

Analysis of Maxillary Sinus Anatomical Variations in Cone Beam Computed Tomography for Dental Implants Treatment Plan

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Article Info	ABSTRACT
Article History Received: 20.11.2024 Accepted: 11.03.2025 Published: 29.08.2025 Keywords: Dental implants, Maxillary sinus, Cone beam computed tomography.	Aim: This study aim was to assess the maxillary sinus anatomical variations and structures using cone beam computed tomography (CBCT), particularly for dental implant treatment planning. Materials and Methods: In this cross-sectional prevalence study, 200 CBCT images were examined. The assessments were conducted independently by two authors to evaluate the anatomical variations of the maxillary sinus. The anatomical variations assessed in the axial images included alveolar pneumatization, anterior pneumatization, exostosis, and hypoplasia. Additionally, the positioning of sinus septa and the posterior superior alveolar artery (PSAA) was also evaluated. Results: Among the 400 maxillary sinuses analyzed, alveolar pneumatization was the most commonly detected morphological abnormality. Anterior pneumatization was detected in 84 sinuses (% 21.0). Antral septa were found in 175 sinuses (% 43.7) and were mostly located in the middle region. Among 254 sinuses, the PSAA was most frequently detected intraosseously, accounting for 63.5% of cases. Conclusion: Maxillary sinus anatomical variations are significant findings in the context of dental implant planning. These variations are frequently observed in CBCT examinations conducted on the maxilla. Understanding the anatomical variations of the maxillary sinus enhances the effectiveness of preoperative dental implant planning and aids in the prevention of potential complications.

Dental İmplant Tedavi Planlaması için Konik Işınlı Bilgisayarlı Tomografide Saptanan Maksiller Sinüsün Anatomik Varyasyonlarının Değerlendirilmesi

Makale Bilgisi	ÖZET
Makale Geçmişi Geliş Tarihi: 20.11.2024 Kabul Tarihi: 11.03.2025 Yayın Tarihi: 29.08.2025 Anahtar Kelimeler: Dental implant, Maksiller sinüs, Konik ışınli bilgisayarlı tomografi.	Amaç: Bu çalışmanın amacı dental implant planlaması için gerekli olan konik ışınli bilgisayarlı tomografilerde (KİBT) maksiller sinüsün anatomik yapılarını ve varyasyonlarını değerlendirmektir. Gereç ve Yöntemler: Bu kesitsel prevalans çalışmasında, 200 KİBT görüntüsü incelenmiştir. İncelemeler, maksiller sinüsün anatomik varyasyonlarını değerlendirmek amacıyla iki yazar tarafından bağımsız olarak gerçekleştirilmiştir. Aksiyal görüntülerde değerlendirilen anatomik varyasyonlar arasında alveolar pnömatizasyon, anterior pnömatizasyon, ekzostoz ve hipoplazi yer almaktadır. Ayrıca, sinüs septa ile posterior superior alveolar arterin (PSAA) yerleşimi de değerlendirilmiştir. Bulgular: İncelenen 400 sinüste en sık görülen anatomik varyasyon maksiller sinüs alveoler pnömatizasyonuydu. 84 sinüste (% 21,0) anterior pnömatizasyon saptandı. Antral septa 175 sinüste (% 43,7) bulundu ve en çok orta bölgede yerleşti. PSAA ise 254 sinüste (% 63,5) en çok intraosseöz olarak tespit edildi. Sonuç: Maksiller sinüsün anatomik varyasyonları, dental implant planlaması açısından önemli bulgular olarak karşımıza çıkmaktadır. Bu varyasyonlar, maksilla üzerinde gerçekleştirilen KİBT incelemelerinde sıkça gözlemlenmektedir. Maksiller sinüs anatomisindeki varyasyonların anlaşılması, dental implant tedavisi öncesi planlama süreçlerinin etkinliğini artırmakta ve potansiyel komplikasyonların önlenmesine yardımcı olmaktadır.

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INTRODUCTION

Dental implant procedures are commonly performed to replace missing teeth for reasons related to appearance, speech, and the mechanics of the mouth. Sufficient bone quantity and quality are crucial for the successful implantation of dental implants and achieving excellent long-term treatment outcomes.¹ The extension of the maxillary sinus and the resorption of the alveolar ridge are the two primary causes of the complexity of posterior maxillary reconstruction. It is essential to understand the anatomical structures in these regions during surgical procedures, such as dental implants, sinus lift surgeries, and bone augmentation.² Anatomical variations raise the likelihood of complications, including sinus membrane perforation and bleeding from the posterior superior alveolar artery (PSAA).¹

Computed tomography (CT) scans provide essential information on anatomical structures, bone dimensions, and jaw topography, which are vital for the planning of dental implants.³ Cone beam computed tomography (CBCT) is a medical imaging method that creates several projections in a single rotation using a conical or pyramidal beam.⁴ While CBCT is sometimes seen as a more economical option to traditional medical CT scans, it is important to note that for maxillofacial imaging, CBCT exposes the patient to higher amounts of radiation compared to classical panoramic radiography.⁵ Antral septa, hypoplasia, exostosis, and maxillary sinus pneumatization are examples of structural abnormalities that can occur in the paranasal sinuses.^{6,7} The maxillary sinus is highly relevant in cases involving dental implants. Accurate identification of anatomical variations of the maxillary sinus on CBCT is crucial, as CBCT is a vital diagnostic tool in dentistry. We aimed to contribute to the literature by providing more comprehensive information about the

prevalence of anatomical variations in the maxillary sinus. Thus, the objective of this study was to evaluate the incidence of alveolar pneumatization, anterior pneumatization, septa, exostosis and hypoplasia of the maxillary sinus using CBCT imaging, a crucial tool for dental implant planning.

MATERIALS AND METHODS

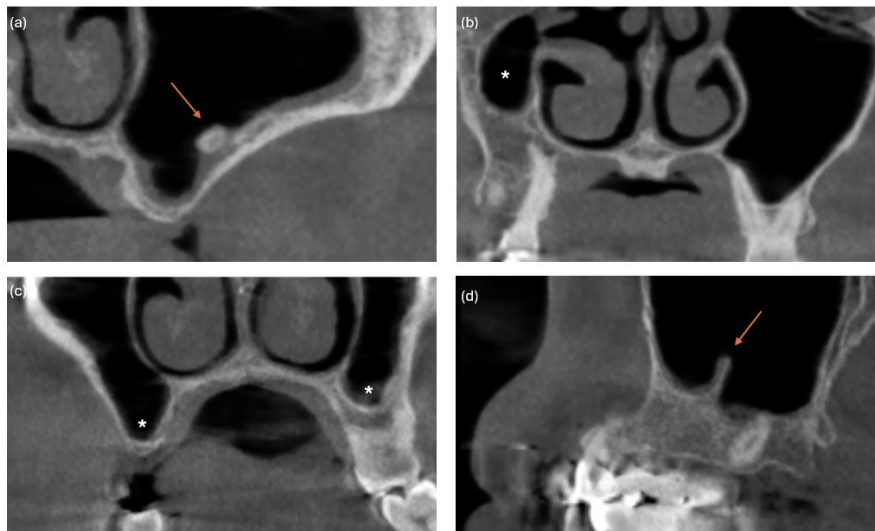
Study design

This cross-sectional prevalence study evaluated 200 CBCT scans collected at Alanya Alaaddin Keykubat University Faculty of Dentistry between 2022-2024. The study received approval from the local ethics committee (6792E-05/06). Inclusion criteria required CBCT images of the maxillary sinus that were clearly visible and utilized for implant planning. Exclusion criteria included CBCT scans where the lower third of the maxillary sinus was not visible, technical artifacts that hindered examination of the maxillary sinus, images indicating pathological changes in the maxillary sinus, or scans showing previous trauma to the maxillary sinus.

Image Acquisition and Analysis

CBCT scans were obtained using Kavo Op 3D Pro device (Biberach, Germany). The images were analyzed with the device's dedicated software, which enabled visualization of axial, coronal, and sagittal planes with 0.2-mm slice thickness. Two independent researchers evaluated the CBCT images, focusing on anatomical variations of the maxillary sinus. All discrepancies among the evaluators were settled by deliberation; if agreement could not be achieved, the patient was omitted from the study. Critical assessments of axial pictures encompassed variables such as alveolar pneumatization, anterior pneumatization, location of the sinus septa, exostosis, hypoplasia, and positioning of the posterior superior alveolar artery (Figure 1).

Figure 1: Exostosis (a), maxillary sinus hypoplasia (b), maxillary sinus pneumatization (c), septa (d)



If a patient's septa height was greater than 2 mm, which is a crucial requirement for sinus floor elevation treatments, they were added to the research. Septa were classified as anterior, middle, or posterior depending on where they were located within the sinus. Anterior (from mesial to second premolar), middle (from distal to second premolar to second molar), and posterior (from distal to second molar) were the three regions that comprised the septum location.⁸

Quantifications were conducted from the artery to the medial wall of the sinus, categorizing the arteries into three distinct types: intraosseous, submembranes, and located inside the outer cortex of the lateral sinus wall (Figure 2). When coronal slices revealed two alveolar antral arteries, the bigger artery was recorded. The existence of septa was also verified on both coronal and sagittal slices.

Figure 2: Coronal view of the maxillary sinus reveals the artery, which is on the outer cortex of the lateral sinus wall (a), below the membrane (b), intraosseous artery (c)



Statistical Analysis

The G*Power program was used to determine the required sample size for the study. The minimum required sample size was calculated as 24, with an expected effect size of 0.70 at a significance level of 0.05. However, in order to ensure demographic diversity and

increase actual power, the sample size was determined as 200. Statistical analysis was performed using SPSS software (Version 22.0). Frequencies and percentages related to incidence of each anatomical variations of the patients were given. The actual statistical power of the study was calculated as 0.99 with G*Power.

RESULTS

In total, 400 maxillary sinuses from 200 CBCT scans were analyzed, consisting of 130 female patients (65%) and 70 male patients (35%). The ages of the patients ranged from 16 to 86 years, with an average age of 52 years. Alveolar pneumatization of the maxillary sinus,

characterized by the sinus extending into the alveolar process, was the most frequently observed anatomical variation, present in 234 sinuses (58.5%). Within this group, pneumatization occurred in multiple zones in 92 patients (64.7%) and in a single zone in 50 patients (35.3%) (Table 1).

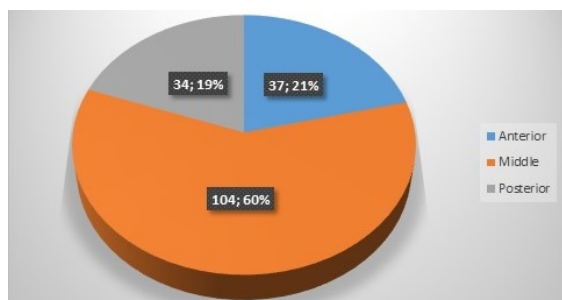
Table 1: Frequency of normal variations

	Hypoplasia	Exostosis	Septa	Alveolar pneumatization	Anterior pneumatization
All sinuses	28 (7.0%)	10 (4.0%)	175 (43.7%)	234 (58.5%)	84 (21.0%)
Unilateral	12 (60%)	2 (33.4%)	65 (54.2%)	50 (35.3%)	40 (64.6%)
Bilateral	8 (40%)	4 (66.6 %)	55 (45.8%)	92 (64.7%)	22 (35.4%)
Total	20 (100%)	6 (100%)	120 (100%)	142 (100%)	62 (100%)

Anterior pneumatization was identified in 84 sinuses (21.0%), appearing as a single zone in 40 cases (64.6%) and as multiple zones in 28 cases (35.4%). Maxillary sinus hypoplasia was found in 28 sinuses (7.0%), with 12 unilateral cases (60%) and 8 bilateral cases (40%) (Table 1).

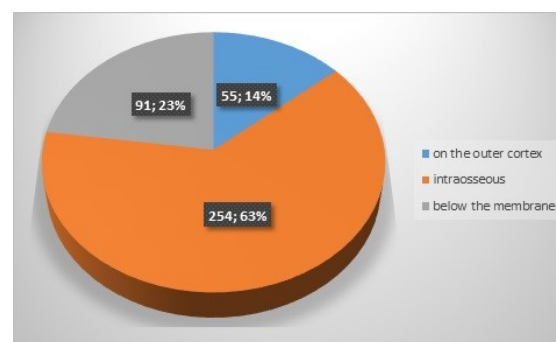
Exostosis was detected in 10 sinuses (4.0%). Antral septa were present in 175 sinuses (43.7%), occurring bilaterally in 55 patients (45.8%) and unilaterally in 65 patients (54.2%) (Table 1). Of the identified sinus septa, 37 (21.1%) were located anteriorly, 104 (59.4%) in the middle region, and 34 (19.5%) in the posterior region (Figure 3). Additionally, septa were observed on coronal images in 54 cases (30.8%) and on sagittal images in 121 cases (69.1%). Among these septa, 96 (54.8%) divided the sinus into two separate cells, and 5 (2.8%) created three separate cells.

Figure 3: Locations of septa



In 26 sinuses (6.5%), PSAA was discovered to be missing. The distribution of artery locations is depicted in Figure 4. Within the outer cortex of the sinus wall, the artery was located in 55 patients (13.7%), intraosseously in 254 sinuses (63.5%), and below the membrane in 91 sinuses (22.8%).

Figure 4: Location of PSAA



DISCUSSION

Maxillary sinus pneumatization, which is characterized as the expansion of the sinus into locations such as the alveolar ridge, anterior region, maxillary tuberosity, palate, zygomatic bone, and orbital area, was the most common morphological variant found in this investigation.⁹ Approximately 50% of the population has alveolar pneumatization.¹⁰ Our analysis revealed this variance in 234 sinuses, accounting for 58.5% of the total. Maxillary

atrophy due to tooth loss is marked by both vertical and horizontal bone resorption.¹¹ Sinus pneumatization, particularly when extending into the alveolar process, can worsen bone loss associated with maxillary atrophy, significantly reducing the bone available for dental implants.¹² As a result, there is not enough space to place dental implants and additional advanced surgical procedures are required. The maxillary sinus floor elevation procedure, which can be executed using either the crestal or lateral fenestration approach, is used to treat this quantitative change of the sinus cavity.¹³

Maxillary sinus hypoplasia (MSH) is defined as the underdevelopment of the maxillary sinus, potentially stemming from factors during embryological development such as trauma, surgical interventions, or structural abnormalities.¹⁴ A constricted infundibulum without a natural ostium can lead to mucosal thickening within the hypoplastic sinus. Sinus floor elevation treatment is contraindicated in cases of ineffective sinus ventilation, blocked sinus pathways, or obstructed sinus drainage.^{13,15} In a previous study, although the prevalence of MSH was 4.8 %, it was found to be 7.0 % in our study. This difference may be caused by racial origin.¹⁴ In a recent study by Misăiloaie et al., the incidence of hypoplasia was found to be 6.5%.¹⁶ Their findings are consistent with our study.

Antral septa, also known as maxillary sinus exostoses, are bony projections that can originate from any wall of the sinus.¹⁷ Although found in almost 50% of CBCT scans, these septa can complicate maxillary sinus floor elevation procedures by raising the likelihood of sinus membrane perforation.¹⁸ Complications such as acute or chronic sinusitis and bone graft resorption may arise from membrane perforation during such operation.¹⁹ The presence of septa can also make the surgical removal of the bone plate and membrane more difficult.^{1,14}

The present investigation revealed a septa prevalence of 43.7%, beyond the range of 16%–33% documented in prior literature.^{1,8} This discrepancy may be attributed to differences in imaging techniques, particularly the use of thin-slice CBCT intervals in our study. Although many studies have identified the middle region as the most common location for septa^{5,20,21} others have reported higher occurrences in the anterior and posterior regions.^{22,23}

An important arterial component found in the maxillary sinus's lateral wall is the alveolar antral artery. It is particularly crucial for surgical techniques like open sinus augmentation and Caldwell-Luc.²⁴ In addition to increasing the danger of Schneiderian membrane perforation, damage to these veins may cause bleeding, which would obscure the surgical field.²⁵ 93% of the sinuses in our study had the posterior superior alveolar artery, with the intraosseous region accounting for the majority (63.5%). The high-resolution imaging methods used in this investigation are responsible for the increased artery detection rate as compared to previous research.^{1,25-27} Apostolakis and Bissoon, Rathod et al., Tehranchi et al., and Velasco-Torres et al. all reach similar results, so our findings are consistent with theirs.²⁸⁻³¹

CONCLUSIONS

In conclusion, anatomical variations in the maxillary sinuses are frequently observed in maxillary CBCT scans used for dental implant planning. These variations can influence surgical planning, particularly for more specialized procedures, and should therefore be carefully identified during clinical evaluations. Assessing the location of the posterior superior alveolar artery, maxillary sinus morphology, and normal anatomical variations in preoperative CBCT imaging can aid in planning surgical treatments and contribute to the design of more successful outcomes.

Ethical Approval

The ethical approval for this study was obtained from the Alanya Alaaddin Keykubat University Clinical Research Ethics Committee (6792E-05/06).

Financial Support

The authors declare that this study received no financial support.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

Author Contributions

Design: BK, KS, Data collection or access: BK, Analysis and comments: BK, KS, Literature search: BK, KS, Writing: BK.

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