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Prevalence of Anatomical Variations Concerning the Drainage of Paranasal Sinuses: A CT-based Retrospective Cross-Sectional Study from Eastern India

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ABSTRACT

Background: Anatomical variations of the paranasal sinuses (PNS) are highly variable among individuals and can significantly affect mucociliary drainage, predisposing patients to rhinosinusitis. Particularly when considering surgery for Functional Endoscopic Sinus Surgery (FESS), which attempts to restore normal sinus drainage, a thorough evaluation of these variances is essential. Despite their clinical importance, there is a lack of in-depth studies on these variations within the Indian population.

Objective: To determine the prevalence of anatomical variations affecting PNS drainage using computed tomography (CT) among patients in Eastern India.

Materials and Methods: A retrospective cross-sectional study was conducted on 100 patients aged 20–70 years who underwent CT evaluation for suspected sinusitis at a tertiary care center in Jharkhand, India, between July and December 2024. Anatomical variations in the osteomeatal complex (OMU) and sphenoethmoidal recess (SER) were assessed using a 128-slice Siemens CT scanner. Data was analyzed using RStudio (v2025.05.1+513). Chi-square test and prevalence ratios (PR) with 95% confidence intervals (CI) were used to explore associations with sex.

Results: Of the 100 patients (mean age 42.9 ± 15.5 years), 51% were male and 49% female. The most common anatomical variations observed were agger nasi cells (98%), supra bullar cells (93%), Type I uncinate process attachment (88%), deviated nasal septum (78%), and enlarged ethmoid bulla (72%). A statistically significant sex difference was found only for frontal bullar cells, which were more prevalent in females (PR = 0.40, 95% CI: 0.20–0.84, $p = 0.01$). Other variations showed no significant sex-based differences.

Conclusion and recommended: Anatomical variations of the PNS are highly prevalent and show considerable inter-individual variability. CT evaluation provides critical insights for individualized surgical planning. Routine preoperative imaging is recommended to minimize complications and improve surgical outcomes, particularly in FESS.

Keywords: *Anatomical variations of Paranasal Sinuses; Computed Tomography; Functional Endoscopic Sinus Surgery; Osteomeatal Unit.*

1. INTRODUCTION

The anatomical variations of Paranasal Sinuses (PNS) are most frequent in the human body. [1] Different ethnic groups have different rates of these anatomical differences. [2] Many of the anatomical variations can hinder the normal mucociliary drainage pathways of the PNS, which predisposes to chronic rhinosinusitis. [3,4] "Computed Tomography" (CT) is the investigation of choice for evaluating paranasal sinus anatomy, and it provides an anatomical roadmap for the surgeon to identify significant anatomical variations for planning "Functional Endoscopic Sinus Surgery" (FESS). To reestablish the normal functioning drainage of the mucociliary pathway, FESS plays a crucial part in the handling of chronic rhinosinusitis. [1,2] Assessing these anatomical variations is essential, yet there is a lack of in-depth studies in the Indian population. The objective of this study is to evaluate the prevalence of anatomical variants concerning the drainage of the PNS in the study population of Jamshedpur, Jharkhand, which benefits the surgeons in the preoperative evaluation and contributes to existing epidemiological data in the literature.

2. MATERIALS AND METHODS

Study design and ethical clearance:

The cross-sectional retrospective study was conducted in the Department of Radiology at Meherbai Tata Memorial Hospital (MTMH), Jamshedpur, Jharkhand. The Institutional Ethics Committee at MTMH provided ethical approval (Ref. No.: MTMH/IEC/140/2024).

Study population and sampling method:

Convenience sampling was used to include the average monthly outpatient flow of patients undergoing CT for suspected sinusitis during a six-month period (July 2024 - December 2024), and the sample size of 100 patients was chosen based on the practical availability of cases in a tertiary care setting and the retrospective nature of the study. While convenience sampling facilitates timely data collection, it may limit the generalizability of the findings due to potential selection bias.

Inclusion and exclusion criteria:

This study includes patients aged 20 to 70 years with symptomatic sinusitis, and other symptoms like headache, nasal block, and allergic rhinitis are included in the study. Patients under 20 years old, those with sinonasal polyposis, fungal sinusitis, pansinusitis, previous sinus surgery, sinonasal malignancy, and facial trauma were excluded from the study.

Radiological Evaluation:

A CT scan of the nose and PNS was taken using the 128-slice Siemens spiral CT scanner. The axial plane was used for obtaining consecutive sections, & multiplanar reformatting was done with images of 1.5 mm slice thickness. Images were stored and retrieved in the SYNGO via PACS system. The data about the anatomical variations concerning the drainage of the PNS is analyzed by both a radiologist and an ENT surgeon with more than nine years of expertise conducted radiological evaluations independently to reduce any potential bias, and it is tabulated in the Microsoft Excel spreadsheet. The following standard operational definitions were used for all patients to ensure consistency in determining the presence of anatomical variations:

- Deviated Nasal Septal (DNS) is defined as "Divergence from the midline. This includes single curvature, Double curvature with an "S" shaped configuration". [5]
- Septal spur is defined as "the nasal septum acute angulations at the junctions". [6]
- Pneumatised nasal septum is defined as "Pneumatisation of the posterior part of the nasal septum". [1]
- Concha bullosa is defined as "Pneumatization of the middle turbinate's inferior bulbous portion". [7]
- Paradoxical middle turbinate is defined as "the middle turbinate's laterally facing and inverted convexity with respect to the lateral nasal wall". [5]
- By the uncinate process of the Superior variant attachments are determined as "the three attachments patterns are, Type I, Attachment to the lamina papryacea directly or indirectly by attaching to the agger nasi cell. Type II, Attachment to the skull base. Type III, Attachment to the middle turbinate". [8,9]
- Pneumatised uncinate process or Uncinate bulla is classified as "Pneumatisation of the anterio-superior part of the uncinate process". [1,10]
- Haller cell or Infraorbital cell is defined as "Air cell located in the top of the maxillary sinus or along the orbit's floor, inferior to the ethmoid bulla and lateral to the lamina papyracea". [4,6,7]
- Ethmoid bulla is defined as "the bulla lamella, also known as the second ethmoid basal lamella, which runs from the lamina papyracea into the middle meatus, is pneumatized to create the anterior ethmoid air cell". [1,7]
- Agger nasi cell is defined as "the most anterior ethmoid air cell, which is located in front of the anterior connection of the middle turbinate, is created when the ethmoid air cell pneumatization extends into the lacrimal bone". [7]
- The ethmoid air cell is located above the ethmoid bulla and is bounded anteriorly by the anterior cranial fossa and superiorly by the frontal recess. It does not extend to the frontal sinus. [7]
- Frontal bullar cell is "an Air cell extending from the suprabullar region along the posterior wall into the frontal sinus". [7]
- Frontal cells, sometimes referred to as frontoethmoid cells, come in four different varieties. One type I frontal cell,

situated under the frontal ostium and above the agger nasi cell. Type II cells are located above the agger nasi cell and beneath the frontal ostium. This term describes a type III solitary cell that occupies less than 50% of the sinus height and extends into the frontal sinus above the agger nasi. A solitary cell above the agger nasi that extends into the frontal sinus over 50% of its height / an isolated cell completely within the frontal sinus above the level of the frontal ostium are characteristics of type IV cells. [1,7]

- Frontal intersinus septal cell is defined as "an intersinus septal cell is formed when the frontal intersinus septum becomes pneumatized". [11]
- Pneumatized crista galli is formed by the frontal sinuses' pneumatization extending. [7,12]

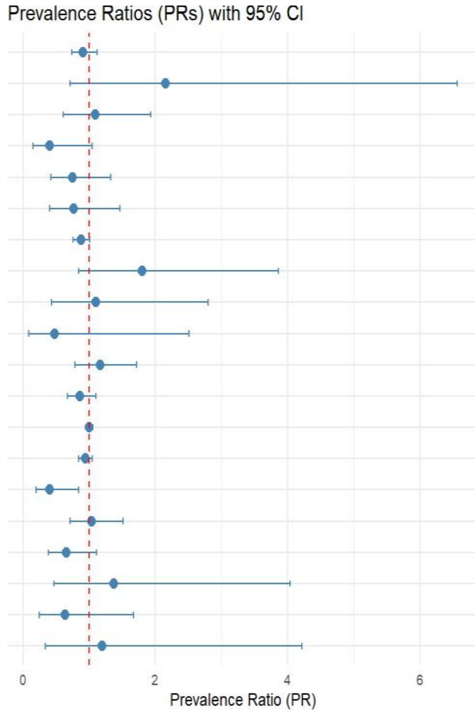
Statistical analysis: -

Data was entered into Microsoft Excel, and RStudio (v2025.05.1+513) was used for statistical analysis. The values for categorical variables were displayed as numbers and percentages, and the association between gender and anatomical changes was inspected using the chi-square test. The mean & standard deviation (SD) are used to display values for continuous variables. All p-values were deemed statistically significant if they were less than 0.05.

3. RESULTS

Out of 100 patients, 51.0% of patients were males, 49.0% of patients were females. Therefore, among the participants in this study, men predominated over women. The mean age of patients was 42.90±15.48 years with a range of 20 to 70 years. 28.0% of patients aged between 20 to 30 years, 19.0% of patients aged between 31-40 years, 20.0% of patients aged between 41-50 years, 15.0% of patients aged between 51-60 years, and 18.0% of patients aged between 61-70 years respectively. There was insignificant association between age group & sex ($p = 0.245$). Graph 1 showed the forest plot of prevalence of anatomical variations associated with paranasal sinus discharge. The most prevalent anatomical variants were Agger Nasi Cell (98%), Supra Bullar Cell (93%), Type I Attachment of the Uncinate Process (88%), Deviated Nasal Septum (78%), and Enlarged Ethmoid Bulla (72%). These features were nearly equally prevalent across sexes (PRs ≈ 1.00). Several anatomical variants showed notable differences between males and females. The "S" shaped deviated nasal septum was more than twice as prevalent in males compared to females (PR = 2.16, 95% CI: 0.71, 6.56, $p = 0.39$). Similarly, Type II attachment of the uncinate process (PR = 1.80, 95% CI: 0.84, 3.86, $p = 0.12$) and Type III frontal cells (PR = 1.37, 95% CI: 0.47, 4.04, $p = 0.57$) were more common in males. Among all the variants assessed, a statistically significant association was observed only for the Frontal Bullar Cell, which was more prevalent in females (38.8%) than in males (15.7%), ($p = 0.01$). The prevalence ratio was 0.40 (95% CI: 0.20, 0.84), indicating that males were 60% less likely to present with this variant compared to females. A marginally non-significant trend was observed in Pneumatized Nasal Septum (PR = 0.40, 95% CI: 0.15, 1.05, $p = 0.05$) with higher prevalence in females (24.5%) than in males (9.8%), and also Type II Frontal Cell (PR = 0.66, 95% CI: 0.39, 1.11, $p = 0.11$) with higher prevalence in females (44.9%) than in males (29.4%) suggesting a potential sex-based difference. Similarly, Females were more likely to have Type I Attachment of the Uncinate Process (93.9%) compared to males (82.4%), (PR = 0.88 95% CI: 0.76, 1.01, $p = 0.08$). No statistically significant sex differences were found for other anatomical variants, including Deviated Nasal Septum ($p = 0.16$), Concha Bullosa ($p = 0.32$), Haller Cell ($p = 0.43$), Agger Nasi Cell ($p = 0.98$), and Enlarged Ethmoid Bulla ($p = 0.23$). The Agger Nasi Cell was present in 98% of both sexes, showing no meaningful difference, (PR = 1.00 ,95% CI: 0.95, 1.06, $p = 0.98$). Variants with low prevalence such as Type IV Frontal Cell ($p = 0.16$) was found exclusively in males, though its overall prevalence was low (2%), and Pneumatized Cristagalli (PR = 1.20, 95% CI: 0.34, 4.21, $p = 0.77$) did not reveal statistically significant correlations, presumably because of small sample sizes within subgroups and inadequate power. These findings suggest that while many anatomical variants are shared across sexes, specific configurations may exhibit sex-based prevalence patterns.

Variant	Males	Females	Prevalence	p_val	PR_CI
Deviated Nasal Septum	38 (74.51%)	40 (81.63%)	78%	0.390	0.91 [0.74–1.12]
S Shaped DNS	9 (17.65%)	4 (8.16%)	13%	0.160	2.16 [0.71–6.56]
Septal Spur	17 (33.33%)	15 (30.61%)	32%	0.770	1.09 [0.61–1.93]
Pneumatized Nasal Septum	5 (9.8%)	12 (24.49%)	17%	0.051	0.40 [0.15–1.05]
Concha Bullosa	14 (27.45%)	18 (36.73%)	32%	0.320	0.75 [0.42–1.33]
Paradoxical Middle Turbinate	12 (23.53%)	15 (30.61%)	27%	0.430	0.77 [0.40–1.47]
Type I Uncinate Process	42 (82.35%)	46 (93.88%)	88%	0.080	0.88 [0.76–1.01]
Type II Uncinate Process	15 (29.41%)	8 (16.33%)	23%	0.120	1.80 [0.84–3.86]
Type III Uncinate Process	8 (15.69%)	7 (14.29%)	15%	0.840	1.10 [0.43–2.80]
Pneumatized Uncinate Process	2 (3.92%)	4 (8.16%)	6%	0.370	0.48 [0.09–2.51]
Haller Cell	28 (54.9%)	23 (46.94%)	51%	0.430	1.17 [0.79–1.72]
Enlarged Ethmoid Bulla	34 (66.67%)	38 (77.55%)	72%	0.230	0.86 [0.67–1.10]
Agger Nasi Cell	50 (98.04%)	48 (97.96%)	98%	0.980	1.00 [0.95–1.06]
Supra Bullar Cell	46 (90.2%)	47 (95.92%)	93%	0.260	0.94 [0.84–1.05]
Frontal Bullar Cell	8 (15.69%)	19 (38.78%)	27%	0.010	0.40 [0.20–0.84]
Type I Frontal Cell	27 (52.94%)	25 (51.02%)	52%	0.850	1.04 [0.71–1.51]
Type II Frontal Cell	15 (29.41%)	22 (44.9%)	37%	0.110	0.66 [0.39–1.11]
Type III Frontal Cell	7 (13.73%)	5 (10.2%)	12%	0.570	1.37 [0.47–4.04]
Frontal Intersinus Septal Air Cell	6 (11.76%)	9 (18.37%)	15%	0.360	0.64 [0.25–1.67]
Pneumatized Cristagalli	5 (9.8%)	4 (8.16%)	9%	0.770	1.20 [0.34–4.21]



Graph 1: Forest plot of prevalence of Anatomical Variants about drainage of paranasal sinuses

4. DISCUSSION

Anatomical PNS are classified into anterior & posterior sinus groups according to their drainage systems. Through the anterior OMU, the maxillary, anterior ethmoid, & frontal sinuses drain into the middle meatus, making up the anterior group. The posterior ethmoid and sphenoid sinuses, on the other hand, drain through the posterior OMU or posterior SER. [7]

The maxillary sinus ostium, ethmoid bulla, uncinate process, ethmoid infundibulum, hiatus semilunaris, frontal recess, and middle meatus make up the anatomical components of the OMU (*Figure 1A*). [1] The maxillary ostium allows the maxillary sinus to drain into the ethmoid infundibulum, which is followed by the hiatus semilunaris, which leads to the middle meatus. [7] The anterior ethmoid air cells and frontal sinus also follow this drainage pathway, with the frontal recess bounded by the agger nasi cell anteriorly, ethmoid bulla posteriorly, lamina papyracea laterally, and the lateral olfactory fossa wall medially (Figure 1B). [13] The frontal sinus drains differently depending on the uncinate process's superior attachment. [7] The SER is the pathway of drainage for the sphenoid & posterior ethmoid sinuses, which are located medially and laterally to the superior turbinate, respectively (*Figures 1C*). [6,7]

Nasal septal deviations (DNS) may present as single or double curvatures, the latter often "S-shaped" (*Figures 1D & 1E*). By moving the middle turbinate & constricting the middle meatus, DNS can interfere with mucus outflow. Previous studies have reported DNS prevalence between 26% and 97%, [1] while the current study observed DNS in 78.0% of participants.

A septal spur, when prominent, may narrow the middle meatus or ethmoid infundibulum, complicating mucociliary clearance (*Figure 1F*). [1,6] Literature reports a prevalence of 34% [10], with the current study finding it in 32.0% of patients. Pneumatized nasal septum, which can narrow the SER (*Figure 1G*) [1,6] was reported at 4% prevalence in past studies [14], while this study observed it in 17.0% of patients.

Concha bullosa, if enlarged, can impair OMU drainage by altering the uncinate process & narrowing the infundibulum; it is frequently associated with contralateral DNS (*Figure 1D*) (6,15). Reported prevalence ranges from 15% to 80%, [1] & this study found it in 32.0% of cases. Similarly, paradoxical middle turbinate may impact OMU drainage, [6] with prevalence reported between 6.2% and 28%; [1] in this study, it was observed in 27.0% of patients (*Figure 1H*).

The uncinate process has 03 patterns of superior attachment. The middle meatus receives the frontal sinus drainage in Type I (55%–82% prevalence; *Figures 2A & 2B*); [7,9] the ethmoid infundibulum is where it drains in Type II (3.6%–22% prevalence; *Figure 2C*); [6,9] and the frontal recess drains into the infundibulum in Type III (1.4%–20%; *Figure 2D*). [6,9] In this study, Type I, II, and III attachments were found in 88.0%, 23.0%, and 15.0% of patients, respectively. In Type II and Type III cells, infundibular obstruction can result in frontal sinus blockage, a finding not commonly associated with Type I cells. [6]

Narrowing of the OMU infundibulum due to pneumatization of the uncinate process can also affect sinus drainage (*Figure 2E*). [1,10] The prevalence in our study was 6.0%, whereas literature has prevalences ranging from 2% to 13.8%. Haller (infraorbital) cells can narrow the maxillary ostium, obstructing sinus drainage and increasing surgical risk (*Figure 2E*). [1] Prevalence in literature ranges from 8% to 57%; [1] this study found it in 51.0% of patients.

Enlarged ethmoid bulla can impede maxillary and frontal sinus drainage (*Figures 1A & 1B*), with reported prevalence from 6.3% to 63.5%; [6] this study found 72.0%. Similarly, enlarged agger nasi cells can constrict the frontal recess. Literature reports prevalence from 10% to 98%, [16], with 98.0% prevalence in this cohort. Supra bullar cells, with a reported range of 13%–88.8%, [1] were present in 93.0% of patients (*Figure 1B*). [7,17]

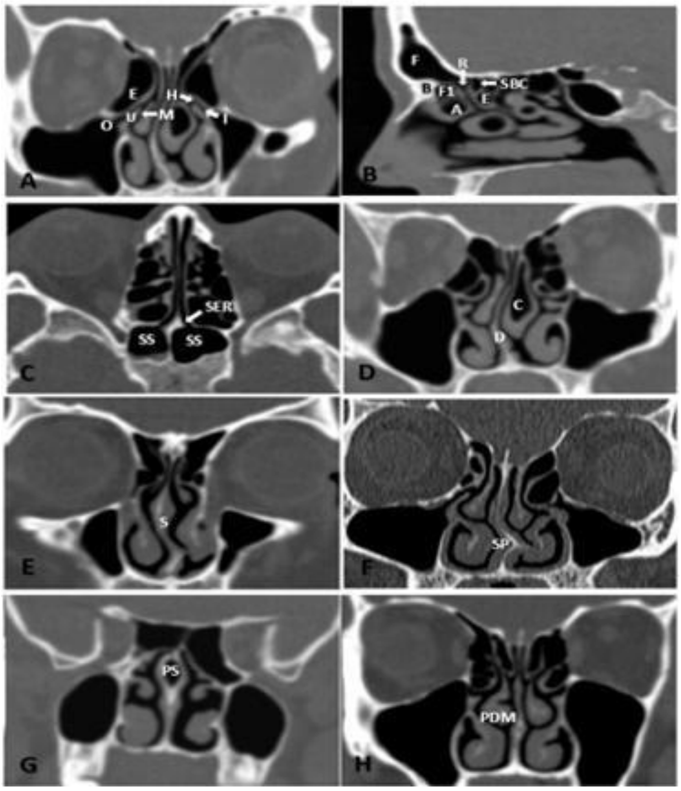


Figure 1: *Plain CT of PNS:* **A)** Coronal section shows Osteomeatal unit components: Maxillary sinus ostium(O), Ethmoid bulla (E), Uncinate process(U), Ethmoid infundibulum (I), Hiatus semilunaris (H), Middle meatus (M); **B)** Sagittal section shows Frontal recess (R) with associated structures: Frontal sinus(F), Frontal beak (B), Agger nasi cell (A), Type I Frontal cell (F1), Ethmoid bulla(E), Supra bullar cell (SBC); **C)** Axial section showing sphenoethmoid recess (SER) and Sphenoid sinus (SS); **D)** Deviated nasal septum towards right side(D), Concha bullosa (C); **E)** S- shaped nasal septum(S); **F)** Septal spur towards left side (SP); **G)** Pneumatized nasal septum (PS); **H)** Paradoxical left middle turbinate (PDM).

Frontal bullar cells, which may narrow the frontal ostium, were found in 27.0% of patients, lower than the reported 63%–66% prevalence (*Figure 2F*). [7] Frontoethmoid (frontal) cells, classified into Types I–IV (*Figures 3A–3D*), contribute to narrowing the frontal ostium or recess. [7] Reported prevalence ranges include 5%–39% for Type I, 3%–10.5% for Type II, 0.5%–12.5% for Type III, and 0.5%–1.3% for Type IV. [1] The current study found these in 52.0%, 37.0%, 12.0%, and 2.0% of patients, respectively.

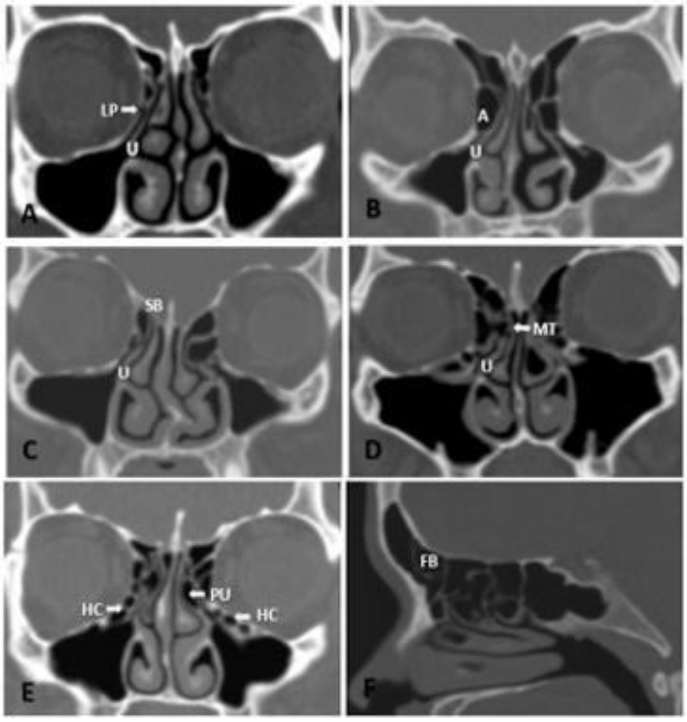


Figure 2: *Plain CT of PNS coronal section:* **A)** Type I (direct) attachment of uncinate process (U) to the lamina papyracea (LP) on right side; **B)** Type I (indirect) attachment of uncinate process (U) to the lamina papyracea through agger nasi cell (A) on right side; **C)** Type II attachment of uncinate process (U) to the skull base (SB) on right side; **D)** Type III attachment of uncinate process(U)to the middle turbinate (MT) on right side; **E)** Pneumatization of uncinate process (PU) on left side. Haller cells (HC); **F)** Plain CT of PNS sagittal section shows frontal bullar cell (FB).

Frontal intersinus septal cells, which may obstruct the frontal ostium, are diverticula from the frontal sinuses (*Figure 3E*). [7] These cells are present in 3.5%–45% of cases, [1] with our study noting 15.0%. Finally, pneumatised crista galli, though rare, may also cause obstruction. It has been reported in 3.3%–22.2% [1] of patients (*Figure 3F*); [7,12] in this study, it was found in 9.0%.

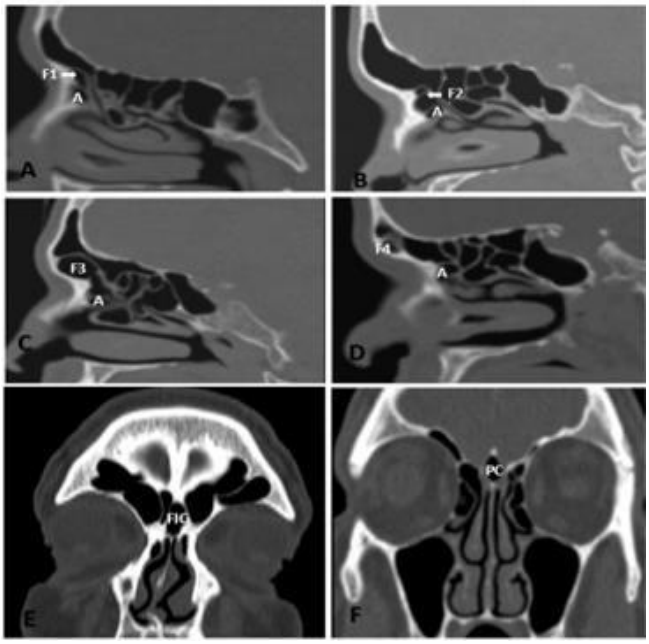


Figure 3: *Plain CT of PNS sagittal section:* **A)** Type I frontal cell(F1); **B)** Type II frontal cell (F2); **C)** Type III frontal cell (F3); **D)** Type IV frontal cell (F4). Agger nasi cell (A); **E)** Plain CT of PNS coronal section shows Frontal intersinus septal cell (FIC); **F)** Plain CT of PNS coronal section shows Pneumatized crista galli (PC).

Limitations of the study

This study has certain limitations. The sample size was relatively small, and the study was conducted at a single center, which may limit the generalizability of the findings. Additionally, the use of convenience sampling, although practical in a retrospective hospital-based setting, may introduce selection bias. To enhance external validity and reduce potential bias, future research should consider larger, multicenter studies employing randomized or stratified sampling methods.

5. CONCLUSION

The PNS are anatomically complex structures that exhibit significant inter-individual variability. Certain anatomical variations may obstruct the anterior OMU and the SER, impairing normal mucociliary clearance and predisposing individuals to rhinosinusitis. CT plays a crucial role in evaluating these variations, offering detailed anatomical information that serves as a roadmap for surgeons in planning FESS. FESS is particularly important in the management of chronic rhinosinusitis to restore effective mucociliary drainage. The most prevalent structural variations of the PNS found in this study were increased ethmoid bulla, type I attachment of the uncinate process, suprabullar cells, and agger nasi cells. Given the wide range of anatomical variability, individualized preoperative evaluation is essential to optimize patient outcomes and reduce surgical risk.

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Conflict of Interest: ***None***

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