



# The effect of frontal sinus pneumatization on anatomic variants of paranasal sinuses

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## Abstract

**Purpose** The aim of this study is to determine the effect of frontal sinus pneumatization on various variations of paranasal sinuses on maxillofacial CT.

**Materials and methods** A total number of 120 patients (62 females, 58 males) were included in this study. Patients were divided into three groups regarding their frontal sinus pneumatization extent on paranasal sinus CT as Type 1 pneumatization (aplasia and hypoplasia), Type 2 pneumatization (medium) and Type 3 pneumatization (hyperplasia). The prevalence of various variations on paranasal sinus CT like pneumatization of upper and middle concha, presence of agger nasi, Haller and Onodi cell, maxillary sinus and sphenoid sinus hypoplasia, pneumatization of anterior clinoid process, pterygoid process and greater wing of sphenoid sinus, dehiscence and protrusion of internal carotid artery and optic nerve and vidian canal types were ascertained and compared within each group.

**Results** The prevalence of upper and middle concha pneumatization, Haller cell, pneumatization of anterior clinoid process, pterygoid process and greater wing of sphenoid and internal carotid artery dehiscence and protrusion was higher in Type 3 group compared with other groups.

**Conclusion** Excessive pneumatization of frontal sinus has various effects on paranasal sinus variations at maxillofacial CT. Surgeons dealing with endoscopic sinus surgery, maxillofacial and skull base surgery must be vigilant of association between certain variations when analyzing CT scan preoperatively for avoiding complications.

**Keywords** Paranasal sinus · Computed tomography · Frontal sinus

## Introduction

Meticulous assessment of the paranasal sinus variations on computed tomography (CT) and digital volume tomography (DVT) is imperative and vital for preoperative evaluation of endoscopic sinus and skull base surgery. Correlating the prevalence of these variations with each other may help the surgeon in predicting coexistence of various abnormalities before surgery. When evaluating paranasal sinus CT and DVT, directing the surgeon's attention to a specific variation in the presence of another may also reduce the risk of surgical complications.

Frontal sinuses are located in the squamous portion of the frontal bone posterior to supraciliary arches. These sinuses are rudimentary or absent at the time of birth reaching their full size after puberty [1]. The size of the frontal sinuses is variable and can be used for sex determination in forensic medicine. The degree of pneumatization of paranasal sinuses depends on genetic and environmental factors and how development of paranasal sinuses interfere with each other is still controversial.

In this study, we analyzed the effects of frontal sinus pneumatization on various variations on paranasal sinus CT scan. We classified frontal sinus pneumatization into three groups and compared the prevalence of these variations and correlated our findings with current literature.

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## Materials and methods

The paranasal sinus CT scan archive of our hospital, which is a tertiary referral center of the region, was reviewed for previous 6 months concerning this retrospective study. Patients aged over 16 years or over were included in this study for full paranasal sinus development and patients having alterations due to surgery, tumoral lesions, facial trauma, sinonasal polyposis or sinusitis on paranasal CT scan were excluded from the study for avoiding misinterpretation. The study was approved by the ethics committee of our own institution (No.: 222/2018).

Patients were classified into three groups regarding their frontal sinus pneumatization extent on paranasal sinus CT scan as proposed by Guerram et al. and Ozcan et al. [1, 2]. Supraorbital line (SOL), horizontal line tangent to the superior edges of both orbits, and midorbital line (MOL), vertical line of midpoint of both orbits parallel to midsagittal line, were designated on coronal sections of paranasal CT frontal sinuses and utilized for the analysis. The frontal sinus pneumatization extent of patients were classified as:

*Type 1 pneumatization (aplasia and hypoplasia)* No or minimal pneumatization under supraorbital line.

*Type 2 pneumatization (medium)* Frontal sinus limited to medial of the midorbital line.

*Type 3 pneumatization (hyperplasia)* Frontal sinus extending to lateral of the midorbital line.

In our study, for meticulous interpretation, only paranasal CT scans of patients having the same frontal sinus types on both sides were added to this study.

The following parameters were evaluated on paranasal sinus CT scan regarding frontal sinus pneumatization extent.

- a) The presence and direction of the nasal septal deviation.
- b) The prevalence of upper concha pneumatization (UCP) and middle concha pneumatization (MCP).
- c) The prevalence of ethmoidal air cell variations including agger nasi cells (ANC), Haller cell and Onodi cell.
- d) The prevalence of maxillary and sphenoid sinus aplasia/hypoplasia.
- e) The prevalence of accessory pneumatization variations of sphenoid bone, including pneumatization of the anterior clinoid process (ACP), pterygoid process (PP) and greater wing of sphenoid.
- f) Optic nerve types.
- g) Vidian canal types.
- h) The prevalence of dehiscence and protrusion of the internal carotid artery in sphenoid sinus.

Optic nerve type was assessed by the classification of Delano et al. [3] In Type I, optic nerve does not form

an indentation on sphenoid sinus wall, while in Type II, the nerve makes an indentation without contact with the posterior ethmoidal cell, whereas in Type III, the nerve courses in the sphenoid sinus while at least 50% of the nerve is surrounded by air and in Type IV, the optic nerve is adjacent to or in the Onodi cell. The classification system proposed by Lee et al. was used for assessing the relationship between Vidian canal and sphenoid bone corpus [4]. In Type 1, the Vidian canal is completely in sphenoid sinus, while in Type 2, the Vidian canal is partially embedded in sphenoid corpus and in Type 3, the Vidian canal is completely embedded in the sphenoid corpus. Maxillary sinus hypoplasia was designated as pneumatization limited medial to the midorbital line.

CT examinations were performed using a 128-slice dual-source CT (Philips Ingenuity Core, Netherlands) with Picture Archiving Communication Systems (PACS) (Akgun, Ankara, Turkey). The imaging parameters were kVp: 120, mAs: 10, pitch: 0.399, helical thickness: 1 mm for coronal images and 0.67 mm for axial images, and rotation time: 0.4 s.

The statistical analysis was completed using SPSS (IBM V23). Descriptive statistics were presented as median (min–max) and frequency (percent). Kruskal–Wallis analysis of variance was performed. Chi square test and Fisher's exact test were used for determining the difference between the groups. Statistical significance was set at  $p < 0.05$ .

## Results

The patients were divided into three groups according to their frontal sinus pneumatization (FSP) type and 40 patients for each group were chosen among the patients fulfilling the inclusion criteria of our study (Figs. 1, 2, 3, 4). It should be emphasized only patients having the same type of frontal sinus on both sides were included in the study. The median ages and gender distribution of the three groups at the time of CT scan are presented at Tables 1 and 2. There was no statistically significant difference between the three groups considering patients' age ( $p = 0.222$ ). However, when we analyzed the gender difference between three groups, we observed more females in Type 1 FSP and more males in Type 3 FSP group and the difference was statistically significant ( $p = 0.012$ ).

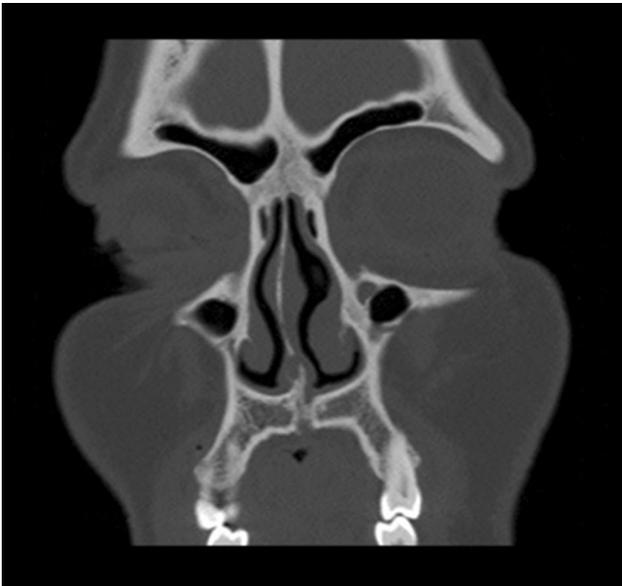
The prevalence of the anatomical variants of the three FSP groups is demonstrated at Table 3. Considering the presence and direction of nasal septal deviation, there was no statistically significant difference between three groups, ( $p = 0.785$ ). The prevalence of upper and middle concha pneumatization in three FSP groups was also analyzed in this study. Type 1 FSP group had the lowest and Type 3 group had the highest pneumatization rate of both



**Fig. 1** Paranasal CT image of Type 1 frontal sinus pneumatization (FSP) on coronal plane



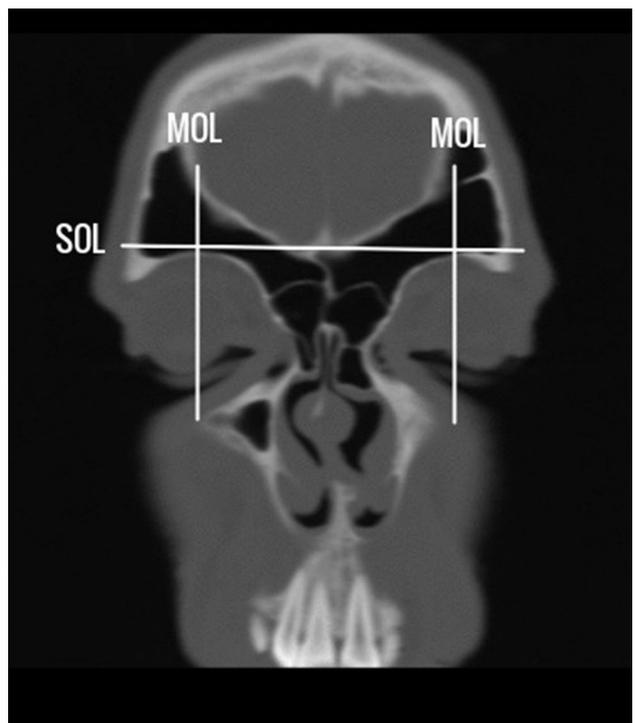
**Fig. 3** Paranasal CT image of Type 3 frontal sinus pneumatization (FSP) on coronal plane



**Fig. 2** Paranasal CT image of Type 2 frontal sinus pneumatization (FSP) on coronal plane

upper and middle concha and the difference between three groups was statistically significant ( $p=0.001$  and  $p=0.011$ , respectively).

We evaluated and compared the prevalence of ethmoidal air cell variations in three FSP groups. Although Type 3 had the highest and Type 1 FSP group had the lowest agger nasi prevalence, the difference was not statistically



**Fig. 4** Paranasal CT image of Type 3 frontal sinus pneumatization (FSP) on coronal plane demonstrating supraorbital line (SOL) and midorbital line (MOL)

**Table 1** The median ages of the patients included in three frontal sinus pneumatization (FSP) groups

Frontal sinus pneumatization	Median (min–max)	<i>p</i>
Type 1	29.5 (16–60)	0.222
Type 2	33 (16–73)	
Type 3	35.5 (16–64)	
Total	34 (16–73)	

**Table 2** The gender distribution of patients included in three frontal sinus pneumatization (FSP) groups

Frontal sinus pneumatization	Female	Male	<i>p</i>
Type 1	28 (70)	12 (30) <sup>a</sup>	<b>0.012</b>
Type 2	19 (47.5)	21 (52.5)	
Type 3	15 (37.5)	25 (62.5) <sup>a</sup>	
Total	62 (51.7)	58 (48.3)	

Bold italic value indicates statistical significance

<sup>a</sup>Statistically significant difference cells

significant, ( $p=0.080$ ). Haller cell prevalence was highest in Type 3 and lowest in Type 2 FSP group, and the difference between three groups was statistically significant, ( $p=0.010$ ). We also assessed the difference of Onodi cell prevalence between the FSP groups and there was no significant difference between them.

In this study, the prevalence of maxillary sinus aplasia/hypoplasia was analyzed and the difference between three groups was not statistically significant. Likewise, the prevalence of sphenoid sinus aplasia/hypoplasia in three FSP groups was assessed, and although Type 1 had the highest and Type 3 group had the lowest sphenoid sinus aplasia/hypoplasia rate, the difference between the groups was not statistically significant ( $p=0.056$ ).

When we analyzed the prevalence of anterior clinoid process pneumatization (ACPP), we observed Type 3 had highest pneumatization prevalence and the difference between three groups was statistically significant ( $p<0.001$ ). We would also like to remark that 17 of the 25 ACP pneumatization cases in Type 3 FSP group were bilateral, higher than Type 1 and 2 groups (Table 4).

The prevalence of pterygoid process pneumatization (PPP), greater wing of sphenoid sinus pneumatization (GWP) and their coexistence were also evaluated in this study (Fig. 5). Type 3 FSP group had the highest and Type 1 had the lowest pneumatization prevalence in both and the difference between three FSP groups was statistically significant (Table 3) ( $p=0.006$  and  $p<0.001$ , respectively).

The difference in prevalence of optic nerve and vidian canal types between three FSP groups was assessed in this study. Type 1 optic nerve was most frequent in Type 1 FSP group and least frequent in Type 3 FSP group and in contrast, type 4 optic nerve was most frequent in Type 3 FSP group and least frequent in Type 1 FSP group. The difference between three FSP was statistically significant considering optic nerve types ( $p<0.001$ ). In addition, type 1 vidian canal was most frequent in Type 3 FSP group and least frequent in Type 1 FSP group, Type 3 vidian canal was most frequent in Type 1 FSP group and least frequent in Type 3 FSP group and the difference between these FSP groups was significant ( $p=0.002$ ).

The prevalence of internal carotid artery dehiscence and protrusion in sphenoid sinus according to three FSP groups was also evaluated and dehiscence and protrusion was most frequent in Type 3 FSP group and least frequent in Type 1 group. The difference between three FSP groups was found to be statistically significant by Chi-squared test ( $p=0.001$ ).

## Discussion

In this study, the authors analyzed the effect of frontal sinus pneumatization on various paranasal sinus CT scan parameters retrospectively. Frontal sinus pneumatization was classified into three groups consisting of 40 patients for solid evaluation. The difference between median ages of the groups was not statistically significant. (Table 1) However, the difference regarding gender distribution was significant with frontal sinus aplasia and hypoplasia more prevalent in females and hyperplasia more frequent in males (Table 2). In literature, the larger size of the frontal sinus in males is implied in many studies and this feature is even used to determine for gender identification in forensic medicine [5–7].

In this study, there was statistically significant difference between three groups considering upper and middle concha pneumatization and Haller cell presence. Type 3 FSP group had the most and Type 1 FSP had the least upper and middle concha pneumatization. Our UCP rate was 30.8%, MCP rate was 44.2% and Haller cell rate was 20.8%. In literature, UCP prevalence varies from 12.2 to 46% and MCP rate varies from 13 to 53% depending on the recency and the target population of the study [8–10]. As there were no studies comparing frontal sinus pneumatization effect on conchal pneumatization, we could not compare our results with literature.

When we assessed the effect of FSP type on maxillary and sphenoid sinus development, there was no statistically significant association between FSP type and maxillary sinus hypoplasia, however, the correlation between FSP type and sphenoid sinus hypoplasia was close to statistical

**Table 3** The prevalence of paranasal sinus CT variations according to frontal sinus pneumatization (FSP) groups

	Frontal Type 1 (n = 40)	Frontal Type 2 (n = 40)	Frontal Type 3 (n = 40)	Total (n = 120)	p
Nasal septal deviation					
Absent	24 (60)	25 (62.5)	27 (67.5)	76 (63.3)	0.785
Right	8 (20)	6 (15)	8 (20)	22 (18.3)	
Left	8 (20)	9 (22.5)	5 (12.5)	22 (18.3)	
Upper concha pneumatization					
Present	5 (12.5) <sup>a</sup>	12 (30)	20 (50) <sup>a</sup>	37 (30.8)	<b>0.001</b>
Absent	35 (87.5)	28 (70)	20 (50)	83 (69.2)	
Middle concha pneumatization					
Present	12 (30) <sup>a</sup>	16 (40)	25 (62.5) <sup>a</sup>	53 (44.2)	<b>0.011</b>
Absent	28 (70)	24 (60)	15 (37.5)	67 (55.8)	
Agger nasi cell					
Present	34 (85)	38 (95)	39 (97.5)	111 (92.5)	0.080
Absent	6 (15)	2 (5)	1 (2.5)	9 (7.5)	
Haller cell					
Present	8 (20)	3 (7.5) <sup>a</sup>	14 (35) <sup>a</sup>	25 (20.8)	<b>0.010</b>
Absent	32 (80)	37 (92.5)	26 (65)	95 (79.2)	
Onodi cell					
Present	9 (22.5)	15 (37.5)	13 (32.5)	37 (30.8)	0.335
Absent	31 (77.5)	25 (62.5)	27 (67.5)	83 (69.2)	
Maxillary sinus hypoplasia					
Present	2 (5)	3 (7.5)	1 (2.5)	6 (5)	0.591
Absent	38 (95)	37 (92.5)	39 (97.5)	114 (95)	
Sphenoid sinus hypoplasia					
Present	5 (12.5)	2 (5)	0 (0)	7 (5.8)	0.056
Absent	35 (87.5)	38 (95)	40 (100)	113 (94.2)	
ACP pneumatization					
Present	5 (12.5)	5 (12.5)	25 (62.5) <sup>a</sup>	35 (29.2)	<b>&lt; 0.001</b>
Absent	35 (87.5)	35 (87.5)	15 (37.5)	85 (70.8)	
PP pneumatization					
Present	2 (5) <sup>a</sup>	7 (17.5)	13 (32.5) <sup>a</sup>	22 (18.3)	<b>0.006</b>
Absent	38 (95)	33 (82.5)	27 (67.5)	98 (81.7)	
Greater wing pneumatization					
Present	3 (7.5) <sup>a</sup>	7 (17.5)	25 (62.5) <sup>a</sup>	35 (29.2)	<b>&lt; 0.001</b>
Absent	37 (92.5)	33 (82.5)	15 (37.5)	85 (70.8)	
PPP and GWP					
Present	1 (2.5) <sup>a</sup>	6 (15)	12 (30) <sup>a</sup>	19	<b>0.003</b>
Absent	39 (97.5)	34 (85)	28 (70)	101	
Optic nerve types					
Type 1	30 (75) <sup>a</sup>	19 (47.5)	5 (12.5) <sup>a</sup>	54 (45)	<b>&lt; 0.001</b>
Type 2	2 (5)	8 (20)	8 (20)	18 (15)	
Type 3	5 (12.5)	2 (5) <sup>a</sup>	15 (37.5) <sup>a</sup>	22 (18.3)	
Type 4	3 (7.5) <sup>a</sup>	11 (27.5)	12 (30)	26 (21.7)	
Vidian canal types					
Type 1	3 (7.5)	5 (12.5)	7 (17.5)	15 (12.5)	<b>0.002</b>
Type 2	13 (32.5)	14 (35)	26 (65) <sup>a</sup>	53 (44.2)	
Type 3	24 (60) <sup>a</sup>	21 (52.5)	7 (17.5)	52 (43.3)	
ICA dehiscence and protrusion					
Present	1 (2.5)	8 (20)	16 (40)	25 (20.8)	<b>0.001</b>
Absent	39 (97.5) <sup>a</sup>	32 (80)	24 (60) <sup>a</sup>	95 (79.2)	

Bold italic values indicate statistical significance

<sup>a</sup>Statistically significant difference cells

**Table 4** The prevalence of anterior clinoid process (ACP) pneumatization according to frontal sinus pneumatization (FSP) groups

	Frontal Tip 1 (n=40)	Frontal Tip 2 (n=40)	Frontal Tip 3 (n=40)	Total (n=120)	<i>p</i>
ACP pneumatization					<b><i>&lt;0.001</i></b>
Absent	35 (87.5)	35 (87.5)	15 (37.5)*	85 (70.8)	
Left	4 (10)	3 (7.5)	3 (7.5)	10 (8.3)	
Right	1 (2.5)	1 (2.5)	5 (12.5)	7 (5.8)	
Bilateral	0 (0)	1 (2.5)	17 (42.5)*	18 (15)	

Bold italic value indicates statistical significance

**Fig. 5** Paranasal CT image of a patient demonstrating both anterior clinoid process (ACP), pterygoid process (PPP) and greater wing of sphenoid (GWP) pneumatization

significance ( $p=0.591$ ,  $p=0.056$ , respectively). Maxillary sinus hypoplasia rate was 5% and sphenoid sinus hypoplasia rate was 5.8%. There were seven sphenoid sinus hypoplasia cases in our study, five of them had Type 1 FSP, two of them had Type 2 FSP and none of them had Type 3 FSP (Table 3). Ozcan et al. implied a statistically significant effect of maxillary sinus hypoplasia on frontal sinus pneumatization and marked the duo's coexistence in their study [2]. On the contrary, this study evaluated the effect of frontal sinus pneumatization on maxillary sinus development and disclosed no significant association between them.

The anterior clinoid process (ACP) is the posteromedial projection of the lesser sphenoid wing, surrounded by complex anatomy of vital structures of the skull base and has a close relationship with internal carotid artery, cavernous sinus, optic nerve and optic chiasm, oculomotor nerve and ophthalmic artery [11]. The ACP maybe pneumatized by sphenoid sinus (mostly) or ethmoid sinus or both sinuses [12]. The lesions of paraclinoid region, the region surrounding the ACP may comprise of

meningiomas, pituitary adenomas, aneurisms of carotid and ophthalmic artery and tumors of cavernous sinus and adjacent structures [11, 12]. Resection of the ACP aka anterior clinoidectomy, intradurally or extradurally, may be required for adequate exposure for microsurgical removal of these lesions. However, anterior clinoidectomy has potential risk for complications such as visual impairment, palsy or paralysis of oculomotor nerve or optic nerve, injury of the internal carotid artery and ophthalmic artery and bleeding of the cavernous sinus [11–13]. Additionally, as anterior clinoidectomy of the pneumatized ACP may cause rhinorrhea because of the opening between ACP and paranasal sinuses, the defect must be repaired by surgical intervention peroperatively [14]. In this study, the pneumatization rate of ACP was 12.5% for Type 1 FSP, 12.5% for Type 2 FSP and 62.5% for Type 3 FSP. The overall ACPP rate was 29.2%. In literature, ACPP rate varies from 6 to 35.5% depending on the year, the location of the study and involvement of optic strut pneumatization as a part of ACPP [15, 16]. In our study, PPP rate was 18.3% and GWP rate was 29.2%. Tawfik et al. reported PPP rate as 9.3% and GWP rate as 31.8% for Egyptian patients, Hewaidi et al. as 29% and 20% for Libyan patients and Lu et al. as 22% and 21.2% for Chinese patients [17–19]. In this study, Type 1 FSP had the least and Type 3 FSP had the most ACPP, PPP and GWP rate in all groups and the association between FSP type and ACP, PPP and greater wing pneumatization was highly significant. It should be also remarked that bilateral ACP was mainly a feature of Type 3 FSP. (Table 4) As this study is the first to analyze the association between FSP types and ACP, PPP and GWP rate, we could not compare our results with literature. Our study suggests for surgeons dealing with skull base and transsphenoidal surgery to be aware of excessive anterior clinoid process and lateral recess pneumatization especially in patients with frontal sinus hyperplasia for avoiding complications especially linked with rhinorrhea.

Type 1 optic nerve (45%) was the most frequent optic nerve type and Type 2 vidian canal (44.2%) was the most frequent vidian canal type in our study (Table 3). The correlation between FSP type and optic and vidian canal types

was statistically significant, as Type 1 optic nerve was most frequent in Type 1 FSP and least frequent in Type 3 FSP as expected. Additionally, Type 1 FSP had the highest and Type 3 FSP had the lowest type 3 vidian canal rate. Type 3 and Type 4 optic nerve types and Type 1 and Type 2 vidian canal types are the most vulnerable nerve types during endoscopic surgery. In literature, Type 1 optic nerve and Type 2 vidian canal is the most prevalent nerve types correlating with the results of this study [3, 4, 20]. In the cases of frontal hyperplasia, surgeons must be aware of the possibility of injuring optic and vidian nerves during interventions comprising sphenoid sinus.

Finally, we analyzed the association between FSP type and the presence of dehiscence and protrusion of the internal carotid artery in sphenoid sinus for advanced endoscopic sinus surgery. As dehiscence is usually a concomitant feature of protrusion and the main aim of this study is to compare the features of three FSP groups, the presence of dehiscence and protrusion of ICA was analyzed together for optimal evaluation. The overall ICA dehiscence and protrusion (ICADP) rate was 20.8%, it was most prevalent in Type 3 FSP (40%) and least prevalent in Type 1 FSP (2.5%) and considering ICADP, the difference between FSP types was statistically significant in this study. In current literature, the protrusion rate of ICA varies from 5.2 to 41% and the dehiscence rate varies from 1.5 to 30% [18, 21]. Our ICADP rate is in concordance with literature and it can be concluded that as the pneumatization of frontal sinus ascends, the surgeon must be cautious of the risk of injuring ICA during endoscopic surgery.

## Conclusion

In this study, we analyzed the effect of frontal sinus pneumatization type on various paranasal CT parameters. We ascertained that FSP type has statistically significant effects on presence of upper and middle concha pneumatization, Haller cells, anterior clinoid process, pterygoid process and greater wing pneumatization, internal carotid artery dehiscence and protrusion and on optic nerve and vidian canal types. Surgeons dealing with endoscopic sinus surgery, transsphenoidal surgery and skull base surgery should preoperatively interpret paranasal sinus CT scan and DVT vigilantly and cautiously especially for excessive frontal sinus pneumatization for avoiding complications such as rhinorrhea, optic nerve, vidian nerve, trochlear nerve, cavernous sinus and internal carotid artery injury.

To our knowledge, this is the first study in literature evaluating FSP type effects on paranasal CT parameters and studies with larger patient groups are needed for further evaluation.

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## Compliance with ethical standards

**Conflict of interest** All of the authors declare that they have no conflict of interest.

**Ethical standards** All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients included in the study.

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