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Original Article

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

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Abstract *Background/purpose:* Inadequate understanding of tooth morphology can lead to missing root canals and procedural errors during root canal treatment. This study assessed the root and root canal morphology of maxillary first molars in a Japanese population, employing two classification systems and utilizing cone-beam computed tomography (CBCT).
Materials and methods: The study included CBCT scans of 833 maxillary first molars from 642 Japanese individuals aged 16–80 years. The evaluations used the Vertucci and Ahmed classification systems to assess root and root canal morphologies and fusions. Data were statistically analyzed based on gender and age using the chi-square test ($P < 0.05$).
Results: Ninety-seven percent of maxillary first molars had three separate roots. The second mesiobuccal canal (MB2) was identified in 52.9 % of teeth. Six root types and 17 tooth types were identified with the Vertucci and Ahmed classifications, respectively. The most common configuration of the mesiobuccal root having the MB2 was Vertucci type IV (31.2 %) followed by type II (15.3 %). A higher occurrence of MB2 was noted among males (58.9 %) and individuals in their 21–40 years (56.8 %) ($P < 0.05$). Root fusion, root canal fusion, and C-shaped root canals, which were unclassifiable by the Vertucci classification, were identified in 2.8 %, 0.9 %, and 0.7 %, respectively.
Conclusion: Maxillary first molar in the Japanese population displayed notable anatomical variations, underscoring the importance of recognizing age- and gender-related anatomical

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characteristics. The Ahmed classification offered a more detailed depiction of morphological diversities, enhancing the understanding and treatment of complex root canal systems.

Introduction

The success of root canal treatment largely relies on effective bacterial infection control throughout the entire root canal system.[1] To achieve this, a profound comprehension of the anatomy of the root and canals is essential.[2] Given the root canal system's complexity and variability, a lack of knowledge on its configuration can lead to overlooked root canals and procedural mistakes, thus increasing the likelihood of treatment failure.[3] Despite technological advances, there has not been a significant improvement in the success rates of root canal treatments over the past decades.[4,5] This highlights the need for a deeper knowledge of the variations in root canal anatomy to enhance treatment outcomes.

Maxillary first molars, especially their mesiobuccal roots, exhibit considerable anatomical heterogeneity, particularly regarding the presence and configuration of the second mesiobuccal canal (MB2). Thus, studies have reported diverse findings across various populations.[6,7] Clinically, the MB2 of the maxillary first molar is among the most frequently overlooked canals, which potentially compromises the long-term success of root canal treatments for this particular tooth type.[8,9]

A range of techniques, such as tooth-clearing,[2] intraoral radiography,[10]cone-beam computed tomography (CBCT),[6,11] micro CT,[12] and swept-source optical coherence tomography,[13,14] have been employed to examine root and root canal morphology. Currently, CBCT is considered a useful tool for studying root and root canal anatomy due to its reliability, broad acceptance, and accurate management of patient information.[15] Research has actually demonstrated that CBCT is equally effective as tooth-clearing or root-sectioning in detecting root canal systems.[11]

The Vertucci classification[2] has been the traditional approach, widely used for its simplicity and ease of sharing among dentists. However, this classification has limitations in describing complex morphologies, including multiple roots, C-shaped roots, or fused roots. Recently, Ahmed et al. proposed a new classification system that integrates canal morphology with the number of roots into a single descriptor, aiming to provide detailed representation of root and root canal anatomy.[16] However, application of the Ahmed classification has been limited to a few studies.[17—20]

Genetic factors significantly contribute to the diversity of root canal morphologies, underscoring the importance of studying root and canal variations across different racial groups.[7] Regarding the MB2 of the maxillary first molar, a meta analysis revealed a worldwide prevalence rate of 69.6 %, with lower rates in Asian (62.2 %) and Oceania populations (53.1 %).[7] However, research on the anatomy of the root and root canal of Asian populations has largely focused on Chinese and Korean groups, with the maxillary first molars of Japanese populations receiving less attention.[20—22] This underscores a significant gap in the literature and highlights the necessity for dedicated research on the distinct root and root canal anatomy of the Japanese population.

No study has yet utilized CBCT in conjunction with the Ahmed classification to investigate the anatomy of the maxillary first molar in the Japanese population. Consequently, this study aimed to examine the configuration of the root and root canal of the maxillary first molar, using CBCT scans from patients at Tokyo Medical and Dental University Dental Hospital, while employing both the Vertucci and Ahmed classifications and correlating the findings with gender and age.

Materials and methods

Sample collection

All experimental procedures in this study received approval from the Ethics Committee, Tokyo Medical and Dental University (D2016-102). The sample size was estimated using G*Power 3.1.9 software (Heinrich-Heine-Universität, Düsseldorf, Germany); at least 543 subjects were chosen based on the calculated sample size for the Japanese population. CBCT scans were taken using the Fine Cube CBCT scanner (Yoshida, Tokyo, Japan) at the Tokyo Medical and Dental University Dental Hospital from 2013 to 2014. The imaging protocol included a field of view of ϕ 81 mm $\times$ 74 mm and operational parameters set at a voxel size of 157 μm.

Inclusion and exclusion criteria

The study included Japanese patients aged 16—80 years who had at least one permanent maxillary first molar, no prior root canal treatment, and fully matured and erupted teeth. The exclusion criteria included teeth with obturations, prosthetic devices, root resorption, caries, periapical lesions, or low-quality images unsuitable for evaluation.

Radiographic evaluation

The CBCT scans were analyzed by an endodontic resident and an experienced endodontist, using a 1280 $\times$ 1024 resolution on a dedicated DICOM viewer (FineCube viewer, Yoshida). The observers conducted their assessments independently and disagreements were addressed through discussion until a consensus was achieved. They received training and calibration that displayed root canal morphology according to the two classification systems employed.

The maxillary first molars were evaluated for the number of roots and root canals, along with their configurations based on the classification proposed by Vertucci (Fig. 1)[2] and Ahmed et al. (Figs. 2 and 3).[16] The evaluations also included an analysis of root fusion, categorized according to the systems proposed by Zhang et al.[23] (Fig. 4). The assessments were repeated twice, with at least a month's gap between sessions to minimize bias. The data were systematically tabulated and analyzed for correlations with age and gender. Age groups were stratified as $\leq$20, 21–40, 41–60, and $\geq$61 years, consistent with previous studies.[24]

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 29.0. The Pearson chi-square test with Bonferroni correction was applied for comparisons across different groups, with a significance threshold established at $P < 0.05$. A kappa test assessed reproducibility and reliability.

Results

This study analyzed 833 maxillary first molars from 642 Japanese subjects, including 205 males and 437 females, with an average age of 42.0 years. The inter- and intra-examiner agreement rates were 88.9 % and 93.1 %, respectively.

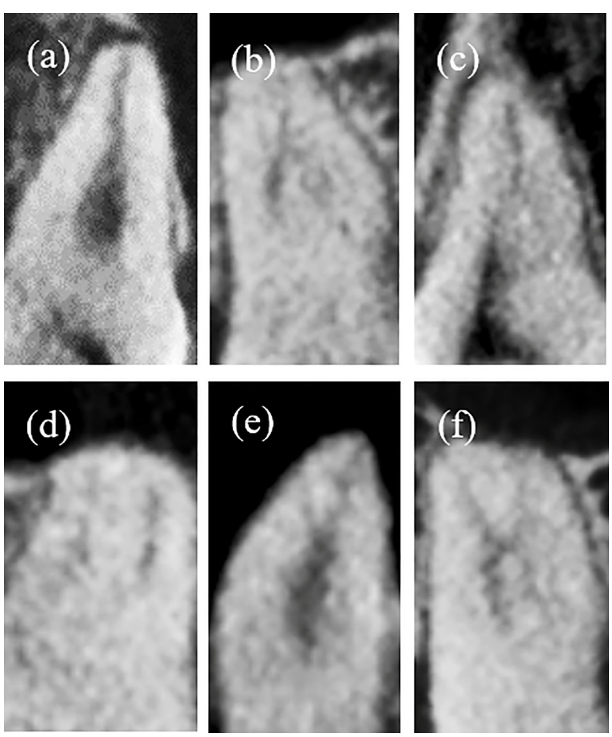

Figure 1 Representative CBCT scans showing mesiobuccal roots of the maxillary first molar classified with the Vertucci classification.[2] (a) Type I (1), (b) Type II (2–1), (c) Type III (1-2-1), (d) Type IV (2), (e) Type V (1–2) and (f) Type VI (2-1-2). Types VII (1-2-1-2) and VIII (3) were not identified in this study.

Three separated roots were predominant in maxillary first molars (97.0 %), and the frequency of the two separated roots was observed at 0.2 % (Table 1). The prevalence of MB2 was 52.9 %. Males (58.9 %) had a significantly higher frequency of having four canals than females ($P < 0.05$) (Table 1). The prevalence of MB2 was significantly higher among individuals aged 21–40 years than those aged 41–60 years (Table 1).

Using the Vertucci classification (Table 2), the MB roots were classified into 6 types with 22 unclassifiable roots. The most common configuration of the mesiobuccal root having the MB2 was type IV (31.2 %) followed by type II (15.3 %). The prevalence of teeth unclassifiable by the Vertucci classification but classifiable by the Ahmed classification was 2.8 %.

According to the Ahmed classification (Table 3), maxillary first molars were classified into 17 types. The most common configurations of teeth with MB2 were ^{3}MFM MB^{2} DB^{1} P^{1} (31.1 %), followed by ^{3}MFM MB$^{2-1}$ DB^{1} P^{1} (15.2 %). The prevalence of ^{3}MFM MB$^{2-1}$ DB^{1} P^{1} was significantly higher in males (23.5 %) than in females (11.9 %; $P < 0.001$). A higher occurrence of ^{3}MFM MB$^{2\text{-}1\text{-}2}$ DB^{1} P^{1} was noted among individuals in their 21–40 years compared to 41–60 years ($P < 0.05$). The prevalence of the mesiobuccal root with a single canal (^{3}MFM MB^{1} DB^{1} P^{1}) increased with age, although the differences were not statistically significant ($P = 0.054$).

The frequency of fused roots, which were unclassifiable by the Vertucci classification, was 2.8 %, according to the Ahmed classification. Among these, root canal fusion and C-shaped roots were recorded at 0.9 % and 0.7 %, respectively, with no differences observed related to gender or age ($P > 0.05$) (Tables 1 and 3). The most common fused root was Zhang's classification type 1 (MB root fused with DB root; 1.1 %), followed by Zhang's type 3 (DB root fused with P root; 0.6 %) without any gender and age differences ($P > 0.05$; Table 3).

Discussion

The complete and meticulous removal of necrotic tissues and infected root dentin is crucial for successful root canal treatment. However, this process is challenging because of the complex and variable morphologies of root canals. Indeed, a study indicates that the rate of missed root canals of maxillary molars can be as high as 40.1 %,[3] with the majority of these undetected canals showing signs of periapical lesions associated with a substantially increased risk of post-treatment apical periodontitis.[9] This study highlights the diversity of root and root canal morphologies of the maxillary first molars within the Japanese population, noting the importance of recognizing anatomical variations associated with gender and age to improve the precision of root canal treatments. Integrating this knowledge with images obtained from advanced visualization equipment, such as dental operating microscopes and CBCT, may provide substantial benefits.

Various clinical methods, including intraoral radiography,[10] CBCT,[11] and dental operating microscopes,[25] have been used to explore root and canal morphology. In the present study, CBCT was selected because of its proven

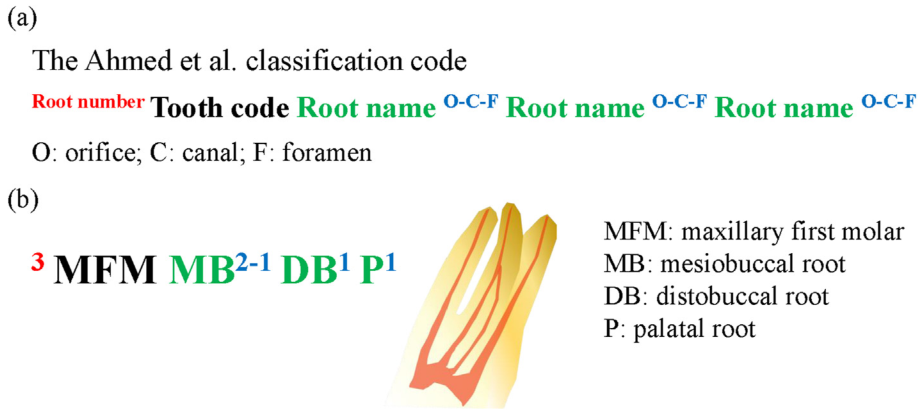

Figure 2 The Ahmed classification codes for root canal morphology.[16]
(a) The number of roots is shown as a red superscript preceding the tooth code, while the root name is noted in green following the code. The configuration of the root canal is indicated by a blue superscript tracing the canal's path from the orifice (O), through the canal (C), to the foramen (F).
(b) The code ^{3}MFM MB$^{2-1}$ DB^{1} P^{1} denotes a three-rooted maxillary first molar (FM) with a mesiobuccal root (MB) featuring two orifices merging into two canals and one apical foramen (2-1), and both the distobuccal root (DB) and the palatal root (P) having a single root canal (1).

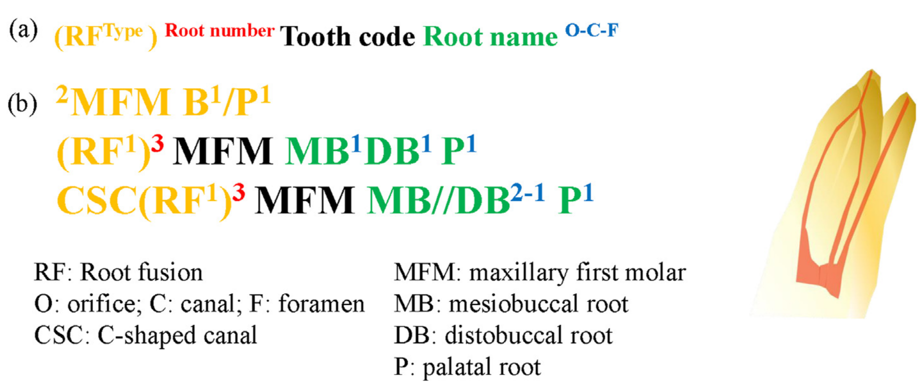

Figure 3 The Ahmed classification codes for root and root canal fusions.[16]
(a) Root fusions, as described by Zhang et al.[23] are denoted using the prefix RF in brackets before the root number. A number directly adjacent to the RF code specifies the type of root fusion (see Fig. 4).
(b) The code (RF^{1})^{3}MFM MB^{1} DB^{1} P^{1} indicates a three-rooted maxillary second molar with a fusion of the MB and DB roots (Type I fusion, featuring one canal per root). C-shaped canals are designated with the prefix CSC in brackets, and double slashes (//) signify root fusions sharing canal. The code CSC (RF^{1})^{3}MFM MB//DB$^{2-1}$ P^{1} describes a three-rooted MFM where the MB and DB roots are fused. This canal system starts as two independent canals that merge into a single canal before exiting through one foramen.

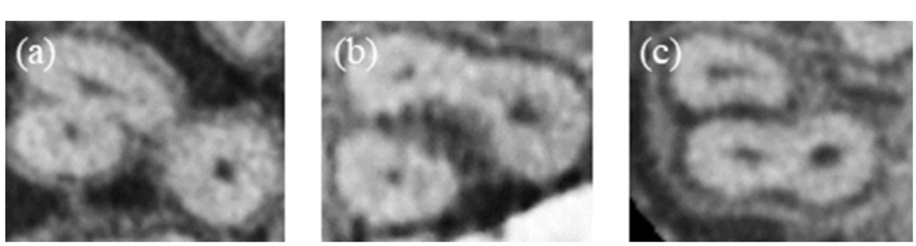

Figure 4 Representative CBCT scans of maxillary first molars exhibiting root fusion classified with the Zhang classification.[23]
(a) Type 1; the MB root is fused with DB root. (b) Type 2; the MB root is fused with P root. (c) Type 3; DB root fused with P root. Type 4 (MB root fused with DB root, and P root fused with MB root or DB root), type 5 (P root fused with MB root and DB root), and type 6 (P root, MB and DB root fused to form a cone-shaped root) were not identified.

Table 1 The number of roots and root canals of maxillary first molar teeth according to gender and age groups.

	Total *n* (%)	Gender *n* (%)		Age group *n* (%)			
		Male	Female	≤20	21–40	41–60	≥61
Number of roots							
Two	2 (0.2)	0 (0)	2 (0.2)	0 (0)	0 (0)	1 (0.5)	1 (1.0)
Three	808 (97.0)	239 (98.4)	569 (96.4)	152 (96.8)	372 (97.4)	184 (97.4)	100 (95.2)
Fused	23 (2.8)	4 (1.6)	19 (3.2)	5 (3.2)	10 (2.6)	4 (2.1)	4 (3.8)
Total	833 (100)	243 (100)	590 (100)	157 (100)	382 (100)	189 (100)	105 (100)
Number of root canals							
Two	3 (0.3)	0 (0)	3 (0.5)	0 (0)	0 (0)	1 (0.5)	2 (1.9)
Three	382 (45.9)	99 (40.7)	283 (48.0)	66 (42.0)	163 (42.7)	102 (54.0)	51 (48.5)
Four	441 (52.9)	143 (58.9)[a]	298 (50.5)[b]	87 (55.4)[ab]	217 (56.8)[a]	85 (45.0)[b]	52 (49.5)[ab]
Five	1 (0.1)	0 (0)	1 (0.2)	1 (0.6)	0 (0)	0 (0)	0 (0)
C-shaped	6 (0.7)	1 (0.4)	5 (0.8)	3 (1.9)	2 (0.5)	1 (0.5)	0 (0)
Total	833 (100)	243 (100)	590 (100)	157 (100)	382 (100)	189 (100)	105 (100)

Values with different superscript letters in a row in each group indicate significant differences ($P < 0.05$).

Table 2 Distribution of maxillary first molars according to Vertucci classification.

Vertucci classification	Root *n* (%)			
	MB	DB	P	B
Type I	376 (45.3)	807 (97.2)	810 (97.2)	2 (66.7)
Type II	127 (15.3)	1 (0.1)	0 (0)	0 (0)
Type III	2 (0.2)	0 (0)	0 (0)	0 (0)
Type IV	260 (31.2)	0 (0)	0 (0)	0 (0)
Type V	16 (1.9)	0 (0)	0 (0)	0 (0)
Type VI	27 (3.3)	0 (0)	0 (0)	0 (0)
Type VII	0 (0)	0 (0)	0 (0)	0 (0)
Type VIII	0 (0)	0 (0)	0 (0)	0 (0)
Not classifiable	22 (2.5)	22 (2.5)	23 (2.6)	1 (33.3)
Total	830 (100)	830 (100)	833 (100)	3 (100)

Type I (1), Type II (2–1), Type III (1-2-1), Type IV (2), Type V (1–2), Type VI (2-1-2), Type VII (1-2-1-2), and Type VIII (3).

reliability, widespread acceptance, and its ability to manage detailed patient information precisely.[15] Although there is no significant difference in canal detection between voxel sizes of 200 and 300 μm,[26] a voxel size of 200 μm or smaller is preferred for achieving more precise imaging. Therefore, previous studies have employed voxel sizes of 200 μm[7] or less[15] as the inclusion criteria, which is consistent with the voxel size of 157 μm in the present study.

The current study demonstrated that most maxillary first molars possessed three separated roots. This finding aligns with the observed high incidence of three-rooted teeth among diverse racial groups, as documented in a comprehensive review of 28 countries.[22]

According to an international survey covering 21 countries revealed that the overall frequency of the presence of the MB2 was 73.8 %, showing variations among racial groups (ranging from 40.8 % to 97.6 %).[6] This report also showed that 76.4 % of the Chinese population displayed MB2 and that 43.6 % of the Chinese population exhibited Type IV in mesiobuccal roots, compared to an average of 22.4 % across various racial populations.[6] The survey also indicated that younger patients and males were more likely to have the MB2. A relatively recent review of 26 studies of maxillary molars using CBCT has reported that MB2 was present in 62.2 % in the East Asian group (Chinese and Korean populations).[7]

In the current study, the prevalence of MB2 in the first molars was 52.9 %; this finding differs somewhat from another study within the Japanese population, which reported a prevalence of 77.5 % employing CBCT.[27] The difference may be attributed to variations in sample size, gender, and age, which can affect the prevalence of the MB2 even within the same population. The most common canal configuration in the MB2 was type IV (31.2 %), followed by type II (15.3 %). This result is comparable to the findings of other Asian[28,29] and Japanese population study.[27]

The prevalence of MB2 was significantly higher among younger individuals (21–40 years) than among middle-aged individuals (41–60 years). This finding may be attributed to the age-related calcification and reduction in pulp chamber volume, which may reduce canal visibility over time, a trend similarly observed in other studies.[24,30]

Gender differences appeared to influence root canal system configuration, potentially linked to genetic factors. The differential effects of the X and Y chromosomes could play a role in gender dimorphism, leading to larger molars and possibly a higher number of root canals in males.[7]

The shape and number of roots are determined by Hertwig's epithelial sheath, which bends in a horizontal plane below the amelocemental junction and fuses in the center, leaving openings for roots.[31] Root fusion is thought to result from increased cementum deposition over time or from a developmental failure of Hertwig's epithelial root sheath in the furcal area.[31] Teeth with fused roots and complex internal morphology pose a therapeutic risk because relying solely on mechanical cleaning instead of chemical disinfection can be detrimental to the tooth's long-term survival.[32] In fact, molars with fused roots have been reported to have a 1.3 times higher prevalence of periapical lesions compared to those with separate roots,[33]

Table 3 Distribution of maxillary first molars according to Ahmed classification.

Ahmed classification	Total *n* (%)	Gender *n* (%)		Age group *n* (%)			
		Male	Female	≤20	21—40	41—60	≥61
^{2}MFM B^{1}P^{1}	2 (0.2)	0 (0)	2 (0.3)	0 (0)	0 (0)	1 (0.5)	1 (1.0)
^{3}MFM MB^{1} DB^{1} P^{1}	376 (45.1)	98 (40.3)	278 (47.1)	65 (41.4)	161 (42.1)	101 (53.4)	49 (46.7)
^{3}MFM MB$^{2-1}$ DB^{1} P^{1}	127 (15.2)	57 (23.5)^{a}	70 (11.9)^{b}	24 (15.3)	63 (16.5)	20 (10.6)	20 (19.0)
^{3}MFM MB^{1-2-1} DB^{1} P^{1}	2 (0.2)	2 (0.8)^{a}	0 (0)^{b}	1 (0.6)	1 (0.3)	0 (0)	0 (0)
^{3}MFM MB^{2} DB^{1} P^{1}	259 (31.1)	72 (29.6)	187 (31.7)	52 (33.1)	132 (34.6)	48 (25.4)	27 (25.7)
^{3}MFM MB$^{1-2}$ DB^{1} P^{1}	16 (1.9)	4 (1.6)	12 (2.0)	5 (3.2)	7 (1.8)	3 (1.6)	1 (1.0)
^{3}MFM MB^{2-1-2} DB^{1} P^{1}	27 (3.2)	6 (2.5)	21 (3.6)	4 (2.5)^{ab}	8 (2.1)^{a}	12 (6.3)^{b}	3 (2.9)^{ab}
^{3}MFM MB^{2} DB$^{2-1}$ P^{1}	1 (0.1)	0 (0)	1 (0.2)	1 (0.6)	0 (0)	0 (0)	0 (0)
^{2}MFM B^{1}/P^{1}	1 (0.1)	0 (0)	1 (0.2)	0 (0)	0 (0)	0 (0)	1 (1.0)
(RF^{1})^{3}MFM MB^{1}DB^{1}P^{1}	2 (0.2)	1 (0.4)	1 (0.2)	1 (0.6)	0 (0)	1 (0.5)	0 (0)
(RF^{1})^{3}MFM MB$^{2-1}$DB^{1}P^{1}	2 (0.2)	0 (0)	2 (0.3)	0 (0)	0 (0)	2 (1.1)	0 (0)
(RF^{1})^{3}MFM MB^{2}DB^{1}P^{1}	4 (0.5)	2 (0.8)	2 (0.3)	1 (0.6)	2 (0.5)	0 (0)	1 (1.0)
(RF^{1})^{3}MFM MB//DB^{1-2-1}P^{1}	2 (0.2)	0 (0)	2 (0.3)	0 (0)^{a}	0 (0)^{a}	0 (0)^{a}	2 (1.9)^{b}
(RF^{2})^{3}MFM MB^{1}DB^{1}P^{1}	1 (0.1)	0 (0)	1 (0.2)	0 (0)	1 (0.3)	0 (0)	0 (0)
(RF^{3})^{3}MFM MB^{1}DB^{1}P^{1}	2 (0.2)	0 (0)	2 (0.3)	0 (0)	2 (0.5)	0 (0)	0 (0)
(RF^{3})^{3}MFM MB$^{2-1}$DB^{1}P^{1}	3 (0.4)	0 (0)	3 (0.5)	0 (0)	3 (0.8)	0 (0)	0 (0)
CSC ^{3}MFMM MB//DB$^{2-1}$ P^{1}	6 (0.7)	1 (0.4)	5 (0.8)	3 (1.9)	2 (0.5)	1 (0.5)	0 (0)
Total	833 (100)	243 (100)	590 (100)	157 (100)	382 (100)	189 (100)	105 (100)

Values with different superscript letters in a row in each group indicate significant differences ($P < 0.05$). The tooth code starts with a superscript for the number of roots, followed by the root name and a superscripted root canal configuration that traces from the orifices to the foramen. MFM: maxillary first molar, MB: mesiobuccal root, DB: distobuccal root, P: palatal root, B: buccal root. RF: root fusion, CSC: C-shaped root canal,/: root fusion,//: root canal fusion.

which should be considered when assessing the predictability of root canal treatment.

The current study identified root fusion in 2.8 % of maxillary first molars, which is consistent with the lower prevalence reported in previous studies, ranging from 0 % in India[11] to 8.1 % in the Spanish population.[34] However, another study using CBCT has reported that a Japanese population exhibited higher prevalences of root fusion in maxillary first molars with a prevalence of 9.5 %.[27] According to the Zhang classification, type 3 root fusion (fusion of DB and P roots) is the most common in the Portuguese population,[34] while type 1 (fusion of MB and DB roots) is reported to be a high occurrence in the Japanese population,[27] consistent with the findings of this study. These variations may have been affected by racial differences as well as variations in study designs and methodologies, including the definition of root fusion.[23,28,35]

The current study found that 0.7 % of maxillary first molars have C-shaped roots, aligning with other findings of 1.1 % in Portuguese,[36] and 0.3 % in Chinese populations,[37] indicating a rare prevalence, regardless of race. In the Ahmed classification,[38] the classification of C-shaped roots was adapted to include the classification by Fan et al.[39] However, this classification primarily applies to mandibular C-shaped teeth and does not accurately represent maxillary C-shaped roots. Therefore, it is necessary to incorporate new classifications, such as Martin et al.'s classification[36] of maxillary C-shaped root canals, into the Ahmed classification.

The study found that while both the Verticci and Ahmed classifications categorized the maxillary first molars effectively, the Ahmed classification provided a more precise description of complex morphologies, including fused roots. This aligns with a recent systematic review that included 15 studies comparing these systems.[20] In particular, teeth with fused roots sharing canal anatomy are deemed unclassifiable using the Vertucci system, while this study identified such roots while they were classifiable using the Armed classification. This study advocates the use of the Ahmed classification in categorizing complex tooth types.

Despite these insights, the study acknowledged limitations such as uncontrolled variables like gender ratio and age distribution, as well as potential biases from CBCT scans, which were primarily intended for orthodontic and implant purposes.

In conclusion, the maxillary first molars in the Japanese population exhibited notable anatomical variations related to age and gender, underscoring the clinical value of CBCT in assessing root and root canal morphology. The findings support the use of the Ahmed classification for more precise depiction of complex morphologies and suggest expanding research to include a broader demographic to verify the universal applicability of these results.

Declarations of competing interest

The authors declare no conflict of interest relevant to this study.

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