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EVALUATING FRONTAL SINUS OPACIFICATION SEVERITY USING THE LUND-MACKAY SCORE BASED ON ANATOMICAL VARIANTS OF POSTERIOR FRONTAL RECESS CELLS THROUGH IMAGING ANALYSIS

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ABSTRACT

Objectives: To determine the prevalence of posterior frontal recess cells (suprabulla cell, suprabulla frontal cell, and supraorbital ethmoid cell) and evaluate their association with frontal sinus opacification on computed tomography.

Subjects and methods: A cross-sectional descriptive study with analysis was conducted on 174 patients (340 sides) at Gia Dinh Peoples's Hospital from January 2024 to June 2025. Posterior wall cell variants were identified on multiplanar CT scans and correlated with frontal sinus opacification status according to the Lund-Mackay score.

Results: The suprabulla cell was the most common posterior variant with a prevalence of 59.7%, followed by the suprabulla frontal cell at 25.0% and the supraorbital ethmoid cell at 7.4%. Statistical analysis showed that the presence of the suprabulla frontal cell was associated with a significantly higher rate of frontal sinus opacification (45.9%) compared to its absence (20.0%), with an odds ratio (OR) of 3.39 (95% CI: 1.90–6.06; $p < 0.001$). In contrast, no statistically significant association was found between the presence of the suprabulla cell ($p = 0.330$) or the supraorbital ethmoid cell ($p = 0.442$) and frontal sinus opacification.

Conclusion: The suprabulla frontal cell was significantly associated with frontal sinus opacification on computed tomography. Accurate preoperative identification of this cell on multiplanar imaging may help optimize frontal recess surgical planning.

Keywords: Suprabulla cell, suprabulla frontal cell, supraorbital ethmoid cell, frontal recess, frontal sinusitis, computed tomography.

1. INTRODUCTION

In endoscopic frontal sinus surgery (EFSS), a thorough understanding of frontal recess anatomy is a prerequisite for ensuring treatment efficacy and surgical safety. The patency of the frontal sinus drainage pathway is governed by the complex arrangement of surrounding anatomical structures, which includes anterior and posterior cell groups. According to the International Frontal Sinus Anatomy Classification (IFAC - 2016), the posterior cell group comprises the suprabulla cell (SBC), the suprabulla frontal cell (SBFC), and the supraorbital ethmoid cell (SOEC) [1].

Mechanically, the pneumatization of these cells tends to push the frontal sinus drainage pathway anteriorly and medially, compressing it against the posterior wall of the agger nasi cell or the frontal beak. In particular, variants that pneumatize extensively into the frontal sinus, such as the SBFC and SOEC, can compromise the anteroposterior diameter of the frontal ostium, thereby obstructing physiological mucociliary clearance [2].

In Vietnam, previous studies have provided substantial data primarily on the anterior cell group, such as agger nasi cells and frontal cells [3]. However, detailed quantitative data regarding the morphological characteristics and prevalence of the posterior cell group utilizing multiplanar computed tomography (CT), as well as their correlation with frontal sinus opacification, remain limited and require updating for comparison with international literature [3,4]. Accurately identifying these anatomical variants is crucial in surgical planning, assisting surgeons in selecting the optimal approach and minimizing the risk of recurrence. Therefore, this study aims to investigate the anatomical characteristics of posterior frontal recess cells and evaluate their association with frontal sinus opacification on CT.

2. SUBJECTS AND METHODS

2.1. Study Subjects

This study included 174 patients (equivalent to 348 sinonasal sides) who were examined and treated at Gia Dinh People's Hospital between January 2024 and June 2025.

- ***Inclusion criteria:*** Patients ≥ 18 years of age with clinical indications for paranasal sinus CT (with or without contrast) for otolaryngological diagnosis and management. The imaging must be of high quality, encompassing all three planes (axial, coronal, and sagittal) with a slice thickness of ≤ 1mm.

- ***Exclusion criteria:*** History of frontal sinus surgery, maxillofacial trauma involving frontal sinus fractures, or congenital facial deformities altering anatomical structures; pathologies causing bone destruction or obscuring anatomical landmarks (e.g., sinonasal tumors,

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invasive fungal sinusitis, or massive nasal polyposis completely obstructing the frontal recess); sides of frontal sinus aplasia or unreadable images due to artifacts.

2.2. Study Design and Instruments

- Study design: Cross-sectional analytic study.

- Research instrument: Siemens Somatom Definition Edge 128-slice CT scanner. Images were reconstructed and analyzed using specialized software (PACS/OsiriX) enabling multiplanar reconstruction.

2.3. Research Variables and Definitions

The posterior frontal recess cells were identified based on the International Frontal Sinus Anatomy Classification (IFAC - 2016) [1]. The severity of frontal sinus opacification was assessed using the Lund-Mackay scoring system [2]. Cell identification was primarily conducted on parasagittal slices and verified on coronal slices.

- Suprabulla cell (SBC): A pneumatized cell located directly above the roof of the bulla ethmoidalis.

Diagnostic criteria: On parasagittal slices, the SBC is situated posterior to the frontal recess but does not pneumatize into the frontal sinus (its superior limit remains below or at the level of the frontal ostium). The SBC forms the posteroinferior boundary of the frontal sinus drainage pathway.

- Suprabulla frontal cell (SBFC): A pneumatized cell originating from the suprabullar region and extending superiorly along the skull base.

Diagnostic criteria: On parasagittal slices, the SBFC is located posterior to the frontal recess but critically pneumatizes into the frontal sinus (extending superior to the frontal ostium), projecting into the sinus from posteriorly. The anterior wall of the SBFC typically pushes the frontal sinus drainage pathway anteriorly.

- Supraorbital ethmoid cell (SOEC): An anterior ethmoid cell that pneumatizes laterally, extending beyond the limits of the lamina papyracea to overlie the orbital roof.

Diagnostic criteria: On coronal slices (the optimal plane for diagnosis), the pneumatized cell is observed extending laterally beyond the lamina papyracea, resting on the orbital roof, and either surrounding or situated posterior to the true frontal sinus. On parasagittal slices, the SOEC is frequently located posterior to the frontal recess. According to the IFAC, the presence of this cell tends to push the frontal sinus drainage pathway anteriorly and medially.

- Evaluation of frontal sinus opacification: Measured by the Lund-Mackay score [2]:

+ 0 points: Clear sinus, normal mucosa.
+ 1 point: Partial opacification or mucosal thickening.
+ 2 points: Total sinus opacification.

For analytical purposes, the variable was dichotomized into: 'clear' (0 points) and 'opacified' (1-2 points).

2.4. Data Processing and Analysis

Data were collected and analyzed using SPSS version 20.0. Qualitative variables were reported as frequencies and percentages. The Chi-square test or Fisher's exact test was utilized to compare the rates of frontal sinus opacification among different anatomical variant groups. Given that each patient contributed two sinus sides, observations per side may not be entirely independent. Therefore, a generalized estimating equations (GEE) logistic regression model, clustered by patient ID, was employed to adjust for the potential correlation between bilateral sinuses within the same patient. Regression results were reported as odds ratios (OR), 95% confidence intervals (CI), and p-values. A p-value of < 0.05 was considered statistically significant.

2.5. Ethical Considerations

The study complied with the Declaration of Helsinki regarding medical ethics. The research protocol was approved by the Institutional Ethics Committee in Biomedical Research. Patient information was strictly encoded and kept confidential.

3. RESULTS

3.1. Prevalence of Posterior and Lateral Frontal Recess Cells

The analysis of 340 valid sinus sides from 174 patients (excluding 8 sides with frontal sinus aplasia) revealed the following distribution of pneumatized cells belonging to the posterior group (originating from the bulla ethmoidalis) and lateral group:

- Suprabulla cell (SBC): Identified in 203 cases, accounting for 59.7%.

- Suprabulla frontal cell (SBFC): Identified in 85 cases, accounting for 25.0%.

- Supraorbital ethmoid cell (SOEC): Identified in 25 cases, demonstrating a lower prevalence (7.4%).

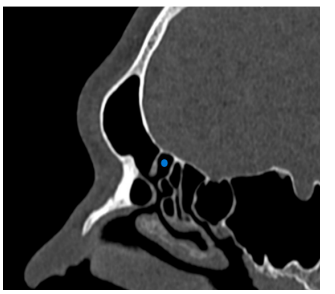


Figure 1. Suprabulla frontal cell - indicated by the blue dot

3.2. Association Between Cell Variants and Frontal Sinus Opacification

The results of the univariate analysis evaluating the association between the presence of each cell type and frontal sinus opacification are presented in the table below:

Table 1. Association between posterior cells and frontal sinus opacification

Anatomical Variant				
Total (n)	**Opacification Rate in Group with Cell**	**Opacification Rate in Group without Cell**	**OR (95% CI)**	**p-value (cluster-robust)**
Suprabulla cell				
203	28.6%	23.4%	1.31 (0.76 – 2.27)	0.330
Suprabulla frontal cell				
85	45.9%	20.0%	3.39 (1.90 – 6.06)	< 0.001
Supraorbital ethmoid cell				
25	20.0%	26.9%	0.68 (0.25 – 1.83)	0.442

95% CIs and p-values were calculated using the cluster-robust method with the patient as the cluster.

Remarks:

- The group with the suprabulla frontal cell exhibited a 3.39-fold increased risk of frontal sinus opacification (OR = 3.39; p < 0.001), with the opacification rate in this group reaching 45.9%.

- No statistically significant difference in frontal sinus opacification rates was observed between the groups with and without the suprabulla cell (p = 0.330).

- No statistically significant association was found between the supraorbital ethmoid cell and frontal sinus opacification (p = 0.442).

4. DISCUSSION

The frontal recess is an inverted funnel-shaped anatomical space that serves as the common drainage pathway of the frontal sinus. It is bounded by fixed structural walls and variable pneumatized cells. The anterior wall of the frontal recess is formed by the agger nasi cell and the frontal beak; the medial wall by the vertical lamella of the middle turbinate; the lateral wall by the lamina papyracea; and crucially, the posterior wall is delineated by the bulla ethmoidalis and cells originating from the suprabullar or retrobullar regions. The spatial interaction between the posterior and anterior walls determines the anteroposterior diameter of the frontal sinus drainage pathway. The posterior cell group, as defined by the IFAC, includes the suprabulla cell, the suprabulla frontal cell, and the supraorbital ethmoid cell, which share a common characteristic of pushing the frontal sinus drainage pathway anteriorly [1]. Accurate evaluation of the location and extent of pneumatization of these cells on multiplanar CT allows the surgeon to conceptualize the three-dimensional architecture of the frontal recess. This facilitates the orientation of a safe surgical approach to open the frontal recess while avoiding injury to the skull base and the anterior ethmoidal artery [5].

Within the posterior cell group, the suprabulla cell is the most frequently observed structure. Our findings from 174 patients reported a suprabulla cell prevalence of 59.7%. This rate is higher than the 46.2% reported by Tran Viet Luan in Vietnam [3], yet lower than the 72% reported in Caucasian populations by Choby et al. [4]. The suprabulla cell is a pneumatized cavity situated in the space between the roof of the bulla ethmoidalis and the skull base, remaining entirely outside the lumen of the frontal sinus. Another significant variant is the suprabulla frontal cell, which demonstrated a prevalence of 25.0% in our study. This result is consistent with the findings of Tran Viet Luan [3] and falls within the reported prevalence range among Asian populations [6]. The fundamental difference between a suprabulla cell and a suprabulla frontal cell lies in the degree of pneumatization: while the suprabulla cell is confined to the frontal recess, the suprabulla frontal cell pneumatizes along the skull base and invades the frontal sinus posterior to the ostium. Regarding the supraorbital ethmoid cell, we observed a prevalence of 7.4%, which closely aligns with the 5.4% reported in a Chinese population by Zhang et al. [7]. Conversely, the prevalence in Caucasian populations reported by Choby et al. [4] was notably higher, underscoring the influence of population demographics on the frontoethmoidal anatomical architecture.

Analysis of pathological associations revealed that the suprabulla frontal cell is the most clinically significant anatomical factor influencing frontal sinus opacification. The data indicate that patients with an SBFC have a 3.39-fold higher risk of frontal sinus opacification compared to those without the cell (OR = 3.39; p < 0.001). This finding is consistent with the study by Johari et al. regarding the association between frontal recess cells and frontal sinusitis [8], and aligns with the conclusions of Nakayama et al. regarding the role of residual frontal recess cells in postoperative frontal sinusitis [9]. The pathogenic mechanism can be explained by the specific anatomical position of the SBFC posterior to the frontal ostium; upon over-pneumatization, it pushes the drainage pathway anteriorly, compressing it against the rigid posterior wall of the frontal beak or the agger nasi cell, thereby significantly narrowing the effective diameter of the ostium. In contrast, the suprabulla cell did not demonstrate a statistically significant association with frontal sinus opacification (OR = 1.31; p = 0.330). This supports the view held by DelGaudio [5], which posits that cells that do not invade the ostium or are located below it are less likely to cause isolated mechanical obstruction. Regarding pathological correlations, contrary to some hypotheses suggesting that the supraorbital ethmoid cell narrows the frontal recess from the posterolateral aspect to obstruct drainage, our study found no statistically significant difference in frontal sinus opacification rates between the groups with and without the SOEC (p = 0.442). This finding may be attributed to the relatively small size of the supraorbital ethmoid cell in the Vietnamese population, which is often insufficient to exert actual mechanical compression on the frontal ostium in the majority of cases.

Based on these data, identifying the posterior cell group carries significant practical implications in endoscopic sinus surgery. Studies by Nakayama et al. [9] and Valdes et al. [10] have established that the failure to recognize and address these cells, particularly the SBFC and SOEC, is a common etiology of surgical failure and disease recurrence. On CT imaging, distinguishing between a suprabulla cell and a suprabulla frontal cell necessitates meticulous observation on the parasagittal plane to determine the extent of pneumatization into the frontal sinus along the skull base. Intraoperatively, the presence of these posterior cells forces the surgeon to alter the standard surgical approach. Instead of attempting to locate the ostium posteriorly according to classical anatomy, instruments must be directed anterior to the face of the posterior cell to identify the true drainage pathway. Only then can the anterior wall of the cell be removed to widen the ostium posteriorly. This precise protocol ensures the complete eradication of the obstructive etiology while preserving healthy mucosa and preventing complications related to skull base violation at the attachment sites of these bony partitions.

5. CONCLUSION

The suprabulla frontal cell is a posterior anatomical variant demonstrating the clearest association with frontal sinus opacification on CT. Meanwhile, the suprabulla cell, despite being more prevalent, showed no statistically significant correlation with frontal sinus opacification. Therefore, accurately identifying the suprabulla frontal cell on multiplanar CT is crucial for surgeons to formulate optimal surgical planning and achieve definitive disease resolution.

6. STATEMENT OF SCIENTIFIC CONTRIBUTIONS

Nguyen Thi Kieu Tho proposed the conceptual framework,

designed the study, directed the data analysis, interpreted the findings, and drafted and revised the manuscript. Nguyen Dinh Chuong acquired and standardized the CT data, participated in radiological evaluation, synthesized the literature, and critically reviewed the manuscript. All authors have read and approved the final manuscript, assuming full responsibility for the accuracy and integrity of the data and published content.

7. CONFLICTS OF INTEREST

The authors declare no conflicts of interest related to this study.

8. ACKNOWLEDGMENTS

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