

# Anatomical variations of the frontal sinus drainage pathway and its related factors on high-resolution computed tomography: prevalence patterns and implications

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## SUMMARY

The extensive adoption of functional endoscopic sinus surgery necessitates a clear understanding of nasal cavity and paranasal sinus anatomy. The frontal sinus drainage pathway displays the most complex anatomy of these areas. This study aimed to explore anatomical variations of the frontal sinus drainage pathway within a South African population, focusing on variations in frontal sinus drainage patterns, superior attachments of the uncinate process and frontal recess pneumatization patterns. Eighty-six frontal sinus drainage pathways were analyzed using computed tomography scans (bilateral analyses). The frontal sinus drained anteromedial to the uncinate process and directly into the middle meatus in 52.3% of cases; and posterolateral to the uncinate process and into the ethmoidal infundibulum in 47.7%. The superior attachment of the uncinate process was the lamina papyracea in 52.3% of cases, skull base in

38.4%, and middle turbinate in 9.3%. Agger nasi cells were the most frequently observed frontal recess cells (95.3%), followed by supra bulla cells (57.0%). Supraorbital ethmoid cells were observed least frequently (15.1%). Detailed preoperative analyses of the frontal sinus drainage pathway that highlight its drainage pattern, the uncinate process' superior attachment and the frontal recess' pneumatization pattern are vital because of their extensive variations. The present study advocates for description of the frontal recess pneumatization pattern using the International Frontal Sinus Anatomy Classification system. Anatomical knowledge gained from this study can be applied to surgical procedures to improve preoperative planning and ensure good postoperative results.

**Key words:** Drainage pattern – Frontal recess – IFAC system – Pneumatization pattern – Uncinate process

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## INTRODUCTION

Functional endoscopic sinus surgery (FESS) has become a widely performed surgical procedure (Başer et al., 2020). FESS is utilized for the management of chronic rhinosinusitis resistant to clinical treatment, an increasing health problem in South Africa (5.83 cases per million) caused by increased air pollution, allergies, and harmful lifestyle choices (such as smoking and excessive alcohol consumption), and associated with intracranial complications that lead to high mortality rates (Friedman and Hockman, 2010; Schlemmer and Naidoo, 2013).

Worldwide, prevalence of the condition ranges between 5% and 12% in urban populations (Alshammari et al., 2021). FESS is also utilized in managing other pathologies, including choanal atresia, mucocoele, optic nerve decompression, sellar and parasellar tumors, nasal polyposis, management of epistaxis, and epiphora caused by lower lacrimal duct obstruction (Pawar et al., 2017). The extensive adoption of FESS warrants a clear understanding of the anatomy of the nose, nasal cavity and paranasal air sinuses (Başer et al., 2020). The anatomy of these areas is complex, but none more so than that of the frontal sinus drainage pathway (FSDP) (Başer et al., 2020).

The FSDP is a challenging area for surgeons due to its narrow confines and variable anatomy making surgery in the area difficult (Başer et al., 2020). In addition, differences in the FSDP influence the likelihood of the frontal sinus being affected by accompanying ostiomeatal complex inflammation (Gupta et al., 2013). Comprehensive anatomical knowledge of the variable frontal sinus drainage patterns and elements that affect drainage and surgery of the frontal sinus and recess (namely, superior attachment of the uncinat process [UP] and frontal recess cells) is a necessity for successful planning and execution of sinus surgery (Gupta et al., 2013; Gnanavelraja et al., 2019; Gotlib et al., 2019; Sharma, 2021).

The frontal sinuses are paired air-filled spaces within the frontal bone (Gray and Standring, 2016). The FSDP extends from within the sinus, as the frontal infundibulum, to the frontal recess resembling the shape of an hourglass

(Stammberger and Kennedy, 1995; Alsaied, 2017). The frontal sinus ostium is the narrowest point of this pathway, lying between the frontal infundibulum (superior) and the frontal recess (inferior) (Stammberger and Kennedy, 1995; Alsaied, 2017). The frontal recess is the most antero-superior part of the ethmoid, continuous with either the ethmoidal infundibulum or the middle meatus, based on the superior attachment of the uncinat process (SAUP) (Lund et al., 2014; Gray and Standring, 2016; Alsaied, 2017).

The UP is a thin, hook-shaped bone regarded as one of the most important structures in frontal recess anatomy and surgery (Mahmutoğlu et al., 2015; Gray and Standring, 2016). Variations of its superior attachment have functional and surgical implications, since they affect the direction of frontal sinus drainage into the middle meatus or ethmoidal infundibulum (thus altering the frontal sinus drainage pathway/pattern) (Gnanavelraja et al., 2019; Sharma, 2021).

The anatomy of the frontal recess is often difficult to understand because of its complex structure, cellular variations, and proximity to vital structures (such as the skull base and eye) (Başer et al., 2020). The radiological and surgical anatomy of this region needs to be well known by a clinician to successfully manage frontal sinus diseases and reduce the risk of surgical complications (Başer et al., 2020). Frontal recess cells are anterior ethmoidal air spaces that occupy the frontal recess (Gotlib et al., 2019). They alter the FSDP and can extend into the frontal sinus and/or impinge on its ostium (Gotlib et al., 2019). Recently, Wormald et al. (2016) modified traditional nomenclature and definitions to provide a more anatomically accurate description of frontal recess cells (frontal recess pneumatization patterns), viz. the International Frontal Sinus Anatomy Classification (IFAC).

Numerous studies have focused on frontal sinus and recess anatomy to better facilitate the understanding, evaluation, and treatment of frontal sinus pathologies (Lee et al., 2004). Earlier literature indicates that different population groups display variations in frontal sinus drainage patterns, superior attachments of the UP, and frontal recess pneumatization patterns (Lee et al., 2004;

Gupta et al., 2013; Mahmutoğlu et al., 2015; Pawar et al., 2017). Information concerning these topics and variations in the South African population is scarce in the literature. Hence, the present study aimed to explore the drainage pathway of the frontal sinus within a South African population, focusing on the frontal sinus drainage patterns, superior attachments of the UP and frontal recess pneumatization patterns.

## MATERIALS AND METHODS

The present study retrospectively reviewed 86 frontal sinus drainage pathways (both left and right) of 43 adult patients (28 males;15 females) using computed tomography (CT) scans. The study consisted of 83.7% Black African, 11.6% Indian, and 4.7% Colored patients. The mean age of the patients was 37.6 years old, ranging between 18 and 88 years of age. Scans were obtained from Inkosi Albert Luthuli Central Hospital in KwaZulu-Natal. The inclusion criteria for scan selection were as follows: patients  $\geq 18$  years of age (based on the expected completion of frontal sinus development); scans without observable evidence of previous surgery or distortion, pathology, and trauma affecting the frontal sinus, anterior ethmoidal sinus, and nasal cavity; and slice thickness  $\leq 1$  mm.

One hundred and fifty CT scans were initially screened to determine study suitability. The final study comprised 43 CT scans that met the inclusion criteria. Inkosi Albert Luthuli Central Hospital acquired the scans during clinical routines with either a 128-slice SOMATOM Definition AS Scanner or SOMATOM Definition Flash CT Scanner (Siemens Healthineers, Forchheim, Germany) and saved images as digital imaging and communications in medicine (DICOM) files. The present study viewed and analyzed the DICOM files at Inkosi Albert Luthuli Central Hospital using syngo.plaza software (version VB20A), the standard software used by this medical facility.

The frontal sinus drainage pattern was analyzed using all three views/planes (coronal, sagittal, and axial) and classified into two groups based on its relation to the UP and course to the middle meatus. Group 1: drainage anteromedial to the UP and directly into the middle meatus. Group 2: drainage

posterolateral to the UP and into the ethmoidal infundibulum, then into the middle meatus via hiatus semilunaris.

The SAUP was identified and described using coronal images by first identifying the uncinata process (typically described as a thin, bony hook-like leaflet with a near sagittal orientation, running from anterosuperior to posteroinferior) near its attachment to the perpendicular plate of the palatine bone and the ethmoidal process of the inferior turbinate. Then by carefully scrolling back and forth, the fine superior aspects of the uncinata process could be traced to their insertion.

The pneumatization pattern of the frontal recess (prevalence of frontal recess cells) was identified and described according to the IFAC system (Wormald et al., 2016). The presence of each cell outlined by the IFAC system was assessed using all three views/planes (coronal, sagittal, and axial) (Wormald et al., 2016). Prevalence of each cell type was subsequently calculated. Cell symmetry between the two sides in individual patients (that is, present bilaterally, present unilaterally, or absent bilaterally) was assessed for each cell type.

### Inter-observer error

A second observer reviewed ten percent of the CT scans in order to determine the inter-observer error of all parameters assessed.

### Statistical analysis

All data were summarized using descriptive statistics (frequencies and percentages). Variations of the frontal sinus drainage pattern and SAUP and the prevalence of frontal recess cells were compared according to sex and laterality using Chi-square tests or Fisher's exact tests, as appropriate. All comparisons also considered the homogeneity test between groups. Inter-observer error was calculated and represented as intra-class correlation coefficient (ICC) values to determine the data's reliability. All data were analyzed using R Statistical Computing Software of the R Core Team version 3.6.3. A p-value of less than 0.05 was considered statistically significant.

## RESULTS

### Frontal sinus drainage patterns

The frontal sinus drained anteromedial to the UP and directly into the middle meatus (Group 1) in 45/86 sides (52.3% of cases) overall (Right: 20/43 [46.5%]; Left: 25/43 [58.1%]; Male: 31/56 [55.4%]; Female: 14/30 [46.7%]) (Figs. 1a-c).

The frontal sinus drained posterolateral to the UP and into the ethmoidal infundibulum, before draining into the middle meatus via hiatus semilunaris (Group 2) in 41/86 sides (47.7% of cases) overall (Right: 23/43 [53.5%]; Left: 18/43 [41.9%]; Male: 25/56 [44.6%]; Female: 16/30 [53.3%]) (Figs. 1d-f).

No statistically significant differences according to sex ( $p=0.442$ , Chi-squared test) or laterality ( $p=0.280$ , Chi-squared test) were identified. Therefore, the drainage pattern of the frontal sinus was found to be independent of sex and laterality. Analyses of frontal sinus drainage patterns between the observer and second observer yielded ICC values of 1.00 for both sides, indicating excellent reliability and repeatability.

### Superior attachment of the uncinete process

The uppermost portion of the UP bent laterally to insert into the lamina papyracea, directly or in-

directly (via an anterior ethmoidal cell or the agger nasi cell [ANC]) in 45/86 sides (52.3% of cases) overall (Right: 20/43 [46.5%]; Left: 25/43 [58.1%]; Male: 31/56 [55.4%]; Female: 14/30 [46.7%]) (Fig. 2a).

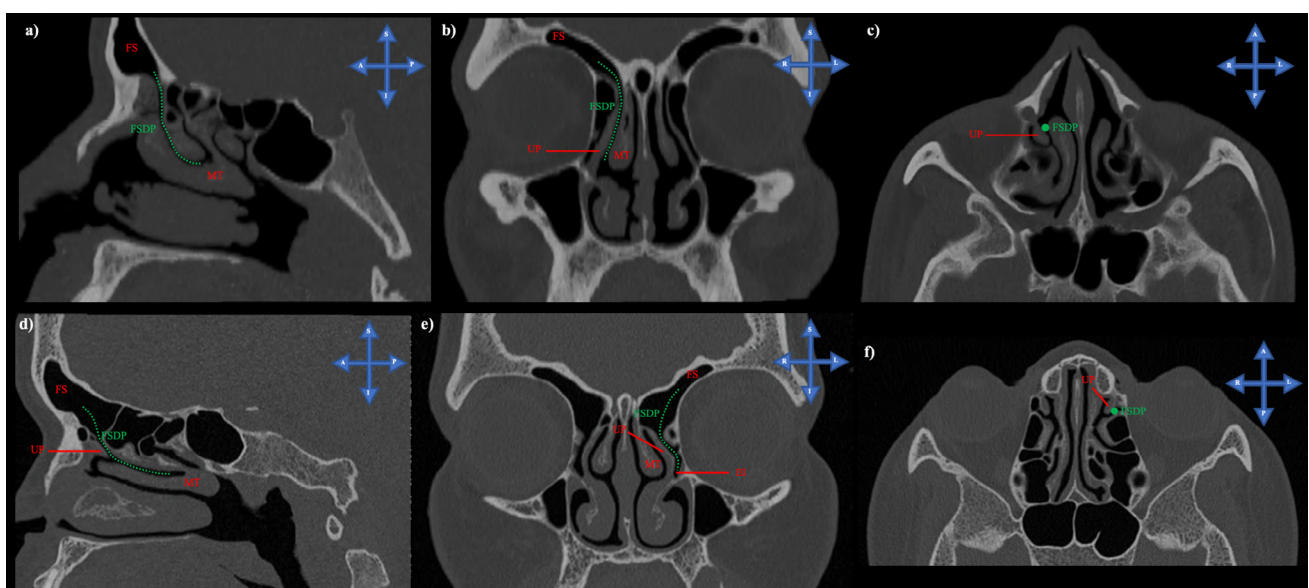
The UP extended superiorly to the skull base (ethmoidal roof) in 33/86 sides (38.4% of cases) overall (Right: 19/43 [44.2%]; Left: 14/43 [32.6%]; Male: 22/56 [39.3%]; Female: 11/30 [36.7%]) (Fig. 2b).

The superior end of the UP turned medially and attached to the middle turbinate in 8/86 sides (9.3% of cases) overall (Right: 4/43 [9.3%]; Left: 4/43 [9.3%]; Male: 3/56 [5.4%]; Female: 5/30 [16.7%]) (Fig. 2c).

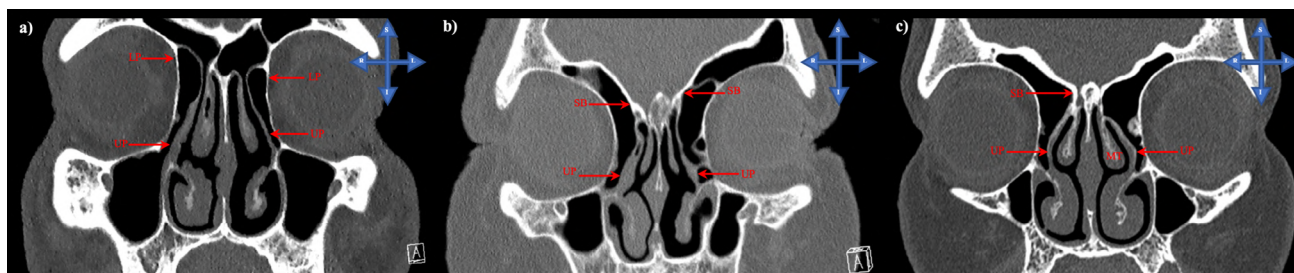
In 25 scans (58.1%), the superior attachment was either identical or similar, bilaterally. No statistically significant differences were identified according to sex ( $p=0.223$ , Chi-squared test) or laterality ( $p=0.533$ , Fisher's exact test). Therefore, superior attachment of the UP was found to be independent of sex and laterality. Analyses of the SAUP between the observer and second observer yielded ICC values of 1.00 on both sides, indicating excellent reliability and repeatability.

### Frontal recess pneumatization patterns

Table 1 illustrates the prevalence of each cell type described in the IFAC system (Fig. 3). The ANC was the most commonly observed cell type (95.3%



**Fig. 1.** - Frontal sinus drainage anteromedial to the uncinete process and directly into the middle meatus (Group 1) in the **a**) sagittal plane, **b**) coronal plane, and **c**) axial plane; and Frontal sinus drainage posterolateral to the uncinete process and into the ethmoidal infundibulum (Group 2) in the **d**) sagittal plane, **e**) coronal plane, and **f**) axial plane. Key: FS = Frontal sinus, FSDP = Frontal sinus drainage pathway/pattern, MT = Middle turbinate, UP = Uncinate process, EI = Ethmoidal infundibulum, S = Superior, I = Inferior, A = Anterior, P = Posterior, R = Right, L = Left.



**Fig. 2.-** Superior attachment of the uncinete process to the **a)** lamina papyracea on both sides, **b)** skull base on both sides, and **c)** skull base on the right side and middle turbinate on the left side (coronal planes). Key: UP = Uncinete process, LP = Lamina papyracea, SB = Skull base, MT = Middle turbinate, S = Superior, I = Inferior, R = Right, L = Left.

of cases), followed by the supra bulla cell (SBC) (57.0% of cases) (Figs. 3a and 3b). The supraorbital ethmoid cell (SOEC) was the least common cell type observed, being identified in only 15.1% of cases (Fig. 3d). No statistically significant differences in the prevalence of any cell type were identified according to sex or laterality ( $p > 0.05$ ). Analyses of the prevalence of each cell type between the observer and second observer yielded ICC values ranging from 0.82 to 1.00, indicating good-excellent reliability and repeatability.

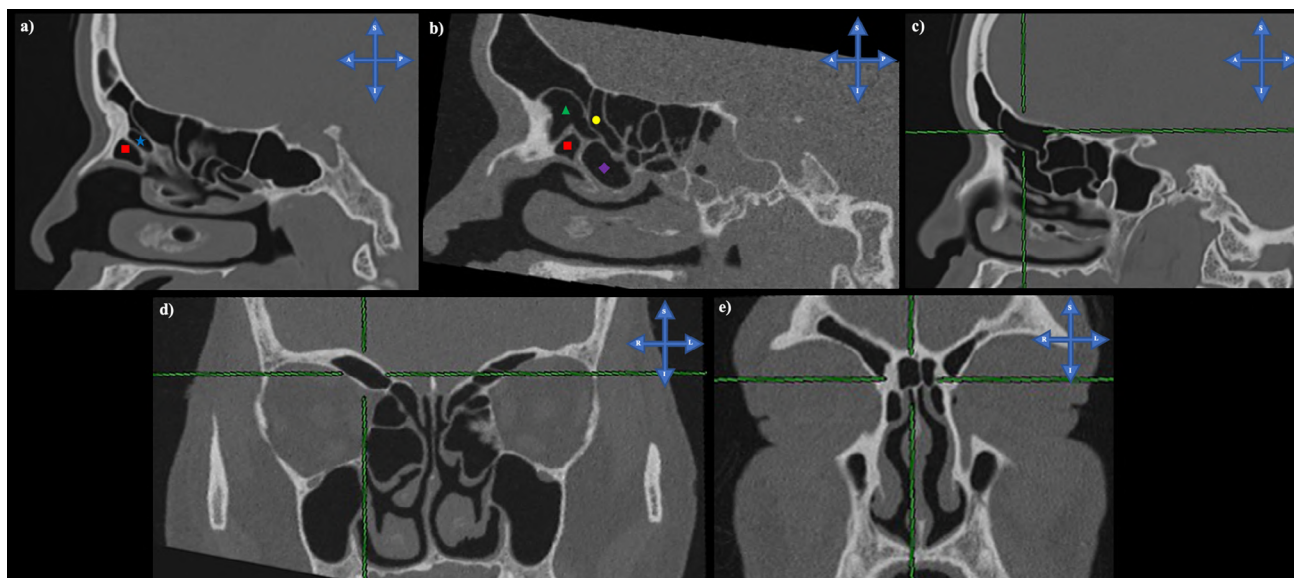
Twenty scans displayed a frontal septal cell (FSC) either attached to the interfrontal sinus

septum on either side, within the sinus septum, or both (46.5% of cases) (Table 1). Scans that displayed an FSC within the septum were classified as bilateral FSC occurrences (present on both sides) since they affect the FSDP bilaterally. The frequency of cell symmetry between the two sides in individual patients, that is, present bilaterally, present unilaterally, or absent bilaterally, was analysed and recorded in Table 1. The ANC was usually observed bilaterally. Supra agger cells (SACs) and SBCs were most frequently seen unilaterally. While, supra agger frontal cells (SAFCs), supra bulla frontal cells (SBFCs), SOECs and FSCs were usually absent bilaterally.

**Table 1.** Prevalence of frontal recess cells and frequency of cell symmetry.

IFAC cell name	IFAC cell type prevalence							Cell symmetry								
	Right n (%)	Left n (%)	p-value	Male n (%)	Female n (%)	p-value	Total n (%)	Bilateral presence n (%)			Unilateral presence n (%)			Bilateral absence n (%)		
								Male	Female	Total	Male	Female	Total	Male	Female	Total
ANC	40 (93.0)	42 (97.7)	0.616*	55 (98.2)	27 (90.0)	0.120*	82 (95.3)	27 (96.4)	12 (80.0)	39 (90.7)	1 (3.6)	3 (20.0)	4 (9.3)	0 (0)	0 (0)	0 (0)
SAC	19 (44.2)	19 (44.2)	1.000#	26 (46.4)	12 (40.0)	0.567#	38 (44.2)	7 (25.0)	2 (13.3)	9 (20.9)	12 (42.9)	8 (53.3)	20 (46.5)	9 (32.1)	5 (33.3)	14 (32.6)
SAFC	7 (16.3)	8 (18.6)	0.776#	9 (16.1)	6 (20.0)	0.647#	15 (17.4)	1 (3.6)	0 (0)	1 (2.3)	7 (25.0)	6 (40.0)	13 (30.2)	20 (71.4)	9 (60.0)	29 (67.4)
SBC	21 (48.8)	28 (65.1)	0.127#	33 (58.9)	16 (53.3)	0.617#	49 (57.0)	10 (35.7)	4 (26.7)	14 (32.6)	13 (46.4)	8 (53.3)	21 (48.8)	5 (17.9)	3 (20.0)	8 (18.6)
SBFC	15 (34.9)	15 (34.9)	1.000#	20 (35.7)	10 (33.3)	0.825#	30 (34.9)	5 (17.9)	2 (13.3)	7 (16.3)	10 (35.7)	6 (40.0)	16 (37.2)	13 (46.4)	7 (46.7)	20 (46.5)
SOEC	6 (14.0)	7 (16.3)	0.763#	9 (16.1)	4 (13.3)	1.000*	13 (15.1)	2 (7.1)	1 (6.7)	3 (7.0)	5 (17.9)	2 (13.3)	7 (16.3)	21 (75.0)	12 (80.0)	33 (76.7)
FSC <sup>a</sup>	15 (34.9)	15 (34.9)	1.000#	20 (35.7)	10 (33.3)	0.825#	30 (34.9)	7 (25.0)	3 (20.0)	10 (23.3)	6 (21.4)	4 (26.7)	10 (23.3)	15 (53.6)	8 (53.3)	23 (53.5)
FSC <sup>b</sup>	-	-	-	13 (46.4)	7 (46.7)	0.988#	20 (46.5)	-	-	-	-	-	-	-	-	-

<sup>a</sup>According to the total number of sides. <sup>b</sup>According to the total number of scans. \*Fisher's exact test. #Chi-squared test. **Key:** IFAC = International Frontal Sinus Anatomy Classification, ANC = Agger nasi cell, SAC = Supra agger cell, SAFC = Supra agger frontal cell, SBC = Supra bulla cell, SBFC = Supra bulla frontal cell, SOEC = Supraorbital ethmoid cell, FSC = Frontal septal cell



**Fig. 3.-** **a)** Sagittal view of an agger nasi cell (red square) and supra agger cell (blue star); **b)** sagittal view of an agger nasi cell (red square), supra agger frontal cell (green triangle), ethmoidal bulla (purple diamond) and supra bulla cell (yellow circle); **c)** sagittal view of a supra bulla frontal cell (within crosshairs); **d)** coronal view of a supraorbital ethmoid cell (within crosshairs), and **e)** coronal view of bilateral frontal septal cells (attached to the frontal septum on either side, right-side FSC within crosshairs). Key: S = Superior, I = Inferior, A = Anterior, P = Posterior, R = Right, L = Left.

## DISCUSSION

The South African population is unique in its diverse composition of population groups. Black African individuals make up the majority of the South African population (80.9%), while Colored (8.8%), White (7.8%), and Indian (2.6%) individuals make up much smaller proportions of the population (Statistics South Africa, 2021). This distribution of population groups across the entire South African population explains the distribution of population groups within the present study's South African cohort (that is, 83.7% Black African patients, 11.6% Indian patients and 4.7% Colored patients). Limitations of this study included sample restrictions that resulted in the uneven distribution of sexes and population groups.

### Frontal sinus drainage patterns

Out of all the paranasal sinuses, the frontal sinus displays the most complex and variable drainage pathway (Mahmutoğlu et al., 2015). Different population groups display variable drainage patterns (Gupta et al., 2013). Sound knowledge of the anatomical details of different populations is necessary for surgical planning (Gupta et al., 2013).

The present study analyzed the FSDP and classified its drainage pattern into two groups,

according to its relationship with the UP and course to the middle meatus. According to the present study's findings, both groups of drainage patterns are relatively common within the South African population. Therefore, comprehensive anatomical knowledge of both patterns is essential for radiologists to interpret CT scans accurately and for surgeons to perform successful frontal FESS in the South African population (Gnanavelraja et al., 2019).

In contrast, Indian populations have demonstrated Group 1 patterns more frequently (Gupta et al., 2013; Arun et al., 2017; Gnanavelraja et al., 2019). While North American and Egyptian populations demonstrated Group 2 patterns more frequently (Lee et al., 1997; Gaafar et al., 2001). This further highlights variations of the FSDP, in terms of drainage patterns, between different populations (Lee et al., 1997; Gaafar et al., 2001; Gupta et al., 2013; Arun et al., 2017; Gnanavelraja et al., 2019).

### Superior attachment of the uncinete process (SAUP)

According to the present study's findings, the lamina papyracea is the most common SAUP in the South African population, followed by the skull base, while the middle turbinate is the

rarest SAUP (Table 2). These results are in agreement with previous literature (Savvateeva et al., 2010; Gupta et al., 2013; Ameye et al., 2014; Arun et al., 2017; Sharma, 2021) (Table 2). However, noteworthy arrangement and frequency variations are reported in many studies and populations (Gaafar et al., 2001; Lessa et al., 2007; Ameye et al., 2014; Arun et al., 2017; Sharma, 2021) (Table 2). Symmetrical superior attachments are also less common in the South African population than in other populations (Arun et al., 2017; Sharma, 2021). Knowledge and identification of these SAUP variations are vital for accurate preoperative planning, avoiding injury to structures such as the lamina papyracea, skull base, and middle turbinate during surgery, facilitating localization of the frontal sinus ostium during procedures, and establishing surgical access to the frontal sinus, in the South African population (Gupta et al., 2013; Mahmutoğlu et al., 2015). According to Sharma (2021), variations of the SAUP displayed no inclination towards any sex or age group defined in their study (those being 15–25, 26–36, 37–47, and >48 years old). The present study agrees with these findings, identifying no statistically significant differences according to sex ( $p=0.223$ ) or laterality ( $p=0.533$ ).

### Frontal recess pneumatization patterns

Numerous studies have documented the prevalence of frontal recess cells using various classification systems (Lee et al., 2004; Jang et al., 2014; Kubota et al., 2015; Sjogren et al., 2017). However, many of these systems are limited by insufficient anatomical detail, subjective interobserver variations and inherent inconsistencies (Choby et al., 2018). This has led to the development of the IFAC (Choby et al., 2018). The IFAC system was designed to describe frontal recess cells in a reproducible, surgically relevant, and anatomically precise manner (Choby et al., 2018). Proper classification of frontal recess cells is imperative for communication among surgeons and assessment of the complexity of endoscopic frontal sinus and recess surgeries (Lee et al., 2004; Gotlib et al., 2019). Frontal sinus surgery becomes increasingly difficult in the presence of these cells (Başer et al., 2020). Currently, there are relatively few studies that have documented the frequency of frontal recess cells (frontal recess pneumatization pattern) according to the IFAC system (Sjogren et al., 2017; Choby et al., 2018; Gotlib et al., 2019; Tran et al., 2019; Başer et al., 2020).

**Table 2.** Comparison of superior attachments of the uncinat process observed in previous studies.

Author	Population group	Superior attachment of the uncinat process (%)				
		LP	ANC	SB	MT	NA
Gupta <i>et al.</i> (2013) <sup>a</sup>	Indian	59.4	-	37.5	-	-
Sharma (2021)	Indian	64.5		5	20	10.5
Gaafar <i>et al.</i> (2001)	Egyptian	16.7	-	83.3	-	-
Arun <i>et al.</i> (2017)	Indian	67.5		18.5	9.5	4.5
Savvateeva <i>et al.</i> (2010)	German	→50 right →63.2 left	-	→ 35.8 right → 26.4 left	→ 10.4 right → 8.5 left	-
Ameve <i>et al.</i> (2014)	Nigerian	83.8	-	2.2	14	-
Lessa <i>et al.</i> (2007)	Brazilian White – 50% Brown – 34% Black – 16%	76.3	-	-	-	-
<b>Present study</b>	<b>South African</b> <b>Black African – 83.7%</b> <b>Indian – 11.6%</b> <b>Coloured – 4.7%</b>	→ 52.3 overall → 46.5 right → 58.1 left		→ 38.4 overall → 44.2 right → 36.2 left	→ 9.3 overall → 46.5 right → 58.1 left	-

<sup>a</sup>Gupta *et al.* (2013) noted absence of the entire uncinat process in 3.1% of cases.

**Key:** LP = Lamina papyracea, ANC = Agger nasi cell, SB = Skull base, MT = Middle turbinate, NA = No attachment

**Table 3.** Comparison of frontal recess pneumatization patterns observed in previous studies.

Author	Population group	Anteriorly based cells (%)			Posteriorly based cells (%)			Medially based cells (%)
		ANC	SAC	SAFC	SBC	SBFC	SOEC	FSC
Başer <i>et al.</i> (2020)	Turkish	94.3	40.0	14.7	59.7	7.3	7.3	29.3 <sup>b</sup>
Lee <i>et al.</i> (2004) <sup>a</sup>	North American	89	56	8	15	9	62	14 <sup>c</sup>
Gotlib <i>et al.</i> (2019)	Polish	86.9	34	17.5	77.2	22.8	5.8	27.2 <sup>d</sup>
Jang <i>et al.</i> (2014)	North American White – 53.7% Black – 46.3%	-	-	-	-	-	44	-
Sjogren <i>et al.</i> (2017)	North American	88.9	29.5	22.1	55.8	18.9	11.6	13.2 <sup>e</sup>
Choby <i>et al.</i> (2018)	North American Asian – 9% Hispanic – 14% African-American – 1% White – 76%	96.5	30	20	72	5.5	28.5	30 <sup>f</sup>
Tran <i>et al.</i> (2019)	Vietnamese	95.7	16.3	13	46.2	4.3	17.3	10.6 <sup>g</sup>
<b>Present study</b>	<b>South African</b> <b>Black African – 83.7%</b> <b>Indian – 11.6%</b> <b>Coloured – 4.7%</b>	<b>95.3</b>	<b>44.2</b>	<b>17.4</b>	<b>57</b>	<b>34.9</b>	<b>15.1</b>	<b>46.5<sup>h</sup> &amp; 34.9<sup>i</sup></b>

<sup>a</sup>Lee *et al.* (2004) utilised an older classification system, however, based on their anatomical description: FC1s and FC2s correspond to SACs, FC3s and FC4s correspond to SAFCs, FBCs correspond to SBFCs, and IFSSCs correspond to FSCs. <sup>b</sup>44/150 scans. <sup>c</sup>14/100 sides. <sup>d</sup>56/206 sides. <sup>e</sup>25/190 sides. <sup>f</sup>30/100 scans. <sup>g</sup>22/208 sides. <sup>h</sup>20/43 scans. <sup>i</sup>30/86 sides.

**Key:** ANC = Agger nasi cell, SAC = Supra agger cell, SAFC = Supra agger frontal cell, SBC = Supra bulla cell, SBFC = Supra bulla frontal cell, SOEC = Supraorbital ethmoid cell, FSC = Frontal septal cell, FC1 = Frontal cell Type 1, FC2 = Frontal cell Type 2, FC3 = Frontal cell Type 3, FC4 = Frontal cell Type 4, FBC = Frontal bullar cell, IFSSC = Interfrontal sinus septal

Differences in frontal recess pneumatization patterns observed between different studies can be attributed to differences in technique (cadaveric dissection, CT scan parameters, computer-enabled CT review vs. review on CT films), patient selection, terminology and definitions (classification system utilized), limiting accurate comparisons (Lee *et al.*, 2004; Jang *et al.*, 2014; Gotlib *et al.*, 2019) (Table 3). Additionally, Lee *et al.* (2004) highlighted the possibility of discrepancies due to anatomical differences in various populations (Table 3). SOECs have previously been found to be more common in White individuals, whereas SBCs were found to be more common in East Asian populations (Korean, Taiwanese, Chinese and Japanese), when the two populations were compared (Choby *et al.*, 2018). Başer *et al.* (2020) noted that further studies in different populations are essential. Regional studies are necessary to acquire global prevalence estimates/rates of frontal recess cells (Başer *et al.*, 2020).

According to the present study, ANCs and SBCs are the two most common cell types in the South African population, and SOECs are the rarest (Ta-

ble 3). These results corroborate many previous studies and further highlight the consistent presence of the ANC across different classification systems (Lee *et al.*, 2004; Sjogren *et al.*, 2017; Choby *et al.*, 2018; Gotlib *et al.*, 2019; Tran *et al.*, 2019; Başer *et al.*, 2020) (Table 3). According to Tran *et al.* (2019), this relatively constant presence is the main reason that the ANC is used as a reference cell for anteriorly based cells in the IFAC system. The present study also noted that SBFCs and FSCs are more common in the South African population, as compared to other populations (Lee *et al.*, 2004; Sjogren *et al.*, 2017; Choby *et al.*, 2018; Gotlib *et al.*, 2019; Tran *et al.*, 2019; Başer *et al.*, 2020) (Table 3). According to Wormald *et al.* (2016), the FSC is associated with the medial aspect of the frontal sinus drainage pathway and pushes it laterally (and frequently posteriorly). The present study observed FSCs both within the interfrontal sinus septum and attached to the septum (bilaterally or unilaterally), an important variation to note. When the cell lies within the sinus septum, the frontal sinus drainage pathway on both sides would be affected by the cell. How-

ever, only the associated side would be affected when the cell is attached to the sinus septum. Lee et al. (2004) states that during endoscopic frontal sinusotomies, unopened SBCs and SBFCs could resemble the appearance of the skull base. Failure to correctly identify these cells could result in an incomplete dissection of the posterior frontal recess and, ultimately, surgical failure (Lee et al., 2004). The high prevalence rates of SBCs and SBFCs within the South African population produce a greater risk of this misidentification and subsequent complications (Table 3). Başer et al. (2020) identified significantly higher SOEC rates in males compared to females. However, the present study noted no significant differences in the prevalence of SOECs between sexes ( $p > 0.05$ ) (Table 1).

Most frontal recess cell symmetry observed in the present study agreed with previous literature (Choby et al., 2018; Başer et al., 2020) (Table 1). However, previous studies observed lower incidences of unilateral SBC presence, bilateral SBFC presence, and unilateral SBFC presence, as compared to the present study (Choby et al., 2018; Başer et al., 2020) (Table 1). Knowledge of these incidences will facilitate preoperative analysis of frontal recess pneumatization patterns in the South African population, which need to be done to develop an approach for dissecting all cells affecting the FSDP (Kubota et al., 2015).

The IFAC system is not without its limitations. Choby et al. (2018) noted relative difficulty in identifying SBCs, due to difficulty in differentiating between the posterior table of the frontal sinus and the skull base. The present study also noted this challenge in some cases. According to Wormald et al. (2016), the frontal ostium is “the narrowest area of the transition zone from the frontal sinus to the frontal recess with its anterior edge formed by the frontal sinus beak and the posterior edge formed by the skull base.” Choby et al. (2018) stated that the frontal beak was easily identifiable, making anteriorly based cells easier to identify and classify; however, the gradual sloping of the skull base as it transitioned into the posterior table of the frontal sinus created uncertainty as to where the frontal sinus actually begins. As a result, Choby et al. (2018) states that it was difficult

to determine if posteriorly based cells adjacent to this portion of the skull base were actually extending into the frontal sinus (SBFC) or not (SBC). The present study recommends the utilization of radiological images in all three view/planes in conjunction with the structure and cell descriptions outlined by Wormald et al. (2016), including details regarding structure boundaries, to facilitate accurate identification of structures and classification of frontal recess cells. Precise identification of the frontal sinus, frontal recess, and frontal sinus ostium prior to classifying frontal recess cells is vital for accurate cell classification.

## CONCLUSION

The FSDP displayed many variations in terms of drainage patterns and factors that affect drainage and surgery of the area (that is, superior attachment of the UP and frontal recess pneumatization patterns). A much higher prevalence of SBFCs and FSCs, as well as a lower incidence of identical superior attachments on either side, was observed in the South African population compared to other populations. The present study recommends detailed preoperative analyses of the frontal sinus drainage pathway that take note of its drainage patterns (in relation to the uncinat process and course to reach the middle meatus), the superior attachment of the uncinat process and the frontal recess pneumatization, owing to their clinical significance and extensive variations. The present study advocates for use of the IFAC system when classifying frontal recess cells because of its effective definitions, ease of use, and excellent reliability. Anatomical knowledge gained from this study can be applied to surgical procedures involving the frontal sinus and/or its drainage pathway (such as frontal FESS), and the skull base, to improve preoperative assessments and planning, reduce the risk of iatrogenic injury to vital structures and subsequent complications, and ensure good postoperative results.

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