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ORIGINAL ARTICLE

Study of frontal sinus drainage pathways and their morphometric characteristics in patients with chronic frontal sinusitis

Badanie dróg drenażowych i ich cech morfometrycznych w przewlekłym zapaleniu zatoki czołowej

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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ABSTRACT:

Introduction: The frontal sinus remains one of the most complex anatomical formations for diagnosis and surgical intervention due to its high variability and intricate architecture. Impaired drainage of the frontal sinus is a critical factor in the development of chronic rhinosinusitis (CRS), particularly chronic frontal sinusitis, which is associated with recurrent disease and severe complications.

Aim: To evaluate the morphometric parameters of the frontal sinus outflow tract (FSOT) and determine their relationship with drainage pathway variants of the frontoethmoidal region in patients with and without chronic frontal sinusitis.

Materials and methods: This analytical study was conducted at Poltava State Medical University and the Regional Clinical Hospital during 2024–2025. Computed tomography scans of 120 patients (147 sides after exclusions) were analyzed. Patients were divided into two groups: First Group (n = 42) – patients with chronic frontal sinusitis, and Second Group (n = 105) – patients without any inflammatory process. FSOT length, antero-posterior (A-P) diameter of the frontal recess and angle were measured using curved planar reformation and 3D reconstruction. Drainage pathways were classified according to Kikawada et al. (2022). Statistical analysis included a t–test with $p < 0.05$ considered significant.

Results: FSOT length did not differ significantly between groups (18.4 ±4.2 mm *vs.* 19.1 ±4.9 mm, $p > 0.05$). The A-P diameter was notably smaller in patients with CRS (2.9 ±1.9 mm *vs.* 3.8 ±2.3 mm, $p = 0.026$). The FSOT angle was also noticeably lower, indicating a more horizontal orientation (59.2 ±6.5° *vs.* 62.1 ±7.2°, $p = 0.017$). The UP-BLEB drainage pathway predominated in CRS (45.2% *vs.* 19.0%, $p < 0.001$), whereas UP-MT was more frequent in controls (55.2% *vs.* 31.0%, $p = 0.001$).

Conclusions: A reduced A-P diameter and more horizontal FSOT orientation are anatomical risk factors for developing chronic frontal sinusitis. The UP-BLEB drainage pathway is strongly associated with CRS, while UP-MT appears protective. Integrating FSOT morphometry with FSDP classification enhances preoperative planning and may reduce surgical complications and recurrences.

KEYWORDS: chronic frontal sinusitis, frontal recess configuration, frontal sinus drainage pathways, frontal sinus morphometry, frontal sinus outflow tract

STRESZCZENIE:

Wprowadzenie: Zatoka czołowa pozostaje jednym z najbardziej złożonych obszarów anatomicznych w diagnostyce i leczeniu chirurgicznym ze względu na dużą zmienność indywidualną oraz skomplikowaną budowę. Zaburzenie jej drenażu jest kluczowym czynnikiem rozwoju przewlekłego zapalenia zatok przynosowych, a szczególnie zapalenia zatoki czołowej, które wiąże się z nawrotowym przebiegiem choroby i ryzykiem ciężkich powikłań.

Cel: Ocena parametrów morfometrycznych przewodu czołowo-nosowego oraz określenie ich związku z wariantami dróg drenażowych w obrębie okolicy czołowo-sitowej u pacjentów z przewlekłym zapaleniem zatoki czołowej i bez niego.

Materiały i metody: Badanie analityczne przeprowadzono w Państwowym Uniwersytecie Medycznym w Połtawie oraz w Wojewódzkim Szpitalu Klinicznym w latach 2024–2025. Analizie poddano tomografię komputerową 120 pacjentów (147 stron po zastosowaniu kryteriów wykluczenia). Chorych podzielono na dwie grupy: grupa 1 (n = 42) – z przewlekłym zapaleniem zatoki czołowej, grupa 2 (n = 105) – bez cech zapalenia. Oceniano długość przewodu czołowo-nosowego, wymiar

przednio-tylny zachyłka czołowego oraz kąt nachylenia, wykorzystując rekonstrukcję krzywoliniową i trójwymiarową. Drogi drenażowe sklasyfikowano według Kikawady i współautorów (2022). Analiza statystyczna obejmowała test t-Studenta oraz test χ^2; za istotne przyjmowano wartości p<0,05.

Wyniki: Długość przewodu czołowo-nosowego nie różniła się istotnie między grupami (18,4 ±4,2 mm *vs.* 19,1 ±4,9 mm; p > 0,05). Wymiar przednio-tylny był istotnie mniejszy u pacjentów z przewlekłym zapaleniem zatoki czołowej (2,9 ±1,9 mm *vs.* 3,8 ±2,3 mm; p = 0,026). Kąt nachylenia przewodu również był mniejszy, co wskazuje na bardziej poziome ułożenie (59,2 ±6,5° *vs.* 62,1 ±7,2°; p = 0,017). Wariant drogi drenażowej UP–BLEB (wyrostek haczykowaty – blaszka podstawna puszki sitowej) dominował u pacjentów z zapaleniem (45,2% *vs.* 19,0%; p < 0,001), natomiast wariant UP-MT (wyrostek haczykowaty – małżowina nosowa środkowa) częściej występował w grupie kontrolnej (55,2% *vs.* 31,0%; p = 0,001).

Wnioski: Zmniejszony wymiar przednio-tylny oraz bardziej pozioma orientacja przewodu czołowo-nosowego stanowią anatomiczne czynniki ryzyka przewlekłego zapalenia zatoki czołowej. Wariant UP–BLEB wykazuje ścisły związek z tym schorzeniem, podczas gdy wariant UP-MT może mieć znaczenie ochronne. Połączenie analizy morfometrii przewodu czołowo-nosowego z klasyfikacją dróg drenażowych zwiększa dokładność planowania przedoperacyjnego i może ograniczyć ryzyko powikłań oraz nawrotów.

SŁOWA KLUCZOWE: drogi drenażowe zatoki czołowej, konfiguracja zatoki czołowej, morfometria zatoki czołowej, przewlekłe zapalenie zatoki czołowej, przewód odpływowy zatoki czołowej

ABBREVIATIONS

ANC – agger nasi cell
BLEB – basal lamella of ethmoidal bulla
BLMT – basal lamella of the middle turbinate
CPR – curved planar reformation
CRS – chronic rhinosinusitis
CT – computed tomography
FR – frontal recess
FS – frontal sinus
FSDP – frontal sinus drainage pathways
FSOT – frontal sinus outflow tract
IFAC – International Frontal Sinus Anatomy Classification
LP – lamina papyracea
MPR – multiplanar reconstruction
MT – middle turbinate
SAC – supra agger cell
UP – uncinate process
UPa – accessory uncinate process

INTRODUCTION

Rhinosinusitis is a highly prevalent condition affecting millions of people worldwide and remains one of the leading reasons for seeking medical care in otorhinolaryngology. Its widespread occurrence and chronic forms contribute to a substantial socioeconomic burden.

The frontal sinus (FS) remains one of the most complex anatomical formations for diagnostics and surgical intervention due to the significant individual variability of its structure and the intricate architecture of the frontoethmoidal region [1]. Impaired drainage of this sinus is a key factor in the development of chronic frontal sinusitis, which markedly reduces patients' quality of life and may lead to severe orbital and intracranial complications.

According to epidemiological research, the prevalence of chronic rhinosinusitis (CRS) worldwide is 8–11% among the adult population, and involvement of the FS is considered one of the most unfavorable variants of the disease due to the difficulty of restoring natural drainage [2]. Studies show that FS involvement is diagnosed in almost half of patients with CRS, and these cases are associated with a higher risk of recurrences and complications [2, 3].

Despite the introduction of the International Frontal Sinus Anatomy Classification (IFAC, 2016), which systematizes anatomical variants, predicting the course of frontal sinusitis and planning surgical interventions remains challenging [4]. In this context, the classification of frontal sinus drainage pathways (FSDP) proposed by Kikawada et al. (2022), which identifies five main variants, deserves attention [5, 6]. Knowledge of these variants allows for a more precise determination of drainage direction and reduces the risk of intraoperative complications.

Equally important is the study of the morphometry of the frontal recess (FR) – its length, diameter, and angle. Recent studies confirm that a narrow and steeply oriented channel is an anatomical predictor of chronic frontal sinusitis and a factor that complicates endoscopic access [7–9]. This highlights the need for a comprehensive analysis of both frontal sinus outflow tract (FSOT) morphometric parameters and drainage pathway variants to establish an individualized surgical strategy.

In recent years, there has been a growing number of studies dedicated to computed tomography-based morphometry of the FSOT and frontoethmoidal cells. This emphasizes the relevance of the topic, as the spatial parameters of the FR have a direct impact on drainage pathway formation and the risk of chronic frontal sinusitis [10, 12–18].

Thus, the integration of morphometric data and drainage pathway classification forms a new concept for predicting the course of chronic frontal sinusitis and optimizing preoperative planning.

AIM

To evaluate the morphometric parameters of the frontal sinus outflow tract and to determine their relationship with the variants of

drainage pathways in the frontoethmoidal region in patients with and without chronic frontal sinusitis.

MATERIALS AND METHODS

The study was carried out at the Department of Otorhinolaryngology, Poltava State Medical University, in close collaboration with the Otorhinolaryngology Department of M.V. Sklifosovsky Poltava Regional Clinical Hospital. The study period spanned 2024–2025. The material consisted of CT scans of the paranasal sinuses from 120 patients (240 sides), of which 147 sides were analyzed according to the specific criteria. The exclusion criteria were: postoperative changes in the frontoethmoidal region; poor quality of tomographic slices; inability to reliably identify the FSOT and/or FSDP; and concomitant conditions that significantly altered the topography (e.g., extensive polypoid growths).

The sample was formed with the division of patients into two groups: Group 1 (n = 42 sides) – patients with tomographically confirmed chronic frontal sinusitis. Group 2 (n = 105 sides) – patients without tomographic signs of inflammatory processes in the frontal sinuses. The two groups were comparable in their basic demographic characteristics, which minimizes selection bias and ensures appropriate validity of intergroup comparisons. The relatively small size of the first group was due to strict inclusion and exclusion criteria, particularly the requirement for clearly identifiable FSOT and drainage pathways on high-quality CT images in patients with tomographically confirmed chronic frontal sinusitis.

The study was analytical in nature and was conducted using radiological diagnostic methods. The main objectives were:

1. to determine the morphometric parameters of the FSOT based on CT data;
2. to assess the prevalence of drainage pathway variants of the frontoethmoidal region according to the Kikawada classification;
3. to compare anatomical parameters between the group of patients with chronic frontal sinusitis and the control group;
4. to identify anatomical factors that may be associated with an increased risk of inflammatory processes in the frontal sinus.

CT was performed using a Siemens SOMATOM go.Up (32-slice, reconstructed to 64) with the standard clinical sinus protocol. To obtain high-resolution images of the bony structures, the slice thickness was set at 0.6 mm.

Scanning was carried out from the anterior wall of the frontal sinuses to the skull base, applying both bone and standard reconstruction algorithms. Particular attention was given to the image quality of the frontoethmoidal region, which is critically important for the adequate visualization of drainage pathways and FSOT morphometry. Subsequent analysis was performed using multiplanar reconstruction (MPR) in the coronal, sagittal, and axial planes.

For a more accurate assessment of the canal's spatial configuration, 3D reconstruction with curved planar reformation (CPR) was additionally applied, allowing the course of the canal to be traced along its central axis [11, 12].

Data processing was performed using RadiAnt DICOM Viewer (Medixant, Poland) and 3D Slicer (version 5.4.0), which enabled both standard morphometric measurements and additional visualization of complex anatomical variants. The study included two levels of analysis. The first level was the FSOT evaluated as a measurable anatomical structure, focusing on its morphometric parameters. The second one was the FSDP analyzed as anatomical variants of the frontal recess configuration according to the IFAC classification. Therefore, the FSOT was studied in a quantitative morphometric aspect, whereas the drainage pathways were assessed as qualitative anatomical variants.

The evaluation of FSOT morphometric characteristics (Fig. 1.) was carried out in several sequential stages. At the first stage, the inferior point of the FSOT was identified, corresponding to its entrance into the middle nasal meatus. Next, the superior point was determined – the transition of the frontal sinus into its drainage canal, i.e., the frontal sinus ostium. After that, a central axis (centerline) was constructed using CPR tools, which allowed a more precise representation of the canal's spatial configuration and helped to avoid errors that may occur when analyzing only standard planes.

Based on the constructed axis, the canal length was determined as the distance between the superior and inferior points of the drainage tract along the defined axis. The A-P diameter was measured from the posterior wall of the agger nasi cell (anteriorly) to the ethmoidal bulla (posteriorly). The angle of inclination, reflecting the spatial orientation of the canal, was analyzed separately and defined as the angle between the central axis of the FSOT and the horizontal plane of the hard palate. This approach allowed us to assess whether the canal was oriented more vertically or more horizontally, which has important clinical significance for predicting sinus drainage.

All measurements were performed independently by two otorhinolaryngologists experienced in interpreting CT of paranasal sinus pathology. In cases where the obtained results differed by more than 1.0 mm for linear parameters or by more than 5° in angle determination, the final value was taken as the mean of the two measurements. This minimized the influence of subjective factors and improved the reproducibility of the results.

The conceptual framework of this study was based on integrating FSOT morphometry with topographic drainage pathway analysis to determine their combined effect on frontal sinus ventilation and inflammation. The underlying hypothesis assumed that specific morphometric thresholds and drainage pathway patterns contribute in common to impaired frontal sinus drainage and predispose patients to chronic frontal sinusitis.

Tab. I.–II. were structured to present both absolute values and comparative statistics, allowing clearer interpretation of the clinical significance of the research. All figures were supplemented with uniform color coding and multiplanar projections to improve spatial correlation between anatomical structures and drainage pathways.

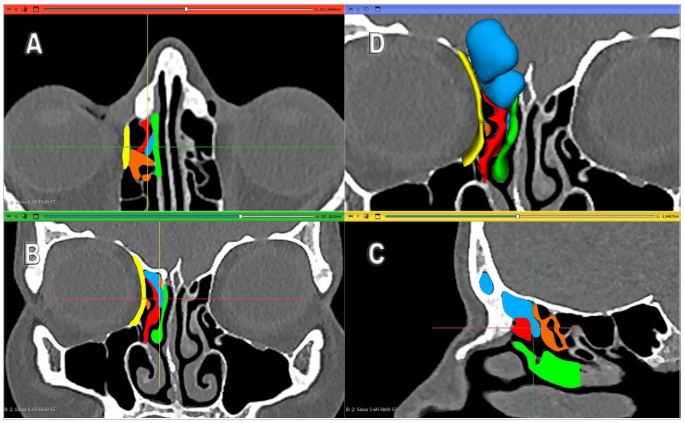


Fig. 1. UP-MT: (A) Axial MPR; (B) Coronal MPR; (C) Sagittal MPR; (D) Anterior view of 3D reconstruction; blue = frontal sinus with drainage pathway (FS + FSDP); red = uncinate process (UP); orange = basal lamella of ethmoidal bulla (BLEB); green = middle turbinate (MT); yellow = lamina papyracea (LP).

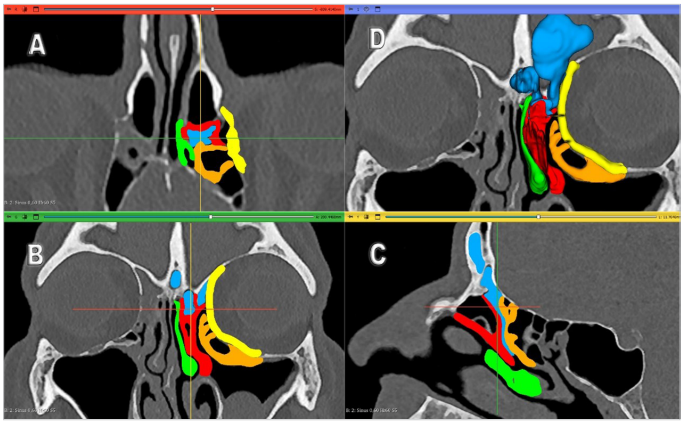


Fig. 2. UP-BLEB: (A) Axial MPR; (B) Coronal MPR; (C) Sagittal MPR; (D) Anterior view of 3D reconstruction; blue = frontal sinus with drainage pathway (FS + FSDP); red = uncinate process (UP); orange = basal lamella of ethmoidal bulla (BLEB); green = middle turbinate (MT); yellow = lamina papyracea (LP).

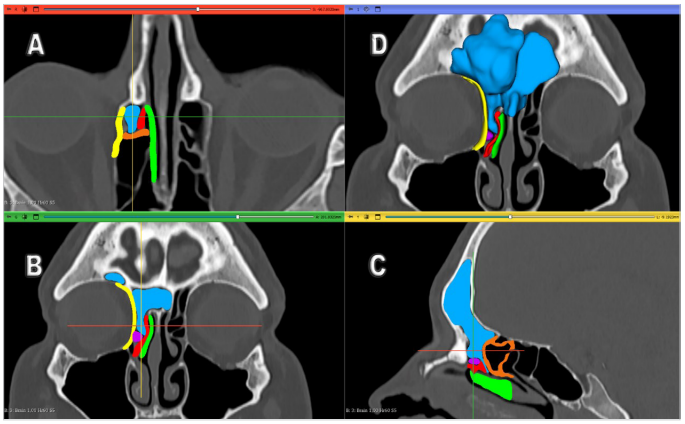


Fig. 3. UP-LP: (A) Axial MPR; (B) Coronal MPR; (C) Sagittal MPR; (D) Anterior view of 3D reconstruction; blue = frontal sinus with drainage pathway (FS + FSDP); red = uncinate process (UP); orange = basal lamella of ethmoidal bulla (BLEB); green = middle turbinate (MT); yellow = lamina papyracea (LP); purple = agger nasi cell (ANC).

Classification of drainage pathways

For each examined side, the variant of the drainage pathway in the frontoethmoidal region was additionally determined according to

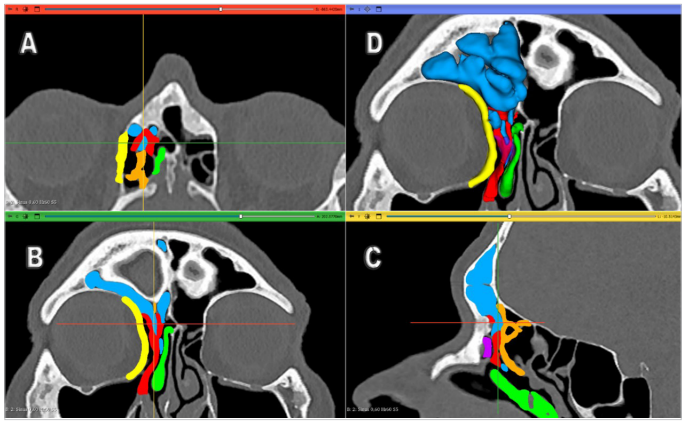


Fig. 4. UP-UPa: (A) Axial MPR; (B) Coronal MPR; (C) Sagittal MPR; (D) Anterior view of 3D reconstruction; blue = frontal sinus with drainage pathway (FS + FSDP); red = uncinate process (UP); orange = basal lamella of ethmoidal bulla (BLEB); green = middle turbinate (MT); yellow = lamina papyracea (LP); purple = agger nasi cell (ANC).

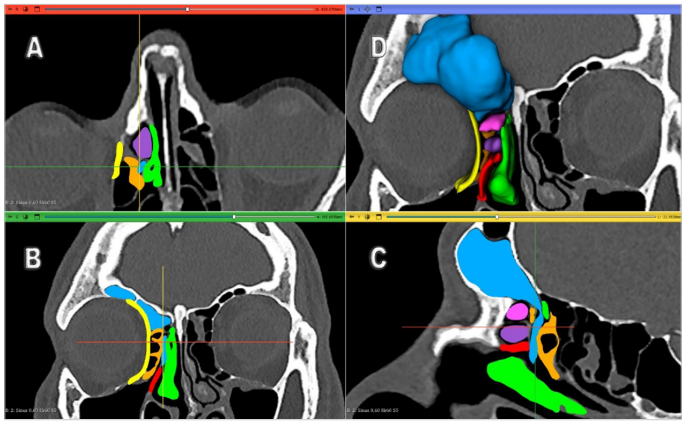


Fig. 5. BLEB-BLMT: (A) Axial MPR; (B) Coronal MPR; (C) Sagittal MPR; (D) Anterior view of 3D reconstruction; blue = frontal sinus with drainage pathway (FS + FSDP); red = uncinate process (UP); orange = basal lamella of ethmoidal bulla (BLEB); green = middle turbinate (MT); yellow = lamina papyracea (LP); purple = agger nasi cell (ANC); pink = supra agger nasi cell (SAC).

the classification by Kikawada et al. (2022) [5]. The topographic relationships of the uncinate process, lamina papyracea, ethmoidal bulla, and adjacent structures were evaluated. Depending on the anatomical correlations, five variants were distinguished: between the uncinate process and the middle turbinate (UP-MT), between the uncinate process and the basal lamella of the ethmoidal bulla (UP-BLEB), between the uncinate process and the lamina papyracea (UP-LP), between the uncinate process and the accessory uncinate process (UP-UPa), and between the basal lamella of the ethmoidal bulla and the basal lamella of the middle turbinate (BLEB-BLMT). This approach made it possible to establish the frequency of different drainage pathway variants from the FS and to assess their potential clinical significance (Fig. 1.–5.).

Statistical analysis

All obtained data were entered into an electronic database and processed using the SPSS v.23.0 software package (IBM, USA). Quantitative variables were presented as mean ±standard deviation (M ±SD). The normality of distribution was assessed using the Shapiro–Wilk test. To compare mean values between two independent groups, Student's t-test was applied; in cases of unequal

Tab. I. FSOT morphometry in the study groups.

PARAMETER	FIRST GROUP (WITH FRONTAL SINUSITIS, n = 42)	SECOND GROUP (WITHOUT FRONTAL SINUSITIS, n = 105)	p-VALUE
FSOT length, mm	18.4 ±4.2	19.1 ±4.9	p > 0.05
A-P diameter of FR, mm	2.9 ±1.9	3.8 ±2.3	p = 0.026
FSOT angle, °	59.2 ±6.5	62.1 ±7.2	p = 0.017

Tab. II. Distribution of frontal sinus drainage pathway variants by study group.

DRAINAGE PATHWAY TYPE	FIRST GROUP (WITH FRONTAL SINUSITIS, n = 42)	SECOND GROUP (WITHOUT FRONTAL SINUSITIS, n = 105)	P-VALUE
UP-MT (Fig. 1.)	13 (31.0%)	58 (55.2%)	p = 0.0078
UP-BLEB (Fig. 2.)	19 (45.2%)	20 (19.0%)	p = 0.0012
UP-LP (Fig. 3.)	5 (11.9%)	10 (9.5%)	p > 0.05
UP-UPa (Fig. 4.)	4 (9.5%)	12 (11.4%)	p > 0.05
BLEB-BLMT (Fig. 5.)	1 (2.4%)	5 (4.8%)	p > 0.05

variances, Welch's correction was used. For qualitative variables, analysis was performed using Pearson's χ^2 test; if the expected frequency in any cell was <5, Fisher's exact test was applied. For each comparison, the 95% confidence interval of the mean difference was additionally determined. The critical level of statistical significance was set at $p < 0.05$.

RESULTS

The mean age of patients in the frontal sinusitis group was 42.8 ±11.6 years (range 21–67 years), while in the control group it was 40.7 ±12.2 years (19–71 years), with no statistically significant difference ($p > 0.05$). The male-to-female ratio did not differ between the groups ($p > 0.05$).

The FSOT length in patients with frontal sinusitis ranged from 14 to 25 mm (mean 18.4 ±4.2 mm). In the control group, the length ranged from 13 to 28 mm (mean 19.1 ±4.9 mm). The intergroup difference was not statistically important ($p > 0.05$), indicating the relative stability of this parameter.

In the sinusitis group, the A-P diameter ranged from 0.8 to 7.4 mm (mean 2.9 ±1.9 mm), while in the control group it ranged from 1.1 to 9.2 mm (mean 3.8 ±2.3 mm). The observed difference was significant ($p = 0.026$), indicating narrowing of the FR lumen in patients with frontal sinusitis.

The FSOT angle in patients with frontal sinusitis ranged from 45° to 72° (mean 59.2 ±6.5°). In the control group, this parameter ranged from 47° to 80° (mean 62.1 ±7.2°). The difference between groups reached statistical significance ($p = 0.017$). This finding confirms that a more vertically oriented canal facilitates more effective gravitational drainage, whereas a horizontally deviated tract creates conditions for secretion stasis. The summarized data are presented in Tab. I.

When analyzing drainage pathway variants according to Kikawada's classification (2022), it was found that the UP-BLEB variant was most frequently observed in patients with chronic frontal sinusitis – 45.2% of cases – whereas in the control group its frequency was only 19.0% ($p < 0.001$). For comparison, the UP-MT variant predominated significantly among individuals without sinusitis (55.2% *vs.* 31.0%; $p = 0.001$). Other variants – UP-LP, UP-UPa, and BLEB--BLMT – were less common and did not show statistically significant differences. The summarized data are presented in Tab. II.

Therefore, the study results clearly demonstrate that the A-P diameter of the FR, its angle of inclination, and the drainage pathway variant are key factors determining susceptibility to chronic frontal sinusitis. The canal length has a less pronounced impact, though it may also contribute to the overall drainage functionality.

The observed differences between groups demonstrate that specific anatomical features are associated with susceptibility to chronic inflammation rather than representing incidental variations.

DISCUSSION

In our research, the length of the FSOT did not show a statistically significant difference between the groups, indicating the limited role of this parameter in the pathogenesis of chronic frontal sinusitis.

The most important factor was found to be the A-P diameter of the FR. In patients with sinusitis, it was almost 1 mm smaller than in those without inflammation (2.9 mm *vs.* 3.8 mm, $p = 0.026$). This suggests that even a slight reduction in lumen size may critically affect drainage.

The angle of inclination was statistically lower in patients with sinusitis, indicating a more horizontal course and impaired outflow. By contrast, a larger angle, corresponding to a more vertical orientation, was associated with more effective gravitational drainage. Regarding drainage pathway variants, the most critical was UP-BLEB, which occurred in 45% of sinusitis cases compared to only 19% in healthy individuals. In contrast, the UP-MT variant predominated in the group without inflammation, confirming its more "functional" role.

The obtained results allow several important conclusions to be drawn and compared with findings from other researchers. The most significant observation is that the A-P diameter of the FR represents the main anatomical factor of risk for the development of chronic frontal sinusitis. A reduction in lumen size, even by a few tenths of a millimeter, substantially affects the hydrodynamics of secretion outflow and creates conditions for its stagnation. Similar results were reported by Nair et al. (2024), who indicated that a narrow canal increases the likelihood of inflammatory processes in the FS [13]. Koliyote (2024) also emphasized that the critical factor is not so much the canal length as its narrowest segment [14].

Another important parameter was the FSOT angle. In our study, it was statistically more horizontal in patients with frontal sinusitis. This is consistent with the findings of Nguyen et al. (2025), who demonstrated that a smaller (more horizontal) canal angle impairs gravitational drainage [15]. From a practical standpoint, this feature is highly relevant for predicting the disease course and planning surgical access.

The spatial orientation of the FSOT angle also deserves special attention. Although no universal threshold value for this parameter has been established in the literature, most authors note that steeper (vertically oriented) trajectories are associated with poorer passive secretion drainage and an increased probability of stagnation. The practical value of this observation is further supported by modern tilted CT scanning techniques of the frontal region, which provide improved visualization of the drainage pathway configuration and allow tracking of its true spatial course (Hemmi et al., 2024) [10]. Our finding of significantly more horizontal FSOT angles in patients with CRS fits well within this pathophysiological context, confirming the role of spatial orientation as a clinically relevant predictor.

From the perspective of surgical tactics, combining morphometric characteristics (particularly the A-P diameter and FSOT angle) with topographic analysis based on the FSDP classification enables more individualized planning of surgical access. This approach minimizes the risk of intraoperative complications and recurrences, as emphasized both by the authors of the IFAC (Wormald et al., 2016) [4] and by researchers developing the concept of "drainage-pathway-guided" surgery (Peng et al., 2022) [16]. Thus, integrating spatial and morphometric parameters with a topographic approach may be considered a new standard for preoperative planning of treatment in patients with chronic frontal sinusitis.

The FSOT length in the analyzed cases ranged from 14 to 25 mm. The mean values were 18 mm in patients with chronic frontal sinusitis and 19 mm in the control group, respectively. Statistical analysis revealed no significant difference between the groups ($p > 0.05$). This indicates that FSOT length is a relatively stable morphometric parameter and cannot, by itself, be considered an independent risk factor for the development of frontal sinusitis.

Striking results were obtained in the analysis of drainage pathway variants. The high prevalence of the UP-BLEB variant in patients with sinusitis supports the conclusions of Kikawada et al. (2022), who emphasized that this configuration creates unfavorable conditions for drainage [5, 6]. In contrast, the UP-MT variant, which was more frequently observed in the control group, can be considered anatomically advantageous. Thus, not only morphometry but also the topography of the frontoethmoidal region determines the clinical course.

The data obtained have direct practical significance. In preoperative planning of endoscopic interventions, it is important to consider not only the FSOT diameter and angle of inclination but also the drainage pathway variant. This approach will help reduce the risk of recurrence and complications. Moreover, the results open perspectives for the development of prognostic models using multivariate analysis, which may allow determination of threshold values for anatomical parameters and more accurate prediction of disease progression.

Thus, patients with a horizontally oriented and narrowed FSOT combined with the UP-BLEB variant have a higher probability of developing CRS. These morphometric and topographic features must be taken into account during preoperative planning of surgical access to the FS.

Overall, the findings of this study enhance the understanding of anatomical factors influencing frontal sinus ventilation and drainage and may contribute to improving preoperative risk assessment in patients with chronic frontal sinusitis. The integration of morphometric and topographic parameters provides a more comprehensive approach to evaluating the frontoethmoidal region in routine clinical practice.

By combining quantitative morphometry with drainage pathway analysis, this study offers a comprehensive approach to understanding frontal sinus pathology and its clinical implications.

CONCLUSIONS

1. A narrowed A-P diameter of the frontal recess correlates with an increased risk of developing chronic frontal sinusitis.
2. A more vertical FSOT angle is associated with better drainage, whereas a smaller (more horizontal) angle is associated with impaired outflow and an increased likelihood of chronic frontal sinusitis.
3. The UP-BLEB drainage pathway variant is most frequently observed in patients with frontal sinusitis, whereas the UP-MT variant predominates in the control group.
4. The combination of FSOT morphometry and the FSDP classification enables more accurate prediction of the course of frontal sinusitis and the complexity of surgical access.

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