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Microcomputed tomography (micro-CT) analysis of apical mandibular premolar in relation to clinical sign presentation: An in vitro study

Samsudin Nurulaqmar Iwani [a,b], Marlena Kamaruzaman [a,*], Afiq Azizi Jawami [a]

[a] Centre of Comprehensive Care Studies, Faculty of Dentistry, Universiti Teknologi MARA, Sg Buloh, Selangor, Malaysia
[b] Conservative Dentistry Unit, School of Dental Sciences, Health Campus, Universiti Sains Malaysia, Kubang Kerian, Kota Bharu 16150, Kelantan, Malaysia

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ABSTRACT

Introduction: Variations in anatomic apex and apical foramina of root canals are common in different teeth types. The sophisticated 3D micro-CT aids researchers in investigating the apical morphology, such as the apical foramen (AF) and constriction (AC).
Objectives: To measure the length between the foramen and the apex and the physiological length to the apex, in lower premolar teeth. Furthermore, a measurement was conducted on the average length from the foramen to the apex of the lower premolar teeth with respect to the presence of clinical and non-clinical signs.
Methods: A total of 80 lower premolar teeth were selected based on the inclusion criteria. All samples were scanned using micro-CT ZEISS X-Radia (17 μm), and the datasets were analysed. The root canal AF and AC were reconstructed using Drishti software (V3.0) by utilising a 4-digit system code in millimetres (mm).
Results: More than half of the lower premolars (n = 47, 58.8 %) demonstrated a clinical signs presentation, while the rest had a non-clinical sign (n = 33, 41.3 %). There was a significant difference (p = 0.013) between the non-clinical and clinical groups in the mean length from the apical foramen to the apex (AFA) at 0.59 mm and 0.47 mm, respectively. Meanwhile, the non-clinical and clinical mean length from apical constriction to apex (ACA) were 0.75 mm and 0.73 mm, and the mean length from AF to AC (AFC) was 0.48 mm and 0.53 mm, respectively. Nonetheless, no significant differences were detected between the ACA and AFC of non-clinical and clinical groups.
Conclusion: The clinical signs presentation observed in lower premolars mainly affected the apical morphology, particularly the position and length of the root AF, and less so the AC position and length. Therefore, the information is useful for clinical purposes.

1. Introduction

Irregularities in the complex the root canal anatomy are common in endodontic practice, requiring care and thoroughness, from a precise diagnosis to establishing the best treatment plan. Detailed knowledge of the complex architecture of the root canal are important for successful endodontic treatment. Furthermore, understanding the typical root canal structure and deviations from the norm is the foundation for adequate debridement, biomechanical preparation, and full obturation in three dimensions (Lu et al., 2006).

Given that conventional, two-dimensional images cannot capture the complex architecture of the root canal, researchers have developed three-dimensional (3D) radiographs for this purpose, such as those produced by the CBCT or micro-CT machines. Investigations on the variance of root canal anatomy have been published to help dentists and endodontists treat complex root canal anatomy (Kim et al., 2013; Versiani et al., 2018; Xu et al., 2020). Micro-CT used in endodontics enables the 3D evaluation of the variation in the complex architecture of the root canal, C-shaped canals, root canal preparation, and obturation quality, thus, enabling the detection of failure zones and voids (Keleş et al., 2014; Peters & Paqué, 2011; Thanaruengrong et al., 2021).

The inability to effectively treat the root canal is the leading cause of failures in endodontic treatment (Vicente et al., 2004). The anatomy and structure of the complex architecture of the root canal of the lower first premolars display variations across diverse ethnic groups. Earlier studies have reported that numerous lower first premolars have multiple root

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* Corresponding author.
E-mail addresses: iwani_1986@yahoo.com, 2021277048@student.uitm.edu.my (S. Nurulaqmar Iwani), marlena@uitm.edu.my (M. Kamaruzaman).

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canals (Cheung et al., 2007; H. Yang et al., 2013). Moreover, the occurrence of lower first premolars with numerous canals ranges from 11.53 % to 46 % (Abdullah et al., 2013; Karobari et al., 2022).

The current study aims to analyze the complex architecture of the root canal in lower premolars, in which previous studies observed for various reasons, such as caries, orthodontics, or periodontal diverse variation in root canal configuration and occurrence of multiple canal and root(Karobari et al., 2023; Vertucci, 1984; L. Yang et al., 2022) and they are thought to be the most difficult to endodontically treat (Cleghorn BM, Christie WH, 2007). By using three-dimensional micro- CT, the distance between the main apical foramen (AF) and lower premolar teeth' physiological and anatomical apex was recorded. The mean foramen to apex distance of the lower premolar teeth was measured in relation to clinical and non-clinical signs presentation.

2. Materials and methods

This study was conducted at Faculty of Dentistry Universiti Teknologi MARA (UiTM), Malaysia and was approved by the ethics committee of Universiti Teknologi MARA (UiTM), Malaysia with references 600-TNCPI (5/1/6); REC/12/2021(MR 930). The study was performed in accordance with the 1964 Declaration of Helsinki and the later amendments. Written informed consent was obtained from all participants prior to conducting this study.

2.1. Samples selection

This study included a sample size of 80 lower premolars that had been previously extracted due to disease. The patient's demographic data, clinical history, and clinical signs and symptoms before extraction, include caries, pain on palpation or percussion, intraoral swelling (periapical abscess or periodontal abscess), periodontal disease such as tooth mobility, and pocket depth greater than 3 mm. The pre-operative conventional two-dimensional periapical radiographs were taken before extraction to access the radiographic findings, including the *peri*-radicular disease. The inclusion criteria of the extracted tooth include 1) patient age 13 years and above, 2) permanent lower premolar tooth with single, straight or curved root, and 3) tooth with a mature apex. Meanwhile, the exclusion criteria were teeth with signs of root caries, root and crown fracture, and immature apex formation.

2.2. Samples preparation

The samples were cleaned of debris and calculus using the ultrasonic scaler (DTE D5 Piezo Scaler,Woodpecker Dental, China) before being placed in labelled individual plastic containers and soaked in 2 % chlorhexidine solution. The labelled samples were dried prior to the micro-CT scanning at the Geology Department, University Malaya using a ZEISS X-Radia 520 Versa Micro CT system (X-Radia 520 Versa, ZEISS, Germany) (detector: 135 mm, source: 64.5 mm, filter: LE1, voltage: 80.024 Kv, power: 7.0 W, exposure: 3.3 s, angles: 9.92°, objective 0.4 X with high-resolution pixel size of 17 μmm).

The datasets were reconstructed using Zeiss Reconstructor Scout and Scan system (XM Reconstructor, ZEISS, Germany) (14.0.160.46), and the file TXM (3D images) was transferred to 3D software, Drishti Software v3.0 (Ajay Limaye of ANU, Australia) to visualise the 3D images (Limaye, 2012). Then the.pxl files were imported into Drishti v3 for rendering and manipulation for the data collection. Finally, the samples were prepared according to the pilot study.

2.3. Data collection

Each sample in the present study generated 1016 3D images after being scanned using a micro-CT scanner with a high-quality image (17 μm pixels). Under the supervision of a professor from the University of Malaya's Geology Department, a micro-CT scanning professional and science officer performed the procedure.

The software (Drishti v3.0 by Ajay Limaye) will then be used to reconstruct and visualise the 3D images in TIFF/DICOM (TXM).

A single examiner (a postgraduate student) who was trained and calibrated by the supervisors made a preliminary evaluation of 10 % of samples at random, and the interpretation of the intraclass correlation coefficients (ICC) was > 0.70, indicating strong agreement.

The 3D images (TIFF/DICOM) were visualized using the Drishtiv3 software, and parameters were measured in duplicates and described using a 4-digit system code mm by an endodontology postgraduate student. All the parameters described in this study are as follows:

1. The root canal anatomy of lower first and second premolars.
2. The position and measurement of AF and apical constriction (AC) to the anatomical apex.
3. The mean differences between AF and AC at the anatomical apex in relation to clinical signs presentation

Figs. 1 and 2 illustrate the micro-CT images of all parameters in this research. The data collection is adapted from a previous study (Estrela et al., 2018) and the pilot study. The data were recorded and analysed using a statistical software programme (IBM SPSS 28, Chicago, Illinois, USA) for descriptive analysis (mean ± standard deviation). In addition, the independent *t*-test was used to compare the two groups,and the significance level was set at $p < 0.05$.

3. Results

Table 1 details the demographic and baseline characteristics of participants in the present study. The study sample comprised 80 teeth, of which 33 were selected for orthodontic reasons, while the remaining 47 showed signs and symptoms of caries, periodontal disease, or intraoral swelling include periodontal abscess or periapical abscess.

A total of 33 (41.3 %) lower premolars had a non-clinical sign presentation, while 47 (58.8 %) had a clinical sign presentation. There was a significant difference between the non-clinical and clinical groups ($p = 0.013$) in the mean length from the apical foramen to the apex (AFA), which was 0.59 mm and 0.47 mm, respectively. The mean length from the apical constriction to the apex (ACA) was 0.75 mm in the non-clinical and 0.73 mm in the clinical sign presentation, whereas the mean length from the AF to the AC (AFC) was 0.48 mm and 0.53 mm, respectively (see Table 2).

4. Discussion

4.1. Important of knowledge root canal morphology

The achievement of a favourable outcome in endodontic therapy is dependent upon a thorough understanding of the complex details of root canal. A comprehensive understanding of the anatomical features of human teeth is necessary in the context of endodontic therapy, which pertains to the manipulation of the internal composition of the tooth, including the precise localization of the AF and AC. The variability, complexity, and anatomical characteristics of root canal systems have been the subject of various studies throughout the years (Kim et al., 2013; Versiani et al., 2018). These studies have influenced clinical practice and contributed to knowledge advancement regarding root canal anatomy.

4.2. Measurement of the working length for successful endodontic treatment

The precise measurement of the working length is an important step in the process of endodontic treatment. Insufficient determination of the working length might lead to either a shortened or too extended obturation. The presence of a working length that is either too short or too

Fig. 1. Micro-CT image of mandibular premolars showed the root canal and apical configuration.

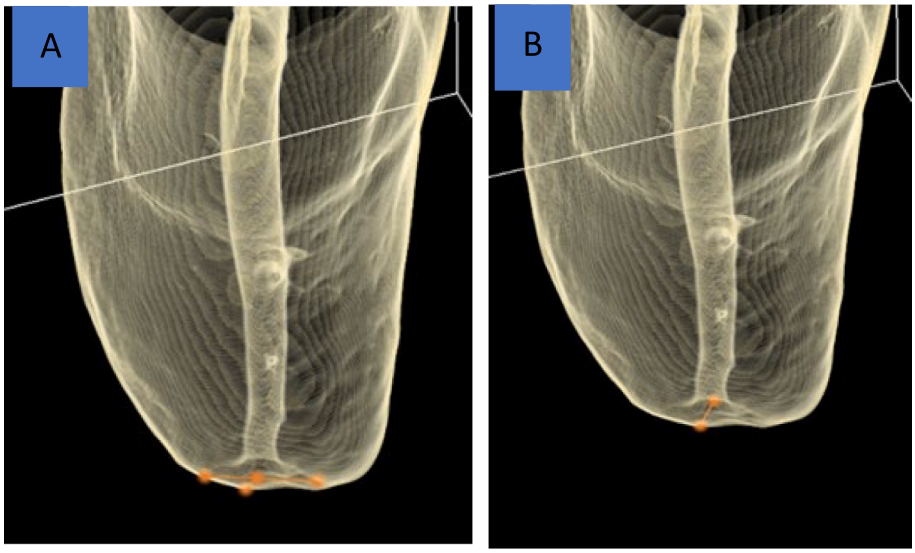

Fig. 2. Micro-CT images display the study's parameters.

Table 1
Distribution of socio-demographic data including clinical finding.

	Variables	Samples (n)	Percentage (%)
Gender	Male	29	36.30
	Female	51	63.70
Race	Malay	54	67.50
	Chinese	23	28.75
	Indian	2	2.5
	Others	1	1.25
Mandibular tooth type	First premolar	49	61.25
	Second premolar	31	38.75
Clinical findings	Orthodontic	33	41.25
	Caries		
	With swelling	13	16.25
	Without swelling	24	30
	Periodontal		
	With swelling	4	5.0
	Without swelling	6	7.5

long may lead to excessive instrumentation or obturation, respectively. Consequently, this can result in the retention of necrotic tissues inside the apical region.

Table 2
Descriptive statistics for samples with and without clinical sign.

Variables Sample Size		With Clinical n (%)	Without Clinical n (%)
		47 (58.8)	33 (41.2)
Gender	Male	19 (40.4)	10 (30.3)
	Female	28 (59.6)	23 (69.7)
Race	Malay	35 (74.5)	19 (57.6)
	Chinese	10 (21.3)	13 (39.4)
	Indian	1 (2.1)	1 (3.0)
	Other	1 (2.1)	0 (0.0)

4.3. Apical limit in endodontic: Apical foramen and apical constriction

Although, the precise working length's apical limit, a key anatomical marker for root canal preparation that includes instrumentation and biomechanical preparation, is still up for controversy. The apical constriction(AC) is considered appropriate, despite disagreement about the precise landmark for ending root canal therapy(European Society of Endodontology, 2006).Classical studies concluded that, the AC is the smallest part of the root canal structure at its highest point; in circumstances of root resorption correlated with pulp and periapical pathosis, it may not be constantly present(Dummer et al., 1984; Laux et al., 2000). Adequate chemo-mechanical debridement and cleaning and shaping

further provided excellent root canal obturation and improve the endodontic outcome for success and survival(Burns et al., 2022; Ng et al., 2011) With some limitation of previous studies, our present data will help the clinician for estimation the accurate apical limits (AF and AC) in relation with patients clinical signs presentation. Therefore, the main focus of this study is the variance in apical morphology mainly apical foramen (AF) and apical constriction (AC) in mandibular premolars, particularly among Malaysians.

4.4. Complexities of root canal anatomy in lower premolar

The first and second lower premolars share a similar form, comprising a single root canal type. Nevertheless, studies have indicated that root canal architecture in premolars is more complex than those visualised on conventional radiographs; several roots may include extra canals and a variety of canal configurations (Karobari et al., 2023). In addition, the root and canal configuration of lower second premolars exhibited less variation than the mandibular first premolars (Al-zubaidi et al., 2022). Asymmetrical apical foramina may develop under normal and pathological circumstances, for example, as a result of the tooth's adaptation to functional activity (Kuttler, 1955) and also due to continuous remodelling of the root apex by external root resorption and cementum apposition that related to clinical presentation(Blaskovic-Šubat et al., 1992).Previous study investigated the teeth without apical resorption the length between the apical foramen and the anatomical root apex was always less than 1 mm and the length between the apical foramen and the anatomical root apex varied a lot between tooth groups (Martos et al., 2009).

4.5. Relation of apical morphology to the clinical sign presentation

However, no recent published study investigated the deviation of AF in relation to clinical sign presentation. In the present research, the variance in the apical root canal anatomy, including the apical and physiological foramen, was examined in the micro-CT analysis of the root canal in lower premolars. Furthermore, the current study discovered a significant difference in the length between the AF and anatomical apex in connection with clinical sign presentation. Conversely, the length between the AC and anatomical apex and the midpoint between the AF and AC were not significantly different (see Table 3).

A previous study discovered that teeth with periapical lesions, mostly near the AF, have external resorption at apical root with uneven surfaces and different depths. Root resorptions may exhibit different shapes and extensively destroy to the apical root structure (Felippe et al., 2009). Another similar study discovered that morphological deviations in the apex of anterior teeth with clinical presentation (apical periodontitis) had shorter length between AC to the anatomical apex and AF, extensive differences between the widths of buccolingual and mesiodistal, and a higher percentage of widening apical constriction (Zhang et al., 2022). The current findings are consistent with previous studies and clinically significant in improving the efficiency of root canal preparation in mandibular premolars, particularly in length determination with AC preservation.

5. Conclusion

The present study utilised micro-CT analysis to obtain accurate information about the root canal anatomy, including the apical configuration, AF, and AC, to ensure a successful biomechanical setup for endodontic treatment. The micro-CT investigation indicated that only the length between the AF and the anatomical apex significantly differed between the clinical and non-clinical presentations. This finding could aid dental professionals in improving diagnosis, decision-making, and root canal treatment. In addition, this information provides the fundamentals for future research in the variation of the apical configuration associated with clinical and radiographic findings.

Table 3
Apical foramen (AF) and apical constriction (AC) to the anatomical apex in relation to clinical presentation.

Parameters(mm)	Clinical presentation	n (%)	mean	SD	F	p value
Distance from AF to anatomical apex (mm)	Orthodontic	33 (41.2)	0.59	0.21	5.082	*0.008
	Caries	37 (46.3)	0.44	0.2		
	Periodontal	10 (12.5)	0.57	0.16		
Distance from AC to anatomical apex (mm)	Orthodontic	33 (41.2)	0.75	0.25	2.907	0.061
	Caries	37 (46.3)	0.68	0.3		
	Periodontal	10 (12.5)	0.94	0.49		
Mid AF to AC	Orthodontic	33 (41.2)	0.48	0.23	1.754	0.18
	Caries	37 (46.3)	0.5	0.27		
	Periodontal	10 (12.5)	0.67	0.49		

Results are expressed as mean ± standard deviation *$p < 0.05$ is significant.

6. Limitation

Several limitations were identified in this study. This study was restricted by the relatively small sample size for the in-vitro investigation. Furthermore, accurate parameters calibration should be standardised to capitalise on highly detailed images provided by the micro-CT analysis.

Ethical statement

This study was approved by the ethics committee of Universiti Teknologi MARA (UiTM), Sg Buloh, Malaysia with references 600-TNCPI (5/1/6); REC/12/2021(MR 930). and the study was performed in accordance with the 1964 Declaration of Helsinki and the later amendments. Written informed consent was obtained from all participants prior to conducting this study.

CRediT authorship contribution statement

Nurulaqmar Iwani Samsudin: Writing – original draft. **Marlena Kamaruzaman:** Visualization, Supervision, Writing – review & editing. **Afiq Azizi Jawami:** Software, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2023.10.009.

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