DOI: https://doi.org/10.54393/pjhs.v6i11.3384

PAKISTAN JOURNAL OF HEALTH SCIENCES
(LAHORE)
https://thejas.com.pk/index.php/pjhs
ISSN (E): 2790-9352, (P): 2790-9344
Volume 6, Issue 11 (November 2025)

Original Article

OPEN ACCESS

Anatomical Variation in Sigmoid Sinus and Its Impact on Mastoid Exploration in Atticoantral Chronic Suppurative Otitis Media Surgery: A Prospective Study at Khyber Teaching Hospital, Peshawar

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ARTICLE INFO

Keywords:
Otitis Media Suppurative, Cholesteatoma, Anatomic Variation, Temporal Bone, Mastoidectomy

How to Cite:
Sajjad, W., Ikram, M. A., Khan, H. D., Zahid, A., Ijaz, F., Mahmood, H. H., & Khan, R. (2025). Anatomical Variation in Sigmoid Sinus and Its Impact on Mastoid Exploration in Atticoantral Chronic Suppurative Otitis Media Surgery: A Prospective Study at Khyber Teaching Hospital, Peshawar: Sigmoid Sinus Variations and Their Impact on Mastoid Surgery in CSOM. Pakistan Journal of Health Sciences, 6(11), 08-13. https://doi.org/10.54393/pjhs.v6i11.3384

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Received Date: 28th July, 2025
Revised Date: 30th October, 2025
Acceptance Date: 10th November, 2025
Published Date: 30th November, 2025

ABSTRACT

Atticoantral Chronic Suppurative Otitis Media (CSOM) with cholesteatoma frequently causes intraoperative complications. Anatomical variations of the sigmoid sinus (SS) can increase surgical risk. This study correlates CT-identified SS variations with operative challenges and outcomes, addressing the limited literature on their specific impact. **Objectives:** To evaluate the anatomical variations of the sigmoid sinus on preoperative CT scans and determine their impact on intraoperative challenges and postoperative outcomes during mastoid exploration for atticoantral chronic suppurative otitis media. **Methods:** This analytical cross-sectional study of 300 patients undergoing radical mastoidectomy at a tertiary care hospital from January to December 2024. Temporal bone CT scans assessed variation in SS position and bony plate integrity. Intraoperative and postoperative complications were recorded. Categorical data were analyzed using chi chi-square test ($p<0.05$). **Results:** CT evaluation demonstrated intact bony plates in 77.3% of cases, with 12.3% showing erosion and 11.3% exhibiting exposure; sinus position was posterior in 63%, anterior in 25%, and normotopic in 12%. Intraoperative observations matched CT findings. Anterior displacement was significantly associated with increased surgeon fatigue ($p= 0.014$), Dural injury ($p < 0.001$), significant hemorrhage ($p=0.032$), facial nerve palsy ($p=0.006$), and incomplete disease clearance ($p<0.001$). Eroded or exposed plates also correlated with higher complication rates ($p<0.01$). No postoperative meningitis occurred. **Conclusions:** Preoperative CT accurately predicts sigmoid sinus variations in atticoantral CSOM, aiding surgical planning and reducing intraoperative complications.

INTRODUCTION

CSOM is a chronic inflammation and infection of the middle ear and mastoid air cell system, characterized by persistent or intermittent ear discharge through a perforated tympanic membrane [1]. CSOM constitutes a significant global health problem affecting an estimated 65–330 million individuals [2]. CSOM is classified into two main types: the mucosal variant, frequently considered benign or 'safe', and the squamosal (atticoantral) variant, categorized as 'unsafe' due to its more destructive nature. The latter subtype essentially affects the posterosuperior part of the middle ear cleft and often shows association with cholesteatoma formation. Cholesteatoma constitutes a well-circumscribed nonneoplastic pathological entity characterized by the accumulation of keratinizing squamous epithelium within a connective tissue stroma, causing localized bone erosion [3]. Tympano-

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mastoidectomy serves as a standard surgical procedure for the definitive management of atticoantral type of CSOM [4]. For a safe and effective tympanomastoidectomy procedure, definitive recognition of anatomical landmarks and their potential variations are essential; otherwise, the likelihood of intraoperative complications is considerably high [5]. The Sigmoid Sinus (SS), a dural venous sinus, traverses along the interface between the endosteal lining of the occipital bone and the inner meningeal layer of dura mater [6]. The substantial anatomical variability in the position of SS within the mastoid cavity profoundly affects the dimensions of Trautmann's triangle, carrying significant considerations for surgical planning and intraoperative exposure [7]. The spatial orientation of SS serves as a significant predictor of surgical accessibility during translabyrinthine and retrosigmoid procedures for inner ear structures. A posterosuperiorly positioned sinus reduces the available surgical space, necessitating increased cerebellar retraction during retrosigmoid surgical procedures, thereby potentially elevating the risk of complications [8]. An anteriorly and inferiorly positioned SS poses a challenge to the translabyrinthine approach by substantially restricting the operative window and limiting exposure to the middle and inner ear structures [9]. Computed tomography (CT) scan has shown robust diagnostic accuracy, evidenced by a pooled sensitivity of 79% and a pooled specificity of 90% [10, 11]. Marked interindividual variability in the anatomical positioning of SS enhances the risk of surgical trauma. Consequently, the integration of image-guided technologies is recommended for accurate identification of these alterations and to avoid adverse outcomes [12]. In atticoantral disease, where cholesteatoma has disrupted the conventional surgical landmarks, SS serves as a consistent anatomical reference point. A thorough understanding of the anatomical variations of SS and their clinical significance is essential for effective preoperative planning to minimize the risk of inadvertent sinus injury and related surgical complications [7, 13]. Although the variability in SS positioning is well documented in the literature, a comprehensive parametric analysis of its impact on mastoid exploration in atticoantral CSOM surgery remains lacking. This study aims to assess both preoperative and intraoperative anatomical variations of the sigmoid sinus during mastoid exploration for atticoantral CSOM. These findings will contribute to enhanced surgical planning and the intraoperative prevention of serious complications.

METHODS

This analytical cross-sectional study was conducted in the Department of Otolaryngology at Khyber Teaching Hospital, Peshawar, over the period from January to December 2024. Ethical approval for the study was granted by the Institutional Research and Ethical Review Board of Khyber Medical College, Peshawar (Ref. No 764/DME/KMC). All participants provided written informed consent. A consecutive sampling technique was employed for recruitment. The study included patients undergoing Modified Radical Mastoidectomy (MRM) for clinically diagnosed atticoantral CSOM with cholesteatoma and extensive granulation tissue formation, and the age range was from 18 to 60 years. Informed consent was taken from all participants. Patients having the diagnosis of cerebral venous sinus thrombosis, congenital or acquired intracranial abnormalities, intracranial space-occupying lesions, prior mastoid surgery, or any abnormal findings on brain imaging were excluded. Sample size was calculated using the formula: $n=Z^2 \cdot P \cdot (1-P)/d^2$, where Z=1.96 (for 95% confidence), P=25.93%. The required sample size was estimated based on the reported prevalence of anatomical variations of the sigmoid sinus (25.93%), with a 95% confidence interval (CI) and a 5% margin of error [6]. The sample size came out to be 296, but it was rounded up to 300. A detailed history, including the age, gender, and previous medical and surgical history, was obtained. The preoperative and postoperative CT scans of the patients were reviewed to evaluate the anatomical location of SS. Imaging was performed using a standardized high-resolution temporal bone CT protocol with a rotation time of 0.5 s, pitch factor of 0.637, and collimation of 0.5 × 80 mm (50 mm total). These acquisition parameters were adopted in accordance with previously validated high-resolution CT protocols for temporal bone and sigmoid sinus evaluation described in the literature [10-11]. Such imaging settings ensure optimal delineation of bony anatomy and venous sinus variations, facilitating accurate preoperative assessment. These findings were compared with intraoperative observations, including the anatomical position of SS, the presence or absence of bony plate covering the SS or its exposure, its influence on the extent of disease clearance during surgery, the occurrence of Dural injury or massive intraoperative haemorrhage, and the overall complexity of the surgical procedure. CT scan source images were meticulously analysed in sagittal planes to identify anatomical variations of the SS. The primary variables assessed included the anatomical classification of the SS as anterior (forward), posterior, superior, or inferior types. Emphasis was placed on the accuracy of source image interpretation to minimize diagnostic errors. Postoperative outcomes were systematically recorded for all participants, including the incidence of complications such as facial nerve palsy, meningitis, encephalitis, and postoperative CT findings documenting residual disease and SS positioning. Data

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were analysed using the Statistical Package for the Social Sciences (SPSS) version 20.0. Continuous variables were presented as mean and standard deviation. "Chi-square tests were applied to evaluate the impact of preoperative anatomical variations of the sigmoid sinus (position and bony plate status) on intraoperative challenges and postoperative outcomes. A p-value ≤ 0.05 was considered statistically significant."

RESULTS

This analytical cross-sectional study evaluated 300 participants, consisting of 125 males and 175 females. The age of the participants ranged from 18 to 55 years, with a mean age of 28.89 years (±8.05). The majority of the participants lie within the 18–30-year age group. Most of the patients presented with active CSOM, and ear discharge is the most common symptom. Almost all patients undergo Modified Radical Mastoidectomy (MRM) as the main surgical treatment (Table 1).

Table 1: Demographic and Clinical Characteristics of Study Participants (N=300)

Characteristics	Category	Frequency (%)
Age Group (years)	18–30	182 (60.7%)
	31–40	99 (33.0%)
	41–50	12 (4.0%)
	51–60	7 (2.3%)
Sex	Male	125 (41.7%)
	Female	175 (58.3%)
Type of Mastoid Exploration	MRM	294 (98.0%)
	RM	6 (2.0%)

MRM: Modified Radical Mastoidectomy, RM: Radical Mastoidectomy

Preoperative CT scan of the temporal bone in 300 patients showed that the majority exhibited an intact sigmoid plate, showing the SS has a normal bony coverage. A smaller proportion demonstrated sigmoid plate dehiscence (12.3%), characterized by thinning or erosion of the bony plate, while 10.3% revealed the sigmoid sinus completely exposed due to absent bony coverage. Anatomic variations in SS position were also noted on CT scans preoperatively. The sinus was posteriorly displaced in 62.7% of cases, anteriorly displaced in 25.3%, and in a standard anatomical location, it is only 12.0%. Intraoperative findings demonstrated identical distribution patterns showing strong correlation with preoperative CT imaging regarding SS position (Table 2).

Table 2: Preoperative CT Findings and Intraoperative Observations of Sigmoid Sinus Anatomy in 300 Cases

Assessment Phase	Category	Findings	Frequency (%)	Assessment Phase
Pre-op CT Findings	Bony Sigmoid Plate	Well-defined	232 (77.3)	Pre-op CT Findings
		Eroded	37 (12.3)	
		Exposed	31 (10.3)	
CT Anatomical Variation	Sigmoid Sinus Position	Posterior	188 (62.7)	CT Anatomical Variation
		Forward	76 (25.3)	
		Normal	36 (12.0)	
Intraoperative Findings	Bony Sigmoid Plate	Well-defined	232 (77.3)	Intraoperative Findings
		Thin plate	37 (10.3)	
		Exposed	31 (12.3)	
	Sigmoid Sinus Position	Posterior	188 (62.7)	
		Forward	76 (25.3)	
		Normal	36 (12.0)	

A statistically significant association was found between forward-lying SS on CT scan and increased intraoperative challenges. Surgeon-reported fatigue due to procedural complexity, Intraoperative Dural injury, and massive hemorrhage was notably higher in patients with forward-positioned SS compared to posterior-lying and no variation groups (p=0.014, p<0.001, and p=0.032, respectively). Forward-lying SS was also associated with higher rates of postoperative facial nerve palsy (p =0.006). Poor disease clearance (51.3%) and residual disease on postoperative CT (50.0%) were significantly more common in the forward-lying group (p < 0.001 for both). No statistically significant association was observed between anatomical variation and postoperative meningitis or encephalitis (p=0.399) (Table 3).

Table 3: Association of Preoperative CT Scan and Intraoperative Anatomical Variations of SS With Surgical Challenges and Postoperative Outcomes (N=300)

Outcome Variables	Forward (Anterior) SS (N=76)	Posterior SS (N| =188)	No Variation (N=36)	p-Value
Surgeon-reported fatigue	18 (10.5)	27 (14.3)	1 (2.8)	0.014*
Dural injury during surgery	8 (10.5)	0 (0.0)	0 (0.0)	<0.001*
Massive hemorrhage during surgery	6 (7.9)	2 (1.1)	0 (0.0)	0.032*
Facial palsy (post-op)	9 (11.8)	4 (2.1)	0 (0.0)	0.006*
Post-op meningitis/encephalitis	1 (1.3)	3 (1.6)	1 (2.8)	0.399
Incomplete disease clearance	39 (51.3)	12 (6.4)	0 (0.0)	<0.001*
Residual disease on post-op CT	38 (50.0)	6 (3.2)	0 (0.0)	<0.001*

* Indicates statistical significance at p ≤ 0.05

Further analysis of preoperative CT and intraoperative findings revealed that patients with eroded bony plates or exposed sigmoid sinuses experienced significantly more surgical complications. Surgeon fatigue was reported in 51.3% of cases with eroded plates and 41.9% of cases with exposed sinuses (p<0.001). Dural injuries and massive hemorrhage occurred more frequently in cases with eroded plates and exposed sinuses (p<0.001 and p=0.007, respectively). Postoperative facial palsy was more prevalent in the eroded and exposed sinus groups (p=0.004). Disease clearance was significantly lower in patients with compromised bony structures (eroded plate and exposed sinus) compared to the well-defined plate

DOI: https://doi.org/10.54393/pjhs.v6i11.3384

group (p<0.001). Residual disease on postoperative CT was highest in the exposed sinus group (61.3%), followed by the eroded plate group (35.1%), compared to 5.2% in the well-defined plate group (p<0.001). Again, no significant correlation was observed between bony sigmoid plate status and postoperative central nervous system infections (p=0.726) (Table 4).

Table 4: Association of Preoperative CT scan and intraoperative Bony Plate Status with Surgical Challenges and Postoperative Outcomes (N=300)

Outcome Variables	Well-Defined Plate (N= 232)	Eroded Plate (N= 37)	Exposed SS (N= 31)	p-Value
Surgeon-reported fatigue	14 (6.0)	19 (51.3)	13 (41.9)	<0.001*
Dural injury during surgery	0 (0.0)	4 (10.8)	4 (12.9)	<0.001*
Massive hemorrhage during surgery	3 (1.3)	3 (8.1)	3 (9.7)	0.007*
Facial palsy (post-op)	6 (2.6)	5 (13.5)	3 (9.7)	0.004*
Post-op meningitis/encephalitis	4 (1.7)	1 (3.2)	0 (0.0)	0.726
Incomplete disease clearance	19 (8.2)	13 (35.1)	19 (61.3)	<0.001*
Residual disease on post-op CT	12 (5.2)	13 (35.1)	19 (61.3)	<0.001*

* Indicates statistical significance at p ≤ 0.05

"The impact of anterior (forward) or posterior displacement of the sigmoid sinus, as well as variations in bony plate coverage, on surgical complexity and postoperative outcomes was assessed using Chi-square tests. Forward-lying or exposed sigmoid sinuses were significantly associated with increased intraoperative challenges, higher rates of dural injury, massive hemorrhage, facial nerve palsy, incomplete disease clearance, and residual disease on postoperative CT (p≤0.05 for all comparisons)."

DISCUSSIONS

This cross-sectional study analyzed 300 patients diagnosed with atticoantral CSOM, with a predominance of females and a mean age of 28.89 (±8.05) years. This is in agreement with a previous study, where the mean age was reported to be 27.5 (±10) years [14]. As the SS anatomy is variable, on pre-op CT sigmoid sinus with an intact bony plate was the most common variation, followed by a thin bony plate and exposed SS, respectively [9]. These are likewise to previous findings [15, 16]. Considering the position of the SS, on pre-op CT scan, a posteriorly displaced sigmoid sinus was the most prevalent. These positions showed a strong correlation with intraoperative observations. The higher rate of surgeon fatigue with the forward (anteriorly) lying SS was associated with a narrow surgical window, reduced instrument mobility, and limited visibility of anatomic landmarks, making the surgery more complex and lengthier. However, previous studies reported no association between the location of the SS and difficulty in mastoidectomy. This contradiction is because of different procedures; in cholesteatoma surgery, a wide cavity is required as compared to cochlear implant surgery [9, 17]. Dural injury was found to be highly associated with forward lying SS (p<0.001); the association can be justified by the fact that forward lying sigmoid sinus restricts the exposure of presigmoidal Dural plate [18, 19]. Moreover, forward displacement was significantly linked to massive intraoperative hemorrhage (p=0.032), potentially resulting from limited access via the post-aural approach, which increases the risk of sinus injury [20]. Facial nerve palsy was also more frequent postoperatively in cases with a forward-lying sinus. This association is likely attributable to the facial nerve lying closely to the semicircular canals, making it more vulnerable to injury during mastoid drilling [21, 22]. Furthermore, the disease was not cleared completely in half of the cases of forward lying SS, which was confirmed by CT scan postoperatively. This may be attributed to restricted access to the middle ear due to narrowing of Trautmann's triangle, thereby limiting the surgical field [7]. Different complications were reported due to variation in the SS bony plate. Bony plate variations were also associated with complications. Surgeon experienced fatigue was more in eroded bony plate cases, which was not reported in previous studies. Partially or completely erosion of the bony plate by cholesteatoma typically reflects more extensive spreads of the disease, making it more time-consuming. In the case of an eroded and exposed sinus, the dual injury and hemorrhage were found to be statistically significant, supported by data from a study in Nepal. The wall of the SS being eroded or exposed makes its injury more likely. Complete diseased clearance was not achieved in patients with exposed sinus and eroded bone plate. The possible reason for residual disease is the extensive spread, making its complete removal a dilemma for the surgeon. Facial nerve palsy was also more common postoperatively, potentially due to dehiscence of the facial canal in advanced disease stages, increasing the risk of intraoperative injury. Interestingly, no case of postoperative meningitis and encephalitis was noted in our study. This can be attributed to the use of aseptic protocols and, use of prophylactic antibiotics. In other studies, meningitis had a low prevalence of 2% [14, 19, 23, 24]. Based on our study, it is recommended that a patient with atticoantral CSOM should be evaluated with a high-resolution contrast-enhanced CT scan in order to determine the anatomy of the sigmoid sinus. Patients with anteriorly displaced or exposed sinuses should be considered high-risk. Surgeons should be prepared in such cases, as there can be a massive hemorrhage during the surgery. Hemostatic preparedness should be done in case of an exposed sinus. Post-operative follow-ups must be considered in case of forward lying and exposed sinus, as there are high chances of residual disease. To reduce intraoperative complications, surgical training workshops should educate the surgeons about sigmoid sinus

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variations and their impact on surgical complications. This study has limitations. The sample size was modest, and all patients were from a single center, limiting generalizability. Although HRCT provides high-resolution images, very subtle microanatomical variations may not be captured, potentially underestimating surgical risks. Future research with larger, multi-center cohorts and adjunct imaging modalities such as MR venography could provide a more comprehensive understanding of sigmoid sinus variations and their impact on surgical planning

CONCLUSIONS

Preoperative high-resolution CT reliably identifies anatomical variations of the sigmoid sinus in atticoantral CSOM, and these variations significantly impact intraoperative challenges, surgical complexity, and postoperative outcomes; recognizing anterior, posterior, or bony plate alterations allows surgeons to anticipate difficulties, minimize complications, and optimize disease clearance during tympanomastoidectomy.

Authors Contribution

Conceptualization: WS, MAI, AZ
Methodology: WS, FI
Formal analysis: MAI, HDK, HHM
Writing review and editing: WS, MAI, HDK, AZ, FI, HHM, RUK

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

All the authors declare no conflict of interest.

Source of Funding

The author received no financial support for the research, authorship and/or publication of this article.

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