ORIGINAL ARTICLE

A micro-computed tomography study of the root canal morphology of the mandibular first premolar in a population from southwestern China

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Abstract

Objectives This study aimed to investigate the root canal morphology of mandibular first premolar teeth in a population from southwestern China by micro-computed tomography (micro-CT).

Materials and methods Human mandibular first premolars (115) were selected and prepared for micro-CT analysis with a slice thickness of 30 μm. Details of root canal orifices, canals, accessory canals, apical foramina–apical delta intercanal communication, loops and isthmuses, and mesial invagination were analyzed from reconstructed three-dimensional (3D) images.

Results Canal patterns categorized according to the classification defined by Vertucci (Endod Top 10:3–29, 2005) as types I (65.2 %), III (2.6 %), V (22.6 %), and VII were identified (0.9 %). Accessory canals were present in 35.7 % of the samples and were predominantly located in the apical third of the root. A single apical foramen was observed in 50.4 % of the samples and two or three foramina in 28.7 % and 14.8 %, respectively. Apical delta was identified in 6.1 % of the samples and the prevalence of intercanal communication and loops was 3.5 % and 7 %, respectively. Mesial invagination of the root was identified in 27.8 % of the samples, the majority of which contained multiple canals.

Conclusions The data obtained in this study revealed complex root morphology with high prevalence of multiple canals, more than half of which exhibited type I canal patterns.

Clinical relevance Micro-CT was used as a noninvasive technique for 3D investigation of root canal morphology in the mandibular first premolars of a population from southwestern China. Furthermore, data obtained revealed complex anatomy of various types.

Keywords Mandibular first premolar · Micro-computed tomography · Root canal

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Introduction

The wide variety and complexity of root canal systems was first reported by Hess in 1925. Accessory canals, intercanal communication, apical delta, multiple foramina, and multiple canals were commonly identified. Variation in root canal morphology is now considered normal and it is generally accepted that a major cause of endodontic failure results from the inability to locate, debride, shape, and obturate all canals of the root system in three dimensions. Therefore, it is critical to gain a thorough understanding of the morphology of the root canal system and its variations in order to achieve successful therapy.

A number of techniques have been used to study the morphologic characteristics of the root canal system. Traditional methods such as radiography [1], cross-sectioning [2], staining and root clearing [3, 4], scanning electron microscopy [5], and stereomicroscopy [6] are either destructive or provide only two-dimensional information. Micro-computed tomography (micro-CT) provides a noninvasive technique for more precise investigation of the root canal system [7–16]. Three-dimensional (3D) imaging of the root canal by micro-CT was first described by Dowker [17]. This technique facilitates detailed investigation of both the external and internal anatomy of the tooth which can be observed simultaneously or separately from different angles by reconstructing the 3D images. Furthermore, the characteristic of the tooth can be assessed both qualitatively and quantitatively [7, 8, 17].

Previous reports of the use of micro-CT for the investigation of the root canal system have focused on the morphology of mandibular and maxillary molars [11], with only three reports describing the root canal morphology of the mandibular first premolar [2, 9, 14]. The complexity and variety of the root canal anatomy in the first mandibular premolar is frequently neglected by endodontists and it has been reported that treatment of the mandibular first premolar has the highest failure rate resulting from an inability to recognize and treat all canals adequately [18].

Although more than half of mandibular first premolars have one canal, multiple canals have been reported with more complex classification [19–21]. The aim of this study was to investigate the complexity of the root canal morphology of the mandibular first premolar in a population from southwestern China by micro-CT.

Materials and methods

Specimen selection and preparation

Human mandibular first premolars (115) were selected for micro-CT analysis from a pool of teeth extracted for orthodontic and periodontal reasons from a population from southwestern China. To ensure that all teeth examined were first premolars, detailed information of the teeth used in this research was recorded, such as the gender, age, position information, and reasons for extraction. The teeth extracted were stored in separate ampoules. Specimens were stored in 10 % neutral buffered formalin and cleaned in 5 % sodium hypochlorite solution for 24 h before being debrided of periodontal tissue and calculus. The criteria for selection were as follows: fully formed apices, no restorations with intact crowns, and no defect or carious lesions. Specimens were attached to the specimen holder (15 mm diameter) of the micro-CT equipment via an acrylic custom-made

accessory. Samples were analyzed in two stages consisting of 2 h for scanning and 2 h for the reconstruction procedure.

Scanning of samples and 3D reconstruction

All samples were scanned using a desktop X-ray microfocus CT scanner (Siemens Inveon CT, Munich, Germany) and the scanning procedure was performed using 80 kV and 500 μA with a 500-ms exposure time. A 360° scan of each specimen was performed around the tooth axis with a pixel size of 14.97×14.97×14.97 μm at a distance of 30.0 μm between each cross-section. Digital data were transferred to Mimics 10.01 software (Materialise, Leuven, Belgium). The anatomy of each mandibular first premolar and root canal system was reconstructed three-dimensionally according to the instructions provided by the manufacturer with a semi-automatic threshold-based segmentation approach combined with manual editing of the slices. The transparency of the image was adjusted to render the tooth transparent while the root canal system was opaque.

Observation of root canal morphology

Reconstructed image analysis was performed by a single observer. The following observations were recorded: number and shape of root canal orifices; number and type of canals present; presence of accessory canals (defined as any branch of the main pulp canal or chamber that communicated with the external surface of the root); number of apical foramina (defined as the circumference or rounded edge, like a funnel or crater, that differentiates the termination of the cemental canal from the exterior surface of the root) [22]; number and location of intercanal communication between a second or third canal, where present (defined as a branch of the pulpal space between the main canals that did not communicate with the root surface) [22]; presence and location of loops (defined as a branch of the main canal that divides from it and then rejoins the original canal) [22]; presence of isthmus (defined as a narrow, ribbon-shaped communication between two root canals that contains pulp tissue) [23]; presence of an apical delta in the apical third of the root canal (defined as a complex ramification of branches of the pulp canal located near the anatomical apex with a main canal not being discernible).

Results

Number and shape of root canal orifices

At least one canal orifice was identified in all specimens. The shape of the canal orifice was oval in 84.3 % (97 of 115) (Fig. 1a), flattened ribbon-shaped in 7.0 % (8 of 115)
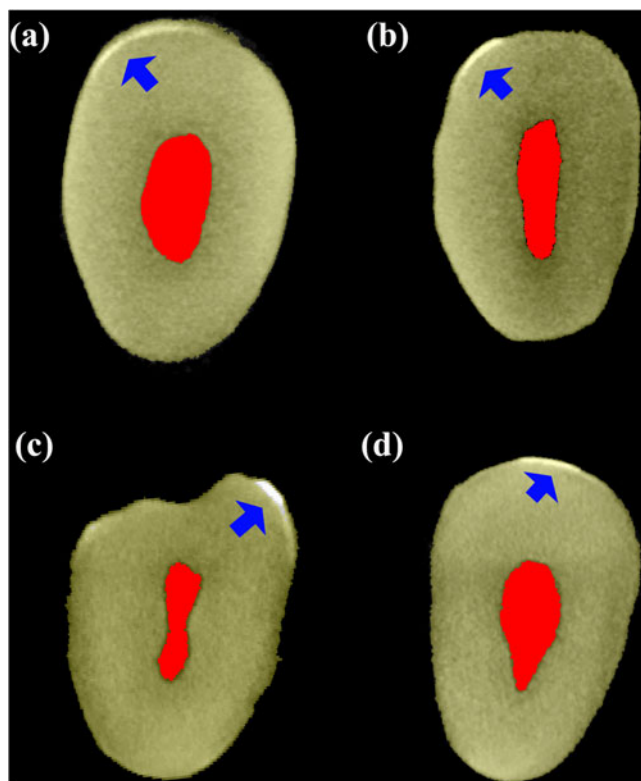
Fig. 1 Shapes of root canal orifices. **a** Oval, 84.3 %; **b** flattened ribbon, 7.0 %; **c** eight-shaped, 7.0 %; **d** triangular, 1.7 %. The *arrow* indicates the margin of the enamel–cementum junction

(Fig. 1b), eight-shaped in 7.0 % (8 of 115) (Fig. 1c), and triangular in 1.7 % (2 of 115) (Fig. 1d).

Canal type

The percentages of root canal configurations in the mandibular first premolars examined are presented in Table 1. Variable root canal configurations were observed in the mandibular first premolars. Of the 115 specimens, 65.2 % (75 of 115) was identified as type I (1-1) (Fig. 2a), 22.6 % (26 of 115) as type V (1-2) (Fig. 2c), 2.6 % (3 of 115) as type III (1-2-1) (Fig. 2b), and 0.9 % (1 of 115) as type VII

Table 1 Pattern and percentage of mandibular first premolar canals

Type of canal	Canal pattern	Number	Percentage of occurrence
Type I	1-1	75	65.2
Type III	1-2-1	3	2.6
Type V	1-2	26	22.6
Type VII	1-2-1-2	1	0.9
Additional type	1-3-2	3	2.6
	1-3	6	5.2
	1-2-3	1	0.9

(1-2-1-2) (Fig. 2d). Ten specimens did not fit Vertucci's classification. Additional types identified included: 2.6 % (3 of 115) type 1-3-2 (Fig. 2e), 5.2 % (6 of 115) type 1-3 (Fig. 2f), and 0.9 % (1 of 115) type 1-2-3 (Fig. 2g).

Accessory canals

Accessory canals were present in 35.7 % (41 of 115) of the specimens. The majority of accessory canals (92.7 %, 38 of 41) were located in the apical third of the root (Table 3). Accessory canals were identified in the middle third of the roots in only three specimens. No accessory canals were observed in the cervical region. Of the specimens identified with accessory canals, the majority of specimens had a single accessory canal (87.8 %, 36 of 41), while four specimens (9.8 %, 4 of 41) had two accessory canals and one (2.4 %, 1 of 41) specimen had four accessory canals (Table 2; Fig. 3).

Apical foramina and delta

Most apical foramina were located laterally (77.4 %, 89 of 115). A single apical foramen was identified in approximately half (50.4 %, 58 of 115; Fig. 4a) of the specimens. Two apical foramina were detected in 28.7 % (33 out 115) of specimens, three in 14.8 % (17 of 115), and four in 6.1 % (7 of 115; Fig. 4b; Table 2). Apical delta was present in 6.1 % (7 of 115) of specimens (Fig. 5).

Intercanal communication, loop, and isthmus

Intercanal communications were observed in 3.5 % (4 of 115) of the specimens (Fig. 6). Loops were present in 7.0 % (8 of 115) of specimens (Fig. 7). Three were located in the apical third of the root and five in the middle third. An isthmus was identified in only two specimens. These were located the middle and apical third of these specimens (Table 3).

Mesial invagination

According to Ash [24], mesial invagination is a deep developmental groove in the mesial surface of the root formed during embryogenesis, which is commonly observed in mandibular premolars. Mesial invagination of the root was observed in 27.8 % (32 of 115) of specimens. All were located in the mesial–lingual third of the root surface. These were categorized according to the classification defined by Vertucci [32] as type V (1-2) (21 of 32; Fig. 8a–d), type I (1-1) (2 of 32), type III (1-2-1) (2 of 32; Fig. 8e–h), and type VII (1-2-1-2) (1 of 32). Additional types identified included type 1-2-3 (1 of 32; Fig. 8i–l), type 1-3 (2 of 32; Fig. 8m–p), and type 1-3-2 (3 of 32; Fig. 8q–t; Table 4). Of those specimens with mesial invagination, 93.8 % (30 of 32) had two canals or more. The
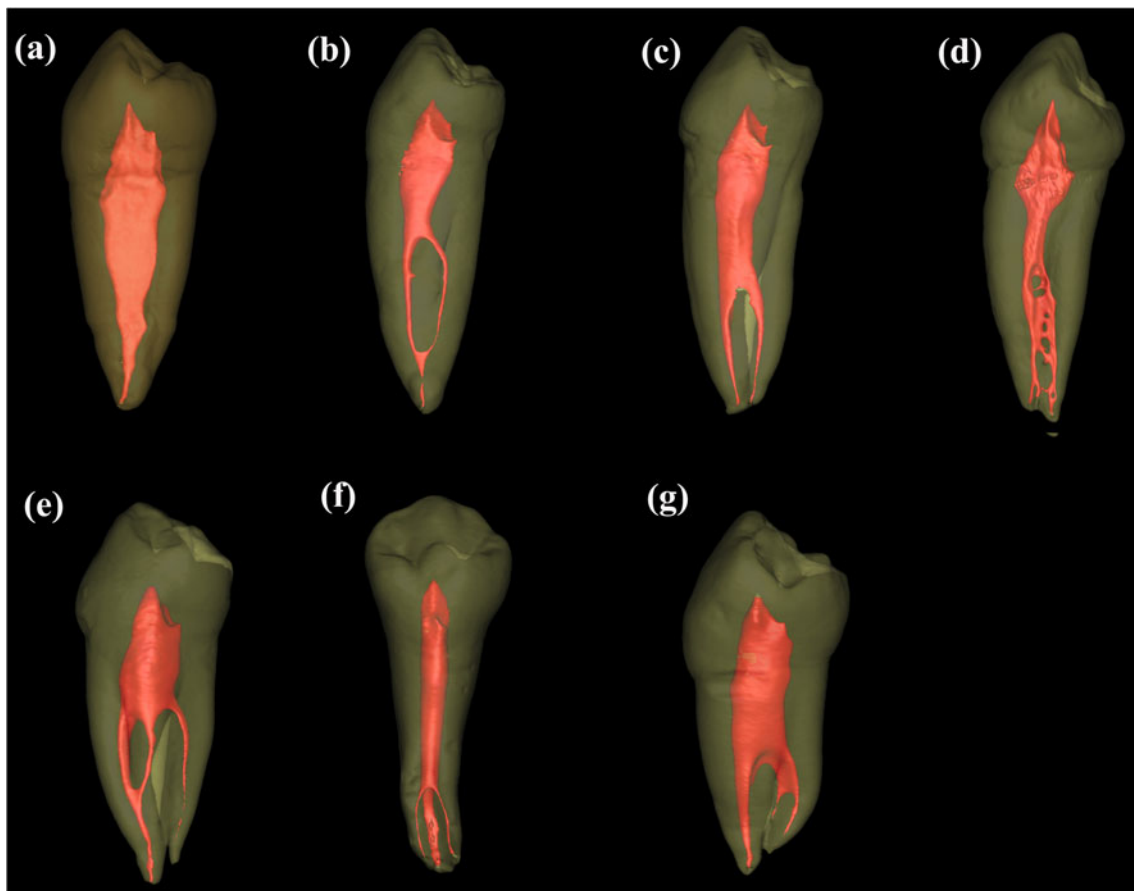
Fig. 2 Canal patterns in mandibular first premolars categorized by Vertucci's classification. **a** Type I (1-1); **b** type III (1-2-1); **c** type V (1-2); **d** type VII (1-2-1-2). Additional types: **e** 1-3-2; **f** 1-3; **g** 1-2-3

majority of invaginations were located in the middle third of the root and extended to the apical third with a minority dividing into two roots at the tip. Invaginations originated in the middle third of the root in 87.5 % (28 of 32) of these specimens, at the coronal third, extending to the middle and apical third of the root in 6.3 % (2 of 32), and at the apical third, extending to the tip of the root in 6.3 % (2 of 32).

Discussion

This study investigated root canal morphology in mandibular first premolar teeth in a population from southwestern

Table 2 Number and occurrence (in percent) of accessory canal and apical foramina of canals in mandibular first premolars

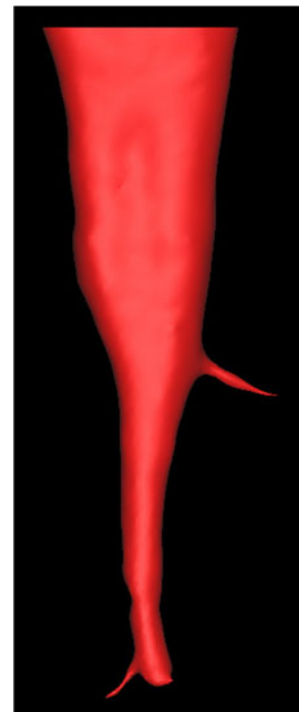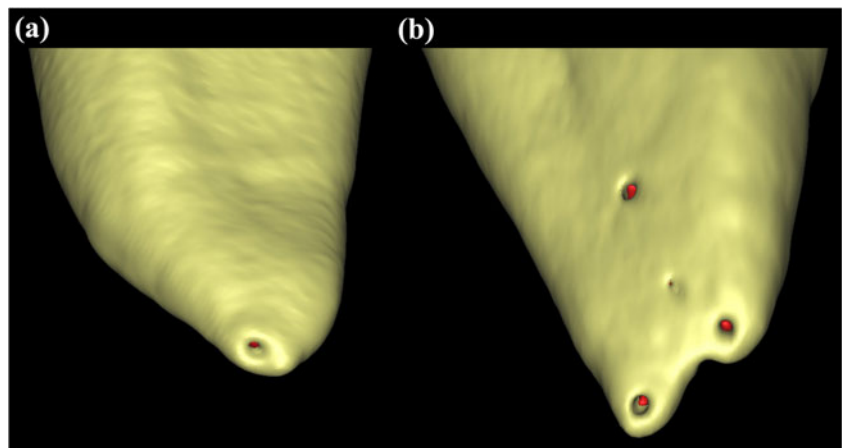|	Overall	1	2	≥3
Accessory canal	41	36 (87.8 %)	4 (9.8 %)	1 (2.4 %)
Apical foramina	115	58 (50.4 %)	33 (28.7 %)	24 (20.9 %)

Fig. 3 Accessory canals located in the apical and middle third of the root

Fig. 4 Apical foramen. **a** Single apical foramen; **b** four apical foramina

China by micro-CT. This nondestructive technique provides detailed and accurate information for the evaluation of the external and internal anatomy of the root canal system through reconstruction of 3D images.

Previous reports of aberrant morphology in the root canal of first mandibular premolars have attributed variation in the number and pattern of first premolar root canal morphology to racial or genetic factors and the investigative technique employed [25]. The occurrence of a single canal in the mandibular first premolar was reported from 54 to 88.5 %, while multiple canals were reported from 11.5 to 46 % [6, 26]. In this study, variable root canal configurations were identified. Canal type I (1-1) was the most common pattern occurring in 64.3 % of specimens and multiple canals were identified in 35.7 %. Approximately 91.3 % (105 of 115) of

specimens were defined according to the traditional Vertucci [22] classification of canal configurations, while 8.7 % (10 of 115) were classified as additional types. In this study, canal orifices were identified in all samples, although type II and type IV patterns were not identified. A higher incidence of single (65.2 vs. 54 %) and double (26.1 vs. 22 %) canal
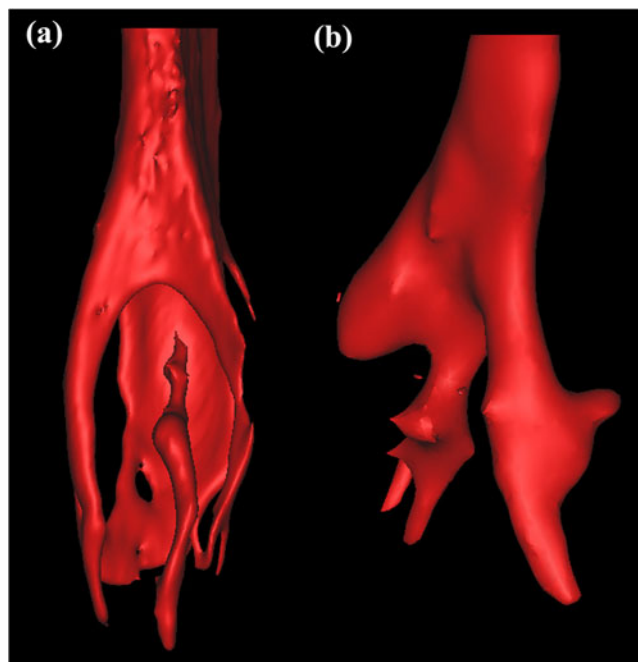

Fig. 5 **a**, **b** Apical delta, the complex structure in the tip of the root canal
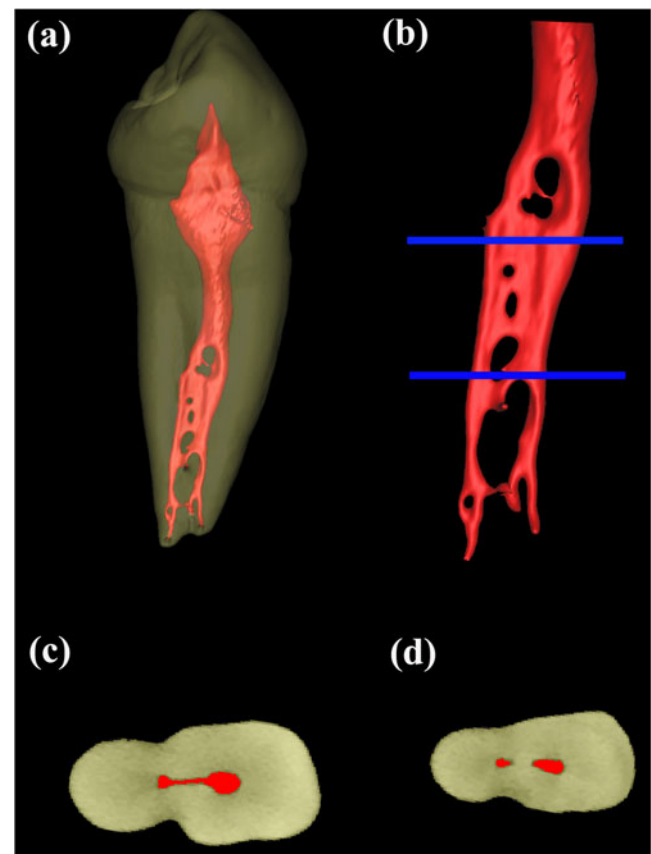

Fig. 6 Intercanal communication and isthmus. **a** Multiple intercanal communication and an uncompleted isthmus in the middle third of the root; **b** intercanal communication in cross-section; **c** an isthmus between the buccal and lingual canals; **d** isthmus viewed in cross-section
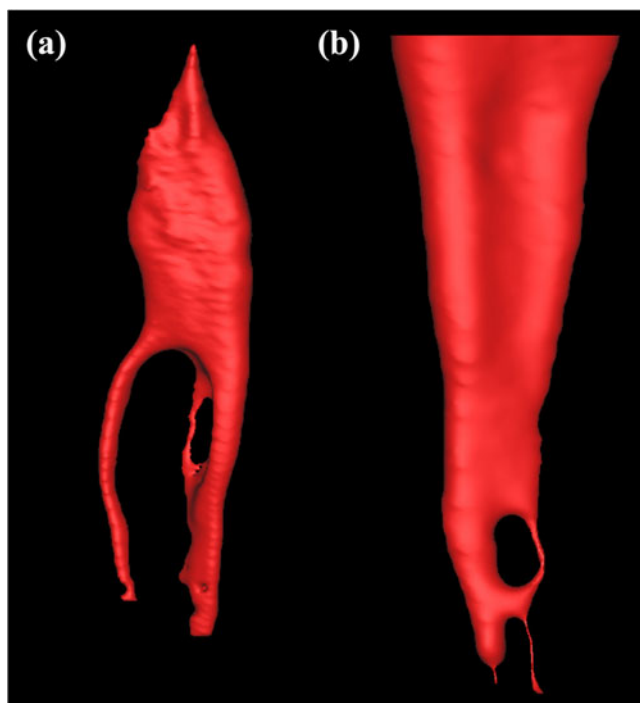
Fig. 7 a Loops in the middle and **b** apical third of the root canal

patterns was observed in this study compared with the study carried out on a Chinese population by Lu et al. [21]. However, the data presented here are consistent with other reports of studies conducted among the Chinese population such as those reported Lin [27] (65.6 and 24.5 %) and Xu [28] (69.1 and 26.3 %). In contrast, a study of a Japanese population conducted using radiography and cleaning methods reported a much higher occurrence (80.6 %) of the single canal type compared with this study [20]. Other studies conducted in a Jordanian population using the cleaning method [29] and in an Iranian population using the cross-sectioning and radiography methods [26] reported the identification of type I canals with incidences of 58.2 and 88.5 %, respectively. These data indicate that root canal morphology is affected by racial factors and that multiple canals occur with a moderate frequency in the Chinese population investigated in this study. It can also be

Table 3 Number and occurrence (in percent) of different types of canals in mandibular first premolars located in the coronal, middle, and apical thirds of the root

	Overall	Coronal	Middle	Apical
Accessory canal	41 (35.7 %)	–	3	38
Intercanal communication	4 (3.5 %)	–	1	3
Loop	8 (7.0 %)	–	3	5
Isthmus	2 (1.7 %)	–	1	1

speculated that the results are influenced by the techniques employed for the investigation.

Radiography, cross-sectioning and staining, and root clearing have been the most commonly used techniques for the analysis of premolar root canal morphology. These techniques are limited to the acquisition of two-dimensional data and there are few previous reports of the use of micro-CT for the 3D investigation of premolar root morphology [2, 9, 14, 30].

In this study, accessory canals were present in 35.7 % of specimens, with most located at the apical third of the root canal. An isthmus is a narrow, ribbon-shaped communication between two root canals that contains pulp tissue or pulpally derived tissue. In this study, isthmuses were identified in 1.7 % in the middle and apical canals. The low incidence of these structures also represents a challenge to successful endodontic therapy for its complexity.

The number of apical foramen was not consistent with the root canal configuration. A relatively low percentage (76 %) of single canal foramen existed in specimens of type I canal. Multiple foramina might be the result of the existence of accessory canal and apical delta. A foramen was unusually identified on the root surface without a connection to the root canal. Approximately 77.4 % of apical foramina were located laterally, thus indicating that particular attention should be paid by clinicians to the relationship between the working length and the root length measured by X-ray imaging.

Apical delta, the most complex structure in the root canal system, was identified with an incidence of 6.1 % in this study (three specimens with one canal and four specimens with multiple canals), which was similar to the observations of Lu et al. [21]. However, the incidence of apical delta has been reported in other populations with variable frequency ranging from 5.7 % [31], 16.9 % [3], and 15.5 % [19] in Turkish populations and 29.2 % in Jordanian populations [29]. A recent study of the apical anatomy of premolars using micro-CT demonstrated that the presence of an apical delta was not an uncommon occurrence, even in a single, straight root canal [32].

Mesial invagination is a developmental groove in the mesial surface of the root, which is commonly observed in premolars. Reports have observed external developmental grooves or deep invaginations on the mesial surface in 17.6 % of first mandibular premolars [29] and mesial invagination in 14 % [33]. Furthermore, a relationship between invagination and C-shaped canal morphology has been postulated [6, 21]. In this study, a high incidence (27.8 %) of invaginations was detected, although the point of initiation and the depth of the invagination varied. Some anatomical correlations between canal configurations and invaginations were also noted. The invaginations were closely associated with canal configurations comprising multiple canals.
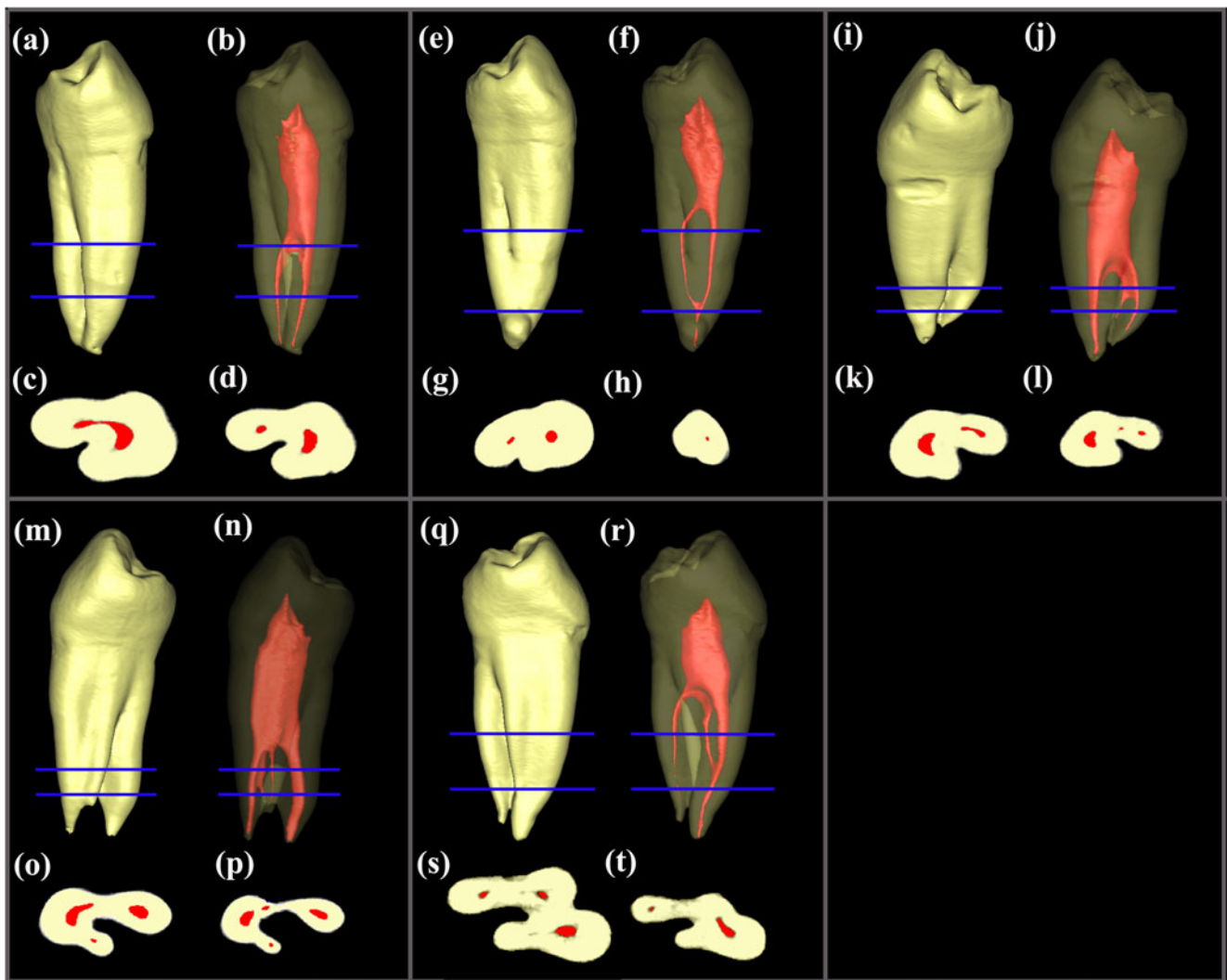
Fig. 8 Mesial invagination and corresponding root canal patterns. **a–d** Type V (1-2), **e–h** type III (1-2-1) canal with mesial invagination. Additional types include: **i–l** 1-2-3; **m–p** 1-3; **q–t** 1-3-2. **a, e, i, m, q** Contour image of the mesial surface; **b, f, j, n, r** 3D reconstruction of tooth; **c, d, g, h, k, l, o, p, s, t** C-shaped canal in cross-section

Among the 32 specimens with mesial invaginations, only 2 were type I canals, with the highest incidence of canal

Table 4 Pattern and percentage of mandibular first premolar canals with mesial invagination

Type of canal	Canal pattern	Number	Percentage of occurrence
Type I	1-1	2	6.25
Type III	1-2-1	2	6.25
Type V	1-2	21	65.61
Type VII	1-2-1-2	1	3.13
Additional type	1-3-2	3	9.38
	1-3	2	6.25
	1-2-3	1	3.13

configurations identified as type V (1-2) with a 65.6 % ratio (21 of 32). Others specimens were associated with more complicated canal types such as type III, type VII, and all additional types described in this study. Among the 40 specimens presenting with multiple canals, 75.0 % (30 of 40) exhibited mesial invaginations, while only 2 specimens with a single canal had invaginations. These data indicate the existence of a close correlation between invagination and a complex canal system which represents a significant challenge for endodontic therapy. Furthermore, it was observed that invaginations, particularly deep invaginations, were predominantly associated with a C-shaped canal, although this relationship requires further analysis. There is no doubt that micro-CT offers exciting potential for 3D assessment of the root canal system in great detail. As with traditional methods, micro-CT is limited to ex vivo

applications only and not suitable for clinical use at the current situation. Cone beam CT (CBCT) provides the clinician with an imaging modality that is capable of achieving a 3D representation of the maxillofacial region, from anatomical tooth anomalies to the composition of periodontal defects [34]. Thus, CBCT is a great aid in dentistry to optimize clinical endodontic procedures.

Conclusion

In this study, micro-CT was used as an accurate and noninvasive technique for the investigation of root canal morphology in a population from southwestern China. Data obtained revealed the complex anatomy of various types. The most common root canal pattern was identified as type I, although multiple root canals also presented with high incidence. Furthermore, the existence of an anatomical correlation between the presence of multiple root canals in first mandibular premolars and mesial invaginations was also identified.

Conflict of interest The authors declare that they have no conflict of interest.

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