Microscopic Evaluation of The Mesial Root Canal Diameter, Wall Thickness, and Root Concavity in Human Permanent Mandibular First Molars

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Abstract

The primary objective of this study is to evaluate the root canal diameter, wall thickness, and root concavity depth of human mandibular first molars' mesial roots across their coronal to apical thirds. By addressing these gaps in knowledge, this study aims to provide valuable insights for improved clinical decision-making and endodontic treatment outcomes.

Ground sections of human mandibular first molars' mesial roots (n = 30) were cut horizontally at 0-, 2-, 4-, and 6 mm below the furcation and at 1 mm above the apex. Their root canal diameter, thickness, and root concavity depth were measured under a computer-aided stereomicroscope.

The concavities of the root were considerably deeper on the distal aspect and at 0- and 2-mm below the furcation than they were on the mesial and other levels, respectively. The root's distal aspect, particularly its coronal third area, was considered the danger zone. The thinnest wall thicknesses were 20.0% in MB- and 16.7% in ML-canals, with their frequent mesial aspect toward the apical third area. The root canal's buccolingual diameter was significantly greater than its mesiodistal one. Furthermore, all canal shapes observed at all levels were oval (70.0%), long oval (22.0%), flat (4.7%), and round (3.3%).

The present findings may assist dentists in selecting the appropriate instruments and techniques to improve root canal instrumentation without causing iatrogenic damage, thereby improving clinical procedures and endodontic treatment outcomes.

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Introduction

Tooth roots and their canal morphology are essential to successful endodontic treatment. A danger zone (DZ) defined as a furcal concavity of human's mesial root can lead to a thin distal root canal wall.[1] An excessive instrumentation during a canal preparation causes this wall to be susceptible to strip perforations[1, 2] and some subsequent treatment failures.[3]

Having adequate knowledge of root canal anatomy, including diameter and thickness, is essential for selecting appropriate instruments and techniques for successful canal preparation and achieving the desired endodontic biomechanical objectives.[4] Previous studies have investigated the thinnest thicknesses of the root canal wall in the DZ by examining different vertical levels from the mandibular molar furcations.[5–8] However, most of these studies have focused on the coronal third area of the root using methods such as root sectioning.[5–8] Additionally, there are variations in the location and direction of the DZ reported in studies that utilized micro-computed tomography (μCT)[9–11] and cone-beam computed tomography (CBCT)[12] of mandibular first molars. Furthermore, while some studies have reported the presence of the DZ in the mesial aspect of the root, likely influenced by the mesial root concavity, information on the mesial root concavity itself is scarce.[10, 11] Despite its limited quantity of sections and the destruction of samples, the sectioning method provides three-dimensional information[13] with some real sample observations

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and measurements,[5–8, 14] when compared with the µCT and CBCT methods.[9–12]

With respect to the round, oval, long oval, flatten (flat or ribbon), and irregular root canal shapes defined earlier,[15] some characteristics of the oval shaped-canal and a greater size of the buccolingual over the mesiodistal are most frequently seen in the apical area of human mandibular molars' mesial roots.[16–19] Data on the long oval canal in 25% human tooth roots' apical area are also available,[18] whereas those in the roots' coronal and middle thirds are not.

Given the limited and inconsistent data available on root canal anatomy, diameter, wall thickness, and root concavity, particularly in the middle and apical thirds of the roots, there is a need for a comprehensive microscopic study. Therefore, the primary objective of this study is to evaluate the root canal diameter, wall thickness, and root concavity depth of human mandibular first molars' mesial roots across their coronal to apical thirds. By addressing these gaps in knowledge, this study aims to provide valuable insights for improved clinical decision-making and endodontic treatment outcomes.

Materials and methods

Naresuan University Ethics Committee approved this research protocol (IRB #0571/60). After all necessary informed consent forms were obtained, thirty human permanent mandibular first molars with fully formed apices collected from hospitals in Thailand's northern region were stored in 10% formalin until used. Teeth were excluded if they had incomplete root formation, previous root canal treatment, root resorption, root canal calcification, a C-shaped canal, severe attrition, or dental anomaly.

Each tooth underwent a buccolingual periapical radiography using an image plate size 2 (Dürr Dental AG; Bietigheim-Bissingen, Germany) and a digital X-ray unit (Myray; Cefla Dental Group, Imola, Italy) at 65 kVp, 6 mA, and 1 sec exposure time. Average tooth length (the distance between mesiolingual (ML-) cusp tip and mesial root apex) and average root length (the distance between furcation and mesial root apex) were measured from the radiograph. In addition, mean root curvature was calculated by using a technique reported elsewhere.[20]

Each tooth was embedded in a cylindrical plastic mold using a clear acrylic resin (Orthocryl; Dentaurum, Ispringen, Germany) with its mesial root's axis parallel to that of the mold. Using a 0.5 mm thick diamond saw (Isomet 4000 Linear Precision Saw; Buehler, IL), ground sections were cut perpendicularly to the mesial root's axis. Collections of the sections (Figure 1; n = 30 per level) were commenced apically at 0- (L1), 2- (L2), 4- (L3), and 6 (L4) mm from the furcation, and at 1 mm above the root apex (L5). The sections from L1–L2, L3–L4, and L5 were the representatives from coronal, middle, and apical thirds, respectively. All sections were investigated by two examiners under a computer-aided stereomicroscope (SZX16; Olympus, Tokyo, Japan) using cellSens imaging software (version 1.18; Olympus). Prior to the investigations, the examiners were calibrated three times, with a 2-week interval between each calibration, by using 10% of the randomly selected sections. Intra- and interexaminer agreements were verified by the intraclass correlation coefficient (ICC).

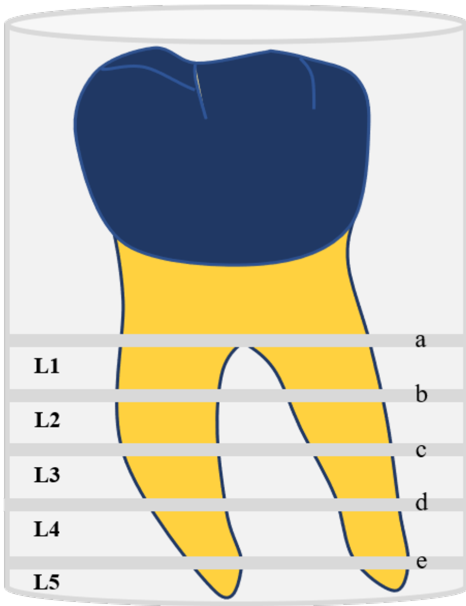

Figure 1. An illustration of the buccal aspect of a human permanent mandibular left first molar embedded in a cylindrical plastic mold. Ground sections are cut perpendicularly to its mesial root's axis. Collections of the sections in levels 1–5 (L1–L5) are commenced apically at 0- (a), 2- (b), 4- (c), and 6 (d) mm from the furcation, and at 1 mm above the root apex (e), respectively.

In stereomicrographs, the buccolingual or mesiodistal root canal diameter was measured from the longest line drawn between the root canal rims in the respective directions. The thinnest thickness of mesial or distal root walls (MT and DT, respectively) was defined as the shortest distance between the root canal rims described above and its nearest external root surface. On the root's mesial or distal aspect, a buccolingual line was drawn tangentially to the external root surfaces at its most prominent point. Depth of root concavity (DC), i.e. the longest perpendicular distances between the tangential lines and the external root surfaces at each aspect, were then measured (Figure 2).

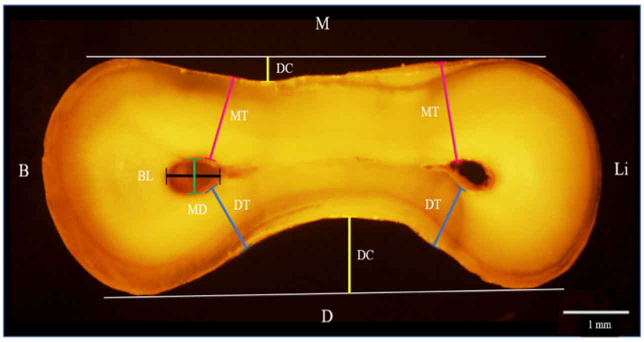

Figure 2. A stereomicrograph of a horizontally sectioned mesial root of a human permanent mandibular first molar showing measurement parameters: BL, buccolingual root canal diameter (black line); MD, mesiodistal root canal diameter (green line); MT, thinnest wall thickness from root canal rim to the nearest mesial root surface (pink line); DT, thinnest wall thickness from root canal rim to the nearest distal root surface; DC, depth of root concavity in the mesial (upper yellow line) and distal (lower yellow line) surfaces. B, buccal; D, distal; Li, lingual; M, mesial.

The frequencies of the roots' thinnest thicknesses at each level were calculated and compared between the mesial and distal aspects. In addition, root canal shapes were determined by using a ratio (R) between its maximum and minimum diameters described elsewhere.[15] Briefly, the canal shape was round if R = 1, oval if 1 < R ≤ 2, long oval if 2 < R ≤ 4, or flat if R > 4.

Using SPSS for Windows (version 23; IBM, NY), all numerical measurements were tested against the normal distribution using the Shapiro–Wilk test at the significance of *P* < .05. Normally and abnormally distributed data were analyzed by a parametric test and a non-parametric test, respectively. The numerical data of the mean root wall thicknesses among levels were analyzed by a one-way analysis of variance (ANOVA) followed by *post hoc* Dunnett's T3 multiple comparisons, between each level on the mesial and distal aspects by a paired *t*-test, and between root canals by an independent *t*-test. The root canal diameters and root concavity depths among levels were analyzed by the Kruskal–Wallis *H* test followed by the Mann-Whitney U-test, and those between each level on both aspects by the Wilcoxon signed-rank test, and between root canals by the Mann-Whitney U-test. The level of significance was set at *P* < .05.

Results

ICC obtained from intraexaminer #1, intraexaminer #2, and interexaminer were 0.970, 0.991, and 0.971, respectively. All of which indicated some excellent reliabilities. The average tooth length, average root length, and mean root curvature were 20.7 ± 1.5 mm, 9.8 ± 1.7 mm, 20.3° ± 7.5°, respectively.

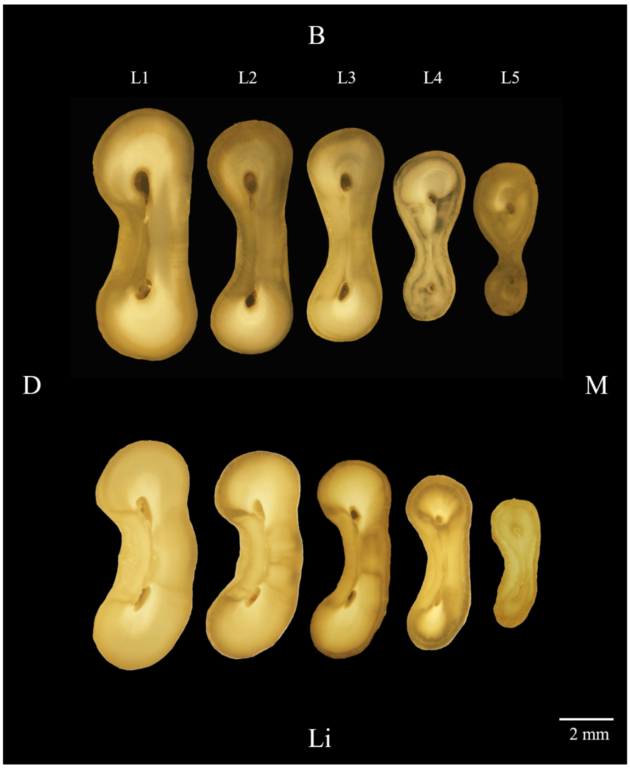

Figure 3. Ground sections of a human permanent mandibular left first molar's mesial roots cut perpendicularly to the root's axis at five levels, i.e. at 0- (L1), 2- (L2), 4- (L3), and 6 (L4) mm below the furcation, and at 1 mm above the root apex (L5), showing the off-centered root canals and the root concavity depth variations on

the distal and mesial aspects. B, buccal; D, distal; Li, lingual; M, mesial.

Figure 3 (upper and lower halves) shows ten ground sections (five sections per half) prepared cross-sectionally from two human mandibular left first molar's mesial roots at L1–L5. A kidney-shaped root was frequently observed. Some off-centered root canals and variations of DC were found on both aspects at all levels. In ML-canal, the flat canal shape was seen at L4 and L5 (Figure 3, lower half), while the oval and long oval ones at the others.

Under a stereomicroscope, DT were commonly found at MB-canal's distolingual and at ML-canal's distobuccal areas. MT were frequently located at MB-canal's mesiolingual and at ML-canal's mesiobuccal areas among the mesial roots with mesial concavities, but on the roots' mesial aspect among those without such concavities. From coronal to apical thirds of the roots, both MT and DT values were decreased with some significant differences (one-way ANOVA; $P < .05$) among levels (Table 1). When compared with MT at the same level in both MB- and ML-canals, some significantly fewer DT values were seen at all levels (paired *t*-test; $P < .05$), except in MB-canal at L4 and in both canals at L5 (Table 1). In addition, independent *t*-tests indicated no significant difference in MT and DT between the root canals ($P > .05$), except DT at L4 ($P = .023$).

	Mesiobuccal root canal		Mesiolingual root canal		Root concavity depth	
Level	MT	DT	MT	DT	Mesial side	Distal side
L1	$1.53 \pm 0.20^{A,a}$	$1.06 \pm 0.14^{A,b}$	$1.58 \pm 0.21^{A,a}$	$1.13 \pm 0.16^{A,b}$	*$0.20 \pm 0.13^{A,a}$*	*$0.70 \pm 0.23^{A,B,b}$*
L2	$1.20 \pm 0.14^{B,a}$	$0.89 \pm 0.15^{B,b}$	$1.27 \pm 0.16^{B,a}$	$0.88 \pm 0.17^{B,b}$	*$0.27 \pm 0.11^{B,a}$*	*$0.77 \pm 0.22^{A,b}$*
L3	$0.99 \pm 0.15^{C,a}$	$0.88 \pm 013^{B,b}$	$1.04 \pm 0.19^{C,a}$	$0.85 \pm 0.12^{B,b}$	*$0.27 \pm 0.12^{B,a}$*	*$0.63 \pm 0.24^{B,C,b}$*
L4	$0.89 \pm 0.18^{C,a}$	$0.87 \pm 0.16^{B,a,*}$	$0.89 \pm 0.22^{C,a}$	$0.77 \pm 0.18^{B,b,**}$	*$0.21 \pm 0.12^{A,a}$*	*$0.50 \pm 0.25^{C,b}$*
L5	$0.57 \pm 0.18^{D,a}$	$0.49 \pm 0.24^{C,a}$	$0.53 \pm 0.18^{D,a}$	$0.49 \pm 0.20^{D,a}$	*$0.11 \pm 0.12^{C,a}$*	*$0.25 \pm 0.29^{D,b}$*

Table 1. The thinnest root wall thickness (mm) and root concavity depth (mm) of mesiobuccal and mesiolingual root canals observed in human mandibular first molars' mesial roots (n = 30 per level) at 0- (L1), 2- (L2), 4- (L3), and 6 (L4) mm below the furcation, and at 1 mm above the root apex (L5) (all values are expressed in mean ± standard deviation).
DT, distal-root wall's thinnest thickness; MT, mesial-root wall's thinnest thickness.
Different superscripted majuscles, minuscles, and asterisks indicate significant intracolumn, intrarow, and intergroup differences significant at $P < .05$ by a one-way analysis of variance, a paired *t*-test, and an independent *t*-test, respectively. The italicized ones with such different superscriptions indicate similar significances, but by the Kruskal–Wallis *H* test and the Wilcoxon signed-rank test, respectively.

Among L1–L5 on both aspects (Table 1), the concavity depths were significantly different (Kruskal–Wallis *H* test, $P = .000$ in both aspects). The greatest value was observed on the distal aspect at L2, despite its non-significant difference with that at L1 ($P = .169$). When compared with the mesial concavity at the same level, some significantly deeper distal concavities were seen at all levels (Wilcoxon signed-rank test; $P < .05$).

Figure 4 shows distributions of the thinnest root wall's thicknesses observed in some selected MB- and ML-root canal sections, with respect to the root's mesial or distal aspect at L1–L5. Most of the thinnest thicknesses were detected on the distal aspect of 80.0% MB- and 83.3% ML-canals, while the rest were on the mesial. The root wall's thinnest thicknesses were seen 100% on the distal aspect at L1 and L2 and decreased toward the apical third area. However, the thinnest thicknesses on the mesial aspect were increased toward the apical third.

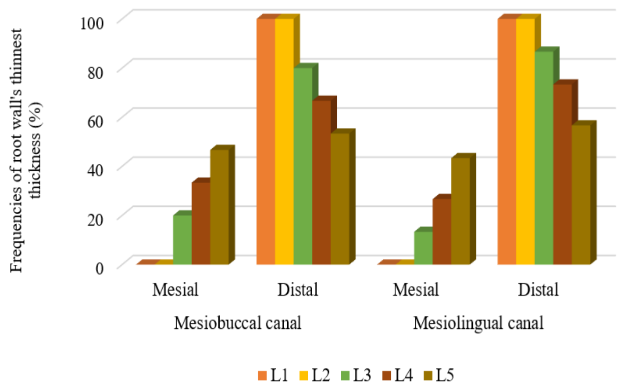

Figure 4. Frequencies of the thinnest root wall's thicknesses of mesiobuccal and mesiolingual canals at each level's mesial and distal aspects (n = 30 per canal).

Table 2 shows MB- and ML-canal diameters of the mandibular first molars' mesial roots measured buccolingually and mesiodistally at all levels. From their coronal to apical thirds of the roots, some descending diameter values were detected with some significant differences (Kruskal–Wallis *H* test; $P < .05$) in the diameters of both root canals and among levels in both directions. When compared to those in the mesiodistal direction in both root canals at all levels, their buccolingual diameters were significantly larger (Wilcoxon signed-rank test; $P < .05$). In addition, the Mann–Whitney U-test indicated some significant differences in the mesiodistal diameters between the root canals at L3 (P = .044) and at L5 (P = .019), respectively.

	Mesiobuccal root canal diameter		Mesiolingual root canal diameter	
Level	BL	MD	BL	MD
L1	$0.76 \pm 0.31^{A,a}$	$0.36 \pm 0.08^{A,b}$	$0.76 \pm 0.32^{A,a}$	$0.36 \pm 0.11^{A,b}$
L2	$0.57 \pm 0.21^{B,a}$	$0.32 \pm 0.07^{B,b}$	$0.60 \pm 0.24^{A,a}$	$0.32 \pm 0.06^{B,b}$
L3	$0.41 \pm 0.13^{C,a}$	$0.28 \pm 0.08^{B,b,*}$	$0.44 \pm 0.21^{B,a}$	$0.25 \pm 0.07^{C,b,**}$
L4	$0.41 \pm 0.12^{C,a}$	$0.22 \pm 0.06^{C,b}$	$0.37 \pm 0.20^{B,a}$	$0.20 \pm 0.05^{D,b}$
L5	$0.21 \pm 0.09^{D,a}$	$0.15 \pm 0.05^{D,b,*}$	$0.20 \pm 0.17^{C,a}$	$0.11 \pm 0.04^{E,b,**}$

Table 2. Mesiobuccal and mesiolingual root canal diameters (mm; mean ± standard deviation) of human mandibular first molars' mesial roots (n = 30 per level) measured buccolingually (BL) and mesiodistally (MD) at 0- (L1), 2- (L2), 4- (L3), and 6 (L4) mm below the furcation, and at 1 mm above the root apex (L5)
Different superscripted majuscles, minuscles, and asterisks indicate significant intracolumn, intrarow, and intergroup differences significant at $P < .05$ by the Kruskal–Wallis H test, the Wilcoxon signed-rank test, and the Mann–Whitney U test, respectively.

Table 3 shows percentages of MB- and ML-root canal shapes seen in the mandibular first molars' mesial roots at all levels. They were oval (70.0%), long oval (22.0%), flat (4.7%), and round (3.3%).

	Mesiobuccal canal				Mesiolingual canal			
Level	Round	Oval	Long oval	Flat	Round	Oval	Long oval	Flat
L1	0%	56.7%	33.3%	10.0%	3.3%	53.3%	33.3%	10.0%
L2	6.7%	63.3%	30.0%	0%	0%	66.7%	26.7%	6.7%
L3	0%	93.3%	6.7%	0%	3.3%	76.7%	16.7%	3.3%
L4	0%	63.3%	33.3%	3.3%	3.3%	63.3%	26.7%	6.7%
L5	3.3%	90.0%	6.7%	0%	13.3%	73.3%	6.7%	6.7%

Table 3. Percentages of mesiobuccal and mesiolingual root canal shapes observed in human mandibular first molars' mesial roots (n = 30 per level) at 0- (L1), 2- (L2), 4- (L3), and 6 (L4) mm below the furcation, and at 1 mm above the root apex (L5).

Discussion

The thinnest root wall thicknesses using the sectioning method have been documented with the data of 1.2 mm at 4 mm from the orifice,[8] 1.119 ± 0.273 mm at 2.8 mm below the furcation,[5] 0.789 ± 0.182 mm at 2 mm below the furcation,[7] and 1.2–1.3 mm at 1.5 mm below the furcation.[6] All of them were reported with a DZ at the location in the coronal third's distal side and the observations were performed mostly at the root's coronal third area. In contrast, the current techniques involved measuring the root canal diameter, wall thickness, and root concavity at the mesial and distal aspects along the roots. Our results confirmed the deeper root concavity on the distal rather than the mesial side. This was consistent with the DT values being substantially lower than the MT values from the coronal to middle thirds of the root, with the exception of the L4 of the MB-canal. From an approximate 1 mm thickness at L1 to an under 1 mm one at L2 toward the root's middle third, our gradual DT decreases coincided with those in a µCT study.[10] The greatest distal concavity depth at L2 (0.77 ± 0.22 mm) was also consistent with those reported at 1–2 mm below the furcation of two hundred and eleven mandibular first and second molars in CBCT study,[21] despite its smaller depth (0.68 ± 0.22 mm) and only 1–4 mm of observation below the furcation on the distal side. The average DT in this area was 0.89 ± 0.15 mm at the MB-canal and 0.88 ± 0.17 mm at the ML-canal, which was slightly greater than that of prior sectioning study.[7] However, ours were thinner when compared to those in other reports. Their measurements, obtained with the µCT, were 1.26 ± 0.25 mm in the MB- and 1.20 ± 0.20 mm in the ML-canals at the coronal third;[10] 1.13 ± 0.21 mm in the MB- and 1.10 ± 0.21 mm in the ML-canals at 4.37 ± 1.68 mm under the furcation area; and 0.95 ± 0.19 mm in the MB- and 0.98 ± 0.19 mm in the ML-canals by using the CBCT.[21] The present findings implied the DZ on the distal aspect of the mesial root which coincided with that in a report,[9] particularly in the coronal third area.

DZ have been reported more toward the root's middle third area at 3–4 mm[12] and 4–7 mm[11] below the furcation and some were on the mesial aspect among 18.0%–35.0% MB- and 22.0%–28.0% ML-canals.[10, 11] Nonetheless, our root wall's thinnest thicknesses were totally disclosed at L1–L2 of the distal one. Some of them were observed on the mesial of 20.0% MB- and 16.7% ML-canals. The phenomena in such canals were gradually detected toward their apical thirds illustrating an increase in the influence of a mesial concavity, which was consistent with those in a report.[10] The gradual decrease in the wall thicknesses from the coronal to the apical thirds in the present study might be caused by the roots' tapering morphology and coincided well with those reported earlier.[5, 10]

Moreover, distributions in the thinnest walls of the root's mesial or distal aspect did confirm several values of the root concavity depth. Taken together, the tapering shape and the root's concavity might affect some spatial distributions of the thinnest wall in the present and the previous reports.[11, 12]

Discrepancies of the thinnest wall thickness, directions, and vertical locations among studies might be contributed to different measurements (root sectioning, CBCT, and μCT), sectioning levels, sections' reference axes such as perpendicular to the root's long axis,[5, 6, 9] and the canal curvature axis.[10, 22, 23] Subjects' age, gender, and ethnicity were also associated with their tooth sizes.[12, 24, 25] When compared with that of the shorter teeth, the wall thickness in the DZ of the longer ones was thinner.[12, 13, 26] In this study, teeth with an average 20.7 ± 1.5 mm length classified into those with a medium length[26] were then controlled, but age and gender factors were not.

From their coronal to apical thirds, the buccolingual and mesiodistal canal widths decreased, albeit not always taper. At every level (L1–L5), some larger canal widths were visible. This reflected the complexity of root canal system, subsequently causing an abnormal distribution of the data. Moreover, at every level, the buccolingual canal diameters were noticeably greater than the mesiodistal ones. The oval shape of the canals that was found in 70.0% of our sections was located in the coronal, middle, and apical thirds, in contrast to prior studies that only showed the oval shape at the root's apical third area.[16–18] Furthermore, in 22.0% of the sections, the frequencies of a long oval shape were lowest at L5 (6.7% in both canals) and highest at L1 (33.3% in both canals) and L4 (33.3% in the MB-canal). These were different from some reports disclosing the long oval shape in 25.0%–47.4% MB- and in none of ML-canals at apical area.[18, 19] It's interesting to note that the flat shape was observable only in some ML-canals at apex (6.7%). Due to the oval shape of root canals, some root canal preparations left an untouched area at both buccal and lingual extensions,[27, 28] and probably some smaller determinations of the apical width. These oval, long oval, and flat shapes could cause at-risk cleaning, shaping, and filling of canals.[18]

At the apex (L5), the average buccolingual extensions were significantly greater than the mesiodistal diameters in both canals. The respective values were 0.21 and 0.15 mm in MB- and 0.20 and 0.11 mm in ML-canals. The MB-canal's mesiodistal diameter shown in this study was significantly greater than that of the ML-canal. Nevertheless, our buccolingual and mesiodistal diameters in the MB- and ML-canals were smaller than those reported in other studies,[9, 10, 17] approximately 35%–80% as large as those in a sectioning report,[17] i.e., their respective diameters were 0.607 ± 0.47 mm and 0.188 ± 0.08 mm in the former, together with 0.329 ± 0.15 mm and 0.204 ± 0.11 mm in the latter. A μCT study has shown 0.31–0.44-mm buccolingual and 0.26–0.33-mm mesiodistal diameters in unmentioned canals.[9] The other μCT study has disclosed 0.24 ± 0.10-mm and 0.22 ± 0.09-mm diameters in MB- and ML-canals, respectively, but without their dimensional descriptions.[10] These discrepancies are explicable by the similar factors that account for the root wall thicknesses.

Despite some mysterious associations between the extent of the apical enlargement and the tapering of instruments,[4] an accurate average and certain values relating to the root canal and each root are worth knowing to prevent any iatrogenic deteriorations during instrumentation procedures. The average maximum buccolingual dimension of the root canal was less than the average mesiodistal thickness, which is the total of the mesiodistal diameter, DT, and MT at every level. The respective values at the apex (L5) were 0.21 and 1.21 mm in the MB-canal, as well as 0.20 and 1.13 mm in the ML-one. It illustrated sufficient wall thicknesses to support the enlargement of an apical dimension to the extent of over three sizes larger than its buccolingual dimension, as well as sufficient wall thickness left over to withstand the pressure of lateral condensation.[23]

The apical canals' buccolingual diameter is inconceivable to measure in clinical practice. Three sizes larger than an initial apical binding file at the working length have been recommended.[2, 29] The operators should keep in mind that the canals' most commonly investigated buccolingual dimension was larger than the mesiodistal one shown in the oval, long oval, and flat shapes, which were challenging to thoroughly clean.[28] Hence, it was advisable to improve the disinfection of the apical canal by using some root canal irrigants and some effective irrigation methods.[30]

Our findings may assist dentists in selecting certain appropriate instruments and techniques for root canal preparation without causing iatrogenic damage, even with the success of endodontic therapy with modern techniques.[31] To maintain more dentin in the DZ, an anticurvature technique might be helpful.[1] However, an increase in the thinnest thickness on the mesial aspect toward the apical third should also be of concern. Taken together, further investigations into suitable instruments and techniques are required.

These comprehensive microscopic findings provided several notations to fill the gap in morphological knowledge, particularly in the middle and apical thirds of the mesial roots. The data on various root canal shapes were provided, with the majority being oval with an off-center position, root canal dimensions, and some irregularly tapered root canals. In addition, the variable root concavity depths were shown on both mesial and distal sides, resulting in the thinnest dentin thickness. When compared with the CBCT[12] and µCT studies,[9–11] ours possessed some limitations, including a smaller sample size, some potential sample destructions and biases in measurement, together with some limitations in assessing the dynamic features.

Conclusions

Within the limitations of this study, the distal side of the mesial root of the human mandibular first molars, particularly the coronal third area, was considered as the DZ associated with the deeper root concavity. The thinnest wall thicknesses were 20.0% in MB- and 16.7% in ML-canals, with their frequent mesial aspect toward the apical third area. The buccolingual root canal diameter was considerably greater than the mesiodistal one. Compared to long oval, flat, and round canals, the oval-shaped canals were noticeably more frequently observed.

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Declaration of Interest

The authors report no conflict of interest.

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