IJTMGH International Journal of Travel Medicine and Global Health

Int J Travel Med Glob Health. 2024 Dec;12(4):241-249 doi 10.30491/ijtmgh.2024.434264.1402
http://ijtmgh.com

Original Article Open Access

Evaluating the Correlation between Maxillary Sinus and Maxillary Canine Root Tip in Cone Beam Computed Tomography

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Received 2024-01-06; **Accepted** 2024-06-15; **Online Published** 2024-12-01

Abstract

Introduction: Recognizing the variable anatomy of the Maxillary Sinus (MS) and its proximity to the developing maxillary canines, this study aimed to evaluate the correlation between MS and maxillary canine root apex in cone beam computed tomography (CBCT).

Methods: In this cross-sectional analytical study all CBCT scans of patients were reviewed retrospectively. Random sampling was used to select the CBCT scans of patients. When the MS extended to the canine area, the vertical distance between them was measured, and their relationship was classified into three types: I (more than 2 mm distance), II (less than 2 mm distance or in-contact), and III (interlock).

Results: Most of the cases of relation between the apex of the canine tooth root and the floor of the maxillary sinus were type 1 (92.9%), followed by type 2a with a frequency of 3.7%, type 3 with a frequency of 2.7% and type 2b with a frequency of 0.7%. The relationship between the apex of the root of the canine tooth and the floor of the maxillary sinus was not significant based on sides (P=0.583), but there was a significant difference based on gender (P=0.025).

Conclusion: In most cases, the MS encroached upon the canine region and occasionally extended into the incisor area. This observation underscores the need for heightened vigilance during surgical interventions involving the maxillary anterior sextant.

Keywords: Maxillary sinus, Anterior extension, Canine apex, Cone beam computed tomography

Citation: Payahoo S, Ghaznavi A, Chehreara Z, Ghoharfar Z. Evaluating the Correlation between Maxillary Sinus and Maxillary Canine Root Tip in Cone Beam Computed Tomography. Int J Travel Med Glob Health, 2024;12(4):241-249. doi:10.30491/ijtmgh.2024.434264.1402

Introduction

Maxillary Sinuses (MS), the largest of the paranasal sinuses, exhibit a rudimentary form at birth and undergo gradual pneumatization until skeletal maturation is complete [1]. These pyramidal-shaped structures [2] are anchored to the lateral nasal wall and culminate in the zygomatic process of the maxilla [3]. At birth, the MS volume averages 6-8 cm^3, expanding progressively to its mature size (8.6-24.9 cm^3) between 12 and 15 years [4]. Their spatial extent typically spans from the distal aspect of the canine tooth to the posterior wall of the maxilla above the tuberosity [5]. Additionally, canine roots may closely approach the MS's inferior wall, particularly when impacted [3].

Prior to the advent of three-dimensional (3D) imaging techniques, the MS size was predominantly assessed using conventional two-dimensional (2D) radiographs [6]. These conventional radiographs, however, offered limited information in fully delineating the complex three-dimensional anatomy of the MS [7]. To address this limitation, 3D imaging modalities have gained prominence, particularly in cases involving suspected sinus issues or the need for a comprehensive sinus assessment prior to surgical interventions [8]. Cone beam computed tomography (CBCT) emerged as a favored 3D imaging modality, endorsed by the American Academy of Oral and Maxillofacial Radiology for its ability to detect and diagnose dental anomalies associated with palatally displaced canines [7]. CBCT excels in providing accurate and distortion-free images of the craniofacial bones while simultaneously delivering a reduced radiation dose compared to multi-slice computed tomography [9, 10]. A study by Guarnieri et al. [11] reinforced the significance

of CBCT in distinguishing subtle anatomical variations and potential complications, highlighting its role in guiding treatment decisions for palatally displaced canines.

The growth and development of the MS may be influenced by the development of the maxillary teeth. While numerous studies have examined the relationships between the posterior teeth and the MS [12], [13], the anterior region of the maxilla is often considered a relatively safe zone for surgical interventions [14]. Cavalcanti et al. [15] demonstrated a positive correlation between the extent of sinus expansion following dental extraction and the length of tooth roots projecting into the sinus. However, research specifically evaluating the connections between the maxillary canine and the MS is limited [16, 17]. A recent CBCT study [12] revealed that the MS extends to the canine region in 68.9% of cases and the incisor region in 15.5%. The prevalence of sinus encroachment into the canine area underscores the need for a thorough assessment of the region to understand the interplay between the MS and the dentition. Notably, only one CBCT study has specifically explored this relationship [18].

Given the variable anatomy of the MS and its proximity to the developing maxillary canines, evaluating the MS during orthodontic treatment planning for patients with maxillary canine displacement could aid in understanding the root causes of canine displacement and enhancing treatment outcomes. This study aimed to quantify the relationship between the MS's vertical extension towards the canine root apex and the distance between the MS's floor and the canine apex, considering variations in gender and anatomical features, employing corrected CBCT planes for precise measurements.

Methods

This cross-sectional analytical study has been performed following the Declaration of Helsinki and was approved by the Ethics Committee of Urmia University of Medical Sciences, Urmia, Iran (Code: IR.UMSU.REC.1401.137). In this study, all CBCT scans of patients who attended the Oral and Maxillofacial Department of Urmia Dental School (from May 2021 to May 2020) were reviewed retrospectively. The CBCT images used in this study were not specifically acquired for this research. Instead, they were obtained for other clinical purposes, but they were selected by convenience sampling method. This sampling approach enabled the inclusion of a diverse range of patients in the study.

To be included in the study, the CBCT images needed to encompass the entire maxilla of individuals over 20 years of age, and both maxillary canines had to be fully erupted and developed. Exclusion criteria included distorted CBCT images due to metallic or motion artifacts, a history of previous apical surgery, evidence of root resorption or fracture, intra-bony pathologies, supernumerary or missing teeth, extracted or impacted teeth in the maxilla, congenital anomalies, or severe jaw deformities. Moreover, high-buccal canines, not aligned with the incisal/occlusal surface of the dentition, were excluded from the study.

Sampling Method

The minimum sample size was calculated using the results of Khojastepour et al.'s study [17], taking into account the prevalence of 68.9% for maxillary sinus expansion in the area of canine teeth and the following formula, finally 330 cases were calculated. Computing power was considered 80%.

$N = Z2.p(1-p)/d2$

$Z = 1.96$ (error coefficient of the relevant study)

$d=0.05$ (dependant standard error)

All CBCT images were acquired using a Planmeca ProMax 3D cone beam computed tomography device (Helsinki, Finland) with the following technical parameters: 10 milliamperes (mA) current, 1.8 seconds exposure time, 90 kilovolt peak (kVp) voltage, 0.3 millimeter [17] voxel size, 0.3 mm axial pitch, and 0.3 mm axial thickness. The Frankfort horizontal plane of all subjects was ensured to be parallel to the floor during image acquisition. To ensure accurate measurements, all measurements were performed using Romixis 5.1.1 software on a 42-inch monitor with high-definition [19] image quality (1080 x 720 optical pixels) in a room with minimal light pollution. Two oral and maxillofacial radiologists independently performed all measurements, and any discrepancies were resolved through consensus. To assess inter-observer reliability, one-third of the CBCT scans (100) were re-evaluated by the same observers after a two-week interval. This re-evaluation demonstrated high intra-observer reliability, with an intraclass correlation coefficient (ICC) of 0.987 for the vertical distance from the apex of the canine tooth to the floor of the maxillary sinus and 0.988 for the horizontal distance between the apex of the canine tooth and the buccal surface of the maxilla.

The study sample was categorized into three age groups: 20–30, 30–40, and 40–50. The subjects were distributed evenly in these age groups as each category of age included 120 scans (240 maxillary sinuses). The evaluators initially identified the most anterior extent of the MS border on axial CBCT images for each subject. Next, they created panoramic views by reconstructing images along a curved line parallel to the dental arch at the cervical level of the dentition. These axial and reconstructed panoramic views served as reference planes

for locating the anterior MS border in cross-sectional images. Bucco-lingual cross-sections were generated perpendicular to the dental arch, with each section spaced 0.5 millimeters apart. Then, the position of the anterior sinus border relative to various teeth was recorded. For cases where the MS extended to the canine region, three additional measurements were taken:

1. AEMS beyond the canine tooth long axis: This measurement assessed the vertical distance between the anterior maxillary sinus border and the long axis of the canine tooth, indicating the extent of sinus penetration into the canine region.
2. Vertical relationship between the maxillary sinus floor and canine apices: This measurement gauged the proximity between the maxillary sinus floor and the apices of the canine teeth, evaluating the potential for sinus intrusion into the root apices.
3. Absolute vertical distance between the maxillary sinus floor and floor of nasal fossa (MS-NF): This measurement determined the vertical separation between the maxillary sinus floor and the bottom of the nasal fossa, providing an overall assessment of sinus pneumatization.

To quantify the extent of sinus penetration into the canine area, the evaluators counted the number of cross-sectional slices where maxillary sinus pneumatization extended beyond the long axis of the canine tooth. The corresponding slice thickness (0.5 mm) was multiplied by the number of slices to calculate the accumulated extension of maxillary sinus (AEMS) beyond the canine tooth long axis. For instance, if sinus pneumatization was observed on eight slices beyond the canine long axis, the AEMS would be 4 mm (8 × 0.5). The canine tooth long axis was defined as a line passing through the center of the tooth, connecting the middle point of the incisal edge to the apex. The vertical relationship between the maxillary sinus floor and canine teeth apices was categorized into three types based on their spatial arrangement (Fig.1):

1. Type 1: Apex located below the sinus floor with more than 2 mm distance. This indicates that the canine root apex lies securely within the alveolar bone and is not in direct contact with the sinus floor (Fig.2).
2. Type 2: Apex located below the sinus floor with less than 2 mm distance. This classification includes two subcategories: a. Type 2a: Less than 2 mm apart (Fig.3). The canine root apex is very close to the sinus floor, with minimal space separating the two structures. b. Type 2 b (Fig.4): Completely stuck to the sinus floor. The canine root apex virtually touches the sinus floor, indicating a high risk of potential sinus intrusion.
3. Type 3 (Fig.5): Apex located above the sinus floor (entered into the sinus). In this type, the canine root apex has penetrated into the maxillary sinus space, potentially causing complications during dental procedures.

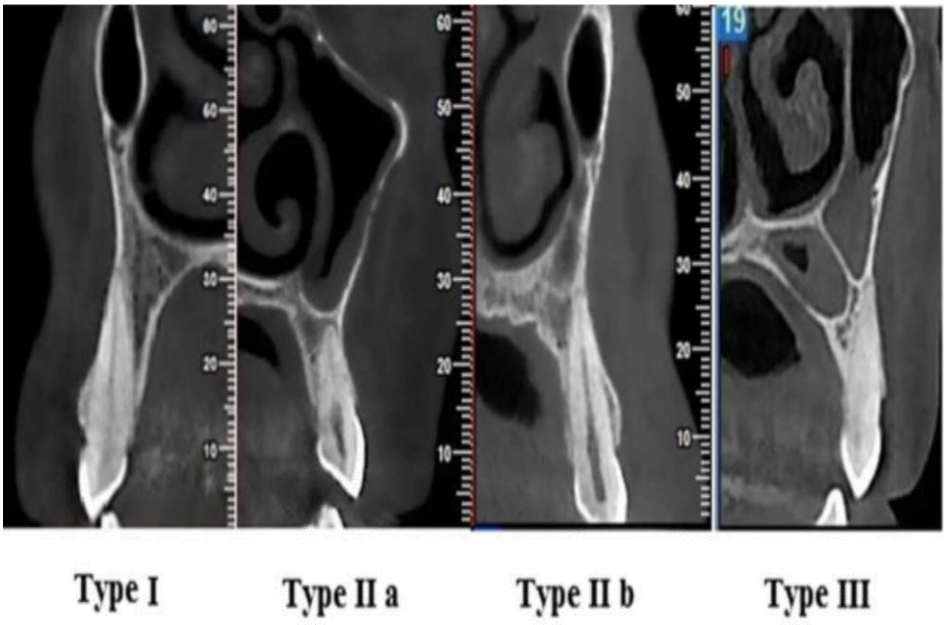

Figure 1. Division of the dental apex position relative to the maxillary sinus (15)

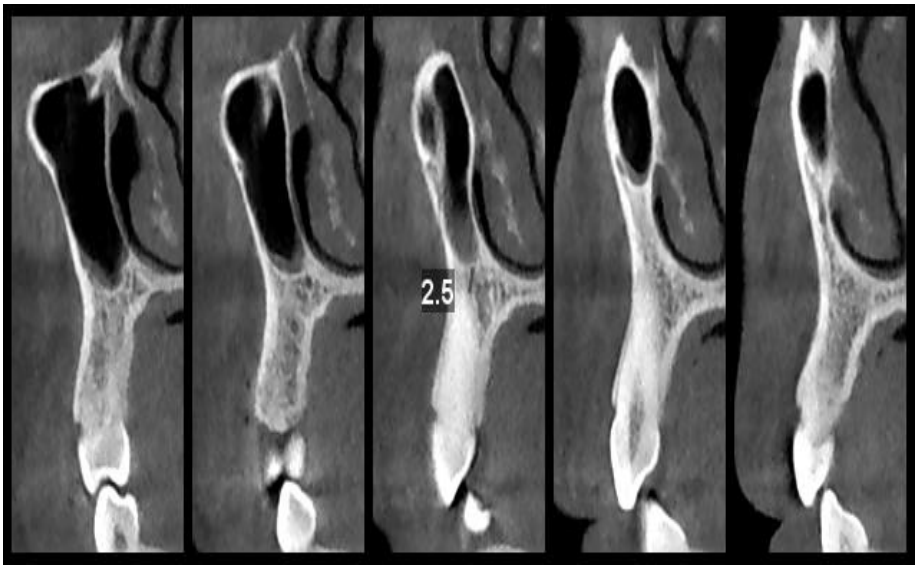

Figure 2. Type 1 relationship between the maxillary sinus and the apex of the canine tooth root

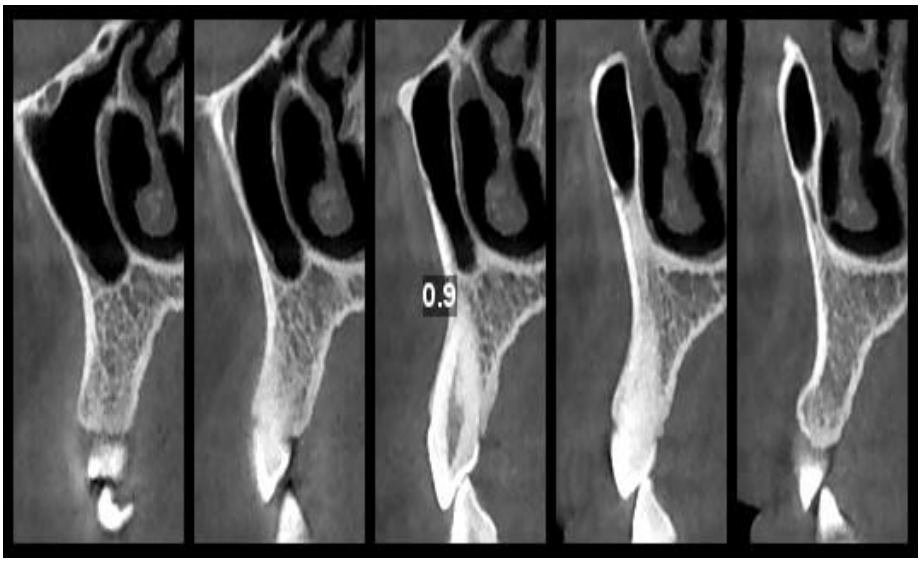

Figure 3. Type a2 relationship between the maxillary sinus and the apex of the canine tooth root

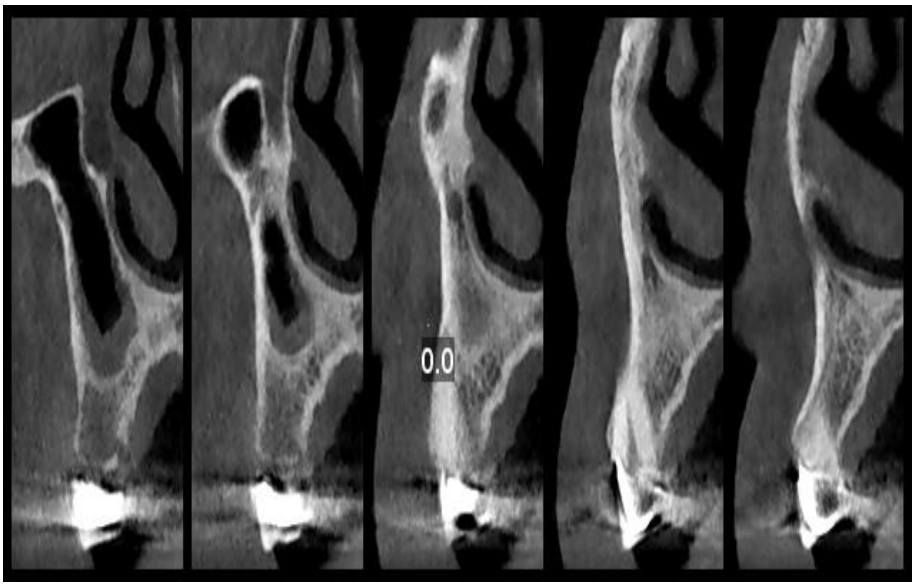

Figure 4. Type b2 relationship between the maxillary sinus and the apex of the canine tooth root

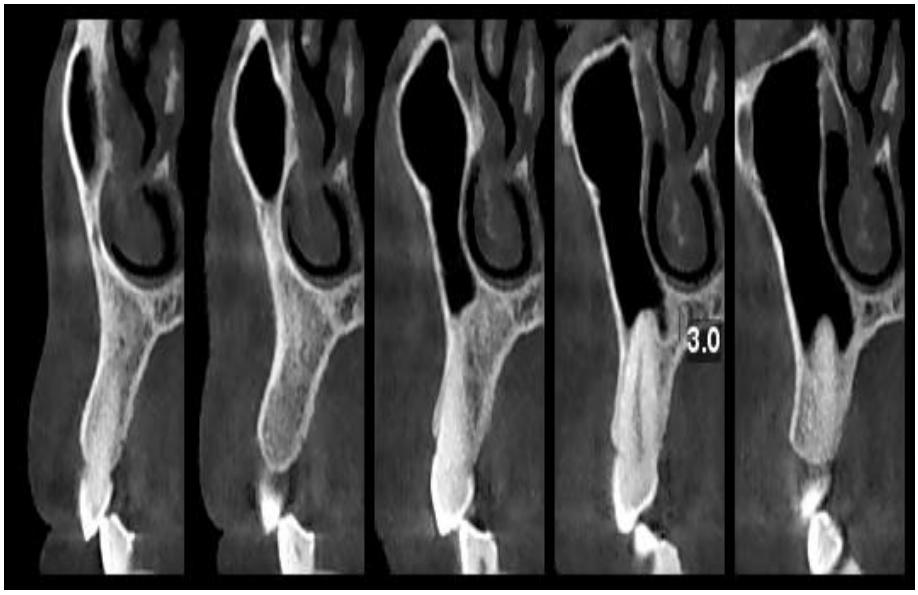

Figure 5. Relationship between the maxillary sinus and the canine root apex

Statistical Analysis

The findings of the study were presented using descriptive statistics, including means, standard deviations, and frequencies (percentages). Statistical tests, such as Fisher's exact test and chi-square, were employed to examine the association between demographic factors, the studied side, and the classification of the relationship between the canine tooth root apex and the MS floor. Statistical analysis was conducted using SPSS version 21 software. The level of significance was set at $P \leq 0.05$.

Results

In this study, of 427 CBCT images of individuals, 360 images (720 Upper canine teeth) met the study inclusion criteria and were evaluated. The mean age of subjects was 35.12 ± 8.40 years. The study sample consisted of 155 (48.5%) women and 16 (51.5%) men. Most of the cases of upper canine contact with MS were Type 1 (92.9%), followed by Type 2a with a frequency of 3.7%, Type 3 with a frequency of 2.7% and Type 2b with a frequency of 0.7% (Table 1).

The type of relation between MS and maxillary canine root apex according to age, gender, and side is shown in Table 2. The frequency of Type 1 was higher than other Types in all three age groups (84.17%, 82.5 %, 86.67 %, respectively). However, no significant difference was observed between type of relation of the MS and the apex of the upper canine tooth root with age groups (P=0.97).

Table 1. Demographic characteristics of the patients and the type of relation between the canine tooth and the maxillary sinus in the investigated cases

Variables	Frequency (%)
Mean age (years)	35.12 ± 8.40
Gender	
Male	186(51.5%)
Female	175(48.5%)
Type of relation	
Type 1	671(92.9%)
Type 2a	27(3.7%)
Type 2b	5(0.7%)
Type 3	19(2.7%)

Frequency of Type 1 was high in male compared to female (94.6% vs. 91.4%), Type 2a was high in women compared to men (4.5% vs. 2.2%), Type 2b was high in men compared to women (1.6% vs. 0.3%), and Type 3 was high in women than men (2.9% vs. 1.9%). According to the results of Fisher's exact test, this difference was significant (P=0.025) and the type of relation between the maxillary sinus and the canine tooth root apex was different between males and females (Table 2).

The frequency of Type 1, 2a and 2b was higher on the right side than on the left side (93.1% to 92.8%, 4.2% to 3.3% and 1.1% to 0.8%, respectively). The frequency of Type 3 was higher on the left side than on the right side

(1.3% vs. 1.7%). However, according to the results of the chi-square test, this difference is not statistically significant (P=0.583) and the type of relation between the maxillary sinus and the apex of the upper canine tooth root has no significant relationship with the side of the jaw (Table 2).

Table 2. Maxillary sinus relation with canine tooth root apex based on gender and side

Variables	Maxillary sinus and canine apex relation				P-value
	Type 1	Type 2a	Type 2b	Type 3	
Age					
20-30	101(84.17%)	6 (5.0%)	5(4.17%)	8 (6.67%)	
30-40	99(82.5%)	7(5.83%)	5(4.17%)	9(7.5%)	0.97
40-50	104(86.67%)	4(3.33%)	6(5.00%)	6(5.0%)	
Gender					
Male	351(94.6%)	8(2.2%)	6(1.6%)	7(1.9%)	0.025
Female	320(91.4%)	19(5.4%)	1(0.3%)	10(2.9%)	
Side					
Right	336(93.1%)	15(4.2%)	4(1.1%)	6(1.7%)	0.583
Left	335(92.8%)	12(3.3%)	3(0.8%)	11(3.1%)	

Discussion

In this study, we analyzed the extent to which the MS extends beyond the long axis of the maxillary canine and the relationship between the root apex of the permanent maxillary canine and the MS floor using 361 CBCT images. These images were acquired for patients undergoing orthodontic treatment, aligning with the recommendations of the American Academy of Oral and Maxillofacial Radiology for evaluating anomalies associated with displaced canines [7]. Bjerklin and Ericsson [20] demonstrated that treatment plans were altered in 43.7% of cases due to the additional information obtained from CBCT scans. CBCT provides detailed measurements of the MS, including its height, width, length, and volume, as well as intricate 3D assessments of the maxillary canine crowns and roots. Such detailed information cannot be obtained from conventional periapical or panoramic radiographs [21]. The proximity between the sinus floor and the root apices of the maxillary teeth is crucial for various clinical procedures, such as endodontic surgery, orthodontic treatment, and implant placement [22].

This study found that when the MS extended to the canine region, the apices were most frequently located below the sinus floor and at least 2 mm away (type 1), accounting for 92.9% of the cases. Type 2a (close contact with the sinus floor) and type 3 (penetration into the sinus) were less common, occurring in 3.7% and 2.7% of cases, respectively. These findings align with those of a recent study by Oishi et al. [18], who also observed a higher prevalence of type 1 and a lower prevalence of type 3 relationships when the sinus extended to the canine area. Notably, Oishi et al. excluded cases where the sinus floor did not rise above the canine apices (type 0) from their analysis. Type 1, 2, and 3 are reserved for separate, in-contact, and interlock relationships between the MS floor and canine apices. Both studies demonstrated that type 1 was the most common relationship and type 3 was the least frequent, highlighting the spatial separation between the maxillary sinus and the canine root apex in most cases. This knowledge is crucial for orthodontists to safely guide canine eruption and avoid potential complications.

Several studies have revealed that unlike canine teeth, the root apices of the posterior maxillary teeth, particularly the molars, are more likely to be in contact with the sinus floor (without penetration) [23]. Khojastepour et al. [17] observed that in most cases, the canine root apex exhibited a type 1 relationship with the MS floor (84.9%), a lower frequency than our findings. Additionally, they reported a frequency of 8.9% and 6.05% for types 2 and 3

relationships, respectively, which were higher than those observed in our study. Zhang et al. [12] also found that approximately 50-60% of the maxillary first and second molar root apices have a type 1 connection with the MS floor, while the occurrence of types 2 and 3 relationships is proportional to the root apex length. In general, while the frequency of different types of relationships between the canine root apex and the MS floor was similar across studies, the frequency of types 2 and 3 relationships, which indicate a closer proximity and increased risk of maxillary sinus involvement during endodontic procedures, is higher in the maxillary posterior teeth compared to the canines. However, the potential for canine root apex penetration into the MS floor cannot be overlooked and should be carefully considered during dental interventions.

The present study revealed a significant gender difference in the prevalence of type 3 relationships between the maxillary canine root apex and the MS floor, with a higher frequency among women than men. Conversely, Tafakhori et al. [24] found no significant association between the frequency of different canine root apex-maxillary sinus floor relationships and gender or age. Similarly, other studies reported no significant correlation between these relationships and gender [25, 23, 26]. This discrepancy among studies can be attributed to variations in maxilla morphology among individuals of different genders and ethnicities.

The study findings demonstrated that Type 1 relationship between the MS and the maxillary canine root apex exhibited a high prevalence across the three age groups evaluated. Moreover, it was observed that Type 1 relationship intensified with advancing age, particularly for the 40-50 age group. These observations align with previous studies by Belgin et al. [27] and Takahashi et al. [28], who also reported a heightened Type 1 relationship between MS and maxillary canine root apex with increasing age. Consistent with these findings, Jun et al. [29] documented an incremental maxillary sinus size until the completion of skeletal development, followed by a subsequent age-related volume reduction. Ariji et al. [30] reported an expanding maxillary sinus volume up to 20 years of age, which subsequently declined. Contrary to these studies, Sahlstrand-Johnson et al. [31] found no association between maxillary sinus volume and age in their sample.

Furthermore, the present study's findings indicate that the relationship between the maxillary canine root apex and the MS floor does not exhibit a significant correlation with the side (left or right) of the jaw. This aligns with the results of other similar studies, which have not observed any substantial difference in the frequency of these relationships between the two sides of the maxilla [12, 17, 32, 33, 19]. This lack of a significant association suggests that the spatial arrangement between the maxillary sinus and the canine root apex is relatively consistent across the two sides of the jaw, potentially attributed to bilateral symmetry in human anatomy.

Limitations of study

This study has certain limitations. One of them is the limited number of subjects with a reduced vertical pattern. Studies have suggested that individuals with a reduced vertical skeletal relationship exhibit an increased width and height of the maxillary sinus compared to those with an increased vertical skeletal pattern [30]. Another limitation is that the study did not account for the influence of facial biotypes, race, and ethnicity on canine tooth-maxillary sinus relationships. Future studies should investigate whether variations in facial morphology, race, and ethnicity play a role in these relationships by considering appropriate parameters.

Conclusion

While the majority of cases with maxillary sinus extension into the canine region exhibited a distance of more than 2 mm between the sinus floor and the root apex, cases with a shorter distance and interlocked relationships were not uncommon, particularly among women. These findings warrant careful consideration during dental procedures to minimize potential complications.

Highlights

What Is Already Known?

The Maxillary Sinuses (MS), the largest of the paranasal sinuses, exhibit a rudimentary form at birth and undergo gradual pneumatization until skeletal maturation is complete

What Does This Study Add?

Given the variable anatomy of the MS and its proximity to the developing maxillary canines, evaluating the MS during orthodontic treatment planning for patients with maxillary canine displacement could aid in understanding the root causes of canine displacement and enhancing treatment outcomes.

Acknowledgments

The authors would like to express their gratitude to the clinical research development unit of Imam Khomeini Hospital, Urmia University of Medical Sciences, for English editing.

Funding support
The authors did not receive support from any organization for the submitted work

Competing interests
The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Urmia University of Medical sciences (No. IR.UMSU.REC.1401.137).

Consent to participate
Informed consent was obtained from all individual participants included in the study.

Author contributions
S P: Conceptualization, the original draft writing, investigation, writing including reviewing and editing and investigation and formal analysis; A Gh: Conceptualization, supervision, and project administration; Z Ch: Investigation, writing including reviewing and editing; Z Gh: Conceptualization, supervision, and project administration

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