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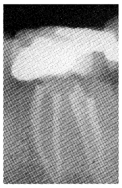

CLINICAL ARTICLE

Root canal morphology of the mesiobuccal root of maxillary first molars: a micro-computed tomographic analysis

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Abstract

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Aim To investigate *ex vivo*, the root canal morphology of the MB root of maxillary first molar teeth by means of micro-computed tomography.

Methodology Thirty extracted intact human maxillary first molar teeth were selected for micro-tomographic analysis (SkyScan 1072, Aartselaar, Belgium) with a slice thickness of 38.0 μm. The following data regarding the MB root were analysed and recorded: number and type of root canals, prevalence of isthmuses, prevalence of intercanal connections, presence of accessory canals, presence of loops and number of apical foramina.

Results The MB2 canal was present in 80% of specimens and was independent in 42% of these cases. When present, the MB2 canal merged with the MB1 canal in 58% of cases. Communications between the two canals were found in all specimens, with isthmuses in 71% of the cases. These communications and isthmuses were respectively in 42% and 54% of the cases in the coronal third, in 59% and 79% of the cases in the middle third and in 24% and 50% of the cases in the apical third. A single apical foramen was found in 37% of specimens, two apical foramina were present in 23% of the cases, with three or more separate apical foramina occurring in 40% of the specimens.

Conclusions The MB root canal anatomy was complex: a high incidence of MB2 root canals, isthmuses, accessory canals, apical delta and loops was found.

Keywords: maxillary first molar, mesiobuccal root, micro-computed tomography, root canal anatomy.

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Introduction

The main objective of root canal treatment is thorough shaping and cleaning of all pulp spaces and its complete filling with an inert filling material (European Society of Endodontology 2006). A major cause of post-treatment disease is the inability to locate, debride or fill properly all canals of the root canal system (Vertucci 2005). Together with diagnosis and treatment planning, a better knowledge of the root canal system and its frequent variations is an absolute necessity for a successful root canal treatment (Friedman 2002). Hess (1921) reported on the wide variation and complexity of root canal systems establishing that a root with a tapering canal and a single foramen was the exception rather than the rule (Hess 1921). Weine *et al*. (1969) divided the position of one or two canals within a root into four basic types (Table 1). Vertucci (2005) described a much more complex canal system and identified eight pulp space configurations (Table 2).

In the literature, the mesiobuccal (MB) root of the maxillary first molar has generated more research and clinical investigation than any root (Cleghorn *et al.* 2006). In studying the MB root of maxillary molars, an increase in the number of second mesiobuccal canals (MB2) was demonstrated clinically when new instruments, equipment and techniques became available (operating microscope, ultrasonic tips, staining the chamber floor, rhomboidal access, etc.; Vertucci 2005).

In recent years, the development of X-ray computed transaxial microtomography (micro-computed tomography, MCT) has gained increasing significance in the study of hard tissues. MCT offers a noninvasive reproducible technique for three-dimensional (3D) assessment of root canal systems and can be applied quantitatively as well as qualitatively. Furthermore, internal and external anatomy can be demonstrated simultaneously or separately (Plotino *et al*. 2006). Unfortunately, this technique is not suitable for clinical use, but cone-beam computed tomography (CBCT) systems have now been introduced for imaging hard tissues of the maxillofacial region (Scarfe *et al.* 2006, Patel *et al.* 2007). CBCT is capable of producing sub-millimetre resolution (ranging from 400 μm to as low as 125 μm) with images of high diagnostic quality. The short scanning time (10–70 s) and radiation dosage is reportedly up to 15 times lower than that of conventional CT scans. Although the CBCT principle has been in use for almost two decades, affordable systems have only recently become commercially available. An increase in availability of

Table 1 The position of one or two canals within a root as described by Weine *et al.* (1969)

Type I	A single root canal extend from the pulp chamber to the apex
Type II	Separate root canals leave the pulp chamber and join short of the apex to form one canal
Type III	Two separate and distinct root canals leaving the pulp chamber and exiting the root in separate apical foramina
Type IV	One canal leaving the chamber and dividing into two separate and distinct canals with separate apical foramina

Table 2 Pulp space configurations as described by Vertucci (2005)

Type I	A single canal with one foramen
Type II	Two canals that join in the apical third
Type III	One canal that divides into two that subsequently reunite and exit as one
Type IV	Two separate canals all the way to the apex
Type V	One canal that divides just short of the apex
Type VI	Two canals that unite in the root and then divide again at the apex
Type VII	One canal that divides, reunites and finally exits through two apical foramina
Type VIII	Three separate canals in one root

this technology provides the clinician with an imaging modality that is capable of providing a 3D representation of the maxillofacial region with minimal distortion. These systems are promising and eminently more suitable than MCT scans which are limited to *ex vivo* applications only and not suitable for patient care.

The purpose of this study was to investigate the root canal morphology of the MB root of maxillary molars by means of MCT.

Material and methods

Thirty extracted human maxillary first molar teeth having three separate roots were randomly selected for micro-tomographic analysis from a pool of extracted teeth from an Italian population (age ranging from 35 to 55 years). After extraction, the teeth were cleaned in 5% NaOCl solution for 24 h, debrided of periodontal tissue and calculus, washed under running water, blotted dry and stored in saline solution. The criteria for selection were the following. Each tooth had to have fully formed apices, no restorations with intact crowns and no defects or carious lesions.

A specimen holder with a diameter of 15 mm was used and a custom made attachment from acrylic resin was made for each tooth to exactly fit the specimen and the specimen holder of the MCT. The analysis of each sample consisted of two stages requiring approximately 4 h in total: 2 h for scanning and 2 h for the reconstruction procedure.

All samples were scanned using a desktop X-ray microfocus CT scanner (SkyScan 1072, SkyScan b.v.b.a., Aartselaar, Belgium) and the scanning procedure was completed using 10 W, 100 kV, 98 μA, a 1-mm thick aluminium plate and 15× magnification with 5.9 s exposure time and 0.45° rotation step, resulting in a pixel size of 19.1 × 19.1 μm. A scanning period of approximately 3.6 s per degree of rotation was found to provide the best contrast and image quality. The average scanning time per sample was approximately 1.5 h. The acquisition procedures consist in the realization of several two-dimensional lateral projections of the specimens during the 180° rotation around the vertical axis. These digital data were further elaborated by a reconstruction software (NRecon V1.4.0; SkyScan b.v.b.a.) providing new axial cross sections with a pixel size of 19.1 × 19.1 μm. The distance between each cross-section was 38.0 μm. The cross sections were collected by sample, and after cone-beam reconstruction, the raw data were converted to 16-bit bit-mapped picture files with a resolution of 512 × 512 pixels. Using a computer software analysis system (CT-analyzer V1.6; SkyScan b.v.b.a.), all files of each sample were re-sliced stepwise using a slice spacing factor 2 in vertical cross-sections. From the reconstruction results, a 3D reconstruction was achieved for each tooth with the use of an external programme, '3D-Creator' (SkyScan b.v.b.a.) to show in detail macromorphology of the teeth analysed. These data were then stored for later use. After completion of the scanning procedure, the samples were replaced in the saline solution.

The observations on the root canal morphology were conducted by a single observer on the actual cross-sections using the t-view software (SkyScan b.v.b.a.) that permits visualization of subsequently all the reconstructed sections on a LCD monitor (LaCie 324, 24″, maximum resolution 1920 × 1200). The data regarding the MB root were analysed and recorded, and averages and percentages were determined for each of the following: number and type of root canals (Weine 2004); presence of accessory canals [defined as any branch of the main pulp canal or chamber that communicated with the external surface of the root (Vertucci 2005)]; presence of loops (defined as a branch of the main canal that divides from it and then rejoins in the original canal); 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 (2005)];

prevalence of isthmuses [defined as a narrow, ribbon shaped communication between two root canals that contains pulp tissue (Weller *et al.* 1995)] and their location; prevalence of intercanal connections (defined as any branch of a canal that communicates with another canal in the same root), and their location. In the analysis of the cross-sections, an isthmus has been identified when the two canals appeared as a single ribbon shaped canal on the same cross-section for several consecutive cross sections, while an intercanal connection between two canals has been identified as an accessory pulp space commencing from a root canal in one cross-section that entered the other root canal in other cross sections, like an accessory canal between the two main canals.

Results

A MB2 canal was present in 80% of the cases (24 teeth). It was a completely independent canal in 42% of specimens (10 teeth) (Fig. 1a). Table 3 presents for each of the different types of canals (conjunction between MB1 and MB2, accessory canals, loops, isthmuses, intercanal connections) the prevalence in percentage for the roots overall, and for the coronal, middle and apical third of the roots respectively. Communications between MB1 and MB2 are found mainly in the coronal and middle part of the root (Fig. 1b) whereas accessory canals and loops were mainly found in apical third of the root (Fig. 1d). In five teeth (21% of the cases in which the MB2 was present), the MB2 canal had its origin some distance down the orifice of the MB1 canal. When the MB root had a single canal (six teeth; 20% of the cases) (Fig. 1c) it was flattened in the coronal and middle third and had a tendency to be round in the last 3–4 mm only (four teeth; 67% of these cases), while it was circular in almost its entire length in the other two cases (33%).

An isthmus (Figs 2 and 4a,b) and an intercanal connection (Fig. 3) could be localized in different regions of the same root. They were predominantly found in the middle part (Table 3: 59% and 79% respectively) and the coronal part (Table 3: 83% and 58% of the cases respectively), while they were present in 24% and 50% of the cases in the apical third (Table 3). A single apical foramen was found 37% of the time (11 teeth), while two apical foramina were present in 23% of these cases (seven teeth) (Fig. 4d). Three separate apical foramina were present 20% of the time (six teeth) (Fig. 4e). In other six teeth (20% specimens), an apical delta (more than three apical foramina) was present (Fig. 4f).

Discussion

Weine (2004) stated that frequent failure of endodontic treatment in maxillary first permanent molar teeth was likely due to the failure to locate and fill the second mesiobuccal canal. The second canal in the MB root has been observed at least since 1921 (Hess 1921). However, it was not until 1969 that its significance appeared to be recognized by Weine *et al.* (1969). Since then, its incidence has been reported and discussed by several authors, and a wide range of variation is present in the reported literature with respect to frequency of occurrence of the number of canals in this root (Cleghorn *et al.* 2006).

The results of this study on an Italian population demonstrated a high prevalence of two canals in the MB root (80%) of permanent maxillary first molar teeth, supporting the view that three roots and four canals are the most common form in fully developed teeth (Cleghorn *et al.* 2006). A recent literature review on the root and root canal morphology of the human permanent maxillary first molar gave a comprehensive review of the laboratory and clinical studies published on the anatomy of roots and root canal systems of this tooth (Cleghorn *et al.* 2006). The present findings were compared with the averages obtained in

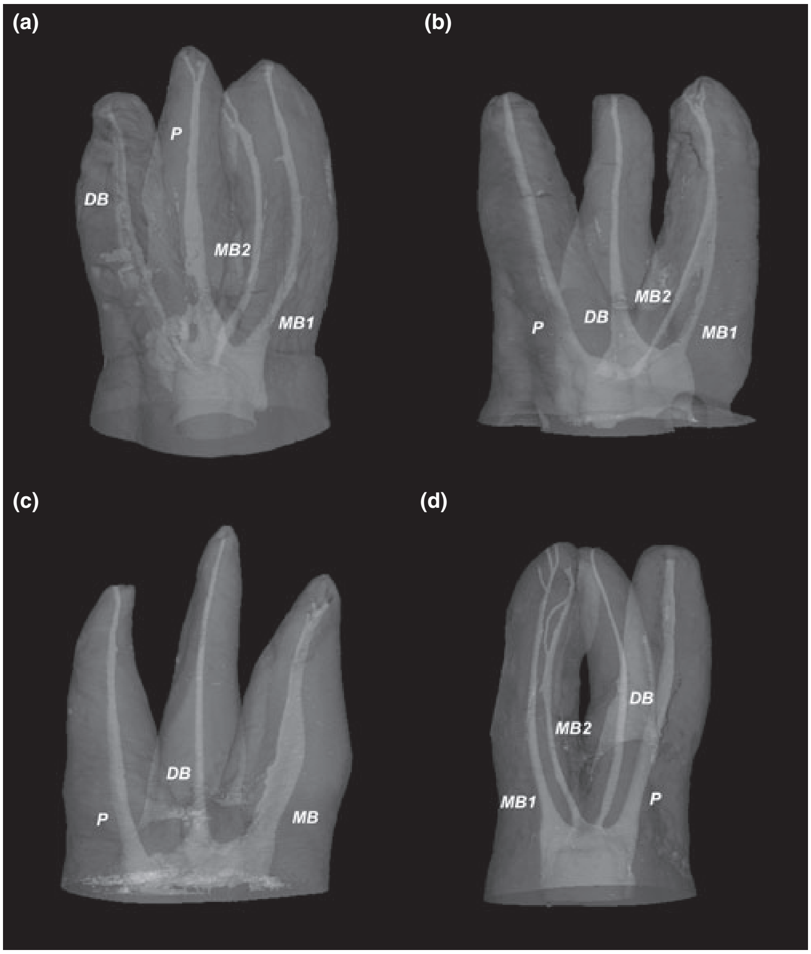

Figure 1 (a–d) Examples of maxillary first molar teeth obtained by micro-computed tomography imaging. Fig. 1a: completely independent mesiobuccal canal (MB)2 canal. MB2 and palatal canals are further complicated by an accessory canal at the apex; despite the high resolution, the complete intercanal connection present between the middle and apical thirds were only partially reproduced. Fig. 1b: MB2 canal joining the MB1 canal in the middle third of the root, thus creating a wide 'lacuna' apically to the conjunction. Fig. 1c: a single canal in the mesiobuccal root, that is flattened in the coronal and middle thirds while showing a delta in the apical end. Fig. 1d: mesial root with two completely separate root canals. MB1 has two accessory canals at the apical end, while MB2 canal is further complicated by a loop in the apical third; despite the high resolution, the complete intercanal connections present in the middle and apical thirds were only partially reproduced.

Table 3 Prevalence (%) of different types of canals in mesiobuccal roots of maxillary first molar teeth, in coronal, middle and apical third of the roots (n = 30)

	Overall	Coronal	Middle	Apical
Merging MB1–MB2	58.4 (14)	64.3 (9)	35.7 (5)	–
Accessory canal	80.0 (24)	8.3 (2)	50.0 (12)	91.6 (22)
Loop	20.0 (6)	–	33.3 (2)	66.7 (4)
Isthmuses	70.8 (17)	41.2 (7)	58.8 (10)	23.6 (4)
Intercanal connections	100.0 (24)	54.2 (13)	79.2 (19)	50 (12)

The number of roots in each category is given in parenthesis.

Figure 2 Micro-computed tomography imaging representing a long complete isthmus between mesiobuccal canal(MB)1 and MB2 root canals in the middle and apical third of a mesiobuccal root of a maxillary first molar.

Figure 3 Multiple intercanal connections between mesiobuccal canal(MB)1 and MB2 root canals at all level in a mesiobuccal root of a maxillary first molar. Mesial and distal root are further complicated by a accessory canals and loops in the apical third.

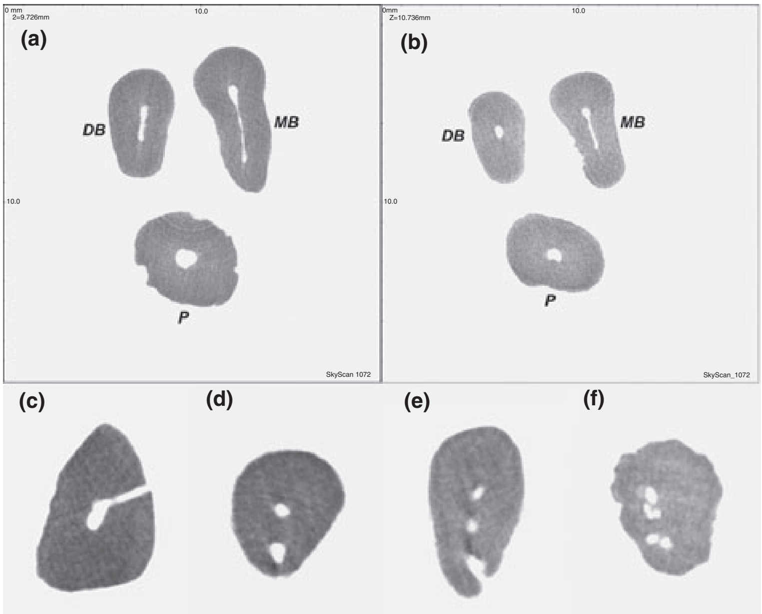

Figure 4 (a–f) Examples of isthmuses between the mesiobuccal canal(MB)1 and MB2 root canals (a, b). The presence of an accessory canal in the apical region of the mesiobuccal root of a maxillary first molar viewed in a horizontal plane (c). Figures d–f emphasize the apical anatomy of different mesiobuccal roots of the maxillary first molar. Two (d) or three separate apical foramina (e) and the apical delta (f) present a considerable challenge in root canal treatment.

Table 4 Findings of this study compared with those reported in a literature review of the laboratory and clinical studies published on the anatomy of the mesiobuccal root of maxillary first molar teeth

	Number of teeth	Type of study	1 canal %	2 canals %	2 into 1 canal at the apex %	2 canals at the apex %
Present study	30	MicroCT	20	80	58.4	41.6
Cleghorn *et al.* 2006	3119	laboratory	39.5	60.5	66.4	33.6
Cleghorn *et al.* 2006	5280	clinical	45.2	54.7	56.9	43.1

this literature review and are shown in Table 4. It outlines that two or more canals were present in 57% of the 8399 teeth of the 34 laboratory and clinical studies analysed. Laboratory studies are more likely to report two canals (60%), ranging from 96% (Kulid & Peters 1990) to 25% (Pecora *et al.* 1992) than *in vivo* clinical studies (55%), ranging from 80% (Neaverth *et al.* 1987) to 19% (Hartwell & Bellizzi 1982). Previous studies that compared *in vivo* versus *ex vivo* techniques (Seidberg *et al.* 1973, Pomeranz & Fishelberg 1974) also reported an increased incidence of MB2 canal when analysing the specimens under laboratory conditions. The above mentioned literature review reported that a single canal at the apex of the MB root was found 62% of the time, while two separate canal at the apex were present 39% of the time in clinical and laboratory studies. When analysing the results of this study, two separate canal at the apex were similarly present 33% of the time (10 teeth), while a single canal at the apex was found 67% of the time. This configuration at the apex is due to the fact that the MB2 canal joined the MB1 canal in 47% of roots and to the fact that in 20% of the time the MB root had a single canal. The incidence of a single canal was lower than that reported by previous investigations (43.1%) (Cleghorn *et al.* 2006).

As frequently observed clinically, the results of this study report that MB1 and MB2 root canals join in most cases in the coronal and middle third of the MB root (64% and 36% respectively).

The high resolution of the equipment utilized in this study may explain the high incidence (20%) of apical deltas (more than three apical foramina). Even when considering one or two main canals at the apex, these can branch in several apical foramina. In fact, a single apical foramen was found only in 37% of the cases, while two or three apical foramina were present respectively in 23% and 20% of the cases. These results are in agreement with Morfis *et al.* (1994) and Briseno Marroquin *et al.* (2004) who observed more than one apical foramen in a high number of teeth.

When the MB root had a single canal, internal root canal system morphology reflected the external root anatomy, as previously stated (Cleghorn *et al.* 2006). In fact, it was flattened in the coronal and middle third, having the tendency to be more circular in the apical portion of the root (67% of these cases), as previously observed in another study (Wu *et al.* 2000).

Stropko (1999) reported that the MB2 canal can be challenging to treat, because on occasion it may share an orifice with MB1 or can be harboured within, or just apical to, that of the MB1 canal. The results of this study confirm that on occasion (20.8% of the cases in which the MB2 was present) the difficult localization and negotiation of this canal can be due to this configuration.

Isthmuses have been found to be present in all types of root in which two canals are normally found (Mannocci *et al.* 2005, Vertucci 2005). The prevalence of isthmuses in the MB root of maxillary molars has been observed in previous studies (Weller *et al.* 1995, Teixeira *et al.* 2003). A complete or partial isthmus was frequently observed in these studies, in particular Weller *et al.* (1995) found a 100% incidence of isthmuses in the apical portion of this root. This study confirms a high-incidence of isthmuses and intercanal connections between the two canals, as they were found in 71% and 100% of specimens. Previous investigations (Weller *et al.* 1995, Teixeira *et al.* 2003, Mannocci *et al.* 2005) focused mostly on the apical 5–6 mm, pointed out the challenge in cleaning and filling these anatomical features through surgical endodontic therapy. The results of this study are in agreement with those of previous studies regarding the high prevalence of isthmuses in the apical third; moreover, the present findings point out the importance of these features even in instrumenting the middle and coronal portion of the root canals. Clinically these canal systems cannot be fully instrumented leaving large areas of the dentinal walls untouched (Davis *et al.* 1972, Peters *et al.* 2001, Rodig *et al.* 2002, Wu *et al.* 2003).

The literature often uses the terms isthmus and intercanal connections to mean the same thing because most of the studies were conducted using histological cross-sections in which one may identify an intercanal connection only if it is a complete horizontal connection between the two canals. In this study, both isthmuses and intercanal connections were considered as separate entities as they represent a communication between two canals in the same root that contain pulp and may contain bacteria. This is to focus the attention on the fact that when two canals are present in the same root, from a biological point of view, they should be considered most as a single entity rather than two separate structures.

The high prevalence of accessory canals in the apical region (92% of the time) (Fig. 4c) is in agreement with those of a previous study (Vertucci 1984). The number of accessory canals has been reported to decrease in an apico-coronal direction (Vertucci 1984); this study confirmed this observation.

The high incidence of MB2 root canals, isthmuses, accessory canals, apical delta and loops reported in the present laboratory study is probably due to the high quality of the methods used (Mannocci *et al.* 2005). The nondestructive approach in this study made it possible to obtain 3D analyses of the external and internal macromorphology of the root complex using a spatial resolution of 38 μm between tomographic slices (Plotino *et al.* 2006). Unfortunately, MCT is expensive and time-consuming and it is not suitable for clinical use, therefore only 30 teeth were examined.

Conclusion

The results of this study report a high incidence of MB2 root canals, isthmuses, accessory canals, apical delta and loops, thus confirming that the MB root of the maxillary first molar has a complex anatomy.

Disclaimer

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