ARTICLE

ASSESSMENT OF RISKY ANATOMICAL VARIATIONS OF SPHENOID SINUS AND ITS RELATED NEUROVASCULAR STRUCTURES WITH MULTIDETECTOR COMPUTED TOMOGRAPHIC STUDY

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ABSTRACT

Introduction: The sphenoid sinus demonstrates considerable anatomical variability and is closely related to vital neurovascular structures such as the internal carotid artery (ICA) and optic nerve. Failure to recognize these variations before endoscopic sinonasal and skull base surgery may increase the risk of serious intraoperative complications. Multidetector computed tomography (MDCT) plays a pivotal role in identifying these high-risk anatomical variations. The present study aimed to assess the prevalence of risky anatomical variations of the sphenoid sinus and its related neurovascular structures using MDCT and to evaluate their association with demographic characteristics, thereby facilitating safer preoperative planning for endoscopic sinonasal and skull base surgeries. Materials and Methods: This hospital-based cross-sectional study was conducted over a period of 18 months (May 2024 to October 2025) in the Department of Radio-diagnosis, Adichunchanagiri Institute of Medical Sciences, BG Nagara, Karnataka, India. A total of 150 patients aged >16 years undergoing CT of the brain or paranasal sinuses were included. Non-contrast MDCT images were evaluated for sphenoid sinus pneumatization patterns, septal morphology, Onodi cells, carotid-optic recess, lateral recess pneumatization, and neurovascular variations including protrusion and dehiscence of the ICA and optic nerve, as well as protrusion of the maxillary and Vidian nerves. Data were analyzed using SPSS version 20.0, and associations were assessed using Chi-square or Fisher's exact test. Results: Sellar pneumatization was the most common pattern (50.7%), followed by postsellar (30.0%), conchal (10.0%), and presellar (9.3%). ICA protrusion was observed in 32.7% and 35.3% of patients on the right and left sides, respectively, while optic nerve protrusion occurred in 22.7% and 21.3%. ICA dehiscence was present bilaterally in 8.0% of patients, whereas optic nerve dehiscence was identified in 5.3% and 4.7% on the right and left sides, respectively. Significant associations were observed between age and pneumatization pattern, ICA protrusion, right ICA dehiscence, right optic nerve protrusion, and Onodi cells. Gender showed significant associations with pneumatization pattern, left ICA protrusion, bilateral ICA dehiscence, bilateral optic nerve protrusion, and Onodi cells. Septum attachment and pneumatization pattern also demonstrated significant associations with neurovascular variations. Conclusion: MDCT is an effective modality for identifying clinically significant anatomical variations of the sphenoid sinus and adjacent neurovascular structures. Routine preoperative evaluation of these variations is essential to facilitate surgical planning, reduce the risk of neurovascular injury, and improve the safety of endoscopic sinonasal and skull base procedures.

Keywords: Sphenoid Sinus, Multidetector Computed Tomography, Internal Carotid Artery, Optic nerve, Anatomical Variations

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INTRODUCTION

The sphenoid sinus is the most deeply situated of the paranasal sinuses and lies in close proximity to several critical neurovascular structures, including the internal carotid artery (ICA), optic nerve, maxillary nerve, vidian nerve, and cavernous sinus [1]. Owing to these intimate anatomical relationships, variations in sphenoid sinus anatomy are of considerable clinical importance, particularly during endoscopic sinus surgery and skull base procedures [2]. Failure to recognize these variations preoperatively may result in serious complications such as massive hemorrhage, visual impairment, or cranial nerve injury [3]. Therefore, a thorough understanding of sphenoid sinus anatomy is essential for accurate radiological interpretation and safe surgical planning.

The sphenoid sinus exhibits marked anatomical variability with respect to its pattern of pneumatization, septal configuration, and relationship with adjacent neurovascular structures [4]. Pneumatization is commonly classified into conchal, presellar, sellar, and postsellar types, each influencing the degree of exposure of the surrounding anatomical structures [5]. Variations such as protrusion or dehiscence of the ICA and optic nerve, attachment of the intersinus septum to the ICA or optic canal, presence of Onodi cells, and lateral recess pneumatization are considered high-risk anatomical variants because they increase the likelihood of iatrogenic injury during endoscopic transsphenoidal and skull base surgeries [6]. Accurate identification of these variations is therefore crucial before any surgical intervention involving the sphenoid sinus.

Multidetector computed tomography (MDCT) is the imaging modality of choice for evaluating sphenoid sinus anatomy because of its excellent spatial resolution and capability for multiplanar image reconstruction [7]. MDCT enables detailed assessment of sphenoid sinus pneumatization, septal attachments, and neurovascular relationships, thereby facilitating comprehensive preoperative evaluation and minimizing surgical complications [8]. Although several studies have reported the prevalence of these anatomical variations, considerable differences exist among various populations, highlighting the need for region-specific data to improve surgical planning and optimize patient safety [9].

The present study aimed to assess the prevalence of risky anatomical variations of the sphenoid sinus and its related neurovascular structures using multidetector computed tomography and to evaluate their association with demographic characteristics, thereby providing clinically relevant information for improved radiological assessment and safer endoscopic sinonasal and skull base surgical procedures.

MATERIALS AND METHODS

This hospital-based cross-sectional study was conducted in the Department of Radio-diagnosis, Adichunchanagiri Institute of Medical Sciences, BG Nagara, Karnataka, India, over a period of 18 months from May 2024 to October 2025, following approval from the Institutional Ethics Committee. The study included patients aged >16 years who underwent computed tomography (CT) of the brain or paranasal sinuses during the study period. Patients with a history of sinonasal surgery, sinonasal tumors involving the sphenoid sinus, or head and neck trauma were excluded. The sample size was calculated using OpenEpi version 3.0 based on the prevalence of internal carotid artery (ICA) protrusion and dehiscence reported in the study by Gian Luca Fadda et al [3]. A minimum sample size of 127 was obtained at a 5% level of significance and 80% study power. After accounting for a 10% attrition rate, the required sample size was 140; however, 150 participants were finally enrolled.

After obtaining written informed consent, demographic and clinical details were recorded using a structured proforma. All participants underwent non-contrast multidetector computed tomography (MDCT) using a 128-slice GE CT scanner. Scanning was performed using standardized imaging parameters with 100 kVp, slice thickness ranging from 0.5 to 1 mm, pitch of 10.6, and gantry rotation time of 0.7 seconds. Images were reconstructed in axial, coronal, and sagittal planes to facilitate detailed evaluation of sphenoid sinus anatomy and its related neurovascular structures.

All CT images were independently reviewed by the principal investigator under expert supervision. The sphenoid sinus was evaluated for pneumatization pattern (conchal, presellar, sellar, and postsellar), intersinus septation, septum attachment, lateral recess and carotid-optic recess pneumatization, and the presence of Onodi cells. Neurovascular variations including protrusion and dehiscence of the internal carotid artery and optic nerve, as well as protrusion of the vidian and maxillary nerves, were assessed using predefined radiological criteria. ICA and optic nerve protrusion were defined as any bulging into the sphenoid sinus cavity, whereas dehiscence was defined as complete absence of the intervening bony wall. Vidian and maxillary nerve protrusion was identified by the presence of surrounding air density on coronal images. All observations were systematically documented in a standardized data collection form.

Data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 20.0. Categorical variables were summarized as frequencies and percentages. Associations between categorical variables were evaluated using the Chi-square test or Fisher's exact test, as appropriate, while comparison of proportions was performed using the Z-test. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 150 patients who underwent multidetector computed tomography (MDCT) evaluation of the sphenoid sinus were included in the study. The majority of participants belonged to the 31–40 years age group (32.7%), followed by 41–50 years (28.7%), 51–60 years (25.3%), and 21–30 years (13.3%). The study population had an equal gender distribution, with 75 (50.0%) males and 75 (50.0%) females. (Table 1)

Table:1 Demographic Characteristics of the Study Population (n=150)

Characteristic	Category	Frequency	Percentage (%)
Age group	21–30 years	20	13.3
	31–40 years	49	32.7
	41–50 years	43	28.7
	51–60 years	38	25.3
Gender	Female	75	50.0
	Male	75	50.0

The sellar type was the most common sphenoid sinus pneumatization pattern (50.7%), followed by postsellar (30.0%), conchal (10.0%), and presellar (9.3%). A single intersinus septum was observed in 69.3% of patients, while the septum most frequently attached to the midline (45.3%), followed by the internal carotid artery (20.0%), optic canal (18.0%), and lateral wall (16.7%). Onodi cells were identified in 20.0% and 21.3% of patients on the right and left sides, respectively. Carotid-optic recess was present in 24.0% on the right and 29.3% on the left, whereas lateral recess pneumatization was observed in 66.0% and 60.0% on the right and left sides, respectively. (Table 2)

Table:2 Overall Prevalence of Sphenoid Sinus Anatomical Variations (n=150)

Variable	Category	n (%)
Pneumatization	Conchal	15 (10.0)
	Presellar	14 (9.3)
	Sellar	76 (50.7)
	Postsellar	45 (30.0)
ICA protrusion	Right	49 (32.7)
	Left	53 (35.3)
ICA dehiscence	Right	12 (8.0)
	Left	12 (8.0)
Optic protrusion	Right	34 (22.7)
	Left	32 (21.3)
Optic dehiscence	Right	8 (5.3)
	Left	7 (4.7)
Maxillary nerve protrusion	Right	24 (16.0)
	Left	20 (13.3)
Vidian nerve protrusion	Right	23 (15.3)
	Left	17 (11.3)
Onodi cell	Right	30 (20.0)
	Left	32 (21.3)
Carotid-optic recess	Right	36 (24.0)
	Left	44 (29.3)
Lateral recess	Right	99 (66.0)
	Left	90 (60.0)
Septum	Single	104 (69.3)
	Multiple	46 (30.7)
Septum attachment	Midline	68 (45.3)
	ICA	30 (20.0)
	Optic canal	27 (18.0)
	Lateral wall	25 (16.7)

Among the neurovascular variations, internal carotid artery (ICA) protrusion was present in 32.7% on the right and 35.3% on the left, while ICA dehiscence was observed bilaterally in 8.0% of patients. Optic nerve protrusion was identified in 22.7% and 21.3% on the right and left sides, respectively, whereas optic nerve dehiscence was less frequent (5.3% and 4.7%). Maxillary nerve protrusion was detected in 16.0% on the right and 13.3% on the left, while Vidian nerve protrusion was noted in 15.3% and 11.3% of cases, respectively. (Table 3)

Table:3 Neurovascular Variations of the Sphenoid Sinus (n=150)

Anatomical Variation	Right	Left
ICA protrusion	49 (32.7)	53 (35.3)
ICA dehiscence	12 (8.0)	12 (8.0)
Optic nerve protrusion	34 (22.7)	32 (21.3)
Optic nerve dehiscence	8 (5.3)	7 (4.7)
Maxillary nerve protrusion	24 (16.0)	20 (13.3)
Vidian nerve protrusion	23 (15.3)	17 (11.3)

Age demonstrated significant associations with several sphenoid sinus anatomical variations. Pneumatization pattern varied significantly across age groups ($p<0.001$), with presellar pneumatization predominantly observed in younger individuals, whereas conchal and sellar patterns were more common in older age groups. Significant associations were also observed between age and right and left ICA protrusion ($p=0.012$ and $p=0.007$), right ICA dehiscence ($p=0.005$), right optic nerve protrusion ($p=0.039$), and bilateral Onodi cell presence ($p<0.001$ and $p=0.006$). However, left ICA dehiscence and left optic nerve protrusion did not demonstrate statistically significant associations with age. (Table 4)

Table:4 Association Between Age Group and Major Anatomical Variations

Variable	21–30 years	31–40 years	41–50 years	51–60 years	χ^2	p-value
Pneumatization pattern					35.034	<0.001
Conchal	2 (13.3)	3 (20.0)	6 (40.0)	4 (26.7)		
Postsellar	1 (2.2)	15 (33.3)	16 (35.6)	13 (28.9)		
Presellar	8 (57.1)	6 (42.9)	0 (0.0)	0 (0.0)		
Sellar	9 (11.8)	25 (32.9)	21 (27.6)	21 (27.6)		
ICA protrusion (Right)	1 (2.0)	17 (34.7)	13 (26.5)	18 (36.7)	10.901	0.012

Variable	21–30 years	31–40 years	41–50 years	51–60 years	χ^2	p-value
ICA protrusion (Left)	5 (9.4)	12 (22.6)	14 (26.4)	22 (41.5)	12.067	0.007
ICA dehiscence (Right)	0 (0.0)	1 (8.3)	3 (25.0)	8 (66.7)	12.961	0.005
ICA dehiscence (Left)	0 (0.0)	2 (16.7)	5 (41.7)	5 (41.7)	4.904	0.179
Optic nerve protrusion (Right)	2 (5.9)	7 (20.6)	11 (32.4)	14 (41.2)	8.359	0.039
Optic nerve protrusion (Left)	3 (9.4)	7 (21.9)	8 (25.0)	14 (43.8)	7.565	0.056
Onodi cell (Right)	3 (10.0)	4 (13.3)	6 (20.0)	17 (56.7)	20.119	<0.001
Onodi cell (Left)	2 (6.2)	4 (12.5)	15 (46.9)	11 (34.4)	12.612	0.006

Gender showed significant associations with several anatomical variations. Pneumatization pattern differed significantly between males and females (p=0.001), with presellar pneumatization observed exclusively in males. Females demonstrated significantly higher frequencies of left ICA protrusion (p=0.004), bilateral ICA dehiscence (p=0.016 for both sides), bilateral optic nerve protrusion (right: p=0.006; left: p=0.017), and bilateral Onodi cell presence (right: p=0.004; left: p=0.001). No significant association was found between gender and right ICA protrusion (p=0.117). (Table 5)

Table:5 Association Between Gender and Major Anatomical Variations

Variable	Female	Male	χ^2	p-value
Pneumatization pattern			15.629	0.001
Conchal	9 (60.0)	6 (40.0)		
Postsellar	25 (55.6)	20 (44.4)		
Presellar	0 (0.0)	14 (100.0)		
Sellar	41 (53.9)	35 (46.1)		
ICA protrusion (Right)	29 (59.2)	20 (40.8)	9.632	0.117
ICA protrusion (Left)	35 (66.0)	18 (34.0)	8.432	0.004
ICA dehiscence (Right)	10 (83.3)	2 (16.7)	5.797	0.016
ICA dehiscence (Left)	10 (83.3)	2 (16.7)	5.797	0.016
Optic nerve protrusion (Right)	24 (70.6)	10 (29.4)	7.454	0.006
Optic nerve protrusion (Left)	22 (68.8)	10 (31.2)	5.720	0.017
Onodi cell (Right)	22 (73.3)	8 (26.7)	8.167	0.004
Onodi cell (Left)	24 (75.0)	8 (25.0)	10.169	0.001

Septum attachment demonstrated significant associations with adjacent neurovascular structures. Septal attachment to the ICA showed the highest frequency of right ICA protrusion, whereas lateral wall attachment was more commonly associated with left ICA and left optic nerve protrusion. Significant associations were observed between septum attachment and right ICA protrusion (p<0.001), left ICA protrusion (p=0.021), and left optic nerve protrusion (p=0.005), indicating that septal attachment may influence the relationship between the sphenoid sinus and adjacent neurovascular structures. (Table 6)

Table:6 Association Between Septum Attachment and Neurovascular Variations

Septum attachment	ICA protrusion Right	ICA protrusion Left	Optic nerve protrusion Left
ICA	18 (36.7)	13 (24.5)	3 (9.4)
Lateral wall	10 (20.4)	14 (26.4)	11 (34.4)
Midline	10 (20.4)	16 (30.2)	10 (31.2)
Optic canal	11 (22.4)	10 (18.9)	8 (25.0)
p value	21.574	9.694	12.837

The pattern of sphenoid sinus pneumatization showed significant associations with neurovascular protrusions. Sellar pneumatization demonstrated the highest frequency of ICA protrusion, optic nerve protrusion, and Vidian nerve protrusion, while no neurovascular protrusions were observed with conchal or presellar pneumatization. Significant associations were identified between pneumatization pattern and right ICA protrusion (p=0.001), left ICA protrusion (p<0.001), right optic nerve protrusion (p=0.005), left optic nerve protrusion (p=0.021), and right Vidian nerve protrusion (p=0.019). (Table 7)

Table:7 Association Between Pneumatization Pattern and Neurovascular Variations

Pneumatization	ICA Right	ICA Left	Optic Right	Optic Left	Vidian Right
Conchal	0	0	0	0	0
Postsellar	18 (36.7)	21 (39.6)	16 (47.1)	12 (37.5)	5 (21.7)
Presellar	0	0	0	0	0
Sellar	31 (63.3)	32 (60.4)	18 (52.9)	20 (62.5)	18 (78.3)
p value	0.001	<0.001	0.005	0.021	0.019

The presence of a right-sided Onodi cell was significantly associated with optic nerve protrusion. Patients with a right Onodi cell showed a higher frequency of left optic nerve protrusion compared to those without an Onodi cell, with a statistically significant association (p<0.001). This finding highlights the close anatomical relationship between Onodi cells and the optic nerve and emphasizes its importance during endoscopic surgical planning. (Table 8)

Table:8 Association Between Right Onodi Cell and Optic Nerve Protrusion

Right Onodi cell	Right optic nerve protrusion	Left optic nerve protrusion
Absent	22 (64.7)	12 (37.5)
Present	12 (35.3)	20 (62.5)
p-value	< 0.001	

DISCUSSION

The present study comprehensively evaluated the anatomical variations of the sphenoid sinus and its related neurovascular structures using multidetector computed tomography in 150 patients. Sellar pneumatization was the predominant pattern (50.7%), followed by postsellar (30.0%), conchal (10.0%), and presellar (9.3%). These findings are comparable with those of Fadda GL et al., who reported sellar pneumatization in 58.7% of patients, and Lokwani MS et al., who observed a prevalence of 63.4% [3,10]. However, Aijaz A et al. reported a higher frequency of postsellar pneumatization (63.3%), while Hiremath SB et al. demonstrated an overwhelmingly predominant sellar pattern (98.8%) [11,12]. Such variations among studies may be attributed to differences in ethnicity, imaging techniques, and classification criteria. In addition, our study demonstrated a significant association between age and pneumatization pattern ($p<0.001$), with presellar pneumatization confined to younger individuals and conchal pneumatization occurring more frequently in older age groups. Gender also showed a significant association with pneumatization ($p=0.001$), with presellar pneumatization observed exclusively in males. These findings suggest that demographic factors may influence sphenoid sinus morphology and should be considered during preoperative evaluation.

The prevalence of internal carotid artery (ICA) protrusion in the present study was 32.7% on the right and 35.3% on the left, while ICA dehiscence was observed in 8.0% bilaterally. These findings fall within the wide range reported in previous studies. Fadda GL et al. reported ICA protrusion in 26.3% of cases, whereas Aijaz A et al. and Valizadeh S et al. reported higher prevalences of 49.0% and 52.7%, respectively [3,11,13]. Similarly, the prevalence of ICA dehiscence in our study closely resembled that reported by Aijaz A et al. (9.3%) but was substantially lower than those observed by Valizadeh S et al. (40.3%) and Singh BP et al. (30.9%) [11,13,14]. We also observed significant associations between age and right- as well as left-sided ICA protrusion ($p=0.012$ and $p=0.007$), and right-sided ICA dehiscence ($p=0.005$). Females exhibited a significantly higher prevalence of left ICA protrusion and bilateral ICA dehiscence than males. Furthermore, ICA protrusion was significantly associated with sellar and postsellar pneumatization and with septal attachment to the ICA, emphasizing the importance of detailed preoperative assessment to minimize the risk of catastrophic vascular injury during endoscopic skull base surgery.

Optic nerve protrusion was identified in 22.7% and 21.3% of patients on the right and left sides, respectively, while optic nerve dehiscence was present in 5.3% and 4.7%. These values are comparable to those reported by Fadda GL et al. (13.0% protrusion and 1.5% dehiscence) but lower than those described by Aijaz A et al. (38.0% protrusion and 16.0% dehiscence) and Valizadeh S et al. (50.0% protrusion and 48.3% dehiscence) [3,11,13]. The lower prevalence in our study may reflect differences in study population and radiological interpretation. Significant age-related increases in right optic nerve protrusion ($p=0.039$) and a higher prevalence among females ($p=0.006$ and $p=0.017$ for the right and left sides, respectively) were observed. In addition, optic nerve protrusion showed a significant association with sellar pneumatization and with septal attachment, while the presence of a right Onodi cell was strongly associated with bilateral optic nerve protrusion, particularly on the left side ($p<0.001$). These findings reinforce previous reports that extensive sphenoid sinus pneumatization and Onodi cells increase the surgical risk of optic nerve injury during endoscopic procedures.

Other clinically important anatomical variations observed in the present study included maxillary nerve protrusion in 16.0% and 13.3% of patients on the right and left sides, respectively, and Vidian nerve protrusion in 15.3% and 11.3%. These prevalences were lower than those reported by Singh BP et al., who documented maxillary and Vidian nerve protrusion in 25.0% and 26.1% of cases, respectively [14]. Onodi cells were identified in approximately one-fifth of patients (20.0% right and 21.3% left), consistent with the prevalence reported in contemporary CT-based studies. A single intersinus septum was present in 69.3% of patients, while multiple septa were observed in 30.7%. Septal attachment to the ICA and optic canal was found in 20.0% and 18.0% of cases, respectively, resulting in neurovascular attachment in 38% of patients. These findings are comparable to those reported by Fadda GL et al. (21.6% ICA attachment) but lower than the 53.0% ICA attachment observed by Lokwani MS et al [3,10]. The significant association between septal attachment and ICA as well as optic nerve protrusion highlights the need for careful intraoperative manipulation of the intersinus septum to prevent inadvertent injury to adjacent neurovascular structures.

The present study demonstrates that multidetector computed tomography provides a comprehensive evaluation of the sphenoid sinus and accurately identifies anatomical variations that may increase the risk of complications during endoscopic sinus and skull base surgery. The observed associations between pneumatization pattern, neurovascular protrusion, septal attachment, and demographic characteristics underscore the importance of meticulous preoperative radiological assessment. Recognition of these high-risk anatomical variants can facilitate appropriate surgical planning, reduce intraoperative complications, and improve overall surgical safety, particularly in transsphenoidal and extended endoscopic skull base procedures.

The present study has certain limitations. Being a single-center, hospital-based cross-sectional study with a relatively modest sample size, the findings may not be generalizable to the wider population. The anatomical variations were assessed solely using multidetector computed tomography without intraoperative or cadaveric correlation, which could have further validated the radiological findings. Additionally, clinical outcomes and postoperative complications were not evaluated; therefore, the direct impact of these anatomical variations on surgical outcomes could not be determined.

CONCLUSION

Multidetector computed tomography is a reliable and indispensable imaging modality for identifying anatomical variations of the sphenoid sinus and its related neurovascular structures. Sellar pneumatization was the most common pattern, and clinically significant variations such as internal carotid artery and optic nerve protrusion, septal attachment to neurovascular structures, and Onodi cells were frequently encountered. Significant associations between demographic factors and several anatomical variations further highlight the diversity of sphenoid sinus morphology. Careful preoperative evaluation of these variations using MDCT is essential for surgical planning, minimizing the risk of neurovascular injury, and improving the safety of endoscopic sinonasal and skull base procedures.

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