



High-resolution CBCT Evaluation of Second Mesio Buccal Canal Configuration According to Vertucci's Classification in Maxillary First Molars: An Iranian Population Study

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Abstract

Introduction: This study assessed the configuration of second mesiobuccal canals (MB2) of maxillary first molars according to Vertucci's classification in an Iranian population using high-resolution cone-beam computed tomography (CBCT). **Materials and Methods:** This cross-sectional study evaluated 385 high-resolution CBCTs of maxillary first molars with three roots (276 females, 109 males). The scans were taken with 110 kVp, 12 mA, 5×5 mm field of view (FOV), and 100 μm (0.1 mm) voxel size. The configuration of MB2 was classified by Vertucci's classification. The relationship of canal types with gender and age group (20-40 and 41-59 years) was analyzed using Fisher's exact test with Monte Carlo simulation. **Results:** The intra-examiner agreement was excellent ($\kappa=0.91$), and inter-examiner agreement for complex configurations was substantial ($\kappa=0.85$). Type IV had the highest frequency (38.2%), followed by type II (22.3%), type VI (14%), type I (10.1%), type III (6.5%), type VII (4.4%), type VIII (2.9%), and type V (1.6%). The frequency of different types significantly varied between males and females ($P=0.002$) but was not significantly different between the two age groups ($P>0.05$). **Conclusion:** In this population, 61.1% of MB2 canals had type IV or higher. Although a significant gender-related association was observed for some configurations, this finding requires cautious interpretation due to the imbalanced sex distributions. High-resolution CBCT is useful in cases with suspected complex anatomy, but should be applied regarding as low as reasonably achievable (ALARA) principle.

Keywords: Cone-beam Computed Tomography; Dental Pulp Cavity; Maxilla; Molar; Vertucci

Introduction

Maxillary molars have the highest failure rate of root canal treatment and often require retreatment [1]. The prevalence of missed canals in maxillary molars has also been reported to vary from 45.6% to 91.5% [1, 2]. The presence of second mesiobuccal (MB2) canals, which are often either missed or misidentified, leads to inadequate root canal treatment. Determining the location of MB2 canals requires clinical skills and accurate imaging, as their anatomical variations pose significant challenges in diagnosis [3].

In maxillary molars, it is possible for the distobuccal and palatal roots to have more than one canal or for the canals to be C-shaped, all of which pose problems during endodontic treatment and

compromise treatment prognosis. The problems encountered during endodontic treatment in maxillary molars highlight the need for enhanced knowledge of canal and root anatomy [4, 5]. Maxillary first and second molars have also attracted the attention of researchers due to their great anatomical diversity [6].

Maxillary molars have two buccal roots and one palatal root, and their palatal and distobuccal roots are single-canal, often showing Vertucci's types I and V configurations. Also, there is a great variation in the number and type of canals in mesiobuccal roots, with more than 50% having two canals [7]. Moreover, the distobuccal root has a type I canal in 98%-100% of cases; this rate is 100% in the palatal root, and the mesiobuccal root has two canals in 65% of first molars and 55% of second molars, which are type IV in 44.2% of cases [8]. At the same time, there is a

great variation in the results of different studies on the morphology of root canals, which is mostly due to the use of different methods for assessment of canal configuration.

To date, various methods have been used to investigate and study the configuration and morphology of canals in different teeth, including clearing and staining methods, radiography, microscopy, and cone-beam computed tomography (CBCT) [9]. Among these methods, the clearing and staining method is the gold standard and has the highest accuracy [10]. The main advantage of this method is no requirement for special instruments to enter the root canal, maintains the original root canal shape, provides a three-dimensional display of root canals, and the possibility of secondary and lateral canals [11, 12].

CBCT is a valuable tool for visualizing the internal anatomy of teeth [13, 14], but its ability to capture the fine details of the MB2 depends on the resolution and image acquisition parameters [15]. Previous investigations have used large field of view (FOV) and specific tomographic factors to capture the details and configurations of MB2, and have had limitations in this regard, indicating that there are large gaps in recognition of the complex anatomy of MB2 [16]. Therefore, further studies are needed in this area.

While previous studies in the Iranian population have reported MB2 canal configurations using conventional CBCT protocols (typically with voxel sizes ≥ 0.2 mm and larger FOVs), the specific contribution of ultra-high-resolution imaging (0.1-mm voxel size combined with a 5×5-mm ultra-small FOV) to accurately differentiate complex subtypes (particularly types VI, VII, and VIII, which require identification of subtle canal merging and separation point) has not been systematically investigated [17–19]. Thus, the present study aimed to provide a refined, high-resolution anatomical dataset using a rigorous methodological framework to determine the true prevalence of complex MB2 configurations in an Iranian sample, thereby offering more reliable data for clinical risk stratification and for comparison with future meta-analyses. This study aimed to assess the configuration of MB2 of maxillary first molars according to Vertucci's classification in an Iranian population using high-resolution CBCT.

Materials and Methods

This cross-sectional study was conducted on high-resolution CBCT scans of three-rooted maxillary first molars of male and female patients over 18 years. The respective teeth had no previous endodontic treatment, and teeth with root fusion, open apex, internal/external root resorption, or root fracture were excluded. The CBCT scans had been taken for purposes not related to this study and were retrieved from the archives of a private radiology

clinic in Tehran, Iran, after obtaining ethical approval from the university ethics committee (IR.SHAHED.MED.REC.1405.024). This retrospective study was conducted in accordance with the Declaration of Helsinki. Due to the retrospective nature of the study, which utilized anonymized data from existing clinical records, additional informed consent was not required and was formally waived by the ethics committee.

Sample size

The sample size was calculated based on the clinically most relevant primary outcome, namely the proportion of complex canal configurations (Vertucci types IV and higher). While the study aims to describe the distribution of all eight Vertucci types, formal sample size estimation for a multinomial distribution across eight categories is not straightforward and typically requires simulation-based approaches. Therefore, we conservatively used the prevalence of types IV–VIII (estimated at 58% in a pilot evaluation of 50 scans) as the primary endpoint for sample size calculation, which also provided sufficient power for subgroup comparisons between genders and age groups. In a preliminary evaluation of 50 randomly selected CBCT scans from the same population, the prevalence of types IV–VIII was estimated at 58%. Using a 5% significance level, a 5% margin of error, a minimum of 385 scans was required to estimate this proportion with adequate precision. This sample size also ensured $\geq 80\%$ power to detect clinically meaningful differences between gender and age subgroups. The originally planned sample of 241 cases, which was based solely on the overall presence of MB2 canals (preliminary prevalence 94%), was increased to 385 to improve the reliability of subtype-specific estimates. A total of 412 CBCT scans were initially screened. Of these, 27 were excluded due to poor image quality ($n=9$), extensive restorative artifacts ($n=11$), or root resorption/fusion ($n=7$), leaving 385 scans for final analysis. The slight discrepancy between the preliminary MB2 prevalence (94%) and the final observed prevalence (approximately 89.9%, as reflected by 10.1% Type I) is attributable to sampling variability and the conservative classification of partially visible or ambiguous canals as Type I.

Data collection

All CBCT scans were acquired using the same NewTom VGi Evo scanner (Celfa S.C. – NewTom Division, Imola, Bologna, Italy) with standardized exposure parameters: 110 kVp, 12 mA, 5×5 mm FOV, and 100 μ m (0.1 mm) isotropic voxel size. Images were reconstructed with a slice thickness of 0.1 mm and a reconstruction increment of 0.1 mm to maintain contiguous sections.

One experienced oral and maxillofacial radiologist evaluated all images using OnDemand3D software version 10.0.1 (Cybermed Inc., Seoul, South Korea) in a dark room with calibrated monitors. The following systematic protocol was applied.

Multiplanar navigation: The entire volume was examined simultaneously in axial, sagittal, and coronal planes. The radiologist scrolled through the entire root length from the pulp chamber floor to the root apex in 0.1-mm steps, using cross-sectional views perpendicular to the longitudinal axis of the mesiobuccal root to track canal pathways continuously.

Image adjustments: Contrast, brightness, and magnification were optimized interactively to enhance canal visibility. No filters or noise reduction algorithms were applied.

Diagnostic criteria for Vertucci's classification: Each canal was traced from its orifice to its apical foramen. Classification strictly followed Vertucci's original definitions [20]. To ensure consistent differentiation among all eight types, the following criteria were applied [20]:

-Type I: A single canal extending from the pulp chamber to the apex with a single foramen.

-Type II: Two separate canals leaving the chamber that merge into one before the apex, forming a single foramen.

-Type III: One canal that divides into two distinct canals within the root and then rejoins into one single canal before the apex.

-Type IV: Two separate, distinct canals extending from the chamber to the apex with two separate foramina.

-Type V: One canal leaving the chamber that divides into two distinct canals near the apex with two separate foramina.

-Type VI: Two separate canals leaving the chamber, merging in the middle third of the root, and then dividing again into two distinct canals near the apex.

-Type VII: One canal leaving the chamber that divides, then merges, and finally divides again into two distinct canals near the apex.

-Type VIII: Three distinct canals extending from the chamber to the apex with three separate foramina.

Rule for ambiguous cases: When the exact merging or division point was unclear due to calcification or artifact, the configuration was recorded as the simpler type (e.g., if a clear merger could not be confirmed in a suspected type II, it was conservatively classified as type IV; if a division could not be confirmed in a suspected type V, it was classified as type I). This approach minimizes overestimation of complex configurations.

Handling of ambiguous or calcified canals: If a canal could not be clearly traced due to calcification or artifact, it was classified as "unclassifiable" only when the entire root length could not be evaluated. Partially calcified canals that remained traceable were classified based on the observed continuity. In cases where the canal was completely invisible but the root morphology suggested its possible presence, it was recorded as type I. In the present study, applying the conservative criteria described above, no tooth was ultimately classified as "unclassifiable"; all 385 teeth were assigned to one of the eight Vertucci types.

In the present study, "configuration" referred specifically to the anatomy of the MB2 canal within the mesiobuccal root, as evaluated from its orifice to its apical foramen. The primary mesiobuccal canal was not classified, as it consistently exhibited a type I configuration.

Consensus review: For 20 randomly selected cases with complex configurations (types VI–VIII), a second oral radiologist independently reviewed the images. Any disagreement (observed in 3 cases; inter-examiner kappa=0.85) was resolved by discussion to reach a consensus. In all three cases, the final classification was type IV (two cases) and type VI (one case). The primary radiologist's initial readings were used for all other cases. The intra-examiner agreement was excellent ($\kappa=0.91$), and inter-examiner agreement for 20 randomly selected complex cases was substantial ($\kappa=0.85$) [21].

Statistical analysis

Associations between canal configuration and gender (male/female) and age group (20–40 vs. 41–59 years) were assessed using Fisher's exact test with Monte Carlo simulation (10,000 replicates) to account for cells with expected frequencies <5. For the significant gender association, post-hoc pairwise comparisons were performed using Fisher's exact test with Bonferroni correction for multiple comparisons (adjusted $\alpha=0.05/8=0.00625$). Effect size for the overall association was measured using Cramér's V.

To further explore the independent effects of gender and age, a multinomial logistic regression model was fitted with Vertucci type as the dependent variable (type I as the reference category). Age group and gender were entered as independent variables. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for each configuration relative to type I. The model's goodness-of-fit was assessed using the likelihood-ratio test. All statistical tests were two-sided, with significance set at $P<0.05$. Analyses were performed using SPSS version 26 (IBM, Armonk, NY, USA) and R version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria).

Results

CBCT images of 385 patients with a mean age of 37.34 ± 9.86 years (range 20 to 59 years) were evaluated. Overall, 240 patients (62.3%) were between 20 and 40 years, and 145 (37.7%) were between 41 and 59 years. There were 276 females (71.7%) and 109 males (28.3%). The intra-examiner agreement was excellent ($\kappa=0.91$).

Fig. 1 shows the relative frequency distribution of different configurations of MB2 in maxillary first molars according to Vertucci's classification. As shown, type IV had the highest frequency ($n=147$, 38.2%; 95% CI: 33.5%–43.2%), followed by

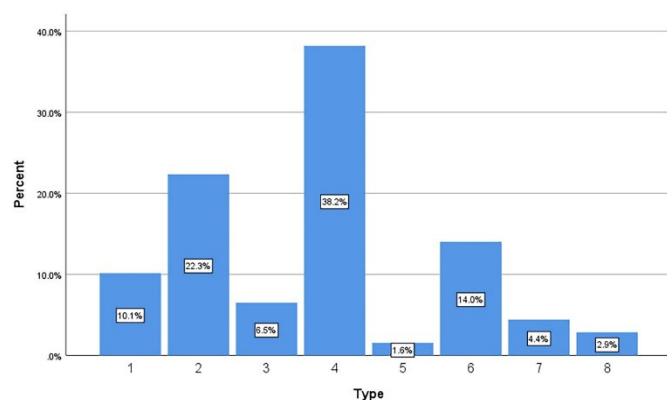


Figure 1. Relative frequency distribution of different configurations of MB2 in maxillary first molars according to Vertucci's classification

type II ($n=86$, 22.3%; 95% CI: 18.5%–26.7%), type VI ($n=54$, 14.0%; 95% CI: 10.9%–17.9%), type I ($n=39$, 10.1%; 95% CI: 7.4%–13.6%), type III ($n=25$, 6.5%; 95% CI: 4.4%–9.4%), type VII ($n=17$, 4.4%; 95% CI: 2.8%–7.0%), type VIII ($n=11$, 2.9%; 95% CI: 1.6%–5.1%), and type V ($n=6$, 1.6%; 95% CI: 0.7%–3.4%).

Table 1 presents the relative (percentage) and absolute (number) frequency of different configurations of MB2 in maxillary first molars according to Vertucci's classification in males and females, along with the 95% CIs for the overall prevalence estimates. Fisher's exact test with Monte Carlo simulation revealed significant differences in the frequency of different configurations between males and females ($P=0.002$).

Table 2 presents the relative (percentage) and absolute (number) frequency of different configurations of MB2 in maxillary first molars according to Vertucci's classification based on age group. Fisher's exact test with Monte Carlo simulation found no significant difference in the frequency of different configurations between the two age groups ($P=0.61$).

The overall association between Vertucci type and gender was significant (Fisher's exact test with Monte Carlo simulation, $P=0.002$; Cramér's $V=0.18$, indicating a weak-to-moderate effect). Post-hoc pairwise comparisons with Bonferroni correction (adjusted $\alpha=0.05/8=0.00625$) revealed that type IV was significantly more frequent in females than in males (44.2% vs. 22.9%, adjusted $P=0.003$). No other pairwise comparisons reached statistical significance after correction. Specifically, the apparent difference for type VIII (5.5% vs. 1.8%, unadjusted $P=0.04$) did not remain significant after Bonferroni adjustment.

In the multinomial logistic regression model (likelihood-ratio Chi-square=28.6, degrees of freedom (df)=14, $P=0.012$), gender remained a significant predictor after adjusting for age. Relative to type I, females had significantly higher odds of presenting type IV (adjusted odds ratio (OR)=2.66, 95% CI: 1.32–5.35, $P=0.006$) and significantly lower odds of presenting type VIII (adjusted

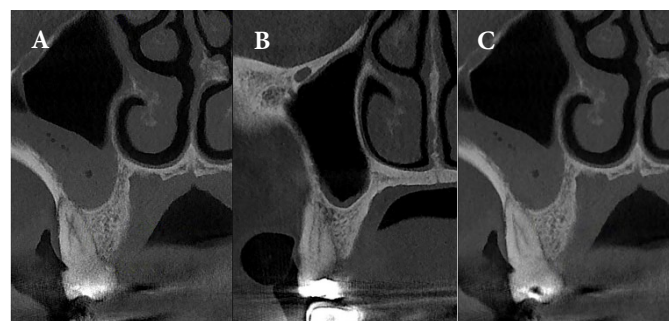


Figure 2. CBCT images demonstrating Vertucci's types: A) Type VI; B) Type IV; C) Type II.

OR=0.32, 95% CI: 0.09–0.98, $P=0.046$). Age group was not a significant predictor for any configuration (all $P>0.05$). No significant interaction was detected between gender and age (likelihood-ratio test, $P=0.38$). Detailed regression results are presented in Table 3.

Fig. 2 show representative samples of Vertucci's types IV, VI, and II.

Discussion

This study assessed the configuration of MB2 of maxillary first molars according to Vertucci's classification in an Iranian population using high-resolution CBCT. The results showed that Vertucci's type IV had the highest frequency (38.2%), followed by type II (22.3%), type VI (14%), type I (10.1%), type III (6.5%), type VII (4.4%), type VIII (2.9%), and type V (1.6%). The frequency of different types significantly varied between males and females but was not significantly different between the two age groups.

Khademi *et al.* [17] examined the root morphology and configuration of MB2 in maxillary first molars in an Iranian population using CBCT and reported that type VI (35%) and type II (19%) had the highest frequency. These findings were different from the results of the present study, although in both studies, type II ranked second and its prevalence was approximately equal. Al-Saedi *et al.* [18] also examined the prevalence of MB2 canals in maxillary first molars in an Iraqi population in Basra city using CBCT and reported that the most common canal configuration was type II (44.58%), followed by type IV (31.30%), and type I (18.32%). Despite the difference in the rank of different configurations, the prevalence of type IV and type I configurations in the two studies was somewhat consistent. In a study by Alves *et al.*, [19] type II was the most common MB2 canal configuration in maxillary first molars of a Brazilian population (38.12%).

On the other hand, Blank-Goncalves *et al.* [20] examined the anatomical configuration of the mesiobuccal roots of maxillary

first molars using Vertucci's classification. According to their results, the most common anatomical configuration of the mesiobuccal root included type IV (35%) and type VI (25%). These findings are somewhat consistent with the results of the present study. Naseri *et al.*, [21] also showed that in the mesiobuccal roots of first molars in the Iranian population, type IV had the highest frequency, and type III had the lowest frequency.

A systematic review by Barbhai *et al.* [22] also reported that in the mesiobuccal root, the most common canal type according to Vertucci's classification was type I (33.29%), followed by types II (27.18%) and IV (26.36%). Overall, type IV in the mesiobuccal root of maxillary first molars was more common among Asians; this finding is in contrast to the results of studies in Caucasian populations in Turkey [23] and the United States [24] where type II was reported to be the most common canal type. At the same time, in a study in a Turkish population, type IV was reported to be the most common canal configuration [25], and in an American

population [26] types II and IV canals had the same prevalence rate.

Pérez-Heredia *et al.* [27] in a study of 119 teeth from a Spanish population reported the frequency of types II, IV, VI, and others as 65.5%, 9.26%, 5%, and 5.2%, respectively. Ratanajirasut *et al.* [28] in a study of 302 teeth from a Thai population demonstrated the frequency of MB2 canal types II, III, IV, V, VI, and others as 45.4%, 4.3%, 39.7%, 8.3%, 1.7%, and 0.7%, respectively. Mheiri *et al.* [29] evaluated 418 teeth in an Emirati population and found the frequency of types II, III, and IV configurations to be 73.7%, 17.2%, and 19.1%, respectively. Mufadhal and Madfa [30] assessed 306 maxillary first molars in a Yemeni population and showed the frequency of types II, III, IV, V, VI, VII, and other configurations to be 30.4%, 28.1%, 13.7%, 6.9%, 8.2%, and 10.1%, respectively.

Differences in the reported values in the literature are likely related to regional, racial, gender, or age differences [27, 30]. Xiang *et al.* [31] examined the morphology of MB2 in 486 maxillary first molars (285 patients) in a Chinese population using CBCT, and

Table 1. Relative (percentage) and absolute (number) frequency of different configurations of MB2 in maxillary first molars according to Vertucci's classification in males and females, with 95% confidence intervals for overall prevalence

Configuration type	Female	Male	Total	95% CI for Total
Type I	26 (9.4%)	13 (11.9%)	39 (10.1%)	7.4%-13.6%
Type II	59 (21.4%)	27 (24.8%)	86 (22.3%)	18.5%-26.7%
Type III	14 (5.1%)	11 (10.1%)	25 (6.5%)	4.4%-9.4%
Type IV	122 (44.2%)	25 (22.9%)	147 (38.2%)	33.5%-43.2%
Type V	4 (1.4%)	2 (1.8%)	6 (1.6%)	0.7%-3.4%
Type VI	38 (13.8%)	16 (14.7%)	54 (14%)	10.9%-17.9%
Type VII	8 (2.9%)	9 (8.3%)	17 (4.4%)	2.8%-7.0%
Type VIII	5 (1.8%)	6 (5.5%)	11 (2.9%)	1.6%-5.1%
Total	276 (100%)	109 (100%)	385 (100%)	-

Table 2. Relative (percentage) and absolute (number) frequency of different configurations of MB2 in maxillary first molars according to Vertucci's classification based on age group, with 95% confidence intervals for overall prevalence

Configuration	20-40 (year)	41-59 (year)	Total	95% CI for Total
Type I	24 (10%)	15 (10.3%)	39 (10.1%)	7.4%-13.6%
Type II	51 (21.3%)	35 (24.1%)	86 (22.3%)	18.5%-26.7%
Type III	16 (6.7%)	9 (6.2%)	25 (6.5%)	4.4%-9.4%
Type IV	94 (39.2%)	53 (36.6%)	147 (38.2%)	33.5%-43.2%
Type V	3 (1.3%)	3 (2.1%)	6 (1.6%)	0.7%-3.4%
Type VI	33 (13.8%)	21 (14.5%)	54 (14%)	10.9%-17.9%
Type VII	9 (3.8%)	8 (5.5%)	17 (4.4%)	2.8%-7.0%
Type VIII	10 (4.2%)	1 (0.7%)	11 (2.9%)	1.6%-5.1%
Total	240 (100%)	145 (100%)	385 (100%)	-

Table 3. Multinomial logistic regression analysis for Vertucci configurations (reference: Type I), adjusted for gender and age group

Configuration	Adjusted OR (Female vs. Male)	95% CI	P-value	Adjusted OR (41-59 vs. 20-40)	95% CI	P-value
Type II	0.92	0.52-1.63	0.78	1.12	0.64-1.96	0.69
Type III	0.81	0.34-1.91	0.63	0.89	0.37-2.13	0.79
Type IV	2.66	1.32-5.35	0.006	0.91	0.54-1.53	0.72
Type V	0.98	0.17-5.56	0.98	1.61	0.31-8.37	0.57
Type VI	1.02	0.49-2.11	0.96	1.11	0.58-2.11	0.75
Type VII	0.58	0.21-1.58	0.28	1.37	0.52-3.62	0.53
Type VIII	0.32	0.09-0.98	0.046	0.18	0.02-1.48	0.11

Values in bold indicate statistical significance ($P < 0.05$). OR=odds ratio; CI=confidence interval.

reported that the most common canal configuration was type IV (65.0%), followed by type II (9.30%), with the total prevalence of other canal configurations is less than 3% [31]. The main issue is that the results of the present study were obtained using a high-resolution CBCT scanner under fixed conditions, including 110 kV tube potential, 12 mA tube current, 5×5 mm FOV, and 100 µm (0.1 mm) voxel size, and few studies have been conducted using these parameters, limiting the possibility of comparing the results.

Micro-computed tomography (micro-CT) of maxillary first molars provides more detailed and clearer images of the internal anatomy, such as loops, secondary canals, and intracanal communications, than other methods. This method is considered the gold standard for assessing the complex root canal system [32]. However, this method is only available *in vitro*, does not apply to dentists and endodontists in the clinical setting, and is used only at the research level. At the same time, in a comparative study of CBCT, digital periapical radiography, and microtomography to determine the number of canals in the mesiobuccal roots of maxillary molars, no significant difference was observed between CBCT and microtomography data, but a statistically significant difference was observed between these two methods and periapical radiography [33]. On the other hand, conventional radiographic modalities have difficulty in detecting MB2 canals [33]. As a result, the internal anatomy of MB2, which ends at the root tip as a separate canal with its own foramen(s), is rarely recognized. In such circumstances, the likelihood of a complete and adequate seal of this canal is low. Therefore, endodontists may need to use CBCT as the imaging modality of choice in routine clinical examinations. Despite these advantages, CBCT has limitations such as higher patient radiation dose, the possibility of artifacts, high levels of scatter or noise, and fluctuations in the dose distribution in the volume of interest, which limit its widespread clinical use [34]. Therefore, the use of CBCT should be limited to cases with complex or unusual morphology. The use of CBCT during treatment is also recommended when unexpected anatomy is observed, or canals are not identified after access cavity preparation [35]. In addition, it is better to perform CBCT with a small FOV, because more accurate anatomical information is obtained when a small FOV is used in CBCT. In fact, although the FOV size is not a fundamental factor for identifying the presence of the MB2 canal, it is necessary for identifying different internal anatomies of tooth roots on CBCT scans [19].

In addition to examining the configuration of MB2 in maxillary first molars of patients using high-resolution CBCT, patient characteristics such as gender and age were also evaluated in this study. Significant differences were observed in the anatomical configuration of MB2 in maxillary first molars according to Vertucci's classification between males and females. The relationship between gender and root canal configuration is a

controversial topic. Naseri *et al.* [21] studied the root and canal anatomy of maxillary first molars using CBCT and according to age and sex of patients, and did not observe significant differences between the canal configurations according to age and sex, or the number of roots or canals. Also, in a study by Altunsoy *et al.* [36] on the root and root canal morphology of maxillary first and second molars in a Turkish population, it was determined that the number of root canals and the structure of maxillary first and second molars did not differ significantly according to sex. In a study by Blank-Goncalves *et al.* [20] no significant differences were observed between the two sexes in terms of the prevalence and anatomical configurations of the mesiobuccal roots of maxillary first molars. These observations are not consistent with the present results. Some previous studies used different ethnic groups or scanners with a 15×15 cm FOV that has a poor resolution [26] or examined older populations [37]. Therefore, the difference between the results of the present study and such studies can be justified.

Although the present study observed a statistically significant association between gender and Vertucci configuration (specifically a higher proportion of type IV in females and type VIII in males), this finding warrants cautious interpretation. The biological plausibility of sex-based differences in root canal morphology remains unclear, and no consistent pattern has emerged across previous investigations [17, 25, 40]. The marked imbalance in our sample (71.7% female) introduces the possibility of selection bias, as the included CBCT scans were derived from a clinical archive and may not be representative of the general population. In addition, the analysis did not account for potential confounders such as the primary reason for CBCT referral, systemic conditions affecting dentin mineralization, or previous restorative procedures that might influence canal visibility. Therefore, our gender-related results should be considered hypothesis-generating rather than conclusive, and independent studies with balanced sex distribution are necessary for confirmation.

Age of patients is an important preoperative predictor of the detection of additional canals in maxillary molars [38]. Additional root canals in maxillary molars are mainly found in patients under 40 years of age [39]. It is possible that with increasing age, the root canals or their orifices become calcified, making it difficult to detect additional canals [29]. Therefore, given that the canals gradually become mineralized over time, even if the MB2 canal is present, it may become completely blocked over time and no longer detectable even with high-resolution CBCT. In the present study, no significant differences were observed in the frequency of different configurations of MB2 in maxillary first molars of younger and middle-aged age groups.

The shape and structure of the root canals of teeth change with age. The pulp chamber gradually narrows, and root canal

calcification occurs over time [40]. These changes make identification and preparation of MB2 more difficult in root canal therapy. Since in 61.1% of cases, the configuration of the MB2 in maxillary first molars was type IV and above with more than one apical foramen, there is a possibility of endodontic treatment failure in more than half of the teeth. The current results do not directly provide specific clinical guidance for endodontists, but they can provide them with important points about the morphology and classification of MB2 in the Iranian population. This finding is of great importance, and endodontists should be aware of it, because MB2 canals have a small volume and their anatomy can cause endodontic treatment failure; when this canal remains unfilled, the apical foramen remains open, and the canal is exposed at the end of treatment. In selected cases where complex MB2 morphology is suspected or when conventional periapical radiography fails to identify additional canals, dental clinicians may consider a high-resolution CBCT with a small FOV to better define the anatomy. However, this should be reserved for cases where the anticipated diagnostic benefit outweighs the radiation risk, in accordance with American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology (AAE/AAOMR) guidelines, and the as low as reasonably achievable (ALARA) principle.

The predominance of Vertucci's type IV (38.2%), followed by types II (22.3%) and VI (14%), observed in the present study may be partially attributed to the use of high-resolution CBCT imaging with a voxel size of 0.1 mm and a limited 5×5 mm FOV. Previous studies have demonstrated that voxel size significantly influences the detection of MB2 canals and their anatomical details [15, 19]. Smaller voxel sizes provide higher spatial resolution and enable more accurate visualization of complex root canal systems. Consequently, studies employing larger voxel sizes or wider FOV may underestimate the prevalence of complex canal configurations [15, 34].

From a clinical perspective, the present findings are highly relevant for endodontic treatment planning. More than 60% of the evaluated teeth exhibited Vertucci's type IV or more complex canal configurations. Such anatomical patterns often involve separate canal pathways and multiple apical exits, increasing the risk of incomplete canal debridement, shaping, and obturation when the MB2 canal is not properly identified and treated. Previous CBCT studies have demonstrated an association between missed canals and apical periodontitis in maxillary molars [1, 2]. Therefore, failure to detect and adequately manage MB2 canals may adversely affect treatment outcomes and long-term prognosis. High-resolution CBCT may be considered in selected cases with suspected complex canal anatomy or when conventional methods fail to identify additional canals.

Although the present study found a significant association between canal configuration and gender, the biological basis of this relationship remains unclear. Differences in ethnicity, sample composition, imaging protocols, and classification methodologies may explain discrepancies among studies [20, 21, 36]. Furthermore, despite the well-documented influence of aging on canal calcification, no significant association was found between age and MB2 configuration, suggesting that the fundamental anatomical pattern may remain relatively stable throughout adulthood [29, 38, 40].

The predominance of complex configurations (types IV, II, and VI) observed is likely influenced by technical, biological, and population-specific factors. From an imaging physics perspective, the use of a 0.1-mm isotropic voxel size and a 5×5-mm FOV provides substantially higher spatial resolution than larger FOV or thicker slice protocols. Small voxels decrease partial volume averaging, improving the detection of fine canal communications, merging points, and separate apical foramina that might otherwise be overlooked. This technical advantage may explain why the present study reported higher proportions of complex types compared with earlier studies that used voxel sizes of 0.2–0.3 mm or wider FOVs [15, 24].

From a biological standpoint, the developmental anatomy of the mesiobuccal root is defined by the pattern of odontoblast differentiation and the fusion of the Hertwig epithelial root sheath during root formation. Variations in the timing and extent of sheath invagination justify the different Vertucci configurations. Population-specific genetic and epigenetic factors may modulate these developmental processes, contributing to the ethnic differences. For example, Asian populations have generally shown higher frequencies of type IV and complex configurations compared with Caucasian populations, although methodological heterogeneity complicates direct comparisons [26].

Several limitations should be considered when interpreting the findings. First, all CBCT scans were derived from a single private radiology center in Tehran, which may not be representative of the broader Iranian population or other geographic regions. Second, the sample exhibited a marked female predominance (71.7%), introducing potential selection bias and limiting the generalizability of the gender-related comparisons. Third, the age range was restricted to 20–59 years; older patients (>59 years) were not included, and age-related progressive canal calcification may render the MB2 canal less detectable in older individuals, influencing the observed prevalence of complex configurations. Fourth, only three-rooted maxillary first molars were evaluated; four-rooted variants or teeth with root fusion were excluded. While this was necessary for methodological consistency, it means that the full spectrum

of anatomical variation in the Iranian population is not captured. Fifth, the clinical significance of the observed configurations remains unknown because treatment outcomes, healing rates, and the actual frequency of missed canals were not assessed. Finally, although a high-resolution CBCT protocol was used, this technique has inherent limitations, including susceptibility to beam-hardening artifacts, noise, and partial volume effects, which may affect the visualization of very fine canal communications. Then, using these results for clinical decision-making should be considered with caution, and the results should be confirmed by future prospective studies with more balanced demographic representation.

The high frequency of complex MB2 configurations observed here underscores the importance of thorough anatomical assessment before and during root canal treatment of maxillary first molars. However, it is essential to emphasize that the present study did not evaluate treatment outcomes. Thus, the association between canal complexity and treatment failure remains inferential rather than established. Clinicians should be aware that when an MB2 canal is present and complex (e.g., types IV, VI, or VIII), endodontic procedures including negotiation, cleaning, shaping, and obturation are technically more demanding, and the risk of missing a separate canal is increased. Nevertheless, the decision to obtain a preoperative CBCT should follow evidence-based guidelines: CBCT is recommended when conventional radiography yields equivocal findings, when unusual anatomy is suspected, or when prior treatment has failed, and retreatment is being planned [45]. Routine use of CBCT for all maxillary first molars is not supported by current evidence and is inconsistent with the ALARA principle. The present results should assist clinicians in risk stratification but should not be interpreted as a mandate for routine advanced imaging.

Conclusion

Vertucci type IV was the most frequent MB2 configuration in maxillary first molars, and 61.1% of examined teeth exhibited complex canal patterns, which are anatomically more challenging for endodontic treatments.

From a clinical perspective, high-resolution CBCT with a small FOV (e.g., 5×5 mm) and fine voxel size (≤ 0.1 mm) can provide valuable anatomical information when complex MB2 morphology is suspected or when conventional periapical radiography fails to identify additional canals. However, such imaging should be used judiciously, in accordance with the AAE/AAOMR joint position statement and the ALARA principle, reserving CBCT for selected cases where the expected diagnostic benefit outweighs the radiation risk.

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Conflict of interest

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Authors' contributions

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