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Original Article

Concurrent measurements of danger zone anatomy in mandibular first molars using micro-computed tomography: a pilot study

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Abstract: The aim of this study is to describe the anatomical characteristics of the 'danger zone' in human mandibular first molars by measuring the thickness of the bending point (point α) and the thinnest point (point β) of each root in human mandibular first molars. Eighteen mandibular first molars were scanned by micro-computed tomography and reconstructed three-dimensionally by Mimics Research 17.0. To identify characteristics of the 'danger zone', the actual root curvature, the minimal dentin thickness of the bending slice and the thinnest slice were selected as parameters. Furthermore, to describe the relationship of point α and point β, the distance between them was also measured. The results showed that the actual canal curvatures in the mandibular first molars were 5-10 degrees larger than those measured in 2-D images including X-ray or CBCT. The thinnest thickness of roots in all canals was less than 1 mm except the two distal roots of three-rooted mandibular first molars. Moreover, as for some two-rooted mandibular first molars, their point α and point β were located in the same furcation surface of root, the result might be coincident in the mesiolingual side; whereas for three-rooted mandibular first molars, the distal two canals were found significantly thicker than the mesial two ($p<0.05$). These results suggest that mesiobuccal and mesiolingual canals of mandibular first molars require more conservative preparation plans to avoid root canal perforations. Considering dentin thickness and root curvature, distobuccal canals might be more suitable for preparation.

Keywords: Danger zone, dentin thickness, mandibular first molars, micro-computed tomography

Introduction

Endodontic management of mandibular first molars (MFMs) with complex root canal configurations can be diagnostically and technically challenging [1]. Root canal perforation is a common complication of endodontic treatment and the frequency of perforations among failures of root canal therapy is reported to be 3-4% [2]. Root canal morphology including calcification of canals, root curvatures, and the excessive cutting of radicular dentin during the preparation are all attributed to the occurrence of root perforations [3, 4]. As a result, in order to quantitatively discuss the risk of root perforations, studies related to root canal morphology need to be conducted.

During clinical practice, because the canal systems cannot be three-dimensionally reconstructed, the actual curvatures of root canals cannot be directly displayed in the X-ray images or CBCT images. Actually, the curvatures measured in those images are the component of the actual curvatures and may led practitioners to underestimate the root curvatures. With the development of micro-CT (μCT), the details of the root canal morphology can be displayed by modeling software from different directions [5]. Therefore, it becomes possible to observe and measure the actual curvatures of the canals through micro-CT. Moreover, canal transportation caused by curved canals could led excessive preparation of root dentin [6]. As a result, measuring the minimal dentin thickness in the bending slice might be of importance.

During root canal preparation, the canals need to be enlarged to allow better access to the api-

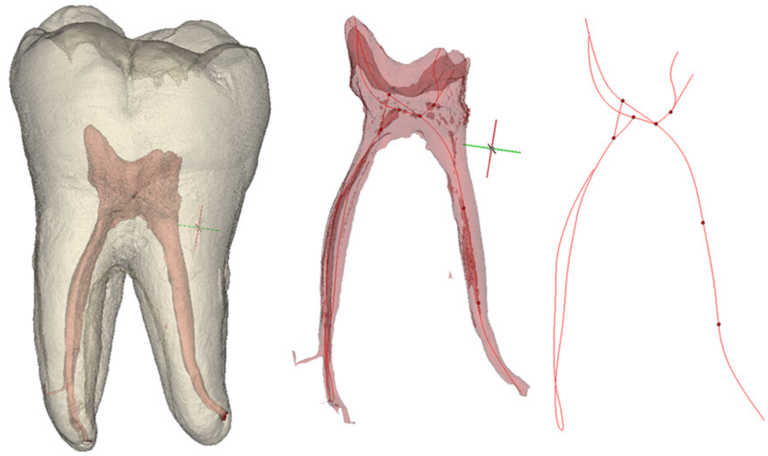

Figure 1. Three-dimensional model of dentin and root canal system constructed by Mimics Reseach 17.0 and centerline drawn by the centerline tool.

cal third, for debris removal, irrigation, medication, and obturation [7]. Therefore, additional enlargement of the root canal space in the coronal 1/3 of the root may be required. Also, some endodontically treated teeth may require an intra-radicular dowel, and more enlargement is needed in this part of root. Furthermore, it is recommended that the minimal residual dentin thickness should no less than 1 mm around the entire circumference of the canal [11]. The dentin removed in these two preparatory procedures may jeopardize root integrity and make teeth vulnerable to perforations [10].

Many studies [8-10] have reported the existence of the 'danger zone' on the furcal surfaces of mandibular first molars. This area was described as a thin area located in the inner surfaces of the furcation of the mandibular first molars. The 'danger zone' was rendered susceptible to root perforations and root fractures [11, 12], especially when there was excessive canal preparation and transportation [13]. However, previous researchers mainly focused on the 'danger zone' in the mesial roots [8, 9], and the studies of the 'danger zone' of the distal roots were limited [10]. Also, research of the 'danger zone' in three-rooted mandibular first molars is rare. Furthermore, although the 'danger zone' was considered relatively thin in the root, the results were analyzed from some limited slices of the roots [8]. As micro-computed tomography is also a noninvasive tool, concurrent measurements can be conducted in the 'danger zone'.

In this study, the actual root curvatures, the minimal dentin thickness of the bending slice, and the minimal dentin thickness of the thinnest slice were selected as parameters to represent the risky factors of roots. Moreover, other features including the positions of the bending point and the thinnest point may also provide valuable information of vulnerable parts of the root in mandibular first molars to guide clinical practice. The aims of the research are to (i) evaluate the actual curvatures of the canals so as to provide accurate data for practitioners. (ii) to locate the bending point and the thinnest point of each root, and to measure the minimal thickness in the slices of these two points. (iii) Moreover, as these two essential points are located on the root surfaces, it is possible to discuss the relationship between them and the 'danger zone'.

Materials and methods

Twenty-two mandibular first molars (15 two-rooted and 7 three-rooted) excluding teeth with serious caries, previous endodontic treatment, restorations, or other major defects were collected from a native Chinese population in the Affiliated Stomatology Hospital of Tongji University from 2016 to 2017. The mandibular first molars were extracted because of serious periodontitis. The study was approved by the Ethics Committee of Tongji University (No. 15,8200,0245,7132), and patients with written informed consent of permission to use their data for scientific purposes. The molar types of specimens were accurately identified by the operators according to external anatomy structures, positions in the dental arch, and dental histories. Each specimen was labelled and individually stored (4°C) in a bottle of 0.9% sodium chloride solution (China National Pharmaceutical Group Corporation (SINOPHARM), Beijing, China). Before investigation, the specimens were cleaned of calculus and remaining external tissues. Specimens were classified into two groups according to the number of root (two-rooted and three-rooted) and

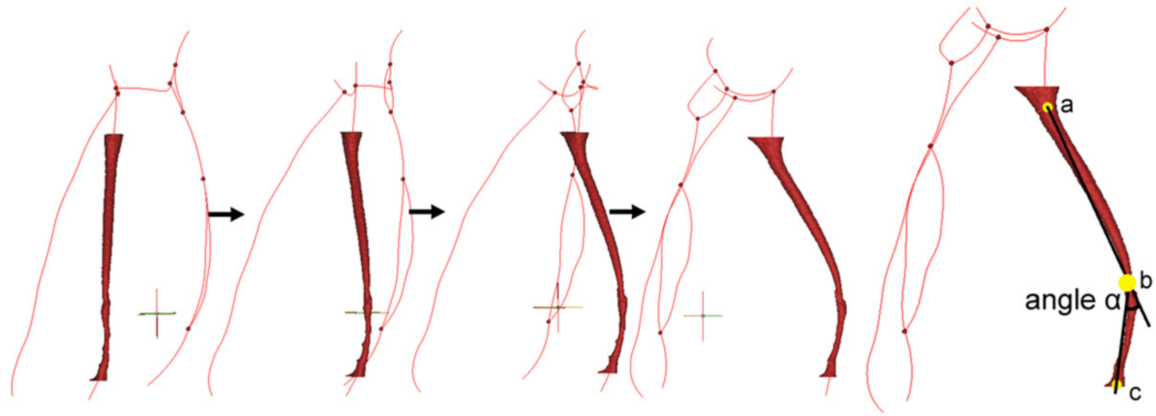

Figure 2. Technique used to show the actual curvature of the canal. The Schneider method was then used to measure the canal curvature. Point a is marked at the canal orifice. Point b is a point where the canal deviated from the original canal long axis. Point c is made at the apical foramen. The acute angle formed by the intersection of the 2 lines was measured to evaluate the canal curvature.

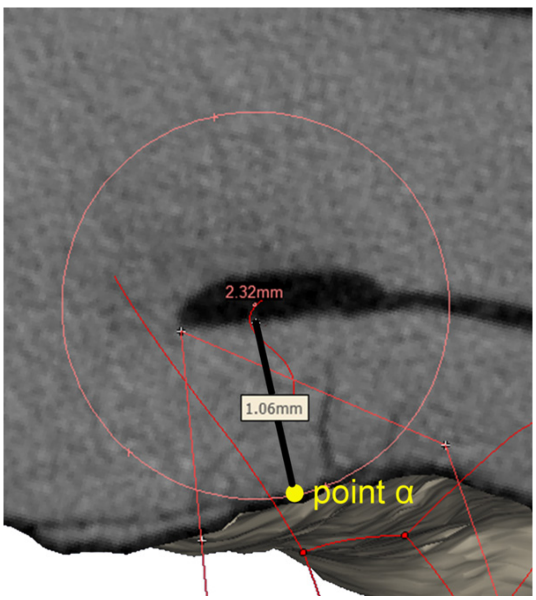

Figure 3. Technique used to locate the minimal thickness on the bending slice. The point α was the yellow point noted on the outer contour of the root. The thickness of dentin was measured by distance measurement tool.

were scanned using a μCT scanner (SCANCO Medical AG, Fabrikweg, Switzerland). Each tooth was scanned along the tooth axis with a voxel slice of 15*15*15 μm. After that, using the Mimics Research 17.0 (Materialise, Leuven, Belgium), models of the dentin and root canals were reconstructed from the source images by using a segmentation threshold (with parameters: 2000 to 8000 for dentin and -1023 to 2000 for root canal systems). Of all specimens, four molars were eliminated because of root canal calcifications, root cracks or root absorptions, and the remaining 18 molars were used for measurement. The example of one of the models is shown in **Figure 1**.

In each tooth, the following measurements were taken.

Angle α: To observe the actual curvature of each canal, the three-dimensional model of the root canal system was first rotated to the angle which the canal for measurement looked like a straight line (the purpose was to concentrate all the curvatures on the vertical intersect plane). The model was then rotated 90 degrees clockwise to observe the maximum curvature of the root canals (**Figure 2**). The curvatures of the canals were measured with the Schneider method [14].

Thickness α: After angle α was measured, a circle (using the circle tool) was placed on the cross-section of the bending point slice. The center of the circle was made to coincide with the center of the canal. The diameter of the circle was determined when the circle was tangent to the outer contour of the root. The cut point on the root surface was the bending point of the root and was named point α (**Figure 3**). If the point was located in the furcal surface of the root, the position was recorded as 'in the furcation area'; otherwise, it was recorded as 'out of the furcation area'.

Method of locating the thinnest point

The root dentin images in the transverse cross-section were masked separately by using a segmentation threshold (with parameter: 2000-

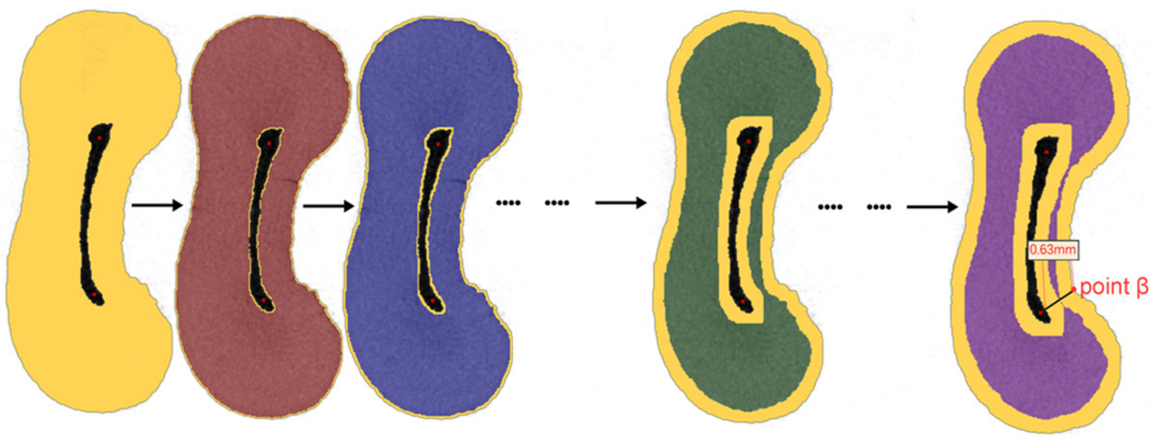

Figure 4. The technique used to locate the thinnest point of root (point β). The yellow mask was the 3D mask of the radicular dentin, the red mask was one pixel smaller than the yellow mask, and the blue mask was two pixels smaller than the yellow mask. After several steps, the purple mask showed an initial discontinuous point among all slices. That point was the thinnest point of the radicular dentin and the red point noted on the outer contour of the root was the point β.

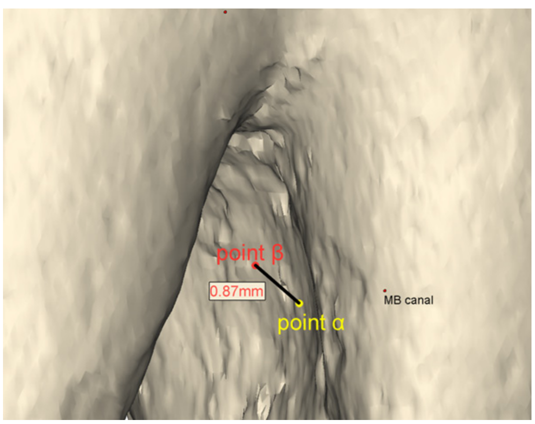

Figure 5. Measurement of the surface distance (distance α-β) between point α and point β. Point α and β were first highlighted on the root surface, then the surface distance tool was used to measure the surface distance between them. If the two points were on the different surfaces, the distance was recorded as >1 mm.

6000). To avoid interference of the thin dentin in the apical region, the apical 4 mm of dentin was trimmed from the root masks. The masks were then modified as follows:

1. Use the erode function (through the segmentation menu and the morphological operation button) one pixel was subtracted concurrently from both the inner and outer contours of the root dentin masks. 2. Repeat two steps above. The dentin masks gradually became thinner. The whole process continued till the masks had a discontinuous point on the root surface, which was the thinnest point of the root. It was named point β (**Figure 4**). Each root had only one point β, no matter how many canals the root had. Then, whether the point was in or out of the furcation area was recorded. Further, if the point was in the furcation, the location was further divided into: in the buccal side, in the lingual side or in the middle of the root.

Thickness β: After locating the thinnest point, the wall thickness was easily measured by the distance measurement tool.

Distance α-β: The relationship of point α to point β was described by the surface distance (use the surface distance tool to measure) between them (**Figure 5**). The coincidence degrees of the two points were divided into the following 2 groups based on the results: coincident (≤1 mm) or irrelevant (>1 mm).

Statistical analysis

Each measurement was repeated three times. Data were analyzed with SPSS 22.0 (IBM Corporation, Armonk, New York, United States). One-way ANOVA and Tukey's test for significance (HSD) were used to compare the thicknesses in the different canals. A level of $p<0.05$ was considered significant.

Results

Canal types

The anatomical types of 18 mesial roots and distal roots were classified according to the classification of Vertucci [15]. The morphology

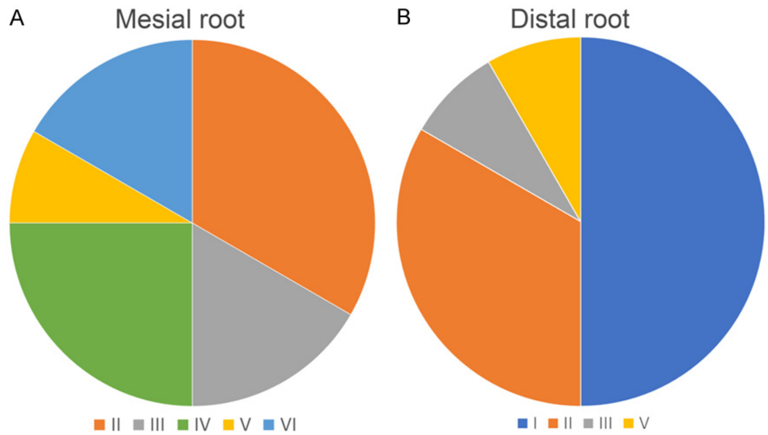

Figure 6. A. Pie chart of the canal types of mesial roots according to the Vertucci classification. B. Pie chart of the canal types of distal roots according to the Vertucci classification.

Table 1. Curvatures of root canals

	n	Two-rooted* (°)	n	Three-rooted* (°)
MB	12	33.17 ± 8.19	6	32.41 ± 9.52
ML	12	31.77 ± 8.69	6	30.99 ± 6.50
DB	6	25.08 ± 8.99	6	22.07 ± 4.49
DL	6	24.74 ± 10.42	6	28.65 ± 8.89
D	6	24.05 ± 7.51		

*, Mean ± S.D.; MB, mesiobuccal canal; ML, mesiolingual canal; DB, distobuccal canal; DL, distolingual canal; D, distal canal.

Table 2. Data of Point α

Point α	Two-rooted		Three-rooted	
	n	Thickness α* (mm)	n	Thickness α* (mm)
MB	12	1.08 ± 0.22	6	0.96 ± 0.12
ML	12	1.05 ± 0.21	6	0.95 ± 0.11
DB	6	1.12 ± 0.30	6	1.22 ± 0.25
DL	6	1.04 ± 0.24	6	1.12 ± 0.20
D	6	0.83 ± 0.15		

*, Mean ± S.D.; MB, mesiobuccal canal; ML, mesiolingual canal; DB, distobuccal canal; DL, distolingual canal; D, distal canal.

of the canals in the mesial root was highly variable, while the one of the canals in the distal root was more consistent (**Figure 6**). Type 1 anatomy was observed in 50% of the teeth. The distribution of root canal types in this study was similar to that of previous studies [16].

Root curvatures

For two-rooted mandibular first molars, the mean values of the curvatures measured by the Schneider method were both over 30 degrees in the two mesial canals, and the curvature degrees of the MB canals were greater than the ML canals by approximately 2 degrees. However, the mean values of the curvatures in the DB, DL, and distal (D) canals were approximately 24-25 degrees but were not significantly different from those of the mesial canals ($p>0.05$). For three-rooted mandibular first molars, the results were similar to the two-rooted group, except the DL canals were 28.65 ± 8.89 degrees. Also there was no significant difference between two groups.

Radicular dentin thickness

The minimal radicular dentin thicknesses in the bending slice and the thinnest slice were showed in **Tables 2** and **3**. The bending thicknesses were about 1 mm in all canals and had no significant difference between one another ($p>0.05$). However, the thinnest thicknesses in both roots of two-rooted mandibular first molars were less than 1 mm and showed no significant differences ($p>0.05$). Meanwhile, for three-rooted mandibular first molars, the mesial roots were significantly thinner than the distal roots ($p<0.05$), and the thicknesses of distal two roots were more than 1 mm.

Discussion

Root curvatures

The Schneider method has been used for evaluating root curvatures in many studies for decades. Although with limitations, it is still considered to be the most efficient and accurate method to measure root curvatures [17]. However, the method was invented to measure the root curvatures displayed on X-ray images with a file [18] or reamer [19] in the canal. As the 2-D images could only show a certain component of the actual root curvature, the result came out of 2-D images might be smaller than the actual curvature. According to previous studies, curvature degrees were observed in clinical view (CV) or in proximal view (PV). These

Table 3. Data of Point β

Point β	Two-rooted			Three-rooted		
	n	Thickness β* (mm)	*p* value	n	Thickness β* (mm)	*p* value
M	12	0.74 ± 0.14	0.114	6	0.75 ± 0.15	0.002[a]
D/DB	12	0.85 ± 0.18		6	1.20 ± 0.24	
DL				6	1.12 ± 0.13	

*, Mean ± S.D.; a, p<0.05; MB, mesiobuccal canal; ML, mesiolingual canal; DB, distobuccal canal; DL, distolingual canal; D, distal canal.

Figure 7. A, B. Position of point α in canals of two-rooted and three rooted mandibular first molars. C, D. Position of point β in canals of two-rooted and three rooted mandibular first molars. MFMs: mandibular first molars, MB = mesiobuccal canal, ML = mesiolingual canal, DB = distobuccal canal, DL = distolingual canal, M = mesial root, D = distal root, IN = in the furcation area, OUT = out of the furcation area, IN (B) = in the buccal side of furcation area, IN (M) = in the middle of furcation area, IN (L) = in the lingual side of furcation area.

two views were perpendicular to each other, and CV was the most commonly used view in clinical practice, and they were both one of the components of the actual curvature. For the mesial roots, in CV, The average angles of curvatures in the MB and ML canals reported by Schäfer [20] were 25 degrees and 22 degrees. These values were also close to the former researches [18, 19, 21]. In PV, the means were smaller than those in CV, which were 18, 17.1, 19.5 degrees for the MB canals and 16, 14.4, 17.0 degrees for the ML canals reported by Schafer [20], Kartal [19], and Gu [21]. For the distal roots, because the type 1 anatomy distal root and three-rooted mandibular first molars existed, the measurements of the curvatures were usually integrated together. According to former studies, Schafer [20] reported a range of 0-11 degrees in both CV and PV. Gu [21] reported a mean of 12.5 degrees for DB+D canal, 8.4 degrees for DL canal in CV, 7.6 degrees for DB canal, and 18.5 degrees for DL canal in PV. These values were also close to those of three-rooted mandibular first molars, except a mean of 32.06 degrees for DL reported by Gu [21], which was much greater than other canals.

In this study, through 3-D modelling software, root canal systems could be displayed and the actual root curvatures could be measured. The values of this study were 5-10 degrees larger than the CV results in above studies (**Table 1**). This deviation should be taken into account because most of the practitioners could only obtain information of root curvatures from 2-D images. Underestimation of the curvatures may mislead clinicians to take inadequate preparation plans, lending to root perforations or instrument separations. Moreover, for the distal roots in three-rooted mandibular first molars, this study also showed a greater curvature of 28.65 ± 8.89 degrees (**Table 1**).

Radicular dentin thickness

In this study, a new method has been used to detect the thinnest thickness of the radicular dentin. The erode tool can subtract the pixels of dentin contour from all the slices and all aspects concurrently. Compared with the traditional method which restricted the analysis to the limited number of available slices and aspects [8, 12], the erode method locates the point more efficiently and can avoid inertia and bias, which are caused by fatigue due to the continuous measurement. Furthermore, because the positions of the thinnest points have been detected, it is possible to analyse the traits and relationships with other anatomical structures. The method used in this study could improve the deficiency of the tradition one and might proposed new perspectives to study the micro-anatomical structures of root canals. Since the scanning axis was along the axis of the tooth, it could be argued that there was a 'bevel effect' in the measurement.

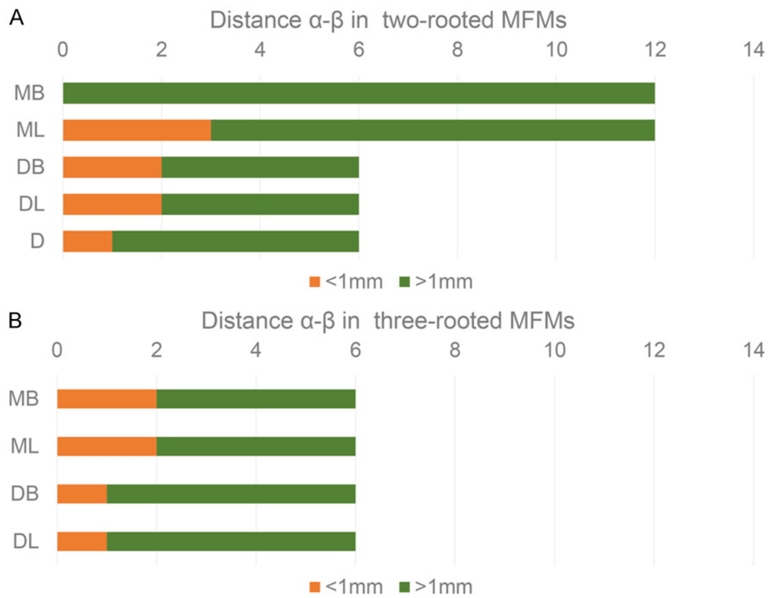

Figure 8. A, B. Proximity degree of point α and point β in canals of two-rooted and three-rooted mandibular first molars calculated in sample number. MFMs = mandibular first molars, MB = mesiobuccal canal, ML = mesiolingual canal, DB = distobuccal canal, DL = distolingual canal, M = mesial root, D = distal root.

However, the scanning level was small in the experiment (15 μm), so the bias should be limited.

According to Berutti [8], the thinnest area of dentin in the coronal aspect of the mesial root was located on the distal surface of the mesial root and 1.5 mm below the furcation and the averages were 1.2-1.3 mm in thickness. Tabrizizadeh [22] reported a similar result: 1.2 mm in the mesial roots and 1.3 mm in the distal roots. However, Garcia Filho [23] reported a thinner thickness of 0.789 mm. Harris [10] measured the μCT data of 22 mandibular first molars and suggested that the dentin may be thinner. Additionally, he suggested that the furcal surface of distal roots may also be an area of risk for strip perforations. Recently, Lee [24] measured 37 mesial roots of mandibular first molars with Kappa2 software. The results were as follows: coronal 1/3: 1.05 mm, middle 1/3: 0.91 mm. apical 1/3: 0.67 mm. The present study measured the thinnest thickness of the dentin 4 mm above apical foramen, and mean values of the mesial and distal roots was 0.74 mm/0.85 mm (M/D) in the two-rooted group and 0.75 mm/1.20 mm/1.12 mm (M/DB/DL) in the three-rooted group. The results were close to the 'danger zone' thicknesses reported in the recent studies [10, 22, 24]. It suggested that the 'danger zone' was one of the thinnest areas in the coronal 2/3 of the roots. As a result, the risks of root canal perforations in this area should be taken into account in the preparation.

Among the results in this study, in the two-rooted group, the thicknesses of the mesial roots were not significantly thinner than those of the distal roots ($p>0.05$) (**Table 3**), however, in the three-rooted group, mesial roots appeared thinner than the distal roots significantly ($p<0.05$) (**Table 3**). The reason might be that the distobuccal roots and distolingual roots of three-rooted mandibular first molars are one-canalled roots. Therefore, the transverse cross-section shapes of those roots were round, not kidney-shaped. As a result, there was no invagination in those roots. Furthermore, the high incidence of isthmuses [25] found between the two canals in the mesial roots also jeopardized the dentin walls.

The position of point α and β

In addition to the curvatures and the dentin thicknesses, the positions of point α and point β were also recorded and calculated as a percentage (**Figure 7**). All point α and point β of the mesial roots in both types of mandibular first molars lay in the furcation area. The reason might be that the distal concavity in the mesial root weaken the wall thickness, and it might also lead to the formation of 'danger zone'. Although half of the two-rooted mandibular first molars in this study were type 1 anatomy, most of the point α and point β in those roots still lay in the furcation side. It suggested that there was a similar 'danger zone' in the distal roots of the two-rooted mandibular first molars. On the other hand, the probability was greatly reduced in the distal roots of three-root mandibular first molars. When the roots were separated and the concavity disappeared, the 'danger zone' might not exist.

Previous research studies usually claimed that the lingual dentin thickness in the 'danger zone' was thinner than the buccal [8, 24]. If so, the point β located in this study should be more on the lingual side. However, the tendency was not obvious in this study (**Figure 7**), and the reason may be that previous studies restricted the analysis to the limited number of available slices and aspects such as buccal, lingual, mesial, distal, or distal-lingual [10, 22, 24], thus ignoring the weak areas between the two canals. In the current study, the thinnest point was selected by the erupt tool from all slices and all aspects. As a result, the selected point was not pre-set and its deviation was smaller.

Relationships between point α and β

According to the results above, the bending point and the thinnest point of the roots in mesial roots of mandibular first molars are located in the same area. Therefore, it can be hypothesized that there might be a more profound significance of 'danger zone' in human teeth, where the 'danger zone' is not only one of the thinnest area of the radicular dentin, but canals in this part also began to curve (**Figure 5**). The dentin moved in this kind of point during preparation could easily cause root perforations due to the thin thickness and canal transportation [26, 27]. To prove that, the surface distances on the root surfaces between point α and β were measured, and if the distance was less than 1 mm, the two points were considered coincident. The number of teeth was recorded and shown in the **Figure 8**. The probability was not high and the example number of this study was limited, but considering the serious complications caused by canal perforations, those canals need a conservative preparation plan and should be considered to avoid post placement.

Conclusion

This study suggests that real curvatures of the root may be 5-10 degrees larger than those measured on the clinical radiographs. Furthermore, considering the curvatures and the thinnest radicular dentin thicknesses, ML canals of both two types of mandibular first molars and the distal-lingual canal of three-rooted mandibular first molars require a more conservative plan during preparation. In contrast, when post space preparation is mandatory, DB root or one-canalled distal root may be more suitable for preparation.

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Disclosure of conflict of interest

None.

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