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Original Research Article

Variations in Frontal Sinus Drainage Pathways and Their Association with Frontal Sinusitis in Chronic Rhinosinusitis Patients - An Observational Cross-Sectional Study

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Abstract:

Background: Understanding the anatomical variations of the frontal sinus drainage pathway is essential for effective diagnosis and surgical planning in chronic rhinosinusitis (CRS). The superior attachment of the uncinate process (SAUP) plays a pivotal role in defining determining whether the frontal sinus drainage is directed medially or laterally, potentially influencing the development of frontal sinusitis. This study investigates the prevalence of SAUP variations and evaluates their association with frontal sinusitis in CRS patients.

Methods: A cross-sectional observational study was conducted among 140 CRS patients attending the ENT department of Dr. Moopen's Medical College over 18 months. All participants underwent thin-section CT of the paranasal sinuses (0.6 mm), reconstructed in the axial, coronal, and sagittal planes. The Landsberg and Friedman classification was used to categorize SAUP into Types 1–6. Clinical profiles, drainage patterns, and the presence of frontal sinusitis were documented. Data were analyzed using descriptive statistics and Chi-square tests, with $p < 0.05$ considered significant.

Results: The mean age of participants was 35.7 years, with a male predominance (60%). Type 2 SAUP (attachment to the agger nasi cell) was the most common drainage pattern, occurring in 62–64% of the sinuses bilaterally. Frontal sinusitis was present in 35.7% of the patients. Although Type 5 drainage showed a relatively higher proportion of frontal sinusitis (42.9%), no statistically significant association was found between the drainage pattern type and the occurrence of frontal sinusitis on either side ($p > 0.05$). Medial drainage patterns (Types 1–3) accounted for more than 80% of cases.

Conclusion: Type 2 SAUP is the most prevalent anatomical variant in CRS patients; however, it does not increase the risk of frontal sinusitis. The study suggests that frontal sinusitis is multifactorial, and that SAUP alone is not a strong predictor. A detailed anatomical assessment remains crucial for individualized surgical planning.

Keywords: Frontal Sinusitis; Superior Attachment of Uncinate Process; Frontal Recess; Chronic Rhinosinusitis; CT Paranasal Sinuses; Sinus Drainage Patterns.

Introduction

The frontal sinus and its drainage pathway form one of the most anatomically complex regions within the paranasal sinuses. The frontal recess, a narrow and highly variable channel influenced by surrounding air cells and the superior attachment of the uncinate process (SAUP), plays a key role in determining ventilation and susceptibility to sinus disease.[1] Even subtle variations in this region may compromise mucociliary clearance, predisposing patients to obstruction and chronic rhinosinusitis (CRS).[2]

CRS affects nearly 12% of the global population, and frontal sinus involvement presents distinct diagnostic and surgical challenges due to the recess's intricate and variable anatomy.[3] The frontal recess is bordered by the agger nasi cell, ethmoid bulla, lamina papyracea, and middle turbinateand anatomical variations in any of these structures can significantly modify frontal sinus drainage dynamics.[4]

Among these variations, the SAUP is considered one of the strongest determinants of the frontal sinus drainage pathway. Depending on its superior attachment, the uncinate process directs drainage either medially toward the ethmoidal infundibulum or laterally toward the frontal sinus ostium.[5]

Landsberg and Friedman proposed six SAUP types, each corresponding to specific drainage patterns and potentially altered frontal sinus ventilation dynamics.[6]

However, existing literature shows conflicting observations regarding the clinical importance of SAUP variations. Some studies found that medial drainage pathways (Types 1–3) may increase the risk of frontal sinusitis due to their direct connection to the middle meatus.[7] Conversely, other CT-based analyses reported no significant association, suggesting that CRS is multifactorial and cannot be explained by anatomical variations alone.[8]

Aims and Objectives: The aim of this study is to evaluate the variations in frontal sinus drainage patterns and assess their relationship with the development of sinusitis, while also determining the proportions of different types of uncinate process attachments within the study population and examining the surgical approaches relevant to the management of frontal sinusitis.

Materials and Methods

Study Design: This observational cross-sectional study was conducted in the Department of Otorhinolaryngology at Dr. Moopen's Medical College over a period of 18 months. Consecutive patients clinically diagnosed with chronic rhinosinusitis and who underwent CT scans of the nose and paranasal sinuses were included, and relevant data were recorded using a pre-designed proforma. Ethical approval was obtained from the institutional review board, and although individual consent was not required due to the observational nature of the study, the confidentiality of patient information was strictly maintained. All selected CT scans were securely stored on digital versatile discs (DVDs) by the investigator, with no additional cost incurred by either the patients or the Department of Radiology.

Inclusion and Exclusion Criteria: The study included all patients aged over 16 years, irrespective of gender, who met the clinical criteria for chronic rhinosinusitis, defined by the presence of at least two major symptoms-such as facial pain or pressure, nasal obstruction, purulent or discoloured nasal discharge, or olfactory disturbance-or one major symptom accompanied by a minimum of two minor symptoms, including headache, dental pain, halitosis, cough, fatigue, or ear pain. Patients were excluded if they were younger than 16 years, had a prior history of sinus surgery or facial trauma, or presented with severe sinus disease that prevented adequate visualization of the anatomical landmarks on imaging.

Sample Size Calculation: Sample size is calculated using the formula:

n = [Z1-α/2. √{2p(1-p)} + Z1-ß √{p1(1-p1) + p2(1-p2)}]2 (p1 - p2)2

The sample size calculation for this study was based on parameters derived from the previous study Suat Turgut.[7] In that study, the distribution of frontal sinusitis was 41% in Group 1 drainage patterns, where the frontal sinus opens medial to the uncinate process (Types 1–3), and 23% in Group 2 drainage patterns, where the frontal sinus opens lateral to the uncinate process (Types 4–6). Using these proportions (P1 = 0.41 and P2 = 0.23), the pooled prevalence was calculated as P = (P1 + P2)/2. With a confidence interval of 95% (α = 0.05) and a study power of 60% (β = 0.40), the minimum required sample size was determined to be 130 subjects.

Data Collection Tools: Data for the study were collected from patients attending the ENT Department at Dr. Moopen's Medical College who were clinically diagnosed with chronic rhinosinusitis and subsequently underwent CT scans of the nose and paranasal sinuses. All CT scans were performed using a Siemens Somatom Emotion 16-slice CT scanner following a standardized imaging protocol, and the images were then transferred to the Radiant DICOM Viewer (version 4.6.5.18450, 64-bit) for detailed evaluation. Relevant clinical and radiological information was systematically recorded for each patient.

Data Collection Procedure: CT scans were obtained in the Department of Radiodiagnosis according to a standardized protocol. Prior to scanning, patients were instructed to clear nasal secretions by gently blowing their nose. Axial images were acquired with the patient in the supine position, with the neck in neutral alignment, and the hard palate positioned perpendicular to the scanner table, ensuring that the external auditory canal aligned with the inferior orbital rim. Imaging was performed in 0.6-mm contiguous axial sections using a bone window algorithm, with coronal and sagittal reconstructions generated subsequently. Scan parameters included an angulation parallel to the infraorbital-meatal line, coverage from the inferior wall of the maxillary sinus to the roof of the frontal sinus, 120 kVp, 250 mAs, and caudo-cranial orientation. All images were then securely transferred to a Dell Inspiron 5559 laptop for analysis using the Radiant DICOM software.

Statistical Analysis: The data were first entered into Microsoft Excel and then cleaned and analyzed using Jamovi software version 2.3.21. Continuous variables were summarized as means with standard deviations after assessing their normality, while categorical variables were reported as frequencies and percentages. Associations between categorical variables were examined using Pearson's chi-square test, with statistical significance determined at $p < 0.05$.

Results

Table 1: Demographic Characteristics of Study Participants (N = 140)

Variable	Category	Frequency (%)
Age Group	16–30 yrs	58 (41.42%)
	31–45 yrs	44 (31.4%)
	46–60 yrs	30 (21.4%)
	>60 yrs	8 (5.7%)
Mean Age ± SD	—	**35.7 ± 14.7**
Gender	Male	84 (60%)
	Female	56 (40%)

Table 1 shows the demographic profile of the study population, indicating that most participants were young adults aged 16–30 years and that males constituted 60% of the cohort.

Table 2: Prevalence of Major and Minor Symptoms (Multiple Responses Allowed)

Major Symptoms	Frequency (%)
Nasal discharge	126 (90%)
Nasal purulence	122 (87.1%)
Nasal obstruction	119 (85%)
Hyposmia/Anosmia	113 (80.7%)
Facial pain	51 (36.4%)
Minor Symptoms	**Frequency (%)**
Headache	139 (99.3%)
Fever	65 (46.4%)
Dental pain	70 (50%)
Halitosis	67 (47.9%)
Cough	69 (47.3%)
Earache	66 (47.1%)

Table 2 illustrates the frequency of major and minor CRS symptoms. Headache was the most common minor symptom, while nasal discharge was the most common major symptom.

Table 3: Distribution of Frontal Sinus Drainage Patterns (SAUP Types) by Side (N = 140)

SAUP Type	Right Side n (%)	Left Side n (%)
Type 1 – Lamina papyracea	16 (11.4%)	17 (12.1%)
Type 2 – Agger nasi	88 (62.95%)	89 (63.6%)
Type 3 – Lamina–Middle turbinate	8 (5.7%)	9 (6.4%)
Type 4 – Middle turbinate–Cribriform	5 (3.6%)	3 (2.15%)
Type 5 – Skull base	14 (10%)	14 (10%)
Type 6 – Middle turbinate	9 (6.4%)	8 (5.7%)

Table 3 shows that Type 2 SAUP (attachment to the agger nasi cell) is by far the most prevalent drainage pattern on both sides, followed by Type 1.

Table 4: Overall Diagnostic Distribution among Study Participants (N = 140)

Diagnosis	Frequency (%)
Frontal sinusitis – Total	50 (35.7%)
– Unilateral	18 (12.8%)
– Bilateral	32 (22.9%)
Sinusitis (Non-frontal: Maxillary/Ethmoid)	51 (36.4%)
Normal CT	39 (27.9%)

Table 4 summarizes diagnostic categories, showing that 35.7% of patients had frontal sinusitis, while non-frontal sinusitis was slightly more common at 36.4%.

Table 5: Frontal Sinus Drainage Type Grouped by Medial vs Lateral Pathways (N = 140)

Drainage Group	Right n (%)	Left n (%)
Medial drainage (Types 1–3)	112 (80%)	115 (82.1%)
Lateral drainage (Types 4–6)	28 (20%)	25 (17.9%)

Table 5 illustrates that medial drainage pathways dominate in the population, accounting for about 80–82% of cases on both sides.

Table 6: Association between SAUP Type and Right Frontal Sinusitis (N = 140)

SAUP Type	No Sinusitis n (%)	Yes n (%)
Type 1	11 (68.8%)	5 (31.3%)
Type 2	60 (68.2%)	28 (31.8%)
Type 3	7 (87.5%)	1 (12.5%)
Type 4	4 (80%)	1 (20%)
Type 5	8 (57.1%)	6 (42.9%)
Type 6	8 (88.9%)	1 (11.1%)
Total	**98 (70%)**	**42 (30%)**
Chi-square (df)	**4.19 (5)**	
P-value	**0.523** (Not significant)	

Table 6 shows that although Type 5 drainage had the highest proportion of right frontal sinusitis (42.9%), the association was not statistically significant.

Table 7: Association between SAUP Type and Left Frontal Sinusitis (N = 140)

SAUP Type	No Sinusitis n (%)	Yes n (%)
Type 1	11 (64.7%)	6 (35.3%)
Type 2	62 (69.7%)	27 (30.3%)
Type 3	8 (88.9%)	1 (11.1%)
Type 4	3 (100%)	0
Type 5	8 (57.1%)	6 (42.9%)
Type 6	8 (100%)	0
Total	**100 (71.4%)**	**40 (28.6%)**
Chi-square (df)	**7.66 (5)**	
P-value	**0.176** (Not significant)	

Table 7 demonstrates no significant association between SAUP type and left frontal sinusitis, despite Type 5 again showing the highest proportion of disease.

Discussion

This study evaluated anatomical variations in the superior attachment of the uncinate process (SAUP) and their association with frontal sinusitis in chronic rhinosinusitis (CRS) patients. The predominance of Type 2 SAUP (62–64%) corresponds to prior CT-based studies that identified the agger nasi attachment as the most frequent uncinate variant and a key determinant of frontal recess morphology.[1,5] The majority of drainage patterns were medial (Types 1–3), consistent with the computer-assisted mapping by Landsberg and Friedman, who reported medial pathways as the most prevalent anatomical configuration.[6]

Despite this predominance, our findings revealed no statistically significant association between SAUP variations and frontal sinusitis. This differs from the findings of Turgut et al., who demonstrated a significant correlation between medial drainage pathways and frontal sinusitis, suggesting increased exposure to inflammatory secretions when drainage enters the middle meatus directly.[7] Similarly, Mahmutoğlu et al. found higher mucosal disease prevalence in medial compared with lateral drainage pathways.[8]

Ethnic and population-based anatomical differences may explain these discrepancies. Previous radiological evaluations have shown that nasal cavity and frontal recess variations differ considerably across populations, potentially altering disease susceptibility patterns. [9,10] Therefore, South Indian anatomical diversity may influence the relationship between SAUP and frontal sinus disease differently than in Turkish or European cohorts.

CRS is known to be multifactorial, and anatomical variations represent only one of the contributing factor. Major roles are played by inflammatory pathways (especially Type-2 inflammation), mucociliary dysfunction, environmental exposures, and microbial imbalances.[11] These factors may overshadow the influence of the SAUP alone. Current international guidelines similarly emphasize that anatomical variants should not be interpreted in isolation and must be correlated with clinical and endoscopic findings.[12]

The relatively higher proportion of frontal sinusitis among patients with Type 5 SAUP drainage (~43%) supports anatomical studies demonstrating that skull-base attachments may narrow the frontal recess and impair ventilation, thereby predisposing to stasis and inflammation.[13] However, the relatively small number of Type 5 cases likely limited statistical power.

The findings reinforce the need for careful CT assessment of frontal recess anatomy but also highlight that SAUP variations alone do not reliably indicate frontal sinusitis. A combined interpretation of anatomy, the inflammatory profile, and endoscopic findings remains essential for accurate diagnosis and surgical planning.

Limitations: This study has several limitations. The small sample size restricts statistical power and limits the generalizability of the findings, and the study population may not represent diverse geographic or ethnic groups, potentially biasing the results. Its cross-sectional design prevents establishing causal relationships, and the exclusion of cases with unclear superior attachment of the uncinate process, while improving clarity, further reduced the sample size and may have omitted important information. Additionally, the study focused solely on anatomical variations in the SAUP, without considering other anatomical, microbial, inflammatory, or environmental factors that could contribute to frontal sinusitis.

Conclusion

In conclusion, this study explored the influence of frontal sinus drainage patterns and uncinate process attachment on the occurrence of frontal sinusitis, emphasizing the importance of understanding the full spectrum of frontal sinus drainage pathways for effective patient management. Although Types 1, 2, and 3 drainage patterns were common among participants, no significant association with frontal sinusitis was found, and the most frequent Type 2 SAUP did not confer a greater risk compared to Type 5. The limited sample size and specific characteristics of the study population may have constrained the generalizability of these findings. Ultimately, the study reinforces that appreciating the three-dimensional variability of sinonasal anatomy is essential for optimizing surgical outcomes, as each patient presents a unique anatomical configuration that allows surgeons to tailor highly personalized and effective treatment plans.

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