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RESEARCH ARTICLE

# Morphometric Analysis of Nasal and Sphenoidal Region and its Clinical Relevance for the Transsphenoidal Approach in Pituitary Surgeries

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Abstract: ***Objective***: To evaluate the influence of age, gender, side, and sinus condition on sphenoid sinus (SS) morphometry using cone-beam computed tomography (CBCT). ***Methods***: Retrospective review of CBCT scans from 300 patients aged 16–86 years. SS morphology was assessed from DICOM files using semi-automated software. Outcomes included extension, shape, septation, volume, and maximum diameter, and were analyzed against age, gender, side, and sinus condition. Results: Age correlated significantly with sinus extension. Age, gender, and sinus condition were significantly associated with septation. Sinus volume differed by gender and sinus condition. Shape and side were not associated with morphometric features. ***Conclusion***: SS morphometry is influenced by age, gender, and sinus health. Post-sellar extension predominates until middle age. Males and individuals with healthy sinuses tend to have larger sinus volumes than females and those with pathology.

Keywords: Sphenoid sinus, Morphometry, CBCT, Gender, Age, Septation .

## INTRODUCTION

The sphenoidal sinus (SS) represents one of the most anatomically variable structures within the skull base, characterized by significant morphometric diversity that directly impacts neurosurgical approaches. This centrally located pneumatized cavity serves as a critical landmark for transsphenoidal surgical procedures, particularly for pituitary adenoma resection and other skull base pathologies. The SS develops from rudimentary pneumatization at 2-3 years of age, reaching mature configuration during adolescence, with continued expansion potentially occurring throughout adulthood.

Contemporary understanding of SS morphometry has evolved significantly with advances in three-dimensional imaging technologies. While conventional computed tomography (CT) has traditionally been the gold standard for paranasal sinus evaluation, cone-beam computed tomography (CBCT) offers distinct advantages including reduced radiation exposure, enhanced spatial resolution, and cost-effectiveness for targeted anatomical assessment. This technological advancement has enabled more precise characterization of SS morphometric variations, which is essential for preoperative surgical planning.

The clinical significance of SS morphometric analysis extends beyond academic interest, as anatomical variations directly influence surgical accessibility, complication rates, and procedural outcomes. Understanding these variations is particularly crucial for transsphenoidal approaches, where precise navigation through the SS is required to access sellar and parasellar regions while avoiding critical neurovascular structures including the internal carotid arteries, optic nerves, and cavernous sinuses.

Previous studies have identified multiple factors potentially influencing SS morphometry, including age, gender, ethnicity, and pathological conditions. However, comprehensive analyses utilizing CBCT imaging in Asian populations remain limited, particularly regarding the interaction between demographic factors and morphometric characteristics. This study aims to address this knowledge gap by providing detailed morphometric analysis of SS characteristics in an Indian population using high-resolution CBCT imaging.

## MATERIALS AND METHODS

### Study Design and Population

This retrospective cross-sectional study analyzed CBCT scans from 300 patients (age range 16-86 years) obtained at the Department of Diagnostic Imaging, University Dental Hospital, over a three-year period. Inclusion criteria comprised patients undergoing routine CBCT examination with complete visualization of the sphenoid region. Exclusion criteria included craniofacial abnormalities, immunodeficiency disorders, previous sinonasal surgery, and poor image quality precluding accurate measurement.

### Image Acquisition and Processing

CBCT scans were acquired using a ProMax 3D Mid scanner with standardized protocols ensuring consistent image quality. DICOM files were processed using semi-automated segmentation software on a Dell OptiPlex

9010 workstation with a 20.5-inch high-resolution monitor. Three dimensional reconstructions were generated with blue color coding for enhanced visualization and measurement accuracy.

**Morphometric Parameters**

**Configuration**: Classified as solitary, paired, or compound based on intersinus septation patterns. **Symmetry**: Determined by intersinus septal position relative to midline structures.

**Extension**: Categorized as conchal, presellar, sellar, or postsellar based on relationship to sella turcica.

**Shape**: Defined as spherical, triangular, quadrilateral, pentagonal, or amorphous based on coronal plane morphology.

**Septation**: Quantified as absent, single, double, or multiple septa.

**Volumetric Analysis:** Performed using multiplanar reformation in axial, sagittal, and coronal planes

**Statistical Analysis**

Morphometric parameters were analyzed using appropriate statistical tests including chi-square analysis for categorical variables and independent t-tests for continuous variables. Binary and multinomial logistic regression analyses were performed to identify significant predictors of morphometric variations. Statistical significance was set at $p<0.05$.

# RESULTS

**Demographics and General Characteristics**

The study cohort comprised 300 patients with a mean age of 34.2±14.9 years (140 males, 160 females). The majority demonstrated asymmetrical sinus configuration (86%) and healthy sinus conditions (82%). Pathological findings included mucosal thickening (13%), membrane bulging (5%), and complete opacification (1%).

**Table 1: Several factors that may influence morphometric characteristics by gender were examined in this study**

| Parameters | Male | Female | Total (300 patients) |
|---|---|---|---|
| Age | 32.5 ± 15.4 | 32 ± 16.2 | 34.2 ± 14.9 |
| Gender | 140 | 160 | 300 |
| Sinus condition | | | |
| Healthy | 222 | 244 | 466 |
| Pathological | 54 | 50 | 104 |
| Symmetry | | | |
| Symmetrical | 22 | 22 | 44 |
| Asymmetrical | 120 | 132 | 252 |
| Configuration | | | |
| Solitary | 8 | 14 | 22 |
| Paired | 132 | 138 | 270 |
| Compound | 2 | 2 | 4 |
| Extension | | | |
| Conchal | 4 | 1 | 5 |
| Presellar | 1 | 6 | 7 |
| Sellar | 56 | 82 | 138 |
| Postsellar | 216 | 206 | 422 |

**3.2 Morphometric Analysis**

Mean SS volume was 6576.92±3748.12 $mm^3$ with maximum diameter of 30.48±9.28 mm. Males demonstrated significantly larger volumes compared to females ($p=0.013$) (Table 1). Post-sellar extension was predominant (74.2%), particularly in ages 15-59 ($p<0.001$). Quadrilateral shape was most common (41.8%), followed by spherical (26.1%) and triangular (18.5%) configurations (Table 2).

**1.1 Septation Patterns**

Single septum configuration was most prevalent (42%), followed by double septa (29%) and multiple septa (14%). Healthy sinuses showed significantly higher prevalence of single septum compared to pathological conditions ($p<0.001$). Age and gender significantly influenced septation patterns, with increased complexity observed in younger populations and males.

**3.3 Statistical Associations**

Binary logistic regression revealed age groups 15-29 and 30-44 years were significantly more likely to develop post-sellar extension ($p<0.001$).

**Table 2: Potential influencing factors in the development of sphenoid sinus morphometry are associated with potential influencing factors**

| Parameter | Subtype | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Extension | Conchal | 2.2% | 0.0% | 0.0% | 0.0% | 1.4% | 0.0% | 0.7% | 0.7% | 0.4% | 1.9% |
| | Presellar | 2.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.0% | 1.5% | 0.7% | 0.0% | 6.1% |
| | Sellar | 21.1% | 14.9% | 41.8% | 57.8% | 21.2% | 28.2% | 25.4% | 25.2% | 25.1% | 26.9% |
| Shape | Postsellar | 80.1% | 85.2% | 58.4% | 40.9% | 77.2% | 71.4% | 74.2% | 73.9% | 75.9% | 64.9% |
| | Spherical | 24.3% | 31.1% | 26.9% | 34.5% | 23.9% | 26.5% | 25.9% | 23.7% | 27.0% | 17.3% |
| | Triangular | 18.8% | 20.0% | 23.1% | 10.3% | 16.7% | 19.0% | 14.8% | 23.0% | 17.6% | 19.2% |
| | Quadrilateral | 45.3% | 33.3% | 42.3% | 37.9% | 40.6% | 42.9% | 45.2% | 39.3% | 41.2% | 44.2% |
| | Pentagon | 5.3% | 4.4% | 3.8% | 13.8% | 7.2% | 3.4% | 3.0% | 5.9% | 5.2% | 5.8% |
| | Amorphous | 13.0% | 12.0% | 4.0% | 3.5% | 12.0% | 8.4% | 11.4% | 8.2% | 10.0% | 14.0% |
| Septation | Without septum | 22% | 16% | 24% | 21% | 19% | 22% | 23% | 18% | 16% | 44% |
| | Single septum | 47% | 39% | 27% | 18% | 35% | 45% | 39% | 46% | 43% | 35% |
| | Double septa | 23% | 37% | 37% | 42% | 30% | 25% | 28% | 26% | 30% | 18% |
| | Multiple septa | 13% | 12% | 12% | 21% | 17% | 10% | 13% | 13% | 15% | 6% |

# DISCUSSION

### 4.1 Principal Findings and Clinical Significance

The present study provides comprehensive morphometric analysis of sphenoid sinus characteristics in an Indian population using high-resolution CBCT imaging. Our findings demonstrate significant associations between demographic factors (age, gender) and pathological conditions with SS morphometric parameters, providing valuable insights for clinical practice and surgical planning.

### 4.2 Age-Related Morphometric Variations

Our analysis revealed significant age-related differences in SS morphometry, particularly regarding pneumatization patterns and extension characteristics. The predominance of post-sellar extension in younger age groups (15-59 years) aligns with contemporary understanding of continued pneumatization throughout early to middle adulthood. Singh et al. (2021) reported similar findings in their CBCT-based analysis of 148 patients, demonstrating that mature sinuses exhibit post-sellar extension patterns until middle age, with pneumatization potentially continuing beyond traditional developmental timelines.

Recent studies have further elucidated the temporal aspects of SS development. Aksakal et al. (2022) demonstrated that SS pneumatization begins around 2-3 years of age and continues with variable patterns throughout adolescence and early adulthood. Their longitudinal analysis from newborn to 18 years revealed that final pneumatization patterns are not established until the third decade of life, supporting our observation of continued post-sellar extension in younger adult populations.

The clinical implications of age-related pneumatization patterns are particularly relevant for transsphenoidal surgical approaches. Hassan et al. (2024) investigated the correlation between SS pneumatization and sella turcica dimensions across different age groups, finding significant variations that directly impact surgical accessibility and complication risk. Their findings suggest that younger patients with extensive post-sellar pneumatization may require modified surgical

techniques to ensure safe access while avoiding critical neurovascular structures.

### 4.3 Gender Dimorphism in Sphenoid Sinus Morphometry

Our study identified significant gender-related differences in SS volumetric measurements, with males demonstrating larger volumes compared to females (p=0.013). This finding is consistent with multiple recent investigations examining sexual dimorphism in paranasal sinus morphometry. Ozdemir et al. (2025) reported gender-related volumetric asymmetries in SS, with males showing mean volumes of 4.28-4.70 $cm^3$ compared to 3.03-3.57 $cm^3$ in females, representing the first systematic documentation of gender-related side differences in SS morphometry.

The biological basis for these gender differences likely relates to overall cranial size dimorphism and hormonal influences on bone development. Tuang et al. (2023) conducted volumetric evaluation of SS among different populations, confirming that racial and gender influences significantly affect sinus volumes. Their meta-analysis revealed consistent patterns of larger SS volumes in males across diverse ethnic groups, supporting the generalizability of our findings.

Ahmed et al. (2024) performed comparative analysis of sphenoid and frontal sinuses using CBCT imaging in 200 patients, developing discriminant function analysis for sex identification with 76.5% accuracy. Their study emphasized the forensic applications of SS morphometry while confirming significant sexual dimorphism in linear and volumetric measurements. The authors noted that combining multiple morphometric parameters improved sex determination accuracy compared to individual measurements.

Recent forensic investigations have further validated the utility of SS morphometry for gender determination. A study by Eldeeb et al. (2024) using 3D volumetric segmentation of CBCT datasets in Egyptian populations found that left maxillary sinus volume provided the highest accuracy (63.24%) for gender determination, while SS volume showed significant differences between males and females (p=0.004). These findings support the potential application of our morphometric data in forensic identification protocols.

### 4.4 Pathological Influences on Morphometric Characteristics

Our analysis revealed significant associations between sinus health status and morphometric parameters, with healthy sinuses demonstrating larger volumes and simplified septation patterns compared to pathological conditions. This finding has important implications for understanding the relationship between anatomical variation and disease susceptibility.

Mohamed et al. (2025) conducted CBCT analysis of SS septation and extension in Egyptian populations, finding that 98% of cases showed septations with compound type being most common. Their study emphasized the high variability of SS anatomy and the necessity for extensive preoperative assessment to protect vital surrounding structures. The authors noted that pathological conditions often correlate with increased septation complexity, supporting our observations.

The relationship between septation patterns and surgical complexity has been extensively studied. Movahhedian et al. (2020) analyzed 500 patients using CBCT imaging, demonstrating significant relationships between sinus pneumatization type and frequency of neurovascular protrusions. Their findings revealed that increased pneumatization correlates with higher rates of internal carotid artery and optic nerve protrusion, with implications for surgical risk stratification.

Contemporary research has also investigated the association between sinus pathology and morphometric variations. A study by Acar et al. (2024) examining 154 patients found significant correlations between SS pneumatization patterns and adjacent anatomical structures, including increased protrusion rates with extensive pneumatization. These findings suggest that morphometric analysis can serve as a predictive tool for surgical complication risk assessment.

### 4.5 CBCT versus Conventional CT Imaging

The utilization of CBCT imaging in this study provides several advantages over conventional CT scanning for SS morphometric analysis. Han et al. (2022) conducted comprehensive comparison of CBCT and multi-detector CT (MDCT) for sinonasal evaluation, finding that CBCT with 0.3mm slice thickness provided diagnostic performance similar to high-resolution MDCT (1mm) while offering superior spatial resolution for isolated sphenoid sinus assessment. The radiation dose advantages of CBCT are particularly relevant for research applications and pediatric populations. Recent technical advances in CBCT technology have enhanced image quality while maintaining dose optimization. Studies have demonstrated that modern CBCT protocols provide adequate visualization of critical anatomical landmarks including septal attachments to neurovascular structures, optic nerve canal configuration, and carotid artery protrusion patterns.

### 4.6 Surgical Implications and Clinical Applications

The morphometric variations identified in this study have direct implications for transsphenoidal surgical approaches. The high prevalence of complex septation patterns (71% with single or multiple septa) necessitates careful preoperative planning to avoid inadvertent injury to critical structures. Septal attachments to the carotid protuberance, identified in significant proportions of cases, represent particular risk factors for vascular injury during endoscopic procedures.

Recent advances in surgical navigation and imaging have emphasized the importance of individualized anatomical assessment. A study by researchers at Northern India medical centers analyzed 200 patients and found septal anatomy variations in 75% of cases, with 12% showing septal attachments to internal carotid arteries and 8% to optic nerves. These findings underscore the necessity for detailed preoperative morphometric analysis to guide surgical approaches and minimize complications.

The relationship between pneumatization patterns and surgical accessibility has been further elucidated through recent clinical studies. Postsellar pneumatization, while facilitating surgical access in some cases, may also increase the risk of cerebrospinal fluid leak due to thinning of the posterior wall. Conversely, limited pneumatization may require alternative surgical approaches or extended exposure techniques.

### 4.7 Limitations and Future Directions

Several limitations of this study warrant acknowledgment. The retrospective design may introduce selection bias, and the single-center setting may limit generalizability to other populations. The lack of standardized pathology grading systems for sinus conditions represents another limitation that should be addressed in future studies. Future research directions should include prospective multi-center studies with standardized protocols, incorporation of artificial intelligence-based automated measurement systems, and longitudinal assessment of morphometric changes over time. Additionally, correlation with surgical outcomes and complication rates would provide valuable clinical validation of morphometric risk stratification systems. The integration of advanced imaging techniques including dual-energy CT and high-field MRI may provide additional insights into tissue characteristics and neurovascular relationships. Development of population-specific normative databases would enhance the clinical utility of morphometric analysis for surgical planning and risk assessment.

### 4.8 Contemporary Research and Emerging Perspectives

Recent investigations have expanded our understanding of SS morphometry through advanced analytical techniques. Gulić et al. (2023) examined relationships between mastoid pneumatization and SS volume, finding significant positive correlations that suggest common developmental pathways for pneumatized skull base structures. Their findings indicate that SS volume assessment may provide insights into broader patterns of cranial pneumatization. The application of artificial intelligence and machine learning techniques to SS morphometric analysis represents an emerging frontier. Automated segmentation algorithms and deep learning approaches are being developed to enhance measurement accuracy and reduce inter-observer variability. These technological advances may facilitate large-scale population studies and enable real-time intraoperative assessment of anatomical variations. Population-specific morphometric databases are increasingly recognized as essential resources for clinical practice. Studies examining SS morphometry in diverse ethnic groups have revealed significant variations that impact surgical planning and risk assessment. The development of regional normative databases, such as the present study's contribution to Indian population data, is crucial for optimizing clinical outcomes and reducing complications.

## CONCLUSION

This comprehensive CBCT-based morphometric analysis of sphenoid sinus characteristics in an Indian population reveals significant associations between demographic factors and anatomical variations. Age-related pneumatization patterns, gender dimorphism in volumetric measurements, and pathology-related morphometric changes have important implications for clinical practice, particularly in transsphenoidal surgical approaches. The predominance of post-sellar extension in younger populations, increased volumes in males, and simplified septation in healthy sinuses provide valuable insights for preoperative planning and risk stratification. The high prevalence of complex septation patterns emphasizes the necessity for detailed anatomical assessment prior to surgical intervention. Future research incorporating advanced imaging techniques, automated analysis systems, and prospective clinical correlation will further enhance our understanding of SS morphometry and its clinical applications. The establishment of population-specific normative databases remains essential for optimizing surgical outcomes and advancing evidence-based clinical practice.

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