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The Impact of Nasal Septum Deviation on Paranasal Sinus Volumes

Nazal Septum Deviasyonunun Paranazal Sinüs Hacimlerine Etkisi

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The Impact of Nasal Septum Deviation on Paranasal Sinus Volumes

ABSTRACT

Objective: Researchers have extensively investigated the reasons behind variations in the volumes of paranasal sinuses, either among different individuals or between the right and left sides of the same individual. These differences in volumes have been associated with nasal septal deviation (NSD) and anatomical variations. In this study, we aimed to retrospectively analyzed the effect of NSD on frontal sinus, maxillary sinus, and sphenoidal sinus.

Material and Method: A total of 281 patients (151 females and 130 males) admitted to Gaziosmanpaşa University Hospital were included in the study. Paranasal sinus computed tomography (CT) images consisting of 0.625-mm-thick slices were obtained from the patients. The areas of the frontal sinus, maxillary sinus, and sphenoidal sinus were determined using ImageJ software. The volume of each sinus was calculated using Cavalieri's principle. We analyzed the relationship between the calculated volumes and nasal septal deviation.

Results: Our study found that the frontal sinus volume values were 4.67 cm^3 on the right side and 5.03 cm^3 on the left side in women. In men, the right-side volume value was 7.07 cm^3 and the left-side volume value was 7.77 cm^3. The sphenoidal sinus volume value was calculated as 6.35 cm^3 on the right side and 6.57 cm^3 on the left side in women. In males, the right-side volume value was 7.34 cm^3 and the left-side volume value was 7.62 cm^3. The maxillary sinus volume was calculated as 19.38 cm^3 on the right side and 19.37 cm^3 on the left side in women. In males, the right-side volume value was 22.80 cm^3 and the left-side volume value was 23.71 cm^3. The frontal sinus volume values in males were larger than those in females *($p=0.04$)*. The maxillary sinus volume values in males were greater than the maxillary sinus volume values in females *($p=0.02$)*. There was no significant relationship between the presence of septal deviation and sinus volumes *($p>0.05$)*. The right, left, or s-shaped deviation direction did not cause a significant difference in sinus volumes *($p>0.05$)*.

Conclusion: The findings show that there is no correlation between volume values and the presence and shape of nasal septal deviation. However, significant differences in volumes were observed between the genders. Because the severity of nasal septal deviation is related to the volume value, different results can be obtained by measuring the frontal sinus, maxillary sinus, and sphenoidal sinus volume values in individuals with more advanced deviation.

Keywords: Cavalieri principle, frontal sinus, ImageJ, maxillary sinus, sphenoidal sinus, volumes.

ÖZET

Amaç: Paranazal sinüslerin hacimlerinin farklı bireylerde ya da aynı bireyin sağ ve sol tarafı arasında farklılık gösterme sebepleri birçok araştırmacı tarafından incelenmiştir. Hacimlerdeki bu farklılıklar nazal septum deviasyonu, anatomik varyasyonlar gibi birçok sebeple ilişkilendirilmiştir. Bu çalışmada, NSD'nin sinus frontalis, sinus maxillaris ve sinus sphenoidalis hacimlerine etkisini retrospektif olarak incelemeyi amaçladık.

Gereç ve Yöntem: Çalışmaya Tokat Gaziosmanpaşa Üniversite Hastanesi'ne başvuran 151 kadın, 130 erkek toplamda 281 hasta dahil edildi. Hastalardan, 0,625 mm kalınlığında kesitlerden oluşan paranazal sinüs bilgisayarlı tomografi görüntüleri alındı. ImageJ programı ile sinus frontalis, sinus maxillaris ve sinus sphenoidalis'in alanları tespit edildi. Her bir sinüsün hacmi Cavalieri Prensibi ile hesaplandı. Hesaplanan hacimlerin nazal septum deviasyonu ile ilişkisi incelendi.

Bulgular: Çalışmamızda, kadınlarda sinus frontalis hacim değerleri, sağ tarafta 4,67 cm^3, sol tarafta 5,03 cm^3 olarak hesaplandı. Erkeklerde ise sağ taraf hacim değeri 7,07 cm^3, sol taraf hacim değeri 7,77 cm^3 olarak hesaplandı. Sinus sphenoidalis hacim değeri, kadınlarda sağ tarafta 6,35 cm^3, sol tarafta ise 6,57 cm^3 olarak hesaplandı. Erkeklerde sağ taraf hacim değeri 7,34 cm^3 iken sol taraf hacim değeri 7,62 cm^3 olarak hesaplandı. Sinus maxillaris hacmi kadınlarda sağ tarafta 19,38 cm^3, sol tarafta ise 19,37 cm^3 olarak hesaplandı. Erkeklerde ise sağ taraf hacim değeri 22,80 cm^3, sol taraf hacim değeri ise 23,71 cm^3 olarak hesaplandı. Erkeklerde sinus frontalis hacim değerleri kadınların sinus frontalis hacimlerinden daha büyüktür *($p=0.04$)*. Erkeklerde sinus maxillaris hacim değerleri kadınların sinus maxillaris hacim değerlerinden daha büyüktür *($p=0.02$)*. Septum deviasyonun varlığı ile sinus hacimleri arasında anlamlı bir ilişki bulunamadı *($p>0.05$)*. Deviasyon yönünün sağa, sola veya s şekilli olması sinüslerin hacimlerinde anlamlı bir fark oluşturmadı *($p>0.05$).*

Sonuç: Bulgularımıza göre hacim değerleri ile nazal septum deviasyonun varlığı ve şekli arasında ilişki bulunamazken, cinsiyetler arasında hacimlerde anlamlı farklılıklar görüldü. NSD'nin şiddeti ile hacim değerinin ilişkili olması nedeniyle daha ileri deviasyona sahip bireylerde sinus frontalis, sinus maxillaris ve sinus sphenoidalis hacim değerlerini ölçmek farklı sonuçlar elde edilebilir.

Anahtar Sözcükler: Cavalieri prensibi, hacim, ImageJ, sinus frontalis, sinus maxillaris, sinus sphenoidalis.

Introduction

The paranasal sinuses are four pairs of cavities found within the bones that make up the nasal cavity. These are the frontal sinus, sphenoidal sinus, maxillary sinus, and ethmoidal cells. They are formed by embedding the nasal mucosa into bones. The formation of paranasal sinuses significantly alters the size and shape of the face. They also contribute to changes related to growth and dental development and can be indicative of an individual's social context, such as gender and sexual maturity. Paranasal sinuses perform multiple functions, including contributing to voice resonance, lightening the weight of the skull, aiding facial growth and shaping, maintaining olfactory membrane moisture through mucus secretion, and balancing internal and external atmospheric pressure (1, 2). The location, shape, and size of nasal sinus openings vary greatly among individuals. This region, where the nasal cavity and paranasal sinuses are located, plays a crucial role in the pathogenesis of diseases and is also where anatomical variations are commonly observed (1, 3). The nasal septum is located in the middle part of the nasal cavity and is divided into the posterior section by the vomer and perpendicular plate of the ethmoidal bone and into the anterior section by the quadrilateral cartilage. NSD is the most common anatomic variation observed in adults, occurring in approximately 80% of cases. The volume of the nasal cavity decreases on the ipsilateral (convex) side of the NSD. Facial anomalies, birth traumas, other injuries, abnormalities in the growth of incisor and upper teeth and prolonged finger sucking are among the causes of NSD (4, 5).

To the best of our knowledge, studies have investigated the relationship between the volume of a single sinus and NSD. Nevertheless, a comprehensive study simultaneously examining all three sinuses, namely frontal sinus, sphenoidal sinus and maxillary sinus, has not been previously undertaken.

The volumes of the sinuses were measured using the Cavalieri principle. The Cavalieri principle provides the advantages of speed, reliability, and obtaining quantitative data compared to other measurement techniques. There are articles that measure the volumes of structures such as the spleen, liver and brain using the Cavalieri principle, but there are not many articles that measure the volumes of paranasal sinuses using this method (6, 7). It is crucial to accurately calculate the volumes of these cavities, which are adjacent to important anatomical structures such as the orbit, pituitary gland, and teeth, and to understand the effect of NSD. This will provide an advantage for the rapid and reliable implementation of surgical procedures in these regions in the future.

In this study, we aimed to evaluate the effect of NSD on the volume of the frontal sinus, sphenoidal sinus and maxillary sinus.

Material and Method

The study was submitted to the Clinical Research Ethics Committee of Gaziosmanpaşa University and approved on 03.11.22 under registration number 22-KAEK-240. Following ethical approval, we evaluated 281 participants who underwent paranasal sinus CT at the Gaziosmanpaşa University Faculty of Medicine Hospital between January 2018 and May 2023. The study included cranial CT images of 281 participants, comprising 151 females and 130 males, with ages ranging from 11 to 75 years (mean age: 36.6 ± 15.5 years). The mean ages for females and males were 36.3±15.9 and 36.01±16.1, respectively. The data were obtained from a GE-branded CT scanner, using images with a slice thickness of 0.625 mm (GE Optima CT660 -128 slice). The inclusion criteria encompass having brain CT images available and absence of any surgical history related to the head region. Patients with a history of head trauma, nasal polyposis, previous surgical interventions in the head region, chemotherapy and radiotherapy history targeting the head region, diagnosis of chronic sinusitis, and patients under the age of 14 years will be excluded.

The radiological images were downloaded from the SECTRA radiological image viewing software of Gaziosmanpaşa University Hospital's information technology system. They were initially transferred to a dedicated folder in DICOM (Digital Imaging and Communication in Medicine) format. Subsequently, the transferred images were opened using ImageJ software. Axial-oriented images with a slice thickness of 0.625 mm were selected from the opened image series for visual examination using the same program.

Images were checked for any intracranial pathologies. After this review, image series that were considered problem-free were sampled, ensuring at least 15 image slices for the frontal, sphenoidal, and maxillary sinuses. The paranasal sinuses were colored red using the 'Threshold' option under the Image, Adjust tab in ImageJ software. The program's polygon selection tool was used to establish the boundaries of the colored sinus. Using this method, the area covered by the sinus in each section was determined (Figure I). To calculate the volume of the sinus, these area values were multiplied by the section thickness in accordance with the Cavalieri Principle and then summed. In this way, the volume value of the respective sinus was calculated (Formula I).

Formula I: $V=t\times (a_1+a_2+..............+a_n)\ cm^3$

In the formula, t represents the average thickness of consecutive sections in centimeters for n number of sections, while $(a_1 + a_2 + ... + a_n)$ represents the cross-sectional areas in square centimeters.

Table I. Difference in sinus volumes according to gender

Group	Measure	Mean (cm^3)	SD	Z	p
Female	Right Frontal Sinus	4.67	3.77	-1.23	*0.22*
	Left Frontal Sinus	5.03	4.10		
Male	Right Frontal Sinus	7.07	4.52	-2.04	*0.04**
	Left Frontal Sinus	7.77	5.01		
Female	Right Sphenoidal Sinus	6.35	3.84	-0.55	*0.59*
	Left Sphenoidal Sinus	6.57	4.07		
Male	Right Sphenoidal Sinus	7.34	3.70	-0.62	*0.54*
	Left Sphenoidal Sinus	7.62	4.17		
Female	Right Maxillary Sinus	19.38	6.58	-0.57	*0.57*
	Left Maxillary Sinus	19.37	6.85		
Male	Right Maxillary Sinus	22.80	7.72	-2.29	*0.02**
	Left Maxillary Sinus	23.71	8.51		

**p<0.05*, SD: Standard Deviation

The direction and angle of NSD were calculated using the approach defined by Gencer et al. Kapusuz Gencer et al. determined the direction of NSD by accepting the convex side of the nasal septum and classified the NSD angle accordingly. They categorized the deviation angle as follows: The deviation angle of the nasal septum is classified as mild (<9 degrees), moderate (angle between 9 and 15 degrees), or severe (>15 degrees) (18).

The Wilcoxon test was employed to compare the volumes of the paranasal sinuses between genders. In addition, the Wilcoxon test was used to assess the relationship between the volumes of sinuses and NSD. The obtained p-value was considered significant when it was <0.05.

Results

In our study, septal deviation was observed in 197 individuals. Among them, 99 had a deviation toward the right, 76 had a deviation toward the left, and 22 had an S-shape deviation. Table 2 provides the values between the volumes of the frontal sinus, sphenoidal sinus, and maxillary sinus and the direction of deviation. The most striking difference was the significantly larger sinus volumes in males (Table I). In male individuals, the volume of the left frontal sinus ($7.77\pm5.01\ cm^3$) was greater than that of the right frontal sinus ($7.07\pm4.52\ cm^3$) (*p=0.04*). There was no significant difference observed between the mean values of the right and left frontal sinus measurements in female participants (*p=0.22*). In both male and female participants, there was no statistically significant difference between the mean values of the right and left sphenoidal sinuses (*p=0.54, p=0.59*). Similarly, in female participants, no significant difference was observed in the mean values of the right and left maxillary sinuses (*p=0.57*). However, in male participants, a significant difference was observed (*p=0.02*), with the average values of the right maxillary sinus ($22.80\pm7.72\ cm^3$) being lower than those of the left ($23.71\pm8.51\ cm^3$). No significant difference was observed in the mean values of right and left frontal sinus measurements based on the variable of participants' deviation status (*p=0.16*). Similarly, there was no significant difference between the mean values of the right and left frontal sinus in participants without deviation (*p=0.052*). There was no significant difference between the mean values of the right and left sphenoidal sinus in participants with or without deviation (*p=0.20, p=0.55*). Similarly, there was no significant difference between the mean values of the right and left maxillary sinus in participants with deviation (*p=0.86*). In male individuals without deviation, the mean value of the right maxillary sinus ($21.06\pm8.14\ cm^3$) was lower than that of the left maxillary sinus ($22.17\pm7.90\ cm^3$) (*p=0.02*) (Table II).

Table II. Comparison of right and left sinus volumes according to deviation status

Group	Measure	Mean (cm³)	SD	Z	p
Deviation	Right Frontal Sinus	5.83	3.90	-1.39	*0.16*
	Left Frontal Sinus	6.33	4.45		
Non-deviation	Right Frontal Sinus	5.67	5.10	-1.94	*0.052*
	Left Frontal Sinus	6.23	5.34		
Deviation	Right Sphenoidal Sinus	6.81	3.88	-1.27	*0.20*
	Left Sphenoidal Sinus	7.34	4.38		
Non-deviation	Right Sphenoidal Sinus	6.81	3.64	-0.60	*0.55*
	Left Sphenoidal Sinus	6.41	3.51		
Deviation	Right Maxillary Sinus	20.92	6.94	-0.17	*0.86*
	Left Maxillary Sinus	21.03	7.97		
Non-deviation	Right Maxillary Sinus	21.06	8.14	-2.32	*0.02**
	Left Maxillary Sinus	22.17	7.90		

**p<0.05*, SD: Standard Deviation

There was no significant difference between the possible directions of septal deviation (right, left, and s-shaped) and the volumes of the right and left side sinuses ($p>0.05$) (Table III, Table IV, Table V).

Table III. Comparison of right and left frontal sinus volumes according to deviation direction

Group	Measure	N	Mean (cm³)	SD	Z	p
De. Dir. Right*	Right Frontal Sinus	99	5.63	3.28	*-1.52*	*0.13*
	Left Frontal Sinus	99	6.33	4.26		
De. Dir. Left**	Right Frontal Sinus	76	6.23	4.52	*-0.23*	*0.82*
	Left Frontal Sinus	76	6.46	4.69		
De. Dir. S Shape***	Right Frontal Sinus	22	6.02	5.81	*-1.58*	*0.11*
	Left Frontal Sinus	22	6.69	6.45		
De. Dir Mid****	Right Frontal Sinus	84	5.48	4.72	*-1.85*	*0.06*
	Left Frontal Sinus	84	6.01	4.86		

*Deviation Direction Right, **Deviation Direction Left, ***Deviation Direction S Shape, ****Deviation Direction Middle, SD: Standard Deviation

Table IV. Comparison of right and left sinus sphenoidal sinus volumes according to deviation direction

Group	Measure	N	Mean (cm³)	SD	Z	p
De. Dir. Right*	Right Sphenoidal Sinus	99	7.04	4.04	-0.16	0.87
	Left Sphenoidal Sinus	99	6.86	4.25		
De. Dir. Left**	Right Sphenoidal Sinus	76	6.77	3.80	-1.19	0.24
	Left Sphenoidal Sinus	76	7.73	4.70		
De. Dir. S shape***	Right Sphenoidal Sinus	22	6.00	3.08	-1.90	0.06
	Left Sphenoidal Sinus	22	8.11	3.79		
De. Dir. Mid****	Right Sphenoidal Sinus	84	6.79	3.71	-0.59	0.56
	Left Sphenoidal Sinus	84	6.38	3.43		

*Deviation Direction Right, **Deviation Direction Left, ***Deviation Direction S Shape, ****Deviation Direction Middle,
SD: Standard Deviation

Discussion

The paranasal sinuses are cavities located inside the bones and have the same name. They all open into the lateral wall of the nasal cavity and have small holes that allow for air balance and mucus clearance through a mucociliary pathway (3). The paranasal sinuses play pivotal roles, including modulating voice resonance during speech and diminishing the overall weight of the skull. Pathologies affecting the paranasal sinuses are of significance because of their proximity to anatomical structures such as the dentofacial region, orbit, nasus, and glandula hypophysialis. The mucosa of the sinuses is common with the nasal mucosa, which is critical for the spread of infection over a wide area (8, 9). The complex shape of certain anatomical structures in fields such as otorhinolaryngology, radiology, neurosurgery, and dentistry can make clinical tasks challenging. Our study found that men have larger paranasal sinus volumes than women. Emirzeoğlu et al. used the Cavalieri principle to measure paranasal sinus volumes on CT images. It was concluded that men have larger paranasal sinus volumes than women and that the volumes of the paranasal sinuses differ significantly between genders, except for the sphenoidal sinus similar to the study being referenced (10). Cavalieri principle produces precise and reliable results in a shorter time than other methods. Diverse methodologies have been employed in the literature for quantifying paranasal sinuses volumes, with our study using the Cavalieri principle (23, 28).

Table V. Comparison of right and left maxillary sinus volumes according to deviation direction

Group	Measure	N	Mean (cm³)	SD	Z	p
De. Dir. Right**	Right Maxillary Sinus	99	20.88	6.87	-0.08	*0.94*
	Left Maxillary Sinus	99	21.01	7.82		
De. Dir. Left***	Right Maxillary Sinus	76	21.24	7.15	-0.28	*0.78*
	Left Maxillary Sinus	76	21.37	8.60		
De. Dir. S Shape****	Right Maxillary Sinus	22	20.47	7.86	-0.23	*0.82*
	Left Maxillary Sinus	22	20.43	6.91		
De. Dir Mid*****	Right Maxillary Sinus	84	20.93	7.94	-2.37	*0.02**
	Left Maxillary Sinus	84	22.08	7.83		

*$p<0.05$, **Deviation Direction Right, ***Deviation Direction Left, ****Deviation Direction S Shape,
*****Deviation Direction Middle, SD: Standard Deviation

In a retrospective study, Sahlstrand-Johnson et al. measured the volume of 120 maxillary sinuses (32 women, 28 men) on cranial CT images of individuals aged 18–65 years. The investigation revealed that the average volume of the maxillary sinus was 15.7±5.3 cm^3, as determined by morphometric measurements. Notably, gender-based analysis demonstrated a larger maxillary sinus volume in males than in females. Furthermore, when evaluating the effect of age on volume measurements, no statistically significant correlation was found in either the right or left side volume measurements, bilaterally, according to age groups (11). Pirner et al. measured the depth, height, and width of the maxillary sinus on CT images of 50 individuals (24 males, 23 females, and 3 cadavers) aged between 16 and 78 years. When evaluating the impact of the gender factor on volume values, it has been indicated that male individuals exhibit larger volume values than female individuals. In their study, Kawarai et al. noted a tendency for the sinuses of males to have larger volumes than those of females (12, 13). The growth rate of bones directly affects the size of these structures. Sinus volumes are larger in men because of physiological and physical differences between the genders. Bone mass peaks in the second decade of life and is influenced by dietary calcium and exercise during childhood and adolescence. In girls, the rate of increase begins to decline with menarche. Bone development continues until approximately 18 years of age in females and 21-22 years of age in males. Therefore, the male skeleton has larger bones (14, 15). In this study, we analyzed the effect of the direction and shape of NSD on the volumes of the paranasal sinuses. We found a significant difference between the mean volume of the right and left maxillary sinuses in participants without deviation. However, it was observed that the mean volume of the right maxillary sinus was lower than that of the left maxillary sinus in participants without deviation. The results showed that there was no significant difference in the volumes of the sinuses based on the deviation direction to the right, left, or S-shaped. The research undertaken by Sapmaz et al. examined coronal CT scans from a cohort of 1568 individuals aged between 18 and 60 years. The study specifically incorporated CT images from 402 participants, and the assessment involved the use of ImageJ software to compute parameters such as hard palate angulation, maxillary sinus volume, and nasal septal deviation angle. The study revealed a statistically significant difference in the volume of the maxillary sinus between the side with deviation and its contralateral counterpart (16). As per Kapusuz Gencer et al., there was an elevation in the volume of the maxillary sinuses on the contralateral side in cases of severe NSD. Likewise, Orhan et al. documented a statistically notable decrease in the volume of the maxillary sinus on the side corresponding to the septal deviation compared with that on the contralateral side (17, 18). Karataş et al. retrospectively analyzed the paranasal sinus volumes of 732 participants (410 males, 322 females) using CT images. Karatas et al. included 83 participants with deviated nasal septum, who were divided into three groups after excluding other concomitant sinonasal pathologies (19). The results showed that only moderate NSD affected maxillary sinus volume but not frontal sinus volume. Stallman et al. conducted a study and discovered that 65% of cases exhibited some degree of NSD. However, their findings did not establish a significant correlation between NSD and sinus conditions. Upon examination of these studies, it can be concluded that severe and moderate septal deviation significantly affect sinus volume (20).

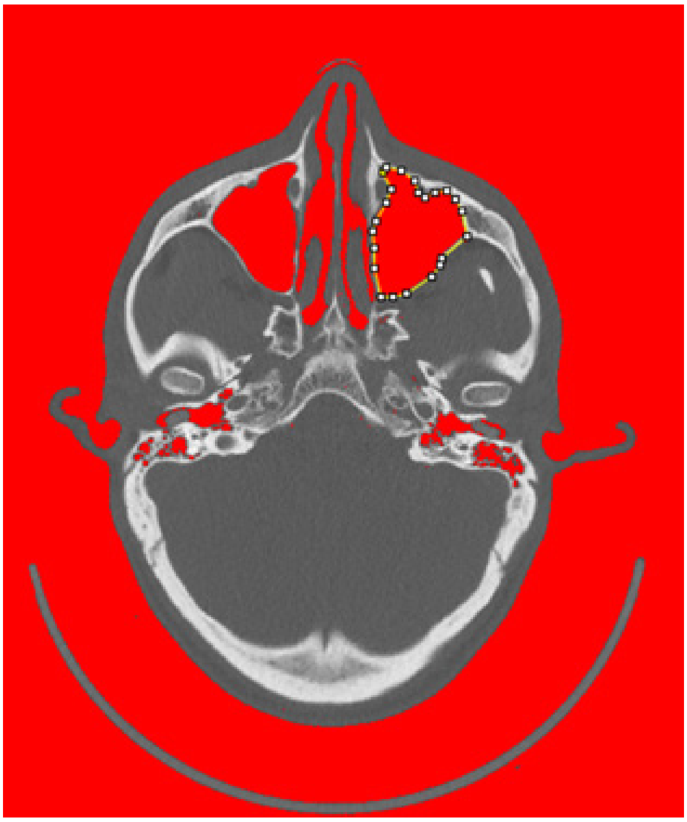

Figure I. Example of volumetric measuring of maxillary sinus. Fig. 1 displays a CT of the maxillary sinus based on the volumes measures by painting all plains of the scan.

In our study, we observed that NSD had no effect on the volume values of the frontal sinus and sphenoidal sinus. The direction of deviation, whether right, left, or s-shaped, does not significantly affect the volumes of the sinuses (21, 22).

Mild septum deviation may not have a significant effect on sinus volume. Consistent with findings in other studies, septum deviation demonstrated no impact on the volume of the frontal and sphenoidal sinuses. Additionally, the presence of mild NSD did not influence the volume of the maxillary sinuses.

Conclusion

The paranasal sinuses vary in shape, morphology, and size depending on gender. In our study, we concluded that the sinus volumes of male individuals were larger than those of female individuals. Additionally, it was determined that NSD had no effect on the volumes of the frontal sinus, sphenoidal sinus, and maxillary sinus. If the degree of NSD is mild, the presence and shape of the deviation have a very weak effect on the volumes of the sinuses. In our study, we observed that applying the Cavalieri principle for measuring volume values had advantages in terms of time, accuracy, and consistency compared to other methods. These conclusions can contribute to the perioperative assessment of craniofacial reconstruction, dental implant procedures, and sinus surgery and potentially facilitate the identification of sinus pathologies in subsequent evaluations. More data should be added to the literature on this subject, and comprehensive studies should be conducted.

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