Original Article

Computed Tomographic Evaluation of Normal Anatomical Variants of the Paranasal Sinuses in Symptomatic and Asymptomatic Patients

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Abstract

Background: Anatomical variations of the nasal cavity and paranasal sinuses are frequently identified on computed tomography and may influence sinus drainage and the development of sinonasal disease. Their clinical significance, however, remains controversial. The objective is to compare the prevalence and distribution of anatomical variations of the paranasal sinuses between symptomatic and asymptomatic patients and evaluate their association with paranasal sinus and osteomeatal complex involvement. **Material and Methods:** A prospective comparative cross-sectional study was conducted over 18 months and included 196 participants undergoing computed tomography of the head, comprising 98 symptomatic and 98 asymptomatic patients. Consecutive eligible participants were enrolled. Computed tomography images were obtained using a standardized protocol and independently evaluated by a blinded radiologist for anatomical variations and sinus involvement. Demographic characteristics, clinical symptoms, and radiological findings were recorded. Statistical analysis was performed using descriptive statistics, Student's independent t-test, Chi-square test, and Z-test, with statistical significance set at $p < 0.05$. **Results:** Symptomatic patients demonstrated a significantly greater burden of multiple anatomical variations than asymptomatic patients ($p = 0.011$). Nasal septal deviation, concha bullosa, agger nasi cells, Haller cells, and pneumatized uncinate process were significantly more prevalent among symptomatic patients, whereas paradoxical middle turbinate and Onodi cells showed no significant differences. Maxillary, ethmoid, frontal, sphenoid, and osteomeatal complex involvement were significantly more frequent in symptomatic patients. Concha bullosa was significantly associated with ethmoid sinus disease ($p = 0.007$), while nasal septal deviation was significantly associated with osteomeatal complex involvement ($p = 0.003$). **Conclusion:** Selected anatomical variations are significantly associated with symptomatic sinonasal disease and radiological sinus involvement. Careful evaluation of these variations on computed tomography may assist clinical assessment and preoperative planning for Functional Endoscopic Sinus Surgery, although radiological findings should always be interpreted alongside clinical and endoscopic evaluation.

Keywords: Anatomical variations, Paranasal sinuses, Computed tomography, chronic rhinosinusitis, Osteomeatal complex.

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Introduction

The anatomy of the nasal cavity and paranasal sinuses exhibits considerable variation. They are easily detected on computed tomography (CT), the preferred imaging technique for the evaluation of sinonasal anatomy and planning of functional endoscopic sinus surgery (FESS). Numerous bony and pneumatization variants can be visualized with CT, such as nasal septal deviation, concha bullosa, Haller cells, Onodi cells, paradoxical middle turbinate, variation of the ethmoid bulla, and the uncinate process. These variations are common and are a reflection of the wide range of anatomical variation in the sinonasal area.[1,2]

There are several anatomic variants in or near the ostiomeatal complex, which is the major drainage route of the anterior paranasal sinuses. Owing to their anatomical relationship with this region, these variants may influence sinus drainage and ventilation and have therefore been implicated in recurrent and chronic rhinosinusitis. There has been prior radiological research to determine if there is any correlation between specific variants and sinonasal mucosal disease, such as concha bullosa and Haller cells. Although some studies have reported significant associations, others have found little or no independent relationship. Nevertheless, these variants remain important during preoperative surgical planning.[3–5]

The clinical significance of sinonasal anatomical variations remains controversial. Systematic reviews and observational studies have found mixed results concerning their correlation with sinus disease, and many variants also have been found in people without sinonasal symptoms. The conflicting results may be due to variations in CT protocols, variants defined, populations studied, and outcome measures. Therefore, additional standardized investigations are needed to differentiate clinically relevant anatomical variants from incidental

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anatomical findings.[3,5,6]

By comparing symptomatic and asymptomatic individuals, this study aimed to identify anatomical variants that are more likely to be clinically relevant rather than incidental findings. Such information may improve radiological interpretation and assist in preoperative planning for FESS by facilitating recognition of anatomical variants that may influence the surgical approach or increase the risk of intraoperative complications if unrecognized.[7]

Materials and Methods

Study Design and Setting: This prospective comparative cross-sectional study was conducted in the Department of Radiology at GSL Medical College & General Hospital, Rajamahendravaram, Andhra Pradesh, India, over a period of 18 months, from 1 March 2024 to 30 August 2025. The study was designed to compare the prevalence and distribution of normal anatomical variations of the paranasal sinuses detected on computed tomography (CT) between symptomatic and asymptomatic patients.

Study Population and Study Size: The study included patients who underwent head CT for clinically indicated reasons during the study period. Consecutive sampling was used to enroll participants, with patients being eligible for enrollment until the predetermined study size of 196 participants was achieved. The total number of patients who participated in the study was 98 symptomatic patients (Group I) and 98 asymptomatic (Group II). Symptomatic patients were those having one or more of the sinonasal complaints, such as nasal obstruction, nasal discharge, facial pain, headache, postnasal drip, recurrent sinusitis, hyposmia, or other complaints. Asymptomatic patients: patients who were undergoing computed tomography (CT) head imaging for reasons other than sinonasal disease and did not have any clinical symptoms of sinonasal disease.

Eligibility Criteria: The study included all patients who had received a computed tomography (CT) head scan with or without sinus and nasal complaints, regardless of sex, who gave written informed consent. The following patients were excluded: pregnant or lactating women, patients without informed consent in writing, patients with a prior history of sinonasal surgery, patients with tumors that caused alteration of the sinonasal anatomy, patients with significant craniofacial deformities that could affect the study or interpretation of the computed tomography findings, and patients with severe medical illnesses that may affect the study or possibility of informed consent.

CT Acquisition Protocol: All CT examinations were performed using a 128-slice Siemens multidetector CT scanner. Measurements were made with non-contrast computed tomography (NCT) scan in the axial plane with a 0.5 mm slice thickness and a tube voltage of 120 kVp. Coronal and sagittal multiplanar reformats were created to better evaluate the paranasal sinuses and osteomeatal complex.

CT Image Evaluation: Images were independently assessed by a radiologist by applying the same radiological criteria. All images were interpreted by the reviewer while blinded to the clinical status of the participants, so that there would be minimal observer bias. Anatomical variations such as deviated nasal septum, concha bullosa, paradoxical middle turbinate, agger nasi cells, Haller cells, Onodi cells, pneumatized uncinate process, ethmoid bulla variations, maxillary sinus septations, and frontal sinus variations were systematically evaluated in each CT examination. Radiological involvement of the maxillary, frontal, ethmoid, and sphenoid sinuses, as well as osteomeatal complex (OMC) involvement, was documented. A proforma for data collection was used in all findings.

Data Collection: All participants were asked about their demographic characteristics such as age, sex, residence, occupation, socio-economic status, smoking history and allergy history. The clinical symptoms of patients in the symptomatic group were recorded. The clinical status of the participants was then correlated with the CT findings, and the prevalence of anatomical variants was compared between the symptomatic and asymptomatic groups and the relationship between selected anatomical variants and associated sinus disease was assessed.

Outcome Measures: The main result of the study was the prevalence and distribution of paranasal sinus anatomical abnormalities obtained on computed tomography scans of symptomatic and asymptomatic patients. Secondary outcomes were whether any anatomical variants were associated with the presence of paranasal sinus or osteomeatal complex involvement in patients with symptoms.

Statistical Analysis: The data collected were stored in the MS Excel 2019 and analysed using IBM SPSS Statistics software version 27.0 (IBM Corp, Armonk, NY, USA). Data on continuous variables were presented as mean ± standard deviation (SD), while data on categorical variables were expressed as frequencies and percentages. Independent Student's t-test was used to compare the continuous variables between the symptomatic and asymptomatic group, while Chi-square test was used for the categorical variables. Where appropriate, the proportion was compared between the two independent groups using the Z-test. All statistical tests were performed two-tailed and a p value <0.05 was deemed to be statistically significant.

Ethical Considerations: The study was approved by the Institutional Ethics Committee prior to commencement. Written informed consent was obtained from all participants before enrolment. Participant confidentiality was maintained throughout the study.

This organization follows the STROBE recommendations for reporting observational studies by clearly describing the study design, participant selection, measurements, methods used to minimize bias, study size, and statistical analysis.

Results

In total, 196 participants were enrolled in the study including 98 symptomatic and 98 asymptomatic subjects. Baseline demographic profile was similar among both groups. The largest percentage of participants among both groups was from the age group of 31-40 years (28.6% and 25.5%, respectively; $p = 0.985$), followed by the age group of 21-30 years (24.5% and 22.4%, respectively; $p > 0.05$). Male participants constituted the majority in both groups in both groups - in the symptomatic (57.1%) and asymptomatic (55.1%) groups ($p = 0.886$). Moreover, residence,

occupation, socio-economic status and smoking habits did not differ between both groups (p > 0.05). Nonetheless, there was a statistically significant difference between the percentage of symptomatic patients and asymptomatic individuals in relation to their allergy history (36.7% and 15.3%, respectively; p = 0.001) [Figure 1].

The most common symptoms among the 98 symptomatic patients were nasal obstruction in 72 (73.5%), nasal discharge in 64 (65.3%), headache/facial pain in 58 (59.2%), and postnasal drip in 47 (48.0%) patients [Table 1]. Sneezing was found in 41 (41.8%) patients. Hyposmia/anosmia was found in 29 (29.6%). Epistaxis was the presenting symptom in 14 (14.3%) patients, the least common presenting symptom.

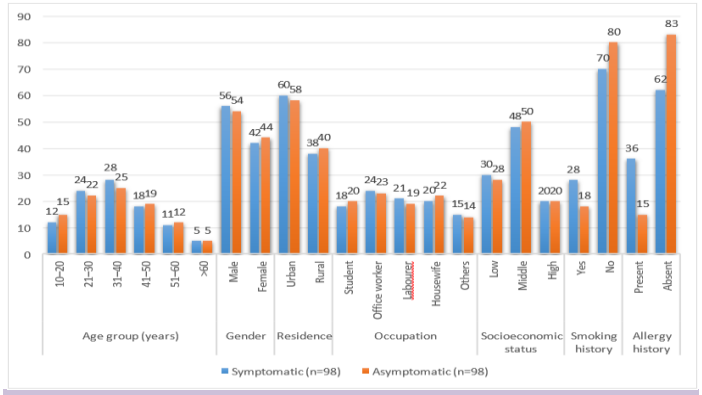

Figure 1: Distribution of Baseline Demographic Characteristics among Symptomatic and Asymptomatic Patients

Table 1: Distribution of Clinical Symptoms among Symptomatic Patients (n = 98)

Category	Number of Patients	Percentage (%)
Nasal obstruction	72	73.5
Nasal discharge	64	65.3
Headache/Facial pain	58	59.2
Postnasal drip	47	48.0
Sneezing	41	41.8
Hyposmia/Anosmia	29	29.6
Epistaxis	14	14.3
Total Patients	98	100.0

The distribution of number of anatomical variants was significantly different between symptomatic and asymptomatic patients (p=0.011) [Table 2 and Figure 2]. The absence of anatomical variants was more often found in asymptomatic patients compared to symptomatic patients (29.6% vs. 12.2%). On the other hand, symptomatic patients had two or more anatomical variants more often, two variants (31.6% vs 21.4%), three variants (16.3% vs 8.2%), and four or more variants (5.1% vs 2.0%). The most frequent finding in both groups was a solitary anatomic variant, seen in 34.7% of symptomatic and 38.8% of asymptomatic patients.

Table 2: Distribution of the Number of Anatomical Variants Among Symptomatic and Asymptomatic Patients

Number of Anatomical Variants	Symptomatic (n = 98)	Asymptomatic (n= 98)	P value
0	12 (12.2%)	29 (29.6%)	0.011
1	34 (34.7%)	38 (38.8%)	
2	31 (31.6%)	21 (21.4%)	
3	16 (16.3%)	8 (8.2%)	
4 or higher	5 (5.1%)	2 (2.0%)	
Total	98 (100.0%)	98 (100.0%)	

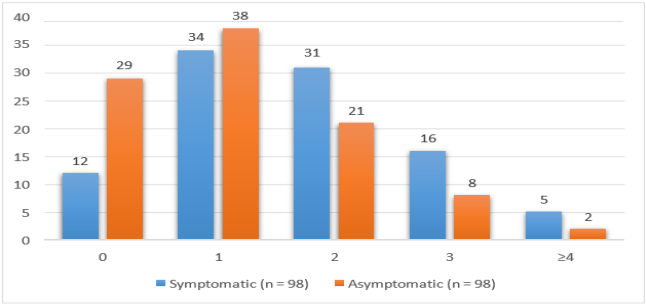

Figure 2: Distribution of the Number of Anatomical Variants Among Symptomatic and Asymptomatic Patients

The prevalence of individual anatomic variants in symptomatic and asymptomatic patients is summarized in [Figure 3]. Septal deviation was the most common anatomical variant in both groups and was significantly more frequent in the symptomatic than in the asymptomatic patients (56.1% vs. 34.7%; p = 0.004). Similarly, concha bullosa (46.9% vs 30.6%; p=0.028), agger nasi cells (49.0% vs 32.7%; p=0.018), Haller cells (27.6% vs 14.3%; p=0.022) and pneumatized uncinate process (24.5% vs 11.2%; p=0.016) were significantly higher in the symptomatic group. However, there was no statistically significant difference between the two groups in the prevalence of paradoxical middle turbinate (18.4% vs. 16.3%; p = 0.850) and Onodi cells (21.4% vs. 17.3%; p = 0.470).

Involvement of paranasal sinuses and osteomeatal complex was seen much more often in symptomatic patients compared to asymptomatic patients in all regions studied (Figure 4). The most common abnormality was involvement of maxillary sinus, which was detected in 64 (65.3%) symptomatic patients versus 15 (15.3%) asymptomatic patients (p < 0.001). Ethmoid sinus involvement was seen in 53 (54.1%) symptomatic patients versus 12 (12.2%) asymptomatic patients (p < 0.001) and osteomeatal complex

involvement in 54 (55.1%) and 12 (12.2%) patients, respectively ($p < 0.001$). Abnormalities in frontal sinuses (28.6% vs. 8.2%, $p = 0.001$) and sphenoid sinuses (21.4% vs. 7.1%, $p = 0.006$) were also significantly more prevalent in the symptomatic group.

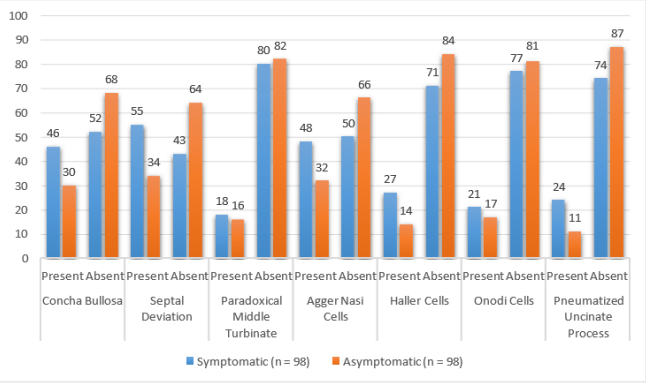

Figure 3: Distribution of Anatomical Variants among Symptomatic and Asymptomatic Patients

Among symptomatic patients, concha bullosa showed a significant association with ethmoid sinus disease ($p = 0.007$) [Table 3]. Ethmoid sinus disease was present in 32 of 46 patients (69.6%) with concha bullosa compared with 21 of 52 patients (40.4%) without concha bullosa. Similarly, septal deviation was significantly associated with osteomeatal complex (OMC) involvement ($p = 0.003$). OMC disease was observed in 38 of 55 patients (69.1%) with septal deviation, whereas 16 of 43 patients (37.2%) without septal deviation had OMC involvement.

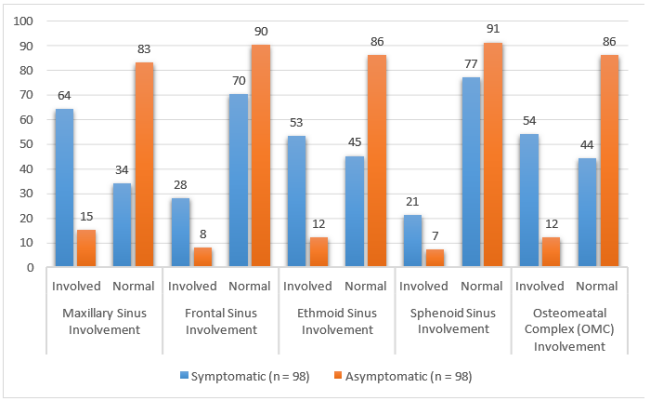

Figure 4: Comparison of Paranasal Sinus and Osteomeatal Complex Involvement Between Symptomatic and Asymptomatic Patients.

Table 3: Association between Anatomical Variants and Corresponding Sinus Disease in the Symptomatic Group (n = 98)

Association	Disease Status	Present	Absent	Total	P Value
Concha Bullosa vs Ethmoid Disease	Present	32	21	53	0.007
	Absent	14	31	45	
	Total	46	52	98	
Septal Deviation vs OMC Disease	Present	38	16	54	0.003
	Absent	17	27	44	
	Total	55	43	98	

Discussion

Three main findings were identified in this comparative study of 196 adults (98 symptomatic, 98 asymptomatic) using CT technology. First, the cumulative burden of sinonasal anatomical variants was significantly greater among symptomatic participants. Second, nasal septal deviation, concha bullosa, agger nasi cells, Haller cells, and a pneumatised uncinate process were significantly more prevalent in the symptomatic group, whereas paradoxical middle turbinate and Onodi cells showed no significant difference between the groups. Thirdly, paranasal sinus and ostiomeatal complex (OMC) involvement was significantly more common in symptomatic patients. In this group, concha bullosa was found to be related to ethmoid sinus disease, and septal deviation was related to OMC involvement. A history of allergy was also much more prevalent in the symptomatic patients. As this was a cross-sectional study, these findings indicate associations rather than causation.

There was a significant difference in allergy history between symptomatic and non-symptomatic groups (36.7% vs. 15.3%, respectively, $p = 0.001$), which reinforces the previously established relationship between CRS and atopy. De Marchi et al. reported an association between local- and dual-allergic rhinitis and an increased risk of CRS with nasal polyps, and DelGaudio et al. described central compartment atopic disease, a type of allergic CRS characterised by ethmoid-centred polypoid changes.[8,9] The higher prevalence of allergy observed in the present study is consistent with these findings.

There was a significant difference in the number of anatomical variants between groups ($p = 0.011$). No anatomical variants were more common in the asymptomatic group (29.6% vs. 12.2%), while two or more co-existing variants were more common in the symptomatic group. The results agree with the systematic review of Papadopoulou et al., who found that there was no consistent association between individual variants and sinus disease; however, some anatomical variants may be hypothesized to be risk factors for sinonasal disease.[5] Conversely, Shpilberg et al. did not detect any anatomical variants that were significantly associated with clinically relevant rhinosinusitis,[3] which indicates that there may be a greater clinical relevance to the combined rather than individual anatomical variants.

The most frequently observed anatomical variant was nasal septal deviation, which was significantly higher in the group of symptomatic patients (56.1% versus 34.7%; $p = 0.004$). It was also highly correlated with OMC involvement (69.1% vs. 37.2%; $p = 0.003$), supporting the notion that septal deviation could lead to the failure of mucociliary clearance and blockage of the OMC. This association has been found by Subbiah et al. and Mendiratta et al.[10,11] In contrast, Duzkalir et al. did not find any significant

correlation between accessory maxillary ostium and septal deviation, suggesting that the significance of a deviated septum might relate to its extent and morphology rather than its presence.[12]

Concha Bullosa was significantly more common among the symptomatic patients (46.9% vs 30.6%, p = 0.028) and also associated with ethmoid sinus disease in this group (69.6% vs 40.4%, p = 0.007). This association is biologically plausible because pneumatisation of the middle turbinate could cause the narrowing of the middle meatus and block the drainage of the ethmoid. Studies have found a significantly greater prevalence of concha bullosa on diseased sides in both patients with allergic fungal rhinosinusitis and those with maxillary sinusitis.[10,13] The relationship of concha bullosa and radiologically apparent rhinosinusitis (RS) remains controversial, however, because Shpilberg et al. found no significant association between the two.[3]

The prevalence of agger nasi cells was also significantly higher in symptomatic patients (49.0% vs. 32.7%; p = 0.018). They are close to the frontal recess, which could have a negative effect on frontal sinus drainage, as suggested by Mendiratta et al and Subbiah et al.[10,11] These results suggest a possible function of agger nasi cells in anterior sinonasal diseases.

A higher prevalence of Haller cells was found among the symptomatic patients (27.6% vs. 14.3; p= 0.022). Given their location adjacent to the maxillary infundibulum, they may contribute to narrowing of the maxillary drainage pathway. Subbiah et al. and Mendiratta et al. have also reported similar associations with maxillary sinusitis.[10,11] However, Haller cells are often found in healthy people and therefore do not necessarily indicate disease.

Pneumatised uncinate processes were much more common in symptomatic patients (24.5% vs. 11.2%, p = 0.016). The uncinate process forms an integral part of the ostiomeatal complex, and the pneumatisation of the uncinate may change sinus drainage. Yaprak et al. showed that differences in the uncinate processes affect frontal recess anatomy and should be taken into consideration when planning frontal sinus surgery.[14] Though there is limited direct evidence linking a pneumatized uncinate process to chronic rhinosinusitis, its higher prevalence among symptomatic patients suggests that it may contribute to impaired sinus drainage and warrants further investigation. There was no significant difference between symptomatic and asymptomatic patients with respect to paradoxical middle turbinate (p = 0.850) and Onodi cells (p = 0.470), respectively. Likewise, İla et al. did not reveal any significant relationship between the superior turbinate pneumatisation and sinusitis, implying that not all anatomical variants are equally associated with sinusitis. Onodi cells are of significant importance during surgery due to their proximity to the optic nerve and internal carotid artery but are not an independent risk factor for sinus diseases.[15] These findings are in line with the systematic review conducted by Papadopoulou et al., who highlighted that the clinical relevance is variant-specific.[5]

This finding further emphasizes the importance of careful preoperative CT evaluation, as recognition of Onodi cells and other critical anatomical variants may help avoid injury to adjacent neurovascular structures during FESS.[7,16]

The most common radiological finding was involvement of the maxillary sinus, which was significantly more common among symptomatic patients (65.3% vs. 15.3%), and is a sinus that is more prone to impaired drainage. Similarly, Srivastava et al. reported opacification of the maxillary sinus as the most common CT feature among chronic rhinosinusitis (CRS) patients.[17] Involvement of the ethmoid sinus and OMC was also significantly higher in the symptomatic patients and supported the central role of the OMC in anterior sinus drainage. Similarly, da Silva et al. showed a correlation between OMC obstruction and anatomic variations on computed tomography.[18] Frontal and sphenoid sinus involvement were less common but were also significantly more common in those with disease, further supporting an association between sinonasal anatomy and inflammatory disease.

Beyond their association with symptomatic sinonasal disease, the anatomical variants identified in the present study also have important implications for preoperative imaging assessment. High-resolution CT provides a detailed anatomical roadmap before Functional Endoscopic Sinus Surgery (FESS), enabling identification of anatomical and critical variants that may influence the surgical approach or make surgery hazardous if unrecognized. Therefore, systematic evaluation of variants such as nasal septal deviation, concha bullosa, agger nasi cells, Haller cells, pneumatized uncinate process, and Onodi cells is important during CT interpretation to facilitate surgical planning and improve anatomical orientation before endoscopic intervention.[2,7,16]

The findings of this study suggest that specific anatomical variants — particularly nasal septal deviation, concha bullosa, agger nasi cells, Haller cells, and a pneumatised uncinate process — may be associated with symptomatic sinonasal disease and paranasal sinus involvement. The significantly greater cumulative variant burden in symptomatic individuals implies that co-occurring variants may have an additive effect on sinus ventilation and drainage. These observations reinforce the value of systematic, variant-specific CT evaluation in patients being considered for FESS, with focused attention to structures that narrow the infundibulum or middle meatus. The higher allergy prevalence in symptomatic patients suggests that mucosal inflammation of allergic origin may amplify the functional consequences of anatomical variants. Importantly, because a substantial proportion of asymptomatic individuals also harboured anatomical variants, these findings support the established recommendation that CT findings must always be correlated with clinical symptoms and endoscopic examination before surgical intervention is planned.

There are several strengths in the current study. Firstly, the study adopted a comparative design that had an equal number of symptomatic and asymptomatic patients to directly assess the relationship between the anatomical variations in the sinonasal region and the clinical disease. Secondly, the use of standardized CT imaging, which is the reference imaging modality for evaluating sinonasal anatomy and preoperative assessment, facilitated the identification of the different anatomical variations and their relationship with the paranasal sinuses and ostiomeatal complex. Thirdly, the similarity in the demographic

characteristics of the two groups minimized the risk of confounding from the demographic variables. Nevertheless, there are several limitations in the current study. First, the cross-sectional nature of the study does not permit the establishment of causality between the anatomical variations and sinonasal disease. Since the study was carried out in a single centre with a fairly small sample size, the results cannot be generalized to other populations. Moreover, the study used CT findings without the routine correlation with nasal endoscopy or long-term clinical follow-up. In addition, the potential confounders like the severity of allergic disease, environmental exposures, and other inflammatory diseases were not assessed in the study.

Conclusion

This comparative CT-based study demonstrated that symptomatic patients had a significantly greater burden of sinonasal anatomical variations than asymptomatic individuals, with nasal septal deviation, concha bullosa, agger nasi cells, Haller cells, and a pneumatized uncinate process showing significant associations with symptomatic disease. Symptomatic patients also exhibited significantly greater paranasal sinus and osteomeatal complex involvement, supporting the potential role of selected anatomical variants in impaired sinonasal drainage. Although several anatomical variants were also identified in asymptomatic individuals, these findings highlight the importance of systematic CT evaluation to distinguish clinically relevant variants from incidental findings. Careful preoperative assessment of sinonasal anatomy may facilitate surgical planning and improve anatomical orientation before FESS. Nevertheless, CT findings should always be interpreted in conjunction with clinical presentation and nasal endoscopic findings. Further multicentre prospective studies incorporating radiological, endoscopic, and surgical outcome measures are warranted to better define the independent clinical significance of individual anatomical variants.

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Conflicts of interest

There are no conflicts of interest.

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