Original Research
Anatomy

Micro-CT evaluation of maxillary first molars: interorifice distances and internal anatomy of the mesiobuccal root

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Abstract: This study aimed to describe the morphometric relationship of root canal orifices on the pulp floor in the presence/absence of mesiobuccal second canal (MB2) in the maxillary first molars and other aspects of its internal anatomy. Sixty-two maxillary first molars were scanned by micro-CT. The presence of the MB2 canal was verified. The distance between the center points of the MB1, MB2, distobuccal (DB), and palatal (P) canal orifices on the pulp floor were measured (MB1-MB2, MB1-DB, MB2-DB, MB1-P, and DB-P). The MB1-P to DB-P ratio was calculated. The distances between the anatomic apex and the MB1 and MB2 apical foramina were measured. The length of the band-shaped isthmus was also measured. Student's t-test was applied to verify the association between the presence of an MB2 canal, the interorifice distances, and the ratio of the MB1-P to DB-P distance ($\alpha = 5\%$). The MB2 canal was present in 43 roots (69.35%). Statistics showed significant differences when MB2 was present for the largest MB1-P distance ($p < 0.05$) and higher values for the MB1-P to DB-P ratio ($p < 0.05$). A band-shaped isthmus was detected in 25.8% of MB roots. The mean distance from the apical foramen to the isthmus floor ranged from 1.74 for MB1 canals to 1.42 for MB2 canals. Canal orifice distances on the pulp floor may predict the presence of MB2 canals. There was a high incidence of isthmus, accessory canals, and apical delta in the critical apical zone in MB roots of maxillary first molars.

Keywords: Dental Pulp Cavity; X-Ray Microtomography; Endodontics; Molar.

Introduction

Knowledge of the internal morphology of different dental groups is essential for proper endodontic treatment.[1,2,3,4] Maxillary first molars have a complex internal anatomy, particularly in the mesiobuccal (MB) roots because of the presence of an additional canal (MB2).[1,2,33] MB2 usually has more atresia and its patency cannot be easily achieved compared with the main canal (MB1).[3,5,6] Consequently, overlooking the presence of MB2 is associated with endodontic treatment failure and with the occurrence of periapical lesions.[1,2,3]

Isthmuses are defined as thin communications between two canals, formed by the fusion or anastomosis of two root canals, establishing a narrow area containing pulp tissue.[7] Isthmus may occur in the MB root because of the relationship between MB1 and MB2 canals.[8,9] These critical zones retain microorganisms in the root canal system (RCS) and are frequently associated with apical periodontitis due to the difficulty in accessing them during cleaning, shaping, and filling procedures.[7,10,11,12]

Furthermore, the position of the major apical foramen in relation to the anatomic apex is highly variable in the MB2 canal.[13] Consequently, determining the working length (WL) and shape is a challenge in clinical practice.[13,14] Anatomically, the "critical apical zone" includes the apical third of the root canal, the apical foramen, and its branches (apical foramina or accessory and secondary canal foramina) located within the 3–5 mm root apex.[2,3,5,13] This area is problematic to manage, and available technologies, *i.e.*, cone-beam computed tomography (CBCT) and dental operating microscope (DOM), present limitations and questionable sensitivity in detecting these complexities.[7,15,16]

Micro-computed tomography (micro-CT) is considered a superior method for the investigation of root canal anatomy in *ex vivo* studies, as it provides greater anatomical detail and quantitative data compared to other imaging methods, and avoids the destruction of the specimen. This non-invasive technique keeps the specimen intact and allows detailed two- or three-dimensional (3D) reconstruction, providing quantitative and qualitative information on external/internal anatomy.[2,5,13,14] Most recently, several micro-CT studies on the anatomical complexity of the RCS have been used as the basis for the development of more efficient methods and protocols for irrigating solutions applied in mandibular molars.[7,9,17,18,19] However, there is a gap in the literature about the investigation into the isthmus and apical anatomy of maxillary molars using micro-CT.[12,20,21]

This micro-CT study aimed to describe the morphometric relationship of root canal orifices on the pulp floor in the presence/absence of MB2 and some aspects of the internal anatomy of the MB root, including isthmus and the apical canal system anatomy.

Methodology

Specimen selection

The study protocol was approved by the Institutional Review Board of the Pontifícia Universidade Católica of Minas Gerais (#037807). A sample of 90 maxillary first molars extracted for reasons unrelated to this study was selected from a human teeth bank. Mesiodistal and buccolingual digital radiographs were taken and, after application of exclusion criteria (root canal fillings, abrupt curvatures, root caries, cracks, fractures, internal or external resorption), 62 teeth were finally selected for this study.

Scans and 3D reconstruction

The teeth were scanned with a micro-CT device (SkyScan 1174v2, Bruker-micro-CT, Kontich, Belgium) using 50 kV, 800 mA, an isotropic resolution of 22.9 µm, rotation step of 0.7°, and 360° of rotation. The acquired images of each specimen were reconstructed with dedicated software (NRecon v.1.6.1.5, Bruker-micro-CT) providing axial cross-sections of the inner structure of the teeth. 3D models of the mesiobuccal roots were recreated after binarization of the source images and exported as P3G files using CTAn software (v.1.15.4, Bruker-microCT).

Presence/absence of the MB2 canal

An endodontist with expertise in microtomographic evaluation determined the presence/absence of a second canal in the mesiobuccal root of each maxillary molar from reconstructed 3D images and Data Viewer software (version 1.5, Bruker-microCT). Continuous observations of the axial plane were made throughout the mesiobuccal root from the cementoenamel junction to the apex to determine the presence of the MB2 canal.

Distances between MB1 and MB2 canal orifices in the pulp chamber

CTAn software (Bruker-microCT) was used to measure the horizontal distances between the MB1 and MB2 canals on the pulp floor. The axial slice corresponding to the pulp floor that allowed the visualization of the entrance of all canals was defined in each maxillary first molar. The center points of MB1, MB2, distobuccal (DB), and palatal (P) canal orifices were defined on the pulp floor, and the distance between those points (MB1-MB2, MB1-DB, MB2-DB, MB1-P, and DB-P) was measured as the interorifice distance, according to a previous study.[6] The MB1-P to DB-P ratio was calculated.

Distances between the anatomic apex and the major apical foramen in MB canals

The distance between the anatomic apex (apical root vertex) and the major apical foramen was measured by CTAn software (Bruker micro-CT) in both MB canals. When an apical delta or more than three apical foramina were present, the canal with the largest diameter was designated as the major apical foramen.

Band-shaped isthmus measurements

The band-shaped isthmus length was measured using CTAn (Bruker micro-CT). The most coronal and apical slices in which the entire isthmus was visible were determined as the isthmus roof and the isthmus floor, respectively. The distance between the isthmus roof and floor was measured and recorded as the isthmus length. The distances between the band-shaped isthmus floor and major apical foramina were measured.

Accessory canal, accessory foramen, and apical delta

The presence or absence of accessory canal, accessory foramen, and apical delta[15] was verified at the apical third of each MB root using Data Viewer software v.1.5.1 64-bit (Bruker-microCT) (Figure 1).

Statistical analysis

Statistical analysis was performed using Statistical Package for the Social Sciences software version 22.0 (SPSS Inc., Chicago, USA). Differences among the interorifice distances (MB1-MB2, MB1-DB, MB2-DB, MB1-P, and DB-P), and the ratio of the MB1-P to DB-P distance in teeth with presence/absence of MB2 canal were compared

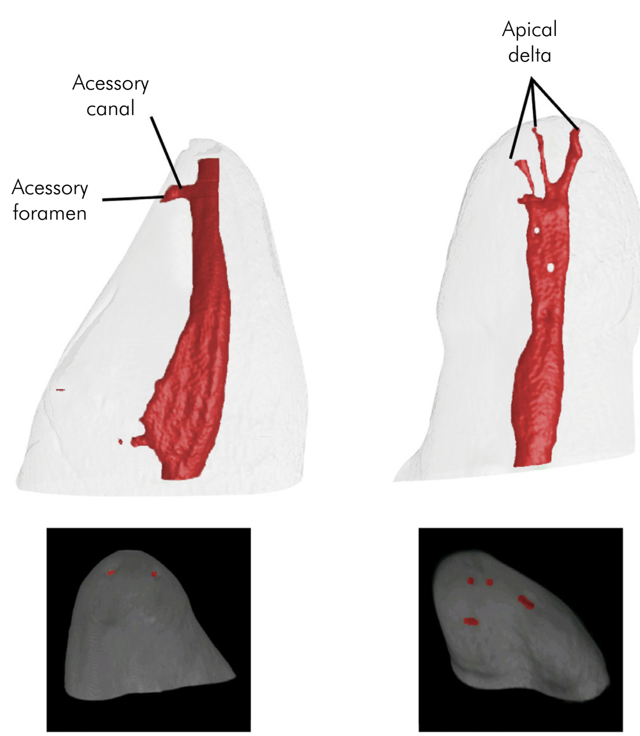

Figure 1. Reconstruction micro-CT image representations showing the accessory canal, accessory foramen, and apical delta.

using Student's t-test. The foramen-apex distances of MB1 and MB2 canals and the band-shaped isthmus length were demonstrated as means and standard deviations. Apical delta, accessory canal, and foramen data are presented as absolute values and relative frequencies. The level of significance was set at α = 5%.

Results

The MB2 canal was present in 43 roots (69.35%). The mean horizontal distance between the MB1-MB2 canals on the pulp floor was 2.30 mm ± 0.57 mm (Figure 2B). Table shows the values of the distances between all root canal orifices. Figure 2A shows the representative anatomical picture of MB1 and MB2 root canals. Student's t-test showed significant differences regarding maxillary first molars with the absence or presence of MB2 for the MB1-P distance (2.37 ± 0.50 when absent and 2.79 ± 0.51 when present; $P < .05$) and for the ratio between the MB1-P and DB-P distances (1.25 ± 0.16 when absent and 1.41 ± 0.25 when present; $p < 0.05$).

Band-shaped isthmus was present in 25.8% of the 62 specimens, and 100% of the specimens with this anatomical feature had an MB2 canal. The distance from the apical foramen to the isthmus floor ranged from 0.69 to 5.72 mm (± 1.67 mm). The presence of a band-shaped isthmus was demonstrated in 16 specimens. The mean of the measurements of the band-shaped isthmus length in all roots is presented in Figure 3. Moreover, 26 (41%) MB roots presented an apical delta,

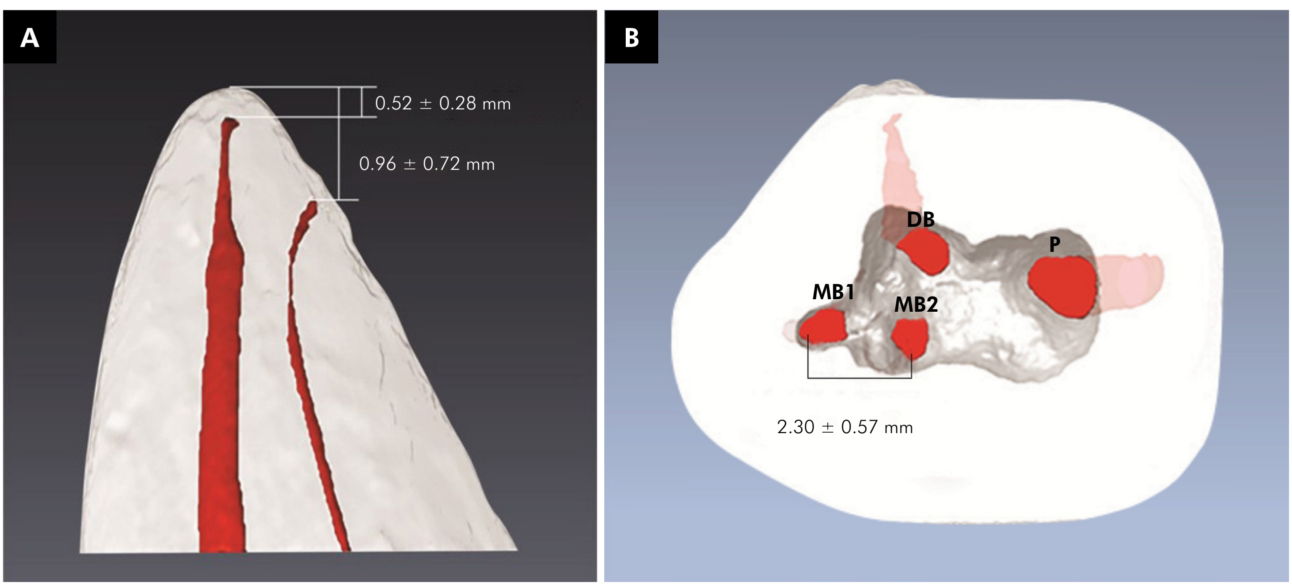

Figure 2. A. Reconstruction micro-CT images of the measurement between the foramen and apex of MB1 and MB2 canals. B. Distance between MB1 and MB2 canal orifices on the pulp floor.

Table. Distances between root canal orifices in maxillary first molars.

Distance	MB1-P orifice (mm)			DB-P orifice (mm)			MB1-DB orifice			MB2-DB orifice (mm)		
	Mean ± SD	Max	Min.	Mean ± SD	Max.	Min.	Mean ± SD	Max.	Min.	Mean ± SD	Max.	Min.
MB2 present	5.388 ± 0.675	6.7	2.88	3.883 ± 0.572	5.66	2.78	2.791 ± 0.507	4.35	1.81	2.301 ±0.570	4.38	1.53
MB2 absent	5.124 ± 0.575	6.09	4.0	4.164 ±0.616	5.47	3.19	-	-	-	-	-	-

DB: distobuccal; MB1: main mesiobuccal; MB2: second mesiobuccal; P: palatal; SD: standard deviation.

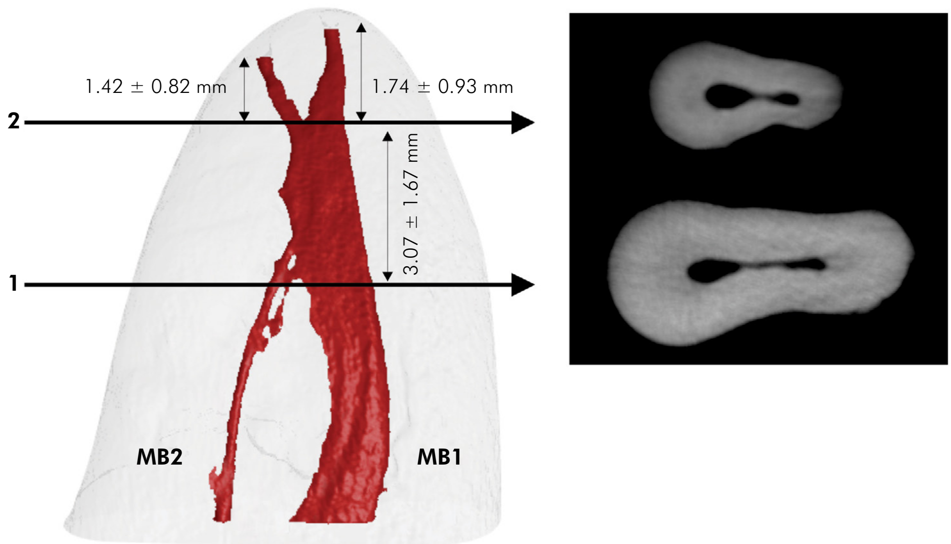

Figure 3. Two and three-dimensional models of specimens showing a band-shaped isthmus and the mean of the measurement for the 16 specimens using CTAn software (Bruker micro-CT).

and 31 (50%) accessory canals were identified in the specimens at the apical third of the canal.

Discussion

In the literature, the frequency of MB2 in maxillary molars ranges from 25% to 100%.[1,2,3,5] The results of this micro-CT study (69.35%) are in agreement with the ones found in a meta-analysis in which two canals were present in 64.2% of maxillary first molars (95%CI: 59.5–68.7).[22] The variances between the results of the studies can be explained by the variation in sample size, ethnicity, and the different methods and techniques employed.[1,14,22] Furthermore, other factors, such as age and sex, seem relevant and also interfere in these results.[22] In clinical practice, radiographs have limitations due to the two-dimensional representation and, therefore, do not have sufficient sensitivity for MB2 canal detection.[13,14,23]

This micro-CT study aimed to assess the relationship between the presence of the MB2 canal and the distribution of the canal orifices in maxillary first molars. Our results support the findings of a CBCT *in vivo* study, *i.e.*, the larger the MB1-P to DB-P ratio (> 1.26), the higher the chance of the existence of an MB2 canal in CBCT images.[6] A visual assessment during endodontic access can provide valuable information about the possibility of the existence of the MB2 canal, when a bigger MB1-P distance is identified, suggesting that the clinician should employ techniques such as DOM and US tips in order to detect MB2.[3,5,6,14,21]

Isthmuses constitute areas of difficult access and clinical identification, establishing an environment for microorganisms, pulp fragments, and necrotic remains.[7,8,12,18] This cross-sectional micro-CT study evaluated the presence of an isthmus and measured the MB roots of maxillary first molars; and 80% of them presented an isthmus. In a previous micro-CT study, the incidence of an isthmus in the apical 5 mm of the mesial roots of mandibular molars was 85%.[18] In a CBCT evaluation, the presence of isthmus was detected in 86% of maxillary molars in *ex vivo* and 62% in *in vivo* assessment.[20] The variations in isthmus incidence between the studies can be explained because of the divergence in the amount of primary dentin deposited during dental development, or secondary dentin, in the physiological deposition, or possible calcification of the pulp canal.[20] In addition, in *ex vivo* evaluations, there is less interference in imaging exams than in *in vivo* studies, facilitating the identification of isthmus by these exams.

The band-shaped isthmus represents an additional challenge in endodontic practice.[7] They are commonly located in the buccolingual direction, and thus radiographic examination is inefficient for their detection.[7,10] The distance from the apical foramen to the band-shaped isthmus floor varied from 0.69 to 5.72 mm (± 1.67 mm) in mesiobuccal roots of maxillary first molars. By contrast, in a study on mandibular molars, the length of the isthmus at the apical 3 mm level presented a minor variation from 0.91 to 2.68 mm (± 1.89 mm).[7] In a similar study, 17.25 to 50.25% of sections showed an isthmus at the apical 5 mm of mandibular molar mesial roots.[17] This isthmus has been widely studied in mandibular molars.[7,10] Although the isthmus is rarely studied in maxillary molars, it is a possible finding in such type of teeth owing to their position in the dental arch, the degree of flattening, and the number of roots and canals.[1,24,25]

Despite the uncertain sensitivity of tomographic exams in identifying the complete anatomical complexity of the RCS, the quality/power/kV of the CBCT or micro-CT device is one of the factors that may interfere with the assessment of the isthmus.[23,28] In the present study, micro-CT was used, since it has been reported to provide a detailed three-dimensional morphological analysis. However, one of the disadvantages of this method is the impossibility of being used in *in vivo* evaluations.[7,12,21] High-resolution CBCT, a method with high clinical value, demonstrates low sensitivity (65%) regarding isthmus detection and has been questioned for this purpose.[8,12] Nevertheless, in clinical practice, CBCT scanning may play an important role in revealing the complex anatomy of roots with unexpected anatomical configurations.[18,26,27]

This study also evaluated the presence of accessory canals, a relevant anatomical finding associated with the failure of endodontic treatment because of the difficulty in cleaning and filling these structures.[13,15] Accessory canals at the apical third were observed in 50% of the specimens. Other studies found a higher prevalence, *e.g.*, 76.7%[24] and 85%,[32] however, these studies evaluated all thirds of the canals, while the present study assessed only the apical third. Additionally, the efficiency of this micro-CT scan showed that 46.5% of maxillary first molars presented an apical delta, a higher incidence compared with the 25% detected in a previous clearing study.[25]

The apical third is a critical area and its incomplete disinfection can lead to apical periodontitis, causing endodontic failure.[7,11,15,18] In the present study, the average distance between the isthmus floor and the apical foramen was 1.74 (± 0.82mm) and 1.42 (± 0.93mm) for the MB1 and MB2 canals, respectively. This suggests that most of these isthmuses are located at the most apical third of root canals. In mandibular molars, the detected mean distances from the isthmus floor to the mesiobuccal and mesiolingual apical foramina were 1.51 mm and 1.05 mm, respectively.[7] Despite the limitations of this study, it is acceptable to recommend the use of magnification for better visualization of the isthmus in both dental groups, as well as additional cleaning methods and irrigation solution activation, as previously described, improving disinfection in untouched areas in the RCS.[9,27,33,34]

Some studies have evaluated the best cleaning protocols for mandibular molars[19,34] and premolars.[33] However, the present study points to the need to investigate the maxillary first molars, due to their complex internal anatomy. Since isthmus occurs in most MB roots of the maxillary first molars, although they cannot be seen by routine imaging, it is recommended to increase the cleaning procedures to accomplish rigorous biomechanical management in these difficult-to-reach areas.[8,10,12,18,21]

Conclusions

Based on the results of the present study, the larger distances between the orifices of the canals in maxillary first molars suggest the existence of MB2 canals. There is a considerable incidence of accessory and apical delta canals in this dental group and a morphometric analysis of the isthmus in MB roots indicates a higher prevalence of band-shaped isthmus at the apical third.

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