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A radiological study on anatomical variations of frontal sinus and its' drainage pathway in a Nepalese adult population*

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Abstract

Background: This study aims to assess anatomical variations in the frontal sinus and its drainage pathway within the Nepalese population.

Methodology: This cross-sectional analytical study was conducted at the Department of ENT-HNS and Radiology, Maharajgunj Medical Campus in Nepal. Digital Imaging and Communications in Medicine (DICOM) computed tomography files of patients were analyzed over a year to assess pneumatization variations, frontal sinus size, presence of intersinus septa, olfactory fossa depth, frontal recess cells, and anterior ethmoidal artery position. Imaging files with obscuring disease processes or obtained in different positions, hindering frontal sinus or recess visibility, were excluded. Data analysis employed SPSS version 25, using descriptive statistics (median, range, interquartile range), Chi-squared tests, and Cramer's V.

Results: Among total sinuses analyzed, 7% exhibited unpneumatized frontal sinuses (3.3% bilaterally, 6.7% unilaterally). Median dimensions for right and left frontal sinuses were 10.2 x 11.15 x 11.7 mm and 10.2 x 11.1 x 11.6 mm, respectively. Predominant findings included mixed upper uncinate process attachments, Type II olfactory fossa, agger nasi as the commonest anteriorly based cells, and supra bulla cells as the prevalent posteriorly based cells.

Conclusion: Investigation of frontal sinus anatomy in the Nepalese population revealed distinct features. While generally well-developed, these sinuses exhibited relatively smaller dimensions compared to other ethnic groups. Consistent with prior studies, agger nasi and supra bulla cells were the most prevalent anteriorly and posteriorly based cells, respectively.

Key words: anatomy, frontal sinus, frontal sinusitis

Introduction

The frontal sinus presents a significant challenge for endoscopic sinus surgeons due to the intricacies related to its location, diverse variations, and proximity to essential structures. Situated within the squamous part of the frontal bone, these paired sinuses drain into the frontal recess through frontal sinus opening. Unlike other sinuses, the frontal sinus drainage pathway (FSDP), stands out due to its complex and variable nature, mainly attributed to the presence of crucial structures nearby [1-3]. These include the medial position of the lateral lamella, the lateral presence of the lamina papyracea, the posterior location of the anterior ethmoidal artery, as well as the assortment of different cells encircling the frontal recess and the varying superior connections of the uncinate process [1,2].

This complexity demands a sound understanding of the frontal sinus and its drainage pathway by the operating surgeons to navigate frontal sinus pathologies meticulously and avoid complications at the same time. To offer a better understanding of the anatomy, several classification systems have been proposed. European position paper on anatomical terminology of the internal nose and paranasal sinus offers comprehensive definitions of the frontal sinus, frontal recess, FSDP and proposes to

classify fronto ethmoidal cells in relation to FSDP [1]. Following this, International frontal sinus anatomy classification was later proposed, aiming to precisely name cells in the frontal recess based on position relative to FSDP [2].
Several studies have explored the variations of the frontal sinus and its drainage pathways across diverse geographical populations, revealing differing results [4,5]. However, there is a dearth of such study done in Nepal. This study aims to bridge this gap by documenting frontal sinus variations pertaining to its pneumatization, presence of various types of inter-sinus septations, dimensional aspects, cells relative to the frontal recess and FSDP, variations in the olfactory fossa, and the association of variations in the anterior ethmoidal artery (AEA) with olfactory fossa (OF) and supraorbital ethmoidal cells (SOEC).

Our intent is to contribute valuable insights not only to ENT surgeons in Nepal but also to enrich the global understanding of the frontal sinus and its drainage pathways. By shedding light on these anatomical variations within a Nepalese context, this study strives to enhance the broader perspective on frontal sinus complexities worldwide.

Methods

This cross-sectional study was collaboratively conducted in the Departments of ENT-HNS and Radiology at Maharajgunj Medical Campus, Tribhuvan University Teaching Hospital in Kathmandu, Nepal. The study spanned one year (January 2023 to December 2023) and has received approval from the Institutional Review Committee [Ref: 515(6-11)E^2]. During this period, we analyzed DICOM CT scan files of nose and paranasal sinuses from patients at our hospital.
We concentrated our analysis on imaging data from patients aged 15 years and older, encompassing all genders from Nepalese population. This age range was chosen considering the likelihood that the frontal sinus might not have completed full pneumatization before this threshold. Cases where the frontal sinus or cells within the frontal recess region were obscured by soft tissue density or improper patient positioning were excluded to mitigate potential biases. Cases coming from a different geographical origin other than Nepal were excluded by assessing the hospital's out-patient record details.
Radiological assessment involved two otolaryngologists, and consensus-based parameters were recorded. All the DICOM files were analyzed in three planes (sagittal, coronal and axial) using software (syngo.via, SIEMENS). In case of disagreement, consultation with radiologists resolved discrepancies. We clearly defined our analysis parameters as follows, and each one is visually represented in Figure 1.

- Unpneumatized (Aplasia) frontal sinus: No pneumatization observed
- Partially pneumatized (Hypoplasia): Pneumatization below the supra-orbital line [6]
- Well-pneumatized frontal sinus: Pneumatization extending beyond the supra-orbital line
- Single intersinus septum: One septum between two frontal sinuses
- Multiple intersinus septum: More than one septum with one or both frontal sinuses apart from intersinus septum

Upper attachment of uncinate process (UP):

- Superior: Attachment to the skull base
- Medial: Attachment to the lateral surface of the middle turbinate
- Lateral: Attachment to the lamina papyracea

Olfactory fossa (OF) depth based on Keros classification [2]:

- Keros I: Depth 1-3 mm
- Keros II: Depth 4-7 mm
- Keros III: Depth 8-16 mm

Additionally, the classification of frontal recess cells was in accordance to EPOS anatomical terminology classification [1] and IFAC [2], however, we further classified supra agger cells (SAC) into Type1 and Type II frontal cells and supra agger frontal cells (SAFC) into Type III and Type IV frontal cells for further differentiation [7]:

- Anterior:
  Agger nasi (AN): Cell above and just anterior to the middle turbinate's origin
  Type 1/SAC: Single cell above the AN
  Type 2/SAC: Multiple cells above the AN
  Type 3/SAFC: Frontal cell pneumatizing into the frontal sinus without involving more than 50% of its height
  Type 4/SAFC: Frontal cell pneumatizing into the frontal sinus involving more than 50% of its height
- Posterior:
  Supra bulla cell (SBC): Cell above the bulla but not extending into the frontal sinus
  Supra bulla frontal cell (SBFC): Cell pneumatizing forward into the frontal sinus
  Supraorbital ethmoid cell (SOEC): Ethmoid cell pneumatizing into the orbital plate of the frontal bone
- Medial:
  Intersinus/Frontal septal cell: Cell pneumatizing into the interfrontal sinus septum

The dimensions of each frontal sinus were assessed across vertical (from the inner surface of the superior wall to the floor), horizontal (maximum inner transverse diameter), and anterior-posterior (maximum distance from the inner surface of the anterior table to the inner surface of the posterior table) planes (Figure 2). Measurements categorized as '0' due to unpneumatized sinuses were excluded from consideration.

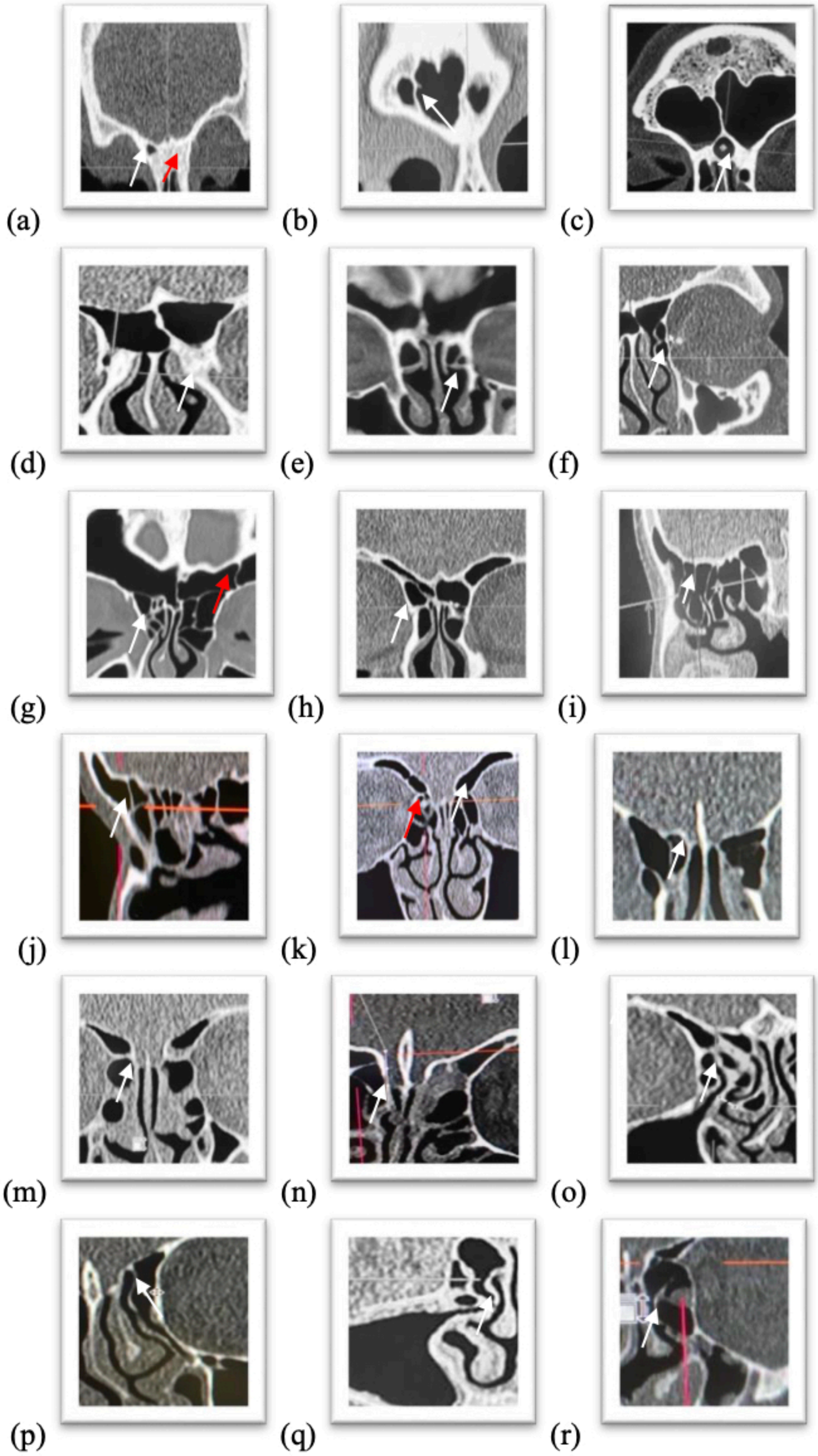

Figure 1. Radiological variations seen in our study (a) Partially pneumatized frontal sinus in right (white arrow) and unpneumatized frontal sinus in left (red arrow) (b) Multiple intersinus septa (c) Intersinus septal cell (d) Absent AN in left side (e,f) SAC (Type I frontal cell in left) (g) SAC : Type II frontal cell in right (white arrow) and Type IV frontal cell in left (red arrow) (h) SAFC (Type III frontal cell) (i) SBC (j) SBFC (k) SOEC (white arrow) with AEA in mesentery (red arrow) (l) Keros Type I OF (m) Keros Type II OF (n) Keros Type III OF (o) Mixed attachment of UP (p) UP attached to skull base (q) UP attached to middle turbinate (r) UP attached to lamina papyracea.

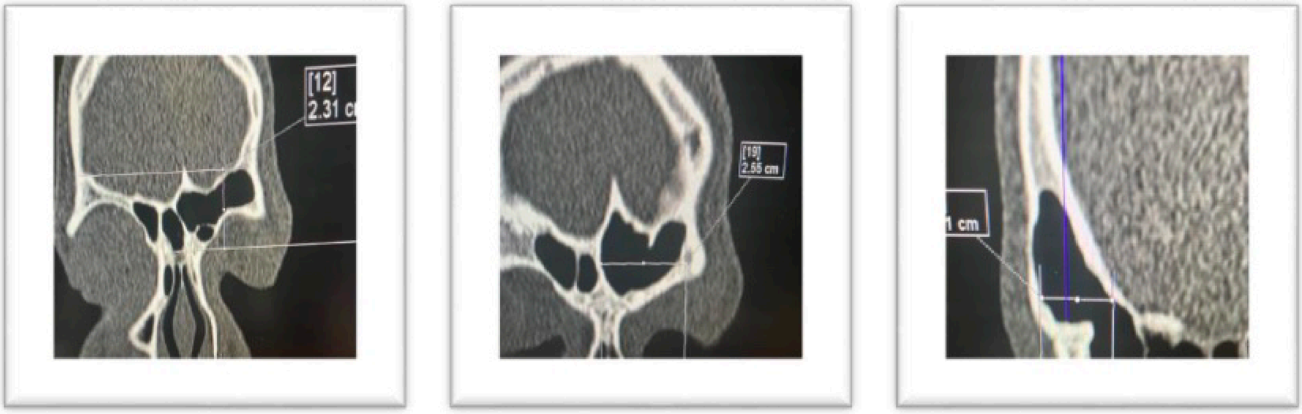

Figure 2. Measurements of frontal sinus dimensions.

Statistical analysis

Data collection utilized Google Forms as the electronic medical record sheet, subsequently uploaded into SPSS version 25 for analysis. Descriptive statistics were employed, and statistical associations and strengths were determined using Chi-squared or Fisher's exact test and Cramer's V test, respectively.

Results

Out of 183 CT scan files assessed, 34 were excluded due to obscured anatomical delineation resulting from sinus pathology. Thus, a total of 149 CT scans were analysed, encompassing 298 frontal sinuses.

The age range of our patients spanned from 15 to 96 years, with a median age of 36 years. Among these individuals, there were 77 males and 72 females, resulting in a male-to-female ratio of 1.06:1.

In our analysis, 7% of the total frontal sinuses were observed as unpneumatized, while 15.7% exhibited partial pneumatization. Notably, the majority, constituting 77.1%, displayed well-pneumatized characteristics. Five cases (3.3%) had bilateral unpneumatized sinuses. Additionally, in 22.1% of cases, multiple intersinus septa were identified. The median dimensions for right frontal sinuses were 10.2 x 11.15 x 11.7 mm, while the left frontal sinuses measured at 10.2 x 11.1 x 11.6 mm (Table 1).

The predominant attachment type of the UP was a mixed variety on both sides, representing 52.3% of all the analyzed frontal sinuses. This was followed by the attachment to the lamina papyracea (33.5%). In contrast, the attachment to the skull base accounted for 9.7%, and the least common form of attachment observed was to the middle turbinate, comprising only 5% (Table 2).

Keros type II OF was the most prevalent on both sides, observed in 63.4% of the total sinuses analysed, followed by Keros type I (32.8%). Keros type III was the least common type observed (3.6%) (Table 3). The disparity between the two sides didn't reach statistical significance.

AN was observed bilaterally, totaling 98.3%, making it the most prevalent anterior-based cell. Similarly, the prevalence of various frontal cells ranged from 2.7% to 25.2%. The most common posterior-based cell was the SBC. Following this, the SOEC was observed, with the prevalence of 26.5%. Intersinus septal cells were detected in approximately 16% of the total sinuses (Table 4).

Anterior ethmoidal artery was sought in the skull base in 71.4% and in the mesentery in 28.5% of sinuses analyzed (Table 5). Statistical analysis showed a highly significant association of AEA in the mesentery when SOEC were present. Similarly, Keros Type II and Type III OF variations also had a statistically significant association with AEA in the mesentery. However, SBC were not found to be statistically significantly associated with AEA in the mesentery (Table 6). Further analysis of the association between the degree of frontal sinus pneumatization with the upper attachment of the uncinate process and the presence of AN cells also yielded nonsignificant results (p-value > 0.05), except for the left side. Interestingly, on the left side, AN cells were notably more frequently absent in partially and unpneumatized frontal sinuses, comprising approximately 10%, compared to the 0.8% observed in well-pneumatized sinuses (Table 7).

Discussion

The frontal sinus begins its development around the fourth month of fetal life [8]. There are two proposed ways this happens: one involves the direct growth of the sinus into the frontal bone, while the other suggests that ethmoidal cells extend into the frontal bone, indirectly contributing to its development [9]. This growth continues through adolescence. By about eight years of age, the sinuses become noticeable in X-rays, reaching adequate expansion typically by 10 to 12 years of age [8,9]. Similarly, ethmoid sinus development starts around the 12th week of fetal life. It begins with the formation of the primordial bulla ethmoidalis. Over subsequent weeks, the anterior group of cells matures and reaches full development by birth. The UP

Table 1. Variations in frontal sinuses based on pneumatization, dimensions and types of intersinus septum.

Frontal Sinus	Right		Left		Total	
• Well-pneumatized	114 (76.5%)		116 (77.9%)		230 (77.1%)	
• Partially pneumatized	26 (17.4%)		21 (14.1%)		47 (15.7%)	
• Unpneumatized	9 (6%)		12 (8.1%)		21 (7%)	
Dimensions	**Right**			**Left**		
	Range (mm)		**Median (IQR)**	**Range (mm)**		**Median (IQR)**
• Vertical	0.89-29.20		10.2 (5.38)	0.72-26.2		10.2 (4.43)
• Horizontal	2.4-30.10		11.15(7.28)	2.6-34.50		11.1(8.05)
• AP	2.10-29.5		11.7 (8.03)	2.4-37.10		11.6(6.05)
Intersinus Septum						
• Single	116 (77.9%)					
• Multiple	33 (22.1%)					

Table 2. Variations in the superior attachment of the uncinate process.

Upper uncinate attachment	Right	Left	Total
Lamina papyracea	45 (30.2%)	53 (35.6%)	98 (33.5%)
Skull base	16 (10.7%)	13 (8.7%)	29 (9.7%)
Middle turbinate	6 (4%)	9 (6%)	15 (5%)
Mixed	82 (55%)	74 (49.7%)	156 (52.3%)

Table 3. Variations in OF depth based on Keros classification.

Olfactory fossa	Right	Left	Total	Fisher's exact test
Keros I	49 (32.9%)	49 (32.9%)	98 (32.8%)	0.628
Keros II	93 (62.4%)	96 (64.4%)	189 (63.4%)	
Keros III	7 (4.7%)	4 (2.7%)	11 (3.6%)	

arises from the descending segment of the first ethmoturbinal while AN develops from its proximal segment. Meanwhile, the frontal recess and ethmoidal infundibulum form from proximal and distal parts of the initial primary furrow between the first and second ethmoturbinals respectively [10]. This developmental proximity between the frontal sinus, its drainage pathway, anterior ethmoids, and the ethmoid infundibulum explains the possibility of ethmoidal pneumatization extending into the frontal sinus or around the frontal sinus drainage pathway (FSDP).

Variations in frontal sinus anatomy

Taking into account the ongoing development of the frontal sinus, we excluded cases involving individuals under 15 years old. Our study's findings on unpneumatized sinuses (3.3% bilaterally and 6.7% unilaterally) echo similar results reported elsewhere. A study, examining CT images of 325 individuals across diverse racial backgrounds: African, Asian, European, and Latin American, revealed that 3.7% lacked bilateral frontal sinuses, while 12% exhibited unilateral absence [11]. A Turkish study conducted among 1,200 individuals also supported these findings, reporting a 3% bilateral absence of the frontal sinus, albeit with a relatively low unilateral absence rate of 4.8% [5]. This disparity in pneumatization between the bilateral sinuses within an individual suggests independent pneumatization. Interestingly, among the Eskimo population, a distinct pattern has been reported, showing a notably higher prevalence of bilateral absent frontal sinuses, ranging from 25% to 48%, coupled with smaller frontal sinus dimensions [12,13]. These discrepancies indicate that external environmental factors might influence pneumatization, as evidenced by variations among populations across different geographic and climatic locations.

Our study's dimensional analysis unveiled marked differences when juxtaposed with findings from other populations. The median maximum dimensions (vertical, horizontal, and anterior-posterior) measured 10.2 x 11.15 x 11.7 mm on the right and 10.2 x 11.1 x 11.6 mm on the left. These measurements appeared notably smaller when compared to studies involving the Sri Lankan population, which reported larger average dimensions of 22.7 x 25.2 x 11.55 mm on the right and 24.2 x 27.7 x 12.03 mm on the left, based on the analysis of 300 CT scan files [14]. In the Indian population, males displayed an average height x width of 14.7 x 26.4 mm on the right side, whereas females showed 11.7 x 22.2 mm on the right and 13.5 x 23.3 mm on the left for males, and 9.6 x 19.4 mm on the left for females, among 300 radiographic files assessed [15]. Similarly, an analysis of 313 CT scan files from an American study across the population from various geographical origins reported even greater dimensions, ranging from 23.72-27.43 mm (vertical), 53.18-56.74 mm (transverse), and 11.19-12.28 mm (anterior-posterior) [11]. The relatively smaller dimensions observed in our study could stem from racial and geographical variations. Additionally, our inclusion criteria involved cases with even minimal pneumatization for dimen-

Table 4. Distribution of frontal sinus and frontal recess cells.

Frontal sinus and frontal recess cells	Right	Left	Total
Anterior			
• AN	148 (99.3%)	145 (97.3%)	293 (98.3%)
• Type I/ SAC	38 (25.5%)	37(24.8%)	75(25.12%)
• Type II/ SAC	10 (6.7%)	12 (8.1%)	22 (7.3%)
• Type III/ SAFC	21 (14.1%)	21 (14.1%)	42 (14 %)
• Type IV/ SAFC	4 (2.7%)	4 (2.7%)	8 (2.7%)
Posterior			
• SBC	106 (71.1 %)	107 (71.8 %)	213 (71.4%)
• SBFC	13 (8.7 %)	11 (7.3 %)	24 (8.05%)
• SOEC	42 (28.2%)	37 (24.8%)	79 (26.5%)
Medial			
• Intersinus/ Frontal septal cell	25 (16.8%)		

Table 5. Variations in the location of anterior ethmoidal artery (AEA).

AEA	Right	Left	Total
• Skull base	102 (68.5%)	111 (74.5%)	213 (71.4%)
• Mesentery	47 (31.5%)	38 (25.5%)	85 (28.5%)

sional analysis (as depicted in Figure 1a, right frontal sinus), excluding only completely unpneumatized sinuses. This approach might have skewed our median value downward, as the data at the higher end of the range are comparable with findings from other studies. Multiple intersinus septum were present in 22.1%, however, not much of studies were found mentioning the prevalence of multiple intersinus septa in other populations.

Variations in superior attachment of UP

The upper attachment of the UP plays a crucial role in determining the drainage pathway of the frontal sinus. Traditionally, three distinct attachments of the UP have been identified: the most common being its attachment to the lamina papyracea, guiding the frontal sinus to drain medially directly into the middle meatus, while attachments to the skull base and middle turbinate direct drainage into the ethmoid infundibulum, lateral to the uncinate process [16,17]. Stamberger and Kennedy noted that in rare instances, the superior attachment of the UP could extend as 'fingers,' forming multiple connections to the lamina papyracea, skull base, and middle turbinate [18]. Recent insights, however, suggest that a mixed attachment of the superior uncinate process is more prevalent than it was thought. Zhang et al.'s study supported this, demonstrating a mixed attachment in 57%, with a single attachment to the lamina papyracea in 33%, and attachments to the skull base and middle turbinate in subsequent frequencies amongst 21 human skulls analyzed radiographically [19]. Our findings align with these results, showcasing mixed attachments in 52.3% of total sinuses, followed by attachments to the lamina papyracea (33.5%), skull base (9.7%), and the middle turbinate (5%).

Variations in olfactory fossa

The OF plays a crucial role due to its thin lateral wall, known as the lateral lamella, which happens to be one of the most delicate bones in the skull base. This makes it particularly vulnerable to injury, given its proximity to the frontal recess. Keros developed a classification system based on the depth of the OF, identifying three types: Type I (1-3 mm deep), Type II (4-7 mm deep), and Type III (8-16 mm deep). Type II is considered the most common, accounting for 49% of cases [20]. In our study, Type II was even more prevalent, representing 63.4% of all sinuses, followed by Type I (32.8%) and Type III (3.6%). This pattern remains consistent across studies conducted in diverse populations, such as those in the Middle east (Quassim region) [21], India [22], South Africa [23] and Turkey [5]. However, there are variations in the prevalence rates: Type II ranging from 63.5% to 76.1%, Type I from 13.4% to 28.4%, and Type III from 7.9% to 10.5% within aforementioned populations. As the depth of the OF increases, so does the risk of skull base injury, particularly with Type III being regarded as the most vulnerable [24]. Furthermore, our study revealed a statistically significant association between the AEA positioned in the mesentery and Type II and Type III OF. Our result was in accordance to studies by Floreani et al. and Çomoğlu et al. showing a good correlation of increasing olfactory depth with AEA in the mesentery [25,26]. This finding hints that surgeries involving lower lying OF could also pose a risk of potential injury to the AEA. This emphasizes the critical necessity for a thorough radiological assessment of the OF and its association with the AEA before any surgical intervention.

Variations in frontal sinus and frontal recess cells

The positioning of cells within the frontal recess, extending into the frontal sinus, can notably alter the trajectory and orientation of the FSDP. The anteriorly located cells can push the FSDP posteriorly, posteromedially or medially [2]. AN cells are the most consistent anteriorly based cells with pneumatization seen in 70-90% of the population [1]. Our findings revealed a prevalence of 98.3% for AN cells, with absence noted in only 1.7% of cases (Figure 1d). Notably, a Brazilian study among 40 individuals mirrored this exact prevalence at 98.7% [27]. Moreover, other literature sources have reported closely aligned results ranging from 90% to 95.7% [4,19,28]. A notable finding in our study was a statistically significant association between poor pneumatization of the frontal sinus and the absence of AN cell. Despite being absent in very few numbers, its absence was proportionately high i.e roughly 10% (1 in 11 unpneumatized and 2 in 19 partially pneumatized frontal sinuses), compared to 0.8% (1 in 115) fully developed frontal sinuses on left side. This finding suggests the development of frontal sinus and AN may be closely related. Above the AN, there are cells that occasionally extend into the frontal sinus. Kuhn's classification assigns these cells to Types I-IV [29]. IFAC however, delineates these cells as SAC (Type I and II) for

Table 6. Association between presence of SOEC, various types of olfactory fossa, and SBC with location of AEA.

	AEA in mesentery	AEA in skull base	Chi-square/ Fisher's exact test	Cramer's V test
Right side				
SOEC Present	37	5	0.000	0.762
SOEC Absent	10	97		
Left side				
SOEC present	31	6	0.000	0.769
SOEC absent	7	105		
Right side				
Keros I	11	38		
Keros II	31	62	0.028	0.219
Keros III	5	2		
Left side				
Keros I	8	41		
Keros II	27	69	0.022	0.227
Keros III	3	1		
Right side				
SBC present	38	68	0.076	0.145
SBC absent	9	34		
Left side				
SBC present	25	81	0.399	0.069
SBC absent	13	30		

Table 7. Association between frontal sinus pneumatization with upper attachment of UP and presence of AN cells.

Frontal sinus	Attachment of UP				Chi-square test	Cramer's V test
	Lamina Papyracea	Middle turbinate	Skull Base	Mixed		
Right side						
Well pneumatized	33	5	13	63		
Partially pneumatized	8	1	2	15	0.956	0.102
Unpneumatized	4	0	1	4		
Left side						
Well pneumatized	41	6	11	58		
Partially pneumatized	9	1	1	10	0.729	0.110
Unpneumatized	3	2	1	6		
	AN present		**AN absent**			
Right side						
Well pneumatized	113		1			
Partially pneumatized	26		0		0.857	0.046
Unpneumatized	9		0			
Left side						
Well pneumatized	115		1			
Partially pneumatized	19		2		0.035	0.212
Unpneumatized	11		1			

cells located above the AN but not extending into the frontal sinus, and SAFC (Type III and IV) for those extending into the frontal sinus [2]. In our study, frontal cells were observed in 49.12% of examined sinuses. Type I was the most common (25.12%), followed by Type III (14%), Type II (7.3%), and Type IV (2.7%) in descending order of frequency. In contrast, Eweiss and Khalil, in their assessment 70 CT scan files, found Type II cells to be the most prevalent (26.4%), followed by Type I, Type III, and Type IV [30]. Conversely, another Brazilian study assessing 103 CT scan files showed nearly equal prevalence between SAC (37.86%) and SAFC (37.37%) [4]. Similarly, a Vietnamese study involving 114 individuals demonstrated a SAC prevalence of 16.3% and SAFC of 13% [28]. The complexity in management increases when these cells extend into the frontal sinus. In cases involving Type IV cells, the conventional frontal sinus approach may prove insufficient, often necessitating the Modified Lothrop's procedure [31]. The FSDP may also experience medial encroachment due to the presence of an intersinus or frontal septal cell, which displaces the FSDP laterally or posteriorly [2]. In situations akin to those seen in SAFC, managing pathology confined within these cells might necessitate intricate frontal sinus surgeries. Although traditionally regarded as an extension of ethmoidal cells, some literature proposes it as a diverticular extension of the frontal sinus into the septum [32,33]. The septal cell can exhibit mild inflammation, but in some cases, it may expand into a mucocele or manifest as Pott's puffy tumor [32]. Our study revealed the prevalence of these cells of 16.8%. However, studies across diverse populations have quoted a different prevalence rates: 10.6% [28], 30.5% [33] and 33.49% [4]. Notably, a Chinese study analyzing CT scans of 200 patients noted the presence of these cells at 45%, the highest prevalence known to us [34].

Finally, the cells situated posteriorly, such as the SBC and SBFC may contribute to the anterior displacement of the FSDP. SBCs are located above the bulla without extending into the frontal sinus and are fairly common. Our study showed its prevalence of 71.4% which aligns to the results from a Brazilian study [4]. However, a study from Vietnam assessing 114 individuals revealed a comparatively lower yet still significant prevalence of 46.2% [28]. SBFCs, also positioned above the bulla, do extend into the frontal sinus. Their prevalence remains relatively low, ranging from 8.05% in our study to figures as 4.3% [28], 17.8% [35] and 30.09% [4] in other studies. A part from an interest in these cells pertaining to the need for their clearance in frontal sinusitis, a recent study has shown the association of higher degree of pneumatization of SBC with lower position of AEA from the skull base [35]. However, our results failed to achieve statistical significance in this association. Another posteriorly based SOEC, have garnered significant attention due to their anatomical complexity and their relationship with the AEA. Primarily originating from the anterior ethmoidal cells and, at times, from the posterior ethmoidal cells, these cells protrude superolaterally over the orbit past the boundaries of the ethmoidal roof and lamina papyracea. The identification of these cells preoperatively is crucial for surgical planning, necessitating precise dissection and the removal of septum between the internal frontal ostium and these cells (36). The literature shows a wide distribution range, ranging from as low as 2.6% in Korean [37], 4.3% in Vietnamese [28], 5.4% in Chinese [38] populations, to as high as 64.6% in Caucasians [37]. Despite consistently low prevalence rates in Asian populations, our finding of a 26.5% prevalence of these cells contradicted this trend. Interestingly, our results were close to a study in the Brazilian population, which reported a prevalence of 32.03% amongst 103 individuals [4]. Owing to the ethmoid pneumatization occurring superolateral over the orbit there is high chance that AEA in cases with SOEC lie in mesentery hanging within the cell. In our study, the AEA was identified within the mesentery in 28.7% of the total sinuses examined, with 86.7% having SOEC present (37 on the right side and 31 on the left). This finding yielded a very strong statistical association. A study from India reported similar findings on assessing 50 CT scan files, indicating that the mean distance of the AEA from the skull base was 4.86 mm when SOEC were present, in contrast to only 1.50 mm when SOEC were absent [39]. Additionally, a study by Sjogren et al. also observed a strong correlation between SOEC and the presence of a low-lying AEA, further supporting these findings [40].

Limitations

While this study presents a comprehensive analysis of the frontal sinus and its drainage pathway, it's important to note that our findings are based on a limited population subset comprising individuals presenting with nose and PNS-related symptoms at our center. As a result, the frontal sinus anatomy observed may not be fully representative of the broader Nepalese population. Nepal, characterized by diverse geographical backgrounds and racial demographics, necessitates subgroup analysis, which, in our case, was challenging due to limited available data and insufficient records containing information on ethnicity. Additionally, the consideration of partially developed sinuses for dimensional analysis has potentially influenced and skewed our data. Furthermore, it's important to note that this study primarily focuses on anatomical classification without delving into the impact of such anatomy on sinus-related processes. Future research could explore this avenue, investigating the implications of anatomical variations on frontal sinus pathology. Examining how these anatomical nuances affect sinus-related processes could provide valuable insights for further studies.

Conclusions

Investigating frontal sinus anatomy within the Nepalese population unveiled notable distinctions. While generally well-developed, these sinuses exhibited comparatively smaller dimensions in contrast to other ethnic groups. Upper attachment of UP was predominantly mixed type and Type II OF was the commonest. Moreover, the anteriorly situated AN cells remained consistently prevalent, while SBC emerged as the most frequent posteriorly located cells. Also, we found that with increasing depth of OF (Type II and III) and the presence of SOEC, there is high likelihood that AEA could be encountered in mesentery.

List of abbreviations

AEA: Anterior ethmoidal artery; AN: Agger nasi; DICOM: Digital Imaging and Communications in Medicine; FSDP: Frontal sinus drainage pathway; LP: Lamina papyracea; SAC: Supra agger cell; SAFC: Supra agger frontal cells; SBC: Supra bulla cell; SBFC: Supra bulla frontal cell; SOEC: Supra orbital ethmoidal cells; OF: Olfactory Fossa; UP: Uncinate process.

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Authorship contribution

Conceptualization: BRG, BP; Data Curation: BRG, URA, PP, KRB; Methodology: BRG, Formal analysis: BRG, BP, NMT; Writing-original draft: BRG, PP; Review and editing: BRG, PP, UG.

Ethics approval and consent to participate

The study was approved by the Institutional Review Committee [Ref: 515(6-11)E2].

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest.

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