CT-BASED EVALUATION OF UNCINATE PROCESS VARIATIONS OF THE ETHMOID BONE IN THE SOUTH INDIAN POPULATION

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ABSTRACT
Background:
The uncinate process is a thin, hook-shaped projection of the ethmoid bone that plays a pivotal role in maintaining ventilation and drainage of the osteomeatal complex (OMC). Anatomical variations of the UP can compromise mucociliary clearance, narrow the OMC, and predispose individuals to recurrent or chronic rhinosinusitis. A thorough understanding of these variants is essential for Functional Endoscopic Sinus Surgery (FESS), as unrecognized abnormalities may increase the risk of complications involving the orbit or skull base.
Methods:
This retrospective observational study evaluated high-resolution computed tomography scans of the paranasal sinuses from 100 adult individuals aged 18–79 years. Patients with a history of previous nasal surgery, major facial trauma, or sinonasal malignancy were excluded. Each uncinate process was systematically assessed for morphological variations and superior attachment patterns using established classification systems, including the Landsberg and Friedman classification.
Results:
A total of 100 patients (52 males and 48 females) were evaluated. A wide spectrum of anatomical variations of the uncinate process was observed. Type 1 superior attachment to the lamina papyracea was the most prevalent, followed by Type 4 attachment involving fusion of the middle turbinate with the cribriform plate. Additional morphological variants, such as pneumatization of the uncinate process (uncinate bulla) and paradoxical curvature, were also identified, indicating considerable anatomical diversity within the study population. Type I superior attachment was the most common pattern, while curved uncinate process was the most prevalent morphological variant. No statistically significant sex-related differences were observed ($p > 0.05$).
Conclusion:
The study demonstrates a high prevalence of morphological and attachment variations of the uncinate process in the South Indian population. Detailed preoperative CT evaluation of the lateral nasal wall is crucial for accurate surgical planning, minimizing intraoperative complications, and improving outcomes in Functional Endoscopic Sinus Surgery.
Keywords: Uncinate Process, Ethmoid Bone, Anatomical Variation, Paranasal Sinuses, Computed Tomography, Osteomeatal Complex, Endoscopic Sinus Surgery
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INTRODUCTION

The osteomeatal complex (OMC) serves as the ultimate conduit for ventilation and mucociliary drainage of the anterior ethmoid, maxillary, and frontal sinuses, rendering its structural integrity essential for sinus health. The uncinate process (UP) is a fundamental component of this complex labyrinth, characterized as a slender, sickle-shaped bone originating from the anteroinferior region of the ethmoid labyrinth [1]. Its essential function transcends the physiological into the surgical domain, where it acts as the principal landmark during functional endoscopic sinus surgery (FESS); its excision, or uncinectomy, constitutes the initial and critical step to access the maxillary ostium and infundibulum.

The management of chronic rhinosinusitis and associated conditions is intrinsically connected to a comprehensive understanding of the osteomeatal complex, the essential pathway for ventilation and mucociliary clearance of the frontal, maxillary, and anterior ethmoid sinuses. The UP of the ethmoid bone is a crucial surgical and physiological element within this complex [2,3].

The most anterior structure in the OMC serves as a significant landmark during functional endoscopic sinus surgery, where its meticulous removal, known as uncinectomy, constitutes the initial step to reach the maxillary ostium and ethmoidal infundibulum. Moreover, inherent morphological abnormalities of the UP, such as pneumatization, pronounced curvature, or bifidity, might further modify the dynamics of the osteomeatal complex, resulting in infundibular stenosis and compromised sinus function [4]. Although the UP is a relatively stable anatomical structure, its complete functional role remains under investigation, with indications that it may serve as a physical barrier, channeling sterile exhaled air toward the sinuses while diverting non-sterile inspired air and particles away from the sinus ostia. Recognition of these variants by computed tomography (CT) is essential to prevent severe consequences, including orbital invasion, lacrimal duct injury, or skull base violation [5].

The embryological origins of the UP are crucial for understanding its anatomical diversity. The paranasal sinuses originate from ectodermal outpouchings of the lateral nasal wall. The UP becomes discernible around the 10th week of gestation, with the ethmoid infundibulum and the primordial maxillary sinus developing concurrently shortly thereafter. By the twelfth week, the fundamental structures of the OMC, including the UP, are formed in a preliminary state, and the specific final attachment of the UP persists throughout fetal development and into early infancy, shaped by intricate developmental dynamics [6,7]. Numerous adult morphological variants, including the uncinate bulla and certain superior attachment patterns, are considered remnants of embryological development, wherein the resolution and fusion of multiple furrows and folds in the lateral nasal wall may occur along divergent pathways. The significant variability observed in the adult UP is fundamentally linked to its embryogenesis, rendering its study a confluence of developmental biology and clinical anatomy [8].

Although prior research has documented these variations, extensive data pertaining to the South Indian population are still limited. Due to recognized ethnic and geographical differences in craniofacial morphology, population-specific morphological data are crucial for enhancing surgical outcomes. This study aims to systematically examine the morphological characteristics and superior attachment patterns of the UP in the South Indian population using CT imaging. The objectives are to categorize the variations, determine their prevalence, and assess their significant clinical and surgical implications, thereby providing an essential anatomical foundation for otorhinolaryngologists and radiologists working with this population.

MATERIALS AND METHODS

Study Design and Setting

A retrospective, cross-sectional, analytical investigation was performed following approval from the Institutional Ethics Committee of SRM Medical College Hospital & Research Centre, Kattankulathur, Chengalpattu, Tamil Nadu with the Ethical Clearance Number – (SRMIEC-ST0724-1527). The research was conducted at the Department of Anatomy in conjunction with the Department of Radiology at our tertiary care facility. The requirement for informed consent was waived owing to the retrospective design of the study and the use of anonymized imaging data [9].

Study Population and Selection Criteria

The study population comprised 100 patients, aged 18 to 79 years, randomly selected from individuals who had undergone paranasal sinus CT scans for various clinical indications, including headache, trauma (without facial fracture), or suspected sinusitis. Patients were included based on the availability of high-resolution CT scans suitable for comprehensive bony assessment of the osteomeatal complex. Rigorous exclusion criteria were applied to eliminate confounding factors: individuals with a history of nasal polyposis, nasal tumors, prior endoscopic sinus or skull base surgery, significant nasal or facial trauma resulting in fractures, or congenital craniofacial syndromes were excluded from the analysis. The anatomical variations observed therefore reflect the natural, unaltered anatomy of the research cohort [10].

Image Acquisition

All computed tomography examinations were performed using a multi-detector CT (MDCT) scanner in accordance with a standardized paranasal sinus protocol. The imaging technique involved obtaining fine-cut axial slices with a thickness ranging from 0.625 mm to 1.25 mm, which were subsequently used to generate high-resolution coronal and sagittal multiplanar reconstructions [11]. The coronal plane was specifically emphasized for its superior visualization of the osteomeatal complex. A standard tube voltage of 120 kV and automatic tube current modulation were employed, and images were reconstructed using a dedicated bone algorithm to enhance the definition of intricate bony structures such as the UP [12].

Studied Variables and Radiological Classification

The following characteristics were systematically assessed for each side (right and left) in every patient:

This study primarily examined the anatomical features of the UP, focusing on its superior attachment type and intrinsic morphology. The superior attachment of the UP was categorized for each nasal side according to the established classification by Landsberg and Friedman, which identifies six distinct types based on their terminal points: Type I (attachment to the lamina papyracea), Type II (attachment to the posterior wall of the agger nasi cell),Type III (Lamina Papyracea and union of middle turbinate with cribriform plate), Type IV (Union of middle turbinate with cribriform plate),Type V (attachment to Ethmoidal skull base) and Type VI (Middle turbinate).

Simultaneously, the inherent morphological variations of the UP were assessed, focusing on the presence of a curved configuration, pneumatization (forming an uncinate bulla), a bifid appearance in which the process bifurcates superiorly, atelectasis, or any other significant anomalies, such as marked hypoplasia or hypertrophy. These observations were meticulously documented for each patient to create a detailed description of the anatomical environment [13].

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics Version 26. Categorical variables were expressed as frequencies and percentages. The association between sex and superior attachment types and morphological variations was assessed using the Chi-square test. A p-value <0.05 was considered statistically significant.

Analysis of Anatomical Variations by Sex

The prevalence and distribution of all aforementioned anatomical abnormalities, including forms of superior attachment and morphological variances, were studied separately for male and female patients to uncover any sex-based discrepancies in the anatomical structure of the UP within the examined group [14].

RESULTS

A total of 100 patients, comprising 52 males and 48 females, with a mean age of 42.7 years (range: 18-79 years), were included in the study. This yielded 200 sides (100 right and 100 left) for the analysis of the UP.

Distribution of UP Superior Attachment Types

This observational study, which conducted a detailed analysis of paranasal sinus CT scans from 100 patients within the South Indian population, revealed a clear hierarchy in the prevalence of different UP superior attachment types, as classified by Landsberg et al. [2] The frequency of each type is detailed in Table 1.

Table 1: Types Of Insertion Of UP

TYPES OF INSERTION OF UP	MALE (n=52)		FEMALE (n=48)	
	R	**L**	**R**	**L**
TYPE 1-Lamina Papyracea	25 (48.07%)	23(44.23%	17(35.41%)	13(27.08%)
TYPE 2-Posterior wall of agar nasi	2 (3.84%)	4 (7.69%)	1 (2.08%)	3 (6.25%)
TYPE 3-Lamina Papyracea and union of middle turbinate with cribriform plate	4 (7.69%)	2 (3.84%)	3 (6.25%)	2 (4.16%)
TYPE 4-Union of middle turbinate with cribriform plate	8 (15.38%)	4 (7.69%)	9 (18.75%)	6 (12.5%)
TYPE 5-Ethmoidal skull base	2 (3.84%)	1 (1.92%)	2 (4.16%)	2 (4.16%)
TYPE 6-Middle turbinate	6 (11.63%)	4 (7.69%)	1 (2.08%)	4 (8.33%)

Type 1 insertion into the Lamina Papyracea was the most prevalent configuration overall, particularly in males, where it was observed in 48.07% of right sides and 44.23% of left sides. In females, Type 1 was also the most common on the right side (35.41%), but was less frequent on the left (27.08%). The second most common type was Type 4 (Union of middle turbinate with cribriform plate), which was notably more frequent in females (18.75% on the right) than in males (15.38% on the right). Type 6 insertion into the Middle Turbinate showed a considerable gender disparity, being over five times more common on the right side in males (11.63%) compared to females (2.08%). In contrast, Types 2 (Posterior wall of agger nasi) and 5 (Ethmoidal skull base) were consistently the least common patterns across all groups, each never exceeding 7.69%. The data also revealed side-to-side differences, such as Type 2 being twice as common on the left side in males, and Type 4 being more prevalent on the right side for both genders (Figure 1).

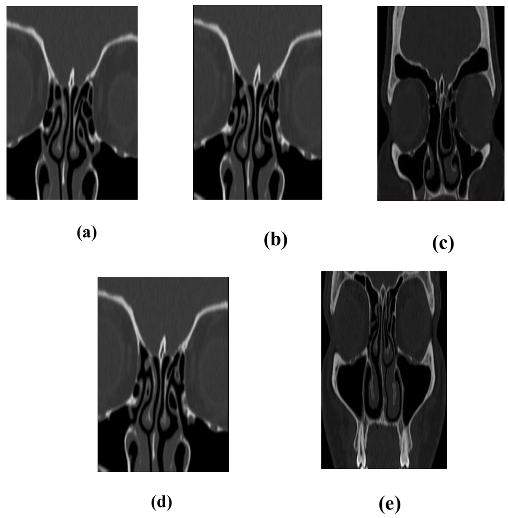

Figure 1: CT Images Demonstrating the Classification of the UP Superior Attachment. TYPE 1- Lamina Papyracea, TYPE 2-Posterior Wall Of Agar Nasi, TYPE 3-Lamina Papyracea And Union Of Middle Turbinate With Cribriform Plate, TYPE 4-Union Of Middle Turbinate With Cribriform Plate, TYPE 5-Ethmoidal Skull Base, TYPE 6-Middle Turbinate.

Analysis of Superior Attachment Types by Sex

The most prominent observation is that Type I attachment (fusion with the lamina papyracea) is the clearly predominant anatomical type. Its incidence 48.07% in males and 35.41% in females indicates that it is the configuration most likely to be encountered clinically. The consistent identification of Type IV attachment (direct fusion with the skull base) as the second most common type (15.38% in males, 18.75% in females) is a noteworthy finding from a patient safety perspective. The 11.66% difference in Type I prevalence between males and females, although not statistically significant in this cohort, suggests a potential trend that may reflect subtle sexual dimorphism in craniofacial anatomy such as a generally more robust orbital frame in males which could influence the developmental fusion point of the UP.

Morphological Variations of the UP

The evaluation of the intrinsic morphology of the UP identified several key variations, with a curved UP being the overwhelming majority. The frequencies are summarized in Table 2.

Table 2 Morphological variations of the UP

SHAPES OF UP	MALE (n=52)	FEMALE (n=48)
Atelectatic	1(1.92%)	0(0%)
Curved	32(61.53%)	28(53.84%)
Deviation of the UP tip	0(0%)	0(0%)
Bifid	1(1.92%)	0(0%)
Uncinate bulla	6(11.53%)	4(8.33%)

Based on the results, the curved shape was by far the most common morphology of the UP for both genders, being observed in 61.53% of males and 53.84% of females. The second most prevalent shape was the uncinate bulla, present in 11.53% of male specimens and 8.33% of female specimens. Atelectatic and bifid shapes were rare anomalies, each found in only 1.92% of the male group and entirely absent in the female cohort (Figure 2).

Association Between Sex and Superior Attachment Type

No statistically significant association was observed between sex and superior attachment pattern (Chi-square test, $p > 0.05$).

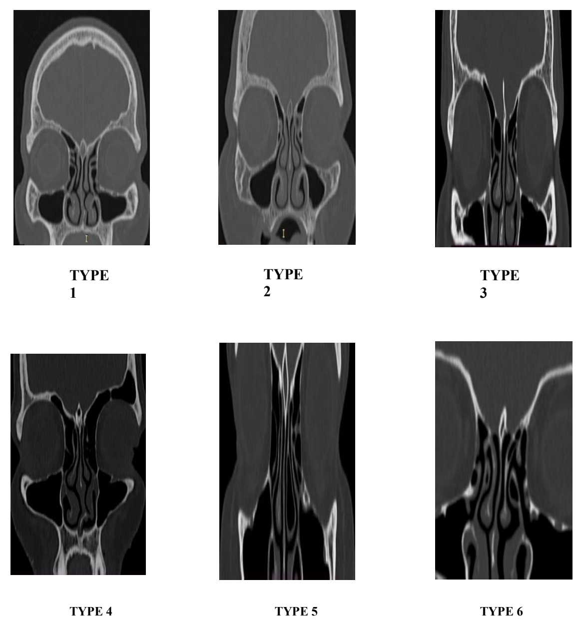

Fig 2: CT morphology of the UP - (a) Unilateral; (b) Bilateral; (c) Pneumatic; (d) Curved; (e) Bifid

Association Between Sex and Morphological Variations

No statistically significant association was observed between sex and morphological variants of the uncinate process ($p > 0.05$).

DISCUSSION

This study delineates the predominant anatomical patterns and superior attachment types of the UP in the South Indian population, providing crucial data that links its embryological origins with its clinical significance. Table 3 presents a comparative analysis of the prevalence of the primary superior attachment type (Type I – Lamina Papyracea) across several studies.

Table 3: Comparative Prevalence of Type 1 (Lamina Papyracea) Superior Attachment of the Uncinate Process

Authors & Population	Sample Size (Sides)	Type 1 (Lamina Papyracea)	Type 2 (Agger Nasi)	Type 3 (Lamina + Skull Base)	Type 4 (Skull Base)	Type 5 (Ethmoid Skull Base)	Type 6 (Middle Turbinate)
Present Study (2024) South Indian	200	41.5 %	4.0 %	5.5 %	13.5 %	3.5 %	7.0 %
Landsberg & Friedman (2001) Mixed	164	64.0 %	6.7 %	4.3 %	16.5 %	2.4 %	6.1 %
Kayalioglu et al. (2019) Turkish	412	48.5 %	8.3 %	6.1 %	18.2 %	3.4 %	5.6 %
Hajitoannou et al. (2010) Greek	210	33.3 %	11.4 %	7.1 %	25.7 %	4.3 %	8.1 %
Joe et al. (2000) North American	102	55.0 %	9.8 %	5.9 %	14.7 %	2.9 %	7.8 %

The comprehensive analysis of uncinate process superior attachments in this South Indian cohort revealed a distinct anatomical architecture, which became particularly evident when compared in detail with prior seminal studies. This investigation found Type I attachment to be the most prevalent configuration; however, its frequency established a notably different baseline compared to other populations. For instance, compared with the foundational work of Landsberg & Friedman (2001) [2], which reported a 64.0% prevalence, the present study found a rate over 22 percentage points lower. This significant disparity suggests that the anatomy often considered "conventional" is substantially less common in this demographic.

A more favourable comparison was observed with Kayalioglu et al. (2019) [15], where Type I prevalence was closer, although a critical divergence emerged in Type II attachment, which was found at only half the rate. The most surgically significant comparison involved Type IV attachment: the present study reported a prevalence of 13.5%, considerably lower than the 25.7% reported by Hajitoannou et al. (2010) [16], yet nearly identical to the prevalence reported by Joe et al. (2000) [17], underscoring its consistent global relevance. The rates of the rarer attachment types showed remarkable consistency across all studies.

In summary, the Indian population exhibits a unique anatomical signature, characterized by a lower prevalence of the standard Type I attachment, a very low frequency of Type II, and a consistent, moderate presence of the high-risk Type IV attachment. This profile emphasizes the need for a tailored, population-specific approach to preoperative CT evaluation and surgical planning for Functional Endoscopic Sinus Surgery [18].

The intrinsic morphology of the uncinate process is a critical determinant of infundibular geometry and a key factor in surgical navigation during Functional Endoscopic Sinus Surgery. This study identified a spectrum of morphological variants, whose prevalence demonstrates significant population-based disparities. Table 4 presents a comparative analysis of the primary morphological variations of the UP across different populations.

Table 4: Comparative Prevalence of Uncinate Process Morphological Variations

Authors	Population	Sample Size (Sides)	Curved (%)	Uncinate Bulla (%)	Bifid (%)

Present Study (2024)	South Indian	200	**57.5**	**10.0**	**0.5**
Bolger et al. (1991)	North American	202	44.5	2.5	4.0
Kayalioglu et al. (2019)	Turkish	412	51.2	6.3	1.2
Hajitoannou et al. (2010)	Greek	210	48.1	4.8	0.9

In contrast to previous research, the present study demonstrates a distinctly higher prevalence of the two most common morphological forms. The curved UP was the predominant configuration in our cohort, observed in 57.5% of sides. This incidence exceeds the rates reported by Bolger et al. [14] (44.5%), Kayalioglu et al. [15] (51.2%), and Hajitoannou et al. [16](48.1%). This variant represents the classic sickle-shaped structure, which optimally facilitates its physiological role in guiding mucociliary flow and airflow within the osteomeatal complex.

A particularly noteworthy finding was the high prevalence of the uncinate bulla, identified in 10.0% of specimens. This rate is substantially higher than the 2.5% reported by Bolger et al. [14] and approximately double the rates observed in Turkish (6.3%) and Greek (4.8%) population [19,20]. The uncinate bulla, resulting from pneumatization of the UP, is a clinically significant variant that can markedly narrow the ethmoidal infundibulum, predisposing to sinus obstruction and recurrent sinusitis. Its higher prevalence in our cohort suggests an increased propensity for this obstructive variant in the studied population. Surgically, a prominent uncinate bulla can be mistaken for an agger nasi cell or the ethmoid bulla, potentially causing disorientation and incomplete surgery if not properly identified and managed [21].

Conversely, the bifid UP was a rare anomaly in our study, found in only 0.5% of sides. This prevalence is lower than the 4.0% reported by Bolger et al. [14] and the 1.2% reported by Kayalioglu et al., [15] indicating that this variation is less common in our demographic. Other variations, such as atelectasis or significant deviation, were exceptionally uncommon or absent.

Collectively, the morphological data from this study reveal a distinct anatomical landscape in the South Indian population, characterized by a very high frequency of the curved UP and a notably elevated prevalence of the surgically relevant uncinate bulla [22]. These disparities likely arise from ethnic and developmental differences in the pneumatization patterns of the lateral nasal wall. For the operating surgeon, this underscores the necessity of meticulous preoperative CT review to map not only the superior attachment but also the presence of these intrinsic morphological variants, thereby ensuring a safe and effective uncinectomy and minimizing the risk of surgical complications [23].

LIMITATIONS

This study was limited by its retrospective design and single-center setting. Clinical correlation between uncinate process variations and chronic rhinosinusitis was not evaluated. Future multicenter studies with larger sample sizes may provide broader population-based data.

CONCLUSION

This anatomical study of the uncinate process established a definitive morphological profile for the South Indian population, confirming a high prevalence of significant anatomical variations. The findings revealed a distinct and diverse spectrum of superior attachments and intrinsic morphologies, underscoring that this structure is far from uniform. The consistent identification of surgically critical variants, particularly those posing a risk to the orbit and skull base, highlighted the indispensable role of detailed preoperative imaging. A comprehensive understanding of this variable anatomy proved fundamental for anticipating surgical challenges and tailoring the operative approach. Consequently, this research affirms that meticulous preoperative computed tomography evaluation is a non-negotiable prerequisite for safe and effective Functional Endoscopic Sinus Surgery. Such knowledge enables surgeons to navigate the complex lateral nasal wall with greater precision, enhancing procedural safety, optimizing surgical outcomes, and minimizing the risk of major complications. This work provides an essential anatomical foundation for both clinical practice and future research within this population.

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Conflicts of Interest: There are no conflicts of interest

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