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ORIGINAL ARTICLE

Evaluation of the relationship between sphenoid sinus morphology and area and volume by computed tomography

Mehmet Serindere[1] · Ceren Aktuna Belgin[2]

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Abstract

Objectives The aim of this study is to investigate the effect of sphenoid sinus pneumatization types, Onodi cell (OC), internal carotid artery (ICA), optic nerve (ON) on sinus volume and area on computed tomography (CT) images.

Methods The CT images of 150 patients were evaluated. Sphenoid sinus pneumatization types, OC prevalence, protrusion and dehiscence of ICA and ON, the volume and area were evaluated.

Results The sinus volume and area were statistically higher in patients with bilateral protrusion of ICA and ON then patients without protrusion of ICA and ON. The mean volume and area of sinus were 9949.4 ± 351.0 mm^3 and 4570.9 ± 1604.9 mm^2, respectively. The volume and area of sphenoid sinus did not differ significantly between groups with and without OC. The postsellar b type sphenoid sinus had the highest volume, while conchal type has the least volume.

Conclusions Bilateral protrusion and dehiscence of ICA and bilateral protrusion of ON caused a significant increase in the sphenoid sinus volume and area. The presence of ICA and ON, the pneumatization of the sinus is an anatomical structure that can affect the sinus volume and area. Before the operation, three-dimensional evaluation should be performed to determine whether these structures are bilateral/unilateral and it should be remembered that the sinus volume and area can change.

Keywords Computed tomography · Internal carotid artery · Optic nerve · Sphenoid sinus volume

Introduction

The sphenoid sinus is the most variable of the paranasal sinuses [1]. The degree and type of pneumatization varies with regard to the number and location of intra and intersinus septa, and its relationship with the neighboring surgical risk factors (II, III, IV, V, VI and Vidian nerves, Internal carotid artery (ICA) in the cavernous sinus and pituitary gland) [2]. Therefore, blindness or heavy bleeding during surgery and even minimal damage to the surrounding structures can lead to irreversible consequences [3].

The degree of pneumatization of the sinus is very important in planning surgical procedures and is generally related to the position of the posterior sinus wall relative to the sella turcica [4]. Three types of pneumatization patterns have been defined in relation to sellar turcica: sellar type (90%), presellar type (9%), and conchal type (1%) [5].

A close relationship can be seen between the sphenoid sinus and some neighboring vital structures, such as the optic nerve (ON) and ICA [6–8]. Accidental rupture of the intersphenoidal septum that attaches to the bony wall of the ICA or ON during endoscopic sinus surgery may cause injury to these structures, resulting in severe intraoperative bleeding or blindness [9].

Onodi cells (OC) are located superior and lateral to the sphenoid sinus. The prevalence of OC is reported to be 8–65.3% [10–12].

Identification of the OC enables surgeons to minimize the injury risk to surrounding structures during endoscopic sinus surgery especially, endoscopic sinus surgery to the ethmoid and sphenoid sinuses [13, 14], transsphenoidal pituitary surgery [15], basilar expansion of the sphenoidal sinus surgery [16]. There is a close relationship between OC and ON, which requires recognition of the surrounding structures during surgery to reduce the risk of injury [13, 17, 18]. Sphenoid sinus volume seems to be one of the most

✉ Mehmet Serindere
drserindere@hotmail.com

[1] Department of Radiology, Hatay Education and Research Hospital, Hatay, Turkey

[2] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Hatay Mustafa Kemal University, Hatay, Turkey

suitable parameters for estimating the range of motion during endoscopic surgery [19].

Computed tomography (CT) is a modality used to diagnose the diseases and to evaluate of injuries. It is also important to diagnose anatomical variations that have relevant implications for clinical decision making during surgical operations. CT of the paranasal sinuses can reveal a wide variety of findings associated with normal pneumatization processes within the sinus cavities and adjacent bone marrow spaces [20].

The aim of this study is to investigate the effect of sphenoid sinus pneumatization types, OC, ICA, ON on sinus volume and area on computed tomography (CT) images.

Materials and methods

This study was approved by Ethical Committee of the XXX University (decision date: 06.10.2022 number: 08) and was in accordance with the principles of the Helsinki Declaration.

Before starting the study, the smallest sample size planned to be included in the study was calculated with the computer program G*Power (3.1.9.2, Franz Faul, Universitat Kiel, Germany). As a result, the total estimated sample size was decided to be 125 patients with 80% power. Paranasal sinus CT images of patients who applied to Hatay Education and Research Hospital for any reason were selected from the database. No examination was requested for the study, and CT images requested for any reason within the indication and already available in the system were included in the study. Sphenoid sinus pathology, history of maxillofacial trauma or previous endoscopic surgery, presence of sinusitis, images of patients younger than 18 years of age and low-quality images were excluded from the study. CT images of 150 patients (58 female, 92 male) aged between 18 and 81 years (mean: 35.4 ± 15.4 years) who met the inclusion criteria were evaluated.

Philips Brilliance 64-slice CT machine (Philips Healthcare, Cleveland, OH, USA) was used for all the CT procedures taken with following parameters; 120 kV, 250 mAs, and 0.625 mm slice thickness. Each patient is placed in the supine position with the head in the gantry. Scanning was done parallel to the hard palate. After the raw images were obtained, the images were reconstructed using the high resolution reconstruction method. For the radiographic evaluation, sphenoid sinus region was performed in coronal scans on all the patients. CT images were analyzed using a 64-bit RadiAnt DICOM viewer software, version 2020.2.3 (Medixant, Poznan-Poland).

Pneumatization types were examined in 4 categories [4–6] (Fig. 1):

Conchal: Incomplete or minimal extension of the sinus.

Presellar: The posterior border of the sphenoid sinus is located in front of the anterior wall of the sell turcica.

Sellar: The sinus is located between the anterior and posterior wall of the sella.

Postsellar: The posterior wall of the sinus has passed the posterior border of the sella.

Postsellar a: Pneumatization does not pass through the posterior clinoid process.

Postsellar b: The posterior clinoid process is also included in the pneumatized region.

OC prevalence, ICA and ON protrusion and dehiscence were evaluated (Figs. 2, 3, 4). ICA and ON were classified according to their relationship with the sphenoid sinus wall [21]. The protrusion of the neurovascular structure was defined as protrusion when it was more than 50% of its circumference [22, 23]. Any disintegration of the bone

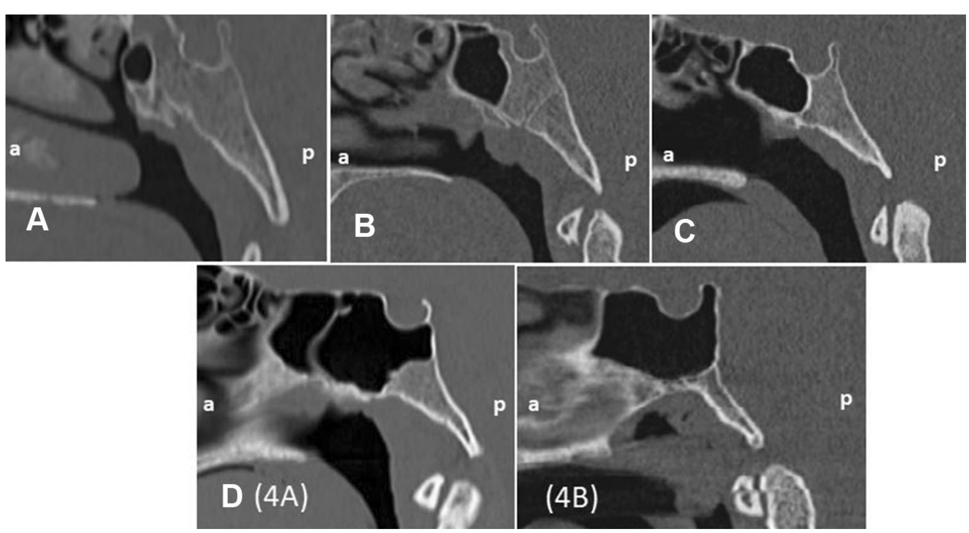

Fig. 1 Types of sphenoid sinus pneumatization in sagittal plane. **A** Conchal, **B** presellar, **C** sellar, **D** postsellar a (without air cells in posterior clinoid process) and postsellar b (with air cells in posterior clinoid process)

Fig. 2 Onodi cell (arrow): the anatomical variant located superior and lateral to the sphenoid sinus

structure between the canals and the sinus cavity was also considered as dehiscence [6].

For the calculated sinus volume and area, the threshold value was selected (minimum -1024 and maximum –526 Hounsfield Units) for marking the paranasal sinuses and airways. In this way, all airways and sinuses were marked. Then, in each axial section, the marked parts except the sphenoid sinus were deleted. Finally, it was checked that only the sphenoid sinus was marked in all three sections (sagittal, coronal and axial). After the sphenoid sinus was manually segmented from the other anatomical structures and the airway in this way, it became ready for measurement and the volume calculation button was pressed. The program automatically calculated and presented both the volume and area measurement of the marked structure to us [24]. InVesalius software (CTI, Campinas, São Paulo, Brazil) was used for volume and surface area measurements (Fig. 5).

To test intraobserver reliability, all observations for categorical variables (age, gender, pneumatization types, OC prevalence, protrusion and dehiscence of ICA and ON) were performed by one examiner (M.S). In addition, measurement analysis using continuous variables (volume and area) was performed by a researcher (C.A.B). At 2-week intervals, two observers (M.S and C.A.B) separately re-performed their own measurements to test for intraobserver reliability. Inconsistent findings were resolved by consensus. All evaluations and measurements were performed on a 15.6-inch full HD notebook monitor with resolution of 1920×1080 pixels. To ensure standardization of all evaluations and to rule out differences in image resolution, two observers used the same laptop.

Statistical analysis

Intraclass correlation coefficient (ICC) values were calculated for intraobserver reliability. ICC less than 0.40 is considered weak agreement, a value between 0.40 and 0.75 is considered fair, and a value greater than 0.75 is considered excellent [25]. P values < 0.05 were considered to indicate statistical significance. In the descriptive statistics of the data, mean, standard deviation, median minimum, maximum, frequency and ratio values were used. The distribution of variables was measured with the Kolmogorov–Smirnov test. ANOVA (Tukey test), Independent sample t test, Kruskal–Wallis, Mann–Whitney *U* test were used in the analysis of quantitative independent data. Chi-square test was used in the analysis of qualitative independent data, and Fischer test was used when the Chi-square test conditions were not met. Spearman correlation analysis was used in the correlation analysis. SPSS 28.0 program was used in the analysis.

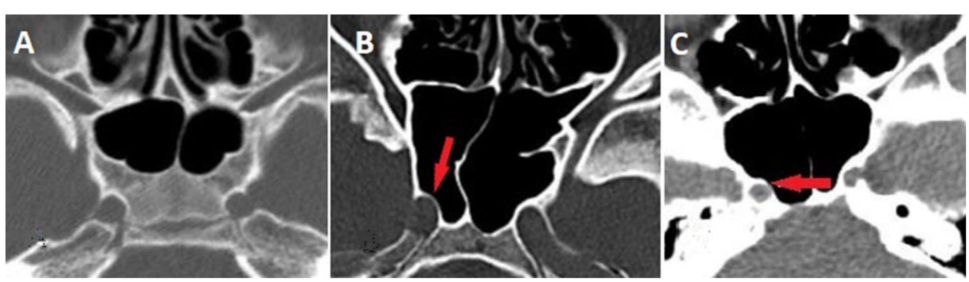

Fig. 3 Protrusion and dehiscence of internal carotid artery. **A** No protrusion and dehiscence, **B** protrusion of internal carotid artery, **C** dehiscence of internal carotid artery (arrow)

Fig. 4 Protrusion and dehiscence of optic nerve. **A** No protrusion and dehiscence, **B** protrusion of optic nerve, **C** dehiscence of optic nerve (arrow)

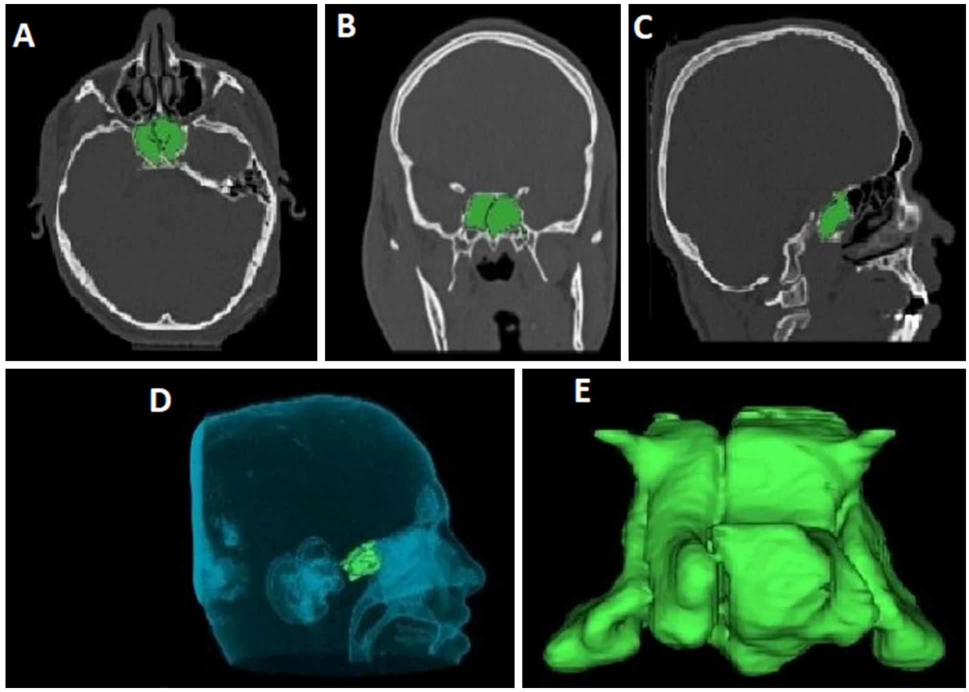

Fig. 5 Volumetric measurement and 3D reconstruction of sphenoid sinus with using InVesalius software. **A** Axial plane, **B** coronal plane, **C** sagittal plane, **D**, **E** 3D reconstruction of sphenoid sinus on sagittal plane

Results

The intraobserver reliability was estimated by Intraclass Correlations (ICC). ICC indicated excellent reliability for all observations (ICC > 0.85).

Protrusion and dehiscence of ICA

In 89 (59.3%) of 150 CTs, neither protrusion nor dehiscence was observed in the ICA. ICA protrusion was observed in a total of 61 CTs (40.7%), 23 (15.3%) were unilateral ICA protrusion and 38 (25.3%) were bilateral ICA protrusion. Out of 61 CTs (40.7%) who showed ICA dehiscence, 51 (34.0%) were unilateral ICA dehiscence, and 10 (6.7%) were bilateral ICA dehiscence. Both the rates of protrusion and dehiscence of ICA did not differ significantly between the gender ($p > 0.05$) (Table 1). However, there was no significant difference between age and the rates of protrusion and dehiscence of ICA ($p > 0.05$) (Table 2). When the effect of ICA on sinus volume and area was investigated, it was observed that sinus volume and area were statistically significantly higher in patients with bilateral protrusion of ICA compared to patients without protrusion of ICA ($p < 0.05$). Similarly, in patients with bilateral dehiscence of ICA, sinus volume and area were found to be statistically significantly higher than those without ICA dehiscence ($p < 0.05$) (Tables 3, 4). On the other hand, unilateral ICA protrusion or dehiscence did not show a statistically significant relationship with other parameters ($p > 0.05$).

Pneumatization types of sphenoid sinus

Out of the 150 sinuses, 58 (38.66%), 47 (31.33%) and 22 (33%) were postsellar a, b and sellar type, respectively. Conchal and presellar types were found in only 4 (2.66%) and 8 (5.33%) sinuses. The sphenoid sinus with postsellar b type had the highest volume, while conchal type had the least volume ($p < 0.05$).

OC prevalence

OC was found in 43 (28.7%) of 150 CTs. OC ratio did not differ significantly between the genders and age (p > 0.05) (Tables 1, 2). The volume and area of sphenoid sinus did not differ significantly between groups with and without OC ($p > 0.05$) (Tables 3, 4).

Protrusion and dehiscence of ON

ON protrusion was observed in a total of 43 CTs (28.7%), 14 (9.3%) were unilateral ON protrusion and 29 (19.3%) were bilateral ON protrusion. Out of 28 CTs (18.7%) who showed ON dehiscence, 17 (11.3%) were unilateral ON dehiscence, and 11 (7.3%) were bilateral ON dehiscence. It was found that there was no significant relationship between the protrusion or dehiscence rate of ON with both gender and age ($p > 0.05$) (Tables 1, 2). When the effect of ON on sinus volume and area was evaluated, sinus volume and area were statistically significantly higher in patients with bilateral protrusion of ON compared to patients

Table 1 Distribution of parameters by gender

	Female			Male			p
	Mean ± SD/*n*-%		Median	Mean ± SD/*n*-%		Median	
Age	39.1 ± 16.1		37.5	33.2 ± 14.6		29.5	***0.019****[m]
Volume	8896.5 ± 3058.3		8768.6	10613.2 ± 4155.9		10343.5	***0.004****[t]
Area	4123.4 ± 1230.7		4149.1	4853.0 ± 1749.4		4591.5	***0.003****[t]
Onodi cell							
Absent	43	74.1%		64	69.6%		0.546^{X^2}
Present	15	25.9%		28	30.4%		
ICA protrusion							
Absent	35	60.3%		54	58.7%		0.965^{X^2}
Unilateral	9	15.5%		14	15.2%		
Bilateral	14	24.1%		24	26.1%		
ICA dehisence							
Absent	35	60.3%		54	58.7%		0.445^{X^2}
Unilateral	21	36.2%		30	32.6%		
Bilateral	2	3.4%		8	8.7%		
ON protrusion							
Absent	47	81.0%		60	65.2%		0.105^{X^2}
Unilateral	3	5.2%		11	12.0%		
Bilateral	8	13.8%		21	22.8%		
ON dehisence							
Absent	49	84.5%		73	79.3%		0.686^{X^2}
Unilateral	5	8.6%		12	13.0%		
Bilateral	4	6.9%		7	7.6%		

[t]Independent sample *t* test, [m]Mann–Whitney *U* test, $^{X^2}$ Chi-square test

*Statistical significance ($p < 0.05$)

Min minimum, *Max* maximum, *SD* standard deviation

without ON protrusion ($p < 0.05$), on the other hand, it was determined that there was no statistically significant relationship between unilateral ON protrusion and other parameters ($p > 0.05$) (Tables 3, 4). It was observed that whether ON showed dehiscence or not did not affect the sinus volume and area statistically ($p > 0.05$).

The volume and area of sphenoid sinus

The mean volume and area of sinus were 9949.4 ± 351.0 mm^3 and 4570.9 ± 1604.9 mm^2, respectively. The sinus volume and area in females were calculated as 8896.5 ± 3058.3 mm^3 and 4123.4 ± 1230.7 mm^2, respectively, and the sinus volume and area in males as 10,613.2 ± 4155.9 mm^3 and 4853.0 ± 1749.4 mm^2, respectively (Tables 3, 4). Sinus volume and area in males were found to be significantly higher than in females ($p < 0.05$). There was a negative correlation between age and sinus volume and area ($r = -0.443$ for volume; $r = -0.380$ for area; $p = 0.000$).

Discussion

As dentomaxillofacial radiologists, we need to recognize the anatomical structures that include our field of view in full-head radiological examinations. One of these structures is the sphenoid sinus. Due to the sphenoid sinus location, it is close to anatomical structures, such as the ON and ICA. The area and volume of the sinus and the presence of OC in the sinus are important in surgeries involving this region. Confirming the morphology of the sphenoidal sinus is also important in terms of predicting the disadvantages that may arise from the treatment of sinusitis. In this respect, it is necessary to recognize the sphenoid sinus on radiographs and to know its morphology, area and volume, and to report its proximity to critical anatomical structures. In addition, an inflammation in the maxillary sinus may spread and reach the sphenoid sinus. In addition, in surgeries to the ethmoid sinus, the anatomy of this region should be carefully examined to pay attention to structures, such as the onodi cell and

Table 2 Distribution of parameters by age

	Age			p
	Min–Max	Median	Mean ± SD	
Onodi cell				
Absent	18.0–81.0	31.0	34.6 ± 15.3	0.277 [m]
Present	18.0–70.0	36.0	37.5 ± 15.6	
ICA protrusion				
Absent	18.0–74.0	34.0	35.9 ± 14.8	0.287 [K]
Unilateral	18.0–63.0	27.0	31.3 ± 14.2	
Bilateral	18.0–81.0	33.0	36.9 ± 17.3	
ICA dehisence				
Absent	18.0–74.0	34.0	35.9 ± 14.8	0.678 [K]
Unilateral	18.0–81.0	31.0	35.1 ± 16.3	
Bilateral	18.0–70.0	28.0	33.4 ± 17.3	
ON protrusion				
Absent	18.0–81.0	34.0	37.3 ± 16.0	0.103 [K]
Unilateral	18.0–60.0	33.0	32.0 ± 11.4	
Bilateral	18.0–69.0	25.0	30.4 ± 13.5	
ON dehisence				
Absent	18.0–81.0	33.0	36.1 ± 15.9	0.644 [K]
Unilateral	18.0–53.0	32.0	31.0 ± 9.9	
Bilateral	19.0–69.0	25.0	35.0 ± 17.0	

[K]Kruskal–Wallis (Mann–Whitney *U* test)

[m]Mann-Whitney U Test

Min minimum, Max maximum, *SD* standard deviation

sphenoid sinus, which are one of the closest anatomical structures. Therefore, in this study, sphenoid sinus morphology, volume and area, and its relationship OC, ICA, ON were evaluated. In addition, since no article investigating the relationship between the area and volume of the spheniod sinus and ICA, ON, OC, pneumatization types of sphenoid sinus was found in the literature, the findings were discussed under separate headings.

Protrusion and dehiscence of ICA

Movahhedian et al. [4] reported the prevalence of ICA dehiscence as 42.8%. Hewaidi et al. [23] reported that protrusion of ICA was observed in 41% of cases, of whom 22.7% were bilateral, 11.3% were right sided, and 7% were left sided. Dehiscence of ICA was observed in 30% of cases, of whom 10.3% were bilateral. Erdoğan et al. [26] reported that the prevalence of ICA protrusion and dehiscence were 45.8% and 2.5%, respectively. Li et al. [27] reported the unilateral and bilateral protrusion as 8.68% and 20.57%, respectively. Parvathy et al. [28] reported that protrusion of ICA was found in 23.3% of cases (19M; 16F), of whom 42.9% was bilateral. Dehiscence of ICA was seen in 4% of cases (2M; 4F) of whom 50% were bilateral. In the study of Anusha et al. [29], the rates of ICA dehiscence and protrusion were 3.0% and 10.0%, respectively. Fadda et al. [9] reported the protrusion and dehiscence of ICA as 26.3% and 0.4%.

Table 3 Distribution of parameters by sinus volume

	Volume (mm^3)			p
	Min–Max	Median	Mean ± SD	
Onodi cell				
Absent	2815.7–22364.5	9947.3	10272.2 ± 3898.9	0.106[t]
Present	851.3–22,419.322419.3	8957.7	9146.2 ± 3649.8	
ICA protrusion				
Absent	2815.7–20624.7	8828.3	9157.5 ± 3484.7	***0.002****[A]
Unilateral	851.3–16097.9	9838.0	10049.2 ± 3699.6	
Bilateral	4479.0–22419.3	11328.3	11743.8 ± 4228.5	
ICA dehisence				
Absent	2815.7–20624.7	8828.3	9157.5 ± 3484.7	***0.000****[A]
Unilateral	851.3–22419.3	9838.0	10564.6± 3993.6	
Bilateral	6634.9–18256.9	13700.2	13859.9 ± 3583.9	
ON protrusion				
Absent	2815.7–22419.3	8828.3	9277.8 ± 3559.6	***0.001****[A]
Unilateral	851.3–18765.6	9901.5	10202.0 ± 4355.6	
Bilateral	5943.0–20624.7	12324.5	12305.3 ± 3825.9	
ON dehisence				
Absent	2815.7–22419.3	9359.3	9726.1 ± 3772.7	0.267[A]
Unilateral	851.3–18765.6	11339.1	11317.6 ± 4478.1	
Bilateral	5943.0–16034.5	9963.5	10311.4 ± 3567.4	

[A]ANOVA, [t]*t* test

*Statistical significance ($p < 0.05$)

Min minimum, Max maximum, *SD* standard deviation

Table 4 Distribution of parameters by sinus area

	Area (mm^2)			p
	Min–Max	Median	Mean ± SD	
Onodi cell				
Absent	1637.7–8941.2	4588.1	4698.2 ± 1621.8	0.126[t]
Present	1547.3–9825.2	4073.7	4254.1 ± 1534.5	
ICA protrusion				
Absent	1637.7–8743.0	4172.9	4291.8 ± 1501.8	***0.005****[A]
Unilateral	3058.3–7212.5	4028.6	4466.0 ± 1291.3	
Bilateral	1547.3–9825.2	5271.5	5288.0 ± 1815.1	
ICA dehisence				
Absent	1637.7–8743.0	4172.9	4291.8 ± 1501.8	***0.003****[A]
Unilateral	1547.3–9825.2	4245.7	4781.5 ± 1706.5	
Bilateral	4669.6–8286.5	5882.3	5980.7 ± 1087.2	
ON protrusion				
Absent	1637.7–9825.2	4167.5	4337.0 ± 1522.6	***0.003****[A]
Unilateral	2248.2–7078.6	4088.5	4517.1 ± 1448.6	
Bilateral	1547.3–8648.9	5341.8	5459.7 ± 1710.6	
ON dehisence				
Absent	1637.7–9825.2	4206.5	4492.2 ± 1613.0	0.383[A]
Unilateral	3058.3–8648.9	4596.1	5060.2 ± 1494.6	
Bilateral	1547.3–7212.5	5004.6	4687.4 ± 1680.4	

Min minimum, *Max* maximum, *SD* standard deviation

*Statistical significance ($p < 0.05$)

[A]ANOVA, [t]*t* test

In 1.1% of the cases, the ICA was dehiscent and protruded simultaneously. In the study of Singh et al. [30], protrusion and dehiscence of ICA was observed in 28% (16% M; 12% F) and 9% (3% M; 6% F) of cases. Dündar et al. [31] reported the prevalence of ICA protrusion as 27.9%. Davoodi et al. [32] reported that the protrusion and dehiscence of ICA in 48.5% and 39% of males, 34.3% and 44.9% of females, respectively. In this study, the prevalence of ICA protrusion was found as 40.7% (15.3% unilateral, 25.3% bilateral) and ICA dehiscence was found as 40.7% (34.0% unilateral, 6.7% bilateral). The reason for this difference is thought to be the anthropological differences and the different sample numbers.

Pneumatization types of sphenoid sinus

Little is known about genetic and environmental factors that can affect the pneumatization process: some authors suggest that nasal airflow and positive air pressure in the nasopharynx can alter the paranasal sinus pneumatization as well as the nasal opening morphology. Other theories consider opportunistic expansion of the epithelium versus the structural configuration of the bone: finally, genetic and pathological factors are taken into account, although their weight in determining pneumatization still needs to be determined [33].

In some studies, it was observed that three types of sphenoid sinus pneumatization were defined as sellar, presellar and conchal type. Sellar type pneumatization was classified as the type reaching posterior to the tuberculum sella [5]. In these reviewed studies [9, 26, 27, 34, 35], the most common type was reported to be the sellar type, with a prevalence ranging from 58.7% to 93%.

Degaga et al. [36] reported the conchal, presellar, sellar and postsellar type prevalence as 2%, 25.5%, 50% and 22.5%, respectively. Movahhedian et al. [4] reported the percentages of the conchal, presellar, sellar, postsellar (a), and postsellar (b) types as 1%, 11.5%, 35.5%, 38.9%, and 13.1%, respectively. Our results with a higher prevalence of postsellar type were generally compatible with the literature. In our study, postsellar a type 38.66%, postsellar b type 31.33% and sellar type 33% were found. Conchal and presellar types were found in only 2.66% and 5.33% sinuses, respectively. Although the results are consistent with the literature, we think that these figures will vary with racial and ethnic differences.

OC prevalence

In the reviewed studies, the prevalence of OC was reported to be 8–65.3% [4, 10–12, 18, 26, 34, 35, 37]. In this study, the prevalence of OC was found as 28.7%. The difference between these rates is due to the fact that OCs are better detected in studies in which axial sections are examined, whereas OCs can be considered as posterior ethmoid cells in coronal section examinations [26].

Protrusion and dehiscence of ON

In the study of Fadda et al. [9], the protrusion and dehiscence rate of ON were 13% and 1.5%, respectively. Hewaidi et al. [23] reported the prevalence of ON protrusion and dehiscence as 35.7% and 30.7%, respectively. Parvathy et al. [28] reported the prevalence of ON protrusion as 27.3% (24M;17F), of whom 78% was bilateral, and dehiscence of ON was seen in 4% of cases (5M;1F) of whom 50% was bilateral. Lupascu et al. [34], Anusha et al. [29], Li et al. [27] and Dündar et al. [31] reported the prevalence of ON protrusion as 65%, 2.3%, 16% and 17.8%, respectively. Movahhedian et al. [4] and Anusha et al. [29] reported the prevalence of ON dehiscence as 64.5% and 7%, respectively. Singh et al. [30] reported the rate of ON dehiscence as 29% (18%M;11%F). Bilateral dehiscence of ON was more common than unilateral. Davoodi et al. [32] reported that the protrusion and dehiscence of ON in 38% and 28.5% of males, 34.9% and 46% of females, respectively. There are different rates of ON dehiscence and ON protrusion in the literature. In our study, the prevalence of ON protrusion and dehiscence were found as 28.7% (9.3% unilateral, 19.3% bilateral) and 18.7% (11.3% unilateral, 7.3% bilateral), respectively. The reason for this difference is thought to be the different ethnic origins of the researched groups and the different sample numbers.

The volume and surface area of sphenoid sinus and its relation to other parameters

Singh et al. [30] reported that the average volume and diameter were 6576.92 mm^3 and 30.48 mm, respectively. The sinus volume was larger in males than in females. Sinus volume was significantly associated with gender and sinus condition. Similarly, in our study, the mean volume and area of sinus were 9949.4 mm^3 and 4570.9 mm^2, respectively. The sinus volume and area in females were calculated as 8896.5 mm^3 and 4123.4 mm^2, respectively, and the sinus volume and area in males as 10,613.2 mm^3 and 4853.0 mm^2, respectively. In the study of Sentürk et al. [37], total sinus volume was found to be 15.07 cm^3 in cases without OC. They stated that total sinus volume was significantly lower in the cases with bilateral OC than without OC. In unilateral OC cases, a significant reduction in sinus volume was seen only for the side with OC. Similarly, Nomura et al. [38] reported that presence of OC reduces the volume. Li et al. [27] reported that the volume depended upon the protrusion degree in sinus and showed statistical differences. The volume of 11.16 cm^3, 14.2 cm^3 and 25.03 cm^3 was measured in cases without ICA protrusion, with the unilateral protrusion, and the bilateral protrusion, respectively. Gibelli et al. [39] reported that the total sinus volume was 10.005 cm^3 and 7.920 cm^3 in males and females, respectively. Presellar type showed the least sinus volume, while the retrosellar type had the highest volumes. In our study, the sphenoid sinus with postsellar b type had the highest volume, while conchal type had the least volume. Similarly, for all types, males showed higher volumes than females in this study.

In the study of Orhan et al. [40], the median sinus volumes were 4.40 cm^3 on the right and 4.20 cm^3 on the left. This study stated the mean volume and area of sinus were 9949.4 ± 351.0 mm^3 and 4570.9 ± 1604.9 mm^2, respectively. Cohen et al. [41] stated that that the volume of sphenoid sinuses decreases with age and stated sexual dimorphism in sphenoid sinus size. Oliveira et al. [42] suggests possible application for gender diagnosis based on the dimorphism of the sphenoid sinuses, although there were no statistically significant differences between males and females in their study. Similarly, in our study, it was observed that there was a decrease in sinus volume and area with increasing age.

In the literature, it is mentioned that different results are reported in the articles evaluating the morphological and volumetric parameters of the sinus separately. These different results may be due to differences in ethnic characteristics, devices and methods used. Therefore, there is a need for detailed and future studies in different populations investigating the relationship between sphenoid sinus morphological parameters and its volume. We think that this study will be a guide for future studies.

Along with the evaluation of sinus wall thickness and protrusion of surrounding noble structures, one of the most relevant information in surgery is the volume of the sphenoid sinuses [43]. However, volume is also one of the most difficult parameters to calculate [39]. In recent years, the introduction of automatic and manual segmentation in CT scans has enhanced research in this area, allowing operators to easily obtain 3D models of anatomical structures and calculate volumes and areas [44]. Although semi-automatic segmentation is faster, manual segmentation is widely used in endoscopic surgery for computer and robotic assistance [44, 45]. Szabo et al. [46] calculated the area and volume of the maxillary sinus and sphenoid sinus in both manual and semi-automatic modes and compared the results with the literature. As a result of their study, they stated that the calculations made in the manual mode are closer to the general literature knowledge. In our study, similar to Szabo et al. [46], it was preferred to measure in manual mode. Another reason for this is that in the measurements made in semi-automatic segmentation, other anatomical structures such as septa, polyps, etc. in the sinus may cause errors in the calculation of the volume and area of the sinus. Measurements were made in each section, making sure that it was completely within the sinus limits.

While there are studies in the literature that only determine the area, volume or morphology of the sphenoid sinus; To our knowledge, there is no article comparing the area and volume of the sphenoid sinus with the morphology of OC, ICA, ON on such a large number of radiographs. This is an advantage of the presented article over other studies.

In conclusion, it was observed that bilateral protrusion and dehiscence of ICA and bilateral protrusion of ON caused a significant increase in the sphenoid sinus volume and area. There was a negative correlation between age and sinus volume and area. The presence of ICA and ON, the pneumatization of the sinus is an anatomical structure that can affect the sinus volume and area. Before the pituitary and skull base surgical procedures, three-dimensional evaluation should be performed to determine whether these structures are bilateral/unilateral and it should be remembered that the sinus volume and area can change. Thus, an important step is taken in preventing complications that may occur.

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Data availability The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no confict of interest.

Ethical approval This study was approved by Ethical Committee of the Hatay Mustafa Kemal University (decision date: 06.10.2022 number: 08).

Informed consent Informed consent was obtained from all individual participants included in the study.

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