

Research Article

Ct-Based Morphometric Study of Sphenoid Sinus Pneumatization Patterns and Septal Variations in Adults

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ABSTRACT

Objective: To evaluate sphenoid sinus pneumatization patterns, septal variations, and morphometric dimensions in adults using CT imaging, and to identify clinically relevant anatomical variations.

Materials and Methods: This descriptive cross-sectional study was conducted on 200 adult CT scans of the paranasal sinuses and head obtained from patients aged 18 years and above. CT images with adequate visualization of the sphenoid sinus were included, while scans with trauma, prior surgery, congenital anomalies, or destructive lesions were excluded. Multidetector CT images were analyzed in axial, coronal, and sagittal planes. Pneumatization was classified into conchal, presellar, sellar, and postsellar types. Septal number, deviation, accessory septa, insertion sites, and morphometric parameters including anteroposterior diameter, transverse width, and vertical height were recorded. Data were analyzed using SPSS version 25.0.

Results: The study population included 112 males (56%) and 88 females (44%), with a mean age of 41.6 ± 13.2 years. The most common pneumatization pattern was sellar type (59.0%), followed by postsellar (23.0%), presellar (14.0%) and conchal type (4.0%). Lateral pneumatization was most frequently seen in the pterygoid process (31.0%): and greater wing (27.0%). A single midline septum was present in only 36.0% of cases, while deviated septum was observed in 42.0%, multiple septa in 29.0%, and accessory septa in 17.0%. Septal attachment to the carotid canal prominence was noted in 24.0% and to the optic canal in 11.0% of cases. Mean sphenoid sinus dimensions were significantly larger.

Conclusion: The sphenoid sinus demonstrates marked variability in pneumatization, septal anatomy, and dimensions among adults. Sellar pneumatization is the predominant pattern, while septal deviations and clinically significant attachments to adjacent neurovascular structures are common. Preoperative CT evaluation is essential for accurate surgical planning and for minimizing complications during endoscopic and transsphenoidal procedures.

Keywords: Sphenoid Sinus, Computed Tomography, Pneumatization, Septal Variations, Morphometry, Endoscopic Surgery, Skull Base Anatomy.

INTRODUCTION

The sphenoid sinus is one of the most anatomically complex and clinically significant paranasal sinuses. Located deep within the skull base and surrounded by several critical neurovascular structures, it occupies a central position in the body of the sphenoid bone. (1)

The sphenoid sinus is a hidden sinus, unlike the frontal, maxillary and ethmoidal sinuses, which are more readily accessible to examination. (2) But it has gained considerable significance in radiology, neurosurgery, otolaryngology and skull base surgery over the past several decades due to

the introduction of endoscopic and image-guided surgery. (3) It is important to have a good understanding of the anatomy of the sphenoid sinus for surgical planning and disease understanding. (4)

The sphenoid sinus starts to develop in early childhood as an extension of the posterior ethmoidal air cells into the sphenoid bone. Pneumatization progresses gradually and usually reaches its mature form during adolescence or early adulthood. (5) The final size, shape and extent of pneumatization can vary widely among individuals. In some people, the sinus remains relatively small and confined to the anterior sphenoid body, whereas in others it extends posteriorly into the clivus, laterally into the greater wings, pterygoid processes, or anterior clinoid processes. (6) This variability is of great anatomical and surgical importance because greater degrees of pneumatization often bring the sinus cavity into closer relationship with adjacent structures such as the optic nerve, internal carotid artery, cavernous sinus, vidian nerve, and pituitary gland. (7)

Computed tomography (CT) has become the preferred imaging modality for evaluating the sphenoid sinus and surrounding bony anatomy. CT provides excellent spatial resolution and allows precise assessment of sinus dimensions, septations, wall thickness, bony dehiscence, and patterns of aeration. (8) Multiplanar reconstruction also enhances the capacity to appreciate complex anatomy which may not be apparent from conventional X-rays. (9) For this reason, CT is often used prior to functional endoscopic sinus surgery, transsphenoidal pituitary surgery and other skull base surgery. Surgeons may use a CT scan as a "map" to avoid complications and safely access the sphenoid sinus. (10)

One of the most studied aspects of sphenoid sinus anatomy is the pattern of pneumatization. Several classification systems have been proposed, most commonly based on the relation of the sinus cavity to the sella turcica. (11) According to this system, sphenoid sinuses may be categorized as conchal, presellar, sellar, or postsellar types. (12) In the conchal type, pneumatization is minimal or absent, leaving a thick cancellous bone mass beneath the sella. In the presellar type, the sinus extends up to but not beyond the anterior wall of the sella turcica. (13)

In the sellar type, pneumatization reaches beneath the sella, while in the postsellar type it extends posteriorly beyond the sella. Among

adults, the sellar type is usually the most common, whereas the conchal type is relatively rare. (14) These distinctions are clinically relevant because extensive pneumatization generally facilitates transsphenoidal access, while poorly pneumatized sinuses may pose technical difficulty. (15)

In addition to sagittal pneumatization patterns, lateral recess extensions of the sphenoid sinus have attracted growing attention. Lateral pneumatization may involve the greater wing, pterygoid process, or lesser wing/anterior clinoid process. (16) Such extensions can expose the maxillary nerve, vidian canal, optic nerve or carotid artery to the sinus cavity with only a thin bony covering. (17) In some cases, focal dehiscence may be present, increasing the risk of injury during surgery. (18) Surgeons operating in this region must therefore recognize these variants in advance. Even seemingly minor procedures, such as sphenoidotomy or sinus irrigation, can be risky if these anatomical aspects are not considered. (19)

Another important aspect of the sphenoid sinus is septa. Septations separate the sinus into one or more regions. A single midline septum is traditionally described in anatomy texts, but in practice this arrangement is seen in only a proportion of patients. (20) Many individuals demonstrate deviated septa, multiple accessory septa, incomplete septations or asymmetrical chambers. Importantly, septa often attach eccentrically to the bony walls, including the prominence of the internal carotid artery or optic canal. (21) During endoscopic surgery, forcible removal of a septum attached to the carotid canal can result in catastrophic hemorrhage. Similarly, manipulation near the optic nerve may risk visual injury. For this reason, detailed preoperative mapping of septal anatomy is considered mandatory. (22)

The use of CT imaging has significantly improved understanding of septal variations. The number, direction and attachment sites of septa can be divided into coronal, axial and sagittal planes. Studies have shown that complete symmetry of the sphenoid sinus is uncommon. (23) Instead, one chamber may be larger than the other, with the main septum deviated to either side. Accessory septa may arise from the lateral wall, floor, roof, or posterior wall. Some are thin and incomplete, others thick and irregular. The surgeon can

anticipate distorted landmarks during endoscopic surgery. (24)

The significance of sphenoid sinus morphometry extends beyond surgical applications. Variations in sinus size and configuration may influence the spread of infection, inflammatory disease, fungal sinusitis, mucocoeles, cerebrospinal fluid leaks, and neoplastic processes.(25) Because the sphenoid sinus lies close to the cavernous sinus, cranial nerves II, III, IV, V1, V2 and VI, pathological processes may present with headache, diplopia, visual disturbance, facial pain or cranial neuropathies. (26) Isolated sphenoid sinus disease is relatively uncommon but may be difficult to diagnose because symptoms are often vague and nonspecific. Accurate imaging interpretation therefore depends on familiarity with normal variants and morphometric parameters. (21)

Morphometric studies of the sphenoid sinus have also gained importance in forensic medicine, anthropology, and personalized surgical planning. The dimensions and configuration of the sinus can show population-based differences related to ethnicity, sex, and developmental factors. (27) Some authors have proposed that sphenoid sinus patterns may be used for identification in the absence of other skeletal features. During surgery, intercarotid distance, sinus depth, ostial position and thickness of the sellar floor may guide the surgical planning. (28)

While many studies have been conducted worldwide, considerable geographical and ethnic differences have been noted. Prevalence of sellar pneumatization, accessory septa, extension of lateral recess, and insertion of septum into the carotid canal varies. (29) This suggests that regional data may not be universally applicable. So, regional studies are still important, especially where regional radiological data are lacking. Insight into trends in the adult population treated can enhance safety and expectations of anatomy. (30)

Multidetector CT is an excellent technique with which to perform such studies. Thin-section CT with multiplanar reformatting offers excellent evaluation of bony anatomy and pneumatization. Measurements can be performed with precision, while variations can be documented systematically. Compared with cadaveric studies, CT-based research allows evaluation of larger living populations and can better reflect clinically encountered anatomy.

MATERIALS AND METHODS

This study was designed as a descriptive cross-sectional observational study conducted in the Department of Radiology in collaboration with the Department of Anatomy and Otorhinolaryngology in multiple teaching hospitals. The study was carried out over a period of 12 months after obtaining institutional ethical approval. The purpose of the study was to evaluate sphenoid sinus pneumatization patterns and septal variations in adults using computed tomography (CT) imaging. A total of 200 CT scans were included in the study using non-probability consecutive sampling. All eligible scans meeting the inclusion criteria during the study period were reviewed until the required sample size was achieved.

The study included adult patients who underwent CT scan of the paranasal sinuses or CT head examinations for various clinical indications during the study period. Only scans that clearly demonstrated the sphenoid sinus anatomy were considered for analysis. Inclusion criteria: Adults aged 18 years and above, patients of either gender, CT scans showing fully developed sphenoid sinuses with adequate image quality and patients with no previous history of sphenoid sinus surgery. Exclusion Criteria: Age below 18 years, history of facial trauma involving skull base or sphenoid bone, previous sinonasal or transsphenoidal surgery, congenital craniofacial anomalies, presence of extensive tumors, severe infection, fractures or destructive lesions distorting sphenoid sinus anatomy and poor-quality CT images with motion artifacts or incomplete visualization.

CT examinations were performed using a multidetector computed tomography scanner. Patients were scanned in supine position with the head immobilized. Images were obtained in axial plane with thin slices ranging from 0.5 mm to 1.25 mm thickness. Coronal and sagittal reformatted images were generated from the raw data for detailed evaluation.

Parameters scanned included: Tube voltage: 120 kVp, Tube current: Automated according to body habitus, Slice thickness: 0.5–1.25 mm, Reconstruction algorithm: Bone window and soft tissue window, Multiplanar reconstructions: Axial, coronal, sagittal.

Only bone window images were primarily used for morphometric analysis. All CT images were reviewed on a dedicated workstation by two experienced radiologists independently. In case of disagreement, consensus was reached

through joint review. Measurements were taken using the electronic caliper tools available on the workstation.

Pneumatization was classified according to relation with the sella turcica into: Conchal type: Minimal or absent pneumatization anterior to sella, Presellar type: Pneumatization extending up to anterior wall of sella, Sellar type: Pneumatization extending beneath sella turcica and Postsellar type: Pneumatization extending beyond posterior wall of sella.

Lateral Extensions of Pneumatization: Presence or absence of pneumatization into: Greater wing of sphenoid, Pterygoid process, Anterior clinoid process and Lesser wing

The following septal features were recorded: Single midline septum, Deviated main septum, Multiple septa, Incomplete septa, Accessory septa and absence of septum (if present).

Site of insertion of the main or accessory septa was noted in relation to: Midline sphenoid wall, internal carotid artery prominence, optic nerve canal prominence, lateral wall and posterior wall.

The following dimensions were measured in millimeters: Maximum anteroposterior diameter, maximum transverse width, maximum vertical height, Intersinus septal deviation angle (where applicable), distance between bilateral carotid prominences and thickness of sellar floor (where visible)

Relevant demographic information including age and gender was recorded from hospital records. Each CT scan was assigned a serial number to maintain confidentiality. Findings

were entered into a structured data collection form designed for the study.

Data was entered and analyzed using SPSS version 22. Quantitative variables such as age and sinus dimensions were expressed as mean \pm standard deviation. Qualitative variables such as pneumatization type and septal variations were presented as frequency and percentage.

Associations between anatomical variations and gender were assessed using Chi-square test or Fisher's exact test where appropriate. Comparison of morphometric measurements between male and female participants was performed using independent sample t-test. A p-value of <0.05 was considered statistically significant.

Approval for the study was obtained from the Institutional Review Board/Ethics Committee before data collection. Since CT scans were reviewed retrospectively without direct patient contact, patient consent was taken where permitted by institutional policy. Patient identity remained confidential and all data were used strictly for academic and research purposes.

RESULTS

A total of 200 adult CT scans fulfilling the inclusion criteria were analyzed for evaluation of sphenoid sinus pneumatization patterns, septal variations and morphometric measurements. The study population consisted of 112 males (56%) and 88 females (44%). The age of participants ranged from 18 to 74 years, with a mean age of 41.6 ± 13.2 years.

Table 1: Distribution of Study Participants by Age and Gender

Variable	Frequency (n=200)	Percentage (%)
Male	112	56.0
Female	88	44.0
Age 18–30 years	52	26.0
Age 31–45 years	74	37.0
Age 46–60 years	49	24.5
Age >60 years	25	12.5

The most common pneumatization pattern observed was the sellar type which was seen in 118 patients (59.0%), followed by the postsellar type in 46 patients (23.0%). The

presellar type was present in 28 patients (14.0%) while the conchal type was least common, identified in 8 patients (4.0%).

Table 2: Distribution of Sphenoid Sinus Pneumatization Patterns

Pneumatization Type	Frequency	Percentage (%)
Conchal	8	4.0
Presellar	28	14.0
Sellar	118	59.0

Postsellar	46	23.0
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Lateral extension into adjacent sphenoid structures was found in a considerable number of scans. Pneumatization into the **pterygoid**

process was the most frequent lateral extension.

Table 3: Lateral Extensions of Pneumatization

Site of Extension	Frequency	Percentage (%)
Pterygoid process	62	31.0
Greater wing	54	27.0
Anterior clinoid process	38	19.0
Lesser wing	16	8.0
No lateral extension	74	37.0

Some patients showed more than one extension.

A single midline septum was seen in only 72 patients (36.0%). Deviated septum was the most common variation and was observed in 84 patients (42.0%). Multiple septa were

present in 58 patients (29.0%), while accessory septa were seen in 34 patients (17.0%). Incomplete septa were found in 26 patients (13.0%).

Table 4: Septal Variations in Sphenoid Sinus

Septal Pattern	Frequency	Percentage (%)
Single midline septum	72	36.0
Deviated septum	84	42.0
Multiple septa	58	29.0
Accessory septa	34	17.0
Incomplete septa	26	13.0
No septum	4	2.0

Septal insertion into clinically significant bony prominences was common. Attachment to the carotid canal prominence was observed in 48

patients (24.0%), while attachment to the optic canal was noted in 22 patients (11.0%).

Table 5: Site of Septal Attachment

Site of Attachment	Frequency	Percentage (%)
Midline wall	102	51.0
Carotid canal prominence	48	24.0
Optic canal prominence	22	11.0
Lateral wall	19	9.5
Posterior wall	9	4.5

The mean dimensions of the sphenoid sinus are summarized below.

Table 6: Morphometric Measurements of Sphenoid Sinus

Parameter	Mean ± SD (mm)
Anteroposterior diameter	28.4 ± 4.6
Transverse width	31.2 ± 5.1
Vertical height	22.6 ± 3.9
Intercarotid distance	19.8 ± 3.2
Sellar floor thickness	2.7 ± 0.8

Male participants demonstrated significantly larger sphenoid sinus dimensions than females.

Table 7: Comparison of Measurements by Gender

Parameter	Male (Mean ± SD)	Female (Mean ± SD)	p-value
AP diameter (mm)	29.6 ± 4.4	26.9 ± 4.3	0.002

Width (mm)	32.8 ± 4.8	29.1 ± 4.7	0.001
Height (mm)	23.4 ± 3.7	21.5 ± 3.5	0.010

Age-Related Findings

More extensive sellar and postsellar pneumatization patterns were more commonly observed in participants above 30 years of age while conchal and presellar types were relatively more frequent in younger adults, though the difference was not statistically significant ($p = 0.08$).

DISCUSSION

The sphenoid sinus is regarded as one of the most variable paranasal sinuses in terms of size, pneumatization, internal septation, and relation to surrounding neurovascular structures. Because of its close proximity to the pituitary gland, optic nerve, internal carotid artery, cavernous sinus, and skull base, detailed anatomical knowledge of this region is essential before endoscopic sinus surgery or transsphenoidal procedures. The present CT-based morphometric study evaluated pneumatization patterns and septal variations of the sphenoid sinus in adults and demonstrated marked anatomical diversity, supporting the importance of routine preoperative imaging.

In the current study, the sellar type of pneumatization was the most common pattern, accounting for 59% of cases, followed by the postsellar type. Similar findings have been reported in several previous studies where sellar pneumatization was identified as the dominant adult pattern. Hammer and Radberg described sellar pneumatization as the usual mature anatomical form in adults, while later radiological studies confirmed that extensive sellar pneumatization is frequently encountered in clinical practice. (31) Elwany et al. also found the sellar type to be more common than presellar or conchal variants. This predominance is clinically favorable because greater sinus expansion beneath the sella offers easier surgical access to the pituitary fossa. (32)

The conchal type was uncommon in our study, being present in only 4% of patients. This result is consistent with prior reports where conchal sphenoid sinus has been considered a rare adult finding. The conchal variant is surgically important because it lacks a well-developed sinus cavity and may make transsphenoidal approaches technically difficult. Surgeons encountering this pattern often require modified drilling techniques or

alternate approaches. Therefore, identification on preoperative CT is particularly valuable.

Lateral pneumatization into the pterygoid process, greater wing, and anterior clinoid process was observed in a substantial proportion of scans. These extensions have been emphasized in previous anatomical studies because they alter the relationship of the sinus to important neural and vascular structures. Pneumatization into the anterior clinoid process may lead to protrusion of the optic nerve canal, whereas pterygoid recess extension may expose the vidian canal and maxillary nerve. Sirikci et al. reported that anterior clinoid pneumatization was associated with optic nerve prominence, increasing the potential risk of optic nerve injury during surgery. (33) Our findings support the view that lateral recess variants are not rare and should be actively assessed during radiological reporting.

A major observation in the present study was the high frequency of septal variations. Only 36% of individuals had a single midline septum, whereas deviated, multiple, or accessory septa were common. This agrees with the work of Renn and Rhoton, who demonstrated that the classical description of a centrally placed single septum is often inaccurate. (34) Similar CT-based studies by Famurewa et al. also reported frequent asymmetry and multiple septations. In practical terms, this means that surgeons cannot rely on the intersinus septum as a dependable midline landmark during endoscopic sphenoidotomy. (35)

Of particular importance was the finding that 24% of septa were attached to the carotid canal prominence, while 11% were related to the optic canal. Comparable rates have been described in previous studies, though frequencies vary across populations. The surgical implication is significant. During endoscopic procedures, forceful avulsion of a septum attached to the internal carotid artery prominence can cause catastrophic hemorrhage, while traction near the optic canal may threaten vision. Chougule and Dixit emphasized that septal insertion onto the carotid protuberance is a critical anatomical hazard and should always be documented preoperatively. (36) Our results strongly support this recommendation.

Morphometric analysis in the present study showed mean sphenoid sinus dimensions that fall within ranges reported in international literature. Male participants had significantly greater anteroposterior diameter, width, and height than females. Sexual dimorphism of sinus size has also been noted in studies by Karakas and Kavakli, who found larger sinus volumes and dimensions in males. These differences are generally attributed to larger craniofacial skeletal dimensions in men. Such findings may also have relevance in forensic anthropology and radiological identification. (37)

The current study further demonstrated wide inter-individual variability in sinus size and internal architecture. This variability highlights why standard anatomical assumptions may be misleading. Even among patients with the same general pneumatization type, internal septa, recesses and wall prominences differed considerably. Modern endoscopic skull base surgery increasingly depends on patient-specific imaging rather than textbook anatomy. Our findings reinforce the need for individualized CT review before intervention.

When compared with previous studies from different regions, some variation in frequencies of sellar pneumatization, accessory septa and carotid-related septal insertion was noted. These differences may be explained by ethnic diversity, genetic influences, environmental factors, sample size and methodological differences in classification systems. Similar population-based differences have been documented in studies from Asia, Africa and Europe. Therefore, regional anatomical data remain clinically meaningful and should not be replaced entirely by foreign reference values.

The strengths of this study include use of multidetector CT imaging with multiplanar reconstruction, direct morphometric measurements and inclusion of adult subjects across a broad age range. CT remains the most reliable modality for assessing bony sinonasal anatomy and is particularly useful for identifying septal attachments, recesses, and critical canal prominences.

However, some limitations should be acknowledged. The study was conducted at a single center and may not fully represent the wider population. Functional correlation with surgical findings was not available in all cases. In addition, volumetric sinus analysis was not performed. Future multicenter studies with larger samples and correlation with

intraoperative anatomy would further strengthen available evidence.

Overall, the findings of the present study are clinically relevant. The predominance of sellar pneumatization suggests that most adults possess a surgically accessible sphenoid sinus, but the frequent presence of septal deviation, accessory septa, and carotid-related attachments indicates that operative risk remains substantial without careful imaging review. Therefore, CT evaluation should be considered indispensable before transsphenoidal and endoscopic sphenoid procedures.

CONCLUSION

This CT-based morphometric study demonstrates that the sphenoid sinus exhibits considerable anatomical variation in adults with respect to pneumatization patterns, septal configuration and dimensions. Sellar pneumatization was the most common type while septal deviation, multiple septa and accessory septa were frequently encountered, with a notable proportion showing attachment to the carotid canal or optic canal prominences. Significant differences in sinus dimensions were also observed between males and females. These findings highlight that the sphenoid sinus cannot be approached as a uniform anatomical structure and careful preoperative CT evaluation is essential to identify patient-specific variations. Such assessment can improve surgical orientation, reduce the risk of injury to adjacent vital neurovascular structures and enhance the safety and success of endoscopic sinus and transsphenoidal skull base procedures.

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