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Original Article

Evaluation of root and root canal morphology in maxillary premolar teeth: A cone-beam computed tomography study using two classification systems in a Japanese population

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Abstract *Background/purpose:* Inadequate knowledge increases the risk of overlooking root canals and causing procedural errors that can lead to root canal treatment failure. This study aimed to analyze the root and root canal morphology in maxillary premolar teeth using two classification systems assessed by cone-beam computed tomography (CBCT) in a large Japanese population.
Materials and methods: This study evaluated 1443 maxillary teeth including 726 first and 717 s premolars, from 642 Japanese individuals aged 16–84 years. CBCT images were analyzed according to the Vertucci and Ahmed classification systems, focusing on the root and root canal morphology. Variations were analyzed based on gender and age using the chi-square test ($P < 0.05$).
Results: Maxillary first premolars were predominantly single-rooted (64.9%) and had two root canals (86.2%). Females exhibited a higher prevalence of single-rooted (71.0%) compared to males (49.8%) ($P < 0.05$). Additionally, single root canals occurred significantly more frequently in females (14.0%) than in males (7.5%) ($P < 0.05$). Maxillary second premolars mostly had a single root (97.8%) with a single root canal (72.1%). The frequency of second premolars with two root canals significantly increased with age ($P < 0.001$). The three-rooted configuration occurred in 1.2% and 0.3% of the first and second premolars, respectively.
Conclusion: Maxillary premolars in a Japanese population showed significant anatomical variations, highlighting the importance of understanding anatomical characteristics specific to age

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and gender. Ahmed's system provides a more comprehensive description of the morphological variations.

Introduction

The effectiveness of root canal therapy depends critically on the comprehensive cleaning, shaping, and filling of the entire root canal system.[1] Achieving these goals requires a thorough understanding of the root and root canal anatomy.[2] However, inadequate knowledge of the anatomy could increase the risk of overlooking root canals and causing procedural errors that can lead to treatment failure. In particular, missed canals potentially harbor necrotic tissue and microorganisms and can contribute to persistent periapical pathology.[3] The root canal system is known for its considerable complexity and diversity, emphasizing the need for dental professionals to recognize these anatomical differences proficiently. Despite technological advances, treatment success rates have not improved significantly over the past century,[4,5] underscoring the importance of a more comprehensive understanding of root canal anatomy.

Various techniques have been employed to study the internal morphology of teeth, including tooth clearing and staining,[2] root sectioning,[6] periapical radiography,[7,8] cone-beam computed tomography (CBCT),[9,10] micro-CT,[11,12] swept-source optical coherence tomography,[13,14] and clinical inspection using a microscope.[15,16] Among these, CBCT provides a non-invasive three-dimensional assessment of maxillofacial structures clinically, making it indispensable for analyzing root and root canal anatomy.[17,18]

The Vertucci classification system[2] is widely used, simple, and easy to share among dentists. Ahmed et al.[19] recently proposed an alternative classification method that integrates root canal morphology and root number into a single descriptive code. This classification system is gaining importance due to its detailed representation of whole tooth information from CBCT.[19–22] However, its application has been limited to only a few studies.[20–22]

Root canal morphology varies widely due to genetic factors, making it essential to assess variations across different racial populations.[23–25] Single-rooted maxillary first premolars are more prevalent in Asian populations than in other races.[23,25,26] Single-rooted maxillary second premolars are also more common in Asians than in Caucasoid populations.[23,25,27]

However, most reports on Asian populations have focused on Chinese and Korean subpopulations,[23,25,26] and research on the maxillary premolars of Japanese populations is limited.[28,29] To the best of our knowledge, this is the first study to use CBCT to evaluate the root and canal morphology of maxillary premolar teeth using two classification systems in a Japanese population. This gap underscores the need for dedicated studies to understand the root and root canal anatomy of maxillary premolar teeth in the Japanese population.

Therefore, this study aimed to use CBCT to analyze the root and root canal structures of maxillary premolar teeth in the Japanese population using two classification systems and to correlate the findings with gender and age.

Materials and methods

Sample collection

All experimental procedures were approved by the Ethics Committee of Tokyo Medical and Dental University (D2016-102). The sample size for this study was calculated using G*Power 3.1.9 software (Heinrich-Heine-Universität, Düsseldorf, Germany), based on a 98% confidence level, a 5% margin of error, and an expected prevalence of 50%. At least 543 subjects were selected according to the sample size calculated for Japanese populations. Cone-beam computed tomography images aimed at diagnosing implant surgery and orthodontic treatment were obtained from the Tokyo Medical and Dental University Hospital between January 2013 and December 2014. The images were taken using Finecube CBCT scanner (Yoshida, Tokyo, Japan) with a field of view of 81 mm $\times$ 74 mm, 90 kVp and 4.0 mA, 16.8 s and voxel size of 157 $\times$ 157 $\times$ 144 μm.

Inclusion and extrusion criteria

This study included scans from Japanese patients aged 16–84 years who had at least one permanent maxillary tooth that was fully mature and erupted, and no history of root canal treatments. Teeth with root canal fillings, crowns, posts, root resorption, extensive caries, periapical radiolucency, and images that could not be evaluated because of low image quality were excluded from the study.

Radiographic evaluation

Two observers, an endodontic resident and an expert endodontist, assessed all scans on a screen with a resolution of 1280 $\times$ 1024 pixels using a dedicated DICOM viewer (Finecube viewer, Yoshida). They evaluated the root and root canal morphology using a three-dimensional multiplanar reconstruction tool and examined the images in the axial, coronal, and sagittal planes. The two observers conducted separate evaluations and resolved any disagreements through discussion until a consensus was achieved. Before evaluation, the observers underwent training and calibration using CBCT scan samples, showing root canal morphology in the maxillary teeth according to the Vertucci and Ahmed classification systems. The criteria for the Vertucci and Ahmed classification systems are expressed in Figs. 1 and 2.

Measurements

Radiographic observations of the maxillary teeth were conducted to assess the frequency of the (i) number of roots, (ii) root canal system configurations according to Vertucci and Ahmed classifications, and (iii) number of root canals.

The observers repeated their reviews and recordings twice, with a gap of at least one month between sessions. The scan sequence in the second review was altered to ensure an unbiased assessment. The findings were concluded based on the recordings from both observers. The findings were then tabulated and correlated with age and gender, with age groups defined as ≤20 years, 21—40 years, 41—60 years, and ≥61 years, in accordance with previous methodologies.[28,30]

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 29.0 (IBM, Chicago, IL, USA). The Pearson chi-square test with Bonferroni correction was used to compare findings across different gender and age groups. The data were subjected to a kappa test to determine reproducibility and reliability. The significance threshold was set at $P < 0.05$.

Results

A total of 642 Japanese individuals (205 male and 437 female) aged 16—84 years (mean age of 42.0 years) met the criteria. A total of 1443 maxillary teeth, including 726 first premolars and 717 s premolars, were evaluated (Fig. 3). Inter- and intra-examiner agreements were 94.8% and 88.0%, respectively, in the maxillary first premolar and 95.1% and 87.0%, respectively, in the maxillary second premolar.

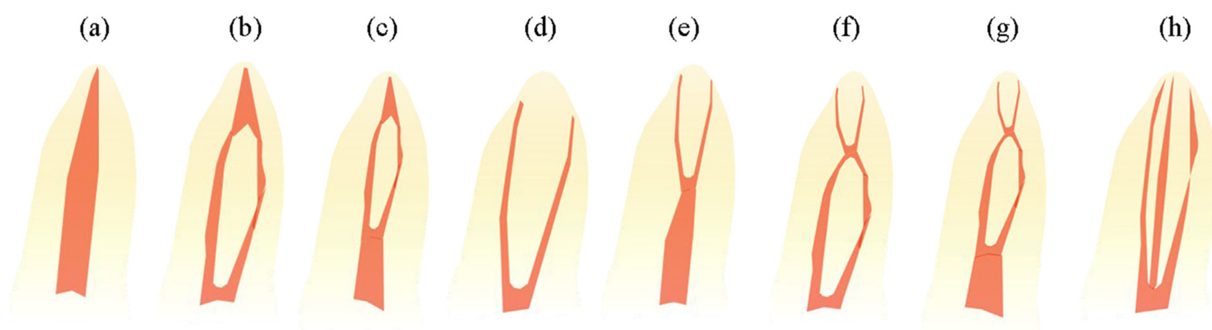

Figure 1 The Vertucci classification system of root canal morphology.[2] (a) Type I (1), (b) Type II (2—1), (c) Type III (1-2-1), (d) Type IV (2), (e) Type V (1—2), (f) Type VI (2-1-2), (g) Type VII (1-2-1-2), and (h) Type VIII (3).

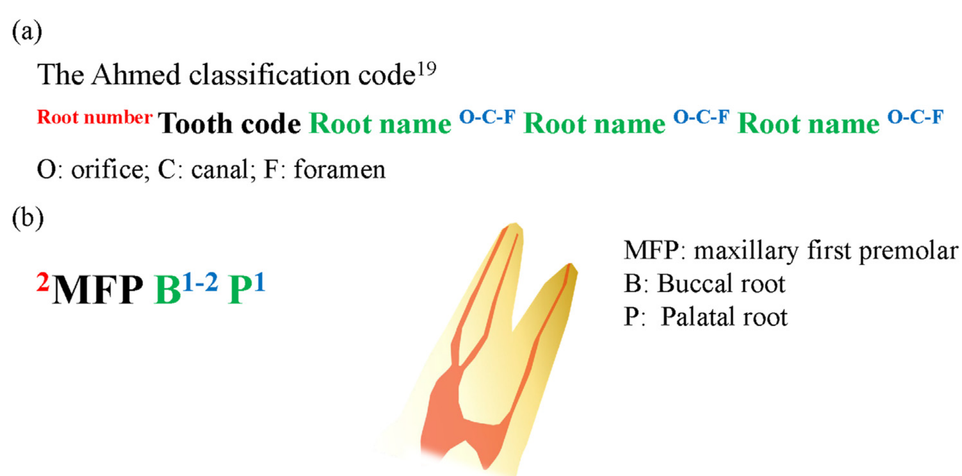

Figure 2 The Ahmed classification system for root canal morphology.[19]
The number of roots is added as a superscript (in red) before the tooth code. Description of root name (in green) after the tooth code and root canal configuration written as a superscript (in blue) on the course of the root canal starting from the orifices [O], passing through the canal [C], ending by the foramen [F].
(b) Representative code of the Ahmed classification system. 2MFP B1-2 P1 indicated two rooted maxillary first premolar (MFP), with one orifice and diverging two canals and two apical foramen (1—2) in the buccal root (B) and single root canal (1) in the palatal root (P).

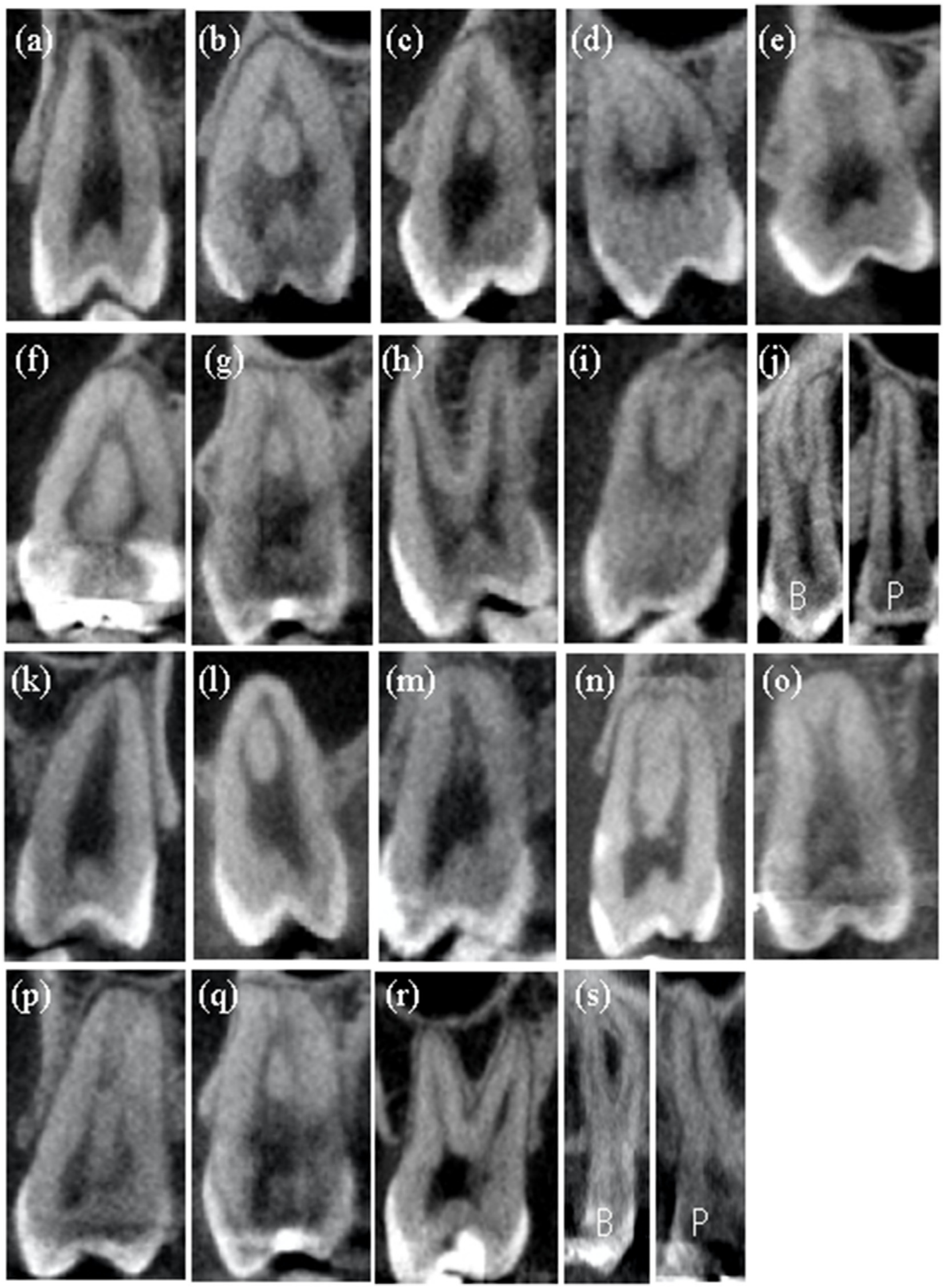

Figure 3 Representative CBCT images of different root canal system configurations in maxillary premolars.
(a) ^{1}MFP^{1}, (b) ^{1}MFP$^{2\text{-}1}$, (c) ^{1}MFP$^{1\text{-}2-1}$, (d) ^{1}MFP^{2}, (e) ^{1}MFP$^{1\text{-}2}$, (f) ^{1}MFP$^{2\text{-}1-2}$, (g) ^{1}MFP$^{1\text{-}2\text{-}1\text{-}2}$, (h) ^{2}MFP B^{1}P^{1}, (i) ^{2}MFP B$^{1\text{-}2}$ P^{1}, (j) ^{3}MFP MB^{1}DB^{1}P^{1}, (k) ^{1}MSP^{1}, (l) ^{1}MSP$^{2\text{-}1}$, (m) ^{1}MSP$^{1\text{-}2-1}$, (n) ^{1}MSP^{2}, (o) ^{1}MSP$^{1\text{-}2}$, (p) ^{1}MSP$^{2\text{-}1-2}$, (q) ^{1}MSP$^{1\text{-}2\text{-}1\text{-}2}$, (r) ^{2}MFP B^{1}P^{1}, (s) ^{3}MSP MB^{1}DB^{1}P^{1}. MFP: maxillary first premolar, MSP: maxillary second premolar, B: Buccul root, P: palatal root, MB: mesiobuccal root, DB: distobuccal root.

Maxillary first premolar

The root morphology of maxillary first premolars was classified as single-rooted (64.7%), two-rooted (34.0%), or three-rooted (1.2%) (Table 1). Teeth with two root canals were predominant (86.2%: Table 1), and two-rooted teeth with two root canals (^{2}MFP B^{1}P:^{1} 33.5%) were the most common (Table 2). Single-rooted teeth with two root canals

Table 1 The number of roots and root canals of maxillary premolars.

	First premolar n (%)	Second premolar *n* (%)
Number of roots		
One	470 (64.7)	701 (97.8)
Two	247 (34.0)	14 (2.0)
Three	9 (1.2)	2 (0.3)
Total	726 (100)	717 (100)
Number of root canals		
One	88 (12.1)	517 (72.1)
Two	626 (86.2)	198 (27.6)
Three	12 (1.6)	2 (0.3)
Total	726 (100)	717 (100)

Table 2 Distribution of maxillary premolars according to two classifications.

Classification	First premolar n, (%)	Second premolar n, (%)
Ahmed classification		
^{1}MPM^{1}	88 (12.1)	517 (72.1)
^{1}MPM$^{2\text{-}1}$	127 (17.5)	64 (8.9)
^{1}MPM$^{1\text{-}2\text{-}1}$	51 (7.0)	38 (5.3)
^{1}MPM^{2}	159 (21.9)	54 (7.5)
^{1}MPM$^{1\text{-}2}$	33 (4.5)	25 (3.5)
^{1}MPM$^{2\text{-}1\text{-}2}$	8 (1.1)	38 (5.3)
^{1}MPM$^{1\text{-}2\text{-}1\text{-}2}$	4 (0.6)	4 (0.5)
^{2}MPM B^{1}P^{1}	244 (33.5)	14 (2.0)
^{2}MPM1B$^{1\text{-}2}$ P^{1}	3 (0.4)	0 (0)
^{3}MPM MB^{1} DB^{1} P^{1}	9 (1.2)	2 (0.3)
Total	726 (100)	717 (100)
Vertucci classification		
Type I	88 (12.1)	517 (72.1)
Type II	127 (17.5)	64 (8.9)
Type III	51 (7.0)	38 (5.3)
Type IV	403 (55.5)	68 (9.5)
Type V	33 (4.5)	25 (3.5)
Type VI	8 (1.1)	38 (5.3)
Type VII	4 (0.6)	4 (0.5)
Type VIII	9 (1.2)	2 (0.3)
Not classifiable	3 (0.4)	0 (0)
Total	726 (100)	717 (100)

Ahmed classification: 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. Vertucci classification: 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). MPM: maxillary premolar, B: Buccul root, P: palatal root, MB: mesiobuccal root, DB: distobuccal root.

(^{1}MFP^{2}) and two root canals merging into one canal (^{1}MFP$^{2-1}$) were also common (21.9% and 17.5%) (Table 2).

Females exhibited a higher prevalence of single-rooted maxillary first premolars (71.0%) than males (49.8%) ($P < 0.001$; Table 3). The incidence of single-root canals was significantly higher in females than in males ($P < 0.05$). Conversely, the occurrence of two-rooted teeth with single root canals (^{2}MFP B^{1} P^{1}) was significantly higher in males than in females ($P < 0.05$) (Table 4). There were no significant differences across all age groups ($P > 0.05$) (Tables 5 and 6).

Additionally, the prevalence of teeth with three root canals was 1.6%; they were classified into three-rooted with three root canals (^{3}MFP MB^{1}DB^{1}P:^{1} 1.2%) and two-rooted with three root canals due to bifurcation of the buccal root canal (^{2}MFP B$^{1-2}$P:^{1} 0.4%) (Table 2).

Maxillary second premolar

The majority of maxillary second premolars (97.8%) were single-rooted; 2.0%, two-rooted; and, 0.3%, three-rooted (Table 1). The prevalence of teeth with two root canals was 27.6% (Table 1). The most common root canal morphology was single root canal (^{1}MSP:^{1} 72.1%), and ^{1}MSP$^{2-1}$ was present in 8.9% (Table 2). No significant gender difference was found in the prevalence of root canals in the maxillary second premolars ($P > 0.05$) (Table 3).

The frequency of teeth having a single root canal (^{1}MSP^{1} configuration) showed a significant decrease with increasing age ($P < 0.001$; Tables 5 and 6), with the proportion of ^{1}MSP^{1} decreased from 91.1% (≤20 years) to 55.3% (>61 years). Simultaneously, the occurrence of ^{1}MSP$^{2-1}$ increased from 0.8% in younger patients (≤20 years) to 18.1% in older patients (>61 years) (Table 6).

Discussion

In root canal therapy, it is essential to completely remove the infected root dentin and necrotic tissues. However, achieving this in clinical practice remains a significant challenge due to the complexity and variations in root canal morphologies. The reported incidence of missed root canals ranges from 12%[31] to 23%.[3] Additionally, periapical lesions are found in 83–98% of these missed root canals, with a risk ratio of 3.1[32] to 6.25.[31] A thorough understanding of race-specific root anatomy is fundamental for designing and implementing effective dental treatment strategies. This study provided the prevalence of root and canal morphology in the premolars of the Japanese population. The anatomical variations between different premolars and the anatomical characteristics of the premolars by gender and age could be considered and used to improve the accuracy of the procedure in root canal therapy. This knowledge is particularly valuable when clinically integrated with detailed visual insights provided by dental operating microscopes and CBCT.

Tooth-clearing procedures,[2,15] root sectioning,[6] periapical radiographic inspections,[7,8] CBCT,[9] and micro CT[11,12] have been utilized to assess the morphology of roots and root canals. Several studies have shown that CBCT is as effective as tooth-clearing or root-sectioning techniques for identifying root canal systems.[9,33] In this study, CBCT scans were utilized due to their reliability, widespread acceptance, accurate management of patient information, and the multitude of studies that have used CBCT.[28] While it has been reported that there was no significant difference in the ability to detect root canals using voxel sizes of

Table 3 The number of roots and root canals of maxillary premolar teeth according to gender.

	First premolar n (%)			Second premolar n (%)		
	Male	Female	P	Male	Female	P
Number of roots						
One	106 (49.8)	364 (71.0)	<0.001***	191 (95.0)	510 (98.8)	0.002**
Two	104 (48.8)	143 (27.9)	<0.001***	10 (5.0)	4 (0.8)	<0.001***
Three	3 (1.4)	6 (1.2)	0.791	0 (0)	2 (0.4)	0.377
Total	213 (100)	513 (100)		201 (100)	516 (100)	
Number of root canals						
One	16 (7.5)	72 (14.0)	0.014*	137 (68.2)	380 (73.6)	0.141
Two	192 (90.1)	434 (84.6)	0.049*	64 (31.8)	134 (26.0)	0.114
Three	5 (2.4)	7 (1.4)	0.344	0 (0)	2 (0.4)	0.377
Total	213 (100)	513 (100)		201 (100)	516 (100)	

*$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$, chi-square test.

200 and 300 μm,[34] a standard 200 μm[35] or less standard has been recommended for optimal detection.[36] Hence, a voxel size of 157 μm was employed as the inclusion criteria in this study.

A previous study investigated racial differences in root and root canal morphologies of maxillary first premolars between the Portuguese and Chinese population.[23] The results showed a significant disparity in the prevalence of single-root morphologies with 83.2% in the Chinese population and 48.7% in the Portuguese population.[23] In the current study, 64.7% of first premolars exhibited single-root morphologies with a higher prevalence in females (71.0%). This is comparable to other findings in the Japanese population, which reported 70.3%[28] and 74.2%,[29] aligning closely with proportions seen in other Asian demographics.[18,28,37]

Regarding the number of root canals of maxillary first premolars, a previous study found no significant differences in two-root canal morphology between the Portuguese (87.8%) and Chinese populations (91.6%).[23] This finding

Table 4 Distribution of maxillary premolar teeth by two classifications and gender.

Classification	First premolar n (%)			Second premolar n (%)		
	Male	Female	P	Male	Female	P
Ahmed classification						
$^{1}MPM^{1}$	16 (7.5)	72 (14.0)	0.014*	137 (68.2)	380 (73.6)	0.141
$^{1}MPM^{2-1}$	31 (14.6)	96 (18.7)	0.179	20 (10.0)	44 (8.5)	0.548
$^{1}MPM^{1-2-1}$	8 (3.8)	43 (8.4)	0.026*	14 (7.0)	24 (4.7)	0.214
$^{1}MPM^{2}$	40 (18.8)	119 (23.2)	0.091	18 (9.0)	36 (7.0)	0.367
$^{1}MPM^{1-2}$	7 (3.3)	26 (5.1)	0.294	2 (1.0)	23 (4.5)	0.023*
$^{1}MPM^{2-1-2}$	4 (1.9)	4 (0.8)	0.197	0 (0)	2 (0.4)	0.377
$^{1}MPM^{1-2-1-2}$	0 (0)	4 (100)	0.196	0 (0)	1 (0.2)	0.532
$^{2}MPM\ B^{1}P^{1}$	102 (47.9)	142 (27.7)	<0.001***	10 (5.0)	4 (0.8)	<0.001***
$^{2}MPM1B^{1-2}\ P^{1}$	2 (0.9)	1 (0.2)	0.155	0 (0)	0 (0)	
$^{3}MPM\ MB^{1}\ DB^{1}\ P^{1}$	3 (1.4)	6 (1.2)	0.791	0 (0)	2 (0.4)	0.377
Total	213 (100)	513 (100)		201 (100)	516 (100)	
Vertucci classification						
Type I	16 (7.5)	72 (14.0)	0.014*	137 (68.2)	380 (73.6)	0.141
Type II	31 (14.6)	96 (18.7)	0.179	20 (10.0)	44 (8.5)	0.548
Type III	8 (3.8)	43 (8.4)	0.026*	14 (7.0)	24 (4.7)	0.214
Type IV	142 (66.7)	261 (36.0)	<0.001***	28 (13.9)	40 (7.7)	0.011*
Type V	7 (3.3)	26 (5.1)	0.294	2 (1.0)	23 (4.5)	0.023*
Type VI	4 (1.9)	4 (0.8)	0.197	0 (0)	2 (0.4)	0.377
Type VII	0 (0)	4 (100)	0.196	0 (0)	1 (0.2)	0.532
Type VIII	3 (1.4)	6 (1.2)	0.791	0 (0)	2 (0.4)	0.377
Not classifiable	2 (0.9)	1 (0.2)	0.155	0 (0)	0 (0)	
Total	213 (100)	513 (100)		201 (100)	516 (100)	

Ahmed classification: 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.Vertucci classification: 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). MPM: maxillary premolar, B: Buccul root, P: palatal root, MB: mesiobuccal root, DB: distobuccal root.

Table 5 Distribution of maxillary premolar teeth in different age groups.

	First premolar *n* (%)					Second premolar *n* (%)				
	≤20	21–40	41–60	≥61	*P*	≤20	21–40	41–60	≥61	*P*
Number of roots										
One	77 (71.3)	199 (64.6)	132 (63.8)	62 (60.2)	0.383	123 (100)	302 (97.1)	186 (98.4)	90 (95.7)	0.135
Two	29 (26.9)	107 (34.7)	72 (34.8)	39 (37.9)	0.351	0 (0)	7 (2.3)	3 (1.6)	4 (4.3)	0.149
Three	2 (1.9)	2 (0.6)	3 (1.4)	2 (1.9)	0.638	0 (0)	2 (0.6)	0 (0)	0 (0)	0.454
Total	108 (14.9)	308 (42.4)	207 (28.5)	103 (14.2)		123 (17.2)	311 (43.4)	189 (26.4)	94 (13.1)	
Number of root canals										
One	19 (17.6)	41 (13.3)	18 (8.7)	10 (9.7)	0.098	112 (91.1)	215 (69.1)	138 (73.0)	52 (55.3)	<0.001***
Two	87 (80.6)	262 (85.1)	186 (89.9)	91 (88.3)	0.114	11 (8.9)	94 (30.2)	51 (27.0)	42 (44.7)	<0.001***
Three	2 (1.9)	5 (1.6)	3 (1.4)	2 (1.9)	0.998	0 (0)	2 (0.6)	0 (0)	0 (0)	0.454
Total	108 (14.9)	308 (42.4)	207 (28.5)	103 (14.2)		123 (17.2)	311 (43.4)	189 (26.4)	94 (13.1)	

***$P < 0.001$, chi-square test.

aligns with the current results that 86.2% (Type IV: 33.6%, and Type II: 26.8%) of first premolars had two root canals. Similarly, another Japanese study that utilized CBCT scans documented that 79.4% of first premolars had two root canals (Type II: 31.3%, and Type IV: 27.3%).[29]

The frequency of teeth with three root canals in maxillary first premolars was reported as 5.0% in the Portuguese populations, compared to no instances (0%) in the Chinese populations.[23] The current study detected the frequency of teeth with three-root canals to be 1.6%, comprising 1.2% of three-rooted teeth with three root canals and 0.4% of two-rooted teeth with three-root canals (^{2}MFP B$^{1-2}$ P ^{1}), which is rare regardless of race.

Regarding second premolars, a previous report indicated that the proportion of single-rooted teeth was significantly higher among the Chinese (99.2%) compared to that among the Portuguese (94.7%).[23] According to studies using CBCT, Asians, including the Chinese (86.5%)38 and Malaysians

Table 6 Distribution of maxillary premolars according to two classifications in different age groups.

Classification	First premolar n (%)					Second premolar n (%)				
	≤20	21–40	41–60	≥61	P	≤20	21–40	41–60	≥61	P
Ahmed classification										
^{1}MPM^{1}	19 (17.6)	41 (13.3)	18 (8.7)	10 (9.7)	0.098	112 (91.1)	215 (69.1)	138 (73.0)	52 (55.3)	<0.001***
^{1}MPM$^{2-1}$	15 (13.9)	43 (14.0)	45 (21.7)	24 (23.3)	0.035	1 (0.8)	23 (7.4)	23 (12.2)	17 (18.1)	<0.001***
^{1}MPM^{1-2-1}	8 (7.4)	31 (10.1)	7 (3.4)	5 (4.9)	0.025	0 (0)	27 (8.7)	4 (2.1)	7 (7.4)	<0.001***
^{1}MPM^{2}	20 (18.5)	67 (21.8)	50 (24.2)	22 (21.4)	0.715	9 (7.3)	19 (6.1)	15 (7.9)	11 (11.7)	0.347
^{1}MPM$^{1-2}$	13 (12.0)	14 (4.5)	14 (4.5)	0 (0)	0.001***	1 (0.8)	17 (5.5)	5 (2.6)	2 (2.1)	0.067
^{1}MPM^{2-1-2}	1 (0.9)	2 (0.6)	5 (2.4)	0 (0)	0.169	0 (0)	1 (0.3)	1 (0.5)	0 (0)	0.789
^{1}MPM$^{1-2-1-2}$	1 (0.9)	1 (0.3)	1 (0.5)	1 (1.0)	0.822	0 (0)	0 (0)	0 (0)	1 (4.3)	0.084
^{2}MPM B^{1}P^{1}	29 (26.9)	104 (33.8)	72 (34.8)	39 (37.9)	0.365	0 (0)	7 (2.3)	3 (1.6)	4 (4.3)	0.149
^{2}MPM1B$^{1-2}$ P^{1}	0 (0)	3 (1.0)	0 (0)	0 (0)	0.252	0 (0)	0 (0)	0 (0)	0 (0)	
^{3}MPM MB^{1} DB^{1} P^{1}	2 (1.9)	2 (0.6)	3 (1.4)	2 (1.9)	0.638	0 (0)	2 (0.6)	0 (0)	0 (0)	0.454
Total	108 (14.9)	308 (42.4)	207 (28.5)	103 (14.2)		123 (17.2)	311 (43.4)	189 (26.4)	94 (13.1)	
Vertucci classification										
Type I	19 (17.6)	41 (13.3)	18 (8.7)	10 (9.7)	0.098	112 (91.1)	215 (69.1)	138 (73.0)	52 (55.3)	<0.001***
Type II	15 (13.9)	43 (14.0)	45 (21.7)	24 (23.3)	0.035	1 (0.8)	23 (7.4)	23 (12.2)	17 (18.1)	<0.001***
Type III	8 (7.4)	31 (10.1)	7 (3.4)	5 (4.9)	0.025	0 (0)	27 (8.7)	4 (2.1)	7 (7.4)	<0.001***
Type IV	49 (45.4)	171 (55.5)	122 (58.9)	61 (59.2)	0.109	9 (7.3)	26 (8.4)	18 (9.5)	15 (16.0)	0.126
Type V	13 (12.0)	14 (4.5)	14 (4.5)	0 (0)	0.001***	1 (0.8)	17 (5.5)	5 (2.6)	2 (2.1)	0.067
Type VI	1 (0.9)	2 (0.6)	5 (2.4)	0 (0)	0.169	0 (0)	1 (0.3)	1 (0.5)	0 (0)	0.789
Type VII	1 (0.9)	1 (0.3)	1 (0.5)	1 (1.0)	0.822	0 (0)	0 (0)	0 (0)	1 (4.3)	0.084
Type VIII	2 (1.9)	2 (0.6)	3 (1.4)	2 (1.9)	0.638	0 (0)	2 (0.6)	0 (0)	0 (0)	0.454
Not classifiable	0 (0)	3 (1.0)	0 (0)	0 (0)	0.252	0 (0)	0 (0)	0 (0)	0 (0)	
Total	108 (14.9)	308 (42.4)	207 (28.5)	103 (14.2)		123 (17.2)	311 (43.4)	189 (26.4)	94 (13.1)	

Ahmed classification: 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. Vertucci classification: 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). MPM: maxillary premolar, B: Buccul root, P: palatal root, MB: mesiobuccal root, DB: distobuccal root.

(91.9%), 37 have higher rates of single-root morphologies compared to those in the Spanish (82.9%)[38] and Germans (82.6%).[27] The frequency of single-root morphologies was also high in the current study at 97.8%, aligning with other CBCT studies on a Japanese population, which reported frequencies of 95.7%[28] and 97.7%.[29]

As for the number of root canals of maxillary second premolars, a single root canal occurs in the Portuguese population at a rate of 39.8%, as revealed by CBCT.[39] For Asians, a range of 45.4%[40] and 74.9%[23] has been reported in Chinese, along with 58.2% in Malaysians,[37] using the CBCT-based method. In the current study, 72.1% of the Japanese population was found to have single-root canals, which is consistent with other studies in the Japanese population that reported frequencies of 64.0%[28] and 72.2%.[29] These results suggest a higher prevalence of single-root canals among Asians compared to other races. The occurrence of three root canals was consistently low across races, generally less than 1 %.[28]

Gender differences have been noted to influence the composition of the root canal system, as observed in the current study. Females exhibited a higher prevalence of single-rooted and single root canals than males in maxillary first premolars. The tendency for females to exhibit a decreased number of roots and root canals aligns with the previous findings.[28] This phenomenon suggests that the differential effects of the X and Y chromosomes contribute to gender dimorphism, including smaller teeth in females and possibly a decrease in the number of root canals.[35]

This study showed a higher prevalence of multiple canals in the maxillary second premolars of older patients. This supports previous findings reporting a decrease in single root canal morphology in older patients and an increase in the number of root canals with increasing age.[28,30] These changes may be attributed to age-dependent dynamic alteration of the root canal system due to the continuous generation of secondary dentin and the gradual calcification process that occurs over the years. It is reasonable that these findings were particularly observed in the maxillary second premolars, which typically have a high proportion of single roots and root canals.

This study utilized two classification systems: the Vertucci and Ahmed classifications. The findings indicated that both systems can effectively categorize simple canal configurations in single-rooted teeth. However, the Ahmed classification provided a more precise and detailed characterization of multi-rooted premolar teeth with complex anatomy. For instance, it remains unclear whether a Vertucci type IV canal is encased within a single- or double-rooted tooth.[20] Additionally, maxillary premolars with three root canals are uniformly classified as Vertucci type VIII, without accounting for variations in the roots and root canals.[20]

A recent systematic review,[22] incorporating 15 studies that compared these systems, confirmed the results consistent with this study. The significant variation observed in the premolars and molars underscores the importance of CBCT in evaluating root and canal morphology. This study enhances our understanding of root canal anatomy and supports the adoption of the Ahmed classification for complex dental types. However, CBCT and the Ahmed classification should be further examined and evaluated across diverse patient populations worldwide.

The study limitations included uncontrolled variables such as gender ratio and age distribution. Additionally, CBCT imaging was primarily intended for implant and orthodontic evaluations, which might introduce a bias compared with the imaging of healthy dentition. The results of this study primarily consisted of a Japanese population, which limits the generalizability of the findings to other populations and groups. Future studies should consider expanding the study population to test the universality of these results. To further understand the causes of the significant effects of gender and age on the anatomical characteristics of maxillary premolars, other potential factors, such as genetic background, geographical area, or lifestyle, should also be considered.

In conclusion, the maxillary premolar in a Japanese subpopulation showed significant anatomical variations, which are more noticeable in the first premolars. This underscores the importance of using CBCT to evaluate root and root canal morphology. Additionally, it is crucial to understand the anatomical characteristics specific to age and gender. The Ahmed classification provided a more comprehensive description of morphological variations, particularly in the maxillary first premolars.

Declaration of competing interest

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

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References

1. Vertucci FJ. Root canal morphology and its relationship to endodontic procedures. *Endod Top* 2005;10:3–29.
2. Vertucci FJ. Root canal anatomy of the human permanent teeth. *Oral Surg Oral Med Oral Pathol* 1984;58:589–99.
3. Karabucak B, Bunes A, Chehoud C, Kohli MR, Setzer F. Prevalence of apical periodontitis in endodontically treated premolars and molars with untreated canal: a cone-beam computed tomography study. *J Endod* 2016;42:538–41.
4. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature - part 1. Effects of study characteristics on probability of success. *Int Endod J* 2007;40:921–39.
5. Burns LE, Kim J, Wu Y, Alzwaideh R, McGowan R, Sigurdsson A. Outcomes of primary root canal therapy: an updated systematic review of longitudinal clinical studies published between 2003 and 2020. *Int Endod J* 2022;55:714–31.
6. Weller RN, Niemczyk SP, Kim S. Incidence and position of the canal isthmus. Part 1. Mesiobuccal root of the maxillary first molar. *J Endod* 1995;21:380–3.
7. Weine FS, Hayami S, Hata G, Toda T. Canal configuration of the mesiobuccal root of the maxillary first molar of a Japanese subpopulation. *Int Endod J* 1999;32:79–87.
8. Peikoff MD, Christie WH, Fogel HM. The maxillary second molar: variations in the number of roots and canals. *Int Endod J* 1996;29:365–9.

9. Neelakantan P, Subbarao C, Subbarao CV. Comparative evaluation of modified canal staining and clearing technique, cone-beam computed tomography, peripheral quantitative computed tomography, spiral computed tomography, and plain and contrast medium-enhanced digital radiography in studying root canal morphology. *J Endod* 2010;36:1547—51.
10. Martins JNR, Alkhawas MAM, Altaki Z, et al. Worldwide analyses of maxillary first molar second mesiobuccal prevalence: a multicenter cone-beam computed tomographic study. *J Endod* 2018;44:1641—1649.e1.
11. Somma F, Leoni D, Plotino G, Grande NM, Plasschaert A. Root canal morphology of the mesiobuccal root of maxillary first molars: a micro-computed tomographic analysis. *Int Endod J* 2009;42:165—74.
12. Park JW, Lee JK, Ha BH, Choi JH, Perinpanayagam H. Three-dimensional analysis of maxillary first molar mesiobuccal root canal configuration and curvature using micro-computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;108:437—42.
13. Iino Y, Ebihara A, Yoshioka T, et al. Detection of a second mesiobuccal canal in maxillary molars by swept-source optical coherence tomography. *J Endod* 2014;40:1865—8.
14. Ding J, Ebihara A, Watanabe S, et al. Application of optical coherence tomography to identify pulp exposure during access cavity preparation using an Er:YAG laser. *Photomed Laser Surg* 2014;32:356—9.
15. Fogel HM, Peikoff MD, Christie WH. Canal configuration in the mesiobuccal root of the maxillary first molar: a clinical study. *J Endod* 1994;20:135—7.
16. Stropko JJ. Canal morphology of maxillary molars: clinical observations of canal configurations. *J Endod* 1999;25:446—50.
17. Zhang R, Yang H, Yu X, Wang H, Hu T, Dummer PM. Use of CBCT to identify the morphology of maxillary permanent molar teeth in a Chinese subpopulation. *Int Endod J* 2011;44:162—9.
18. Tian XM, Yang XW, Qian L, Wei B, Gong Y. Analysis of the root and canal morphologies in maxillary first and second molars in a Chinese population using cone-beam computed tomography. *J Endod* 2016;42:696—701.
19. Ahmed HMA, Versiani MA, De-Deus G, Dummer PMH. A new system for classifying root and root canal morphology. *Int Endod J* 2017;50:761—70.
20. Saber S, Ahmed MHM, Obeid M, Ahmed HMA. Root and canal morphology of maxillary premolar teeth in an Egyptian subpopulation using two classification systems: a cone beam computed tomography study. *Int Endod J* 2019;52:267—78.
21. Taha NA, Makahleh N, Hatipoglu FP. Root canal morphology of anterior permanent teeth in Jordanian population using two classification systems: a cone-beam computed tomography study. *BMC Oral Health* 2024;24:170.
22. Ahmed HMA, Rossi-Fedele G, Dummer PMH. Critical analysis of a new system to classify root and canal morphology - a systematic review. *Aust Endod J* 2023;49:750—68.
23. Martins JNR, Gu Y, Marques D, Francisco H, Carames J. Differences on the root and root canal morphologies between Asian and White ethnic groups analyzed by cone-beam computed tomography. *J Endod* 2018;44:1096—104.
24. Cleghorn BM, Christie WH, Dong CC. Root and root canal morphology of the human permanent maxillary first molar: a literature review. *J Endod* 2006;32:813—21.
25. Martins JNR, Marques D, Silva E, Carames J, Versiani MA. Prevalence studies on root canal anatomy using cone-beam computed tomographic imaging: a systematic review. *J Endod* 2019;45:372—386.e4.
26. Ahmad IA, Alenezi MA. Root and root canal morphology of maxillary first premolars: a literature review and clinical considerations. *J Endod* 2016;42:861—72.
27. Burklein S, Heck R, Schäfer E. Evaluation of the root canal anatomy of maxillary and mandibular premolars in a selected German population using cone-beam computed tomographic data. *J Endod* 2017;43:1448—52.
28. Martins JNR, Versiani MA. Worldwide assessment of the root and root canal characteristics of maxillary premolars - a multi-center cone-beam computed tomography cross-sectional study with Meta-analysis. *J Endod* 2024;50:31—54.
29. Ogawa A, Seki S. Evaluation of root anatomy and root canal configurations in a Japanese population using dental cone-beam computed tomography: maxillary premolars. *J Japan Endod Assoc* 2020;41:16—21.
30. Martins JNR, Ordinola-Zapata R, Marques D, Francisco H, Carames J. Differences in root canal system configuration in human permanent teeth within different age groups. *Int Endod J* 2018;51:931—41.
31. Costa F, Pacheco-Yanes J, Siqueira JFJr, et al. Association between missed canals and apical periodontitis. *Int Endod J* 2019;52:400—6.
32. Baruwa AO, Martins JNR, Meirinhos J, et al. The influence of missed canals on the prevalence of periapical lesions in endodontically treated teeth: a cross-sectional study. *J Endod* 2020;46:34—39.e1.
33. Blattner TC, George N, Lee CC, Kumar V, Yelton CD. Efficacy of cone-beam computed tomography as a modality to accurately identify the presence of second mesiobuccal canals in maxillary first and second molars: a pilot study. *J Endod* 2010;36:867—70.
34. Vizzotto MB, Silveira PF, Arús NA, Montagner F, Gomes BP, da Silveira HE. CBCT for the assessment of second mesiobuccal (MB2) canals in maxillary molar teeth: effect of voxel size and presence of root filling. *Int Endod J* 2013;46:870—6.
35. Martins JNR, Marques D, Silva E, Caramês 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.
36. Martins JNR, Kishen A, Marques D, et al. Preferred reporting items for epidemiologic cross-sectional studies on root and root canal anatomy using cone-beam computed tomographic technology: a systematized assessment. *J Endod* 2020;46:915—35.
37. Pan JYY, Parolia A, Chuah SR, Bhatia S, Mutalik S, Pau A. Root canal morphology of permanent teeth in a Malaysian subpopulation using cone-beam computed tomography. *BMC Oral Health* 2019;19:14.
38. Yang L, Chen X, Tian C, Han T, Wang Y. Use of cone-beam computed tomography to evaluate root canal morphology and locate root canal orifices of maxillary second premolars in a Chinese subpopulation. *J Endod* 2014;40:630—4.
39. Abella F, Teixido LM, Patel S, Sosa F, Duran-Sindreu F, Roig M. Cone-beam computed tomography analysis of the root canal morphology of maxillary first and second premolars in a Spanish population. *J Endod* 2015;41:1241—7.
40. Martins JNR, Marques D, Mata A, Carames J. Root and root canal morphology of the permanent dentition in a Caucasian population: a cone-beam computed tomography study. *Int Endod J* 2017;50:1013—26.