-Means Clustering Analysis and Local Cut-off

This study is the first to report local 10th and 90th percentile cut-offs for Eustachian tube anatomical parameters in the Indonesian CSOM cholesteatoma population. The P90 value for pretympanic diameter (3.96 mm) carries particular clinical relevance: a number of subjects in Cluster C had a diameter as high as 7.01 mm, indicating the presence of a subgroup with notable pretympanic widening that may require special attention in surgical planning.

The K-Means method was chosen because it does not require an assumption of normal distribution and is able to group subjects based on multidimensional similarity. Z-score standardization prior to clustering is essential, given that the units of mm and degrees are not comparable. A silhouette value of 0.342 at k=3 falls within the "weak to moderate structure" category, which is acceptable for biomedical data with high natural variability [33]. Because there was no healthy control group and the analysis is exploratory in nature, these findings are interpreted as a mapping of anatomical heterogeneity within the cohort, not a definitive diagnostic classification.

To test the clinical relevance of the three clusters to the degree of cholesteatoma extension, a descriptive analysis of STAM score distribution per cluster was conducted. The results show that all three clusters have a nearly equal predominance of STAM score 4: Cluster A 87.5% (14/16), Cluster B 91.2% (31/34), and Cluster C 90.9% (10/11). This absence of difference in STAM distribution between clusters is consistent with the ceiling effect that constitutes the main limiting factor for all association analyses in this study. Nevertheless, the informative value of K-Means lies not in predicting STAM score, but in identifying anatomical profiles that can guide surgical planning: Cluster C, with extreme pretympanic widening (mean 4.36 mm, range up to 7.01 mm), is a finding not previously reported in HRCT-based CSOM literature in Indonesia. The study by Varghese et al. (2022) reported a mean pretympanic diameter in the COM population of around 2.5 to 3.5 mm, so Cluster C in this study is far above that value [19]. Radiologists are advised to explicitly report a pretympanic diameter >4 mm in preoperative HRCT reports as an anatomical marker requiring special attention during exploration of the pretympanic area in mastoidectomy procedures.

It should be acknowledged that the absence of an association between K-Means clusters and STAM score constitutes a major clinical limitation of this analysis. The K-Means analysis in this study is entirely exploratory-descriptive and cannot be used for individual prediction of disease severity; the same ceiling effect also limits the ability to find STAM differences between clusters. Its clinical value lies in identifying ET morphological heterogeneity that is hidden from single-parameter analysis. Future prospective research needs to test whether these three cluster subtypes are associated with more clinically relevant outcomes, such as risk of recurrence after mastoidectomy or the need for a specific surgical approach.

4.6.1. Cluster B (n=34; 55.7%): "Small, Narrow, Flat" Pattern. Cluster B is the dominant group (55.7%). Hypothetically, a shorter ET, smaller diameter, and smaller (more horizontal) angle may be associated with more severe tubal dysfunction. Studies by Takasaki et al. (2007) and Nemade et al. (2018) show that a more horizontal ET angle is associated with impaired middle ear drainage and ventilation in COM patients [18], [20]. Ridwan et al. (2021), from an Indonesian population, also reported that the unsafe type of CSOM (cholesteatoma) has a smaller angle and shorter ET compared with the safe type [3]. Thus, the anatomical pattern of Cluster B is consistent with the "high-risk" profile documented in the literature, although without a control group, causal statements cannot be made. What can be concluded is that, within this CSOM cholesteatoma population, this is the most commonly encountered pattern.

4.6.2. Cluster A (n=16; 26.2%): "Long and Steep" Pattern. Cluster A shows a longer ET and larger (steeper) angle. Theoretically, a steeper angle facilitates drainage and ventilation. A relevant question arises: why do patients with this theoretically more protective anatomical pattern still develop cholesteatoma? Possible explanations include: (1) excessive ET length (>P90 = 43 mm in some subjects) may reduce the efficiency of tube opening by the tensor veli palatini muscle; (2) other pathological factors such as chronic inflammation, biofilm, or muscle dysfunction are more dominant than static anatomical variation; and (3) the cholesteatoma pattern in this group may have a different pathogenetic pathway, a hypothesis that can be tested in further research through correlative analysis with clinical outcomes and surgical type.

4.6.3. Cluster C (n=11; 18.0%): "Pretympanic Diameter Widening" Pattern. Cluster C is the most striking finding. A very large pretympanic diameter (mean 4.36 mm, range up to 7.01 mm) is rarely reported in normal radiological literature; the study by Varghese et al. (2022) reported a mean pretympanic diameter in the COM population of around 2.5 to 3.5 mm [19]. This widening may be congenital (anatomical variation) or acquired due to a chronic inflammatory process that damages the cartilaginous tube wall. From a surgical perspective, extreme pretympanic widening has the potential to expand the pathway of cholesteatoma spread toward the tube, as well as to complicate hemostasis during exploration of that area. Follow-up studies are needed to test whether Cluster C is associated with a history of prolonged otitis media with effusion, cholesteatoma extension toward the tympanic sinus area, or the need for a particular surgical approach. Radiologists are advised to explicitly state in HRCT reports if pretympanic diameter exceeds 4 mm as an anatomical finding to be alert to during surgical planning.

Overall, the K-Means analysis successfully identified three distinct ET anatomical subtypes within the CSOM cholesteatoma population. Although all three clusters share the same diagnosis, their anatomical heterogeneity is meaningful and opens opportunities for patient stratification based on anatomical pattern in subsequent correlative research, for example linking clusters with STAM score, mastoid pneumatization, type of surgical procedure, or risk of postoperative recurrence.

4.7 Interobserver Reliability

The interobserver reliability test showed highly satisfactory results for measurement of Eustachian tube anatomical parameters. ICC for length (0.954), diameter (0.997), and angle (0.966) of the Eustachian tube all fell within the excellent agreement category (ICC > 0.90). This finding indicates that measurement of Eustachian tube anatomical parameters on temporal HRCT can be performed reliably by trained radiologists.

ICC for total STAM score (0.690) fell within the good agreement category, although lower compared with the Eustachian tube anatomical parameters. This value may be influenced by the very homogeneous STAM score distribution (90.2% with score 4), which limits interobserver variability and can artificially lower the ICC value. Cohen's Kappa for tympanic sinus (0.615) and tympanic cavity (0.737) showed substantial agreement, while kappa values for attic and mastoid could not be calculated because of constant ratings by both observers.

These high reliability results provide validity for the data used in the main correlation analysis. Consistency of measurement between observers shows that measurement variability is not a major confounding factor in the non-significant results found in the correlation analysis.

4.8 Clinical Interpretation, Research Novelty, and Practical Relevance

Although the main correlation results were not statistically significant, this study makes several meaningful scientific and clinical contributions. The valid negative finding, that static ET anatomy does not predict the degree of cholesteatoma extension in an advanced-stage population, is scientifically equal in value to a positive finding, because it directs clinicians not to rely on a single anatomical parameter to estimate disease severity.

First, this study is the first study in Indonesia to specifically correlate three quantitative Eustachian tube anatomical parameters on temporal HRCT (length, pretympanic diameter, and angle relative to Reid's plane) with the STAM cholesteatoma extension score based on the international EAONO/JOS classification. The absence of a significant correlation is itself an important contribution: it confirms that a predictive model for cholesteatoma extension cannot be built from static HRCT anatomical parameters alone. Intrinsic biological factors, including matrix metalloproteinase enzyme activity, keratinocyte proliferation, and local inflammatory response, identified by Jackler et al. (2015) and Kuo et al. (2015) as primary mediators of osteolysis and cholesteatoma extension, need to be integrated into future predictive models along with HRCT anatomical parameters [30], [34]. The EAONO/JOS classification [15], which forms the basis of the STAM score used in this study, was designed primarily for surgical planning, not for prediction of anatomical risk factors, an intrinsic limitation of this scoring system that needs to be considered in interpreting the results of this study.

Second, this study provides normative data on Eustachian tube anatomy in the Indonesian population, which remains very limited in the literature. This local reference data is important given the existence of anatomical variation between ethnic groups that may influence normal reference values.

In terms of clinical relevance, although Eustachian tube anatomy was not significantly correlated with cholesteatoma extension in this study, these parameters retain potential utility in a broader context. Evaluation of Eustachian tube anatomy on preoperative HRCT can assist in: (1) surgical approach planning, particularly in cases requiring exploration of the pretympanic area; (2) prediction of postoperative recurrence risk, given that Eustachian tube dysfunction is a recognized risk factor for cholesteatoma recurrence; and (3) patient selection for tuboplasty procedures or tubal function rehabilitation measures.

5. Conclusion

This study has several limitations that need to be considered in interpreting the results. The retrospective cross-sectional design does not allow for determination of a causal relationship between variation in Eustachian tube anatomy and cholesteatoma extension, and the absence of a control group limits comparison with a normal population or with CSOM without cholesteatoma. The STAM score distribution, which is heavily dominated by the maximum score, caused a ceiling effect, so that statistical power to detect an association became low and ordinal multivariate analysis could not be optimally performed. In addition, a number of important confounding factors, such as disease duration, frequency of recurrent infection, socioeconomic status, access to health services, and Eustachian tube physiological function, were not available in the retrospective data. Assessment of degree of cholesteatoma based on HRCT also has limitations in distinguishing soft tissue, potentially giving rise to overestimation of STAM score compared with intraoperative findings. The study being conducted at only one tertiary referral center also limits generalization of results. Nevertheless, the failure of multivariate analysis reflects more the homogeneity of a population dominated by advanced-stage cases than an indication that Eustachian tube anatomical parameters lack clinical relevance. Therefore, a multicenter prospective study with a larger sample, a more balanced STAM score distribution, the use of additional imaging modalities such as non-EPI DWI MRI, inclusion of a control group, as well as integration of Eustachian tube physiological function assessment and more comprehensive clinical data, is highly recommended to obtain a better understanding of the role of Eustachian tube anatomy and function in the pathogenesis and progression of cholesteatoma.

Based on a study of 59 patients (61 ears) with unsafe-type CSOM with cholesteatoma at Dr. Soetomo General Hospital during the 2023 to 2025 period, the mean Eustachian tube length was found to be 38.21 ± 3.89 mm, pretympanic diameter 2.93 ± 0.89 mm, and angle relative to Reid's plane 29.18 ± 4.27°, with mastoid pneumatization dominated by the pneumatic type. Most cases had a STAM score of 4, reflecting the characteristics of a tertiary referral population with advanced-stage disease. Three Eustachian tube anatomical subtypes could be identified, with excellent interobserver measurement reliability. However, no significant association was found between variation in Eustachian tube anatomy or degree of mastoid pneumatization and extent of cholesteatoma, which is likely influenced by the ceiling effect and the multifactorial nature of disease pathogenesis. For future research, a multicenter prospective study with a larger sample size and a more even distribution of severity levels is recommended, using a combination of HRCT and non-EPI DWI MRI, involving a control group, performing measurement standardization, and integrating clinical data and assessment of Eustachian tube physiological function, in order to obtain a more comprehensive and valid predictive model.

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