

ORIGINAL ARTICLE

Computed tomography-based evaluation of anatomical variations in the sinonasal region in symptomatic patients: A cross-sectional study

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Abstract

Background: Sinonasal anatomical variations are common structural alterations that influence nasal airflow, sinus drainage, and the safety of functional endoscopic sinus surgery. Computed tomography of the paranasal sinuses (CT PNS) is the gold standard for preoperative assessment of these variations; however, region-specific prevalence data from South Indian cohorts remain limited. **Aim:** This hospital-based descriptive cross-sectional study aimed to systematically evaluate the prevalence and patterns of key sinonasal anatomical variations in symptomatic patients. **Methods:** Fifty patients aged 18 years and above who presented to the ear, nose, and throat (ENT) outpatient department of a tertiary care hospital and had undergone CT PNS imaging were enrolled through convenience sampling over a three-month period. Patients with prior sinonasal surgery or recent facial trauma were excluded. CT images were reviewed using standardized high-resolution parameters by an experienced radiologist in collaboration with the ENT team. Data were summarized using descriptive statistics, including frequencies, percentages, means, and standard deviations. **Results:** Among the 50 patients (mean age, 33.0 ± 14.0 years; 58% female), 70% had a deviated nasal septum, with left-sided deviation being the most common pattern (38.0% of all patients). Septal spurs were present in 46.0%, with spur-induced turbinate impingement in 34.0% of all patients. Inferior turbinate hypertrophy was the most prevalent finding (86.0%), predominantly bilateral (58.0%). Middle turbinate pneumatization (concha bullosa) was identified in 34.0%. Keros type II (62.0%) and Delano type I (74.0%) were the dominant skull base and optic nerve configurations, respectively. **Conclusion:** Common anatomical variations were frequently identified in symptomatic South Indian patients. **Relevance for patients:** Systematic CT PNS evaluation is essential for preoperative planning, and region-specific normative data are recommended to enhance surgical safety.

Keywords: Computed tomography of the paranasal sinuses; Sinonasal anatomical variations; Deviated nasal septum; Concha bullosa; Keros classification; Functional endoscopic sinus surgery

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1. Introduction

The sinonasal region encompasses the nasal cavity and paranasal sinuses, a complex anatomical space¹ critical for respiration, olfaction, mucociliary clearance, and vocal

resonance.² Anatomical variations within this region are common and encompass a wide spectrum of structural alterations—ranging from deviated nasal septum (DNS) and septal spurs to turbinate hypertrophy, concha bullosa, and variations in skull base and optic nerve anatomy.³ These variations are not merely incidental radiological findings; they carry considerable clinical relevance in determining nasal airway patency, predisposing individuals to chronic rhinosinusitis⁴, and significantly influencing the safety and outcomes of functional endoscopic sinus surgery (FESS).^{5,6}

Computed tomography of the paranasal sinuses (CT PNS) has become the definitive preoperative imaging modality for sinonasal evaluation.⁶ CT imaging provides high spatial resolution in both coronal and axial planes, allowing detailed assessment of bony architecture, mucosal changes, and critical anatomical relationships. Unlike clinical examination alone, Preoperative CT should primarily identify anatomical variants associated with potentially catastrophic complications, including ICA protrusion or dehiscence, Onodi cells, optic nerve dehiscence, and deep olfactory fossa (Keros III)—before undertaking endoscopic procedures. The introduction of multiplanar reconstruction has further enhanced CT PNS utility by enabling simultaneous coronal, axial, and sagittal assessment of the sinonasal complex. Modern protocols employing thin-slice (0.5–1 mm) high-resolution bone-algorithm reconstructions permit accurate Keros typing of the olfactory fossa, Delano classification of the optic nerve, and precise measurement of turbinate dimensions in a reproducible manner. These capabilities make CT PNS not only a diagnostic instrument but a precision surgical planning tool that should be integrated into the standard workup for all patients scheduled for functional nasal or endoscopic sinus surgery.

The prevalence of sinonasal anatomical variations shows considerable inter-ethnic and geographic variation. Studies from South Asia, particularly India, report distinctly different frequencies of DNS, concha bullosa, and skull base configurations compared to Western populations, likely reflecting differences in craniofacial morphology, genetic background, climate, and environmental exposures. Within India, regional variation also exists, with studies from different states demonstrating variable rates of specific anatomical findings. For example, DNS prevalence has been reported at rates ranging from 45% to as high as 79% in different Indian ear, nose, and throat (ENT) center-based studies, while concha bullosa rates vary from 14% to 51% depending on the study population. This considerable heterogeneity in reported prevalence underscores the importance of establishing local and region-specific normative data, which directly informs surgical training,

preoperative counseling, and clinical decision-making at regional medical centers. Despite this, published CT PNS data from tertiary ENT centers in Telangana and the broader South Indian region remain sparse, creating a gap that the present study seeks to address.

The clinical consequences of unrecognized sinonasal variations are significant. Septal spurs that impinge upon the inferior or middle turbinate can create mucosal contact points responsible for headache, nasal obstruction, and altered sinonasal physiology. Inferior turbinate hypertrophy compounds nasal airway resistance, while concha bullosa may obstruct the ostiomeatal complex^{7,8}, predisposing to recurrent sinus infections.⁹ From a surgical safety perspective, variations in the olfactory fossa depth (Keros classification)¹⁰, internal carotid artery (ICA) dehiscence, Onodi cells, and optic nerve course (Delano classification)⁷ define the risk of catastrophic complications including cerebrospinal fluid leak, skull base violation, and optic nerve injury during FESS.¹¹

Despite growing international literature, comprehensive regional data integrating septal, turbinate, and skull base/optic nerve variations in a single cohort remain scarce from South India. The prevalence of sinonasal anatomical variations is known to differ substantially across ethnic populations; differences in craniofacial development, nasal dimension, and sinus pneumatization between South Asian and Western populations mean that normative data from European or American studies cannot be uncritically extrapolated to Indian patients. For example, the olfactory fossa depth defining the Keros classification and the prevalence of concha bullosa subtypes have both been shown to vary significantly across populations, with Indian studies reporting patterns distinct from those reported in Caucasian cohorts. Establishing region-specific data is therefore clinically important not only for epidemiological purposes but also for designing appropriate surgical training curricula and refining FESS protocols suited to the anatomical characteristics of the South Indian population. The present study was therefore undertaken to systematically evaluate the prevalence and patterns of key sinonasal anatomical variations on CT PNS in patients presenting to a tertiary care ENT outpatient department, with specific emphasis on spur-turbinate impingement, Keros olfactory fossa classification, and Delano optic nerve classification. We recognize that other surgically critical posterior ethmoid and sphenoid sinus variants—notably the Onodi (sphenoethmoidal) cell and ICA protrusion or dehiscence at the paraclival–parasellar segment—are of critical anatomical variant importance for comprehensive pre-FESS planning and posterior skull base surgery; these variables lay outside the defined scope and original data

collection protocol of the present study and are discussed as a limitation and direction for future work.

The present study aims to determine the prevalence of sinonasal anatomical variations in CT PNS scans and to describe their patterns and co-occurrence with turbinate impingement in patients presenting to the ENT Outpatient Department (OPD). Specifically, the study aims to:

- (i) determine the prevalence and laterality of DNS and septal spurs;
- (ii) determine the prevalence and pattern of spur-induced turbinate impingement and identify whether the inferior or middle turbinate is involved;
- (iii) determine the prevalence and laterality of inferior turbinate hypertrophy;
- (iv) determine the prevalence and type distribution of middle turbinate pneumatization (concha bullosa); and
- (v) document the distributions of Keros classification types (olfactory fossa depth) and Delano classification types (optic nerve course).

2. Materials and Methods

2.1. Study Design and Setting

A descriptive cross-sectional study was jointly conducted by the Departments of Radiology and Otorhinolaryngology at Mamata Medical College, Khammam, over a three-month period. The study was carried out at a tertiary care teaching hospital serving a predominantly South Indian population presenting with sinonasal symptoms.

2.2. Sample Size and Sampling Technique

Convenient sampling was employed. A total of 50 patients who attended the ENT OPD and had available CT PNS imaging were consecutively enrolled during the study period. The sample size of 50 was selected to provide a preliminary descriptive dataset on local sinonasal anatomical variation frequencies, consistent with the protocol's scope and resource availability.

This study was designed as a descriptive cross-sectional anatomical survey rather than a case-control investigation; therefore, an asymptomatic control group was not methodologically required. All patients underwent CT PNS as part of routine clinical care for genuine sinonasal symptoms, and findings are presented as prevalence data within this symptomatic clinical population. As the study population consisted exclusively of symptomatic patients, the reported prevalence of septal deviation, turbinate hypertrophy, septal spurs, and concha bullosa may not reflect the true prevalence of these findings in the general population, and conclusions should be interpreted within this symptomatic cohort.

2.3. Inclusion and exclusion criteria

Patients were considered eligible for inclusion if they met all of the following criteria:

(a) Inclusion criteria:

- Patients aged 18 years or above presenting with sinonasal symptoms
- Availability of high-resolution CT PNS imaging
- Willingness to participate and provide clinical data

(b) Exclusion criteria:

- Patients below 18 years of age
- Patients with recent facial trauma that could distort normal sinonasal anatomy
- Patients who had previously undergone sinonasal surgeries

2.4. Imaging technique and interpretation of computed tomography scans of the paranasal sinuses

Computed tomography scans of the paranasal sinuses were retrieved, anonymized, and reviewed using standardized high-resolution imaging parameters. Axial and coronal multiplanar reconstructions were utilized for systematic evaluation. All scans were acquired on a multi-detector CT scanner using a standardized sinus protocol: slice thickness 1–3 mm, field of view 16–18 cm, with coronal reformations perpendicular to the hard palate. Images were reviewed at bone window settings (window width 2,000–3,000 HU, window level 500–700 HU) to delineate bony sinonasal landmarks and at soft tissue windows (window width 300–400 HU, window level 40–60 HU) to assess mucosal changes. All scans were interpreted by the principal investigator (an experienced otolaryngologist) in consultation with a senior radiologist, and both interpreters were blinded to each other's findings until consensus was reached. The following sinonasal parameters were systematically assessed and recorded for each patient:

- DNS: classified as right (R), left (L), S-shaped, or absent (midline)
- Septal spur: noted as present (Right/Left) or absent (AB)
- Spur-turbinate impingement: site recorded as inferior turbinate, middle turbinate, or absent
- Inferior turbinate hypertrophy: assessed as bilateral, unilateral (left or right), or absent
- Middle turbinate pneumatization (concha bullosa): classified by laterality and type (B-type)

All data were recorded in individual patient proformas and entered into a computerized database. Statistical analysis was performed using SPSS Statistics version 25.0 (IBM Corp., United States of America). Descriptive statistics including frequencies, percentages, mean, and standard deviation were computed for all variables. Results were summarized in tabular format. The study was observational and descriptive; inferential statistical tests were not applied as the primary objective was prevalence estimation.

2.5. Ethical considerations

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. As the study involved retrospective review of anonymized CT PNS images and was entirely observational in nature with no direct patient intervention, no additional risk was imposed on study participants. Ethics approval was obtained from the Institutional Ethical Committee before the study commenced (approval no. MMC/IEC/2022/2945/03/2026). Patient confidentiality was protected, and all data were anonymized throughout the study.

3. Results

3.1. Clinical presentation

All 50 patients included in this study presented with sinonasal symptoms to the ENT outpatient department; patients were not asymptomatic individuals incidentally undergoing CT PNS. The most common presenting complaint was nasal obstruction, reported by 38 patients (76.0%), followed by headache, predominantly facial or frontal in distribution, in 21 patients (42.0%), and rhinorrhea in 19 patients (38.0%). Twenty-four patients (48.0%) presented with a combination of two or more of these symptoms (Table 1). Anterior rhinoscopy and diagnostic nasal endoscopy were performed in all patients as part of routine ENT clinical assessment prior to CT referral; however, detailed endoscopic grading data were not systematically recorded in a standardized format during the study period and are therefore not reported quantitatively here. This represents a limitation of the study and is discussed further in Section 5.

3.2. Demographic characteristics

A total of 50 patients were enrolled in the study. The mean age of the study population was 33.0 ± 14.0 years, with an age range of 14 to 70 years. The majority of patients (52.0%) were below 30 years of age, followed by the 30–49-year group (30.0%), and the 50 years and above group (18.0%). Female patients constituted 58.0% ($n = 29$) of the study cohort, with male patients comprising 42.0% ($n = 21$). The

demographic distribution is detailed in Table 2. Septal spur and spur-turbinate impingement data are also summarized in Table 2, and a representative case is illustrated in Figure 1. DNS was detected in 35 of 50 patients (70.0%), with left-sided deviation being the most common type (38.0%), followed by right-sided deviation (30.0%). S-shaped deviation was observed in only one patient (2.0%), while 15 patients (30.0%) had a midline septum. Septal spurs were identified in 23 patients (46.0%), with left-sided spurs predominating (30.0%) and right-sided spurs detected in 16.0% of cases. Spur-induced turbinate impingement was recorded in 17 patients (34.0% of the total cohort), comprising inferior turbinate impingement in 14 patients (28.0%) and middle turbinate impingement in 3 patients (6.0%). Thirty-three patients (66.0%) had septal spurs without associated turbinate contact.

3.3. Inferior turbinate hypertrophy

Inferior turbinate hypertrophy was the most prevalent anatomical finding in this study, detected in 43 of 50 patients (86.0%). Bilateral hypertrophy was the dominant pattern ($n = 29$; 58.0%), followed by unilateral involvement—both left-only and right-only hypertrophy were observed in seven patients each (14.0% each). Only seven patients (14.0%) had no inferior turbinate hypertrophy. Details are provided in Table 3. Of note, bilateral inferior turbinate hypertrophy co-existed with DNS in the majority of affected patients, suggesting a dual anatomical burden on nasal airway patency that is likely to compound the degree of symptomatic nasal obstruction experienced by the patient.

3.4. Middle turbinate pneumatization (concha bullosa)

Middle turbinate pneumatization consistent with concha bullosa was identified in 17 patients (34.0%). Among these, bilateral B-type concha bullosa was the most common pattern ($n = 12$; 24.0%), followed by left B-type ($n = 4$; 8.0%) and right B-type ($n = 1$; 2.0%). The majority of patients ($n = 33$; 66.0%) had no middle turbinate pneumatization. These findings are shown in Table 3.

Middle turbinate pneumatization was further sub-classified into three morphological types based on CT PNS findings⁹:

- (a) Lamellar type: Pneumatization is confined to the vertical lamellar (vertical plate) portion of the middle turbinate. This type is associated with the least degree of middle meatus narrowing and is the least likely to obstruct the ostiomeatal complex. On coronal CT PNS, it appears as a thin air-containing cleft within the vertical portion of the turbinate.

Table 1. Distribution of presenting symptoms (*n* = 50)

Presenting symptom	<i>n</i>	%
Nasal obstruction	38	76.0%
Headache (facial/frontal)	21	42.0%
Rhinorrhea	19	38.0%
Combination of ≥ 2 symptoms	24	48.0%

Table 2. Demographic characteristics and prevalence of deviated nasal septum (DNS), septal spur, and turbinate impingement (*n* = 50)

Characteristic	<i>n</i>	%
Sex		
Male	21	42.0
Female	29	58.0
Age (years)		
Mean $\pm$ SD	33.0 $\pm$ 14.0	
Range	14–70	
Age group		
<30 years	26	52.0
30–49 years	15	30.0
≥ 50 years	9	18.0
Nasal septal configuration		
Right deviation	15	30.0
Left deviation	19	38.0
Midline (no deviation)	15	30.0
S-shaped deviation	1	2.0
DNS present (R + L + S)	35	70.0
No DNS (midline)	15	30.0
Septal spur		
Right-sided spur	8	16.0
Left-sided spur	15	30.0
Absent	27	54.0
Total with Spur	23	46.0
Spur-induced turbinate impingement		
Inferior turbinate impingement	14	28.0
Middle turbinate impingement	3	6.0
No impingement	33	66.0
Total with impingement	17	34.0

Table 3. Inferior turbinate hypertrophy and middle turbinate pneumatization (*n* = 50)

Characteristic	<i>n</i>	%
Inferior turbinate hypertrophy		
Bilateral	29	58.0
Left only	7	14.0
Right only	7	14.0
Absent	7	14.0
Total with hypertrophy	43	86.0%
Middle turbinate pneumatization (concha bullosa)		
Bilateral B-type	12	24.0
Left B-type	4	8.0
Right B-type	1	2.0
Absent	33	66.0
Total with pneumatization	17	34.0

- (b) Bullous type (B-type/concha bullosa): Pneumatization is restricted to the bulbous (inferior) portion of the middle turbinate. This is the most prevalent and clinically significant variant, as the enlarged bullous portion directly encroaches on the middle meatus. Bullous concha bullosa accounts for all 17 cases identified in the present study (bilateral in 12, unilateral left in 4, unilateral right in 1) and is the most likely type to obstruct sinus drainage and predispose to recurrent sinusitis.
- (c) Mixed/extensive type: Pneumatization extends to involve both the lamellar and the bulbous portions of the middle turbinate, resulting in generalized enlargement of the entire turbinate. This is the most extensive form and poses the greatest risk of middle meatal obstruction. On CT PNS, the entire middle turbinate appears air-filled and markedly expanded, frequently causing significant narrowing or obliteration of the infundibulum.

In the present cohort, all identified cases of concha bullosa were of the bullous (B-type) variety. Lamellar and mixed/extensive types were not encountered, consistent with reports from similar South Asian studies where the B-type predominates. The distribution by type is summarized in [Table 3](#).

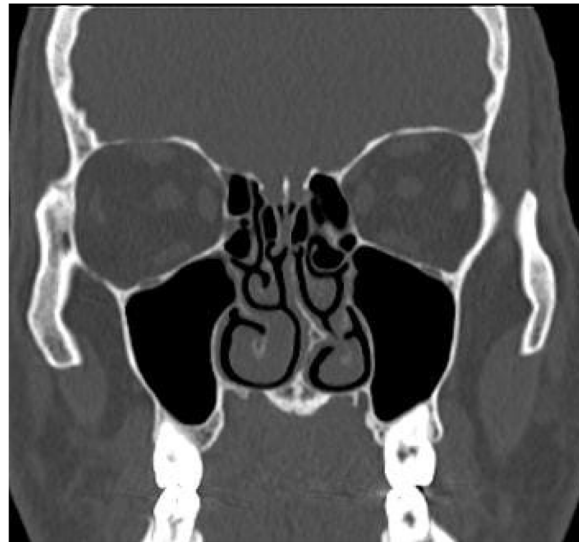


Figure 1. Representative coronal computed tomography image of the paranasal sinuses showing a left-sided septal spur impinging on the left inferior turbinate

3.5. Keros classification

Keros classification of olfactory fossa depth was determined for all 50 patients. Keros type II (depth 4–7 mm) was the most prevalent, found in 31 patients (62.0%), indicating a moderately deep olfactory fossa. Keros type I (depth 1–3 mm) was identified in 18 patients (36.0%), reflecting a shallow fossa with lower surgical risk. Only one patient (2.0%) had Keros type III (depth > 7 mm), representing the highest surgical risk for skull base violation. No patient had an asymmetric classification between sides. Details are shown in [Table 4](#) and illustrated in [Figure 2](#).

3.6. Delano classification

Assessment of optic nerve course using the Delano classification revealed that the large majority of patients—37 of 50 (74.0%)—had type I configuration, where the optic nerve lies adjacent to but does not indent the sphenoid sinus wall, representing the lowest surgical risk. Delano type II (nerve indenting the sphenoid wall) was present in 13 patients (26.0%). Delano types III and IV, which represent progressively more dangerous configurations involving the nerve traversing the sinus lumen or being dehiscent, were not observed in this cohort. [Table 4](#) and [Figure 3](#) summarize these findings.

4. Discussion

This cross-sectional CT-based study systematically evaluated the prevalence of major sinonasal anatomical

variations in 50 symptomatic patients presenting to the ENT OPD. The findings comprehensively document the burden of DNS, septal spurs with turbinate impingement, inferior turbinate hypertrophy, concha bullosa, and skull base/optic nerve anatomy in a South Indian population cohort, providing region-specific data relevant to clinical and surgical practice.

4.1. Demographics and study population

The mean age of the study cohort was 33.0 ± 14.0 years, consistent with the epidemiology of chronic sinonasal disease, which predominantly affects working-age adults. Female preponderance (58.0%) in this cohort aligns with patterns reported in multiple Indian studies examining ENT OPD populations, possibly reflecting greater healthcare-seeking behavior among women or sex-related differences in sinonasal anatomy. The youngest patient was 14 years and the oldest 70 years, spanning a broad age range indicative of the universality of sinonasal complaints across the lifespan.

4.2. Deviated nasal septum

Deviated nasal septum was detected in 70.0% of patients in the present study. This prevalence is consistent with existing Indian literature—Kumar *et al.*¹² reported DNS in approximately 60%–78% of symptomatic patients evaluated by CT PNS, while Gouripur *et al.*¹³ documented DNS in 74.4% of patients with chronic sinusitis. Left-sided deviations (38.0%) were slightly more frequent than

Table 4. Keros and Delano classifications (*n* = 50)

Classification/type	Description	<i>n</i>	%
Keros type			
Type I	Olfactory fossa depth 1–3 mm	18	36.0
Type II	Olfactory fossa depth 4–7 mm	31	62.0
Type III	Olfactory fossa depth > 7 mm	1	2.0
Total	–	50	100
Delano classification of the optic nerve course			
Delano Type	Optic Nerve Course	<i>n</i>	(%)
Type I	Nerve adjacent to sphenoid, not indenting	37	74.0
Type II	Nerve indenting sphenoid sinus wall	13	26.0
Type III	Nerve traversing sinus lumen	0	0.0
Type IV	Dehiscent nerve with pneumatized anterior clinoid	0	0.0
Total	–	50	100

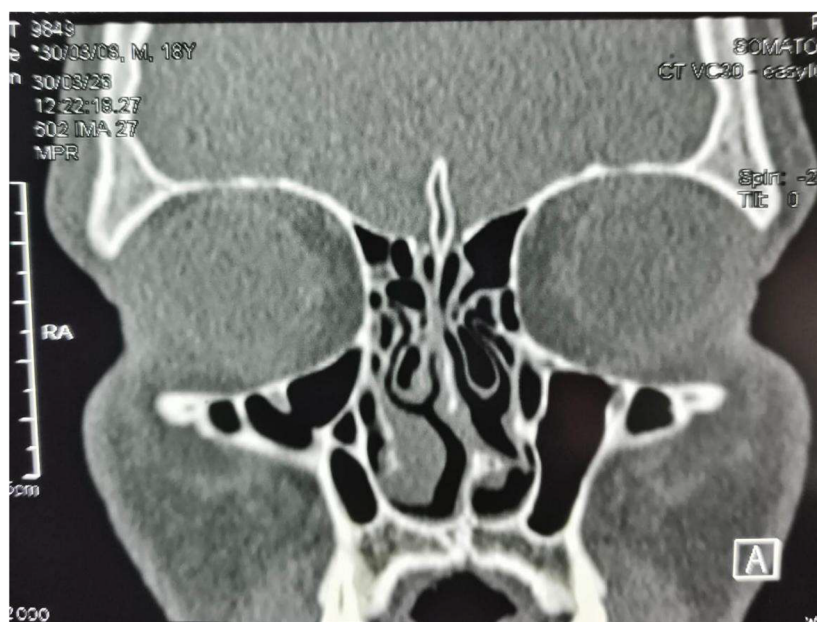


Figure 2. Coronal computed tomography image of the paranasal sinuses showing a Keros type II olfactory fossa (coronal multiplanar reformatted image)



Figure 3. Coronal computed tomography image of the paranasal sinuses showing a Delano type I course of the optic nerve adjacent to the sphenoid sinus

right-sided deviations (30.0%); however, given the limited sample size and the absence of statistical testing, no conclusion regarding true lateral dominance can be drawn.

The S-shaped deviation was an uncommon finding (2.0%), as expected, given its complex biomechanical basis. From a surgical standpoint, left-sided DNS predominance suggests that ENT surgeons operating in this region should be specifically vigilant about right-to-left surgical approaches during septoplasty and endoscopic surgery.¹⁴ The degree of nasal obstruction caused by DNS is not solely determined by the direction or magnitude of the deviated septum; associated mucosal hypertrophy, concurrent septal spurs, and secondary turbinate changes collectively determine the functional impairment experienced by the patient. Preoperative CT allows the surgeon to map each of these variables and plan a tailored, staged correction rather than a uniform approach. Furthermore, DNS is known to alter nasal aerodynamics and mucociliary clearance by disrupting laminar airflow, with downstream effects on the ostiomeatal complex and paranasal sinus ventilation.¹⁵ Recognition of these dynamics on CT PNS is essential for predicting postoperative outcomes and counseling patients regarding realistic expectations from septoplasty.

4.3. Septal spurs and turbinate impingement

Septal spurs were identified in 46.0% of patients, a higher prevalence than in many reported series. Badia *et al.*¹⁶ and Mokhasanavisu *et al.*¹⁷ reported varying spur prevalence across ethnic groups, with South Asian populations generally showing higher rates. The marked predominance of left-sided spurs (30.0%) over right-sided spurs (16.0%)

mirrors the left-sided predominance of DNS observed in this cohort, suggesting a biomechanical relationship between the direction of septal deviation and spur formation at its base.

A clinically critical finding in this study was the detection of spur-induced turbinate impingement in 34.0% of all patients. This is a recognized cause of contact-point headache, paradoxical nasal obstruction, and altered mucociliary flow. Inferior turbinate impingement was far more common (28.0%) than middle turbinate impingement (6.0%), consistent with anatomical proximity of the inferior turbinate to the septal floor where spurs typically originate. The 34.0% impingement rate in this series is clinically significant—these patients represent a subgroup who may benefit from targeted septoplasty with spur resection rather than turbinoplasty alone, and precise CT identification of impingement site is essential for surgical planning.

4.4. Inferior turbinate hypertrophy

Inferior turbinate hypertrophy was the single most prevalent anatomical variation in this cohort, detected in 86.0% of patients. This exceptionally high prevalence likely reflects selection bias—as the study exclusively enrolled symptomatic ENT OPD patients, the cohort is enriched for individuals with nasal obstruction and chronic rhinitis, conditions intrinsically associated with turbinate hypertrophy.¹⁸ The predominantly bilateral pattern (58.0%) suggests systemic mucosal inflammatory states—such as perennial allergic rhinitis—as the underlying etiology, rather than a compensatory response to unilateral

DNS, which would predominantly produce contralateral hypertrophy.¹⁹ CT PNS further enables sub-classification of turbinate hypertrophy into bony and mucosal (soft tissue) components, which has direct therapeutic relevance: bony hypertrophy requires surgical reduction (outfracture or partial turbinoplasty), whereas isolated mucosal hypertrophy may initially be managed medically or with radiofrequency coblation and submucosal diathermy.²⁰ The coexistence of inferior turbinate hypertrophy with DNS (70.0%) and septal spurs (46.0%) in this population indicates that a majority of patients presenting to this ENT center have multiple concurrent anatomical anomalies that collectively impair nasal airflow, potentially compounding their symptomatic burden. Recognizing these comorbid anatomical variations preoperatively is therefore essential for planning combined surgical correction—simultaneous septoplasty and turbinoplasty—rather than staged procedures, thereby minimizing the total surgical burden on the patient and optimizing long-term outcomes.²¹

From a management perspective, this anatomical overlap highlights a broader clinical reality: septal surgery alone is often insufficient for complete nasal airway rehabilitation, and concurrent inferior turbinate reduction is frequently required. In published series, combined septoplasty and turbinoplasty consistently achieves superior patient-reported outcomes compared to septoplasty alone when bilateral turbinate hypertrophy is preoperatively documented. This has practical implications for surgical consenting: patients should be counseled preoperatively that turbinate surgery may be simultaneously performed based on CT and intraoperative findings, rather than being unexpectedly informed of an additional procedure during their postoperative visit. The ability of CT PNS to objectively document turbinate size, asymmetry, and subtype preoperatively thus directly enhances informed consent quality and reduces patient confusion regarding the scope of surgery performed.

4.5. Middle turbinate pneumatization (concha bullosa)

Concha bullosa was identified in 34.0% of the study population, with bilateral B-type being the dominant pattern (24.0%). This prevalence is consistent with the range reported in existing literature; Papadopoulou *et al.*²² noted concha bullosa prevalence ranging from 8.0% to 53.0% across different populations in their systematic review. The B-type concha bullosa—involving pneumatization of the bulbous portion of the turbinate—is considered the most likely to obstruct the middle meatus and ostiomeatal complex, predisposing to recurrent maxillary and ethmoid sinusitis.²³ Bilateral concha bullosa in this series represents

a surgically relevant finding, as its presence narrows the middle meatus bilaterally and may necessitate concha bullosa resection during FESS to adequately restore drainage pathways. The absence of lamellar or mixed type concha bullosa in this series may reflect a genuine population-level anatomical tendency or a limitation of sample size; larger studies would help clarify this pattern.²⁴ From a clinical perspective, not all patients with concha bullosa require surgical intervention; the decision to resect should be guided by the degree of middle meatus obstruction, symptom burden, and failure of medical therapy.²⁵ CT PNS provides the only reliable means of identifying the extent and type of pneumatization, making it indispensable for individualized surgical decision-making.²⁶

4.6. Keros classification

Keros type II was the predominant olfactory fossa configuration (62.0%), followed by type I (36.0%) and type III (2.0%). This distribution pattern—with type II being most common—has been consistently reported in Indian and Asian populations.²⁷ Kumar *et al.*¹² from India and Mokhasanavisu *et al.*¹⁷ similarly found type II to be the most frequent Keros variant in South Asian patients. The predominance of type II over type III in this series is surgically reassuring; however, even a single type III case (2.0%) in a relatively small cohort of 50 patients underscores the imperative for individual preoperative CT review, as type III configurations carry significantly elevated risk of iatrogenic skull base perforation during anterior ethmoidectomy due to the lateral lamella of the cribriform plate being particularly attenuated and elongated. A practical implication is that this data provides a center-specific baseline for estimating surgical risk at a population level.²⁸ When approximately two-thirds of patients presenting for FESS have a type II olfactory fossa, the routine use of image-guided navigation systems or intraoperative fluoroscopic confirmation should be considered standard practice in this setting. Surgeons who rely exclusively on tactile feedback without integrating the preoperative CT Keros classification are at increased risk of unrecognized skull base perforation, with potentially catastrophic consequences including cerebrospinal fluid leak, meningitis, and intracranial hemorrhage.²⁹

4.7. Delano classification

Delano type I was the dominant optic nerve configuration (74.0%), with type II present in 26.0% of cases. No patients with type III or type IV configurations were identified. Delano types III and IV, where the optic nerve traverses the sphenoid sinus lumen or is dehiscant, are the configurations associated with greatest intraoperative risk.³⁰ Their absence

in this cohort is consistent with reports from other Indian populations; Mokhasanavisu *et al.*¹⁷ also found types III and IV to be rare. Nevertheless, the 26.0% prevalence of type II—where the nerve indents the sphenoid sinus wall—is noteworthy, as the presence of nerve indentation indicates a higher likelihood of dehiscence of optic canal, increasing the risk of optic nerve injury during posterior ethmoidectomy and sphenoid sinus surgery.³¹ Preoperative identification of type II configurations in 1 in 4 patients should prompt surgeons to exercise heightened caution when operating in the posterior ethmoid and sphenoid region.

4.8. Clinical and surgical implications

The findings of this study collectively reinforce the critical role of routine preoperative CT PNS evaluation in all patients being considered for FESS. The co-occurrence of multiple anatomical variations in a single patient—particularly the combination of DNS with septal spur impingement, bilateral inferior turbinate hypertrophy, and concha bullosa—creates a functionally compromised nasal airway requiring a comprehensive, individualized surgical plan.³² The presence of Keros type III in even 2.0% of patients and Delano type II in 26.0% means that for every 4–50 surgeries performed, the operating surgeon must have already identified and planned for these high-risk anatomical configurations. This underscores the need for systematic, structured CT PNS reporting in every FESS candidate rather than selective reporting only when the radiologist perceives a clinical concern.³³ We recommend that ENT departments adopt a standardized CT PNS checklist that includes the following eight parameters as mandatory reporting items: (i) presence and type of DNS, (ii) presence and laterality of septal spurs, (iii) spur-turbinate impingement (inferior vs. middle turbinate), (iv) inferior turbinate hypertrophy (laterality and estimated subtype), (v) middle turbinate pneumatization (concha bullosa type and laterality), (vi) agger nasi cell presence, (vii) Keros olfactory fossa classification (bilateral), and (viii) Delano optic nerve classification (bilateral). Such a structured approach ensures that no surgically critical anatomical variant is overlooked and that the operative consent and planning process is based on individualized anatomical information rather than population averages.³⁴

The data from this study support the incorporation of structured CT-based anatomical checklists in ENT surgical planning, ensuring that all relevant variations are systematically reviewed prior to FESS rather than identified incidentally at surgery. Such protocols have been shown to reduce intraoperative complication rates and improve surgical efficiency.³⁵ Structured checklists also facilitate communication between the radiologist and the operating surgeon, promote documentation of anatomical risk

factors in operative notes, and provide a defensible record in medico-legal contexts. Beyond surgical planning, these data have direct relevance for ENT postgraduate training. Trainees learning FESS should systematically review CT PNS images using a structured anatomical checklist before their first supervised endoscopic case. Familiarity with normal CT anatomy and its common variants allows the trainee to develop the three-dimensional spatial understanding of the surgical field that is critical for safe navigation. Simulation-based CT PNS interpretation training, now available through dedicated radiology teaching software and cadaveric courses, should therefore be incorporated into the ENT residency curriculum as a mandatory component alongside clinical endoscopy skills.

5. Limitations

This study has several limitations that should be acknowledged. First, the sample size of 50 patients, while sufficient for preliminary prevalence estimates, limits the statistical power for subgroup analyses and association studies. Second, the use of convenient sampling in an exclusively symptomatic ENT OPD population introduces selection bias, and the prevalence figures are not generalizable to an asymptomatic general population. Third, this study did not include assessment of the Onodi (sphenothmoidal) cell or evaluation of ICA protrusion or bony dehiscence at the paraclival–parasellar segment relative to the sphenoid sinus. Both are recognized as surgically critical variants in posterior ethmoid and sphenoid sinus surgery, given the risk of optic nerve injury associated with a pneumatized Onodi cell and the catastrophic potential of unrecognized ICA dehiscence during endoscopic or trans-sphenoidal approaches. These variables were outside the predefined scope of the study and were therefore not analyzed. We acknowledge this as a significant limitation in anatomical scope and have noted it as a priority variable for inclusion in future prospective work from our center.³⁶ Fourth, bilateral spur occurrence was not separately tabulated in the dataset, which may represent a minor underestimation of spur burden. Fifth, intra-observer and inter-observer reliability of CT interpretation was not formally assessed. Future studies with larger sample sizes, probabilistic sampling, and dual-reader validation are recommended to build upon these findings.³⁷ Additionally, a prospective design incorporating preoperative and postoperative functional outcomes—such as SNOT-22 scores, peak nasal inspiratory flow, and endoscopic grading of the ostiomeatal complex—would substantially enrich the clinical translation of CT-based anatomical data. Comparative studies across multiple tertiary centers from diverse geographic regions of India would also help establish robust national normative data

for sinonasal anatomy, which are currently lacking.³⁸ The integration of volumetric CT analysis and multiplanar reconstruction techniques in future protocols would further enhance the precision and reproducibility of anatomical classification, particularly for Keros and Delano grading.

6. Conclusion

This CT-based cross-sectional study demonstrates a high prevalence of sinonasal anatomical variations in symptomatic patients attending a tertiary ENT OPD in South India. Inferior turbinate hypertrophy (86.0%), DNS (70.0%), and septal spurs (46.0%) are the predominant findings, with spur-induced turbinate impingement present in one-third of patients.³⁹ Middle turbinate pneumatization (concha bullosa) was identified in 34.0% of cases, with bilateral B-type being the dominant pattern.⁴⁰

Among skull base and optic nerve configurations, Keros type II was the most frequent olfactory fossa classification (62.0%), and Delano type I was the most common optic nerve variant (74.0%). Notably, the presence of Keros type III and Delano type II in 2.0% and 26.0% of patients, respectively, highlights the surgical risk requiring individualized preoperative assessment.

These findings underscore the paramount importance of systematic and standardized CT PNS evaluation as a preoperative prerequisite before FESS. Region-specific anatomical data, as presented here, serve to improve surgical preparedness, refine preoperative counseling, and ultimately enhance patient safety. We recommend larger prospective multicentre studies to further characterize the epidemiology of sinonasal variations in the Indian population and to establish evidence-based anatomical risk stratification frameworks for ENT surgical planning.

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Conflict of interest

The authors declare no conflicts of interest.

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Ethics approval and consent to participate

This study was reviewed and approved by the Institutional Ethics Committee of Mamata Medical College & Hospital, Khammam (IEC Reference: MMC/IEC/2022/2945/03/2026). The study was conducted in accordance with the Declaration of Helsinki. As this study involved retrospective review of anonymized, pre-existing CT PNS images with no direct patient intervention, a waiver of individual written informed consent to participate was granted by the IEC.

Consent for publication

Not applicable. This manuscript does not contain any individual person's identifiable data, images, or other personal or clinical information that would require consent for publication. All CT images used are fully anonymized and contain no identifying information.

Availability of data

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Further disclosure

Claude was used during manuscript preparation solely to assist with language polishing, formatting, and reference organization under direct human supervision. The AI tool was not used to generate scientific findings, conduct data analysis, or draw scientific conclusions; all such content represents the original work and judgment of the authors.

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