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Original Article

Complex root canals of maxillary second premolars are associated with the occurrence of multiple roots in maxillary first premolars: A cone-beam computed tomographic study in a Taiwanese population

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KEYWORDS
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Abstract *Background/purpose:* Detecting two roots is generally easier than identifying complex canals within a single root using periapical films. We aimed to assess relationship between root number of permanent maxillary first premolars (PMFPs) and canal complexity in adjacent permanent maxillary second premolars (PMSPs) in a Taiwanese population using cone-beam computed tomography (CBCT).
Materials and methods: A CBCT analysis was performed on 600 teeth (300 PMFPs and 300 PMSPs) from 150 patients. Canal morphology of PMSPs was classified according to Vertucci, bilateral symmetry was assessed, and multivariable logistic regression was applied to evaluate the association between PMFP root number and PMSP canal configuration, adjusting for sex, age, and side.

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Results: Of PMFPs, 56 % had a single root and 44 % had multiple roots. PMSPs showed predominantly one root (96 %) and displayed mainly Type I canals (53.3 %), followed by Type III (16.7 %) and Type II (12.3 %). Complex canals were observed in 46.7 %. Males were more likely to present with multi-rooted PMFPs and complex PMSP canals ($p < 0.05$). Logistic regression demonstrated that multi-rooted PMFPs were significantly associated with complex PMSP canals (adjusted OR = 2.507; $p < 0.001$). Bilateral symmetry was high for both PMFP root number (77.3 %) and PMSP canal type (81.3 %).

Conclusion: Multi-rooted PMFPs predict greater canal complexity in PMSPs. Periapical radiographs that include both premolars may provide a practical preliminary tool before CBCT, enhancing diagnostic accuracy while reducing radiation exposure.

Introduction

A successful root canal treatment fundamentally depends on effective chemomechanical debridement and the appropriate obturation of the root canal system.[1] These critical steps are strongly influenced by a comprehensive understanding of the root and root canal system's morphological and anatomical complexities.[1] Detailed awareness of possible variations, such as the presence of additional canals, accessory branches, apical deltas, or unusual root structures significantly enhances a clinician's ability to locate, negotiate, and thoroughly clean the canal system during endodontic procedures. Conversely, insufficient knowledge of such anatomical intricacies may lead to missed canals, inadequate disinfection, or poor obturation, all of which are major contributors to persistent periapical pathology and treatment failure.[2,3] The development of advanced diagnostic tools, particularly cone-beam computed tomography (CBCT), has further underscored the value of three-dimensional imaging in accurately assessing root canal anatomy and facilitating more effective treatment planning.[4] Continued education and research into the complex nature of root canal morphology remain essential for improving the precision, effectiveness, and outcomes of contemporary endodontic practice.

Regarding the root and root canal anatomy of permanent maxillary second premolars (PMSPs), the existing literature appears relatively limited. A PubMed search conducted on 5th September 2025 revealed 2771 publications related to the term "maxillary second premolar". In contrast, searches for "maxillary first premolar", "maxillary first molar", and "maxillary second molar" yielded 4,080, 7,532, and 4382 results, respectively. These findings indicate that PMSPs are the least studied among the posterior maxillary teeth. Nonetheless, a cone-beam computed tomography (CBCT) investigation conducted in China provided insight into PMSP morphology. The study reported that the majority of maxillary second premolars (94.2 %) had a single root, while 5.8 % exhibited two roots. In terms of root canal configuration, one canal was found in 55.1 % of cases, two canals in 44.7 %, and a rare three-canal configuration was observed in 0.2 % of the sample, however, there were 39.1 % complex canals (Vertucci's type II to type VIII).[5]

In contrast to PMSPs, there were more literature describing the root and root canal morphology of permanent maxillary first premolars (PMFPs). Although the exact reason was unclear, it may be attributed to the higher ratio of multiple roots in PMFPs compared to PMSPs. A CBCT-based study with a robust ethnic relevance to the Taiwanese population reported that 66 % of PMFPs had one root, 33 % had two roots, and only 1 % exhibited three roots.[6]

To detect two roots was relatively easier than to determine the complex canals in one root by taking periapical film, therefore, the present study aimed to evaluate the association between the root number (single root vs. multiple roots) of PMFPs and the root number and root canal category (single canal vs. complex canals) of PMSPs in a Taiwanese cohort. Our hypothesis was the presence of multiple roots of PMFPs increased the incidence of complex canals in PMSPs. Additionally, this study investigated the symmetry of root number in PMFPs and root canal category (single and complex) in PMSPs.

Materials and methods

Database confidentiality, retrieval, and image acquisition

All CBCT scans used in this investigation were obtained from a secure, encrypted database. The repository stored images in Digital Imaging and Communications in Medicine (DICOM) format, which had been collected from patients attending the Department of Dentistry at Tri-Service General Hospital, Taipei, Taiwan, between July and December 2024. Therefore, the images were not originally acquired with the intention of being used in this study. Two authors de-identified patients' personal information, such as names, medical record numbers, and phone numbers by replacing them with serial numbers during image evaluation. This protocol was permitted by the Institutional Review Board of Tri-Service General Hospital, National Defense Medical Center (TSGHIRB No. C202505122) and informed consent waiver was granted.

To maintain image quality while adhering to the "as low as reasonably achievable" (ALARA) principle, the scans

were obtained by three board-certified radiologists using a CBCT machine (Planmeca ProMax 3D ProFace; Helsinki, Finland). The x-ray tube operated at an accelerated potential of 80 kVp, with a beam current of 15 mA, and automatic exposure time adjustment based on the scanned region (approximately 12 s for full arches), the voxel size was 0.15 mm. CBCT images from 342 patients were initially reviewed, and 150 patient scans met the inclusion criteria for further analysis.

1. Bilateral presence of PMFPs and PMSPs with fully developed roots.
2. No history of root canal treatment or radio-opaque root canal filling material.
3. No presence of restorations or post-and-core.
4. Nonexistence of extensive metallic restorations that could interfere with image analysis.
5. No signs of root resorption or periapical radiolucency.
6. No prior root amputation or hemisection.
7. High-quality CBCT imaginings in which canal orifices and root canal configurations were clearly discernible.

The surveyed images (1920 $\times$ 1080-pixel resolution) were reoriented such that the maxilla appeared symmetrical, and the occlusal plane whether in the sagittal or frontal view, was aligned parallel to the ground.[7]

Calibration on examiner reliability

Two calibrated examiners independently assessed the CBCT images, and the discrepancies in clarification were resolved through discussion with corresponding author until consensus was achieved. Intra- and inter-examiner calibration for nominal variables was conducted to assess data reliability, based on the anatomical diagnosis of 50 randomly selected CBCT images. Kappa analysis was performed prior to resolving disagreements among the examiners.[8] The kappa coefficient values for nominal variables were 0.976 and 0.943 for intra- and inter-examiner agreement, respectively (data not shown).

Sample size calculation and power analysis

To establish the required sample size, a preliminary analysis was conducted using data assessed by two examiners, who independently evaluated 50 cases. The objective was to determine the minimum number of teeth needed to detect a statistically significant difference between one-rooted and multi-rooted PMFPs with adequate statistical power. Observations indicated that 35.48 % of PMSPs exhibited complex canals in the one-rooted PMFP group, compared with 55.26 % in the multi-rooted PMFP group. Assuming an enrolment ratio of 0.61 between the groups, a two-sided test was employed, with a significance level (α) set at 0.05 and a desired power of 80 % ($\beta = 0.20$). Based on these parameters, the calculated total sample size was 208 teeth (104 patients), ensuring sufficient power to detect the expected difference. This sample size minimizes the probability of both Type I and Type II errors, thereby enhancing the reliability of the findings.

Root and root canal analysis and classification

All qualified images of PMFPs and PMSPs were carefully assessed using OsiriX Lite software (Pixmeo SARL, Bernex, Switzerland). A series of cross-sectional images were evaluated from the crown to the apex to analyze root canal in PMFPs and PMSPs. For PMFPs, the number of dental roots were recorded. To evaluate the number of root and configuration of root canals by Vertucci's classification in PMSPs, serial cross-sectional images were analyzed from the cementoenamel junction (CEJ) to the apex. Canal configuration was first divided into two categories: single canal and complex canals, then also sorted according to Vertucci's classification:[9]

1. Single canal: A single canal present in a PMSP (Fig. 1A).
2. Complex canals: More than one canal present within the slices of PMSPs' CBCT images (Fig. 1B).

The symmetry of root number in PMFPs and root canal category (single and complex) in PMSPs were further recorded (Fig. 1C).

Statistical analysis

Descriptive statistics were presented as means with standard deviations, frequencies, or percentages, depending on the nature of each variable, and were calculated at either the subject or tooth level. The chi-square test was employed to assess differences in categorical variables, including sex (female vs male), age group ($<$50 years vs $\geq$ 50 years), side (right vs left), number of roots (one root vs multiple roots) of PMFPs, and canal configuration of PMSPs (single canal vs complex canals).[7] To evaluate the independent association between the root number of PMFPs and the canal configuration of PMSPs, a multivariable logistic regression analysis was performed. This model adjusted for potential confounders such as sex, age, and side. All statistical analyses were conducted through SPSS for Mac (Version 31.0; SPSS Inc., Chicago, IL, USA). A *P*-value of $<$0.05 was considered to indicate statistical significance.

Results

Characteristics of the study population and teeth

We reviewed 325 patients' CBCT images and included 150 patients who fitted the inclusion criteria, comprising 69 females (46 %) and 81 males (54 %), with ages ranging from 20- to 83-year-old. The overall mean age was 46.6 $\pm$ 15.6 years. A total of 600 teeth were examined, including 300 PMFPs and 300 PMSPs (Table S1).

Prevalence and distribution analyzed by variables

Among the PMFPs, males demonstrated a significantly higher prevalence of multiple roots (53.7 %) compared to females (32.7 %). No significant differences were observed between age groups or between right and left sides. A

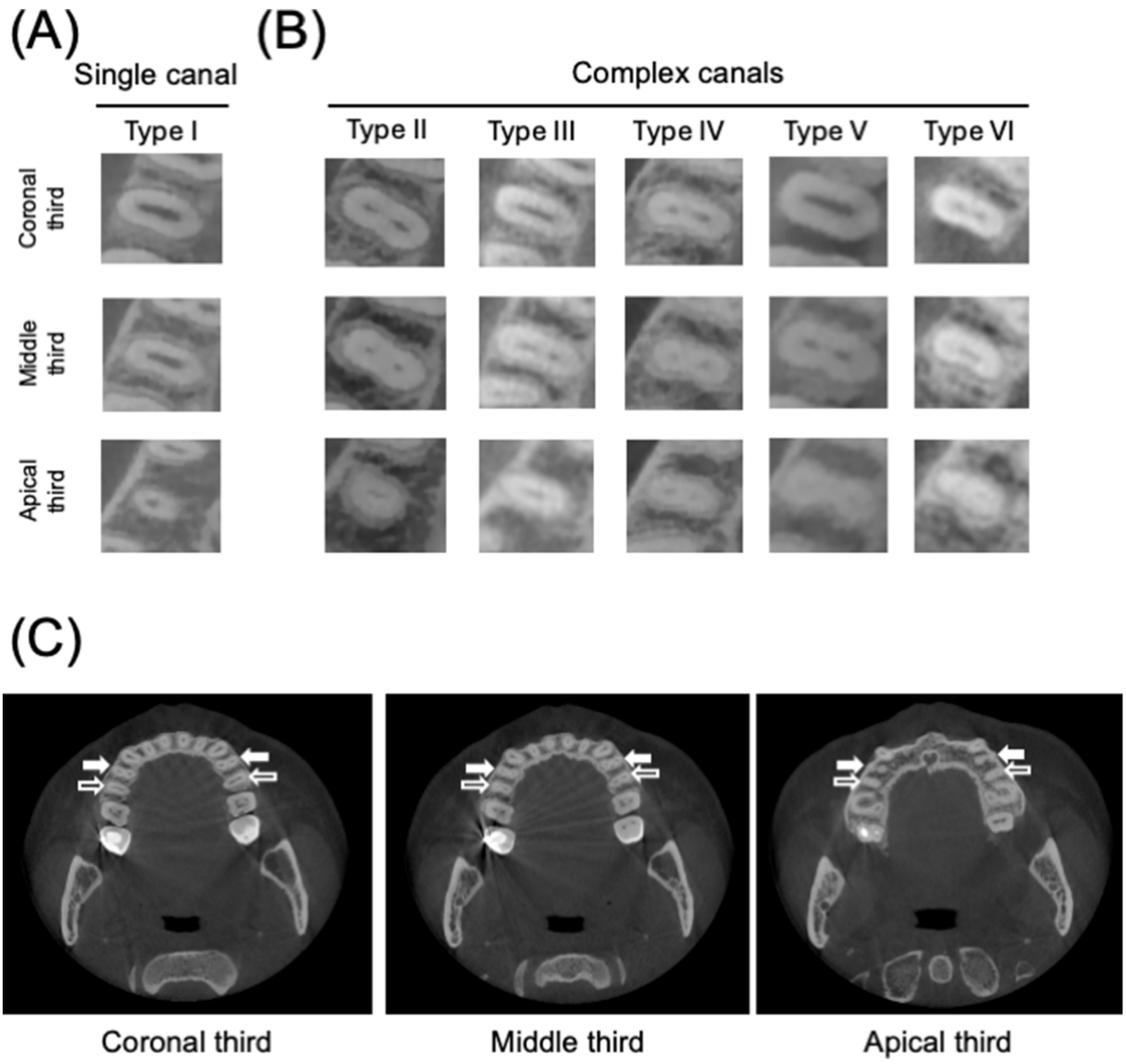

Figure 1 Representative images of root canal anatomy were categorized by Vertucci's classification of permanent maxillary second premolars (PMSPs) and the symmetry of root number of permanent maxillary first premolars (PMFPs) and PMSPs. (A) Type I canal of PMSPs were regarded as single canal. (B) Except type I canal, other Vertucci's type canals were regarded as complex canals. Here, we showed type II to type VI. (C) The symmetry of PMFPs had two roots were indicated with white solid arrows, whereas black open arrows represent PMSPs had one root.

similar trend was found in PMSPs, where males exhibited a significantly higher proportion of complex canals (54.3 %) than females (37.7 %), with no significant variation by age or tooth side (Table 1).

With respect to the primary aim of this research, the presence of multiple roots in PMFPs was found to be significantly associated with increased frequencies of multiple roots and complex canal configurations in PMSPs (Fig. 2). To control for potential confounding variables, a multivariable logistic regression analysis was performed. This revealed that the presence of multiple roots in PMFPs was independently associated with the canal category of PMSPs, with an adjusted odds ratio of 2.507 ($P < 0.001$) compared to one-rooted PMFP group. Detailed results are presented in Table 2.

Vertucci's classification of PMSPs' canal configurations

The canal configurations of PMSPs were subsequently evaluated in accordance with Vertucci's classification. Over half of the PMSPs (53.3 %) exhibited a single root with a single canal, corresponding to Vertucci's Type I configuration. This was followed in prevalence by Type III (16.7 %) and Type II (12.3 %) configurations. The remaining canal types each accounted for between 0.7 % and 9.0 % of the sample (Table 3).

Table 1 The prevalence and distribution of PMFP root number classifications and PMSP root canal categories were analysed according to sex, age, and side.

	PMFPs, n (%)		Total	*P*-value	PMSPs, n (%)		Total	*P*-value
	One root	Multiple roots			Single canal	Complex canals		
Sex								
Female	93 (67.3)	45 (32.7)	138 (100)	<0.001***	86 (62.3)	52 (37.7)	138 (100)	0.004**
Male	75 (46.3)	87 (53.7)	162 (100)		74 (45.7)	88 (54.3)	162 (100)	
Age								
<50 years	77 (52.1)	71 (47.9)	148 (100)	0.171	85 (57.4)	63 (42.6)	148 (100)	0.16
≥50 years	91 (59.8)	61 (40.2)	152 (100)		75 (49.3)	77 (50.7)	152 (100)	
Side								
Right	82 (54.7)	68 (45.3)	150 (100)	0.642	83 (55.3)	67 (44.7)	150 (100)	0.487
Left	86 (57.3)	64 (42.7)	150 (100)		77 (51.3)	73 (48.7)	150 (100)	
Total	168 (56.0)	132 (44.0)	300 (100)		160 (53.3)	140 (46.7)	300 (100)	

PMFPs, permanent maxillary first premolars; PMSPs, permanent maxillary second premolars; SD, standard deviation; n, tooth number. Data were analysed using chi-square test. The level of statistical significance was set at $P < 0.05$*. $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

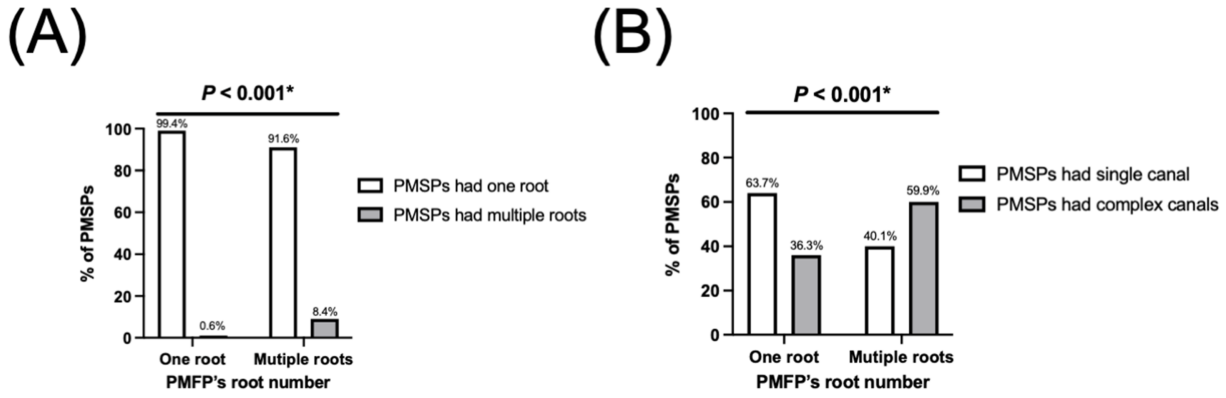

Figure 2 Fig. 2 **Analysis of the presence of multiple roots in permanent maxillary first premolars (PMFPs) and prevalence of multiple roots and complex canals in permanent maxillary second premolars (PMSPs).** (A) The presence of multiple roots in PMFPs significantly increased the incidence of multiple roots in PMSPs. (B) The presence of multiple roots in PMFPs also significantly increased the prevalence of complex canals in PMSPs. The chi-square test was used to assess differences in number of roots (one root vs multiple roots) of PMFPs, root number and canal configuration of PMSPs (single canal vs complex canals). A *P*-value of <0.05 was considered to indicate statistical significance.

Symmetry of PMFPs and PMSPs

To assess the symmetry in the root number of PMFPs and the root canal category of PMSPs, we examined the correlation between the contralateral PMFP root number and the corresponding root canal category of PMSPs. A notably high degree of symmetry was observed, with 77.3 % of PMFPs demonstrating identical root numbers on both sides, and 81.3 % of PMSPs exhibiting symmetrical root canal category (Table 4).

Discussion

This study examined the anatomical correlation between the root number of PMFPs and the root canal morphology of PMSPs using cone-beam computed tomography (CBCT) in a Taiwanese population. The findings demonstrated a significant association between the presence of multiple roots in PMFPs and the incidence of complex canal configurations in PMSPs. Specifically, patients with multi-rooted PMFPs were more likely to present with PMSPs exhibiting complex root canal morphologies, with an adjusted odds ratio of 2.507, even after controlling for confounding variables such as sex, age, and side.

The results align with previous anatomical studies suggesting that root and canal morphologies within the same quadrant or dentition may be developmentally interrelated.[7,10,11] The significantly higher prevalence of complex canal systems in PMSPs among male participants is consistent with some earlier literature reporting sex-related anatomical variations in root morphology,[10,12] although, there are several studies reported the root canal anatomy not related to sex.[13,14] Furthermore, no significant differences were observed in canal complexity across different age groups or between right and left sides, suggesting that these variables exert minimal influence in this context.

Table 2 The association between the variables and the presence of complex canals in PMSPs was analysed using multivariable logistic regression.

	PMSPs			
	Adjusted OR	95 % CI		*P*-value
		Lower	Upper	
Sex				
Female	Referent			
Male	1.637	1.011	2.651	0.045*
Age				
<50 years	Referent			
≥50 years	1.493	0.926	2.406	0.1
Side				
Right	Referent			
Left	1.221	0.76	1.96	0.409
PMFPs				
One root	Referent			
Multiple roots	2.507	1.541	4.08	<0.001***

PMSPs, permanent maxillary second premolars; OR, odds ratio; CI, confidence interval. The level of statistical significance was set at $P < 0.05$*. $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

Interestingly, the study also revealed a high degree of bilateral symmetry in both PMFP root number (77.3 %) and PMSP canal configurations (81.3 %), corroborating prior research suggesting that contralateral comparisons may aid clinicians in anticipating canal anatomy during endodontic procedures.[7]

Vertucci's classification further confirmed that the majority of PMSPs exhibited Type I canal configuration (53.3 %), followed by Type III and Type II. However, nearly half of the cases (46.7 %) demonstrated more complex canal systems,[5] highlighting the clinical relevance of advanced diagnostic tools such as CBCT in treatment planning.

To the best of our knowledge, this is the first study to directly investigate the anatomical correlation between PMFP root number and PMSP canal complexity in the literature. The findings emphasise the importance of holistic anatomical assessment across adjacent teeth and offer an easy method by just taking a periapical film including maxillary first and second premolars for clinicians aiming to have a better assessment before treatment. While the sample was rigorously selected and calibrated, potential limitations include the retrospective design and the single-centre setting, which may affect generalisability to other ethnic or geographical populations. Further multicentric

Table 3 Distribution of Vertucci's classification of permanent maxillary second premolars' (PMSPs') canal configurations (n = 300).

Root number	Canal classification		Type III	Type IV	Type V	Type VI	Type VII	Total
	Type I	Type II						
One root	160 (53.3)	37 (12.3)	50 (16.7)	15 (5.0)	23 (7.7)	1 (0.3)	2 (0.7)	288 (96.0)
Two roots	0	0	0	12 (4.0)	0	0	0	12 (4.0)
Total	160 (53.3)	37 (12.3)	50 (16.7)	27 (9.0)	23 (7.7)	1 (0.3)	2 (0.7)	300 (100.0)

Table 4 The correlation between the root number of the contralateral PMFPs and the root canal category of the PMSPs was analysed. (N = 150).

	PMFPs, right (N)				*P*-value
	One root	Two roots	Three roots	Total	
PMFPs, left (N)					
One root	67	19	0	86	<0.001***
Two roots	15	47	0	62	
Three roots	0	0	2	2	
Total	82	66	2	150	
	PMSPs, right (N)				*P*-value
	Single canal	Complex canals	Total		
PMSPs, left (N)					
Single canal	66	11	77		<0.001***
Complex canals	17	56	73		
Total	83	67	150		

PMFPs, permanent maxillary first premolars; PMSPs, permanent maxillary second premolars; N, number of patients. Data were analysed using chi-square test. The level of statistical significance was set at $P < 0.05$*. $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

studies involving broader population samples are warranted to validate these findings.

In conclusion, this CBCT-based investigation demonstrated a statistically significant relationship between the presence of multiple roots in maxillary first premolars and the complexity of root canal morphology in adjacent maxillary second premolars. These findings suggest that the anatomical features of PMFPs may serve as predictive indicators for the canal configuration of PMSPs. Bilateral symmetry in both root number and canal type further supports the utility of contralateral reference during endodontic planning. Provide a clinical implication for treatment efficacy and suggest a simple alternative to CBCT.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jds.2025.10.026.

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