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Apical Foramen Positional Variability and Its Minimal Distance from the Anatomical Apex in Premolars

A CBCT-Based Analytic Study

Maysaloon S. Saeed[1]

[1]*College of Medicine, University of Duhok, Iraq*

Abstract

Objectives: This study aimed to determine the position of the AF in relation to the root surfaces of human permanent premolar teeth in the region using cone-beam computed tomography (CBCT) imaging.

Materials and Methods: A descriptive cross-sectional study was conducted using CBCT images of 206 patients from the Iraqi Kurdistan region. Multiplanar CBCT scans were analyzed to determine the AF position relative to the root canal surface of the premolars. The mean distance between the AF and anatomical apex was measured and compared between quadrants and sexes. Statistical analysis was performed using Fisher's chi-square and t-tests, with a significance threshold set at p = 0.05.

Results: The central AF location was the most prevalent in premolars, followed by distal and mesial locations. However, the central and mesial positions were the most prevalent in the mandibular right second premolar. The mean AF-anatomic apex distance for the first premolars on the right side was 0.6205 mm. For the second premolars, the distances were 0.6205 mm in males and 0.5854 mm in females. No significant variations were observed based on the parameters outlined in the methodology.

Conclusion: The apical foramen was predominantly located centrally in the premolars, followed by the distal position. To enhance the success rate of root canal therapy, a minimum of 1 mm safety margin from the anatomic apex in premolars is recommended to improve treatment outcomes.

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Email: maysaloonshaman@gmail.com

Introduction

Complete cleaning and shaping of the root canals, along with a three-dimensional sealed root canal system (RCS) filling, are considered the most essential and widely practiced endodontic procedures worldwide [1]. Accurate morphological knowledge of the apical region is crucial, as instrumentation and filling of root canals are based to a significant extent on this information [2,3]. Understanding the apical area and morphology of the tooth root canal is a complex and critical aspect that clinical practitioners must consider when making decisions during endodontic treatment [3]. Numerous factors contribute to the variations found in studies on root canals and apical foramina (AF), including ethnicity, age, and sex. A successful endodontic procedure commences with a comprehensive assessment of the root canals and their anatomical variability [1-3].

Cone beam computed tomography (CBCT) is a valuable 3D orthogonal imaging tool for the maxillofacial skeleton and its internal structures. It utilizes a lower dose of radiation compared to conventional CT [4] and has been demonstrated to be more accurate than digital X-rays in identifying RCS. It precisely determines root canal morphology and AF location in relation to the root surfaces, which requires exact identification during access preparation, and reduces errors and failures in endodontic treatments by eliminating the issue of root superimposition from neighboring anatomical structures. The precise assessment of the AF distance has proven to be a highly beneficial tool in clinical dental practice and must be taken into consideration during root canal procedures. Complete debridement of these regions through mechanical instrumentation is impractical, and necrotic tissue remnants and microorganisms in the apical portion affect post-treatment outcomes [5]. CBCT images provide insight into the spatial resolution of anatomical variations and enable clinicians to visualize any necessary access modifications for treatment. From an anatomical and clinical perspective, the narrowest part of the root canal is the apical constriction or minor foramen. From this point, the canal gradually widens and terminates at the AF or major foramen. The cementodentinal junction is the histological landmark where the pulp ends and the periodontal ligament begins. It is expected to be located at the apical constriction, but its position can be irregular (Figure 1). The AF is the main opening to the apical portion of the root canal and constitutes the site where endodontic filling is performed [6]. In numerous instances, the terms "apex" and "AF" have been used interchangeably. The anatomical apex refers to the anatomical terminus of the root, as observed on radiography. In contrast, the AF is the main opening of the root canal in relation to the apex. The AF can be in mesial, distal, buccal, and lingual positions [7]. Recent studies have reported that in over 60% of canals, the AF is not located at the apex. Furthermore, the distance between the AF and radiographic apex can vary by up to 3 mm [8]. This apical deviation of the foramen is attributed to aging and cementum deposition. Additionally, the degree of deviation varied according to tooth type. Over the past three decades, various methods, such as clearing, modeling, and histologic and radiographic techniques, have been employed to assess the structure of the root canal. Recently, the application of CBCT has increased significantly. CBCT can provide 3D observations of anatomical structures and pathological conditions [9].

Material and Methods

The study protocol was approved by the Institutional Ethics Committee of the College of Dentistry, University of Duhok, Kurdistan Region, Iraq. The case records of 696 premolars from 206 patients (102 males and 104 females) who underwent CBCT scans between November 2021 and September 2024 were retrieved from the databases of three private dental imaging centers located in three governorates in the Kurdistan Region of Iraq. In this retrospective study, CBCT images of permanent premolar teeth from Duhok, Erbil, and Sulaymaniyah were included. To obtain a representative sample of the Kurdish population in this region, the main public dental clinic in the capital of these governorates was selected as the data collection setting. CBCT images were obtained using a NewTom Giano (Verona, Italy) CBCT system. Two types of software were used for image analysis and evaluation: Villa 3D Planner (Italy) for treatment planning and Anatomage I In Vivo Dental Viewer (Italy) for 3D visualization.

The machines were operated at 90 kVp and 10mA. The field of view was 8 × 8 cm, and the voxel size was 75 µm. Images in sections of 0.5 mm with intervals of 1 mm in the coronal and sagittal planes in terms of the 10 mm were prepared using NNT software for appropriate examination of the teeth. In the axial view, only the lower one-third of the roots was investigated, and the roots were examined horizontally (parallel to the occlusal surface) so that they passed through the upper sections of the teeth and were parallel to the sagittal plane. In the first mode, images were cross-sectional or in the sagittal view, enabling examination of the buccal and lingual surfaces. In the second mode, the coronal view of the mesiodistal teeth was investigated. It is noteworthy that the AF may be positioned mesiodistally or buccolingually relative to the outer surface of the tooth. Consequently, in both the coronal and sagittal views, the distance between the AF and the perpendicular and tangential lines on the radiographic apex (in 10 mm) was measured using NNT software. Furthermore, the distance from the AF to the anatomic apex was observed in the axial, sagittal, and coronal planes. Healthy teeth with no previous endodontic treatments, restorations, or root resorption were chosen as inclusion criteria. Teeth with open apices (not fully formed), root resorption, or calcification (partial or complete radiographic obliteration of the pulp chamber and root canals), as well as teeth with previous endodontic treatment, were excluded. Healthy teeth with no prior treatment or restoration were included. The images were evaluated, and the data were captured using Microsoft Excel 2016. The data were subsequently exported to the Statistical Package for the Social Sciences (SPSS version 26, IBM Corp., IL, and USA).

Chi-square test was used to compare proportions. Fisher's exact test was used instead of the chi-square test when the expected value of more than 20% of the cells of the table was <5. Kolmogorov–Smirnov test, unpaired "t", and paired "t" tests were used for sample comparison. The level of significance was set at 0.05. The results were presented using SPSS software, and the outcomes were represented in the form of tables and bar charts.

Results

Six hundred and ninety-six premolars that met the specific inclusion criteria and were from individuals between the ages of 18 and 60 were included in this study. The sample comprised 102 males (49.51%) and 104 females (50.49%), as presented in (Table 1).

Table 1. Prevalence of AF locations in maxillary premolar teeth in both genders.

Tooth Type	Location	Male (%)	Female (%)	Total (%)
Right UFPT	Central	58.3	51.1	54.7
	Distal	37.5	42.2	39.8
	Mesial	4.2	6.7	5.5
Right USPT	Central	69.2	66.7	68.0
	Distal	28.2	31.1	29.6
	Mesial	2.6	2.2	2.4

Left UFPT	Central	53.2	47.9	50.5
	Distal	44.7	52.1	48.4
	Mesial	2.1	0.0	1.1
Left USPT	Central	54.1	63.4	58.7
	Distal	40.5	29.3	34.9
	Mesial	5.4	7.3	6.4

For the right maxillary first premolar teeth (R.UFPT), the majority of apical foramina in both males and females were centrally located, accounting for 58.3% and 51.1%, respectively. The second most prevalent location was distal in both males and females, with percentages of 37.5% and 42.2%, respectively. The least common location was mesial, occurring in 4.2% of males and 6.7% of females. For the left maxillary first premolar teeth (L.UFPT), the distribution of the apical foramina was relatively similar between males and females. The most frequent location was central, accounting for 53.2% in males and 47.9% in females. The second most common location was distal, observed in 44.7% of males and 52.1% of females. A minimal percentage of apical foramina was mesially located in males (2.1%). For the right maxillary second premolar teeth (R.USPT), the majority of apical foramina in both males and females were centrally positioned, occurring in 69.2% and 66.7% of cases, respectively. The second most prevalent location was distal, recorded in 28.2% of males and 31.1% of females. A minimal percentage of apical foramina was mesially located in both males and females (2.6% and 2.2%, respectively). For the left maxillary second premolar teeth (L.USPT), the majority of apical foramina were centrally positioned, observed in 54.1% of males and 63.4% of females. A smaller percentage was distally located in both males and females (40.5% and 29.3%, respectively), while the mesial location was the least common, occurring in 5.4% of males and 7.3% of females (Table 2).

[refer to the last page for Table 2]

By Fisher's exact test. **By Chi-square test. LFPT: Lower First Premolar Teeth; LSPT: Lower Second Premolar Teeth. There is a statistically significant difference in the location of apical foramina between males and females, for the location of apical foramina in the left first premolar teeth. The p-value for this location is 0.067, which is marginally significant at the 0.05 level.

For the right mandibular first premolar teeth (R.LFPT), the majority of apical foramina were centrally located in both males and females, comprising 58.1% and 53.5%, respectively. The second most prevalent location was the distal, occurring in 30.2% of males and 23.3% of females. The least frequent location was mesial, observed in 11.6% of males and 23.3% of females. For the left mandibular first premolar teeth (L.LFPT), the majority of apical foramina were centrally positioned, recorded in 48.8% of males and 72.7% of females. A smaller proportion was distally located in both males and females (29.3% and 18.2%, respectively), while the least common location was mesial in both males and females (22% and 9.1%, respectively). The majority of apical foramina in the right mandibular second premolar (R.LSPT) were centrally situated in both males and females (65% and 58%, respectively). The second most prevalent location was mesial in both males and females (20% and 26%, respectively), while the least common location was distal (15% and 16%, respectively). For the left mandibular second premolar teeth (L.LSPT), the central location was the most prevalent in both males and females, occurring in 75.7% and 68.8% of the cases, respectively. The second most common location was distal, observed in 16.2% of males and 22.9% of females, while the mesial location exhibited the lowest percentage in both males and females (8.1% and 8.3%, respectively).

The average (±standard deviation [SD]) distance from the AF to the anatomic apex of the first and second premolars in males was 0.61–0.62 mm with ± SD of 0.142 and p=0.54 in the right and left quadrants, and for females was 0.58–0.60 mm with ± SD of 0.129 and p=0.22 for both right and left quadrants. According to the t-test, no statistically significant difference was observed in the distance between the AF and the anatomic apex of the first and second premolars in both the right and left quadrants (p = 0.857). A comparison of the mean distance between the AF and anatomic apex of the first and second premolars between the right and left sides in both males and females is presented in Tables 3 and 4.

Table 3. Comparison of mean distance between apical foramen and anatomic apex of right first premolar and right second premolar between males and females (mm).

Age group	Mean ± Standard Devition		p-value
	Males	Females	
First premolars	0.62±0.14	0.59±0.12	0.544
Second premolars	0.62±0.14	0.58±0.11	0.204

Table 4. Comparison of mean distance between apical foramen and anatomic apex of left first premolar and left second premolar between males and females.

Tooth Type	Right (Mean ± SD)	Left (Mean ± SD)	p-value
First premolars	0.62 ± 0.14	0.62 ± 0.14	0.86
Second premolars	0.6 ± 0.13	0.59 ± 0.12	0.28

Discussion

A comprehensive understanding of root anatomy and canal morphology is essential for the efficient execution of biomechanical cleaning and shaping, which is crucial for achieving predictable endodontic outcomes. However, variations in root canal morphology present clinical challenges that may result in unfavorable endodontic treatment outcomes. CBCT is an excellent ex vivo and in vivo method for evaluating external and internal root morphology compared with conventional 2D radiography [6-9].

In the present study on the maxillary first premolars (R.UFPT and L.UFPT), the most prevalent deviation in the location of the apical foramina in males and females was central (52.6%), followed by distal (44.1%) and mesial (3.3%). Variations were observed between quadrants and genders for these teeth. No cases were recorded for females in the mesial location on the left side, and the distal location was more prevalent on the left side for both sexes than that on the right side. Similar results were also reported in a recent study conducted on the Brazilian population [9], which indicated that the most common AF location in the maxillary first premolars (39.9%) was central. In the present study, the most common location for the maxillary second right and left premolar teeth (R.USPT, L.USPT) was the central position, accounting for 63.4% of cases. This was followed by the distal (32.2 %) and mesial (4.4 %) locations. Almost all AF locations were consistent in both quadrants and both sexes, except for the distal location in the left upper second premolar tooth (L.USPT), which was more prevalent in males than in females. A similar result was reported in a study conducted on a subpopulation in

Yemen, which also indicated that the center was the most frequently observed location for the second upper premolars [10]. In a study conducted in Brazil [9], it was found that the most common location for AF among the second upper premolars was central, accounting for 57.4%. In the present study, the location of the AF for the lower first right and left premolars (R.LFPT, L.LFPT) in both sexes was predominantly in the center (58.3%), followed by distal (25.1%) and mesial (16.6%). In the R.LFPT, the distal and central locations were similar between the sexes, but the mesial location was more prevalent in females than in males. However, in the left LFPT, the central location was more prevalent in females than in males, whereas mesial and distal locations were more prevalent in males than in females. These results were corroborated by other studies conducted in the Kuwaiti population [11] and Brazil [9], where the central location was found to be the most common among the sample studies of the mandibular first premolars. However, a specific subgroup within the Iranian population contradicted the present findings. They reported that the most common location for the apical foramina among mandibular first premolars was the distal [12]. Significant variations were observed among different populations, which may be attributed to factors such as sex, sample size, ancestry, data collection methods, and study design [13].

For the mandibular right and left second premolars (R.LSPT, L.LSPT) in our study, both sexes exhibited a predominant central location, accounting for 66.9% of the cases. This was followed by the distal (17.5 %) and mesial (15.6 %) locations. The central location in both quadrants was more prevalent in males than females. On the right side, the mesial and distal locations were approximately equivalent in both sexes. Regarding the mesial location, both sexes demonstrated similar percentages on the left side. However, in females, the distal location was more prevalent compared to males. A comparable finding was observed in the Yemeni subpopulation, where the center was reported as the most frequent location [10]. Furthermore, a similar observation was noted in the Brazilian population [9], where the most common location was central, accounting for 42.85% and 50.98% of cases, respectively. The present study determined that the average distance from the AF to the anatomic apex of the first and second premolars in males and females was 0.61–0.62 mm (± SD 0.142, p=0.54) and 0.58–0.60 mm (± SD 0.129, p=0.22), respectively. The results of the apex-to-foramen distance measurements in this study were in close concordance with previous findings. Burch and Hulen [14] reported the AF distance to be 0.59 mm in a study of all tooth types, and a study conducted by Arora and Tewari [15] reported the distance between the AF to be in the range of 0.052–2.91 mm. A similar study conducted by Naseri et al. [16] revealed that the mean distance between AF was found to be in the range of 0.3–0.7 mm, which is consistent with the values calculated in the present study. In another study by Martos et al. [17], which was conducted using a stereomicroscope on mandibular molars of a Brazilian population, the mean distance from the apex to the AF was 0.80 (±0.54) mm. Akhlaghi et al. [18] in an ex vivo study on a local Iranian population using India ink on mandibular second molars demonstrated that the mean (±SD) distance from the apex of the AF was 0.30–0.47 mm. India ink was used in this study, which renders the evaluation method distinct from that of the present study. A study conducted by Cheung et al. [19] indicated that the average distance of the AF from the anatomic apex at the C-shaped mandibular second molars in a Chinese population is 0.79–0.89 mm, as determined using micro-CT. These minor variations are, to some extent, attributable to the varying methods employed to measure the distance as well as to the different reference points that were likely utilized. Moreover, the other reason for this difference may be due to variations among diverse populations.

In a recent study conducted by Reda et al. in 2022, they found that one AF was the most common among all the premolars and that the mean distance of AF from the anatomic apex recorded between 3.40 ± 1.80 and 5.12 ± 1.98 [20]. A study conducted among the Chinese population by Yang et al. reported an average distance of 1–2 mm within their study sample [21]. This variation in the AF distance suggests a potential racial predilection. In a recent comparable study conducted by Arsari et al, in 2021 on the anterior maxillary teeth, they observed that the mean apical foramen distance to the anatomical apex in anterior maxillary teeth in males and females was 0.64±0.36 and 0.58±0.32 mm, respectively (p=0.003). This difference was statistically significant according to their statistical indices ,while the mean distance between apical foramen and anatomical apex in central incisor and canine teeth was not significant in males and females (P=0.06, and p=0.25, respectively), but they observed a significant difference concerning the mean interval between apical foramen and lateral apex in lateral incisor teeth of men and women (P=0.02) [22]. In another study [23], mandibular premolars were compared and the mean length from the apical foramen to the apex was 0.59 mm and 0.47 mm, respectively. Meanwhile, the non-clinical and clinical mean lengths from the apical constriction to the apex were 0.75 mm and 0.73 mm, respectively. Nonetheless, no significant differences were detected between the apical constriction and the apex and apical foramen and apex [23].

Conclusions

Accurate evaluation of apical anatomy using CBCT is essential for performing root canal treatment. The most common location for the apical foramina of all premolar teeth was the central AF, followed by the distal. The distance between the AF and anatomic apex in the mandibular premolars of the Kurdistan population was approximately 1 mm. Therefore, the extent of obturation should be 1 mm short of the radiographic apex, and the root canal procedure should be terminated at this point.

Conflict of Interest

The authors have no conflicts of interest to declare.

Author Contributions

As the sole author of this manuscript, M.S. Saeed contributed to the conception, design, data collection, analysis, and interpretation of results. M.S. Saeed drafted the manuscript, approved the final version, and is responsible for all aspects of the work.

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Ethical Considerations

Before commencing the study, permission was obtained from the College of Dentistry at Duhok University. The official paper number was 917, dated 23/11/2021. Approval was also obtained from the Ethics Committee at the Directorate General of Health in Duhok Governorate. The official paper number was 4255 on October 20, 2020.

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Table 2. Prevalence of AF locations in mandibular premolar teeth for both genders.

Tooth Type	Location	Male No. (%)	Female No. (%)	Total No. (%)
Right LFPT	Central	50 (58.1)	46 (53.5)	96 (55.8)
	Distal	26 (30.2)	20 (23.3)	46 (26.6)
	Mesial	10 (11.6)	20 (23.3)	30 (17.6)
	Total	86 (100)	86 (100)	172 (100)
Right LSPT	Central	52 (65)	58 (58)	110 (61.5)
	Distal	12 (15)	16 (16)	28 (15.5)
	Mesial	16 (20)	26 (26)	42 (23)
	Total	80 (100)	100 (100)	180 (100)
Left LFPT	Central	40 (48.8)	64 (72.7)	104 (60.7)
	Distal	24 (29.3)	16 (18.2)	40 (23.7)
	Mesial	18 (22.0)	8 (9.1)	26 (15.6)
	Total	82 (100)	88 (100)	170 (100)
Left LSPT	Central	56 (75.7)	66 (68.8)	122 (72.3)
	Distal	12 (16.2)	22 (22.9)	34 (19.5)
	Mesial	6 (8.1)	8 (8.3)	14 (8.2)
	Total	74 (100)	96 (100)	170 (100)