Original articles

A cone-beam computed tomography - based survey of the root canal morphology of maxillary first premolars

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Abstract

Introduction: The maxillary first premolar (MFP) is characterized by a highly diverse root canal system. Variations in root canal morphology can complicate endodontic treatment.

Objective: To evaluate the root canal morphology and curvature of MFP using Cone Beam Computed Tomography (CBCT).

Materials and Methods: An in vitro experimental study was conducted on 63 extracted MFP. The samples were scanned using CBCT to analyze the canal morphology and canal curvature on CBCT images.

Results: In the group of MFP with one root, 6 out of 8 Vertucci root canal morphology types were observed (types I, II, III, IV, V, and VII), with proportions of 13.2%, 21%, 36.8%, 13.2%, 13.2%, and 2.6%, respectively. No type VI or VIII root canals were recorded. In the group of MFP with two roots, only 2 out of 8 Vertucci types were observed (types I and V), with proportions of 96% and 4%, respectively. No type II, III, IV, VI, VII, or VIII root canals were recorded. In the buccolingual direction**,** most canals were moderately curved (52.1%); followed by straight canals (29.3%); and severely curved canals (18.6%). The mean canal curvature was 15.63° ± 10.95°. In the mesiodistal direction**,** most of the canals were also moderately curved (55.3%); followed by straight canals (41.4%); and severely curved canals (3.3%). The mean canal curvature was 9.08° ± 7.01°.

Conclusion: The morphology and curvature of the root canals in maxillary first premolars are highly variable, increasing the complexity of endodontic treatment. CBCT plays an important role in identifying canal morphology and curvature.

Keywords: *root canal system; maxillary first premolar; CBCT.*

1. INTRODUCTION

The premolar group of teeth has a highly diverse root canal system, typically characterized by mesiodistally flattened canals and isthmuses connecting the main canals in teeth with two or three canals. As transitional teeth, premolars often exhibit a high prevalence of curved canals, particularly those with L-shaped or double-curved (S-shaped) configurations. Cross-sectional images of these canals reveal a wide variety of complex shapes, which makes endodontic treatment of these teeth particularly challenging. Various classification systems, such as those proposed by Vertucci, Weine, and Gulabivala, have been used to enhance the understanding of root canal system morphology.

Variations in the morphology of the root canal system can complicate endodontic treatment if any canals are missed and left untreated. An untreated canal can result in the persistent presence of bacteria and necrotic tissue inside the canal, leading to a high root canal treatment failure rate. Therefore, a thorough understanding of canal morphology and its potential variations is a prerequisite for minimizing endodontic treatment failures.

According to a study by Hà Ngọc Chiều and colleagues, most maxillary first premolars (MFP) have a single canal (86.3%). In another study by Saad M. Al-Zubaidi on extracted MFP using CBCT imaging, it was found that 39.8% of the teeth had a single root; 58.6% had two roots; and three-rooted teeth accounted for the lowest proportion (1.6%). Vertucci's Type IV canal configuration was the most common (57.8%), followed by Type II (32.8%) [1].

In the past, the morphology of maxillary first premolar root canals was studied using various methods, such as examining extracted teeth, clearing techniques, and periapical radiographs. Recently, CBCT has emerged as a valuable technique that provides accurate three-dimensional images of both the internal and external dental anatomy.

To achieve optimal treatment outcomes for patients and help clinicians gain a more comprehensive understanding of root canal morphology - as well as better orienting the treatment process - we conducted the study: "A cone-beam

computed tomography - based survey of the root canal morphology of maxillary first premolar".

2. SUBJECTS AND METHODS

2.1. Study subjects

The study was conducted on extracted permanent MFP that met the following criteria: fully formed apices, intact crowns (no carious lesions, no large fractures, no restorations, no previous endodontic treatment, no root resorption, no root caries, and no root cracks or fractures).

2.2. Methods

2.2.1. Study design

Descriptive observational study.

2.2.2. Sample size

The study sample consisted of 63 MFP selected using a convenience sampling method.

The sample size was calculated using Cochran's formula for estimating a proportion:

$$n = \frac{Z_{(1-\alpha/2)^2} \times p(1-p)}{d^2}$$

where n is the minimum required sample size; $Z_{(1-\alpha/2)}$ is the standard normal deviate corresponding to a 95% confidence level (1.96); p is the prevalence of maxillary first premolars with three root canals (3.9%) according to the study by Ha Ngoc Chieu et al. [7]; and d is the desired margin of error, set at 0.05. Based on this formula, the minimum required sample size was calculated to be 58 teeth.

2.2.3. Study Procedure

Step 1: Sample Preparation

Tooth cleaning and preservation process: Extracted teeth meeting the inclusion criteria were immersed in hydrogen peroxide solution for 24 hours to disinfect and remove debris and soft tissue remnants.

After cleaning, the teeth were stored in 0.9% NaCl solution at room temperature. Once the required number of samples was collected, the study proceeded. Each tooth was labeled with a code number for data recording.

Step 2: Sample Preparation and Cone-Beam Computed Tomography (CBCT) Imaging

- Sample fixation: Alginate was mixed in the proper ratio and poured into a plastic mold with a flat bottom. Once the alginate had partially set, a guiding rod was placed perpendicular to the base of the mold. Teeth were then arranged in the mold to resemble the natural dental arch. Each tooth was positioned with its long axis parallel to the orientation rod, immersed in the anatomical cervical line. The buccal surface of each tooth faced outward, and the mesial surface faced the midline.

- Sample holder placement: The sample mold was positioned to lie within the CBCT machine's X-ray beam. The sample base was secured to the holder using adhesive tape. The height of the sample holder and base was adjusted to match the chin rest position used for patient imaging. The dental arch mold was inserted so that the buccal cusps of the MFP were aligned with the bite stick. The sample mold and holder were adjusted to ensure parallel alignment.

- Imaging: CBCT scans were performed using the Vatech Pax-I 3D machine according to the manufacturer's instructions. The scans were taken by an experienced radiographic technician.

+ Note: The position of the tripod stand and sample mold was not changed between scans.

Step 3: Evaluation of Root Canal Morphology and Curvature

- Image Processing and Analysis: The acquired images were processed and analyzed using Blue Sky Plan 4 software.

- Assessment of the number and morphology of root canals:

+ Teeth and areas of interest were selected with slice intervals of 0.1 mm. To avoid confusion and omission, the teeth were evaluated from left to right, starting from the cusp tip of each tooth.

+ Each tooth was examined in three planes - sagittal, axial, and coronal—to assess the root canal system: number of roots, number of root canals, root canal morphology according to Vertucci's classification, and number of apical foramina.

- Assessment of root canal anatomy based on Vertucci's 1984 classification [2]:

+ Type I: A single canal from the pulp chamber to the apex.

+ Type II: Two canals leave the pulp chamber and merge into one before exiting at a single apical foramen.

+ Type III: One canal leaves the chamber, divides into two within the root, and then merges into one before exiting.

+ Type IV: Two separate and distinct canals from chamber to apex with two apical foramina.

+ Type V: One canal leaves the chamber and divides into two separate canals with two separate apical foramina.

+ Type VI: Two canals leave the chamber, merge in the body of the root, and then divide again into two before exiting.

+ Type VII: One canal leaves the chamber, divides and rejoins within the root, and then redivides before exiting with two apical foramina.

+ Type VIII: Three separate and distinct canals from chamber to apex with three apical foramina.

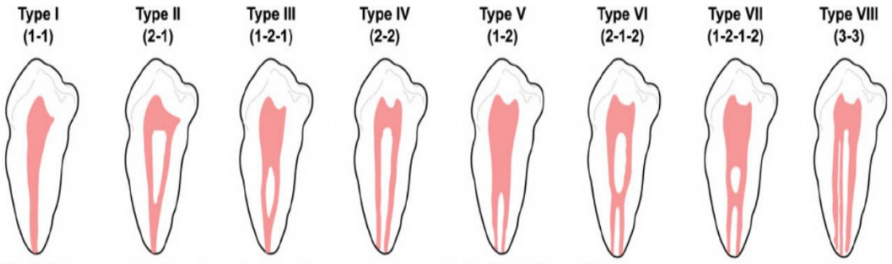

Figure 1. Root canal morphology types according to Vertucci (1984) [2]

- Assessment of Root Canal Curvature

+ Curvature: The canal curvature was measured using Schneider's method and classified according to Schneider (1971) [3].

+ Schneider measured the canal curvature by calculating the acute angle formed between the long axis of the canal (a) and a line drawn from the apical foramen to the point where the canal begins to curve (b) on the radiographic image.

+ Canal curvature was evaluated in both the mesiodistal and buccolingual directions.

+ Two slices (one in the buccolingual and one in the mesiodistal direction) were selected to visualize the canal clearly. The curvature of each canal was measured in both directions.

+ The angle measuring tool on the software toolbar was used to assess canal curvature.

+ The tool required selecting three points: the first point at the apical foramen, the second at the point where the canal starts to curve, and the third on the long axis of the canal. Subtracting the measured angle from 180° yielded the curvature angle. The canals were then classified into three groups:

- Type I: Straight canal (≤ 5°)
- Type II: Moderately curved canal (5° - 25°)
- Type III: Severely curved canal (> 25°)

All observations and measurements were performed by two pre-trained examiners. Any discrepancies were resolved through discussion to reach a consensus. In cases of unresolvable disagreement, the tooth would be excluded from the study sample; however, no such case occurred.

2.2.5. Statistical Data Processing

Statistical data were processed using SPSS version 20.0 and Microsoft Excel 2016, with descriptive statistics calculated as frequencies and percentages.

2.2.6. Ethical Approval

This study was approved by the Ethics Committee for Biomedical Research of Hue University of Medicine and Pharmacy (Approval No. H2024/595).

3. RESULTS

Table 1. Distribution of Maxillary First Premolars According to Number of Roots

Tooth position	One root	Two roots	Total
Left MFP	22 (66.7%)	11 (33.3%)	33
Right MFP	16 (53.3%)	14 (46.7%)	30
Total	38 (60.3%)	25 (39.7%)	63

- The majority (60.3%) of the MFP had one root, more than those with two roots (39.7%).
- For the left MFP, teeth with one root accounted for 66.7%, compared to 33.3% with two roots.
- For the right MFP, teeth with one root accounted for 53.3%, compared to 46.7% with two roots.
- No teeth with three roots were recorded in both groups.

Table 2. Distribution of the Number of Root Canals in Maxillary First Premolars

	One canal	Two canals	Three canals	Total
Left MFP	2 (6.1%)	31 (93.9%)	0	33
Right MFP	3 (10%)	25 (83.3%)	2 (6.7%)	30
Total	5 (7.9%)	56 (88.9%)	2 (3.2%)	63

- For the left MFP, teeth with two root canals accounted for 93.9%, while those with one root canal accounted for 6.1%. No teeth with three root canals were recorded in this group.

- For the right MFP, the proportions of teeth with one, two, and three root canals were 10%, 83.3%, and 6.7%, respectively.

Table 3. Classification of Root Canal Morphology of Maxillary First Premolars According to Vertucci

	Maxillary First Premolars		Total
	One root	Two roots	
Type I	5 (13.2%)	48 (96%)	53 (60.2%)
Type II	8 (21%)	0	8 (9.1%)
Type III	14 (36.8%)	0	14 (15.9%)
Type IV	5 (13.2%)	0	5 (5.7%)
Type V	5 (13.2%)	2 (4%)	7 (8%)
Type VI	0	0	0
Type VII	1 (2.6%)	0	1 (1.1%)
Type VIII	0	0	0
Total	38	50	88

- Type I was the most prevalent (60.2%), followed by type III (15.9%) and type II (9.1%).

- In the group of MFP with one root, 6 out of 8 Vertucci root canal morphology types were observed, including types I, II, III, IV, V, and VII.

- In the group of MFP with two roots, only 2 out of 8 Vertucci types were observed, including types I and V, with respective proportions of 96% and 4%. No type II, III, IV, VI, VII, or VIII root canals were recorded.

Table 4. Distribution of Root Canal Curvatures of Maxillary First Premolars in Buccolingual and Mesiodistal Directions

	Straight canal	Moderately curved canal	Severely curved canal	Total	Mean curvature
Buccolingual direction	36 (29.3%)	64 (52.1%)	23 (18.6%)	123 (100%)	15.63° ± 10.95°
Mesiodistal direction	51 (41.4%)	68 (55.3%)	4(3.3%)	123 (100%)	9.08° ± 7.01°

- In the buccolingual direction**,** most of the canals were moderately curved, accounting for 52.1%; followed by straight canals at 29.3%; and severely curved canals at 18.6%. The mean canal curvature was 15.63° ± 10.95°.

- In the mesiodistal direction**,** most of the canals were also moderately curved, accounting for 55.3%; followed by straight canals at 41.4%; and severely curved canals at 3.3%. The mean canal curvature was 9.08° ± 7.01°.

- The difference was statistically significant ($p < 0.01$).

4. DISCUSSION

- Regarding the number of roots:

In our study of 63 maxillary first premolars, single-rooted teeth accounted for a higher proportion (60.3%), while double-rooted teeth accounted for 39.7%. No cases of three-rooted teeth were recorded. This result is consistent with the study by Hà Ngọc Chiều (2023), which also did not report the presence of three-rooted teeth. However, compared to the study by Loh HS, the frequency of single-rooted teeth in that research (49.4%) was lower than that observed in our study. Conversely, the proportion of two-rooted teeth was higher (50.6%) [4]. Some other studies have recorded the presence of maxillary first premolars with three roots, but such findings are uncommon. For example, Al-Zubaidi reported that 1.6% of maxillary first premolars had three roots [1]. These differences may be explained by variations in anthropological characteristics, assessment methods, and sample sizes across studies.

- Regarding the number of root canals:

The number of root canals in MFP exhibited a distinctly different distribution. Teeth with a single root canal accounted for 7.9% (5 teeth), while the majority of the teeth in the study had two root canals, representing 88.9% (56 teeth). Cases with three root canals were rare, comprising only 3.2% (2 teeth). These results are entirely consistent with previous studies, further reinforcing the consensus on the anatomical features and root canal morphology of maxillary first premolars. Bellizzi R (1985) conducted a study in the Saudi subpopulation and found that 6.2% had one canal, 90.5% had two canals, and 3.3% had three canals [5]. These results are nearly identical to our findings, especially in the prevalence of two canals, the most common anatomical configuration of the MFP. However, clinicians should carefully consider this variation to avoid missing a third root and canal during endodontic procedures.

- Regarding root canal morphology according to Vertucci's classification (1984):

Type I was the most prevalent (60.2%), followed by type III (15.9%) and type II (9.1%). One-rooted maxillary first premolars had a more variable canal configuration: 36.8% had type III canal configuration, whereas the frequency of type II (21%) was lower, and the remaining types (I, IV, V, and VII) accounted for 42.2%. Amongst one-rooted teeth, 73.6% had a complex canal system with bifurcation and/or combination (types II, III, V, and VII).

The main canal configuration amongst two-rooted teeth was type I (96%). The study by YY Tian (2013) on 300 MFP in Chinese individuals using CBCT imaging showed that, in the single-root group, type II canals accounted for 35%, followed by type IV (29%), type I (22%), type III (7%), type V (4%), type VI (3%), and type VII (1%). In the two-rooted group, our findings were similar, with type I accounting for 96% and type V for 4% [6]. Differences in canal type distribution between studies may be attributed to ethnicity and sample size variations. YY Tian's study was conducted in China with a larger sample size (300 MFP), while our research was focused on the Hue city region in Vietnam with a smaller sample size (38 MFP). Since the late 19th century, dental anatomists and anthropologists have described dental morphology and noted its association with racial or ethnic background. Researchers have observed that the number and morphology of root canals can vary significantly across different populations (Walker 1988, Melton 1991, Haddad 1999…).

- Evaluation of root canal curvature:

Root canal curvature in MFP's buccolingual and mesiodistal directions was recorded in Tables 3 and 4. The findings showed that moderately curved canals were the most common in both directions, followed by straight canals, while severely curved canals were the least common. Similarly, in the study by Hà Ngọc Chiều et al (2023), conducted on 51 MFP in Vietnamese individuals, moderately curved canals also had the highest prevalence at 86.9%, followed by straight canals at 7.1% and severely curved canals at 6,1% (buccolingual direction). The average curvature was 14.12° ± 7.02° [7]. The study by Xin Qiao (2021), which analysed 125 MFP in a Chinese population using CBCT, yielded similar findings regarding the distribution of canal curvature. The mean curvature was 9.42° ± 7.16° in the buccolingual direction and 7.73° ± 5.30° in the mesiodistal direction [8]. The mean canal curvatures in both the studies by Xin Qiao (2021) and Hà Ngọc Chiều (2023) were lower than in our study, with the difference being more pronounced in the findings of Xin Qiao.

The differences in our findings on MFP compared to the study by Xin Qiao (2021) may stem from several important factors. Firstly, racial and genetic differences may significantly influence the results. Different ethnic groups can lead to biological variations. Moreover, discrepancies in research methodology between the two groups may also contribute. Factors such as study design, data collection procedures, and analytical techniques may differ and affect the final outcomes. For instance, using different research tools may result in inconsistent data. The subjectivity in sample interpretation and result analysis could also contribute to these differences. Even when standardised technical methods are used, the way observers interpret data can be influenced by their personal perspectives and professional experience.

The MFP typically exhibits a root canal anatomy characterised by a wide oval shape in the coronal half, which then transitions rapidly into a curved configuration. In the apical third, the canal is usually narrow and may reverse direction, creating a sharp curvature. Besides the complexity of the canal system, the MFP is also known to have complicated curved canals in S or L shapes [7].

A limitation of this study was the sample collection process, as extracted teeth were used, resulting in a relatively small sample size. An insufficient sample size may reduce the accuracy in reflecting morphological features or identifying the smallest variations in teeth. This limitation also weakens statistical power, making it more difficult to detect statistically significant differences.

5. CONCLUSION

The morphology and curvature of the root canals in maxillary first premolars are highly variable, adding to the complexity of endodontic treatment. CBCT plays an essential role in identifying root canal morphology and curvature. Therefore, clinicians need to clearly understand the root canal system characteristics to improve the success rate of endodontic therapy.

Conflict of Interest: The authors declare no conflicts of interest regarding the research, authorship, and publication of this article.

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