Apical Anatomy in Mesial and Mesiobuccal Roots of Permanent First Molars

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Abstract

The purpose of this in vitro study was to investigate the canal configuration types, and the prevalence and location of anatomical variations in the mesiobuccal (MB) and mesial roots of permanent maxillary and mandibular first molars after instrumentation. The number and the type of canals were determined before instrumentation using conventional methods. All root canals from the 47 MB roots and 42 mesial roots were then instrumented to size #30 with ProFile .04 taper rotary instruments in a crown-down method and then filled with a single gutta-percha cone and sealer. Transverse 1 mm-thick cross-sections at 2, 3, 4, and 5 mm from the apex were obtained, stained and examined using a stereomicroscope. The canal configuration types and the prevalence and location of isthmi and accessory canals in roots with two canals were evaluated. The prevalence of two canals was 80.8% in the maxillary MB roots and 95.2% in the mandibular mesial roots. There were six types of canal configurations in the instrumented root apices. The prevalence of anatomical variations was highest at the apical 4 mm level, and was more frequent in mandibular first molars, and in roots with Weine type III canal. χ^2 test showed that the prevalence of the anatomical variations was statistically higher in the maxillary MB roots with Weine type III canals than in those with Weine type II canals ($p < 0.05$). Different canal configurations were often found at different levels in the same root. The results indicate that anatomical variations persist following instrumentation of roots with two canals in first molars. These anatomical variations should be considered during surgical or nonsurgical endodontic procedures of the permanent first molars.

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The recognition and management of canal isthmi and accessory root canals is a factor that may improve the success rate of surgical endodontic treatment (1). These anatomical structures can as reservoirs for bacteria or necrotic pulp tissue, and may account for the failure of endodontic treatment.

Cambruzzi and Marshall (2) first reported the significance of an isthmus in molar surgery and a 30.1% and 60.2% incidence of canal isthmus in the mesiobuccal root of the maxillary first molar and the mesial roots of mandibular first molars respectively. In a study of 50 maxillary first permanent molars, Weller et al. (3) presented the concept of a partial isthmus and reported a 100% prevalence of an isthmus at the apical 4 mm level of the MB roots with two canals. Hsu and Kim (1) classified isthmi into five types, a classification that is useful for understanding the anatomy of the complex root canal system during surgical endodontics. Teixeira et al. (4) also showed that the incidence of canal isthmus was greatest at the apical 3 to 5 mm level of the MB root of maxillary first molars and the mesial root of the mandibular first molars. Tam and Yu (5, 6) differentiated between the accessory root canals and canal isthmi and reported that 12.5% of the maxillary first molars have one or more accessory root canals located between the mesiobuccal (MB_1) and the mesiolingual (MB_2) root canal. Previous studies, however, have investigated the prevalence and positions of canal isthmi and accessory root canals using the cross-sectional configurations of extracted molars without root canal preparation (1–6). These anatomical structures may be altered in three dimensions during root canal preparation (7). Therefore, information on the anatomical variations in serially sectioned root apices of instrumented molars may be more useful to endodontic practitioners, especially during surgical endodontics.

The purpose of this in vitro study was to investigate, in a sample of mesiobuccal roots from maxillary first molars and mesial roots of mandibular first molars with two canals, the canal configuration types and the prevalence and location of canal isthmi and accessory root canals at the apical 2 to 5 mm levels after root canal preparation.

Materials and Methods

Tooth Preparation

Forty-seven maxillary first molars and 42 mandibular first molars with fully developed, sound roots were collected from the Department of Oral Maxillofacial Surgery at Yonsei Dental Hospital in Seoul, Korea. All the teeth were extracted for periodontal or prosthodontic reasons and did not have previous endodontic treatment. Age and sex were unknown. All teeth were kept in 0.5% sodium azide solution at 4°C until use. To facilitate the measurement of the working length and root canal preparation, the maxillary MB roots and the mandibular mesial roots were resected using a Minitom (Struers, Rodovre, Denmark) at the furcation level. The coronal one-third of each root was then embedded in self-curing acrylic resin (Jet acrylic resin; Lang Dental MFG. Co., IL). Before root canal preparation, #15 K-flex file (Maillefer, Dentsply, Ballaigues, Switzerland) was placed into the canal or canals under an OPMI dental surgical microscope (Carl Zeiss, Oberkochen, Germany) at 25× magnification, and two periapical radiographs were taken in the buccolingual and mesiodistal directions. Using these radiographs, the number of root canals and the root canal types of each root were determined according to the classifications of Weine (8): where type I is single canal from pulp chamber to apex, type II is two canals leaving the chamber and merging to form a single canal short of the apex, type III is two separate and distinct canals from chamber to apex, and type IV is one canal leaving the chamber and dividing into two separate and distinct canals. The working length of each canal was established by measuring the penetration depth of the initial instrument (K-flex file, Dentsply, Maillefer) at the apical foramen and then subtracting 1 mm. All root canals were instrumented to apical size #30 using .04 taper ProFile rotary instrument (Dentsply, Maillefer). Root canal preparation was performed by crown-down method using a gear-reduction handpiece (16:1, W & H Dentalwerk Burmoos GmbH, Burmoos, Austria) and an electric motor (TCM 3000, Nouvag AG, Goldach, Switzerland). The coronal part of the root canal was instrumented with 0.10/#20 and 0.08/#20 Greater Taper (Dentsply, Maillefer) at 150 rpm. This was followed by the sequential use of .04 taper ProFile from #15 to #30 at 280 rpm to the working length using gentle pressure. The instruments were used in the canal with a continuous, slight pecking movement and were never forced apically. Irrigation was performed after each instrument using 2 ml of 2.5% NaOCl solution. To identify the main canals, a nonstandard medium-sized gutta-percha cone (Meta Dental Corp., Chungju, Korea) was coated with TubliSeal (SybronEndo, CA), and then placed into the prepared canal without pressure. The filled roots were placed in an incubator for 7 days at 37°C to allow the sealer to set. A Minitom (Struers, Rodovre, Denmark) was used to section each root containing two canals, at 2, 3, 4, and 5 mm from the root apex, perpendicular to the long axis. Each section was stored in 17% EDTA solution for 30 s to remove the smear layer on the cutting surface, and then cleaned in an ultrasonic cleanser for 5 min. Each section was then rinsed in water and dried. Only the apical side of each section was evaluated. The resected surface was stained with 2% methylene blue (Duksan Co., Ansung, Korea) and examined under a Micro Hiscope System (Hirox Co. Ltd., Tokyo, Japan) at 30× magnification, and areas of special interest were photographed at 100× magnification. Using these photographs, the canal configurations present at each recording level were then classified. Canal configurations containing one or two original main canal(s) filled with gutta-percha and sealer, without accessory root canal or isthmi, were classified as type A or type B. An isthmus was defined as a narrow extension from either one or two main canals, and subdivided as incomplete (type C1) or complete (type C2). Canal structures separated from a main canal were regarded as accessory canals. Accessory canals were usually relatively small and round, and were located between two main canals (type D1) or between the main canal and the outer root surface (type D2). The presence of two canals, an isthmus and/or an accessory all in the same root was categorized as type S. This canal type may potentially be more clinically significant during surgical endodontics.

Statistical Analysis

The statistical association between the root canal type proposed by Weine (8) and the prevalence of the anatomical variations at each cutting levels in the instrumented roots with two canals was determined by χ^2 test with p set at 0.05.

Results

The prevalence of two canals was 80.8% (38/47) in the MB roots of the maxillary first molars and 95.2% (40/42) in the mesial roots of the mandibular first permanent molars (Table 1).

Canal configuration types at each cutting level are summarized in Tables 2 and 3. There were six configurations of root canals in the different section levels of the instrumented roots with two canals. The

TABLE 1. The Number and Type of Main Canal in the MB Root of the Maxillary First Molar and the Mesial Root of the Mandibular First Molar

Tooth Root	One Root Canal	Two Root Canals		Total
		Type II (%)	Type III (%)	
Maxillary MB root	9 (19.2)	16 (34.0)	22 (46.8)	47 (100)
Mandibualr mesial root	2 (4.8)	20 (47.6)	20 (47.6)	42 (100)

The values in the parenthesis are percentages of all roots in that group.
Type II and III refers to the Weine classification (8).

TABLE 2. The Types of Canal Configuration at Each Sectioning Level in the MB Roots of the Maxillary First Molars with Two Canals

Level from Apex (mm)	Configuration Types							
	A	B	C1	C2	D1	D2	S*	Total
2	10 (26.3)	8 (21.0)	6 (15.8)	5 (13.2)	5 (13.2)	4 (10.5)	20 (52.7)	38 (100)
3	9 (23.7)	9 (23.7)	4 (10.5)	9 (23.7)	4 (10.5)	3 (7.9)	20 (52.6)	38 (100)
4	7 (18.4)	7 (18.4)	2 (5.3)	13 (34.2)	5 (13.2)	4 (10.5)	24 (63.2)	38 (100)
5	12 (31.6)	9 (23.7)	1 (2.6)	14 (36.8)	2 (5.3)	0 (0)	17 (44.7)	38 (100)

S* = sum of the prevalence of roots with type C1, C2, D1, and D2.
The values in the parenthesis are percentage of all roots at the specific level.

TABLE 3. The Types of Canal Configurations at the Each Sectioning Level in the Mesial Roots of the Mandibular First Molars with Two Canals (%)

Level from Apex (mm)	Configuration Types							
	A	B	C_1	C2	D1	D_2	S*	Total
2	10 (25.0)	6 (15.0)	5 (12.5)	10 (25.0)	9 (22.5)	0 (0)	24 (60.0)	40 (100)
3	5 (12.5)	4 (7.5)	8 (20.0)	14 (35.0)	10 (25.0)	0 (0)	32 (80.0)	40 (100)
4	1 (2.5)	6 (15.0)	9 (22.5)	17 (42.5)	7 (17.5)	0 (0)	33 (82.5)	40 (100)
5	1 (2.5)	11 (27.5)	6 (15.0)	15 (37.5)	6 (15.0)	1 (2.5)	28 (70.0)	40 (100)

S* = sum of the prevalence of roots with type C1, C2, D1, and D2.
The values in the parenthesis are percentage of all roots at the specific level.

TABLE 4. The Types of Canal Configurations in the Maxillary MB Roots and the Mandibular Mesial Roots According to the Canal Types Suggested by Weine (8)

Tooth Root	Canal Type	Level from Apex (mm)	Canal Configurations							
			A	B	C1	C2	D1	D2	S*	Total
Mx MB Root	II	2	10 (62.5)	1 (6.3)	2 (12.5)	2 (12.5)	0 (0)	1 (6.3)	5 (31.2)	16 (100)
		3	9 (56.3)	2 (12.5)	1 (6.3)	3 (18.7)	0 (0)	1 (6.3)	5 (31.2)	16 (100)
		4	7 (43.8)	2 (12.5)	2 (12.5)	4 (25.0)	0 (0)	1 (6.3)	7 (43.7)	16 (100)
		5	9 (56.3)	1 (6.3)	0 (0)	6 (37.5)	0 (0)	0 (0)	6 (37.4)	16 (100)
	III†	2	0 (0)	7 (31.8)	4 (18.2)	3 (13.6)	5 (22.7)	3 (13.6)	15 (68.1)	22 (100)
		3	0 (0)	7 (31.8)	3 (13.6)	6 (27.3)	4 (18.2)	2 (9.0)	15 (68.1)	22 (100)
		4	0 (0)	5 (22.7)	0 (0)	9 (40.9)	5 (22.7)	3 (13.6)	17 (77.3)	22 (100)
		5	3 (13.6)	8 (36.4)	1 (4.5)	8 (36.4)	2 (9.0)	0 (0)	11 (50.0)	22 (100)
Mn Mesial Root	II	2	10 (50.0)	1 (5.0)	3 (15.0)	6 (30.0)	0 (0)	0 (0)	9 (45.0)	20 (100)
		3	5 (25.0)	0 (0)	2 (10.0)	11 (55.0)	2 (10.0)	0 (0)	15 (75.0)	20 (100)
		4	1 (5.0)	2 (10.0)	3 (15.0)	13 (65.0)	1 (5.0)	0 (0)	17 (85.0)	20 (100)
		5	1 (5.0)	5 (25.0)	3 (15.0)	10 (50.0)	1 (5.0)	0 (0)	14 (70.0)	20 (100)
	III	2	0 (0)	5 (25.0)	2 (10.0)	4 (20.0)	9 (45.0)	0 (0)	15 (75.0)	20 (100)
		3	0 (0)	3 (15.0)	6 (30.0)	3 (15.0)	8 (40.0)	0 (0)	17 (85.0)	20 (100)
		4	0 (0)	4 (20.0)	6 (31.0)	4 (20.0)	6 (30.0)	0 (0)	16 (80.0)	20 (100)
		5	0 (0)	6 (30.0)	3 (15.0)	5 (25.0)	5 (25.0)	1 (5.0)	14 (70.0)	20 (100)

S* = sum of the prevalence of roots with type C1, C2, D1, and D2.
† = statistically significant in the prevalence of type S (χ^2 test, $p < 0.05$).

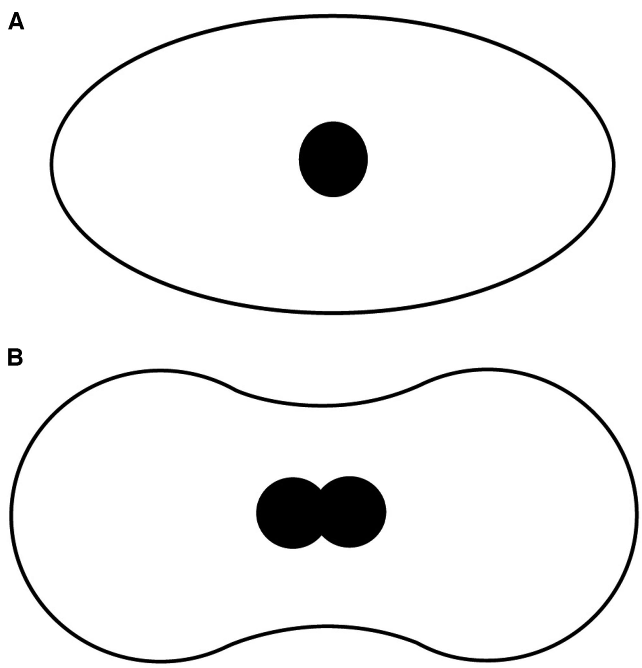

Figure 1. Diagrams of type A configuration. (*A*) One canal with filled with gutta-percha cone and sealer, (*B*) two canals merged into one canal filled with gutta-percha cone and sealer.

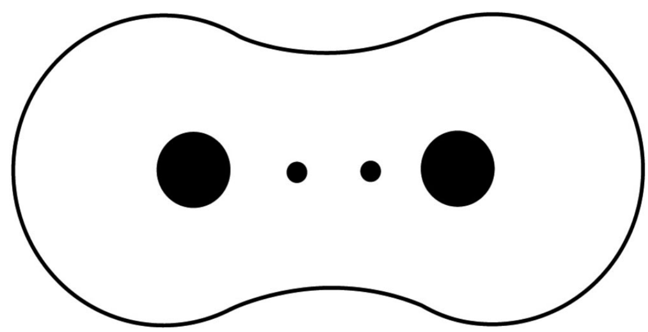

Figure 2. A diagram of type D1 configuration showing two separate canals and one or more accessory canals in between.

prevalence of type S (sum of type C1, C2, D1, and D2) ranged from 44.7 to 63.2% in the maxillary MB roots and from 60 to 82.5% in the mandibular mesial roots. The greatest prevalence of accessory root canals and canal isthmi was found at the apical 4 mm level in the instrumented roots.

Canal configurations according to the root canal classification proposed by Weine are presented in Table 4. The prevalence of type S was generally higher in molar roots with Weine type III canal. There was a significantly higher prevalence of the anatomical variations in roots with Weine type III canals than in those with Weine type II canals in the maxillary MB roots ($p < 0.05$). The prevalence of type A configuration (Fig. 1) was higher in the maxillary MB roots, and in roots with Weine type II canal.

For Weine type II canals, there was no type D1 configuration in the instrumented MB roots. In case of Weine type III canals, however, type D_1 configuration was 9 to 22.7% in the maxillary MB roots and 25 to 45% in the mandibular mesial roots (Fig. 2). In addition, type D2 configuration was found only in the maxillary MB roots with the incidence of 6.3% in the roots with Weine type II canals and of 9 to 13.6% in the roots with Weine type III canals. Different canal configurations were often found at different levels in the same root (Fig. 3).

Discussion

A thorough knowledge of root canal morphology and configuration in the apical third of posterior teeth plays an important role in the success of endodontic therapy (1–6, 9–12). In the present study, the incidence of two canals detected with the combined use of a microscope and radiographs was 80.8% in the maxillary MB roots. Marroquín et al. (12), using a computer-aided stereomicroscope, reported a 71.15% incidence of two physiological foramina in the mesiobuccal (71.15%) roots of maxillary first molars. In an in vitro study, Buhrley et al. (13) reported that the frequencies of MB_2 canal detection for the microscope group and no magnification group in the maxillary first molars were 71.1% and 17.2%, respectively. Wolcott et al. (14) reported that the

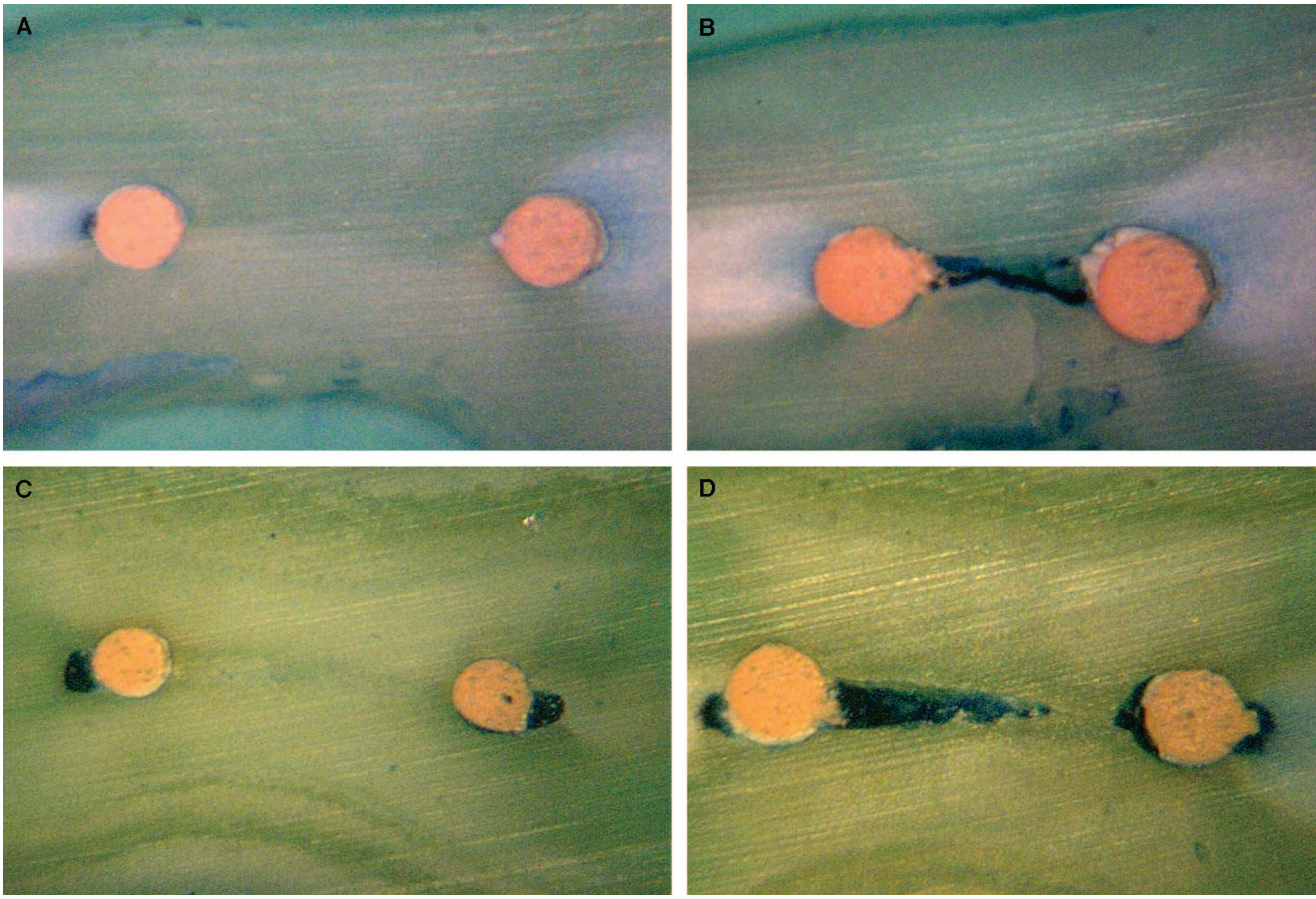

Figure 3. In the MB root of maxillary first molar, type B was shown at the 2 mm level (*A*), but type C2 (complete isthmus) was found at the 4 mm level in the same root (*B*). Type B canal configuration was shown at the apical 2 mm level of the mesial root of mandibular first molar (*C*), but the configuration at the 4 mm level was like type C1 (partial isthmus) in the same root (*D*). Original magnification: 100×.

incidence of a MB_2 canal in maxillary first molar reteatment was 67% compared to a 59% incidence in initial treatment. These findings suggest that failure to find and treat existing MB_2 canals will decrease the long-term prognosis. Therefore, during endodontic practice in the permanent first molars, more emphasis should be placed on the importance of using magnification for locating additional canals (9, 10, 13, 14).

The present results also show that the prevalence of accessory canals and canal isthmi is still high in the apical 2 to 5 mm of the instrumented mesial or MB roots with two canals. Clinically, this finding may be important because the complete debridement of these anatomical areas through chemomechanical preparation is impossible, and necrotic pulp tissues and microorganisms remaining in the apical portion are considered a primary cause of treatment failure (15). Card et al. (16) showed that infected mesial canals of mandibular molars without clinically detectable apical communication were rendered bacteria-free more often than those with clinically detectable communication after instrumentation to size 60, although the numbers in these categories were too low to establish statistical significance.

One of the intriguing findings of the present study was the location of an accessory root canal between a main root canal and the outer root surface. Although this finding was very rare in the mandibular mesial roots, the maxillary MB roots showed prevalence of 7.9 to 10.5% at the apical 2 to 4 mm level. Furthermore, the accessory canal was mainly located at the lingual side of the MB_2 root canal (Fig. 4). This suggests that the lingual side of the maxillary MB roots should be thoroughly searched with a microscope during surgical procedures. We do acknowledge, however, that given the size of these canals and the anatomical restrictions in situ, this might be difficult to achieve.

Figure 4. Suspected accessory canal located in the lingual side of the MB_2 canal (type D2) at the apical 4 mm level of the MB roots of the maxillary first molars (arrowhead). Original magnification: 30×.

The distribution of canal configuration types shown in this study was compared to the canal types suggested by Weine (8). In roots with Weine type II canals, the prevalence of type A configuration was higher in the maxillary first molars than in the mandibular first molars. This result might be a result of the shorter anatomical distance between the MB_1 and the MB_2 root canal, and thus the convergence of two root canals into one by the root canal preparation. In roots with Weine type III canals, however, no type A configuration was observed at the apical 2 to 5 mm level of mandibular mesial roots, but the prevalence of type S was over 70%. Therefore, during surgical procedures in the mandibular mesial roots containing Weine type III canal, it is necessary to identify these anatomic variations and include them in the apical preparation.

In the present study, the prevalence of an accessory root canal located between the MB_1 and the MB_2 root canal was 5.3 to 13.2% in the maxillary MB roots, which is similar with previous studies (5, 6). Weller et al. (3) showed that the prevalence of a partial isthmus was 23.1 to 88% in the MB root of the maxillary first molar. In the present study, however, the prevalence of partial isthmus was lower (2.6–15.8%) than that found by Weller et al. (3). This result may be a result of the different definitions of a partial isthmus in the two studies. Weller et al. (3) treated accessory root canals between two main root canals as a partial isthmus while in this study we placed this type into a separate category. Another possible reason may be a result of the inclusion of a partial isthmus into the main root canal by the root canal preparation. Current evidence indicates that wider apical preparation are feasible and with that probably improved irrigation efficacy and obturation quality (16, 17). We prepared all root canals to size 30/.04 taper. If we had increased the instrumentation size to a size 60 Light Speed instrument, as suggested in the study by Card et al. (16) the prevalence of partial isthmus may have been lower. This further illustrates that examining the root canal anatomy following instrumentation is more relevant to surgical endodontics than preoperative analysis. Our results illustrate that different canal configurations were often found at different levels in the same root. This is in agreement with the finding of Weller et al. (3) but differs from that of Tam et al. (5, 6) who reported similar configurations in sections at the 3 to 5 mm apical levels in the same root. It is difficult to explain the difference, though it may be a result of a methodological difference or a race-specific effect. However, this anatomical information may be important to clinicians. If the root-end preparation only includes the main root canal, bacteria and the other harmful irritants from an isthmus or from an accessory root canal may gain access to the periradicular tissue via the poorly filled root canal system. This would negatively affect the surgical endodontic treatment outcomes.

Therefore, extrapolated to the clinical situation, the present findings strongly suggest that it is not possible to reliably eradicate all pulp tissues and/or microorganisms from many infected root canals through chemomechanical preparation, because of their complex anatomical variations. This concern may lend some support to the practice of medicating infected root canals with an antimicrobial agent for a suitable period of time before obturation (16, 18).

In conclusion, our data demonstrate that the MB roots of the maxillary first molars and the mesial roots of the mandibular first molars with two canals may have high prevalence of variably located accessory root canals and isthmi at the apical 2 to 5 mm level despite a complete root canal preparation. These anatomical variations should be considered during surgical or nonsurgical endodontic treatment of the posterior first molars.

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