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Relationship Between the Protrusion of the Optic Nerve and Internal Carotid Artery and Sphenoid Sinus Volume

Optik Sinir ve İnternal Karotid Arter Protrüzyonu ile Sfenoid Sinüs Hacmi Arasındaki İlişki

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ABSTRACT

Objective: This study was conducted to investigate the relationship between the protrusion of the optic nerve (ON) and internal carotid artery (ICA) and sphenoid sinus volume.

Methods: A total of 142 patients (284 sphenoid sinuses) were included in the study. The study population was classified into the four groups according to ON and ICA protrusion into the sphenoid sinuses as follows: no protrusion of any structure (group 1); protrusion of ICA (group 2); protrusion of ON (group 3); and protrusion of both ICA and ON (group 4). A three-dimensional volumetric assessment of the bilateral sphenoid sinuses was performed with ITK-SNAP 3.8.0 software separately for both sides.

Results: Group 1 was the most common group and included 138 sinuses (48.6%), while group 3 was the rarest group and included 25 sinuses (8.8%). Statistically significant differences in the volume of sphenoid sinus were found between group 1 and group 2 ($p=0.002$) and group 1 and group 4 ($p<0.001$).

Conclusion: Larger sphenoid sinuses have a higher probability of ICA protrusion compared to smaller sphenoid sinuses. Although ON protrusion is considered to be rarer than ICA protrusion, it can be observed regardless of the volume of the sphenoid sinuses.

Keywords: Sphenoid sinus, optic nerve, internal carotid artery, paranasal sinus, sphenoid sinus volume, protrusion

ÖZ

Amaç: Bu çalışma, optik sinir (OS) ve internal karotid arter (İKA) protrüzyonu ile sfenoid sinüs hacmi arasındaki ilişkiyi araştırmak amacıyla yapılmıştır.

Yöntemler: Çalışmaya 142 hasta (284 sfenoid sinüs) dahil edildi. Çalışma popülasyonu, OS ve İKA'nın sfenoid sinüs içine doğru protrüzyonuna göre dört gruba ayrıldı: Grup 1; herhangi bir yapının protrüzyonu yok, grup 2; izole İKA protrüzyonu mevcut, grup 3; izole OS protrüzyonu mevcut, grup 4; hem OS hem de İKA protrüzyonu mevcut. Bilateral sfenoid sinüslerin üç boyutlu hacimsel değerlendirmesi her iki taraf için ayrı ayrı ITK-SNAP 3.8.0 programı kullanılarak hesaplandı.

Bulgular: Grup 1 en sık görülen grup olup [138 sinüs (%48,6)], grup 3 en nadir görülen grup [25 sinüs (%8,8)] olarak belirlendi. Gruplar arasında sfenoid sinüs hacmi karşılaştırılınca grup 1 ve grup 2 ($p=0,002$) ve grup 1 ve grup 4 ($p<0,001$) arasında istatistiksel olarak anlamlı bir fark saptandı.

Sonuç: Daha büyük hacimli sfenoid sinüsler, daha küçük hacimlilere kıyasla daha yüksek İKA protrüzyonu olasılığına sahiptir. OS protrüzyonu ise İKA protrüzyonundan daha nadir olarak görülmekle birlikte sfenoid sinüslerin hacminden bağımsız olarak gözlenebilmektedir.

Anahtar kelimeler: Sfenoid sinüs, optik sinir, internal karotid arter, paranazal sinüs, sfenoid sinüs hacmi, protrüzyon

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INTRODUCTION

The sphenoid sinuses (SS) are intricate anatomical formations that display substantial variations in their dimensions and structural characteristics (1). These variations can be observed within the two sides of a single individual (2). The anatomical variations of the SS become especially significant for patients who are subjected to procedures such as functional endoscopic sinus surgery or trans-sphenoidal pituitary surgery due to their close proximity to neighboring neurovascular formations, including the optic nerve (ON) and internal carotid artery (ICA) (3).

The paranasal computed tomography (CT) scan serves as an indispensable imaging technique, providing an intricate evaluation of the structural composition of the paranasal sinuses. Widespread pneumatization within the SS has the potential to cause the ON and/or ICA to protrude into the sinus space (4). In light of the potential catastrophic consequences of iatrogenic injury to these vital structures, a pre-operative radiological evaluation of the SS and the surrounding ON and ICA is essential (5).

The aim of this study is to investigate the connection between SS volume and the extension of the ON and ICA into the sinus.

METHODS

All the paranasal CT scans and clinical records of patients admitted to the Kırklareli Training and Research Hospital Otolaryngology Department between January 2020 and January 2021 were retrospectively analyzed. Patients with nasal polyposis, signs of sinusitis, craniofacial deformities, a history of maxillofacial trauma, prior sinonasal surgery, or systemic diseases that could affect the anatomical configuration of the paranasal sinuses were excluded from the study. After these exclusions, 142 patients (comprising 284 SS) were enrolled in the study. This retrospective study was approved by the Kırklareli University Local Ethics Committee (approval date: 15.03.2021, decision no: 11).

All the paranasal CT scans were performed utilizing identical CT scanners (Somatom go.Now, Siemens, Forchheim, Germany) adhering to the following specific acquisition parameters: kV: 130; mAs: 80; reconstruction filters: H40 smooth for soft tissues and H70 sharp for bone; and slice thickness: 0.75 mm. The segmentation and three-dimensional (3D) volume analysis of the SS on both sides were independently carried out for each side utilizing ITK-SNAP 3.8.0 open-source software (Figure 1). ITK-SNAP enables semi-automatic segmentation of the paranasal sinuses based on gray levels, produces 3D models, and computes the volumes of these models (6). This software has been validated and is widely used for the volumetric assessment of paranasal sinuses (7,8). For the creation of the 3D model and volumetric assessment, an automatically increasing "seed" was placed for measurement in each sinus. These seeds then permeated the entire airspace within the boundaries of the bone walls. All volumetric measurements were repeated twice with a 14-day interval, and the average of the measurements was utilized.

For each patient, the extensions of the ON and ICA into the SS were assessed using both coronal and axial CT scans of the left and right SS. Based on the protrusion of the ON and ICA, the subjects of the study were categorized into the following four distinct groups: no protrusion of either structure (group 1), protrusion of only the ICA (group 2), protrusion of only the ON (group 3), and protrusion of both the ICA and ON (group 4). (Figure 2). The proportion of cases allocated to each group was determined in conjunction with the median volume of the SS.

Statistical Analysis

The analysis was conducted using the Statistical Package for the Social Sciences 15.0 for Windows (SPSS Inc., Chicago, IL), and the results are depicted as medians and interquartile ranges, where relevant. Categorical variables are described by their numbers and percentages. The Pearson chi-square test was used

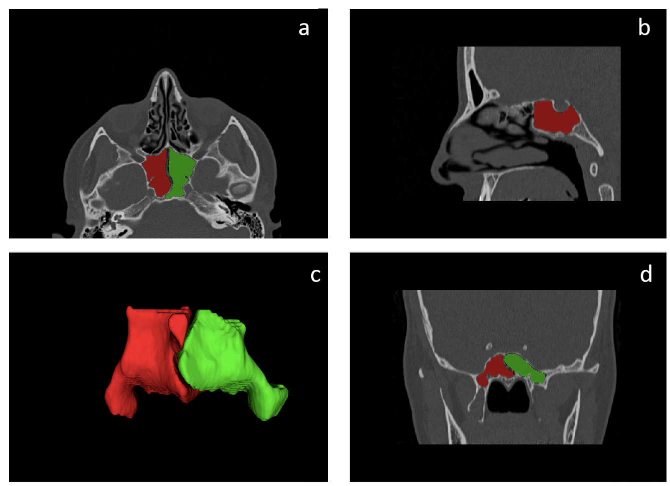

Figure 1. Three-dimensional (3D) volumetric analysis of sphenoid sinuses with ITK-SNAP Software. **a.** Cross-sectional view in the transversal plane of the sphenoid sinuses. **b.** Longitudinal section in the sagittal plane of the sphenoid sinuses. **c.** Visualization of a 3D model showing the right (red) and left (green) sphenoid sinuses. **d.** Frontal section in the coronal plane of the sphenoid sinuses

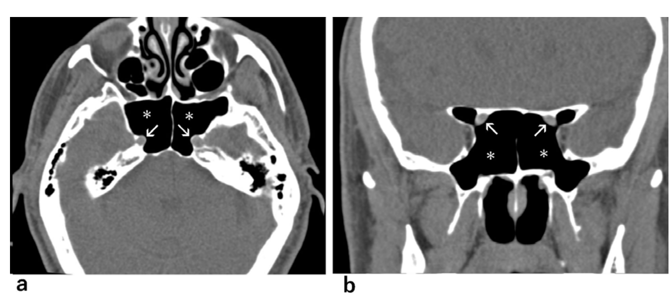

Figure 2. Axial and coronal computed tomography (CT) images of a group 4 subject. **a.** Axial CT image highlighting the protrusion of right and left internal carotid artery (arrow) into the sphenoid sinus cavity (*). **b.** Coronal CT image illustrating the protrusion of right and left optic nerve (arrow) into the sphenoid sinus cavity (*).

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Table 1. Prevalence, age and gender distribution and sphenoid sinus volumes of each group

	Number (%)	Age (years)	Gender	Sphenoid sinus volume (cm³)
		Median (IQR)	Female/male n (%)	Median (IQR)
Group 1	138 (48.6)	30 (16)	71 (51.4)/67 (48.6)	3.35 (3.03)
Group 2	65 (22.9)	28 (16.5)	34 (52.3/31 (47.7)	4.95 (4.29)
Group 3	25 (8.8)	30 (19)	12 (48.0)/13 (52.0	5.77 (4.82)
Group 4	56 (19.7)	31.5 (15.5)	27 (48.2)/29 (51.8)	6.77 (4.81)
		*p=0.627	**p=0.958	*p<0.001

*Kruskal-Wallis test, **Pearson chi-square test, IQR: interquartile range

to compare the independent groups. The normal distribution of the data was evaluated using the Kolmogorov-Smirnov test. When the numerical variables across the groups did not meet the normal distribution criteria, the Kruskal-Wallis test was used for comparisons among more than two independent groups. Paired comparisons of groups were performed utilizing Dunn's post-hoc test. A significance level of $p<0.05$ was deemed meaningful.

RESULTS

The study retrospectively analyzed paranasal sinus CT scans from 142 patients, encompassing a total of 284 SS. Within this population, there were 72 females (144 sinuses) (50.7%) and 70 males (140 sinuses) (49.3%), and there was no significant difference among the four groups in terms of age (p=0.627) and gender (p=0.958) (Table 1).

Group 1 was the most common, with 138 sinuses (48.6%), and median SS volume was 3.35 cm³. Group 2 was the second most common, with 65 sinuses (22.9%), and median SS volume was 4.95 cm³. Group 3 was the least common, with 25 sinuses (8.8%), and median SS volume was 5.77 cm³. Group 4 included 56 sinuses (19.7%), and median SS volume was 6.77 cm³ (Table 1, Figure 3). The analysis revealed a statistically significant difference in SS volume among the groups (p<0.001).

Table 2 displays the outcomes and comparisons of the groups. Significant statistical differences in SS volume were observed between group 1 and group 2 (p=0.002) and group 1 and group 4 (p<0.001). In contrast, there were no significant volume disparities found between the subjects without protrusions (group 1) and those with only ON protrusion (group 3) (p=0.063), between the subjects with only ICA protrusion (group 2) and those with only ON protrusion (group 3) (p=1.00), between the subjects with only ICA protrusion (group 2) and those with protrusion of the ICA and the ON (group 4) (p=0.057), and between the subjects with isolated ON protrusion (group 3) and those with protrusion of both the ICA and the ON (group 4) (p=0.349).

Table 2. Paired comparisons of groups

	p-value*
Group 1 vs. group 2	0.002
Group 1 vs. group 3	0.063
Group 1 vs. group 4	<0.001
Group 2 vs. group 3	1.00
Group 2 vs. group 4	0.057
Group 3 vs. group 4	0.349

*Dunn's post-hoc test

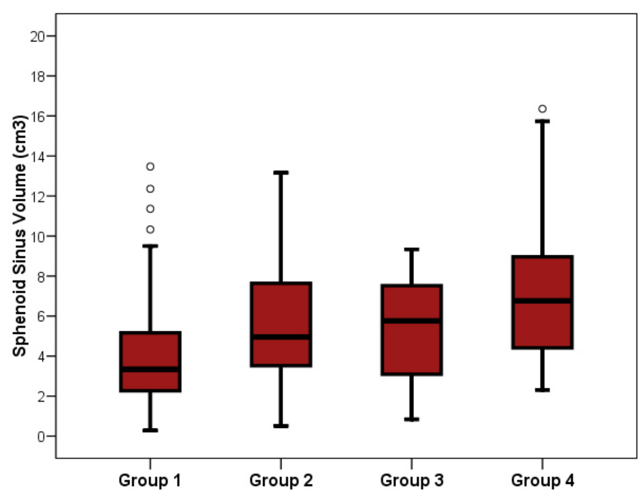

Figure 3. Sphenoid sinus volumes of each group

DISCUSSION

The SS, a complex and fluctuating structure, is centrally positioned within the base of the skull. It has a close association with numerous vital neurovascular components, including the ON and the ICA (9). The optic canal, hosting the ON, resides in the superolateral portion of the sinus and frequently composes its roof. The absence of bone covering the ON, a condition known as dehiscence, can lead to the ON's direct contact with the sinus in 4% to 30% of instances (10,11). Conversely, the ICA follows a path that is inferolateral to the ON and is a substantial contributor to the SS's lateral wall (11). Variations in the ICA's course and the pneumatization of the SS may cause dehiscence of the bone over the ICA. This can expose the ICA to the sinus cavity, thereby heightening the potential for injury during surgical interventions (11).

While functional endoscopic sinus surgery and trans-sphenoidal pituitary surgery are generally considered safe, rare but significant complications can occur, including injuries to the ICA and the ON.

The close proximity to the surgical field of these vital structures renders them susceptible to damage during surgical maneuvers. Although the prevalence of ICA injury in endoscopic sinus surgery is relatively low, the potential consequences are severe. Studies have reported the incidence of ICA injury to be below 0.1% of cases (12). Despite its rarity, ICA injury can lead to significant morbidity and mortality due to severe hemorrhage and potential vascular complications such as stroke, carotid-cavernous fistula formation, cranial nerve palsies, and even death (13). Another rare but serious complication of endoscopic sinus surgery is ON injury. The reported incidence varies widely, ranging from 0.03% to 0.1% (14). ON injury can lead to visual impairment or even permanent blindness, significantly affecting a patient's quality of life (14). It is important to note that the prevalence and incidence of these complications can vary based on several factors, including the surgeon's experience, patient anatomy, and the complexity of the surgical procedure. To minimize the risk of these complications, surgeons must thoroughly understand the anatomical relationships and employ meticulous surgical techniques.

The existing literature reveals considerable variation in the reported prevalence of ICA and ON protrusions. Estimates for ICA protrusion range from 3.9% to 46.2%, while ON protrusions have been reported to vary between 2.8% and 41.5% (15-17). A potential explanation for this significant discrepancy may lie in the lack of a universally accepted definition of "protrusion." Some authors have characterized protrusions as situations in which the invagination into the sphenoid air cavities extends beyond half the diameter of a specific neural or vascular structure (11,17). However, others in the field do not adhere to a specific definition for this term. In the context of our study, we opted to encompass all instances in which either the ICA or the ON resulted in an indentation of any magnitude within the SS. We adopted this broad approach to ensure comprehensive coverage of all potential cases. In the current study, we detected ICA protrusions in 42.6% of sinuses and ON protrusions in 28.5% of cases.

A recent investigation spearheaded by Fadda et al. (18) revealed the incidence of ICA and ON protrusion to be more common in instances of significant SS pneumatization. They observed a higher frequency of ICA and ON protrusion within the sellar and postsellar classifications (18). Similarly, research conducted by Dal Secchi et al. (19) identified a direct association between the extensive lateral pneumatization of the SS and a heightened probability for ICA protrusion. Additionally, Fatihoglu et al. (4) delineated that the pneumatization of the anterior clinoid process is correlated with an increased prevalence of protrusions involving both the ICA and ON.

Though numerous investigations have delved into the relationship between the pneumatization of the SS and that of the ICA and ON, only a select few have specifically focused on the connection between the SS's volume and these vital neurovascular elements. A study conducted by Gibelli et al. (17), employing a classification methodology analogous to our own, determined that the SS volume was higher in categories displaying ICA protrusions, whether occurring alone or in combination with the ON, relative to other groupings. Interestingly, they did not detect a statistically significant variation in SS volume between groups with no protrusions of any kind and those with only ON protrusion (17).

Our findings are consistent with the previously mentioned study, revealing a correlation between the SS volume and the protrusion of certain anatomical structures. Specifically, cases exhibiting a concomitant protrusion of both the ICA and ON were linked with the largest volume of the SS. Conversely, we did not discern a statistically significant disparity in the volume of the SS between the groups with no protrusions of any anatomical structures and those with an isolated protrusion of the ON. Additionally, we identified a significant increase in SS volume in cases with isolated ICA protrusions compared to the group with no protrusions. From a surgical standpoint, these results suggest that larger sinuses have a higher probability of ICA protrusion than do smaller SS. However, ON protrusion, which is less common than ICA protrusion, can be observed in both small and larger SS dimensions.

Study Limitations

The present study is characterized by certain limitations, most notably the relatively small sample size of 142 patients. This restriction necessitates caution in extrapolating the findings to a broader population. Further investigations employing a more extensive and diversified cohort are required to uncover additional variables that may influence the protrusion of the ICA and the ON into the SS. Replication of these results in larger and more heterogeneous samples would contribute to a more comprehensive understanding and validation of the complex interplay between SS volume and the proximity of these vital neurovascular structures.

CONCLUSION

Larger SS have a higher probability of ICA protrusion compared to smaller SS. Although ON protrusion is considered to be rarer than ICA protrusion, it can be observed regardless of the volume of the SS. This implies that even in cases with smaller SS, the possibility of ON protrusion should not overlooked or underestimated.

Ethics Committee Approval: This retrospective study was approved by the Kırklareli University Local Ethics Committee (approval date: 15.03.2021, decision no: 11).

Informed Consent: Patient consent is not required for this study.

Peer-review: Externally and internally peer-reviewed.

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