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Research Article

Root Canal Isthmi and Associated Radicular Grooves in Mandibular First Premolars using Micro-computed Tomography

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Abstract

Introduction: This study aimed to investigate the anatomical features of root canal isthmi in mandibular first premolars with radicular grooves and determine the correlation between radicular groove depth and isthmus wall thickness and shape using micro-computed tomography.

Methods: Fifty-two mandibular first premolars with mesial radicular grooves were scanned using micro-computed tomography. The wall thickness in different parts of the detected isthmi was measured using Mimics 10.01 software and the isthmus shapes were quantified by the form factor. The correlation of these two parameters with groove depth was analyzed.

Results: Twenty-three teeth had isthmi located within approximately one-fifth of (2.36 ± 1.76 mm) the root lengths. All isthmi were located within the scope of the radicular grooves. The mean minimum wall thickness was significantly lesser for the mesial than for the distal wall. A significant negative correlation was observed between the minimum mesial wall thickness and groove depth. The mean form factor ranged from 0.31 to 0.78 and correlated negatively with the groove depth.

Conclusions: Our results suggested that the highest incidence of isthmi is observed between 4.93 and 7.29 mm from the apex in mandibular first premolars with radicular grooves. The isthmus wall thickness and shape in the radicular groove region can vary, presenting anatomical considerations for endodontic and prosthetic treatment.

Keywords: Root canal isthmus, Radicular groove, Mandibular first premolar, Micro-computed tomography

Introduction

The key goals of endodontic therapy include the removal of pulp remnants, necrotic tissue, micro-organisms, and microbial byproducts from the root canal system. Although this may be achieved through endodontic preparation, complete removal is difficult because of the intricate root canal anatomy [1]. Isthmi, apical deltas, intercanal communications, and loops are commonly observed in root canal systems and limit the actions of instruments, irrigants, and intracanal medicaments, leading to endodontic treatment failure [2-6].

A root canal isthmus is a narrow ribbon-shaped communication from either one or two main root canals and can be considered as a lateral connection between canals within the same root [7]. An isthmus may be found in roots with C-shaped canals or in two adjacent canals, such as those in the mesial roots of mandibular molars and mesiobuccal roots of maxillary molars and premolars. Most studies of root canal isthmi have generally focused on their type, position, and incidence, among other factors [7-12].

Radicular grooves are developmental depressions on the root surface and may further complicate the anatomy of the root canal system. Studies have indicated that radicular grooves may influence the wall thickness and root canal shape and type [13-19]. In a study by Li et al. [19], a significant negative correlation was observed between the groove depth and root canal shape. Micro-computed tomography (micro-CT) investigations by Fan et al. [13] showed that radicular grooves may present relevant morphologic variations in the root canal system of a C-shaped root. Chen et al. [16] discovered that the anatomy of radicular grooves may influence the root canal morphology and type. All these studies indicate a strong correlation between the radicular groove and root canal morphology. However, studies performing quantitative assessments of the correlation between radicular grooves and root canal isthmi are scarce.

Several methodologies are available for studying the relationship between the internal anatomy and external configuration of root canal systems, such as clearing techniques, scanning electron microscopy, cross-sectioning, cone beam computed tomography (CBCT), and micro-CT [3,5,20,21]. In recent years, micro-CT has been increasingly used for anatomical studies because it offers a reproducible technique that can facilitate quantitative and qualitative three-dimensional (3D) assessments of the external and internal anatomy of a tooth. This study aimed to investigate the anatomy of root canal isthmi in mandibular first premolars with radicular grooves and quantitatively analyze the correlation between radicular grooves and root canal isthmi using micro-CT.

Materials and Methods

Sample preparation and micro-CT

After ethics committee approval, fifty-two extracted mandibular first premolars with radicular grooves caused by orthodontic or periodontal factors were selected from a native Chinese population. Immediately after extraction, the teeth were cleaned of calculus and any attached soft tissue and stored in 10% neutral buffered formalin until further assessment. All samples showed fully formed apices and were devoid of restorations, defects, or previous endodontic treatment.

All samples were scanned using a desktop X-ray micro-focus CT system (Siemens Inveon CT, Erlangen, Germany) using the following settings: 80 kV, 500 μA, and a 500-ms exposure time. According to the manufacturer's instructions, each sample was scanned 360° around the tooth axis, with a pixel size of 14.97 × 14.97 × 14.97 μm. The scanning interval was 30.0 μm. After calibration and segmentation of the scanned cross-sectional images, the 3D configuration of each tooth was reconstructed using Mimics 10.01 software (Materialise, Leuven, Belgium).

Locations of the root canal isthmi and radicular grooves and their measurements

Vertical measurements for the root canal isthmi and radicular grooves were obtained (Figure 1A). Six planes were selected to determine the location of each isthmus and radicular groove: (1) the cementoenamel junction plane (CEJP), which was a cross-sectional plane with enamel occupying one half of the perimeter; (2-3) the isthmus top plane (ITP) and the groove top plane (GTP), which were the cross-sectional planes at the coronal top of the root canal isthmus and radicular groove, respectively; (4-5) the isthmus bottom plane (IBP) and the groove bottom plane (GBP), which were the cross-sectional planes at the apex of the root canal isthmus and radicular groove, respectively; and (6) the apex plane (AP), which was the cross-sectional plane at the anatomical apex of the root. Subsequently, the distances between ITP and AP, ITP and IBP, IBP and AP, GTP and AP, GTP and GBP, GBP and AP, and CEJP and AP (root length) were measured.

Isthmus wall thickness and groove depth measurements

The wall thicknesses and groove depths were horizontally

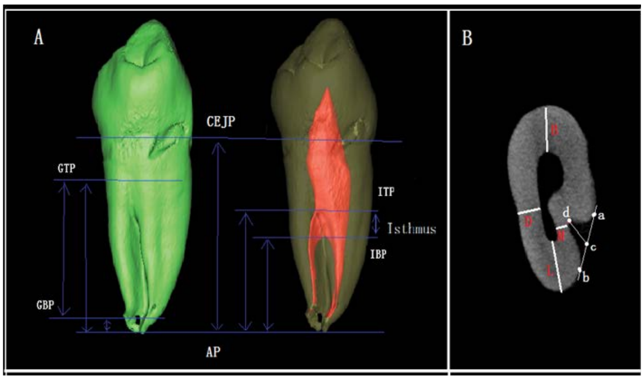

Figure 1: (**A**) Measurements for the root canal isthmi and radicular grooves in mandibular first premolars. Six planes are selected to determine the location of each root canal isthmus and radicular groove: CEJP, cementoenamel junction plane; ITP, isthmus top plane; IBP, isthmus bottom plane; GTP, groove top plane; GBP, groove bottom plane; AP, apical plane. **(B)** Measurement of isthmus wall thicknesses: M, minimum mesial wall thickness; D, minimum distal wall thickness; B, buccal wall thickness; L, lingual wall thickness. Measurements of groove depth: line ab, groove tangential line; poind c, midpoint of line ab; point d, bottom of groove; line cd, groove depth

measured (Figure 1B). In each cross section of the root canal isthmus, the following wall thickness measurements were obtained: minimum mesial wall thickness, minimum distal wall thickness, buccal wall thickness, and lingual wall thickness. Four points were selected to determine the groove depth: points a and b, which were the tangency points on the contour line of the groove; poind c which was midpoint between the two tangency points; and point d, which was the bottom point of the groove. The groove depth was measured as the distance between points c and d.

Analysis of the isthmus shapes

Cross-sectional images of the root canal isthmus in each sample were analyzed using Image-Pro Plus 6.0 software (Media Cybernetics, Inc, Bethesda, MD) according to the method of Li et al. [19]. In each cross section of the isthmus, the boundary of the root canal was automatically segmented and its area and perimeter were automatically measured. The form factor (FF) of the root canal in every cross section was measured using the following formula:

$$FF = \frac{4 \times \pi \times Area}{Perimeter^2}$$

Statistical analysis

Each measurement was repeated three times, and the means were used for analysis. The isthmus location data were subjected to descriptive statistics. The minimum wall thicknesses were compared using the paired-sample t test. The correlation of FF and wall thickness with groove depth was analyzed using Pearson correlation coefficients. Statistical significance was set at $P < 0.05$. All statistical analyses were performed using SPSS 13.0 (SPSS, Inc., Chicago, IL, USA).

Results

Locations of the root canal isthmi and radicular grooves and their measurements

The prevalence of root canal isthmi was 44.2% (23/52). Of

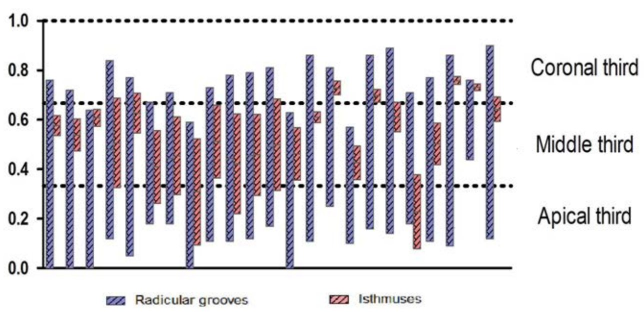

Figure 2. Distribution of root canal isthmi and radicular grooves in mandibular first premolars.

the 23 isthmi, 39.1% (9/23) were located in the middle third of the root, 17.4% (4/23) in the coronal third, and the remaining 43.5% (10/23) originated in the coronal or middle third and terminated in the middle or apical third, respectively. Most of the radicular grooves (18/23) originated in the coronal third and terminated in the apical third, and 28% (5/18) of these extended to the apex. The distributions of the root canal isthmi and radicular grooves are shown in Figure 2. The mean distances from ITP and IBP to the apex were 7.29 ± 1.38 mm and 4.93 ± 2.04 mm, respectively. The isthmi were located within 2.36 ± 1.76 mm of the roots, which was approximately one-fifth of the mean root length (11.58 ± 1.90 mm). The mean groove length was 7.35 ± 1.62 mm. The ratio of the groove length to the root length was nearly 65%. The mean distances from GTP and GBP to the apex were 8.69 ± 1.32 mm and 1.34 ± 1.17 mm, respectively. The isthmi and groove measurements are shown in Table 1.

Wall thicknesses and shapes of the isthmi and the associated groove depths

The mean minimum wall thickness was significantly lesser for the mesial (0.71 ± 0.21 mm) and buccal walls (1.48 ± 0.29 mm) than for the distal (0.98 ± 0.18 mm) and lingual walls (1.59 ± 0.31 mm), respectively (paired-sample *t* test, $P < 0.01$ for all). The mean groove depth (MGD) was 0.66 mm and ranged from 0.22 to 1.24 mm. The correlation between the minimum mesial wall thickness and groove depth was analyzed for each sample, and a significant negative correlation was observed (Pearson correlation test: r = −0.648 to −0.988, $P < 0.05$).

The mean FF (MFF) was 0.48 and ranged from 0.31–0.78. The correlation between the FF and groove depth was analyzed for each sample, and a significant negative correlation was observed (Pearson correlation test: r = −0.617 to −0.994, $P < 0.05$). The wall thickness, MFF, and MGD values are shown in Table 2.

Discussion

The present study investigated the anatomical features of root canal isthmi in mandibular first premolars with radicular grooves and determined the correlation between radicular grooves and isthmi using micro-computed tomography.

The prevalence of root canal isthmi was found to range from 16% to 89% in different tooth positions [7,9,11,12,22,23]. However, these studies mostly focused on mandibular molars, maxillary molars, and mandibular incisors, with no study on mandibular first premolars. Our study showed a prevalence of 44.2% in mandibular first premolars. This diversity may be caused by differences in tooth positions or regional or ethnic populations. The previous studies showed that the incidence of isthmi was the highest between 2 and 7 mm from the root apex [7,9,11,12,23]. In the present study, similar characteristics were found. The isthmi were located within approximately one-fifth of the mean root length. The mean distances from ITP and IBP to the apex were 7.29 ± 1.38 mm and 4.93 ± 2.04 mm, respectively, indicating that the highest incidence of isthmi was between 4.93 and 7.29 mm from the apex. Furthermore, 78.3% grooves (18/23) originated in the coronal third and terminated in the apical third, and 28% of these (5/18) extended to the apex. The mean groove length was 7.35 ± 1.62 mm. The ratio of the groove length to the root length was nearly 65%. As shown in Figure 2, the isthmi were primarily located in the middle third of the roots and within the scope of the radicular grooves. The presence of isthmi increases the difficulty of instrumentation and obturation; therefore, a thorough understanding of the anatomic features of isthmi is paramount for the clinician. The current data will provide clinicians with a better understanding of the locations of

Measurement	ITP–AP (mm)	ITP-IBP (mm)	IBP-AP (mm)	GTP-AP (mm)	GTP-GBP (mm)	GBP-AP (mm)	CEJP-AP (mm)
Minimum	4.37	0.3	0.96	5.48	3.74	0	8.2
Maximum	9.52	6.07	8.29	11.29	11.25	5.03	14.81
Mean	7.29	2.36	4.93	8.69	7.35	1.34	11.58
SD	1.38	1.76	2.04	1.32	1.62	1.17	1.9

ITP-AP, distance between the isthmus top plane (ITP) and apex plane (AP); ITP-IBP, distance between ITP and the isthmus bottom plane (IBP); IBP-AP, distance between IBP and AP; GTP-AP, distance between the groove top plane (GTP) and AP; GTP-GBP, distance between GTP and the groove bottom plane (GBP); GBP-AP, distance between GBP and AP; CEJP, cementoenamel junction plane; CEJP-AP, length of the root

Table 1. Measurements for the root canal isthmi and radicular grooves evaluated in this study (N = 23).

Measurement	Mesial (mm)	Distal (mm)	Buccal (mm)	Lingual (mm)	MGD (mm)	MFF
Minimum	0.28	0.58	0.87	0.66	0.22	0.31
Maximum	1.33	1.38	2.14	2.16	1.24	0.78
Mean	0.71	0.98	1.48	1.59	0.66	0.48
SD	0.21	0.18	0.29	0.31	0.3	0.11

MGD, mean depth of the radicular groove in each sample; MFF, mean form factor of the root canal isthmus in each sample
Mesial-Distal: t = −23.6, P < 0.001; Buccal-Lingual: t = −11.76, P < 0.01 (paired-sample *t* test)
MGD-MFF: r = −0.6, P < 0.01 (Pearson's correlation test)

Table 2. Isthmus wall thickness, MFF, and MGD values (N = 23).

root canal isthmi in mandibular first premolars, which will lead to an increase in the success rate of endodontic treatment for these teeth.

Previous studies showed that the presence of a radicular groove may influence the wall thickness and root canal morphology [13-16]. Lammertyn et al. (18) and Li et al. [19] mentioned that the wall thickness in the radicular groove region varies in maxillary first premolars. Gu et al. [15] quantitatively evaluated the wall thickness of C-shaped canals in 29 mandibular first premolars using micro-CT and found that the mesial canal walls facing the radicular groove were the thinnest. All previous studies primarily focused on the wall thickness in different aspects of the entire root, while none performed quantitative evaluations of the correlation between the isthmus wall thickness and radicular groove depth. The wall thicknesses of isthmi and their correlation with groove depth were analyzed in this study. Table 2 shows that the mean minimum mesial wall thickness of isthmi was less than 1 mm, with a minimum value of only 0.28 mm, and significantly lesser than the mean minimum distal wall thickness. A significant negative correlation was observed between the minimum mesial wall thickness and groove depth. These findings further indicate that the radicular groove depth directly impacts the isthmus wall thickness in that region, with a strong correlation between the two. A few studies [24,25] suggested that at least 1 mm of root dentin should be present around a post for resistance to root fracture. Lim and Stock [26] considered that the root may not withstand the forces of compaction, which could result in perforation during obturation, when the remaining wall thickness was less than 0.3 mm. The walls of the isthmi were found to be the thinnest zones in the teeth. However, the presence of a radicular groove can further complicate restorations with posts and root canal instrumentation and obturation. To prevent root fracture, clinicians should understand the correlation between the isthmus wall thickness and radicular groove depth in mandibular first premolars and try to avoid the high-risk zone during restoration with posts.

The presence of a radicular groove is reportedly related to root anatomy and root canal shape [14,16,19]. Chen et al. [16] found that the anatomy of the radicular groove may influence root canal types. In the study by Li et al. [19], the FF was used to quantify the transverse shape of the buccal root canal in maxillary first premolars with furcation grooves. The FF has commonly been used to evaluate the shape of an object in the field of medicine; when the shape of the object is rounder, the FF is close to 1, and when the shape of the object is flatter or irregular, the FF is close to 0. In the present study, the FF was used to evaluate the transverse shape of root canal isthmi, and its correlation with the groove depth was analyzed. The MFF quantifies the shape of the entire isthmus space. The MFF was 0.48 in this study, indicating a flat or irregular isthmus shape. Furthermore, a significant negative correlation was observed between FF and groove depth, which indicates a flatter or more irregular shape with an increase in the groove depth. In other words, the main root canal would be divided into two or more separate canals when the groove depth is raised to threshold values.

In conclusion, the present study suggested that the highest incidence of isthmi is found between 4.93 and 7.29 mm from the apex in mandibular first premolars with radicular grooves, with the isthmi walls facing the radicular groove being the thinnest zones. FF and the isthmus wall thickness in the region of the grove are significantly and negatively correlated with the groove depth. Clinicians should be aware that the region comprising the radicular groove is a high-risk zone during restorations with posts and during root canal instrumentation. The results of this study provide an important basis for further studies on the relationship between radicular grooves and root canal bifurcations.

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The authors deny any conflicts of interest related to this study.

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