Is There a Relationship Between Maxillary Sinus's Inferior Pneumatisation and Sinonasal Variations? A Retrospective CBCT Study

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ABSTRACT

Objectives: This retrospective study aims to analyse alveolar and palatal process pneumatisation and their relationships with sinonasal variations using cone-beam computed tomography.
Material and Methods: The study included 500 patients aged 18 to 87 years, involving 1000 maxillary sinuses with cone-beam computed tomography scans. We examined the relationship between inferior maxillary pneumatisation and the following anatomic variations: Haller cell, concha bullosa, paradoxical concha, bifid concha, and septal deviation.
Results: Among the 1000 maxillary sinuses assessed, we found 223 (22.3%) with alveolar process pneumatisation (APP), 37 (3.7%) with palatal process pneumatisation (PPP), and 23 (2.3%) with the presence of both APP and PPP. Significant relationships were observed between the Haller cell ($P = 0.005$), nasal septum deviation ($P = 0.000$), and middle concha bullosa ($P = 0.01$) with APP. However, there were no significant relationships between the paradoxical middle concha ($P = 0.07$), bifid middle concha ($P = 0.74$), and APP. Similarly, significant relationships were observed between the Haller cell ($P = 0.001$), paradoxical middle concha ($P = 0.009$), bifid middle concha ($P = 0.000$), and PPP. However, there were no significant relationships between concha bullosa ($P = 0.799$) and PPP. Additionally, we found significant relationships between the Haller cell ($P = 0.003$) and the presence of both APP and PPP.
Conclusions: This study provides an anatomical basis for imaging diagnosis by investigating the frequency of inferior pneumatisation of the maxillary sinus and its relationship with certain sinonasal variations.

Keywords: anatomic variation; cone-beam computed tomography; maxillary sinus.

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INTRODUCTION

The maxillary sinus is located within the body of the maxilla and is the largest of the paranasal sinuses and is the first to develop. The alveolar process of the maxilla forms the lower border of the maxillary sinus [1]. Pneumatisation of the maxillary sinus is the physiological process that causes the volume of the maxillary sinus to increase. After birth, the maxillary sinuses are fully developed and continue to pneumatize as the permanent teeth erupt [2].

The common occurrence of inferior pneumatisation, where the maxillary sinus extends into the alveolar process, holds significant clinical importance when considering tooth extraction or dental implant placement in the area [3]. Increased levels of pneumatisation of the alveolar bone can result in a higher incidence of odontogenic sinusitis, leading to complications in dental implantation [4]. Studies have shown that maxillary sinus pneumatisation increases after extraction of maxillary posterior teeth [5]. Due to the extensive pneumatisation of the maxillary sinus, there is a risk of oro-antral fistula (OAF) development after the extraction of teeth whose roots are associated with the maxillary sinus, forming a pathological relationship between the oral cavity and the maxillary sinus [6,7]. Inferior pneumatisation of the maxillary sinus also increases the possibility of tooth roots displacing into the maxillary sinus [8].

The natural tendency of the maxillary sinus to pneumatise the bone throughout one's lifetime and the rapid alveolar bone resorption following tooth loss lead to inadequate bone volume for implant placement. The size of the maxillary sinus cavity also plays a role in determining the extent of bone regeneration. The insufficient bone volume for implant placement carries the risk of oro-antral communication, necessitating the possibility of elevating the maxillary sinus floor and/or using graft material in such cases. Having a good understanding of this region and conducting preoperative three-dimensional assessments will boost the clinician's confidence, familiarity with common anatomical variations, and help them avoid such serious complications [2,5,6,9].

Various imaging modalities, including cone-beam computed tomography (CBCT) [3,10,11] and computed tomography (CT) [4,12], have been employed in existing literature to assess the nasal cavity and maxillary sinuses. CBCT is essential in oral and maxillofacial surgery, implantology, endodontics, periodontics, orthodontics, and the diagnosis of temporomandibular disorders for three-dimensional imaging [13,14]. It is also employed in dental applications, including the evaluation of tooth morphology, determination of nerve pathways, assessment of bone defect morphology, as well as in maxillofacial contexts, such as the evaluation of paranasal sinuses [15,16]. With the widespread use of CBCT, the examination of the maxillary sinus can be done in more detail, and anatomy anomalies and pathologies can be detected better [17,18].

Anatomical variations are common in the sinonasal region and their effects on the maxillary sinus are still controversial [11]. Previous studies have assessed the incidence and findings of sinonasal variations on maxillary sinus volume [10-12,19-22]. The role of sinonasal variations as potential contributors to the development of inferior pneumatisation of the maxillary sinus remains relatively less understood. These obstructions may result in alterations in sinus air pressure, potentially leading to pneumatisation [3]. However, to the best of our knowledge, there are a few studies investigating the relationship or effect of these findings on the alveolar process pneumatisation (APP) and/or palatal process pneumatisation (PPP) of the maxillary sinus [3,4].

The aims of this retrospective study were to evaluate the extensive pneumatisation of the maxillary sinus using cone-beam computed tomography and to determine the anatomic factors affecting maxillary sinus pneumatisation.

MATERIAL AND METHODS

Study design

For this retrospective study, a total of 500 patients' CBCT images in the archives of the Vadi Ankara Clinic in Ankara, Turkey, between January 1, 2020, and January 1, 2023, were assessed by a dentomaxillofacial radiologist with 10 years of clinical expertise. Before analysis of the all data, the dentomaxillofacial radiologist (S.G.) and oral surgeon (A.Y.G.) assessed CBCT scans of 30 patients for calibration. Inter-observer reliability - the calibration was done ($\kappa = 0.912$, $P < 0.001$). Whenever there was a suspected scan the two researchers (S.G., A.Y.G.) made the final decision together.

The ethical approval for the study was obtained from the Institutional Review Board, Department of Dentomaxillofacial Radiology, Ankara Medipol University, Ankara, Turkey (Decision No: 28).

Eligibility criteria

Inclusion criteria: dentulous CBCT scans of patients who had to be at least 18 years of age and both sinuses had to be revealed completely were included in the study. The pneumatization of the maxillary sinus into the alveolar process is frequently observed after tooth extraction in the molar maxilla; therefore, patients with molar teeth were included in the study [23].

Exclusion criteria: scans exhibiting errors, artifacts, and inadequate coverage of the area of interest (images in which the sinonasal region, nasal cavity, and maxillary sinus are not visualized) were eliminated from the analysis. Additionally, CBCT scans from patients with orofacial syndromes impacting skeletal structures and patients with cleft palate were also excluded. CBCT scans showing evidence of sinus pathologies, signs of prior surgical interventions in the sinus region, and artifacts that hindered accurate assessment were excluded from the study. CBCT scans that showed sinuses with polyps, sinus opacifications, retention cysts, tumours, and malignancies were excluded from the study. However, mucosal thickenings were not excluded from the study.

CBCT images acquisition and evaluation

The CBCT scans were acquired utilizing the X-Radius Trio Plus (Castellini; Bologna, Italy), which operated at 90 kVp and 10 mA for image acquisition. The tomography device had a voxel size of 68 µm and a field of view (FOV) measuring 130 x 160 mm.

The data were evaluated with the iRYS viewer software version 6.2 (MyRay CBCT; Bologna, Italy) with Advantech KT R240FEE 24-inch medical LCD monitor (Advantech by Kostec; Gangwon, South Korea) with a 1920 x 1080 pixels resolution in order to achieve a higher-quality radiographic examination.

Intra-observer agreement of the dentomaxillofacial radiologist (S.G.) on the radiographic parameters was determined by calculating Cohen's kappa (κ) value by re-evaluating 30 randomly selected CBCT images at an 8-week interval ($\kappa = 0.934$, $P < 0.001$).

For dentate patients, the condition is classified as pneumatized when the apices are encased by the sinus mucosa. In the case of partially edentulous patient, pneumatisation is determined if the vertical height of the alveolar bone measures less than 10 mm [3]. Sinonasal variations such as nasal septum deviation, Haller cell, middle concha bullosa, middle bifid concha, and paradoxical middle concha in the maxillary sinus were recorded (Figure 1). Nasal septum deviation was characterized by a displacement of more than 4 mm from the midline to either the left or right side. To define a Haller cell, the criteria involve identifying air cells located along the medial section of the orbital floor and/or the lamina papyracea, below the bulla ethmoidalis, and considering these air cells regardless of their size [3]. Concha bullosa refers to the pneumatisation, or air cell development, within the middle turbinate, making it the most prevalent anatomical variation found in the osteomeatal unit [22]. In our study, we classified the bifid concha as either a bifid morphology or a duplication of the middle turbinate. Paradoxical middle concha was identified by its convexity from the lateral to medial direction, which contrasts with the typical course of the middle concha [11].

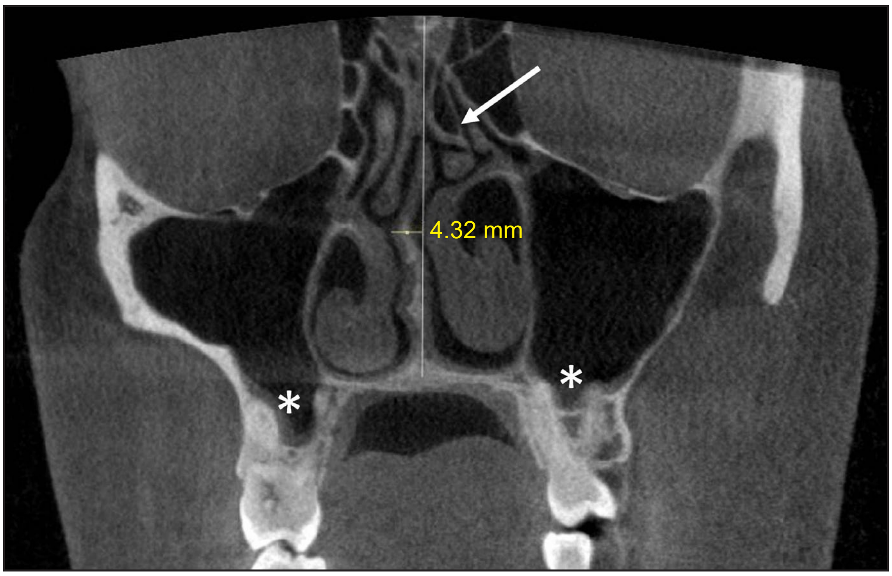

Figure 1. The figure illustrates the pneumatisation of the alveolar process in both bilateral maxillary sinuses using asterisks in the CBCT coronal section. A notable finding is the rightward deviation of the nasal septum by 4.32 mm. Moreover, the figure highlights the presence of concha bullosa and paradoxical concha variations in the left middle turbinate, conveniently marked by an arrow.
*Pneumatisation of the alveolar process.

Statistical analysis

The data were statistically analysed using IBM SPSS® Statistics software version 25 (IBM Corp.; Armonk, New York, USA). Parametric data were expressed as mean and standard deviation (M [SD]). A statistically significant level was determined with P-values less than 0.05 using the Chi-square test (χ^2) for the data analysis.

RESULTS

In a total of 500 patients, 250 male and 250 female patients with a mean age of 40.16 (SD 15.79; min 18, max 87), involving 1000 maxillary sinuses were evaluated.

In a total of 1000 maxillary sinuses, 223 (22.3%) APP, 37 (3.7%) PPP, 23 (2.3%) both APP and PPP were found.

When the pneumatisation of the inferior maxillary sinus are compared according to gender, APP is more common in men (1.04 : 1), PPP is seen at an equal rate (1 : 1) in both genders, and the incidence of both APP and PPP is more common in women (1.09 : 1), but there is no statistical difference. Comparison of gender and inferior maxillary sinus pneumatisation is shown in Table 1.

When nasal septum deviation was evaluated, nasal septum deviation was recorded in 303 (60.6%) of 500 patients. Of the patients with septal deviation, 112 (22.4%) had alveolar process pneumatisation, 20 (4%) had palatal process pneumatisation, and 4 (0.8%) had both alveolar and palatal process pneumatisation. A statistically significant difference was found between alveolar process pneumatisation and nasal septum deviation (P = 0.000) as shown in Table 2.

Statistically significant differences were observed in the comparison of inferior maxillary sinus pneumatisation with Haller cell and conchal variations and are revealed in detail in Table 3.

Table 1. Gender distribution of inferior pneumatisation of maxillary sinus

	Female	Male	P-value[a]
	Presence	Presence	
	N (%)	N (%)	
APP	75 (15)	78 (15.6)	0.771
PPP	15 (3)	15 (3)	1
APP and PPP	12 (2.4)	11 (2.2)	0.831

[a]Statistically significant at level P < 0.05 (Pearson Chi-square test).
APP = alveolar process pneumatisation; PPP = palatal process pneumatisation; N = number.

DISCUSSION

A retrospective analysis of 1000 maxillary sinuses belonging to 500 patients' CBCT scans was performed. The present study revealed a statistically significant difference in alveolar process pneumatisation concerning nasal septum deviation, Haller cell, and conchal variations (including concha bullosa, paradoxical concha, and bifid concha). These variations were chosen because they have the potential to impact both the airflow velocity and the pneumatisation of the sinus [4,24-26].

Table 2. Relationship between septal deviation and pneumatisation

	Nasal septum deviation		P-value[d]
	Presence	Absence	
	N (%)	N (%)	
APP	112 (22.4)	41 (8.2)	0.000[a]
PPP	20 (4)	10 (2)	0.611[b]
APP and PPP	4 (0.8)	3 (0.6)	1[c]

[a]Pearson Chi-square test; [b]Yates's continuity correction; [c]Fisher's exact test.
[d]Statistically significant at level P < 0.05.
APP = alveolar process pneumatisation; PPP = palatal process pneumatisation; N = number.

Table 3. Relationship of Haller cell, concha bullosa, paradoxical concha and bifid concha with pneumatisation

	Haller Cell			Concha bullosa			Paradoxical concha			Bifid concha		
	Presence	Absence	P-value[a]	Presence	Absence	P-value[a]	Presence	Absence	P-value[a]	Presence	Absence	P-value[a]
	N (%)	N (%)		N (%)	N (%)		N (%)	N (%)		N (%)	N (%)	
APP	18 (1.8)	205 (20.5)	0.005	130 (13)	93 (9.3)	0.01	46 (4.6)	177 (17.7)	0.074	1 (0.1)	222	0.74
PPP	6 (0.6)	31 (3.1)	0.001	18 (1.8)	19 (1.9)	0.799	12 (1.2)	25 (2.5)	0.009	2 (0.2)	35	0.000
APP and PPP	4 (0.4)	19 (1.9)	0.003	11 (1.1)	12 (1.2)	0.78	7 (0.7)	16 (1.6)	0.074	0	23	0.706

[a]Statistically significant at level P < 0.05 (Pearson Chi-square test).
APP = alveolar process pneumatisation; PPP = palatal process pneumatisation; N = number.

Physiologically, the maxillary sinus is constantly ventilated after birth. It has been reported in the literature that sinus pneumatisation may occur due to uncertain heredity, growth hormones, air pressure in the sinus cavity, craniofacial configuration, bone density and sinus surgery [3,27]. Clinicians performing preprosthetic and preimplant surgical procedures in the posterior maxilla must carefully consider the extent of teeth root protrusion into the sinus. This consideration is crucial due to the potential risk of sinus pneumatisation following tooth extractions, which could reduce the available bone at the implant or denture site. Being mindful of this factor is essential to ensure successful treatment outcomes and optimal long-term stability for dental prosthetics and implants in this region [28].

Implant treatment in the posterior maxilla raises a significant concern due to the presence of the maxillary sinus. The sinus's varying extension towards the coronal direction can pose limitations on the bone height required to accommodate implants of sufficient length. Consequently, the available bone height plays a crucial role in determining the level of surgical invasiveness needed for the procedure [27]. Frequent anatomical variations in the sinonasal region are quite common, and these variations can significantly influence the development of the maxillary sinus due to their close anatomical proximity [11].

The largest paranasal sinus is the maxillary sinus, characterized by its pyramid shape. It is situated immediately behind the anterior bone surface of the midface, encompassed by surrounding bone structures. The development of the maxillary sinuses initiates during the prenatal period, with a volume ranging from 6 to 8 cm^3 at birth. The postnatal period encompasses two rapid developmental phases for the maxillary sinus: from birth to three years old and between the ages of 7 and 12. Further development of the maxillary sinus continues between the ages of 12 and 15 until it reaches its adult size at the age of 15 [11].

Histologic examinations have demonstrated that the pneumatisation process in the sinus involves osteoclastic resorption of its cortical walls and the deposition of osteoid below them, where physiological appositional bone growth can contribute to pneumatisation, and tooth extraction can expedite this process [3]. Nevertheless, hereditary factors, bone density, and variations in sinus air pressure may influence its efficiency, resulting in a sinus pneumatisation process governed by an unclear and multifactorial mechanism [27].

Diverse developmental and pathological conditions may influence maxillary sinus morphology [29]. The maxillary sinus shares a close connection with the roots of the posterior maxillary teeth, and it is widely acknowledged that mucosal diseases and sinusitis of odontogenic origin occur frequently in this context [30]. The anatomical characteristics of the paranasal sinuses in individuals with chronic rhinosinusitis, especially those without cystic fibrosis, have not been thoroughly investigated. In a study by Kim et al. [31], it was observed that patients with chronic rhinosinusitis exhibited similar paranasal sinus pneumatization compared to healthy controls, although cystic fibrosis patients displayed compromised sinus development. In a previous study, in cases of long-standing pediatric chronic rhinosinusitis, there is a reduction in the volume of the maxillary sinuses, accompanied by an increase in the thickness of the sinus walls [30]. Conversely, another study by Marino et al. [32] revealed that chronic sinusitis is associated with increased paranasal sinus pneumatization when evaluated using a comprehensive and validated clinical measure.

Additionally, pneumatisation may be affected by the narrowing of the osteomeatal complex and the presence of accompanying maxillary sinus disease. Göçmen et al. [3] did not observe any statistically significant relationship between pneumatisation and these anatomical variations: septal deviation, concha bullosa and Haller's cell. Based on the findings of Anbiaee et al. [4], it was observed that nasal septal deviation did not have a significant impact on maxillary sinus volume and pneumatisation. Additionally, Demir et al. [20] demonstrated no correlation between the presence of concha bullosa and the volume of the maxillary sinus. Furthermore, the findings of Anbiaee et al. [4] revealed that there were no associations between maxillary sinus pneumatisation and anatomical variations, such as the size of the ostium, nasal septal deviation, sinus septa, and concha bullosa. According to the research conducted by Tassoker et al. [22], there was no observed association between the presence of concha bullosa, nasal septum deviation, and the volume of the maxillary sinus. Contrary to the others, Kapusuz Gencer et al. [26] demonstrated that in cases of severe septum deviations, maxillary sinus volumes tended to be higher on the contralateral side. The present study showed a statistically significant difference in inferior pneumatisation of the maxillary sinus concerning anatomical variations like nasal septum deviation, Haller cell, and conchal variations. Nonetheless, this study is subject to several limitations. We utilized CBCT images from both patients with and without mucosal thickening, which introduces a potential source of confounding due to the heterogeneous patient characteristics. Additionally, other limitations are inherent to the cross-sectional study design, which inherently carries bias owing to its retrospective nature.

CONCLUSIONS

In conclusion, our study has revealed significant correlations between various anatomical features and the pneumatization of the maxillary sinus. Notably, we found that the presence of a Haller cell, nasal septum deviation, and middle concha bullosa were all significantly associated with alveolar process pneumatisation, highlighting the impact of these anatomical variations on maxillary sinus morphology.

Furthermore, our analysis demonstrated significant relationships between the Haller cell, paradoxical middle concha, and bifid middle concha with palatal process pneumatisation. These findings underscore the importance of considering these anatomical factors when evaluating maxillary sinus pneumatization.

Additionally, our study revealed that individuals exhibiting both alveolar process pneumatisation and palatal process pneumatisation were significantly associated with the presence of a Haller cell. This suggests a potential synergistic effect between these anatomical variations, further emphasizing the intricate interplay between maxillary sinus morphology and surrounding anatomical structures.

Overall, our findings contribute to a better understanding of the complex relationships between anatomical features and maxillary sinus pneumatization, providing valuable insights for clinicians and researchers in the field of oral and maxillofacial surgery.

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The authors report no conflicts of interest related to this study.

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