Original articles

Cone-beam computed tomography assessment of root canal morphology and the relationship of maxillary first molars with adjacent anatomical structures in a Vietnamese sub-population

Le Ha Thuy Nhung**[*]**, ***Nguyen Quang Khai, Pham Thi Thuy Hien***

Faculty of Odonto-Stomatology, University of Medicine and Pharmacy, Hue University

***Corresponding author:** Le Ha Thuy Nhung; Email: lhtnhung@huemed-univ.edu.vn

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Abstract

Background: Dental treatment of the maxillary first molar is often challenging due to its complex anatomical configuration and the close proximity of its roots to the maxillary sinus.

Objective: This study investigated the root canal morphology and the spatial relationship between the maxillary first molar roots and the maxillary sinus floor using cone-beam computed tomography (CBCT).

Materials and methods: A retrospective cross-sectional study analyzing 459 maxillary first molars from 255 CBCT images across axial, coronal, and sagittal planes was conducted. Parameters assessed included the number of roots and canals, canal configurations according to the Vertucci classification, the spatial relationship between canal orifices, and the distance from the root apices to the maxillary sinus floor.

Results: 100% of maxillary first molars possessed three roots and 56.9% exhibited second mesiobuccal canal. The MB root canal showed significant morphological diversity, with Vertucci Type I (43.1%) being the most prevalent configuration. Regarding spatial orientation, 78.2% of the second mesiobuccal orifices were located mesially relative to the line connecting the first mesiobuccal and palatal orifices. The mean distance between the two mesiobuccal canal orifices was 2.00 ± 0.34 mm, with a statistically significant difference observed between genders. A substantial proportion of roots exhibited Type III (contact) and Type IV (protrusion) sinus-root relationships, particularly in the younger age groups (≤ 20 and 21-30 years). Increased age was significantly associated with a greater distance to the sinus floor and the sinus-root distance was smaller in females compared to males across all roots.

Conclusion: Maxillary first molars demonstrate a high prevalence of a second mesiobuccal canal and an intimate anatomical relationship with the maxillary sinus floor. These findings underscore the necessity of CBCT as an essential diagnostic tool in complex endodontic and oral surgical procedures in the posterior maxilla, crucial for accurate canal localization, precise treatment planning, and minimizing the risk of sinus-related complications.

Keywords: *Maxillary first molar; root canal anatomy; maxillary sinus; cone-beam computed tomography.*

1. BACKGROUND

Endodontic therapy plays a vital role in preserving masticatory function and dental aesthetics in teeth compromised by pulpal and periapical pathologies. The clinical success of conventional endodontic procedures, typically reported from 80.85% to 88.75%, is typically linked to the comprehensive elimination of bacterial infection within the entire root canal system [1, 2]. Thus, a thorough understanding of the internal root and canal architecture is a fundamental prerequisite to increase treatment outcomes due to the complex and variable anatomy of the root canal system [2].

The maxillary first molar (MFM) represents one of the most formidable anatomical challenges in permanent dentition. While typically characterized by three roots and three main canals, the high prevalence of a second mesiobuccal canal (MB2), often featuring intricate fusion or branching, significantly complicates debridement. Notably, a study of 1,873 MFMs identified a higher frequency of MB2 canals in retreatment cases compared to primary treatments, suggesting that the failure to detect this canal remarkably compromises long-term prognosis [3]. Besides, the MB2 canal remains an endodontic challenge due to its branching in the middle or apical thirds and typically concealed orifice by a dentinal layer at the pulp floor [4]. Studies have also indicated a mean distance between first mesiobuccal (MB1) and MB2 orifices ranges from 1.87 mm to 2.95 mm, depending on the population studied [5]. Geometrically, the MB2 is usually positioned palatal (P) to the MB1 and mesially offset from the MB2-P line, providing a reliable landmark for clinical negotiation [6]. This underscores the necessity of a deeper understanding of MFM canal variations to optimize clinical success.

Beyond internal canal morphology, the MFM is defined by its intimate proximity to the maxillary sinus floor (MSF) [7]. The variable expansion of the sinus into the jaw can result in roots being protruded into the sinus cavity. This relationship poses significant clinical risks; for instance, bone thickness overlying MFM roots can be as thin as 0.5 mm, increasing the likelihood of iatrogenic complications, including oroantral communication during tooth extraction, orthodontic movement, or dental implant placement [7], [8]. Additionally, the extrusion of endodontic materials or the spread of odontogenic infections can induce odontogenic maxillary sinusitis, which account for 10 - 12% of all sinusitis cases [9]. Consequently, comprehensive preoperative cone-beam computed tomography (CBCT) imaging is essential to thoroughly evaluate these complex sinus-root spatial relationships, serving as a critical diagnostic measure to prevent iatrogenic MSF perforation and significantly reduce the incidence of subsequent odontogenic sinusitis.

To navigate these complexities, various classification frameworks have been developed, with the Vertucci system remaining the most widely used due to its practical 8-type configuration and its prevalence in existing literature [2]. While micro-computed tomography represents the gold standard for high-resolution anatomical research, its clinical translation is hindered by prohibitive costs, extensive processing times, and radiation doses that exceed safe thresholds for patients; consequently, CBCT has driven a paradigm shift in dental diagnostics [10]. CBCT offers non-invasive, three-dimensional visualization that enables clinicians to accurately locate MB2 canals and evaluate the surrounding bone structures, thereby mitigating risk factors associated with treatment failure [10]. For instance, CBCT has illuminated the intricate complexity of MB roots, with studies across diverse populations indicating a 60 to 80% prevalence of two canals [11-14].

Notably, maxillofacial anatomy is profoundly influenced by regional and ethnic factors, highlighting the imperative to investigate root canal variations and maxillary sinus volume across various racial cohorts to ensure diagnostic accuracy [15]. Furthermore, the effects of sex and age on these parameters have revealed conflicting results. In Vietnam, a recent study reported a remarkably high endodontic treatment failure rate (63.87%) based on periapical radiographs. Maxillary molars account for 21.41% of these cases, with missed or underfilled canals contributing to 3.67% of the failures [16]. Moreover, previous research has focused primarily on the MB2 canal prevalence, frequently overlooking its precise location relative to primary landmarks and the proximity of root apices to the MSF [17, 18]. To date, a systematic characterization of MFM morphology and its spatial correlation with the MSF remains sparse within the Vietnamese population. MSFs within the Vietnamese populationDriven by the need for population-specific reference data to enhance clinical outcomes, we conducted a study: "Cone-beam computed tomography assessment of root canal morphology and the relationship of maxillary first molars with adjacent anatomical structures in a Vietnamese sub-population". The aim was to investigate the root canal anatomy of MFMs and the spatial relationship between their root apices and the MSF using CBCT imaging.

2. MATERIALS AND METHODS

2.1. Study design and patient selection

This retrospective study was approved by the Medical Ethics Committee of Hue University of Medicine and Pharmacy (H2026/051).

The minimum sample size was determined using the single proportion formula for a descriptive cross-sectional study:

$$n = Z_{1-\alpha/2}^2 \times \frac{p(1-p)}{d^2}$$

Where: n is the minimum sample size. $Z_{1-\alpha/2}$ is the standard normal deviation corresponding to a 95% confidence level (α = 0.05), which equals 1.96. p is the estimated prevalence of the MB2 canals in MFMs, derived from the study by Tran (2020), with p = 0.607 [17]. d is the margin of error, set at 5% (d = 0.05). Based on these parameters, the minimum required sample size is 367 MFMs. To compensate for a potential 10% dropout rate due to poor image quality or metal artifacts, the final target sample size was established at a minimum of 404 teeth.

The inclusion criteria were as follows: individuals with at least three generations of Vietnamese ancestry, aged 16-80 years, who had at least one erupted MFM in the correct arch position; and fully developed roots with closed apices. Selected teeth had to be free of prior endodontic treatment, large restorations encroaching upon the pulp horns, or signs of apical resorption. The maxillary sinus had to be free of deformities, trauma, or tumors. Images with significant artifacts or poor clarity were excluded.

The study evaluated a CBCT database of 459 MFMs from 255 Vietnamese patients referred for CBCT examinations at Hue University of Medicine and Pharmacy Hospital between 2025 and 2026. The mean age of the patients was 33.3 ± 14.6 years old, comprising 117 males (age ranging from 16 to 77 years; the average age of 36.6 ± 15.9 years) and 138 females (ages ranging from 16 to 80 years; the average age of 31.8 ± 14.1 years).

2.2. Radiographic protocol and evaluation

All scans were acquired using the Axeos system (Dentsply Sirona Inc., Germany). To ensure high diagnostic quality while adhering to ALARA (As Low As Reasonably Achievable) principles, the following parameters were utilized: 6-10mA, 60-90kVp, 14-20s scan time, a voxel size of 160 µm and a field of view of 8 x 8 cm. DICOM data were analyzed using RadiAnt DICOM Viewer (Medixant, Poland). To eliminate observer bias and ensure strict objectivity, a double-blind evaluation protocol was implemented. Prior to analysis, all CBCT images were completely anonymized and de-identified by an independent research assistant, effectively masking all patient demographic data and clinical records. The images were then independently evaluated by two calibrated endodontists. Discrepancies were resolved consensus and intra-rater reliability was validated by re-evaluating 25% of the total scans after a one-month interval using Cohen's Kappa coefficient (κ), with a value of κ ≥ 0.75 considered excellent.

2.3. Assessment of canal morphology and spatial orientation

Root number and configuration were assessed on the axial, coronal, and sagittal planes. MFMs were oriented in the sagittal reference planes to standardize observations of the MB2 canal at the lowest level of the pulp chamber floor (Figure 1).

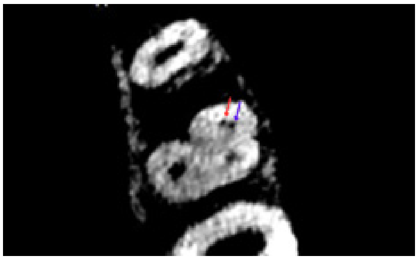

Figure 1. Axial section images illustrating the identification of first mesiobuccal canal (blue arrow) and second mesiobuccal canal (red arrow) in a 3-rooted maxillary first molar.

Root canal types were categorized according to Vertucci's classification (Type I-VIII) (Figure 2): Type I, where a single canal runs from the pulp chamber to the apex; Type II, in which two separate canals exit the pulp chamber and merge short of the apex to create a single canal; Type III, where a single canal exits the pulp chamber, divides into two within the root, and then joins back to exit as one canal; Type IV, featuring two individual canals extend from the pulp chamber to the apex; Type V, where a canal leaves the pulp chamber and divides before reaching the apex into two distinct canals with their own apical foramina; Type VI, in which two separate canals depart from the pulp chamber, merge in the root's body, and then spilt again near the apex to emerge as two separate canals; Type VII, where one canal leaves the pulp chamber, divides and then rejoins within the body of the root, and finally redivides into 2 distinct canals short of the apex; and Type VIII, which consists of three individual canals stretch from the pulp chamber to the apex [2].

Figure 2. Representative CBCT images in cross-sectional (A-F) views, displaying mesiobuccal root canal morphology of the maxillary first molar according to the Vertucci classification. A. Type I; B. Type II; C. Type III; D. Type IV; E. Type V; F. Type VI. Type VII and VIII were not identified in this study.

Spatial analysis of the MB2 orifice was performed relative to a reference line connecting the centers of the MB1 and P (P) orifices, classifying its position as "on the line," "mesially displaced," or "distally displaced" (Figure 3A, B).

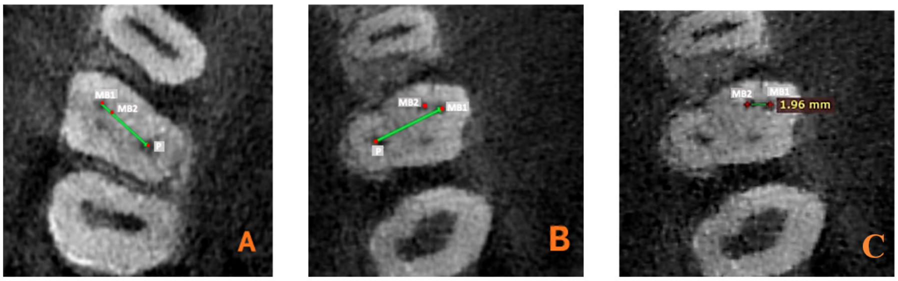

Figure 3. Spatial relationship of the second mesiobuccal (MB2) canal orifice: A. Positioned on the line connecting the first mesiobuccal (MB1) and palatal (P) orifices. B. Mesially displaced relative to the MB1-P line. C. The linear distance between MB1 and MB2 orifices.

To measure inter-canal distance of canal orifices, the standard plane was identified by the axial slice at the lowest level of the pulp chamber floor. The linear distance (mm) was recorded from the center of the MB1 orifice to the center of the MB2 orifice (Figure 3C).

To evaluate the root-to-sinus positional relationships, the vertical distance was measured from the radiographic apex of each root (MB, distobuccal - DB, and P) to the MSF in the coronal planes and the shortest distance was recorded in mm (Figure 4). To ensure reproducibility and minimize inter-observer variation, the MSF landmark was strictly defined as the lowest point of the sinus cortical border directly vertical or closest to the respective root apex. A negative value was recorded when the root apex protruded anatomically into the MSF, representing the vertical depth of the root protrusion into the MSF. The vertical relationships were categorized according to Shahbazian's method: Type 1, the root apex was located below the MSF, with a distance larger than 0.5 mm; Type 2, the root apex was close to the MSF, with a distance less than or equal to 0.5 mm but larger than 0 mm; Type 3, the root apex was in direct contact with the MSF, with a distance equal to 0 mm; Type 4, the root apex protruded into the MSF, with a distance recorded as negative [19].

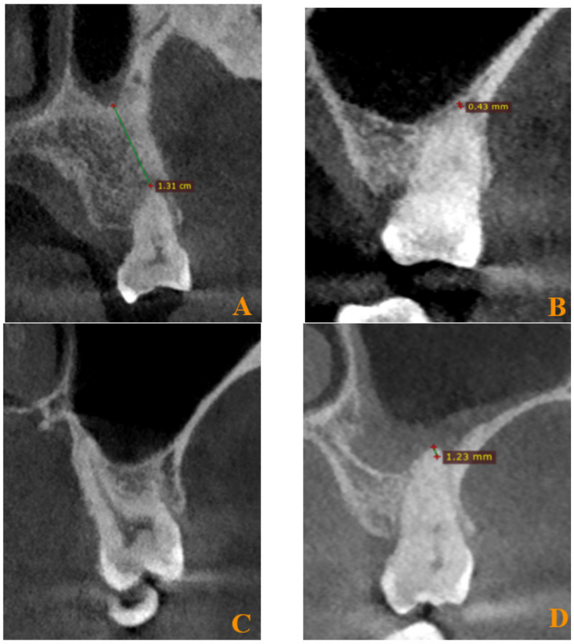

Figure 4. CBCT images of four vertical relationships between maxillary first molars (MFMs) and maxillary sinus floors in the coronal plane. A. Type I: Mesiobuccal root of a left MFM; B. Type II: Distobuccal root of a left MFM; C. Type III: Palatal root of a left MFM; D. Type IV: Mesiobuccal root of a left MFM.

2.4. Statistical analysis

Data were managed using Microsoft Excel 2016 and analyzed with SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). The normal distribution of continuous data was evaluated using the Shapiro-Wilk test. The Chi-square or Fisher's exact test was used to compare the number of roots and canals configuration according to sex and tooth type. For the comparison of inter-orifice distances between two independent groups, the independent-sample *t*-test was applied for normally distributed data, whereas the Mann-Whitney U test was used for non-normally distributed data. To compare the root-to-sinus distances across different roots, one-way ANOVA test was performed for normally distributed data, followed by Tukey's post-hoc test for pairwise comparisons. Intra-rater reproducibility and reliability were assessed using Cohen's kappa coefficient. Statistical significance was set at $p < 0.05$.

3. RESULT

3.1. Morphology of roots and the root canal system of maxillary first molars on CBCT

The study included 459 MFMs from 255 CBCT scans, with 195 (42.5%) of the evaluated teeth belonging to male patients and 264 (57.5%) to female patients. The intra-examiner reliability showed an excellent agreement rate (κ = 0.83).

Table 1. The number of root canals of maxillary first molars according to tooth position and gender

Number of Canals/Roots	Tooth position n (%)			Gender n (%)			Total
	Right	Left	*p1*	Male	Female	*p2*	
3 canals/3 roots	105 (44.3%)	93 (41.9%)	0.601	69 (35.4%)	129 (48.9%)	0.039*	198 (43.1%)
4 canals/3 roots	132 (55.7%)	129 (58.1%)		126 (64.6%)	135 (51.1%)		261 (56.9%)
Total	237 (100%)	222 (100%)		195 (100%)	264 (100%)		459 (100%)

p1: Comparison between right and left teeth; p2: Comparison between genders; n: Number of teeth.

Among the 459 teeth examined, all teeth (100%) possessed three separate roots (MB, DB, and P). The majority of MFMs exhibited four canals (56.9%; 261/459), while 43.1% (198/459) had three canals. No other configurations were observed. Although left MFMs showed a slightly higher prevalence of four canals (58.1%) compared to right tooth (55.7%), the difference was not statistically significant (*p1* > 0.05). Conversely, the prevalence of MB2 canals was notably higher in male (64.6%) compared to females (51.1%) (*p2* < 0.05).

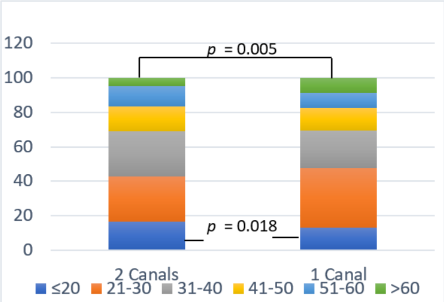

Chart 1. Prevalence of the second mesiobuccal canal (MB2) according to age group.

The overall prevalence of MB2 canals among MFMs was 56.9%, with the majority of samples were concentrated in the ≤ 20 to 40 age groups (330/459; 71.9%). A significant correlation was observed between age and MB2 canal existence ($p < 0.05$); prevalence peaked in the 31 - 40 age group (26.2%) and reduced markedly in patients over 60 years of age (4.8%) (Chart 1).

Table 2. Root canal morphology of maxillary first molars according to Vertucci classification

Vertucci type	Root n (%)								
	Mesiobuccal			Distobuccal			Palatal		
	Male	Female	*p*	Male	Female	*p*	Male	Female	*p*
Type I	69 (35.4%)	129 (48.9%)	< 0.0001	183 (93.8%)	253 (95.8%)	0.457	195 (100%)	264 (100%)	1.000
Type II	15 (7.7%)	30 (11.4%)		0	0		0	0	

Type III	15 (7.7%)	15 (5.7%)	2 (1.0%)	1 (0.4%)	0	0
Type IV	66 (33.8%)	33 (12.4%)	7 (3.6%)	4 (1.5%)	0	0
Type V	24 (12.3%)	42 (15.9%)	3 (1.5%)	6 (2.3%)	0	0
Type VI	6 (3.1%)	15 (5.7%)	0	0	0	0
Total	195 (100%)	264 (100%)	195 (100%)	264 (100%)	195 (100%)	264 (100%)

p: Comparison between genders; n: Number of teeth.

Using the Vertucci classification, the P root canal showed the least anatomical variation, with 100% Type I across both genders. The DB root was also predominantly Type I (95%), showing no significant gender-based difference (*p* = 0.457). In contrast, the MB root canal displayed the greatest morphological diversity and a significant correlation with genders. While Type I was the most frequent in females (48.9%), males exhibited a notably higher prevalence of Type IV configurations (33.8% in males and 12.5% in females). Complex canal systems (types II-VI) were frequent in the MB root than in any other root studied (Table 2).

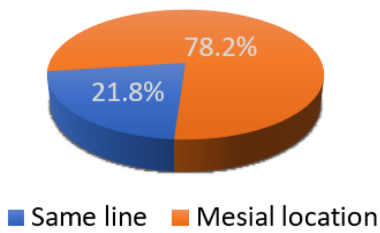

Chart 2. Spatial orientation of the second mesiobuccal orifice concerning the line connecting the first mesiobuccal to palatal root canals.

Although the MB2 canals were anatomically present in 261 MFMs, its orifices were clearly identified on the pulp chamber floor in only 165 cases. Among these detectable orifices, the majority (78.2%; 129/165) were located mesially relative to the MB1-P reference line (*p* < 0.0001) while the remaining 21.8% were situated directly on the line. No cases of distal displacement were observed (Chart 2).

Table 3. Inter-orifice distance between MB1 and MB2 measured at the pulp chamber floor

Age group	**Male** n Mean ± SD (mm)	***p1***	**Female** n Mean ± SD (mm)	***p1***	**Total** n (Mean ± SD) (mm)	***p2***
≤ 20	9 (2.23 ± 0.62)		24 (1.93 ± 0.28)		33 (2.00 ± 0.33)	0.021*
21 - 30	27 (2.32 ± 0.37)		12 (2.02 ± 0.11)		39 (2.07 ± 0.19)	< 0.001*
31 - 40	21 (2.52 ± 0.39)		18 (1.73 ± 0.54)		39 (2.03 ± 0.354)	< 0.001*
41 - 50	12 (2.06 ± 0.48)	0.003*	15 (1.67 ± 0.23)	0.009*	27 (1.85 ± 0.39)	0.012*
51 - 60	12 (2.05 ± 0.31)		9 (1.96 ± 0.23)		21 (2.01 ± 0.26)	0.457
> 60	6 (2.04 ± 0.08)		0		2 (2.04 ± 0.08)	-
Total	87 (2.12 ± 0.34)		78 (1.87 ± 0.31)		165 (2.00 ± 0.34)	< 0.001*

p1: Comparison between age; p2: Comparison between genders; n: Number of teeth.

There was a statistically significant difference in inter-orifice distance between genders ($p < 0.001$), with males exhibiting a higher mean (2.12 ± 0.34 mm) than females (1.87 ± 0.31 mm). Age also markedly impacted the inter-orifice distance ($p1$ for males = 0.003; $p1$ for females = 0.009), the distance peaked in the 31-40 age group for males (2.52 ± 0.39 mm) and the 21-30 age group for females (2.02 ± 0.11 mm), followed by a notable decrease in older cohorts. Overall, the study population showed a mean distance of 2.00 ± 0.34 mm, with gender differences remaining most pronounced in the 21-40 age ranges ($p2 < 0.001$) (Table 3).

3.2. Evaluation of the relationship between maxillary first molars and the maxillary sinus floor

Table 4. Distribution of the relationship between the maxillary first molar root apices and the maxillary sinus floor by age

Age group		≤ 20	21 - 30	31 - 40	41 - 50	51 - 60	> 60	Total
MB root (n, %)	Type I	37 (18%)	25 (12.1%)	59 (28.6%)	43 (20.9%)	23 (11.2%)	19 (9.2%)	206 (44.8%)
	Type II	0	7 (22.6%)	16 (51.6%)	4 (12.9%)	4 (12.9%)	0	31 (6.8%)
	Type III	37 (27.6%)	49 (36.6%)	28 (20.9%)	13 (9.7%)	7 (5.2%)	0	134 (29.2%)
	Type IV	34 (38.6%)	34 (38.6%)	10 (11.4%)	0	10 (11.4%)	0	88 (19.2%)
DB root (n, %)	Type I	33 (16.4%)	21 (10.4%)	57 (28.4%)	51 (25.4%)	18 (9%)		201 (43.8%)
	Type II	0	8 (38.1%)	5 (23.8%)	0	8 (38.1%)	0	21 (4.6%)
	Type III	23 (15.5%)	56 (37.8%)	47 (31.8%)	17 (11.5%)	5 (3.4%)	0	148 (32.2%)
	Type IV	35 (39.3%)	35 (39.3%)	8 (9%)	0	11 (12.4%)	0	89 (19.4%)
P root (n, %)	Type I	23 (11.4%)	41 (20.4%)	56 (27.9%)	44 (21.9%)	20 (10%)	17 (8.4%)	201 (43.7%)
	Type II	0	8 (25%)	11 (34.4%)	8 (25%)	0	5 (15.6%)	32 (7%)
	Type III	41 (30.8%)	29 (21.8%)	32 (24.1%)	17 (12.8%)	14 (10.5%)	0	133 (29%)
	Type IV	35 (37.6%)	32 (34.4%)	16 (17.2%)	0	10 (10.8%)	0	93 (20.3%)

Applying Shahbazian's classification, the spatial relationship between MFM root apices and the MSF varies significantly with age. While Type I (root apex extending > 0.5 mm) was the most frequent across all roots, younger cohorts (≤ 30 years) showed a higher prevalence of Type III (contact) and Type IV (roots protrusion). Specifically, Type IV protrusion was observed in 38.6% of MB roots, 39.3% of DB roots, and 37.6% of P roots in patients ≤ 20 years. Conversely, older patients (> 60 years) predominantly exhibited Type I relationships, indicating a trend toward increased root-to-sinus distance with age (Table 4).

Table 5. The average vertical distances between the maxillary first molar root apices and the maxillary sinus floors according to age

Age group	MB root (Mean ± SD, mm)	DB root (Mean ± SD, mm)	P root (Mean ± SD, mm)	*p*1
≤ 20	- 0.2 ± 1.41	0.12 ± 1.35	- 0.1 ± 1.98	< 0.001
21 - 30	- 0.15 ± 1.49	- 0.28 ± 1.33	- 0.13 ± 1.53	
31 - 40	1.49 ± 2.28	1.42 ± 2.16	1.11 ± 2.27	
41 - 50	2.52 ± 3.28	2.5 ± 2.64	2.48 ± 2.42	
51 - 60	1.89 ± 2.99	2.08 ± 4.35	2.37 ± 4.61	
> 60	3.88 ± 1.61	5.78 ± 1.88	3.63 ± 2.62	
***p*2**	< 0.001	< 0.001	< 0.001	

p1: Comparison between roots; p2: Comparison between age.

The vertical distances generally increased with age across all groups ($p < 0.001$). Notably, in the ≤20 age group, the MB root showed a mean distance of - 0.2 ± 1.41 mm, whereas this distance increased to 3.88 ± 1.61 mm in the > 60 age group. The DB root exhibited the greatest average distance from the sinus floor in the oldest cohort (5.78 ± 1.88 mm) (Table 5).

Table 6. The average vertical distances between the maxillary first molar root apices and the maxillary sinus floors according to sex

Gender	MB root (Mean ± SD, mm)	DB root (Mean ± SD, mm)	P root (Mean ± SD, mm)	*p*1
Male	1.45 ± 2.8	1.73 ± 3.13	1.86 ± 2.94	< 0.001
Female	0.63 ± 2.08	0.65 ± 1.93	0.31 ± 2.1	
Total	0.98 ± 2.45	1.11 ± 2.56	0.97 ± 2.6	
***p*2**	0.003	0.001	< 0.001	

p1: Comparison between roots; p2: Comparison between genders.

The mean distances were 0.98 ± 2.45 mm for the MB root, 0.97 ± 2.6 mm for the P root, and 1.11 ± 2.56 mm for the DB root (Table 6). Gender significantly influenced the root-to-sinus distance for all three root types. Males consistently exhibited greater vertical distances than females across all root types, with the P root showing the most drastic difference (male: 1.86 ± 2.94 mm; female: 0.31 ± 2.1 mm; $p < 0.001$).

4. DISCUSSION

4.1. Morphological characteristics of root and canal systems in maxillary first molars

The results of this study reaffirm that the MFMs possess one of the most intricate anatomical configurations in the permanent dentition. Due to its early eruption and primary masticatory role, it frequently requires endodontic intervention. Success is fundamentally linked to the identification of all canals; an untreated canal increases the risk of apical periodontitis by 6.25 times, with failure occurring in 72.7% of cases when canals remain unfilled [19]. While traditional *in vitro* method provided direct visualization, CBCT has emerged as the modern diagnostic tool, as endorsed by the American Association of Endodontics (AAE) for identifying complex anatomy and missed canals [20]. Similarly, the European Society of Endodontology (ESE) also recommends CBCT for complex endodontic cases and retreatments involving potentially missed canals [21]. In alignment with previous studies, the current methodology provides a reliable framework for both canal location and the measurement of specific distances.

In this cohort of 459 MFMs, 100% exhibited three distinct roots (MB, DB, and P), aligning with existing Vietnamese and Asian data with the prevalence of 99.55-100% [17, 18, 23]. This consistency suggests that three-rooted MFMs are the norm in Asian populations, and variations in root number are exceedingly rare [18]. Therefore, utilizing the clearing and staining technique on Thai molars, Alavi et al. (2002) observed that 100% of the MFMs exhibited three separate roots [24]. This may contribute to an evolutionary adaptation for superior masticatory force distribution; consequently, Asian populations tend to possess a higher number of roots compared to those in Europe and America [15]. Regarding bilateral symmetry, no statistically significant differences were observed between right and left sides. This high correlation confirms the anatomical symmetry and stability of MB2 variations across the dental arch [5], [23].

A significant increase in MB2 prevalence was observed in males compared to females. While the correlation between gender and canal numbers in the MB roots of MFMs remains a point of debate in the literature, our findings align with the study by Watanable, which reported significantly higher MB2 rates in males [25]. Generally, larger tooth dimensions in males may facilitate the formation of accessory canals and more complex morphologies [17]. Conversely, Guo and Pawar found no significant sexual dimorphism, arguing that gender does not influence canal number within certain homogenous population [14, 26]. These inconsistencies likely arise from variations in sample sizes and specific demographics of the study cohorts.

The observed MB2 canal prevalence was 56.9% aligns with the 50% - 70% range reported in Asian populations, including local findings by Tran et al. (60.7%), Vu et al. (64.3%), and an international report by Watanabe et al. (52.9%) [17, 25, 27]. Discrepancies between studies-such as the higher 75.6% reported by Nguyen et al.- are largely attributable to the transition from *ex vivo* to *in vivo* conditions, where biological noise, motion artifacts, and ALARA-limited radiation doses can obscure fine structures [28]. Although a voxel size of 200 µm or less is generally acceptable for root canal evaluation, the utilization of a medium-resolution voxel size (160 µm) in this study may fail to visualize extremely narrow or calcified MB2 orifices, potentially leading to a slight underestimation of the true prevalence [25]. Nonetheless, the setting of a restricted FOV (8 x 8 cm) optimized spatial resolution, enhancing diagnostic precision for detecting small or partially calcified canals [23]. Given that prevalence still exceeds 50%, a meticulous clinical exploration of the MB root remains mandatory.

Age-wise, MB2 detection peaked in middle-age cohorts but declined in patients over 60, a trend consistent with Faraj (2021) (Chart 1) [29]. This is likely driven by continuous secondary dentin deposition, which can transform a flattened canal into two distinct canals or lead to partial calcification [24]. While Martin et al. suggested that age is not a primary determinant, our findings indicate that canal visibility is significantly influenced by physiological and pathological calcification [15]. Clinically, since MB2 canals can be present at any age, clinicians must not use patient age as a rationale to bypass comprehensive canal mapping.

Regarding Vertucci's classification, Type I was the most prevalent configuration in the MB roots of MFMs, followed by Type IV and Type V. These results are consistent with local and international data, where Types I and IV predominated [17, 28, 25]. Notably, while Type IV rate in this cohort was lower than in Chinese and Korean populations, the high prevalence of Type V presents a distinct morphological characteristic of the Vietnamese population [4, 11, 26]. In contrast, the P and DB roots exhibited minimal variation, with Type I configuration present in over 90% of samples across both genders. This consistency matches observations in Japanese, Indian, and Malaysian populations [14, 23, 25]. Given that the MB root possesses a more complex anatomy than any other roots, it represents a high-risk zone for procedural errors such as ledge formation or perforations [23]. Understanding these population-specific variations enables clinicians to better navigate the challenges of identifying and debriding the entire canal systems, ultimately improving endodontic outcomes.

The localization of the MB2 orifice is a primary focus in endodontic anatomy because its orifice is typically concealed by a reparative dentinal layer or calcified shelf at the pulp chamber floor, making visual and tactile location difficult [4]. Similar to findings by Normando, our study confirms that the MB2 orifice is predominantly positioned on the mesial side of the MB1–P reference line [30]. Shen et al. in China reported that the MB2 orifice was always situated mesial to the reference line and about 2 - 3 mm P to the MB1 orifice [4]. However, a precise geometric evaluation of the MB2 orifice location relative to the MB1 and P landmarks has not been investigated in Vietnam, leaving a significant gap in localized endodontic literature. This mesio-palatal orientation validates established anatomical patterns in the present study, although the prevalence was lower than 91.4% reported in Brazilian populations, likely due to ethnic diversity or CBCT resolution limits [30].

The inter-orifice distance (2.00 ± 0.34 mm) measured at the pulpal floor corresponds closely with data from China (1.90 mm) and the USA (2.03 mm) [31, 6]. Nevertheless, this distance varies globally, being longer than that of Saudi Arabian cohort (1.87mm) but shorter than Brazilian (2.31 mm) group, suggesting that ethnicity significantly influences pulp floor landmarks [5, 30]. Besides, males exhibited significantly greater inter-orifice distances than females, likely due to larger crown dimensions. Clinically, this gender-based variation implies that female patients possess a narrower anatomical safety zone between two orifices; hence, clinicians must take greater caution to avoid strip or furcation perforations during MB2 exploration. Furthermore, our data suggest that the pulp floor configuration may be influenced by aging, a vital clinical indicator for locating orifices across different age groups. Given that CBCT is not a diagnostic tool for all endodontic cases, by utilizing valuable predictive insights, specifically the MB1-MB2 distance and mesial localization, clinicians can perform more efficient, targeted searches with a dental operating microscope. This approach facilitates canal localization while minimizing radiation exposure, upholding the ALARA principle.

4.2. Relationship between root apices and the maxillary sinus

Proximity between root apices and the MSF is a critical determinant for success in endodontic surgery, implantology, and managing odontogenic sinusitis. Unlike 2D imaging, which suffers from overlapping structures, CBCT provides three-dimensional, cross-sectional visualization, accurately determining if a root is merely adjacent or actually penetrating the sinus floor [7, 32].

Although most sinus-root vertical distances exceeded 0.5mm, the high frequency of contact and root protrusion in younger cohorts presents a novel finding that has not yet been reported in Vietnam. While these protrusion rates align with international data (26.1 - 46%), they contrast with studies the superior positioning patterns found in Turkish populations, likely due to ethnic and methodological variations [32, 33]. The present data establish the first baseline for these anatomical variations within the Vietnamese population, thereby filling a significant gap in localized literature. Clinically, the frequent presence of root protrusion cases in young patients creates a significantly thinner safety zone, posing a high risk for sinus membrane perforation during endodontic or surgical interventions.

Our study indicates intimate proximity between MFM roots and the sinus floor with a mean distance significantly closer than the previously reported 1.97 mm average. This is most pronounced in younger groups, where mean distances were negative. Such proximity, often less than 2 mm, increases the risk for odontogenic maxillary sinusitis [7]. Our results corroborate data from Mir et al., suggesting that younger individuals and specific ethnic groups exhibit deeper root penetration due to incomplete sinus remodeling and unique craniofacial skeletal structures [34]. These variations underscore critical role of ethnicity and age in sinus floor positioning.

In this study, the P root exhibited the shortest mean distance to the MSF, identifying them as the most frequent offenders for sinus proximity. This aligns with findings by Sarilita et al., who reported that 20% of all P root of the MFMs were found to actually penetrate the MSF, though contradict study in Turkey populations where the DB root was closest [35, 33]. This discrepancy may be due to variations in root curvature and the convex morphology of MSF, which reaches its lower vertical point near the first and second molars [35].

We observed a significant correlation between age and this vertical distance. Younger cohorts (≤ 30 years), frequently showed negative distances, indicating root protrusion, whereas the safety zone peaked in the > 60 group. This age-dependent widening is primarily attributed to secondary cementum deposition at the root tips, which compensates for functional attrition (occlusal wear) by effectively pushing the roots further from the MSF [35]. Additionally, while the maxillary sinus undergoes intense pneumatization until approximately age 20, the distance subsequently increases as sinus expansion slows and the continuous tooth eruption gradually moves the apices away from the MSF [37, 38].

A significant sexual difference was observed in the vertical distance of MB root to the MSF, with males exhibiting a larger safety zone than females. This corroborates Oishi et al., who noted that males typically possess a thicker alveolar process and a more superiorly positioned sinus floor [38]. While Kilic reported that gender had no effect on anatomical relationship between these structures, data from Pei conversely revealed a non-significant trend toward greater bone volume in males [33, 37]. Therefore, our findings highlight a notably narrower gap in Vietnamese females. This suggests that female patients in this cohort may be at a higher risk for iatrogenic sinus communication during endodontic surgery [37]. Consequently, clinicians must be particularly vigilant when treating both younger patients and females to navigate these anatomical risks.

Given the high individual variability, CBCT is essential to assess the sinus proximity before surgical or complex endodontic procedures. When the sinus-root distance is minimal, the risk of sinus membrane perforation increases, potentially leading to acute or chronic infection and procedural failure [8, 9]. Furthermore, clinical errors, such as inaccurate working length determination, high-pressure irrigation, or overextension of filling materials, can introduce bacteria and debris into the antrum, resulting in odontogenic maxillary sinusitis [7]. In cases of extreme proximity, clinicians employ precautionary measures or sinus elevation techniques to mitigate post-operative complications [8]. In the absence of prior precise data, these baseline measurements of the intimate sinus-root relationship provide an essential reference for the Vietnamese population, enabling clinicians to perform precise preoperative mapping and safeguard sinus cavity integrity regardless of specific techniques used.

This study acknowledges several limitations that warrant consideration for future research. Primarily, due to the use of a convenience sample, the results of this study may not be entirely representative of the diverse ethnic groups within Vietnam. Future investigations using randomized sampling are needed for greater accuracy and deeper anatomical insight. Additionally, the cross-sectional design limits the determination of causality regarding age and gender while a longitudinal approach would provide super statistical power to track age-related changes and gender associations. Moreover, the voxel size of 160 μm may limit the detection of extremely fine anatomical structures; therefore, future investigations utilizing ultra-high-resolution CBCT imaging with smaller voxel sizes (ranging from 75 to 100 μm) are recommended to provide a more definitive anatomical assessment. Finally, inter-rater reliability was not evaluated, which may limit the statistical verification of observer agreement despite strict intra-rater calibration.

5. CONCLUSION

In summary, the root canal system in the MB roots of MFMs is highly complex, demonstrated by an MB2 canal prevalence of 56.9%, with the study population predominantly clustered in the ≤20 to 40 age groups. Anatomically, 78.2% of MB2 orifice is located on the mesial side of the MB1-P reference line and males exhibited a significantly greater inter-orifice distance than females, which may assist clinicians in canal localization. Furthermore, the P roots showed the shortest sinus-root distance (0.97mm) and younger cohorts exhibited a higher tendency for root protrusion into the sinus. As a key novelty, this study provides a precise quantitative mapping of MB2 locations and sinus-root distances in relation to gender and age, while such localized data were previously limited. These findings offer an essential anatomical reference database specific to the Vietnamese population, highlighting the impact of genetic and ethnic diversity on maxillofacial morphology. From a clinical standpoint, these insights are vital for mitigating procedural risks; recognizing the high frequency of MB2 canals and the thinner osseous safety zone in young and female patients allows clinicians to optimize access cavity designs and prevent Schneiderian membrane perforation. Consequently, these data serve as a useful reference to enhance predictability and success rates in endodontics, oral surgery, and prosthodontics.

REFERENCES

1. Almufleh LS. The outcomes of nonsurgical root canal treatment and retreatment assessed by CBCT: A systematic review and meta-analysis. Saudi Dent J. 2025;37:14.

2. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol. 1984;58:589-99.

3. Wolcott J, Ishley D, Kennedy W, Johnson S, Minnich S. Clinical investigation of second mesiobuccal canals in endodontically treated and retreated maxillary molars. J Endod. 2002;28(6):477-9.

4. Shen Y, Gu Y. Assessment of the presence of a second mesiobuccal canal in maxillary first molars according to the location of the main mesiobuccal canal: a micro-computed tomographic study. Clin Oral Investig. 2021;25(6):1-13.

5. Alnowailaty Y, Alghamdi F. The prevalence and location of the second mesiobuccal canals in maxillary first and second molars assessed by cone-beam computed tomography. Cureus. 2022;14(5):e24900.

6. Zhuk R, Taylor S, Johnson JD, Paranjpe A. Locating the MB2 canal in relation to MB1 in Maxillary First Molars using CBCT imaging. Aust Endod J. 2020;46(2):184-90.

7. Sharan A, Madjar D. Correlation between maxillary sinus floor topography and related root position of posterior teeth using panoramic and cross-sectional computed tomography. J Periodontol. 2006;7(7):1215-21.

8. Iliescu VI, Nimigean V, Nimigean VR, Georgescu L, Preoteasa CT. Maxillary sinus implications in endodontics and implant dentistry—A literature review. Rom J Oral Rehabil. 2024;16:147–61.

9. Iliescu VI, Nimigean VR, Preoteasa CT, Georgescu L, Nimigean V. Evaluation of the proximity of the maxillary teeth root apices to the maxillary sinus floor in romanian subjects: A Cone-Beam computed tomography study. Diagnostics (Basel). 2025;15(14):1741.

10. Pires M, Martins JN, Pereira MR, Vasconcelos I, Costa RP, Duarte I, Ginjeira Z. Diagnostic value of cone beam computed tomography for root canal morphology assessment - a micro-CT based comparison. Clin Oral Investig. 2024;28(3):201.

11. Yang S, Li C, Shi H, Liu M, Wang X. Cone-beam computed tomography evaluation of root and canal morphology of maxillary molars in a Chinese kazakh population. BMC Oral Health. 2025;25(1):1538.

12. Sharma M, Gupta S, Bhayya DP, Upadhyay K, Pandya D, Srivastava A, Gupta S. CBCT Analysis of Maxillary First Molar in Indian Population. Int J Clin Pediatr Dent. 2022;15(3):258-62.

13. Shetty A, Bhat R, Babu B, Hegde NM, Shetty C, Shetty P, et al. Occurrence and morphology of MB2 canals in maxillary first molars in an Indian subpopulation: a cone beam computed tomography study. J Health Allied Sci NU. 2022;12:101–5.

14. Pawar A, Thakur B, Machado R, Kwak SW, Kim HC. An In-vivo cone-beam computed tomography analysis of root and canal morphology of maxillary first permanent molars in an Indian population. Indian J Dent Res. 2021;32(1):104-9.

15. Martins JN, Marques D, Silva E, Carames J, Mata A, Versiani MA. Second mesiobuccal root canal in maxillary molars - A systematic review and meta-analysis of prevalence studies using cone beam computed tomography. Arch Oral Biol. 2020;113:104589.

16. Nguyen DH, Nguyen AN. Assessment of the failure rate of endodontic treatment of patients who come for examination and treatment at the general dental treatment department of the national hospital of ondoto stomatology at Ho Chi Minh city. Vietnam Med J. 2024;540:44-51.

17. Tran TLA, Ta AT. Evaluating the effectiveness of CBCT in surveying the root canal morphology of the maxillary first and second molars. J 108 Clin Med Pharm. 2020;15(5):1-4.

18. Truong TMA, Phạm TTH, Đỗ TTH, Phạm NH, Nguyễn TNT. Morphological characteristics of the root canal system of the maxillary first molar on Conebeam CT. Vietnam Med J. 2021;503(2):238-42.

19. Shahbazian M, Xue D, Hu Y, Cleynenbreugel J, Jacobs R. Spiral computed tomography based maxillary sinus imaging in relation to tooth loss, implant placement and potential grafting procedure. J Oral Maxillofac Res. 2010;1:e7.

20. Karabucak B, Bunes A, Chehoud C, et al. Prevalence of apical periodontitis in endodontically treated premolars and molars with untreated canal: A cone-beam computed tomography study. J Endod. 2016;42(4):538-41.

21. Special Committee to Revise the Joint AAE/AAOMR Position Statement on use of CBCT in Endodontics. AAE and AAOMR Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015;120(4):508 12.

22. European Society of Endodontology. European Society of Endodontology position statement on the use of CBCT in endodontics. Int Endod J. 2019;52(12):1675-8.

23. Rahman NA, Halim MS, Khamis MF, Ghani HA. Analysis of root and canal morphology of maxillary first and second molars among Malay ethnic in the Malaysian population with the aid of cone beam computed tomography: A retrospective study. Eur J Gen Dent. 2020;9(2):84-9.

24. Alavi AM, Opasanon A. Root and canal morphology of Thai maxillary molars. Int Endod J. 2002;35(5):478-85.

25. Watanabe S, Yabumoto S, Ikeda S, Okiji T. Evaluation of root and root canal morphology in maxillary first molar teeth: A cone-beam computed tomography study using two classification systems in a Japanese population. J Dent Sci. 2025;20(3):1554-61.

26. Guo J, Vahidnia A, Sedghizadeh P, Enciso R. Evaluation of root and canal morphology of maxillary permanent first molars in a North American population by cone-beam computed tomography. J Endod. 2014;40(5):635-9.

27. Vu TQH, Chu TM, Pham TL, Vu VD, Nguyen TC. Root morphology and root canal system of the maxillary first molar in a Vietnamese group using CBCT. Vietnam Med J. 2024;541(1):261.

28. Nguyen MD, Huynh HTH. Anatomical morphology of the mesiobuccal root canal system of the maxillary first molars. Ho Chi Minh Med J. 2016;20(2):76-81.

29. Faraj BM. The frequency of the second mesiobuccal canal in maxillary first molars among a sample of the Kurdistan Region-Iraq population - A retrospective cone-beam computed tomography evaluation. J Dent Sci. 2021;16(1):91-5.

30. Normando PHC, Santos JCMD, Akisue E, Paiva HC, Candeiro GTM. Location of the second mesiobuccal canal of maxillary molars in a brazilian subpopulation: analyzing using Cone-beam Computed Tomography. J Contemp Dent Pract. 2022;23(10):979-83.

31. Zhang Y, Xu H, Wang D, Gu Y, Wang J, Tu S, et al. Assessment of the second mesiobuccal root canal in maxillary first molars: a cone-beam computed tomographic study. J Endod. 2017;43(11):1-7.

32. Themkumkwun S, Kitisubkanchana J, Waikakul A, Boonsiriseth K. Maxillary molar root protrusion into the maxillary sinus: a comparison of cone beam computed tomography and panoramic findings. Int J Oral Maxillofac Surg. 2019;48(12):1570-6.

33. Kilic C, Kamburoglu K, Yuksel SP, Ozen T. An assessment of the relationship between the maxillary posterior teeth root tips using dental cone-beam computerized tomography. Eur J Dent. 2010;4:462-7.

34. Mir HA, Shafiq S, Khan M, Mukhtar S, Asif A, Akhter Q. Relationship of maxillary sinus and maxillary first molar root using Cone Beam Computed Tomography. J Islamabad Med Dental Coll. 2023;12(1):147-52.

35. Sarilita E, Muhammad RM, Nugraha HG, Murniati N, Yusuf HY, Takeshita Y, Asaumi J. Anatomical relationship between maxillary posterior teeth and the maxillary sinus in an Indonesian population: A CT scan study. BMC Oral Health. 2024;24:1014.

36. Chan PS, Sung CE, Tsai YWC, Yuh DY, Chen YW, Wung HH, et al. The Relationship between the Roots of Posterior Maxillary Teeth and Adjacent Maxillary Sinus Floor was Associated with Maxillary Sinus Dimension. Diagnostics (Basel). 2021;11(8):1435.

37. Pei J, Liu J, Chen Y, Liu Y, Liao X, Pan J. Relationship between maxillary posterior molar roots and the maxillary sinus floor: Cone-beam computed tomography analysis of a western Chinese population. J Int Med Res. 2020;48(6):300060520926896.

38. Oishi S, Ishida Y, Matsumura T, Kita S, Sakaguchi-Kuma T, Imamura T, et al. A cone-beam computed tomographic assessment of the proximity of the maxillary canine and posterior teeth to the maxillary sinus floor: Lessons from 4778 roots. Am J Orthod Dentofacial Orthop. 2020;157(6):792-802.