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Original Article

Cone-Beam CT Evaluation of Root Canal Variations in Permanent Mandibular Premolars

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ABSTRACT

A thorough understanding of the root canal system configurations is essential for increasing the success of root canal treatments and ensuring favorable long-term outcomes. This cross-sectional study aimed to evaluate the differences in root canal morphology of mandibular premolars. A total of 151 mandibular premolars were evaluated using cone-beam computed tomography (CBCT). The pulp canal configurations of both first and second mandibular premolars were analyzed across coronal, axial, and sagittal sections. Findings showed that 89.4% of the examined teeth exhibited more than 1 canal in the apical third, while 10.6% had a single root canal. Among the observed morphologies, Vertucci's type V was the most common (50.3%), followed by type I (10.6%) and type III (9.3%). In addition, 11.3% of the cases had root canal configurations that were not classified under Vertucci's system. The study concluded that type V is the predominant root canal configuration in mandibular premolars, followed by type I. These findings underscore the importance of recognizing anatomical variations in root canal morphology. This study also emphasizes the need to re-evaluate existing classification systems with the aid of advanced three-dimensional CBCT imaging.

Keywords: Endodontics, Cone-beam computed tomography, Root canal, Mandibular premolars, Root canal configuration, Root canal morphology.

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Introduction

Successful endodontic treatment relies on the complete elimination of infection, followed by proper sealing of the root canal system. The anatomical complexity of root canal morphology plays a crucial role in the success of the procedure. Failure to recognize variations in root canal anatomy can lead to complications or even treatment failure [1-4].

The primary causes of endodontic failure are microbial infections or an inability to locate and properly access root canals. Incomplete biomechanical preparation and inadequate canal obturation also contribute to unsuccessful outcomes. However, persistent or secondary infections remain the most significant factor in endodontic failures [5, 6]. Posterior teeth, particularly mandibular premolars, have a higher rate of failure compared to anterior teeth due to their complex root canal anatomy. Undetected accessory or lateral canals and procedural errors further contribute to treatment challenges [5-8].

Vertucci's classification of root canal morphology, developed using two-dimensional imaging techniques, has been widely used to understand root canal variations. However, the advent of cone-beam

computed tomography (CBCT) has revolutionized endodontic diagnostics [6, 9]. CBCT provides three-dimensional visualization of root canal systems, offering detailed insights comparable to medical-grade CT scans but with lower radiation exposure and cost. This advanced imaging technique has significantly improved the accuracy of root canal morphology assessments, particularly in cases of failed endodontic treatments [6-10].

Since root canal morphology varies based on ethnic background, it is essential to validate the classifications derived from conventional two-dimensional imaging with data obtained from three-dimensional CBCT scans. While studies worldwide have analyzed root canal configurations using CBCT, research focusing on mandibular premolars in the Saudi Arabian population remains limited. Given the importance of understanding regional anatomical variations, this study aims to evaluate the root canal morphology of first and second mandibular premolars using CBCT imaging. The findings will aid dental practitioners in improving endodontic treatment outcomes, particularly in cases where conventional therapy has failed.

Materials and Methods

This study was conducted following the preferred reporting of observational studies in endodontics (PROBE) guidelines. A retrospective cross-sectional study was carried out using CBCT scans from 151 cases. These scans were obtained using the Sirona Galileos CBCT system (Germany) with settings of 85 kV, 5-7 mA, and an exposure time of 14 seconds. The scans were sourced from the radiology section of a private dental university affiliated with the investigators' institution. The analysis was performed using the Galileos Viewer software (version 1.9, Germany).

The study adhered to the ethical principles outlined in the Declaration of Helsinki (2013) and received approval from the Institutional Review Board (RC/IRB/2019/308). Data were screened from records spanning 2018 to 2023, applying specific inclusion and exclusion criteria to ensure appropriate case selection for the study.

The criteria for including consisted of patients aged sixteen to sixty years, CBCT scans displaying a complete view of 1 or more mandibular premolars, fully developed roots, and the absence of root resorption, periapical lesions, or previous endodontic treatments. Cases with posts, coronal restorations, or image distortions were excluded. CBCT scans with artifacts such as white streaking or beam hardening, which could compromise data accuracy, were also excluded. Additionally, cases with dental pathologies, fractures, or prior endodontic treatment were omitted. Personal identifiers were not counted in the study to maintain confidentiality.

Methodology

The CBCT scans were examined to assess root canal configurations using the Galileos CBCT viewer (version 1.9) with a resolution of 286 µm. A three-dimensional digital imaging system was utilized by an experienced oral and maxillofacial radiologist following the Vertucci 1994 classification, ensuring that no interobserver bias occurred. To minimize intraobserver bias, each observation was recorded three times, and the final value was determined by averaging these readings.

Root canal morphology was analyzed using axial and coronal cross-sectional views with multi-planar reformatted images. The evaluation process involved tracing the root canal structure from the cementoenamel junction (CEJ) along the tooth's long axis and examining axial parts from its origin to the apical foramen. The CBCT scans were reviewed by an oral and maxillofacial radiologist with over nine years of expertise in CBCT image interpretation. A co-investigator assisted in data analysis to derive statistical inferences.

The study included CBCT images of mandibular 1st and 2nd premolars from Saudi individuals, ensuring high diagnostic image quality. Participants were within the age range of sixteen to sixty years. The exclusion criteria comprised non-Saudi individuals, CBCT scans with artifacts or errors affecting the region of interest, implants in the studied area, periapical pathologies, and teeth that had undergone previous endodontic treatment.

Statistical analysis was calculated using the Statistical Package for Social Sciences (SPSS) version 26.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics, including frequencies and percentages, were used to summarize the data. To compare the distribution of Vertucci's morphological types across different groups, a chi-square test for independence and Fisher's exact test were applied. A P-value of < 0.05 was considered statistically significant.

Results and Discussion

This study analyzed the root canal morphology of mandibular premolars using cone beam computed tomography (CBCT) and classified them based on Vertucci's system. A total of 270 CBCT scans from the years 2018 to 2023 were reviewed, with patient data being refined through strict exclusion and inclusion

criteria. Several premolars were omitted from the analysis due to various factors, including 45 teeth that had undergone root canal treatment (RCT), 37 cases where the premolars were missing, 4 replaced with implants, and 2 exhibiting periapical pathologies. Additionally, 8 CBCT images contained artifacts or errors that interfered with accurate assessment, while 7 cases were entirely edentulous. 16 non-Saudi patients were excluded, and 22 individuals fell outside the age range of 16 to 60 years—either too young for complete root formation or older, where age-related pulp canal changes could influence findings. After applying these criteria, 151 mandibular premolars were selected for final analysis.

The study sample consisted predominantly of male participants (56.0%), with the most common age group being 31 to 45 years (46.0%) (**Table 1**). The majority of the teeth examined (55.0%) were first mandibular premolars. CBCT analysis revealed that 89.4% of the evaluated teeth exhibited more than 1 canal, while 10.6% contained a single root canal. Among the various root canal configurations, Vertucci's type V morphology was the most prevalent, identified in 50.3% of cases. This was followed by type I (10.6%) and type III (9.3%) (**Figure 1**). Additionally, 11.3% of cases presented variations that did not fit into any category defined within Vertucci's classification (**Figure 2**).

Table 1. Demographic characteristics of patients (n = 50) and the distribution of Vertucci classification in premolar teeth (n = 151)

Parameter	Category	Frequency	Percentage
Gender	Male	28	56.0
	Female	22	44.0
Age group (years)	16 to 30	16	32.0
	31 to 45	23	46.0
	46 to 60	11	22.0
Premolars*	First premolar	83	55.0
	Second premolar	68	45.0
Vertucci classification*	Type I (1 -1)	16	10.6
	Type II (2-1)	7	4.6
	Type III (1-2-1)	14	9.3
	Type IV (2-2)	10	6.6
	Type V (1-2)	76	50.3
	Type VI (2-1-2)	6	4.0
	type VII (1-2-1-2)	5	3.3
	Type VIII (3-3)	0	0.0
	Other types	17	11.3

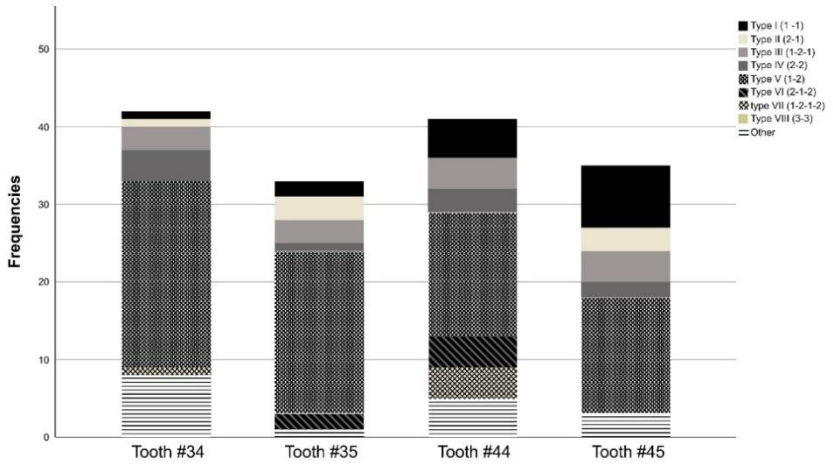

Figure 1. The distribution of different Vertucci's morphological types in mandibular premolars

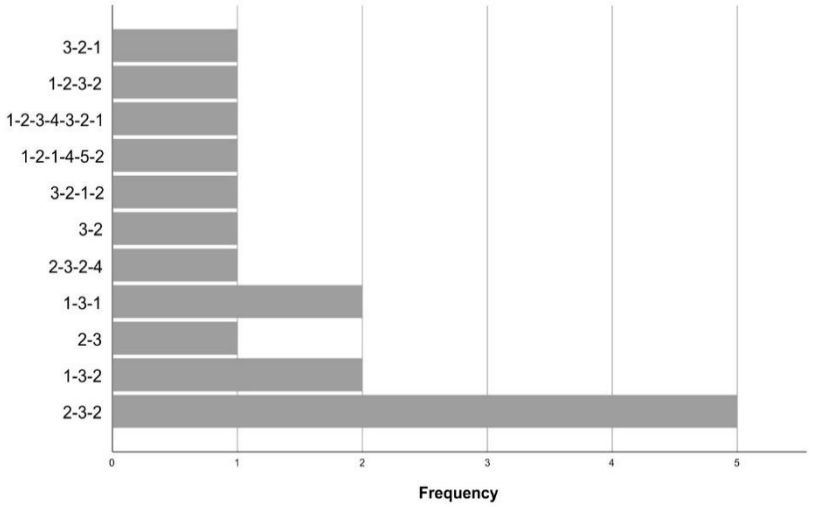

Figure 2. The frequencies of 'other' types of root canal morphologies in the mandibular premolar

The analysis revealed notable differences in root canal configurations based on gender. Males demonstrated a significantly higher prevalence of type II canal configuration compared to females (6.9% vs. 1.6%), as well as a greater occurrence of other variations within Vertucci's classification (14.9% vs. 6.3%, p = 0.016) (**Table 2**).

Additionally, a significant distinction was observed between the mandibular first and second premolars concerning root canal morphology. Type I and type II canal configurations were found at lower frequencies in the mandibular first premolars compared to the second premolars (7.2% vs. 14.7% and 1.2% vs. 8.8%, respectively). Conversely, other variations in Vertucci's classification were more frequently identified in first premolars than in second premolars (15.7% vs. 5.9%, p = 0.030). Among these additional configurations, both the 1-3-1 and 1-3-2 patterns were equally prevalent. However, no significant differences in root canal configurations were observed across different age groups within the study population (**Table 2**).

Table 2. Distribution of Vertucci classification in premolar teeth according to gender, age, and tooth location

Parameter	Category	Vertucci's classification (n (%))							*P*
		Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII	Other	
Gender	Male	10 (11.5)	6 (6.9)	8 (9.2)	10 (11.5)	35 (40.2)	3 (3.4)	2 (2.3)	13 (14.9)	**0.016**
	Female	6 (9.4)	1 (1.6)	6 (9.4)	0 (0.0)	41 (64.1)	3 (4.7)	3 (4.7)	4 (6.3)	
Age group (years)	16 to 30	3 (6.1)	3 (6.1)	3 (6.1)	3 (6.1)	31 (63.3)	1 (2.0)	1 (2.0)	4 (8.2)	0.207
	31 to 45	8 (11.4)	1 (1.4)	8 (11.4)	5 (7.1)	28 (40.0)	4 (5.7)	3 (4.3)	13 (18.6)	
	46 to 60	5 (15.6)	3 (9.4)	3 (9.4)	2 (6.3)	17 (53.1)	1 (3.1)	1 (3.1)	0 (0.0)	
Premolars	First premolar	6 (7.2)	1 (1.2)	7 (8.4)	7 (8.4)	40 (48.2)	4 (4.8)	5 (6.0)	13 (15.7)	**0.030**
	Second premolar	10 (14.7)	6 (8.8)	7 (10.3)	3 (4.4)	36 (52.9)	2 (2.9)	0 (0.0)	4 (5.9)	

The study analyzed the division level of root canals in single bifurcated root canal morphology types—those that divide only once from the cementoenamel junction (CEJ) to the apical foramen. These included type III (1-2-1), type IV (2-2), type V (1-2), and type VI (2-1-2). Among the 151 mandibular premolars evaluated, 87 exhibited single bifurcated root canals. Type V was the most observed morphology, accounting for 80.5% of cases, followed by type II (9.2%), type IV (8%), another variant of type IV (1.15%), and an additional unidentified type (1.15%).

Regarding the location of root canal division within these bifurcated types, the middle third of the root was the most common site (64.4%), followed by the apical third (23%) and the cervical third (12.6%). Specifically, type V bifurcation occurred predominantly in the middle third of the root (58.6%), with fewer cases in the apical third (25.7%) and the cervical third (15.7%). The study findings reinforce the increased occurrence of many canals in mandibular premolars.

This research, conducted on a subset of the Saudi Arabian population, underscores the significance of three-dimensional imaging in detecting intricate anatomical and morphological details that conventional two-dimensional radiographs often overlook. The high prevalence of type V root canal morphology in mandibular premolars, along with the

notable finding that 89.4% of cases exhibited more than 1 canal, aligns with a micro-CT study from Brazil, which reported a 58.57% prevalence of type V root canal configurations in mandibular first premolars [7, 9, 10].

The 3D models generated in this study offer a precise visualization of these minute anatomical features, supporting the value of CBCT imaging in endodontic evaluation. These results are consistent with a recent review and meta-analysis focused on mandibular premolar root canal configurations using CBCT, which also identified type V as the most prevalent, followed by type IV, type III, and another variation of type IV [11]. Notably, CBCT imaging has revealed a higher incidence of type V root canals compared to previous studies based on traditional imaging techniques [7, 12-15].

The findings of this study align with prior research conducted on Caucasian populations, specifically a study analyzing four hundred dark-skinned and four hundred white-skinned mandibular premolars. That study reported a higher prevalence of multiple root canals in the mandibular first premolars of dark-skinned individuals compared to white-skinned individuals. Additionally, at least 1 premolar with more than 1 canal was significantly more common in dark-skinned individuals (39%) than in white-skinned individuals (13.7%) [16, 17]. Another investigation, which examined 2,331 mandibular premolars using radiographic imaging and mechanical probing, identified two or more root canals in 23.1% of first premolars and 12.1% of second premolars [18, 19]. While these earlier studies relied on two-dimensional imaging, the presence of canal divisions and ramifications was still observable.

In the present study, root canal divisions were predominantly located in the apical and middle thirds of the root, with type V morphology being the most frequently observed. This distribution is consistent with findings from studies conducted on mandibular premolars in populations from western China and Shanghai (87% and 75% in first and second premolars, respectively) [20-22], as well as India [23], Venezuela [24], Spain [25], and Iran [26]. The increased prevalence of multiple root canals with complex configurations reinforces the value of three-dimensional imaging for accurately visualizing root canal anatomy [20, 21, 23-29]. Existing literature also supports that type I and type V configurations are the two most commonly encountered root canal types [12, 13, 20, 21, 23, 28, 29].

However, the results of this study differ from a previous investigation conducted on mandibular first premolars in Saudi Arabia, which analyzed 216 teeth. That study found type I to be the most frequent root canal morphology, particularly in single-rooted teeth (74%), whereas type V was the predominant configuration in two-rooted mandibular first premolars (55.5%) [30]. Interestingly, the increased occurrence of 2 canals in male participants observed in that study aligns with the findings of the present research. Additionally, another study conducted in different regions within Saudi Arabia reported a strikingly high prevalence (99.1%) of type I root canals [30, 31].

The differences in root canal morphology observed in this study highlight the need for further classification beyond Vertucci's widely used system. These findings are consistent with multiple studies employing micro-computed tomography, which have also suggested the presence of additional morphological variations beyond the traditional classification framework [32-35].

Currently, there are no definitive criteria to distinguish root canal ramifications from lateral or secondary canals [36]. As research utilizing advanced imaging techniques continues to expand, many previously undocumented anatomical intricacies are being uncovered [32, 37-39]. A newly proposed root canal classification system highlights the need for a more detailed and comprehensive approach to categorizing root canal morphology [36].

Despite the advancements in three-dimensional imaging, a significant portion of studies employing CBCT still rely on Vertucci's conventional classification system, which was developed using a two-dimensional approach. A key factor contributing to this continued reliance on outdated classification methods is the lack of involvement of oral radiologists in many of these studies. In several cases, research has been conducted by individuals who are not experts in radiographic interpretation, and studies have lacked proper calibration or interexaminer reliability assessments before data collection [29, 40-45]. This may explain why type I remains the most frequently reported root canal configuration in numerous studies, despite evidence suggesting otherwise. This aspect warrants further investigation.

Additionally, multiple micro-CT studies have demonstrated that root canal morphology often deviates from traditional classification systems. These studies have identified variations beyond the commonly reported type I canal and have also confirmed that most teeth contain more than one canal [7, 46, 47].

The present study was done with a sufficiently large sample size, making its findings generalizable to the

target population. However, future research should focus on multicenter studies within the same population using different CBCT imaging systems. Studies should also incorporate experienced, calibrated investigators and larger sample sizes drawn from the same ethnic group to ensure greater accuracy. Researchers should further leverage three-dimensional imaging technology to refine root canal classification and move beyond conventional two-dimensional methods.

Conclusion

This study identified type V and type I as the most prevalent root canal configurations in mandibular premolars. The findings highlight the intricate nature of root canal morphology in these teeth, often influenced by the presence of radicular grooves. Additionally, the results underscore the necessity of re-evaluating existing root canal classification systems, as advanced cone beam computed tomography provides a more detailed and accurate representation compared to traditional two-dimensional radiographic methods.

From a clinical standpoint, recognizing and understanding these anatomical variations is essential for endodontists to minimize the risk of treatment failure. A thorough comprehension of complex root canal morphologies can significantly enhance the success rates of endodontic procedures, ensuring more effective patient outcomes.

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