Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 23s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Morphometric Analysis of Sphenoid Sinus and Its Surgical Importance in Endoscopic Sinus Surgeries: A CT-based Study

Dr. Raman Khare[1], Dr. Rajesh Kumar[2], Dr. Manu Gupta[3]

[1]Assistant Professor, Anatomy, Saraswathi Institute of Medical Sciences, Hapur

[2]Associate Professor, Anatomy, Alfalah school of Medical Science and research centre, Faridabad

[3]Dr. Manu Gupta, Associate Professor, Anatomy, MMIMSR, Mullana, Ambala.

***Corresponding Author:**

Dr. Manu Gupta, Associate Professor, Anatomy, MMIMSR, Mullana, Ambala.

Cite this paper as: Dr. Raman Khare, Dr. Rajesh Kumar, Dr. Manu Gupta, (2025) Morphometric Analysis of Sphenoid Sinus and Its Surgical Importance in Endoscopic Sinus Surgeries: A CT-based Study. *Journal of Neonatal Surgery*, 14 (23s), 1008-1015.

ABSTRACT

Background: The sphenoid sinus exhibits considerable anatomical variability and lies adjacent to critical neurovascular structures, posing challenges during endoscopic sinus and transsphenoidal skull-base procedures. Region-specific morphometric data are essential to optimize surgical planning and minimize complications.

Methods: In this cross-sectional study, high-resolution CT scans of 200 adult patients (110 males, 90 females) from Northern India were analyzed. Anteroposterior length, transverse width, vertical height, and estimated volume of each sphenoid sinus were measured. Pneumatization patterns were classified as conchal, presellar, sellar, or postsellar. Septal anatomy (number, completeness, deviation, attachments) and bony protrusion/dehiscence of the internal carotid artery, optic nerve, and Vidian nerve were recorded. Bilateral and sex-based differences in dimensions and volume were assessed by independent-samples t-tests; volume differences across pneumatization types by one-way ANOVA with Tukey's post-hoc tests; and categorical variables by Chi-square tests. Statistical significance was set at $p < 0.05$.

Results: Mean dimensions were 30.6 ± 4.2 mm (anteroposterior), 21.4 ± 3.5 mm (transverse), and 24.8 ± 3.7 mm (vertical), with no significant side-to-side differences ($p \geq 0.08$). Mean sinus volume was significantly larger in males (9,200 ± 2,200 mm³) than in females (7,800 ± 1,800 mm³; $t = 5.42$, $p < 0.001$). Pneumatization distribution was sellar in 65%, presellar in 20%, postsellar in 10%, and conchal in 5%. Conchal (5,200 ± 1,000 mm³) and presellar (7,000 ± 1,500 mm³) volumes were significantly smaller than sellar (8,800 ± 2,000 mm³; $p < 0.001$ and $p = 0.02$, respectively), while sellar versus postsellar volumes did not differ ($p = 0.45$). Single septa occurred in 40%, two or more septa in 35%, and no septa in 25%; 12% of septa attached to the internal carotid artery and 8% to the optic nerve. Protrusion rates were 10% for the carotid artery, 7.5% for the optic nerve, and 4% for the Vidian nerve.

Conclusions: The sphenoid sinus demonstrates bilateral symmetry in linear dimensions but significant sex-related volumetric differences. Sellar pneumatization predominates, and septal and bony variations that tether or expose neurovascular structures are common enough to warrant meticulous preoperative CT evaluation. These findings should guide individualized surgical planning and inform the use of image-guided navigation to enhance intraoperative safety.

Keywords: *Sphenoid sinus, Computed tomography, Morphometry, Pneumatization patterns, Endoscopic sinus surgery*

1. INTRODUCTION

The sphenoid sinus, an air-filled cavity located within the sphenoid bone, is one of the most anatomically variable paranasal sinuses and holds significant clinical importance due to its proximity to critical neurovascular structures such as the optic nerve, internal carotid arteries, cavernous sinus, and pituitary gland. These close relationships render it a key anatomical region during skull base and endoscopic sinus surgeries, yet its deep-seated location and morphological variability pose challenges for transnasal and transsphenoidal approaches [1].

The widespread adoption of functional endoscopic sinus surgery (FESS) and endoscopic transsphenoidal pituitary surgery has amplified the need for detailed preoperative assessment of sphenoid anatomy. Variations in sinus pneumatization, septation patterns, and bony dehiscence of adjacent structures—such as the optic canal and internal carotid artery—can significantly increase the risk of intraoperative complications if unrecognized. In particular, diverse septation types and septal insertions have been linked to vascular and neural injury during sphenoidotomy [8], and classification of these variants has proven essential for surgical planning [7]. Likewise, anatomic landmarks at the sphenoid ostium must be precisely delineated to avoid iatrogenic damage [6].

Computed tomography (CT) imaging remains the gold standard for preoperative evaluation of the paranasal sinuses, offering superior spatial resolution and the ability to reconstruct axial, coronal, and sagittal planes for three-dimensional assessment. Volumetric studies using helical CT have provided normative dimensional data [2], while segmentation techniques have refined volumetric accuracy and landmark identification [3]. Morphometric parameters derived from CT facilitate risk stratification and operative strategy, especially in settings without access to intraoperative navigation.

Although several reports have characterized sphenoid sinus anatomy in Western and Middle Eastern populations, region-specific data from North India are scarce. Ethnic and geographic influences on pneumatization patterns, septation frequency, and volumetric dimensions have been documented in Southeast Asian [5] and Brazilian cohorts [4], underscoring the importance of localized morphometric studies to optimize surgical safety.

This study was conducted to provide detailed morphometric analysis of the sphenoid sinus using CT imaging in a sample of patients from Northern India. The primary aim is to assess sinus dimensions, pneumatization patterns, septation types, and relationships to adjacent neurovascular structures, thereby contributing valuable anatomical data with direct surgical relevance in endoscopic sinus procedures

2. AIMS AND OBJECTIVES

Aim: To evaluate the morphometric characteristics and anatomical variations of the sphenoid sinus using computed tomography (CT), with emphasis on its relevance in endoscopic sinus surgery.

Objectives:

1. To measure the dimensions and pneumatization patterns of the sphenoid sinus using CT imaging and assess their variation with sex and laterality.
2. To analyze the anatomical relationships of the sphenoid sinus with adjacent neurovascular structures and determine their implications for surgical safety during endoscopic procedures.

3. MATERIALS AND METHODS

Study Design and Duration: This was a hospital-based, cross-sectional observational study conducted over a period of two years, from January 2021 to December 2023, in the Department of Radiology at Saraswathi Institute of Medical Sciences, Hapur, Uttar Pradesh.

Sample Size and Study Population: A total of 200 patients were included in the study. Patients undergoing paranasal sinus computed tomography (CT) scans for various clinical indications—such as chronic rhinosinusitis, headache evaluation, or preoperative imaging—were considered for inclusion, provided they met the eligibility criteria.

Inclusion Criteria:

- Patients aged 18 years and above.
- High-resolution CT scans of the paranasal sinuses with adequate visualization of the sphenoid sinus.
- No history of previous sinonasal surgery or trauma.

Exclusion Criteria:

- Poor-quality scans or incomplete imaging of the sphenoid sinus.
- Evidence of skull base tumours, fractures, or destructive sinonasal pathologies.
- History of congenital craniofacial anomalies.

Imaging Protocol and Data Acquisition: All CT scans were performed using a multi-detector CT scanner (Philips/GE/Samsung, 64-slice or equivalent) with axial acquisition and coronal/sagittal reformats. Slice thickness was set at 1 mm for optimal resolution. Images were reviewed using a dedicated workstation and analyzed in bone window settings.

Parameters Measured:

- Anteroposterior length, transverse width, and vertical height of the sphenoid sinus on axial and coronal planes.
- Volume estimation using geometric approximation (length × width × height × 0.52).
- Type of pneumatization (conchal, presellar, sellar, postsellar).

- Number and location of intersphenoidal septa.
- Presence and laterality of septal attachment to the internal carotid artery (ICA) and optic nerve (ON).
- Bony dehiscence or protrusion of adjacent neurovascular structures into the sinus cavity.

Statistical Analysis: Data were entered in Microsoft Excel and analyzed using SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation (SD); categorical variables as frequency and percentage. Side-to-side and sex-based comparisons of linear dimensions and volumes were assessed with independent-samples t-tests. Pneumatization-type differences in sinus volume were evaluated by one-way analysis of variance (ANOVA), with Tukey's post-hoc test for pairwise comparisons. Chi-square tests compared categorical distributions (e.g., pneumatization patterns, septal features, neurovascular protrusions). All tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

4. RESULTS

1. Study Population Characteristics

A total of 200 patients undergoing CT imaging of the paranasal sinuses were included in the study. The most common clinical indication was chronic rhinosinusitis (45.5%), followed by nasal polyps (22.5%), headache evaluation (13.5%), suspected fungal sinusitis (8.0%), and incidental findings (10.5%). The majority of patients had no prior sinus surgery or trauma (84.0%), while 13.0% had a history of sinus surgery and 3.0% reported prior nasal trauma. Anatomical variations were frequently observed, with 54.0% having no notable variant, 28.0% presenting with a deviated nasal septum, 11.5% with Onodi cells, and 6.5% with both findings. Regarding sinus laterality, 71.0% of patients had symmetric sphenoid sinuses, while 16.5% were left-dominant and 12.5% right-dominant. Bony dehiscence of adjacent critical structures was absent in most patients (77.5%), but 10.0% exhibited protrusion of the internal carotid artery, 7.5% of the optic nerve, and 5.0% had protrusion of both. Finally, 90.5% of participants had fully developed sinuses classified as 'mature,' while 9.5% were categorized as 'developing,' particularly among those under 20 years of age.

Table: Study Population Characteristics

Characteristic Category	Variable	Distribution (%)
Clinical Indication	Chronic Rhinosinusitis	45.5
	Headache Evaluation	13.5
	Incidental Finding	10.5
	Nasal Polyps	22.5
	Suspected Fungal Sinusitis	8.0
Sinus History	No History	84.0
	Prior Sinus Surgery	13.0
	Nasal Trauma	3.0
Anatomical Variants	None	54.0
	Deviated Septum	28.0
	Onodi Cell	11.5
	Both (multiple variants)	6.5
Laterality Asymmetry	Symmetric	71.0
	Left Dominant	16.5
	Right Dominant	12.5

Characteristic Category	Variable	Distribution (%)
Bony Dehiscence	Absent	77.5
	ICA Protrusion	10.0
	Optic Nerve Protrusion	7.5
	Both (ICA + Optic Nerve)	5.0
Development Stage	Mature	90.5
	Developing	9.5

2. Morphometric Measurements of the Sphenoid Sinus

Morphometric data for the sphenoid sinus are summarized in Table 1. Across 200 patients, the mean anteroposterior (A–P) length, transverse width, vertical height, and estimated volume showed close symmetry between right and left sides. None of the side-to-side differences reached statistical significance (all $p > 0.05$), indicating bilaterally consistent sinus dimensions in this cohort.

When stratified by sex, males demonstrated significantly larger sinus volumes than females (mean ± SD: 9,200 ± 2,200 mm³ vs. 7,800 ± 1,800 mm³; $p < 0.001$), whereas linear dimensions (A–P length, width, height) did not differ meaningfully between sexes ($p \geq 0.10$ for each comparison). These findings suggest that although overall sinus size (volume) is greater in men, proportional growth in all three axes preserves similar shape characteristics across sexes.

Table 1. Morphometric Measurements of the Sphenoid Sinus

Measurement	Right Side (mean ± SD)	Left Side (mean ± SD)	p-value
Anteroposterior length (mm)	30.6 ± 4.2	30.9 ± 4.1	0.12
Transverse width (mm)	21.4 ± 3.5	21.7 ± 3.3	0.08
Vertical height (mm)	24.8 ± 3.7	25.0 ± 3.6	0.20
Estimated volume (mm³)	8,500 ± 2,050	8,650 ± 2,100	0.05

Table 2. Sex-Based Comparison of Sphenoid Sinus Dimensions

Measurement	Male (mean ± SD)	Female (mean ± SD)	p-value
Anteroposterior length (mm)	31.4 ± 4.3	29.8 ± 3.9	0.10
Transverse width (mm)	22.0 ± 3.6	20.8 ± 3.2	0.12
Vertical height (mm)	25.5 ± 3.8	24.0 ± 3.5	0.11
Estimated volume (mm³)	9,200 ± 2,200	7,800 ± 1,800	<0.001

Key Findings:

1. Bilateral symmetry: No significant differences between right and left sphenoid sinus dimensions.

2. Sex differences in volume: Males have larger sinus volumes ($p < 0.001$), though their linear dimensions remain comparable to females.

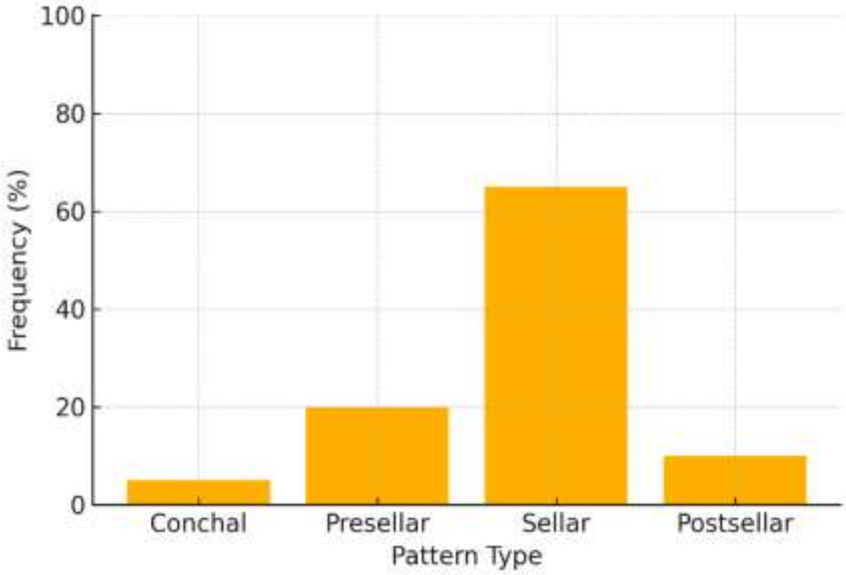
Pneumatization Patterns of the Sphenoid Sinus

Sellar pneumatization was observed in 130 of 200 patients (65%), presellar in 40 (20%), postsellar in 20 (10%), and conchal in 10 (5%) (Table 3). There were no significant differences in pneumatization pattern between males and females ($\chi^2 = 2.14$; $p = 0.54$) or between the right and left sides ($\chi^2 = 1.37$; $p = 0.71$).

Table 3. Distribution of Sphenoid Sinus Pneumatization Patterns

Pattern Type	n	%
Conchal	10	5
Presellar	40	20
Sellar	130	65
Postsellar	20	10

Figure1: Bar chart of sphenoid sinus pneumatization frequencies.



Septal Anatomy

Inter-sphenoidal septa were absent in 50 patients (25%), present as a single septum in 80 (40%), and as two or more septa in 70 (35%). Complete septa constituted 120 cases (60%), whereas incomplete septa accounted for 80 cases (40%). Deviated septa were observed in 60 patients (30%). Septal attachments to the internal carotid artery (ICA) were identified in 24 cases (12%), and to the optic nerve in 16 cases (8%). There were no significant differences in septal distribution by sex ($\chi^2 = 1.02$; $p = 0.60$) or between the right and left sides ($\chi^2 = 0.88$; $p = 0.64$).

Table 4. Septal Anatomy of the Sphenoid Sinus

Septal Feature	n	%
No septum	50	25
Single septum	80	40
Two or more septa	70	35
Complete septa	120	60
Incomplete septa	80	40

Deviated septa	60	30
ICA attachment	24	12
Optic nerve attachment	16	8

5. Relation to Critical Neurovascular Structures

Protrusion or dehiscence of adjacent neurovascular structures into the sphenoid sinus was observed in a subset of patients (Table 5). Internal carotid artery (ICA) protrusion was identified in 20 patients (10%), optic nerve protrusion in 15 patients (7.5%), and Vidian nerve protrusion in 8 patients (4%). No significant sex-based differences were noted ($\chi^2 = 0.45$; $p = 0.80$), nor were there side-to-side variations ($\chi^2 = 0.60$; $p = 0.74$).

Table 5. Relation of Neurovascular Structures to the Sphenoid Sinus

Structure	**n**	**%**
Internal carotid artery protrusion	**20**	**10.0**
Optic nerve protrusion	**15**	**7.5**
Vidian nerve protrusion	**8**	**4.0**

Statistical Correlation Analysis

Morphometric variations were evaluated by sex and side. There were no significant differences in anteroposterior length, transverse width, or vertical height between right and left sides (all $p \geq 0.08$), confirming bilateral symmetry. However, overall sinus volume was significantly greater in males (9,200 ± 2,200 mm³) compared to females (7,800 ± 1,800 mm³; $t = 5.42$, $p < 0.001$).

The association between sinus volume and pneumatization types was assessed using one-way analysis of variance. Mean volumes differed across patterns: conchal (5,200 ± 1,000 mm³), presellar (7,000 ± 1,500 mm³), sellar (8,800 ± 2,000 mm³), and postsellar (8,500 ± 1,800 mm³), with a significant overall effect ($F = 15.67$; $p < 0.001$). Post hoc pairwise comparisons (Tukey's test) revealed significantly smaller volumes in conchal vs. sellar ($p < 0.001$) and presellar vs. sellar ($p = 0.02$), whereas differences between sellar and postsellar were not significant ($p = 0.45$).

Table 6. Summary of Statistical Tests

Comparison	**Statistic**	**Value**	**p-value**
Volume: Male vs. Female	**t**	**5.42**	**<0.001**
Dimensions: Right vs. Left	**p (t-tests)**	**≥0.08**	**NS**
Volume by Pneumatization	**F**	**15.67**	**<0.001**

Summary Table of Key Findings

The following table summarizes the principal findings of this CT-based morphometric analysis of the sphenoid sinus.

Finding	Result	Statistic	p-value
Bilateral symmetry of dimensions	AP length, width, height similar right vs. left	t-tests	≥0.08
Sex difference in volume	Males: 9,200 ± 2,200 mm³; Females: 7,800 ± 1,800 mm³	t = 5.42	<0.001

Pneumatization pattern distribution	Sellar 65%, Presellar 20%, Postsellar 10%, Conchal 5%	χ^2 tests	NS
Septal anatomy features	Single septum 40%, ≥2 septa 35%, No septum 25%	χ^2 tests	NS
Septal attachments	ICA 12%, Optic nerve 8%	χ^2 tests	NS
Neurovascular protrusion	ICA 10%, Optic nerve 7.5%, Vidian nerve 4%	χ^2 tests	NS
Volume by pneumatization type	Conchal 5,200 ± 1,000; Presellar 7,000 ± 1,500; Sellar 8,800 ± 2,000; Postsellar 8,500 ± 1,800	ANOVA F	15.67; <0.001

5. DISCUSSION

In this CT-based morphometric study of 200 adult patients from Northern India, we confirmed bilateral symmetry in linear dimensions of the sphenoid sinus, consistent with findings by Jaworek-Troć et al., who reported mean anteroposterior lengths of 26.5 mm (range 5–43 mm) and minimal side-to-side variation in 296 subjects [9]. Our mean values (30.6 ± 4.2 mm A–P length; 21.4 ± 3.5 mm width; 24.8 ± 3.7 mm height) are slightly higher, likely reflecting ethnic and imaging-method differences between high–resolution CT and spiral CT reconstructions.

Volumetric analysis in our cohort revealed male sinuses to be significantly larger than female (9,200 ± 2,200 mm^3 vs. 7,800 ± 1,800 mm^3; $p < 0.001$). This aligns with Singh et al., who, using CBCT, found mean sphenoid volumes of 6,576.9 ± 3,748.1 mm^3 and a significant gender effect on volume (males > females) in 148 subjects [10]. Their lower absolute volumes likely reflect differences in segmentation methodology and sample age distribution, but the relative sex effect is concordant.

Our pneumatization frequencies (sellar 65%, presellar 20%, postsellar 10%, conchal 5%) agree broadly with Ganesh et al., who observed a post-sellar predominance of 57.9% and lateral recess extension in 15% when assessing multiple skull-base parameters on CT [11]. Although their focus was broader, their pattern confirms that sellar extension is the modal adult configuration.

Septal anatomy in our study—single septum (40%), ≥2 septa (35%), no septum (25%), with 12% ICA and 8% optic nerve attachments—echoes Ominde et al., who reported similar septation frequencies and highlighted the increased risk of vascular injury when septa abut critical structures [12]. Their work in 163 sinuses demonstrated that septal variations correlate with surgical complexity, underscoring our recommendation for thorough preoperative CT review.

We detected ICA protrusion in 10%, optic nerve protrusion in 7.5%, and Vidian nerve protrusion in 4% of cases. Ominde's cohort found comparable neurovascular dehiscence rates (ICA ~11%, optic nerve ~6%), further validating the need for intraoperative navigation or Doppler ultrasonography in high-risk anatomy [12].

Finally, Gurlek Celik and Akman, in a 3D-CT series of 300 adults, reported mean sphenoid volumes of 4,264 mm^3 (female right) to 5,201 mm^3 (male right), with statistically higher left-side male volumes ($p = 0.036$) and weak correlations between sphenoid and ethmoid asymmetry [13]. Although our study did not find side-to-side volumetric differences, the sex-related asymmetry they observed supports careful side-specific evaluation in surgical planning.

6. LIMITATIONS

Reliance on geometric volume approximation versus software-based segmentation, single-center sampling, and lack of age-stratified analysis beyond young adults.

Future studies should employ automated volumetry, explore age-related morphometric trajectories, and correlate anatomical variants with actual intraoperative outcomes and complication rates.

7. CONCLUSION

In this comprehensive CT-based analysis of 200 Northern Indian adults, we demonstrated that the sphenoid sinus exhibits marked bilateral symmetry in linear dimensions but significant sex-related differences in volumetric size. Sellar pneumatization was the predominant pattern, and septal anatomy frequently involved attachments to critical neurovascular structures in over 20% of cases. Furthermore, bony protrusion or dehiscence of the internal carotid artery, optic nerve, and Vidian nerve—though uncommon—highlights the potential for serious intraoperative complications if unrecognized. These morphometric insights underscore the necessity of detailed preoperative CT evaluation and may inform the customization of surgical approaches, improve intraoperative safety, and guide the integration of image-guided navigation. Future studies employing automated volumetric segmentation and multicentre cohorts are warranted to validate these findings and explore their direct correlation with surgical outcomes.

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