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Microcomputed tomography evaluation of the root canals morphology of the mandibular first molars

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SUMMARY

Objective. The knowledge of the internal anatomy of the root canal system and its variations has a significant impact on the quality and outcome of endodontic treatment. The aim of this study was to evaluate the three-dimensional anatomical features of the root canals of mandibular first molars by using micro-computed tomography.

Material and methods. Sixty mandibular first molars were scanned using a high-resolution micro-computed tomography device. The 2- and 3-dimensional anatomical features of each root such as distance between anatomical apex and apical foramen, the number of the lateral canals and configuration of the isthmuses, were evaluated.

Results. The average distance between the anatomical apex and the apical foramen was 1.047 mm. Lateral canals were present in 85% of the cases, while 76% of them were localized in the apical third of the root. 80% of the mesial roots had isthmuses and the configuration of Type I, according to the Fan classification, was the most prevalent (35%).

Conclusion. The results of this study revealed the wide variations of internal root canal anatomy in mandibular first molars, including lateral canals and isthmuses. A clinician should always consider the possible difficulties of anatomical variations before starting root canal treatment, to select the best and optimal treatment strategies.

Keywords: microcomputed tomography, root canal anatomy, mandibular first molar.

INTRODUCTION

One of the aims of the endodontic treatment is to remove affected pulp tissue, clean, shape and hermetically fill the root canal system whilst saving as much dentin as possible (1). Mandibular first molars are one of the first permanent teeth that erupt, undergo endodontic treatment and therefore, due to the possible complications, are the most frequently extracted teeth as well (2). During root canal treatment, failures may occur due to the complex and unpredictable internal anatomy of the teeth. Therefore, the precious knowledge of anatomy is mandatory for clinicians to achieve the desired treatment results (3).

There are three anatomical structures in the apex of the root, which are used to describe the anatomy of the root apex: apical constriction, apical foramen and anatomical apex. The anatomical apex is the most protruding point in the apex of the root; while, the preparation of the root canal preferably should terminate at the apical constriction. However, the determination of this critical point is complicated, challenging or even impossible for the clinicians (4, 5). Therefore, the definition of the apical foramen is usually used to describe the endpoint of root canal cleaning and shaping. At the level of apical foramina, the root canal space starts to communicate with the periodontal ligament (6). It has been shown, that clinically, the difference between apical foramina and anatomical apex might affect the working length up to 3 mm (7).

Lateral canals are described as the branches of the pulp space, which reach the external/lateral surface of the root – periodontal ligament (8). Ricucci and Siqueira have determined that 75% of premolars and molar teeth have lateral canals (9). The number of lateral canals in one root may vary from 1 to 7 (10).

The isthmus is described as a narrow, ribbon-shaped communication between two root canals

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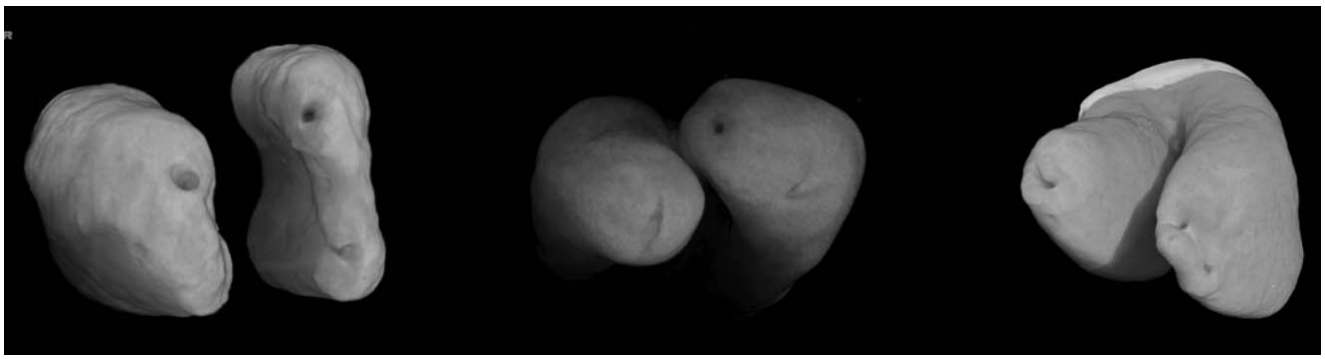

Fig. 1. Apical foramina in 3-dimensional reconstruction of three different mandibular first molars

that contain pulp or pulpal derived tissue (11). Isthmuses can be detected in any root which has two or more canals (11).

Before the era of microcomputed tomography (micro-CT), Hsu and Kim classified the isthmus configuration into five types using 2-dimensional evaluation methods (12). In 2010, Fan using the micro-CT data defined the configuration of the isthmuses in the mesial roots of mandibular molars into the four categories (13):

- Type I, sheet connection: narrow sheet and complete connection existing between 2 canals from the top to bottom of the isthmus. Sometimes, one or more small dentin fusions were detected in the isthmus area.
- Type II, separate: narrow but incomplete connection existing between 2 canals from the top to bottom of the isthmus.
- Type III, mixed: incomplete isthmus existing above and/or below a complete isthmus.
- Type IV, cannular connection: narrow cannular communication between 2 canals.

Almost all 2-dimensional methods for the evaluation of the internal

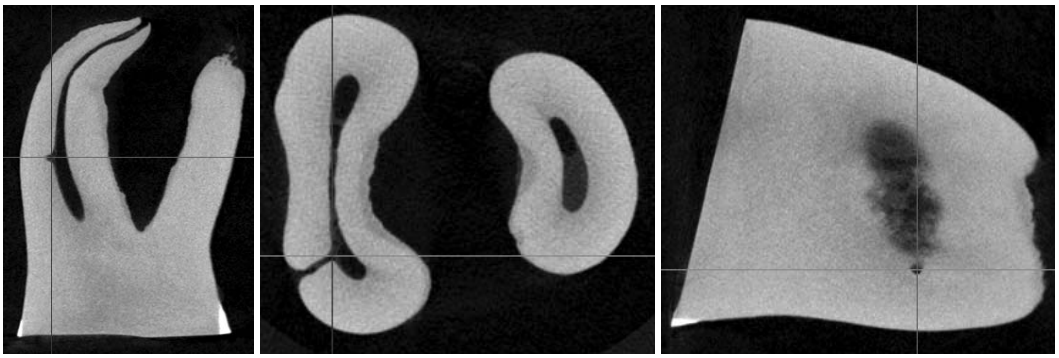

Fig. 2. Evaluation of lateral canals in 3 dimensions

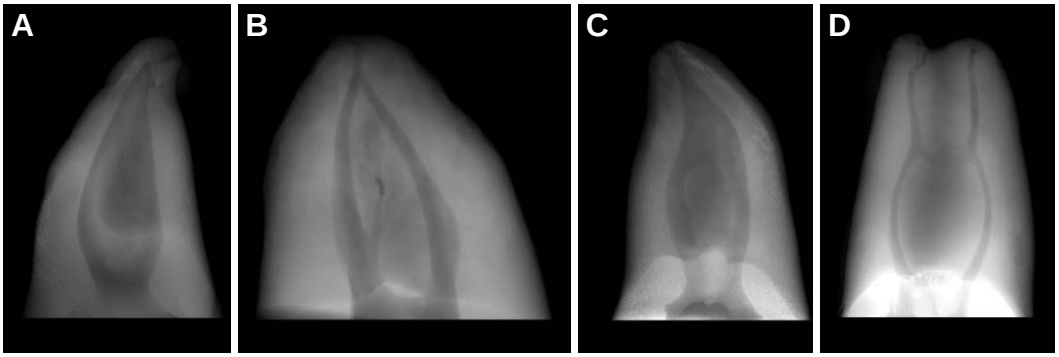

Fig. 3. Fan's classification of isthmuses: A – Type I; B – Type II; C – Type III and D – Type IV.

Table 1. Average distance between anatomical apex and apical foramen

	All teeth	Mesial root	Distal root
Distance	1.047 mm	1.014 mm	1.089 mm

Table 2. Frequency and localization of the lateral canals of the first mandibular molars

		Mesial root	Distal root	In total
Root third	Apical	69.57%	90.32%	76%
	Middle	15.24%	9.68%	14%
	Coronal	14.49%	0%	10%
In total		**N=69**	**N=31**	**N=100**

Table 3. Isthmuses by Fan classification

Type of isthmus	No isthmus	I	II	III	IV
Number and percent of mesial roots	12 (20)	21 (35)	5 (8.33)	12 (20)	10 (16.68)

root canals anatomy are harmful and destructive for the dental tissues of the specimens. In comparison, the micro-CT is a noninvasive, nondestructive, precise and repeatable method for the three-dimensional root canal anatomy investigation (6).

The aim of this study was to evaluate the anatomical features such as apical foramen, lateral canals and isthmuses of human mandibular first molars using micro-computed tomography.

MATERIALS AND METHODS

For this study, the approval of the local ethical committee was obtained (protocol No. EK-2). The total of sixty not previously treated, non-carious for medical reasons extracted mandibular first molars with fully developed root apices were used in this study. The age and gender of the patients were unknown. Teeth were left in 2.5% sodium hypochlorite solution for 30 minutes after extraction to remove soft tissues. After that, they were rinsed under tap water for 30 minutes and kept in 0.1% thymol solution until further use. The crowns of the teeth were removed using high-speed diamond bur. The specimens were scanned with high-resolution micro-CT scanner (SkyScan 1173; Bruker microCT, Kontich, Belgium) using constant parameters: 110 kV, 50 mA, 1-mm aluminum filter, 180° rotation around the vertical axis with rotation step of 0.18 and an isotropic resolution of 22.8 μm. Appropriate software (NRecon v.1.6.9, Bruker-microCT) was used to reconstruct each specimen. Finally, the CTVol 1.10.1.0 software (Bruker-microCT) was used for 3D volumetric visualization.

The anatomical apex, apical foramina, lateral canals and isthmuses were evaluated in three dimensions. The most protruding root point in the apex was selected as the apical foramina. If the root had two most protruding points in the apex, it was considered as having two anatomical apices. The center point of the root canal opening was marked as an apical foramen. If there were few openings, the widest one was selected as the apical foramina, and the other ones were evaluated as the apical delta. The distance between apical foramina and anatomical apex was calculated using DataViewer software (1.5.2 v., Brucker-microCT). The configurations of the lateral canals and isthmuses were evaluated by analyzing the three-dimensional reconstructions of the specimens. Lateral canals were subdivided into three-thirds regarding on the point it branched off from the main root canal. All data were processed using Microsoft Excel 2016 v16.0 (Microsoft, Redmond, WA, USA).

RESULTS

The three-dimensionally reconstructed volumetric models of the mesial and distal roots of the molars were used for assessment (Figure 1). All distal roots had one anatomical apex, which in 96.67 % of the cases had one foramen, while 3.33% had two foramina. Meanwhile, 90% of the mesial roots had one, and 10% had two anatomical apices. In 81.48% of cases, roots with one anatomical apex had one, 16.67% - two and 1.85% - three apical foramina, respectively. The data about the average distances between the anatomical apex and apical foramina are detailed in Table 1. The average distance in distal roots were 0.075 mm greater than in mesial.

The lateral canals were identified in 85% of molars evaluated (Figure 2). Of the 100 lateral canals detected, 69 of them were in the mesial roots and 31 in the distal roots. The prevalence and distribution of lateral canals in the different thirds of the root are summarized in Table 2.

The isthmuses have been detected in 80% of mesial roots. The type and the prevalence of the isthmuses, according to Fan classification, are detailed in Figure 3 and Table 3. No isthmuses were identified in the distal roots of the specimens.

DISCUSSION

On average, the roots of mandibular molars have from one to three apical foramina (12, 13). However, according to Guttierez *et al.*, one root can have up to 16 apical foramina, demonstrating the vast variety in internal anatomy of the teeth (14). Even though the micro-CT is a very precise method for assessment of the internal anatomy of the teeth, there were no teeth detected with an extreme number of foramina in our study. Vertucci has shown that approximately 50% of mesial roots of mandibular molars had more than one apical foramen (11). The results of our study confront with these findings, as only 26% of mesial roots had more than one apical foramen.

It has been shown that the deviation of the anatomical foramen from the anatomical apex is quite common (15). According to the published data, the coincidence of apical foramina and anatomical apex varies from 17% to 100% of cases, while the average distance between these anatomical features is 1 mm (15). Furthermore, Alothmani revealed that the distance between the apical constriction and apical foramen varies from 0.4 to 1.2 mm (15). Martos *et al.* showed that deviation is more frequent in mandibular teeth (16). However, the same author has

found that it is more common in maxillary teeth (17). In this study, all of the apical foramina did not match with anatomical apices, and the distance between them varied from 0.215 to 2.908 mm. In distal roots, the average distance was higher than in mesial roots. Micro-CT studies commonly detect more discrepancies between localization of apical foramen and anatomical apex because the anatomical points are evaluated very precisely. It is mandatory to understand that even though it is very hard to discern the anatomical apex from apical foramen clinically, the average distance between them of 1 mm may be crucial in the successful endodontic treatment.

In this study, 85% of teeth had lateral canals, while the majority of them (76%) were localized in the apical third of the root. The distribution of lateral canals between the root thirds was comparable to previous findings published by Vertucci (11). Also, in our study, the incidence of lateral canals was almost the same as in Ricucci and Siqueira investigation (9).

Fan *et al.* (2010) classified isthmuses into four categories, while the study results revealed that 85% of mesial roots of mandibular molars had isthmuses (13). Meanwhile, Hsu *et al.* have shown that the incidence of isthmuses in the mesial roots of the mandibular molars varies from 54% to 89%. The majority of them are located in the middle and apical thirds of the root (12). Our results are in agreement with previous findings – 80% of the mesial roots of the first mandibular molars had isthmuses. However, the distribution among types of isthmuses was slightly different. In our study, isthmus Type I was the most frequent (35%), while in the Fan's study, Type II was the most prevalent (29%). However, it should be mentioned that root canal anatomy in all mesial roots which did not have isthmuses was classified as a type I by Vertucci classification.

Micro-CT has a higher resolution than cone-beam computed tomography; therefore, it provides more precise and detailed information about the three-dimensional internal root canal anatomy (1). The drawback of this investigation method is that it is time-consuming, expensive and can only be used on extracted teeth. Moreover, due to these reasons, the sample size of micro-CT investigations usually is reduced to the reliable minimum; therefore, the anatomical findings among different investigations can vary substantially. Hence, the new studies on the internal 3D anatomy of the teeth add valuable information to the existing and published data.

CONCLUSION

Within the limitations of this in vitro study, the results revealed the wide variations of internal root canal anatomy in mandibular first molars, including the localization and number of apical foramina, lateral canals and isthmuses. The mandibular first molars showed a high prevalence of lateral canals (85%), localized predominantly in the apical third of the root, and isthmuses (80%), with the most common Type I according to Fin's classification. The average distance of 1.047 mm from apical foramen and the anatomical apex was identified.

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