Three root canals in the mesiobuccal root of maxillary molars: case reports and literature review

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Abstract: INTRODUCTION The knowledge of root canal anatomy is essential to ensure a successful outcome of surgical and nonsurgical root canal treatment. The aims of this article were to present 2 cases of maxillary molars with 3 mesiobuccal root canals and to review the available literature on this anatomic variation. METHODS The first case described a nonsurgical root canal treatment of tooth 16 in a 29-year-old man with the aid of a dental operating microscope. In the second case, an extracted maxillary right first molar was scanned by a micro-computed tomographic system and reconstructed 3-dimensionally using modeling software. RESULTS In both cases, the mesiobuccal root had 3 canals (type 3-2 in case I and type 3-3 in case II), whereas the distobuccal and palatal roots had a single canal. The literature review showed that the overall incidence of 3-canaled mesiobuccal roots in maxillary molars ranged from 1.3%-2.4% and that the most common root canal configuration was type 3-2. CONCLUSIONS Clinicians should always anticipate the presence of extra canals in maxillary molars and use all the available tools to locate and treat these.

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Running title: maxillary molars morphology

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Key words:
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Abstract

Introduction: Knowledge of root canal anatomy is essential to ensure a successful outcome of surgical and non-surgical root canal treatment. The aims of this paper were to present 2 cases of maxillary molars with three mesiobuccal root canals and to review the available literature on this anatomic variation.

Methods: The first case described a non-surgical root canal treatment of tooth #16 in a 29-year-old male with the aid of dental operating microscope (DOM). In the second case, an extracted maxillary right first molar was scanned by a micro-computed tomography (μ-CT) system and reconstructed three-dimensionally using modeling software.

Results: In both cases, the mesiobuccal root had 3 canals (type 3-2 in case I and type 3-3 in case II) while the distobuccal and palatal roots had a single canal. The literature review showed that the overall incidence of three-canalled mesiobuccal root in maxillary molars ranged from 1.3-2.4% and that the most common root canal configuration was type 3-2.

Conclusions: Clinicians should always anticipate the presence of extra canals in maxillary molars and use all the available tools to locate and treat these.

Key words:

Anatomic variation, dental operating microscope (DOM), maxillary molars, mesiobuccal root, micro-computed tomography (μ-CT), root canal system

Introduction

Sound knowledge of the internal morphology of the teeth and its variations is essential to ensure a favorable outcome of root canal treatment. Inability to locate and treat the entire root canal system is a major cause of post-treatment disease (1, 2). The anatomy of the mesiobuccal root (MBR) of maxillary molars has been extensively investigated by several clinical and laboratory studies. Cleghorn *et al.* (3) reviewed the studies that evaluated the morphology of maxillary first molars and found that about 57% of MBRs had two or more root canals (60.5% in laboratory studies and 54.7% in clinical studies) while the majority of distobuccal (DBR) and palatal (PR) roots had a single canal (98.3% and 99.0%, respectively). The high incidence of multiple canals in the MBR is attributed to broad bucco-lingual dimension of the root and the presence of concavities on its mesial and distal surfaces. The DBR and PR are more conical in shape and are, therefore, more likely to contain one single root canal (4).

The occurrence of three root canals in a single MBR was first documented by Acosta Vigouroux & Trugeda Bosaans (5). Since then, an increasing number of laboratory, clinical studies and clinical case reports of this anatomic variation have been published in the dental literature. Therefore, the clinician should always assume the presence of extra canals in maxillary molars and should utilize all the available diagnostic tools to locate and treat them. The aims of this study were: (1) to present two cases of maxillary molars with three root canals in a single MBR and (2) to review the available literature regarding this anatomic variation.

Case reports

Case 1

A 29-year-old male was referred to the endodontic department to continue root canal therapy on tooth #16. The tooth had undergone an emergency treatment that involved pulp extirpation and dressing with an intracanal medicament (Ledermix, Haupt Pharma GmbH, Wolfratshausen, Germany). The clinical examination revealed a swelling in the buccal sulcus adjacent to the involved tooth and the tooth was tender to vertical percussion. The preoperative radiograph taken during the emergency visit showed #16 to have three separate roots and a radiolucent lesion was evident around the MBR (Figure 1A). Based on the clinical and radiographic examinations, a diagnosis of previously initiated treatment with acute apical abscess was made and a non-surgical root canal treatment was planned.

The tooth was anesthetized using 1 carpule of 4% Articaine containing 1:100000 epinephrine (Septocaine, Septodont, Saint-Maur-des-Fosse, France) and isolated using rubber dam. The temporary filling was removed and the mesial wall was subsequently rebuilt with LuxaCore (DMG Chemisch-Pharmazeutische Fabrik GmbH, Hamburg, Germany). After refining the access cavity, three canal orifices were detected: mesiobuccal (MB), distobuccal (DB) and palatal (P). Careful exploration of groove between the MB and P canals under dental operating microscope (OPMI PROergo, Carl Zeiss Meditec AG, Jena, Germany) revealed the presence of two extra canals: second mesiobuccal (SMB) and mesiobuccopalatal (MBP) canals. The three mesiobuccal canals had separate orifices that were located in a straight line (Figure 1B). The working length of all canals was determined using an apex locator (Root ZX II, J. Morita, Tokyo, Japan) and confirmed radiographically. The MBR had type 3-2 root

canal configuration: the MB and SMB canals joined in the apical third and existed through a common foramen while MBP canal had a separate foramen. The canals were instrumented with ProTaper universal files (Dentsply Maillefer, Ballaigues, Switzerland) to size # F1 in SMB canal, size # F2 in MB, MBP and DB canals and # F3 in P canal using 1% sodium hypochlorite (NaOCl) as an irrigant. The canals were then dried with paper points and filled with non-setting calcium hydroxide. Finally, tooth was temporized with Cavit (ESPE, Seefeld, Germany) and an overlying layer of glass ionomer cement (Ketac Fil Plus, 3M ESPE, MN).

At the second visit, the canals were irrigated copiously with 1% NaOCl followed by a final rise of 17% EDTA. Then, the canals were dried and filled with gutta percha and AH-Plus sealer (Dentsply Maillefer, Ballaigues, Switzerland) using the continuous wave of condensation technique (Figures 1C, 1D & 1E). Finally, the access opening was restored with LuxaCore. At the 1-year recall visit, the patient was asymptomatic and the clinical and radiographic examinations revealed the tooth and its surrounding tissues to be within normal limits (Figure 1F).

Case 2

A right maxillary first molar extracted for unknown reasons from a Jordanian patient was evaluated. External anatomical characteristics showed the presence of three separate roots and a MBR with wide bucco-lingual dimension, suggesting the presence of extra canals (Figure 2A and 2B). The internal morphology was evaluated by scanning the tooth using a micro-computed tomography device (mCT40; Scanco Medical, Bruttisellen, Switzerland) at the following settings: 70 kV, 114 mA and 20 μm isotropic resolution. Then, the tooth was reconstructed using 3D modeling software (IPL V5.06B, Scanco Medical). The MBR showed

a type VIII canal configuration (3-3) while each of the DBR and PR had type I root canal system (Figure 2C).

Literature review

Search strategy

The PubMed (http://www.ncbi.nlm.nih.gov/pubmed) and Scopus (http://www.scopus.com) databases (last accessed 5th May 2014) were searched for relevant articles using combination of the following search terms: maxillary molars, mesiobuccal root and three root canals. After removal of duplicate articles, the title/abstract of the remaining articles were screened by the two authors for their relevance according to the below inclusion criteria and potential articles were retrieved in full-text. Then, the references list of each article was manually checked for further eligible articles.

Inclusion and exclusion criteria

Studies that reported three root canals in a single and separate MBR in maxillary molars and published in a peer-reviewed journal were included in the current review. The exclusion criteria were: (1) studies that reported three root canals in more than one MBR (2) studies in which the MBR was fused with other roots.

Data extraction

Overall, 55 studies (5 clinical, 19 laboratory and 31 case reports [36 teeth]) met the inclusion criteria and were subjected to further analysis (Table 1). From the clinical/laboratory studies (5-28), the following information was extracted: (1) study author(s); (2) country of the study; (3) the study sample (number of MBRs and the origin of the sample [if mentioned]); (4) the method used to study the internal morphology; (5) the incidence of three-canalled MBR and (6) the root

canal configurations of MBR according to the Vertucci classification and its variations (Table 2 and 3). For each case report (29-59), the following information were recorded: (1) study author(s); (2) country of the study; (3) the age and gender of the patient; (4) the type (1^{st} or 2^{nd} molar) and location (right or left) of the treated tooth; (5) the internal root canal morphology (number of canals and their configuration in each root) and (6) the diagnostic tools that were used to detect and/or confirm the presence of extra canals (Table 4).

Discussion

The first attempt to study the internal morphology of teeth is accredited to Preiswerk (60) who used a canal remodeling technique. Later, several authors including Fischer (61), Hess (62) and Zürcher (63) further investigated the root canal morphology of different teeth groups using a similar technique. Since then, several laboratory and clinical techniques were used to investigate the internal anatomy of teeth. The laboratory methods include root sectioning (1), radiographic examination (64), canal staining and tooth clearing (65), microscopic examination (66) and tooth scanning and three-dimensional reconstruction using micro-computed tomography (μ-CT) (19). The clinical techniques include clinical evaluation during root canal treatment (67, 68), retrospective evaluation of patients' records (7), radiographic examination using conventional (6) or advanced radiographic techniques such as cone beam computed tomography (CBCT) (23, 25). The current paper presents 2 cases (one *in vivo* and one *ex vivo*) of maxillary first molars with three mesiobuccal canals. The first case described the clinical management of tooth #16 that had type 3-2 canal configuration in the MBR. The second case presented a μ-CT scan and three-dimensional reconstruction of tooth#16 with type VIII (3-3) configuration in the MBR.

Nomenclature of canals

There is a variation in the literature with respect to the terminology used to describe extra canals in the MBR of maxillary molars (Table 5). To avoid this confusion, Karthikeyan & Mahalaxmi (69) suggested naming additional canals in a single root starting from the most buccal canal and heading in a palatal direction. Therefore, the three canals in MBR are referred to as mesiobuccal (MB), second mesiobuccal (SMB) and mesiobuccopalatal (MBP).

Incidence

Three-canalled MBR have been reported to occur in 0.2 to 12.5%, 0.6 to 4.2% and 1.3 % of first, second and third molars, respectively (Table 2). Overall, the laboratory studies revealed a higher incidence of three canals than the clinical studies (2.3 to 12.5% and 0.2 to 3.4%, respectively). Sert & Bayirli (14) studied the anatomy of 400 maxillary first and second molars in Turkish population and found MBR with three canals in 5 (1.3%) of their specimens. Four of these teeth were extracted from male patients. The majority (28 out of 36) of the clinical cases also reported this anatomic variation in male patients (Table 4). A review of the clinical case reports showed that three-canalled MBR occurred unilaterally with no side predisposition (19 on left side and 15 on right side). Bilateral occurrence of this phenomenon was documented by two reports (53, 54). The patient's age is an important preoperative predictor for detection of extra canals in maxillary molars (70). Table 3 shows that the majority (30 out of 36) of the case reports were documented in patients younger than 40 years, a finding that is consistent with results of previous studies that concluded that patients between 20 and 40 years old had a higher incidence of extra root canals compared to older patients (7, 23). It can be assumed that with age, root canals or their orifices may calcify making detection of extra canals more

difficult (9, 70).

Internal morphology

The internal morphology of three-canalled MBR was investigated by a number of clinical and laboratory studies (Table 3). The most common root canal configurations were types 3-2, 2-3, 1-3 and 3-3. More complex configurations such 1-2-1-3, 1-2-3-2, 2-3-2-1-2, 2-3-2-3-2 and 3- 2-1-2-1 have been also reported in some laboratory studies (14, 24, 28). In the clinical case reports, type 3-2 was the predominant configuration and it occurred in three forms (Table 4). The prevalent form was a separate MB canal and joined SMB and MBP canals (29, 31, 32, 32, 35, 36, 38, 40, 43, 48, 49, 51, 52, 57) followed by separate MBP canal and joined MB and SMB canals (37, 41, 47, 54, 58) while one case reported separate SMB canal and joined MB and MBP canals (33). Joining of the two canals occurred either in the apical (29, 31, 32, 40, 57, 58) or middle (36, 37, 41) thirds of the root. Other root canal configurations were also reported including types 3-3 (30, 34, 42, 45, 46), 3-1 (39) and 3-2-1 (44, 59).

The three root canals are usually located on a straight line and the distance between their orifices ranges from 1 to 2 mm (29, 42, 46, 57). Nevertheless, two reports (37, 54) presented clinical cases with unique position of the MBR canals: the MB2 canal was located between MB1 and DB1 canals while the MB3 canal was located midway between the MB and P canals.

Degerness & Bowles (21) compared the root thickness and the dimensions of the 3 canals in cross-sections of 153 MBRs from maxillary first and second molars. They found that the main MB canal was larger and had more taper than the two other canals at all root levels. No differences were noted in the dentin thickness between the mesial and distal surfaces at the apical and middle thirds. However, in the coronal area, the distal wall was significantly thinner

than the mesial wall. This “danger zone” should be taken into consideration during canal instrumentation to avoid stripping perforation.

Concurrent anatomic aberrations in maxillary molars with three MB canals have been also reported. These teeth may have extra root canals in DBR (18, 29, 33, 46), PR (51) or both of them (37, 41, 50, 54). Therefore, the clinician should always keep in mind the possibility of having additional canals in other roots of maxillary molars.

Clinical considerations

The complex root canal system of the MBR represents a constant challenge for the dental practitioners during root canal treatment. Therefore, the clinicians should utilize all the available tools to find and treat all canals to ensure a successful treatment outcome.

Careful examination of preoperative and working radiographs taken at different horizontal angulations is essential to detect extra canals (71). However, additional MB canals are sometimes difficult-to-locate on conventional radiographs due to their small size and superimposition of the main MB canal over them (1). Advanced radiographic techniques such as computed tomography (CT) and cone-beam computed tomography (CBCT) may be also used to detect or confirm the presence of root canal aberrations. These techniques are highly sensitive and allow three-dimensional evaluation of the root canal anatomy (72). However, routine use of CBCT is contraindicated because of the high radiation dose that is incurred (73).

Proper design and preparation of access cavity is of utmost importance to visualize the entire pulp chamber floor and to establish straight line access to canal orifices. When extra canals in the MBR are suspected, the access opening is extended on the mesial side to have a trapezoidal

rather than a triangular shape (36, 40, 41, 48, 51, 56). Next, the clinician should read the "road map" of the pulpal floor to locate potential canal orifices. This may include exploring the floor with an endodontic explorer (29, 31, 36, 37, 39, 42, 55, 58), troughing the floor with round burs (31, 36) or ultrasonic tips (41, 49, 56). In addition, staining the pulpal floor with a dye, performing the champagne test with sodium hypochlorite, visualizing canal bleeding points are important aids in locating canal orifices (2). In this regard, the use of magnifying tools such as eye loupes and dental operating microscope enhance the vision in the operating field and thus increase the probability of finding extra canals as compared to the naked eye (68). Apart from the aforementioned diagnostic tools, the increased operator experience (74) and longer time spent per appointment (67) play a major role in the detection and management of extra canals.

The clinicians should consider the internal and external morphological features of MBR while planning for surgical and non-surgical root canal treatment. The success of non-surgical treatment depends on sealing all the apical foramina. When three separate canals are present, each canal should be debrided and filled up to its apical end. If all the canals or two of them share a common apical foramen, the canal with direct access to the apex is prepared and obturated to the full working length while the other canal(s) are filled to the junction point. Preparing all canals to the full length is not recommended for two reasons. First, an hourglass preparation will result with the joining point between the canals being more constricted than the apical preparation, leading to voids in the obturation of the apical area below the constriction. Second, fracture of instruments, particularly rotary files, may occur as they traverse the sharp curvature into the common part of the canal (2). In surgical treatment, all the apical foramina and isthmuses apparent on the resected root surface should be adequately

prepared and filled (15). The MBR has a wide bucco-lingual dimension and incomplete resection of the root may fail to expose the more palatally located canals. This can be avoided by resecting the root perpendicular to its long axis, stain the root end with a dye and inspect it under magnification to delineate the root outline and apical terminus of all root canals (75). Finally, the relative size of the three MB canals should also be considered. The main MB canal is larger and more tapered than the two other canals; hence, overenalgement of the additional canals should be avoided to prevent unnecessary thinning of the root walls or occurrence of lateral root perforation (21).

Conclusions

Although the incidence of three root canals in a single MBR in maxillary molars is low, this anatomic variation must be considered while performing surgical and non-surgical root canal treatment of these teeth. The clinicians should always assume the presence of extra canals and utilize all the clinical and radiographic diagnostic tools to locate and treat them.

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Figure legends

Figure 1 A maxillary right first molar with three canals in the mesiobuccal root during and after the course of endodontic treatment (*A*) Preoperative radiograph. (*B*) An occlusal view showing the orifices of the three mesiobuccal canals (*C* and *D*) Postoperative radiographs. (*E*) Occlusal view showing obturation of all root canals. (*F*) One-year recall radiograph.

Figure 2 An extracted maxillary right first molar with three canals in the mesiobuccal root (MBR) (*A*) A photograph showing a wide bucco-lingual dimension of MBR. (*B*) A palatal view showing the three roots. (*C*) μ-CT of the same tooth showing type VIII root canal configuration in the MBR and type I configuration in the DBR and PR (μ-CT was performed by Dr. Frank Paqué).

Table 1. Incidence of maxillary molars with three-canalled mesiobuccal root

Reference	Population (Country)	Study method	Sample (root)	Three canals (%)		
				1st molar	2nd molar	3rd molar
Acosta Vigouraux & Trugeda Bosaans 1978	Unspecified (Chile)	*In vitro* (ground sectioning & exploring)	134	3 (2.3)		
Hartwell & Bellizzi 1982	Unspecified (USA)	*In vivo* (radiographs)	538	1 (0.2)		
Martinez-Berna & Ruiz-Badanelli 1983	Unspecified (Spain)	*In vivo* (radiographs)	338	3 (0.9)		
Neaverth *et al.* 1987	Unspecified (USA)	*In vivo* (review of records)	228	7 (3.1)		
Kulild & Peters 1990	Unspecified (USA)	*In vitro* (cross section)	51	1 (2)		
Thomas *et al.* 1993	Caucasian (Australia)	*In vitro* (radiographs)	216	27 (12.5)		
Çalişkan *et al.* 1995	Turkish (Turkey)	*In vitro* (clearing)	100		4 (4)	
Al-Shalabi *et al.* 2000	Irish (Ireland)	*In vitro* (clearing)	82	1 (1.2)		
Ng *et al.* 2001	Burmese (UK)	*In vitro* (clearing)	90	2 (2.2)		

			77		2 (2.6)	
Alavi *et al.* 2002	Thai (UK)	*In vitro* (clearing)	52	1 (1.9)		
			65		2 (3.1)	
			77			1 (1.3)
Sert & Bayirli 2004	Turkish (Turkey)	*In vitro* (clearing)	200	2 (1)		
			200		3 (1.5)	
Yoshioka *et al.* 2005	Unspecified (Japan)	*In vitro* (clearing)	98	1 (1)		
			110		1 (0.9)	
Rwenyonyi *et al.* 2007	Ugandan of African descent (Uganda)	*In vitro* (clearing)	221	1 (0.5)		
Baratto Filho *et al.* 2009	Unspecified (Brazil)	*In vitro* (microscopic examination & radiographs)	140	1 (0.7)		
Park *et al.* 2009	Korean (Canada)	*In vitro* (μCT)	46	3 (6.5)		
Beljic-Ivanovic & Teodorovic 2010	Unspecified (Serbia)	*In vitro* (radiographs)	200	18 (9)		

Degerness & Bowles 2010	Unspecified (USA)	*In vitro* (cross sectioning and microscopic examination)	90 63	1 (1.1)	1 (1.6)
Neelakantan *et al.* 2010	Indigenous Indians (India)	*In vitro* (CBCT)	215	2 (0.9)	
Zheng *et al.* 2010	Chinese (China)	*In vivo* (CBCT)	624	3 (0.5)	
Gu *et al.* 2011	Unspecified (South Korea)	*In vitro* (μCT)	101	11 (10.9)	
Lee *et al.* 2011	Korean (South Korea)	*In vivo* (CBCT)	458 467	6 (1.3)	3 (0.6)
Verma & Love 2011	Unspecified (New Zealand)	*In vitro* (μCT)	20	2 (10)	
Kim *et al.* 2012	Korean (South Korea)	*In vitro* (CBCT)	802	1 (0.1)	
Kim *et al.* 2013	Unspecified (South Korea)	*In vitro* (μCT)	154	17 (11.0)	

Maxillary 1st molars (No. of roots = 4760)	112 (2.4)		
Maxillary 2nd molars (No. of roots =1082)		16 (1.5)	
Maxillary 3rd molars (No. of roots =77)			1 (1.3)

μCT, micro-computed tomography; CBCT, cone-beam computed tomography

Table 2. Common root canal configurations in three-canalled mesiobuccal roots

Reference	Sample (root)	Root canal configuration (%)								
		1-3	**2-3**	**3-1**	**3-2**	**3-3**	**1-3-1**	**3-1-3**	**3-2-1**	**Others**
Martinez-Berna & Ruiz-Badanelli 1983	3				3 (100)					
Neaverth *et al.* 1987	7			2 (28.6)	4 (57.1)	1 (14.3)				
Al-Shalabi *et al.* 2000	1					1 (100)				
Ng *et al.* 2011	4		1 (25)		1 (25)		2 (50)			
Alavi *et al.* 2002	4				1 (25)	1 (25)	2 (50)			
Sert & Bayirli 2004	5					1 (20)			2 (40)	2 (40)*
Yoshioka *et al.* 2005	2	2 (100)								
Rwenyonyi *et al.* 2007	1	1 (100)								
Park *et al.* 2009	3	3 (100)								
Baratto Filho *et al.* 2009	1								1 (100)	
Neelakantan *et al.* 2010	2		2 (100)							
Gu *et al.* 2011	11		2 (18.2)		2 (18.2)	1 (9.1)			1 (9.1)	5 (45.5)**

Verma & Love 2011	2				1 (50)			1 (50)		
Kim *et al.* 2012	1				1 (100)					
Kim *et al.* 2013	17	1 (5.9)	6 (35.3)		3 (17.6)	1 (5.9)			1 (5.9)	5 (29.4)***
Total	64	7 (10.9)	11 (17.2)	2 (3.1)	16 (25)	6 (9.4)	4 (6.3)	1 (1.6)	4 (6.3)	12 (18.8)

* Types 1-2-3-2 and 2-3-2-1-2
** Types 2-1-3, 1-2-1-3 and 3-2-1-2-1
*** Types 1-2-1-3, 2-1-3, 2-3-2-3-2 and 3-2-1-2-1

Table 3. Case reports of maxillary molars with three mesiobuccal root canals

Reference	Country	Tooth	Sex	Age	Type of study	Root canal morphology			Aids to locate/ confirm extra canals
						MBR*	DB	PR	
Martinez-Berna & Ruiz-Badanelli 1983	Spain	#16	M	10	Clinical RCT	3-2 (Separate MB)	2-1	1-1	Exploring (Probe) Angled radiographs
	Spain	#26	M	17	Clinical RCT	3-2 (Separate MB)	2-2	1-1	Exploring (Probe) Angled radiographs
	Spain	#26	M	39	Clinical RCT	3-2 (Separate MB)	2-2	1-1	Exploring (Probe) Angled radiographs
Beatty 1984	USA	#26	M	14	Clinical RCT	3-3	1-1	1-1	Angled radiographs
Ferguson *et al.* 2005	USA	#16	M	18	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Exploring (Probe) Toughing (bur) Magnification (DL)
Favieri *et al.* 2006	Brazil	#26	M	15	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Exploring (Probe) Angled radiographs
Ibrahim 2009	Lebanon	#26	F	30	Clinical RCT	3-2 (Separate SMB)	2-1	1-1	Angled radiographs
Stöckl 2009	Germany	#16	M	46	Clinical Retreatment	3-3	1-1	1-1	Exploring (bur)

									Angled radiographs
Chopra & Sachdev 2010	India	#26	M	15	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Exploring (Probe)
									Angled radiographs
Garg *et al.* 2010	India	#26	M	41	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Access modification
									Exploring (Probe)
									Troughing (bur)
									Magnification (DL)
									SCT
Kottoor *et al.* 2010	India	#16	M	37	Clinical RCT	3-2 (Separate MBP)	2-1	2-1	Exploring (Probe)
									Magnification (DOM)
									CBCT
Prabu *et al.* 2010	India	#26	M	28	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Exploring (Probe)
									Angled radiographs
Ayranci *et al.* 2011	Turkey	#26	M	22	Clinical RCT	3-1	1-1	1-1	Exploring (Probe)
									Magnification (DL)
Chourasia *et al.* 2011	India	# 26	M	28	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Exploring (K-file)
Kottoor *et al.* 2011	India	#26	M	30	Clinical RCT	3-2 (Separate MBP)	3-2	2-1	Access modification

									Troughing (US) Magnification (DOM) CBCT
Ma *et al.* 2011	China	#16	M	46	Clinical RCT	3-3	1-1	1-1	CT
Zhang & Mao 2011	China	# 26	M	42	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Angled radiographs
Ahmed & Saini 2012	Malaysia	#26	M	37	Clinical RCT	3-2-1	1-1	1-1	Exploring (Probe) Angled radiographs Magnification (DL)
Chandra *et al.* 2012	India	#16	M	24	Clinical RCT	3-3	2-1	1-1	Exploring (Probe) Angled radiographs Helical CT
Islam & Alam 2012	Bangladesh	#26	F	31	Clinical Retreatment	3-2 (Separate MBP)	1-1	1-1	Exploring (Probe) Angled radiographs
Kakkar & Singh 2012	India	#16	M	19	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Access modification Exploring (Probe) Magnification (DOM) Spiral CT
Pais *et al.* 2012	Brazil	#16	F	35	Clinical	3-2 (Separate MB)	1-1	1-1	Exploring (Probe)

					Retreatment				Troughing (US)
									Magnification (DOM)
Kaushik & Mehra 2013	India	#26	F	28	Clinical RCT	3-2 (Separate MB)	1-1	2-1	Access modification
									Exploring (Probe)
									Magnification (DOM)
									CBCT
Martins & Baharestaani 2013	Portugal	#16	M	30	Clinical Retreatment	3-2 (Separate MB)	1-1	1-1	Angled radiographs
									Magnification (DOM)
	Portugal	#26	M	35	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Angled radiographs
									Magnification (DOM)
Badole *et al.* 2014	India	#26	M	28	Clinical RCT	3-3	2-2	2-2	Exploring (Probe)
									Magnification (DOM)
									CBCT
	India	#16	M	28	Radiographic examination (CBCT)	3-3	1-2	2-2	CBCT
Second molars									
Shrivastava *et al.* 2005	India	#17	M	40	Clinical RCT	3-2	1-1	1-1	Exploring (Probe)

Gusiyska 2009	Bulgaria	#17	M	27	Clinical RCT	3-2	1-1	1-1	Access modification Transillumination Exploring (Probe & C^+ file) Troughing (US)
Ozcan *et al.* 2009	Turkey	#17	M	21	Clinical RCT	3-2 (Separate MB)	1-1	1-1	Angled radiographs
Zhao *et al.* 2011	China	#17	F	40	Clinical RCT	3-2 (Separate MBP)	1-1	1-1	Angled radiographs Exploring (Probe) Multi-slice CT
Arora *et al.* 2013	India	#27	F	36	Clinical RCT	3-2-1	1-1	1-1	Exploring (Probe) Magnification (DL) MDCT

* Mesiobuccal canals were named according to the nomenclature proposed by Karthikeyan and Mahalaxmi (2010)
CBCT, cone beam computed tomography; DBR, distobuccal root; DL, dental loupes; DOM, dental operating microscope; F, female; M, male; MB, mesiobuccal; MDCT, multi-detector computed tomography; MBP, mesiobuccopalatal; MBR, mesiobuccal root; PR, palatal root; SCT, spiral computed tomography; SMB, second mesiobuccal, US; Ultrasonic tips

Table 4 Nomenclature of root canals in a single mesiobuccal root

Terminology	References
MB1, MB2 & MB3 canals	Baratto Filho *et al.* 2009, Gusiyska *et al.* 2009, Ozcan *et al.* 2009, Stöckl 2009, Garg *et al.* 2010, Kottoor *et al.* 2010, Prabu *et al.* 2010, Ayranci *et al.* 2011, Kottoor *et al.* 2011, Ma *et al.* 2011, Ahmed & Saini 2012, Chandra *et al.* 2012, Kakkar & Singh 2012, Pais *et al.* 2012, Kaushik & Mehra 2013, Martins & Baharestaani 2013, Bodule *et al.* 2014
MB, MB2 & MB3 canals	Zhang & Mao 2011, Zhao *et al.* 2011
MB1, MB2 & MP canals	Favieri *et al.* 2006, Chopra & Sachdev 2010, Islam & Alam 2012
MB, MC & MP canals	Martinez-Berna & Ruiz-Badanelli 1983, Ibrahim 2009
MB, middle & ML canals	Degerness & Bowles 2010
MB, ML & second ML canals	Kulild & Peters 1990
MB, middle MB & palatal MB canals	Arora *et al.* 2013
MB, collateral MB & second collateral MB canals	Acosta Vigouraux & Trugeda Bosaans 1978
Buccal-most canal & two lingual-most canals	Ferguson *et al.* 2005, Chourasia *et al.* 2011
Main canal & two accessory canals	Shrivastava *et al.* 2005

MB, mesiobuccal; MC, mesiocentral; ML, mesiolingual; MP, mesiopalatal

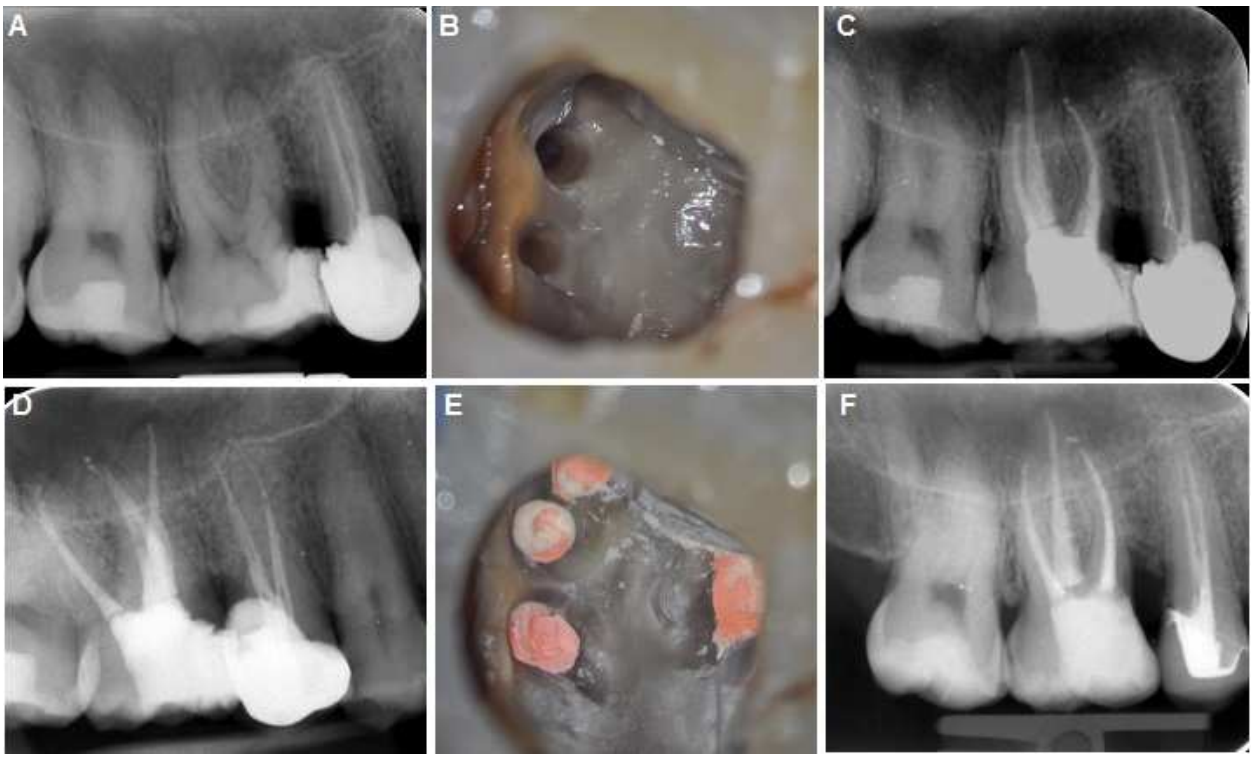

Figure 1 (*A*) A preoperative radiograph of the right maxillary first molar. (*B*) An occlusal view showing three root canal orifices in the MBR. (*C* and *D*) Postoperative radiographs. (*E*) Occlusal view showing obturation of the mesiobuccal canals. (*F*) One-year recall radiograph.

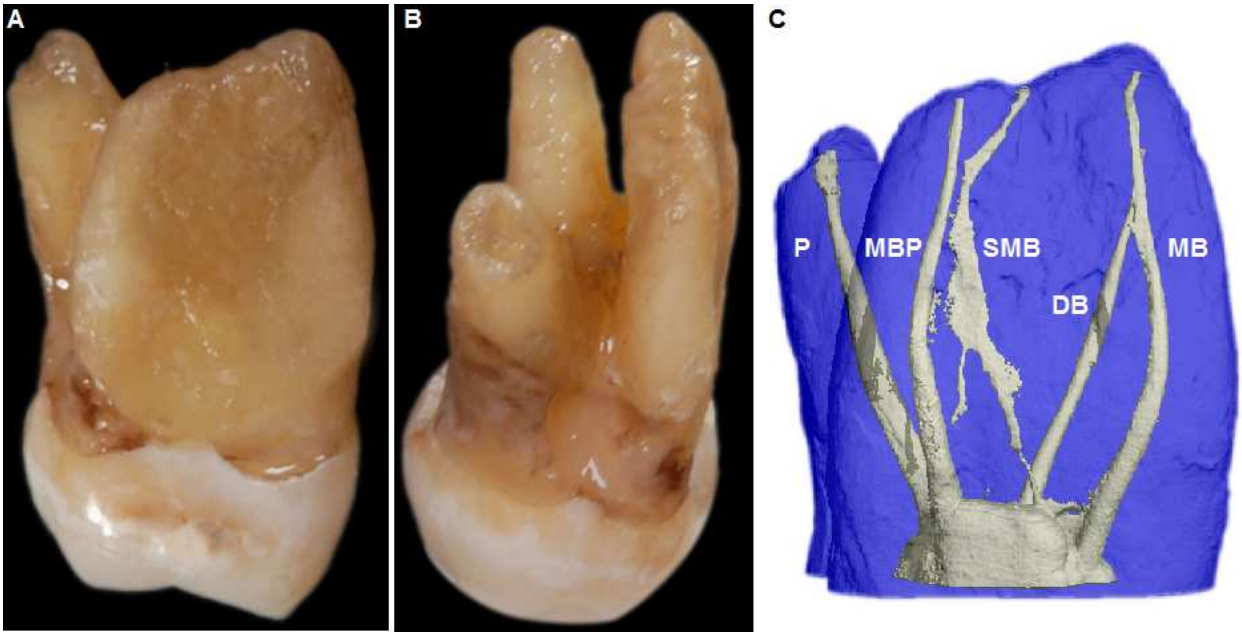

Figure 2 (*A*) A photograph of a three-rooted maxillary right molar showing a wide bucco-lingual dimension of MBR that obscure the distobuccal root. (*B*) A palatal view showing the three roots. (*C*) A µ-CT of the same tooth showing type VIII root canal configuration in the MBR (µ-CT was kindly performed by Dr. Frank Paqué).