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Research Article

Evaluation of the Relationship of Sphenoid Sinus Pneumatization with Adjacent Neurovascular Structures Using Computed Tomography

Sfenoid Sinüs Pnömatizasyonunun Komşu Nörovasküler Yapılar ile İlişkisinin Bilgisayarlı Tomografi ile Değerlendirilmesi

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Keywords
sphenoid bone
sphenoid sinus
pneumatization
neurovascular structures
computed tomography

Abstract

Objective: The aim of this study is to evaluate the relationship between the pneumatization type of the sphenoid sinus (SS) and adjacent neurovascular structures in computed tomography (CT) images.

Materials and Methods: A total of 235 patients (108 women, 127 men; age range 7-85 years) who underwent paranasal sinus CT examination were evaluated retrospectively. The degrees of pneumatization of the SS in the sagittal plane were classified as Conchal, Presellar, Sellar, or Postsellar type. In the evaluation of the coronal plane, the presence and degree of lateral extension of SS pneumatization were analyzed. The evaluation included the optic nerve, internal carotid artery (ICA), vidian canal, and foramen rotundum in relation to the SS. Spearman correlation analysis was used to evaluate the relationships between SS pneumatization patterns and neurovascular structures.

Results: The most common type of pneumatization was the sellar type on both sides. In the coronal plane, the most common type of pneumatization was postrotundum type on both sides. By assessing the degree of pneumatization of the SS in the coronal plane with adjacent neurovascular structures in relation to the SS; The correlation between the protrusion of ICA into the SS from the right wall and the degree of pneumatization of the SS was found to be statistically significant.

Conclusion: Detailed classification, imaging, and definition of SS pneumatization with CT, especially revealing its relationship with neurovascular structures, can prevent significant surgical complications and offer guidance for surgical procedures.

Anahtar Kelimeler
sfenoid kemik
sfenoid sinüs
pnömatizasyon
nörovasküler yapılar
bilgisayarlı tomografi

Özet

Amaç: Bu çalışmanın amacı bilgisayarlı tomografi (BT) görüntülerinde sfenoid sinüsün (SS) pnömatizasyon tipi ile komşu nörovasküler yapılar arasındaki ilişkiyi değerlendirmektir.

Gereç ve Yöntemler: Paranazal sinüs BT incelemesi yapılan 235 hasta (108 kadın, 127 erkek; yaş aralığı 7-85 yıl) retrospektif olarak değerlendirildi. SS sagittal düzlemdeki pnömatizasyon dereceleri Konkal, Presellar, Sellar veya Postsellar tipi olarak sınıflandırıldı. Koronal düzlemin değerlendirilmesinde, SS pnömatizasyonunun lateral uzanım derecesi, lateral uzanımın varlığı ve derecesine göre analiz edildi. Değerlendirme, SS ile ilişkili olarak optik sinir, internal karotid arter (İKA), vidian kanal ve foramen rotundumu içeriyordu. SS pnömatizasyon paternleri ile nörovasküler yapılar arasındaki ilişkileri değerlendirmek için Spearman korelasyon analizi kullanıldı.

Bulgular: Her iki tarafta da en sık görülen pnömatizasyon tipi sellar tipti. Koronal planda en sık görülen pnömatizasyon tipi her iki tarafta postrotundum tipiydi. Sfenoid sinüsün koronal düzlemdeki pnömatizasyon derecesinin, sfenoid sinüs ile ilişkili olarak komşu nörovasküler yapılarla değerlendirilmesi; İKA'nın sağ duvardan SS'ye çıkıntı yapması ile SS'nin pnömatizasyon derecesi arasındaki korelasyon istatistiksel olarak anlamlı bulundu.

Sonuç: BT ile SS pnömatizasyonunun ayrıntılı sınıflandırılması, görüntülenmesi ve tanımlanması, özellikle nörovasküler yapılarla ilişkisinin ortaya konulması, önemli cerrahi komplikasyonları önleyebilir ve cerrahi işlemler için yol gösterici olabilir.

Introduction

The sphenoid bone comprises the body, small and large wings, pterygoid processes, and anterior and posterior clinoid processes. It is a complex bone situated at the base of the middle cranial fossa, shaping the medial wall of the orbit and a portion of the lateral skull wall. The sphenoid sinus (SS) is a paranasal sinus located in the body of the sphenoid bone

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(1). The pneumatization of the mastoid process typically occurs postnatally, reaching adult size by the age of 12 (1). The SS may demonstrate varying degrees of pneumatization, ranging from none to extensive (2). Pneumatization of the SS can extend to adjacent structures such as the clinoid processes (CP), greater sphenoid wings (GWS), and pterygoid processes. Depending on the level of sinus pneumatization, different degrees of protrusion of the internal carotid arteries (ICA), optic nerves (ON), foramen rotundum (FR), and Vidian canals (VC) into the sinus may occur, accompanied by thinning and complete disappearance of the bony structure covering these components (3).

SS is surrounded by significant neurovascular structures. The superior aspect is adjacent to the hypophyseal fossa and optic chiasm, the inferior aspect is in proximity to the nasopharynx and pterygoid canal, the lateral aspect is bordered by the cavernous sinus and therefore the ICA and the 3rd, 4th, 5th.1, 5th.2, and 7th cranial nerves, and the anterior aspect is connected to the nasal cavity. These neighboring structures underscore the importance of the SS in functional endoscopic sinus surgery (FESS) and procedures utilizing the transsphenoidal approach (4). Therefore, a meticulous preoperative assessment of pneumatization and the relationships with adjacent structures through computed tomography (CT) is crucial to identify anatomical variations in the sinus and anticipate potential surgical complications (5).

Numerous studies in the current literature discuss the various types of pneumatization of the SS (1,5). Nevertheless, research investigating the correlation between the extent of pneumatization of the SS and adjacent structures is relatively limited (3,6). The objective of this study is to assess the correlation between the pneumatization type of the SS and the neighboring neurovascular structures in CT images within the context of current literature.

Materials and Methods

Study Population: The research received approval from the İstanbul Haseki Training and Research Hospital Ethics Committee (approval no: 2019-8, 26.03.2019). 235 patients (108 women, 127 men; aged between 7 and 85 years) who had undergone paranasal sinus CT examinations between 2018 and 2019 were enrolled. The analysis was carried out retrospectively. Patients with a history of craniofacial surgery or trauma, craniofacial anomalies, tumors in the craniofacial region, any inflammatory conditions in the SS, and cases with artifacts on CT scans that rendered them unsuitable for evaluation were excluded from the study.

Imaging: The imaging process utilized a 128-detector CT device (Philips Ingenuity, Amsterdam, Netherlands). The scanning parameters were set to encompass the upper limit of the frontal sinus superiorly and the hard palate inferiorly. Contrast agents were not administered during image acquisition, and scans were performed in parallel to the hard palate in the axial plane, field of view (FOV) was adjusted to 14-25 cm, with a collimation of 0.625 mm.The peak kilovoltage (kVp) used was 120, and the tube current-time product (mAs) was set at 150. Following this, sagittal and coronal reformatted images were acquired. A sole radiologist, possessing a decade of expertise in head and neck radiology, assessed all the images.

Evaluation Parameters: The pneumatization degrees of the SS were assessed individually in the sagittal and coronal planes, on both the right and left sides.

1. The pneumatization degrees of the SS in the sagittal plane

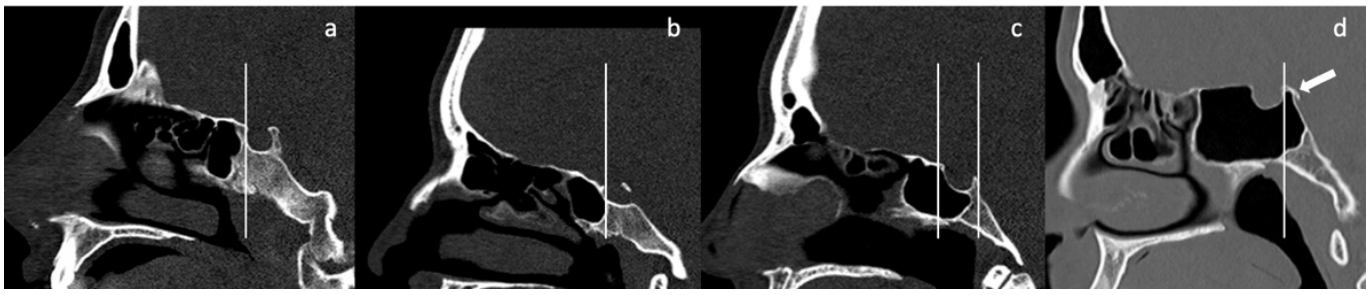

Figure 1: The pneumatization degrees of the sphenoid sinus in the sagittal plane are categorized as follows: **a)** conchal type, **b)** presellar type, **c)** sellar type, **d)** postsellar type, with the dorsum sella (white arrow).

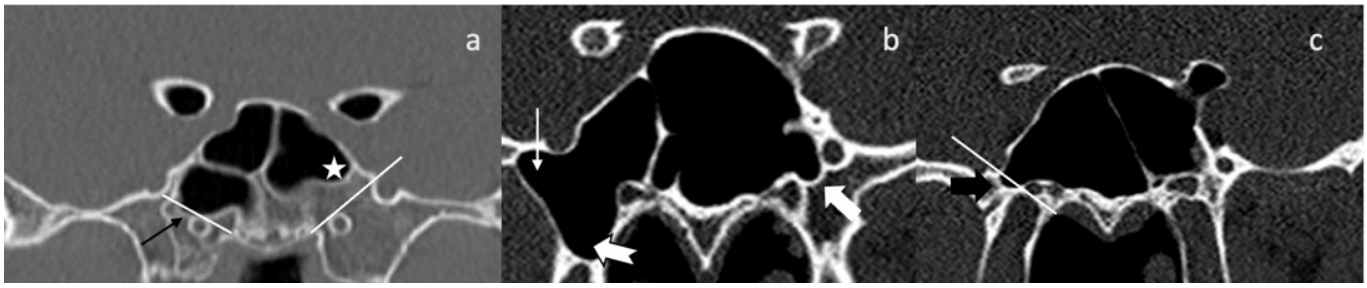

Figure 2: The pneumatization degrees of the sphenoid sinus in the coronal plane are as follows: **a)** previdian type with extension of the vidian canal (black arrow) and no extension (white asteriks), VR line (white line), **b)** Pterygoid Process (thick notched arrow) and Greater Wing of Sphenoid extension (thin arrow), vidian canal extension (white thick arrow), **c)** Post-rotundum type (black thick arrow), VR line (white line), (black thick arrow).

were assessed following the classification system proposed by Güldner et al. (7). The evaluation was conducted based on the sphenoid sinus's positioning relative to the sella turcica (Figure 1).

a. Conchal type: None or minimal pneumatization of the suprasellar region.
b. Presellar type: The SS posterior wall does not surpass the anterior border of the sella turcica; instead, it is positioned in front of it.
c. Sellar type: SS posterior wall, which is situated between the anterior and posterior borders of the sella turcica.
d. Postsellar type: SS posterior wall extends posterior to the sella turcica.

2. The assessment in the coronal plane evaluated the lateral extension of the SS pneumatization concerning the study by Wang et al. (8). The VR line, connecting the VC and the FR, served as the reference for assessing the lateral extension. The analysis of the SS pneumatization pattern was conducted by considering the presence and degree of lateral extension (Figure 2).

0. Absence of any extension
1. Previdian
2. Intercanal
3. Postrotundum
4. Extension of the pterygoid process
5. Extension of the greater wing of the sphenoid bone
6. Classified as 4+5

Pneumatization of the dorsum sella was assessed solely in the sagittal plane. The presence of pneumatization in the dorsum sella was categorized as either present or absent.

Stokovic et al.'s study (9) was cited for its investigation into the association between the neurovascular structures adjacent to the SS. The analysis of the correlation between neurovascular structures and the degree of pneumatization was conducted exclusively in the coronal plane. The assessment encompassed the ON, ICA, VC, and FR (maxillary nerve) in proximity to the SS.

For ICA

0. No protrusion
1. Protrusion
2. Dehiscence

For the optic ON, ICA, VC, and FR

0. Normal
1. Touching but no protrusion
2. Less than 25% of protrusion
3. 25-50% of protrusion
4. A protrusion ranging from 50% to 75%
5. More than 75% of protrusion
6. The condition was categorized as the presence of dehiscence.

Statistical Analysis: Analyses to determine the distribution of the patients were performed using software SPSS version 29.0 (2023, IBM Corp, USA). Age distribution analysis involved determining the minimum and maximum age values, calculating the median, and assessing the interquartile range (IQR). The frequency and percentage calculations were employed to identify the right and left sinus pneumatization patterns in the sagittal plane. The relationship between dorsum pneumatization and right and left SS pneumatization patterns in the sagittal plane was evaluated using the Chi-square test (χ^2 Test). Additionally, the right and left SS pneumatization patterns in the coronal plane were determined through frequency and percentage calculations. Spearman correlation analysis was utilized to assess the relationships between SS pneumatization patterns and neurovascular structures. Statistical significance was considered at $p < 0.05$.

Results

Among the 235 patients enrolled in the study, 108 (46%) were female, and 127 (54%) were male. The median age of all patients in the study was 34 (24-48). The median age for women was 37 (22-48), while for men, it was 24 (24-48). In the assessment of SS pneumatization, the predominant type observed in the sagittal plane was sellar pneumatization on bilateral sides, with a prevalence of 47.7% on the right and 43.8% on the left (Table 1). In the coronal plane, the predominant form of pneumatization observed was the postrotundum type bilaterally, with a prevalence of 27.7% on the right side and 29.8% on the left side (Table 2).

Dorsum sella pneumatization was observed in 15.7% of the patients enrolled in the study. The study investigated the association between the presence of pneumatization in the dorsum sella and the types of pneumatization of the SS in the sagittal plane. Postsellar pneumotization patterns were identified in 28.4% of the patients, with dorsum sella pneumotization observed on the right side in 28.4% and on the left side in 9.4% of cases. A statistically significant association was found between the presence of dorsum sella pneumotization and the extent of SS pneumotization on both sides (right: $p = 0.010$, left: $p < 0.001$; chi-square test) (Table 3 and 4).

Table 1: Types of pneumatization of the right and left sphenoid sinüs in the sagittal plane

	Right sphenoid sinus pneumatization		Left sphenoid sinus pneumatization	
	n	%	n	%
Conchal type	10	4.3	3	1.3
Presellar type	46	19.6	64	27.2
Sellar type	112	47.7	103	43.8
Postsellar type	67	28.5	65	27.7

Table 2: Types of right and left pneumatization of the sphenoid sinus in the coronal plane

	Right sphenoid sinus pneumatization		Left sphenoid sinus pneumatization	
	n	%	n	%
None	48	20.4	43	18.3
Previdian type	42	17.9	42	17.9
Intercanal type	55	23.4	53	22.6
Postrotundum	65	27.7	70	29.8
GWS	2	0.9	4	1.7
PP+GWS	23	9.8	23	9.8

GWS: *Greater Wing of Sphenoid,* ***PP:*** *Pterygoid Process*

Table 3: Relationship between dorsum sella pneumatization and right sphenoid sinüs pneumatization

		Right sphenoid sinus pneumatization				
Dorsum sella pneumatization		**Conchal**	**Presellar**	**Sellar**	**Postsellar**	**Total**
None	n	9	42	99	48	198
	%	90.0	91.3	88.4	71.6	84.3
Yes	n	1	4	13	19	37
	%	10.0	8.7	11.6	28.4	15.7
Total	n	10	46	112	67	235
	%	100.0	100.0	100.0	100.0	100.0

Table 4: Relationship between dorsum sella pneumatization and left sphenoid sinüs pneumatization

		Left sphenoid sinus pneumatization				
Dorsum sella pneumatization		**Conchal**	**Presellar**	**Sellar**	**Postsellar**	**Total**
None	n	3	53	99	43	198
	%	100.0	82.8	96.1	66.2	84.3
Yes	n	0	11	4	22	37
	%	0.0	17.2	3.1	33.8	15.7
Total	n	3	64	103	65	235
	%	100.0	100.0	100.0	100.0	100.0

A correlation analysis was conducted to examine the relationships between the anatomical course and position of the adjacent neurovascular structures in relation to the SS by assessing the degree of pneumatization of the SS in the coronal plane. This analysis included factors such as contact with the wall, degrees of protrusion into the sinus, and the presence of dehiscence.

The statistical analysis revealed a significant correlation between ICA and the SS on the right side. A moderate positive correlation was observed on the right side, while a weak positive correlation was noted on the left side (right ICA: $p < .001$, $r = 0.403$; left ICA: $p < .001$, $r = 0.252$). A weak positive correlation was observed between the ON and the SS on both sides. This correlation was determined to be statistically significant (right ON: $p < .001$, $r = 0.252$; left ON: $p < .001$, $r = 0.291$). For the VC, a strong positive correlation was observed on both the right and left vocal cords, which was determined to be statistically significant (right VC: $p < .001$, $r = 0.763$; left VC: $p < .001$, $r = 0.675$). A moderate positive relationship was identified on both sides for the FR and was determined to be statistically significant (right FR: $p < .001$, $r = 0.541$; left FR: $p < .001$, $r = 0.481$).

Discussion

The assessment of SS pneumatization is commonly carried out using imaging modalities such as CT scans or Magnetic Resonance Imaging (MRI). These imaging techniques provide detailed information on the size, shape, and degree of pneumatization. The use of preoperative CT scans allows radiologists to proactively detect any anatomical irregularities that could increase the risk of surgical complications in patients (10). In children, MRI can be a suitable alternative (11). It is essential to comprehend the clinical significance of different levels of pneumatization when planning surgical procedures involving the sphenoid sinus and adjacent structures. Variations in pneumatization can impact the choice of surgical techniques (12).

The evaluation of variations in the SS and the extent of pneumatization is essential due to the potential consequences of increased pneumatization on neighboring structures, leading to their protrusion into the sinus (13). Previous literature comprises studies that explore the types and degrees of pneumatization in the SS. These investigations examine various pneumatization patterns in the sphenoid sinus and their relevance for surgical preparation (13,14). Research that delves into the association between the SS and adjacent neurovascular structures suggests that the degree of SS pneumatization significantly impacts the interaction between neighboring neurovascular structures and the sinus (15,16).

In the existing literature, there is a scarcity of studies that assess the correlation between the extent of SS pneumatization and the neighboring neurovascular structures, leading to a deficiency of information for preoperative and perioperative planning (17). Thakur et al. (17) conducted a study to examine the relationship between SS pneumatization and adjacent neurovascular structures, including the FR, ON, and VC. The predominant type of pneumatization observed in the sagittal plane of the SS was identified as the sellar type, accounting for 89.5% (358 out of 400 cases). Consistent with the literature, our study also found the sellar type to be the most prevalent in the sagittal plane. Similarly, Vaezi et al. (14) reported in their study involving 102 patients that the sellar type was the most common in the sagittal plane, whereas the intercanal pneumatization was the most frequent in the coronal plane.

In the study conducted by Doubi et al. (18) involving 150 patients, the intercanal type was identified as the most prevalent in the coronal plane. Conversely, in our research, the postrotundum type pneumatization was the most frequent type observed in the coronal plane for both sides. This discrepancy is attributed to the varying sample sizes across the studies, highlighting the necessity for multicenter investigations with larger cohorts. Hardy et al. (19) categorized the presence of dorsum sella and postclinoid process pneumatization as type 4B when combined with postsellar pneumatization. Our study also examined dorsum sella pneumatization. Existing literature indicates that dorsum sella pneumatization is the predominant postsellar pneumatization type (20). Our findings revealed that dorsum sella pneumatization was predominantly linked with postsellar pneumatization type, and its correlation with the extent of pneumatization was deemed statistically significant for both sphenoid sinuses. Based on our study's outcomes, we propose that evaluating dorsum sella pneumatization as a distinct anatomical element would be more appropriate than incorporating it into the classification as type 4B. Notably, ON dehiscence or protrusion can result in severe complications in scenarios such as trauma, surgery, and SS infection.

Numerous studies in the literature have examined the prevalence of ON dehiscence and protrusion, with reported values showing significant variation (3,21). Hewaidi et al. (22) and Sagar et al. (23) identified a significant relationship

between the pneumatization of the anterior clinoid process and ON protrusion. In our study, we found a weak positive correlation between the ON and the SS on both sides, and this association was statistically significant. This finding is consistent with the results of Cho et al. (13), who explored the impact of SS pneumatization on the ON. They noted that the proximity of the ON to the SS wall and the degree of protrusion were linked to the type of sinus pneumatization.
In the context of the relationship between the internal ICA and the SS wall, a moderate positive statistical significance was observed with the degree of pneumatization on the right side of the SS, while a weakly positive statistical significance was noted with the degree of pneumatization on the left side of the SS. This finding is consistent with previous research that has explored the impact of SS pneumatization on the ICA (24,25). The anatomical correlation between the ICA and the SS is crucial for surgical planning, and this correlation was found to be statistically significant in the present study.

A statistically significant and highly positive correlation was identified between the relationship of the VC and the SS type concerning the protrusion and dehiscence of adjacent neurovascular structures. The precise positioning of the VC and the extent of pneumatization of the SS are essential factors to consider in clinical interventions (3).

Hewaidi et al. (22) conducted a study that revealed a significant correlation between the pneumatization of the greater wing of the sphenoid (GWS) and the protrusion of the FR. Similarly, our study identified a moderately positive correlation between the degree of pneumatization of the SS and the FR. This correlation was evaluated in the coronal plane bilaterally and was found to be statistically significant. It is important to highlight that some studies in the existing literature do not show a statistically significant relationship between the extent of SS pneumatization and the FR (26,27). Given that the maxillary nerve is susceptible to iatrogenic damage in cases of a protruded or dehiscent FR during surgical procedures, we recommend the implementation of multicenter studies with a larger patient cohort to further investigate this matter.

Limitations of the study include the evaluation of images by a single radiologist, which precluded the assessment of interobserver reliability. The sample size in the study is relatively small for drawing definitive conclusions, although it was larger compared to other studies in the literature. The study utilized reference articles for evaluation criteria, suggesting that the results obtained may be comparable.

Conclusion

SS pneumatization denotes the inherent progression of air cell formation within the SS, exhibiting considerable diversity among individuals and carrying clinical significance for medical and surgical interventions concerning the skull and nasal cavity. A comprehensive categorization, imaging analysis, and elucidation of SS pneumatization using CT scans, particularly highlighting its proximity to neurovascular structures, can provide valuable insights for surgical interventions. Furthermore, such assessments can substantially augment the utility of preoperative imaging reports for consulting otolaryngologists and mitigate the risk of substantial surgical complications.

Ethical Approval and Consent: The study was approved by the İstanbul Haseki Training and research Hospital Ethics Committee (approval no: 2019-8, 26.03.2019).

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