Original Article

Root and canal configuration of the maxillary first molar in a Saudi subpopulation: A cone-beam computed tomography study

Sultan Al-Shehri, Saad Al-Nazhan[1], Shreen Shoukry[2], Emad Al-Shwaimi[3], Ra'ad Al-Sadhan[4], Bader Al-Shemmery[5]

Departments of Endodontics, Ministry of Health, King Salman Hospital, [2]Riyadh Colleges of Dentistry and Pharmacy, [5]King Faisal Specialist Hospital and Research Center, Riyadh, [1]Department of Restorative Dental Science, Division of Endodontics, College of Dentistry, King Saud University, [4]Department of Oral Medicine and Diagnostic Sciences, College of Dentistry, King Saud University, Riyadh 11545, [3]Department of Restorative Dental Science, Division of Endodontics, College of Dentistry, Dammam University, Dammam, Kingdom of Saudi Arabia

Abstract

Introduction: The aim of this study was to investigate the root and root canal morphology of permanent maxillary first molars in a Saudi subpopulation and the effect of age and gender on the morphology of these teeth using cone-beam computed tomography (CBCT).

Materials and Methods: A total of 351 CBCT images of the maxillary first molars of 207 Saudi patients were examined. The number of root canals, root canal configuration (Vertucci's classification), and prevalence of fusion were investigated. Chi-square was used to analyze the data, and Kappa test was used to examine inter- and intra-examiner reliability.

Results: A high prevalence of three separated roots was observed in 94% of the teeth. A 55.6% of mesiobuccal roots (MBRs) had two canals of Vertucci's Type IV. The proportion was higher in males than females of a young age. Two-fused roots in three-rooted teeth were present in 5.98%. There was a statistically significant correlation between the number of canals and gender ($P = 0.010$).

Conclusion: The morphological configurations of the root canal of maxillary first molars in Saudi subpopulation were consistent with previously reported data. The majority had three roots and four canals. The additional fourth canal was located in the MBR, and Type IV was the most prevalent. CBCT is an appropriate imaging modality that helps assess complex root canal morphology of human teeth.

Keywords: Cone-beam computed tomography, maxillary first molar, mesiobuccal root morphology, root canal configuration

Address for correspondence:
Prof. Saad Al-Nazhan, Department of Restorative Dental Science, Division of Endodontics, College of Dentistry, King Saud University, P.O. Box 60169, Riyadh 11545, Kingdom of Saudi Arabia. E-mail: snazhan@ksu.edu.sa

INTRODUCTION

The morphology of the root canals of the maxillary first molar was described by Vertucci[1] as being the most intricate among the maxillary teeth. However, proper diagnosis, instrumentation, obturation, and restoration of the tooth

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will increase the outcome of root canal treatment. Failure to locate and treat all canals including the second mesiobuccal canal (MB2) was associated with frequent failure of endodontic treatment of this tooth.[2,3] Therefore, the clinician must be aware of possible anatomical variation. Hess and Zurcher[4] published one of the earliest reports recognizing MB2 in the mesiobuccal root (MBR) of the maxillary first molars. Subsequently, other researchers studied the morphology of the maxillary first molar[5-7] and reported a high incidence of a second MBR canal in most cases, with a range of variation in the results attributable to differences in ethnic background, age, and gender.[7-10]

Al-Nazhan,[11] Al-Fouzan *et al*.,[12] and Alrahabi and Sohail Zafar[13] studied the morphology of the permanent maxillary first molar in a Saudi Arabian subpopulation using conventional radiographs (*in vivo*) and cone-beam computed tomography (CBCT) (*in vitro*). The reported incidence of two canals in the MBR ranged from 23.3% to 51.3% *in vivo* and 70.6% *in vitro*. The use of conventional radiographs to study the morphology of human teeth has the serious limitation of showing the subject in two-dimensional (2D) views instead of in three dimensions, resulting in the superimposition of structures.[14]

The introduction of CBCT allowed for greater frequency of 3D diagnoses in dentistry, including morphological analyses. Baratto Filho *et al*.[15] used three methods (*ex vivo*, clinical, and CBCT) to assess the internal morphology of maxillary first molars and concluded that CBCT was effective for initial morphological identification. CBCT was reported to be more accurate and reliable than conventional radiographs in detecting MB2 canals, as well as determining the morphology of the root canal system.[16]

Fine details of the root and canal morphology of permanent maxillary first molars in a Saudi Arabian subpopulation using CBCT have not been reported previously. Thus, the aim of this study was to examine the root and canal morphology of the permanent maxillary first molar in a Saudi subpopulation using CBCT.

MATERIALS AND METHODS

Sample collection

This study was approved by the Ethical Review Committee of the Research Centre at Riyadh College of Dentistry and Pharmacy (RCsDP), as well as the Research Centre at the College of Dentistry, King Saud University (KSU). Data were obtained from archived CBCT images, held at the oral radiology clinics of different dental centers (RCsDP, KSU, King Faisal Specialist Hospital and Research Centre, and Dammam University) in Riyadh and Dammam, Saudi Arabia.

In total, 760 CBCT images were screened. High-quality CBCT images of 351 permanent maxillary first molars (174 males, 177 females) with fully formed roots among 207 Saudi patients (103 males, 104 females) were selected because they met the following inclusion criteria:

- No periapical lesions, resorption, or canal calcification
- No root canal fillings, cemented posts, or coronal restorations
- Between 16 and 75 years of age (mean age is 26 years).

Gender data were recorded for all selected teeth, but age data were recorded in only 330 teeth. The presence or absence of bilateral maxillary first molars was also noted. The CBCT images were captured with three different CBCT machines: I-CAT (Imaging Science International, Hatfield, PA, USA), Galileos (Sirona Dental Systems, Germany), and Carestream CS 9300 (Carestream Health, Inc., Rochester, NY, USA). All machines were operated at 85 kV, 5–7 mA, with a voxel size of 0.3 mm (14-bit grayscale).

Radiographic evaluation

Two examiners evaluated the CBCT images: A senior postgraduate (PG) endodontic student (Examiner 1) and a certified oral and maxillofacial radiologist (Examiner 2). Before evaluation of the CBCT images, adequate training of the PG student in image processing and reconstruction was conducted. Then, case definitions and criteria for reading and recording data were set. The CBCT volumes were processed and reconstructed using the OnDemand3D software (Cybermed, Seoul, Korea). Axial, coronal, and sagittal sections, as well as multiplanar reconstructed (MPR) sections of the maxillary first molars, were displayed on a 32-inch HP LCD monitor at a resolution of 1280 × 1024 pixels.

The reading of the CBCT images was performed in a dark room. The image magnification, display contrast, and window size were adjusted to ensure optimal visualization. Then, a careful examination was performed by rolling the mouse wheel forward and backward (to scroll through the sections) to eliminate any lateral canal that may have interfered with the reading. After examination, the roots and canals were identified by a series of clicks on the scroll tool, from the canal orifice to the root apex in axial planes. Cross-sectional and MPR sections along the root axes were used for root and canal identification.

The recording criteria for canal identification were as follows: (1) The pulp floor was measured when last faint radiolucent line connected two orifices; (2) the canal orifice was documented as a radiolucent spot at which canal evaluations began; (3) the main canal was recorded as a long connecting line that started from the orifice and ended in the apical foramen; (4) the apical foramen was located in the apical third of the root; and (5) the

root tip represented the final radiopaque appearance of the root structure. A secondary canal was confirmed as a second radiolucent spot located off-center from the main canal.

Root morphology was categorized as fused roots (two or more roots) or totally separate roots. The following criteria were used: (1) MBR and distobuccal root (DBR) were fused and palatal root (PR) was separated, (2) DBR and PR were fused and MBR was separated, (3) PR and MBR were fused and DBR was separated, and (5) all roots were fused.

The number of canals (Cs) was recorded as 2Cs, 3Cs, 4Cs, or 5Cs. The root canal configurations of fused and separated roots were recorded according to the Vertucci's classification.[6]

Patients were classified into five age groups (years).

- Group A (16–25)
- Group B (26–35)
- Group C (36–45)
- Group D (46–55)
- Group E (≥56).

Gender was also included as a variable. Teeth were compared according to age, gender, and contralateral molar (present or absent).

Statistical analysis

Descriptive statistics were recorded for the frequency of root canal, morphology, gender, age of patient, and contralateral tooth status. The relationships among age, gender, tooth position, and incidence of additional canals in the MBR were determined using Chi-square tests. Inter- and intra-examiner reliability data were analyzed with Kappa tests. The SPSS for Windows software (ver. 22.0; SPSS Inc., Chicago, IL, USA) was used to conduct the statistical tests.

RESULTS

Intra-examiner reliability was found to be good (kappa test >0.76). The kappa test showed inter-reliability of the examiner one 86%, where radiologist showed 93%.

Root morphology

Most teeth (99.7%) had three roots: 94% were separated and 6% were fused [Table 1]. Fusion was observed more frequently in females (71.4%) than males (28.6%). Fusion between the DBRs and PRs was observed more often (4.8%) than fusion between the other roots. More fused roots were observed on the right side (61.9%). Bilateral maxillary first molars with fused roots were found in only six females and one male.

Number of root canals

In terms of the number of canals, 4Cs per tooth was noted in 55.6% of teeth, while 2Cs (3.7%), 3Cs (40.4%), and 5Cs (0.3%) were observed less frequently [Table 1]. A higher incidence of MB2 was noted in males (31.9%) than females [23.7%; Table 1]. There was a statistically significant correlation between the number of canals and gender ($P = 0.010$).

Data on age were missing for some of the examined images. Thus, only 162 patients (who had 268 maxillary first molars) for whom age was known were included in the descriptive and correlation analyses. The incidence of 4Cs was high among all age groups [Table 2]. There was no statistically significant correlation between number of canals and age ($P = 0.500$).

Root canal configuration

The incidence of canal configuration of separated and fused roots according Vertucci's classification is summarized in Table 3. Type I root canal morphology in separated roots was

Table 1: Root and root canal morphology of maxillary first molars according to gender

Gender	Sample number	Number of roots (%)		Roots fusion (%)		Number of canals per tooth (%)				
		2	3	Yes	No	1	2	3	4	5
Males	174	0	174 (49.6)	6 (28.6)	168 (47.9)	0	2 (0.6)	57 (16.2)	112 (31.9)	1 (0.3)
Females	177	1 (0.3)	176 (50.1)	15 (71.4)	162 (46.1)	0	11 (3.1)	85 (24.2)	83 (23.7)	0
Total	351	1 (0.3)	350 (99.7)	21 (5.98)	330 (94)	0	13 (3.7)	142 (40.4)	195 (55.6)	1 (0.3)

Table 2: Root and root canal morphology of maxillary first molars according to age

Age group*	Sample number	Roots fusion (%)		Number of canals per tooth (%)				
		Yes	No	1	2	3	4	5
A (16-25)	145	4 (1.5)	141 (52.6)	0	2 (0.8)	60 (22.4)	83 (31)	0
B (26-35)	60	2 (0.8)	58 (21.6)	0	2 (0.8)	21 (7.8)	35 (13.1)	1 (0.4)
C (36-45)	31	1 (0.4)	30 (11.2)	0	0	13 (4.9)	19 (7.1)	0
D (46-55)	16	0	16 (6)	0	0	4 (1.5)	12 (4.5)	0
E (56≤)	16	1 (0.4)	15 (5.6)	0	0	6 (2.2)	10 (3.7)	0
Total	268	8 (3.0)	260 (97.0)	0	4 (1.5)	104 (38.8)	159 (59.3)	1 (0.4)

*268 samples (roots) had known age. This number was included in the statistical analyses only

identified in 35.1% of the MBR; 33.3% showed Type IV morphology (33.3%), whereas only 1.2% of the MBR showed Type VI canal configuration [Figure 1]. In addition, 99.3% of the DBR and 100% of the PR were Type I. An additional canal configuration (2-1-2-1) was identified in the MBR [Figure 2] and DBR [Figure 3]. In fused roots, the incidence rates of Types I (50%) and IV (50%) were high in the DBR and PR [Figure 4].

DISCUSSION

When additional canals (such as the MB2) are studied with 2D projection radiographs (such as periapical radiographs), they are detected less frequently than with 3D sectional views.[5,11,17,18] Some authors recommend CBCT assessment for preintervention diagnosis.[16] This approach was also recommended by the American Academy of Oral and Maxillofacial Radiology,

Table 3: Incidence of canal configuration of separated and fused roots according Vertucci classification

Root configuration	Sample number	Root canal configuration (%)							
		Type I (1-1)	Type II (2-1)	Type III (1-2-1)	Type IV (2-2)	Type V (1-2)	Type VI (2-1-2)	Type Vii (1-2-1-2)	Others
2 fused roots	1			-	1 (0.3)	-	-	-	
3 separate roots									
MBR	330	116 (35.1)	80 (24.4)	12 (3.6)	110 (33.3)	6 (1.8)	(2-1-2) 4 (1.2)	(1-2-1-2) 1 (0.3)	(2-1-2-1) 1 (0.3)
DBR	330	327 (99)	-	1 (0.4)		1 (0.3)	-	-	(2-1-2-1) 1 (0.3)
PR	330	330 (100)			-	-	-	-	-
3 fused roots									
MBR	16	12 (75)	1 (6.2)	2 (12.5)	1 (6.3)	-	-	-	-
DBR and PR fused	16	8 (50)	-	-	8 (50)	-	-	-	-
3 fused roots									
DBR	2	2 (100)	-	-	-	-	-	-	-
MBR and PR fused	2	-	-	-	2 (100)	-	-	-	-
3 fused roots									
PR	2	2 (100)	-	-	-	-	-	-	-
MBR and DBR fused	2	-	-	2 (100)	-	-	-	-	-

DBR: Distobuccal roots; MBR: Mesiobuccal root; PR: Palatal root

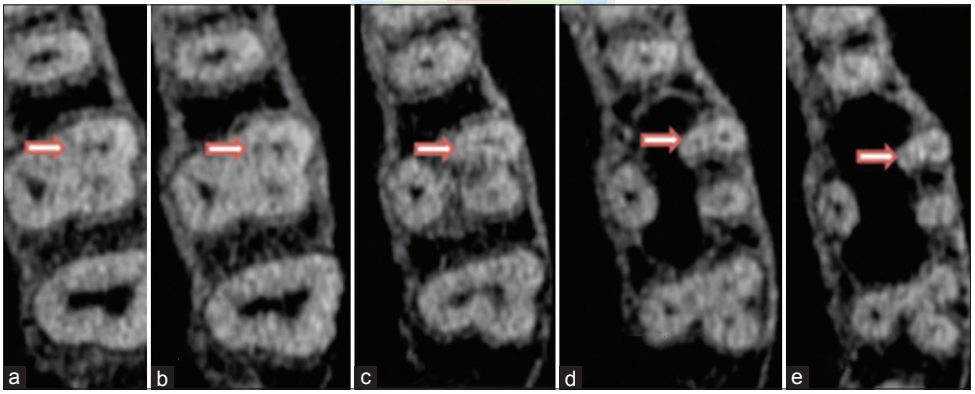

Figure 1: Cone-beam computed tomography images of maxillary first molar showing Type VI root canal morphology of (2-1-2) in mesiobuccal root in axial direction, (a and b) two canals, (c) joined into one canal, (d and e) redivided onto two canals

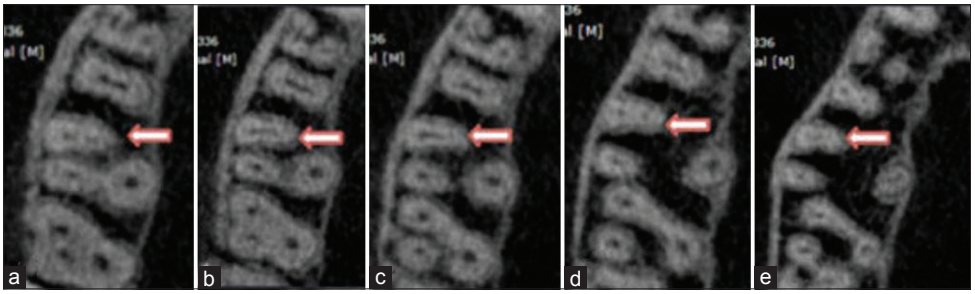

Figure 2: Cone-beam computed tomography images of maxillary first molar showing root canal morphology (2-1-2-1) of mesiobuccal root in axial direction, (a) two canals in mesiobuccal root, (b and c) merged in one canal, (d) canals divided, and (e) canals rejoined

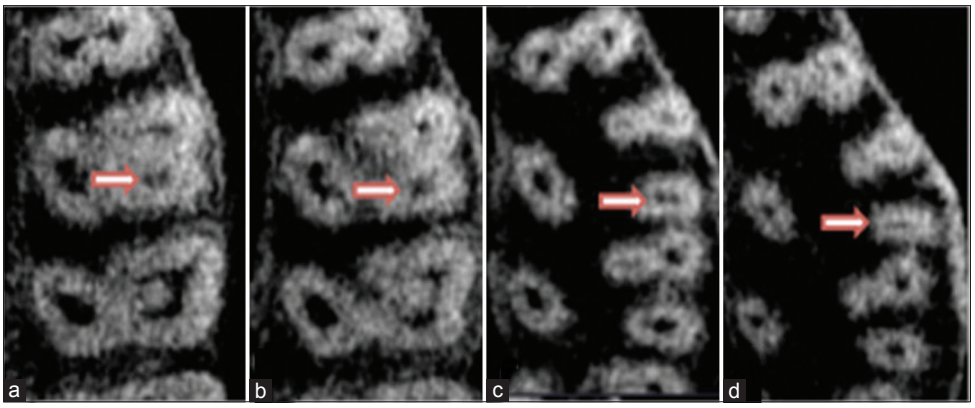

Figure 3: Cone-beam computed tomography images of maxillary first molar showing root canal morphology (2-1-2-1) of distobuccal root in axial direction, (a) two canals in distobuccal root, (b) joined to one canal, (c) canal dived in two, and (d) joined to one apical foramen

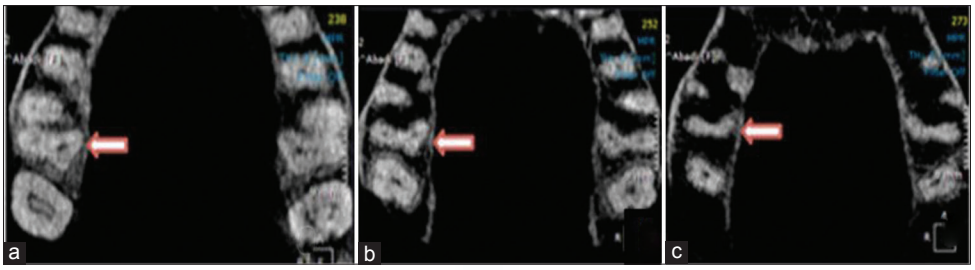

Figure 4: Cone-beam computed tomography images of maxillary first molar of fused distobuccal root and palatal root in axial direction, (a) coronal one-third, (b) middle one-third, (c) apical one-third

the American Association of Endodontics, and the European Society of Endodontology for assessing the complexity of the root canal system.[19,20]

In addition, the accuracy of detecting additional canals depends on the voxel dimension and contrast resolution used. Bauman *et al*.[21] showed the importance of resolution in the CBCT system: ≤0.2 mm voxel sizes are optimal for the detection of MBR canals. In the present study, the voxel size of all CBCT machines was set at 0.3 mm (14-bit grayscale) to reduce the number of variables. This voxel dimension conferred good diagnostic performance and lowered the radiation dose; furthermore, it seems unlikely that it had a large impact on the reliability of additional canal detection.[21,22]

Vertucci's classification system,[6] which is the most widely accepted, clinically relevant, and compensated classification scheme for studying root canal anatomy, was used in this study. All of the Vertucci's root canal classes were identified in the current study, except for Type VIII. This is consistent with Jordanian, Ugandan, and Korean reports.[8,9,23]

Most of the teeth in the present study had three separated roots (94%), consistent with the previous CBCT findings in Saudi,[13] Indian,[24] Chinese,[25] Korean,[9] North American,[26] and Brazilian populations.[27]

Two-rooted maxillary first molars are uncommon. In the present study, only one case was found to have two roots (0.3%). Two-rooted teeth have been rarely detected using CBCT in previous studies with Indian,[26] Korean,[9] and North American populations.[26] No single-rooted maxillary first molar was found in the present study. Only two CBCT studies have reported the presence of a single root in the maxillary first molar.[9,24]

None of teeth investigated herein showed anomalies, such as C-shaped canals. Similar findings in CBCT studies were reported by Kim *et al*.,[9] Neelakantan *et al*.,[24] and Silva *et al*.[27] However, low incidences were reported by De Moor.[28]

Fusion of DBR and PR was observed more than fusion of other roots in the current study. The incidence of fused roots in the total sample was 5.98%, which is higher than the incidence rates reported by Kim *et al*.,[9] Thomas *et al*.,[29] and Zheng *et al*.[30] but lower than the rate observed in an Irish population.[31] Studies of maxillary first molars in Ugandan, Indian, and Brazilian populations showed no fusion.[23,24,27] Differences in reported incidence rates are likely related to differences in sample size and the ethnic background of patients.

The MBR and DBR fusion rate in the present study was found to be 9.5% ($n = 2$). This is in contrast to reports on Chinese[30] and Irish[31] populations, which had higher incidence rates of

58.8% ($n = 10$) and 55.6% ($n = 5$), respectively, for total fused roots. These differences highlight the influence of ethnic background on maxillary molar root morphology. Fusion of the MBR and PR in the current study was seen only in females (two cases) and at a lower rate than that reported for a Ugandan population.[23] In addition, the incidence rate of fused roots according to age was only previously reported by Al Shalabi *et al*.;[31] in their study, older age was associated with a higher tendency for root fusion. This was attributed to the deposition of secondary cementum. The incidence of fused roots in the current study, in all age groups, was very low.

Fusion of all roots was not found in the present study, which is consistent with reports on Korean populations[9] and Indian[24] but differs from the findings in Ugandan[23] and Chinese populations.[30] These differences again emphasize the influence of ethnic background.

The MBR of the maxillary molar has a complex anatomy. According to Weine *et al*.,[2] it is broad buccolingually and relatively slender mesiodistally, which presents a challenge when conventional periapical radiographs are used to visualize canal anatomy before starting root canal treatment. This is due to the small width of MB2 and its proximity to the main canal.[32] Conventional periapical radiographs provide little information due to the alignment of the MBR canals in a buccolingual plane, making it difficult to differentiate them from each other in the buccolingual dimension.[33]

The prevalence of MB2 in the first maxillary molar has been investigated extensively.[2,22,26,30,34] The reported incidence is very high, but with wide variations related to the race, gender, and age of the studied population, and the method of investigation. The incidence of MB2 in the present study was 55.6%. This was higher than in two previous studies conducted in Saudi populations.[11,12] The difference is likely to be attributable to differences in evaluation methodology.

Guo *et al*.,[26] Lee *et al*.,[34] and Reis *et al*.[35] reported higher proportions of MB2 in the MBR than the current study. Guo *et al*.[26] compared five ethnic groups (African-American, Asian, Hispanic, non-Hispanic White, and others) in North America and found no differences in the occurrence rates of MB2. Although previous studies have included large sample sizes and used CBCT as the detection method, ethnic origin might have influenced the results. The higher incidence of MB2 reported in the majority of CBCT studies, including the current study, demonstrates that CBCT is an appropriate imaging modality that helps clinicians assess complex root canal morphology.[36]

Type I, II, and IV canal configurations have been reported to be the most common morphologies in the MBR regardless of gender and ethnicity. Kuwaiti,[18] Ugandan,[23] Chinese,[30] Brazilian,[37] and Japanese[38] populations had high frequencies of Type I canal morphology (75.1%, 75%, 58.2%, 48%, and 42%, respectively), with lower frequencies reported in Turkish,[7,39] Jordanian,[8] Indonesian,[40] Pakistani,[41] and Korean[9] (34.4%, 6.5%, 22.6%, 31,5%, 33.3%, and 36.4%, respectively) populations. Al-Nazhan[11] reported a high frequency of Type I (76.7%) canal morphology in a Saudi subpopulation, and Al-Fouzan *et al*.[12] reported Type II and Type IV frequencies of 33.1% and 18.2%, respectively. In the present study, the incidence rates of Type I, II, and IV morphologies were 36.9%, 23.3%, and 31.9%, respectively. Our findings probably differed from those of Al-Nazhan[11] and Al-Fouzan *et al*.[12] due to differences in the method of evaluation. These results show the value of CBCT as a tool for canal detection.

In the current study, an additional canal configuration (2-1-2-1) was identified in the MBR and DBR. This was not reported before. The frequency of Type I morphology in the DBR was 99.4%. Similar frequencies were found in Turkish,[39] Irish,[31] Ugandan,[23] and Korean populations[9] of 98.5%, 97.5%, 97.7%, and 98.7%, respectively. However, Pakistani,[41] Burmese,[42] and Indian populations[43] had lower incidences of Type I morphology.

The incidence rate of the Type I canal configuration, in the PR in the present study, was 100%. This result is similar to those reported for Saudi,[13] Turkish,[7,39] Korean,[9] Ugandan,[23] Pakistani,[41] Burmese,[42] and Indian populations.[43]

Few studies have reported 5Cs in the maxillary first molar. Hartwell and Bellizzi[17] found 5Cs in 0.2% of cases, consistent with the present study. A higher incidence (1.75%) was reported in a Chinese population.[30] Recently, a case of Saudi male with six canals, two in each root, was reported by Al-Habboubi and Al-Wasi.[44]

Regarding the diversity and number of teeth studied, it seems that racial/ethnic differences are important with respect to the differences observed in root canal configuration. Sert and Bayirli[7] concluded that both gender and ethnic origin should be considered during preoperative evaluations for root canal therapy.

In the present study, there was a statistically significant relationship between gender and number of canals ($P > 0.05$). This result is in agreement with those of Kim *et al*.[9] and Fogel *et al*.[45] In contrast, no statistically significant relationship ($P < 0.050$) was reported by Al-Nazhan[11] or Zhang *et al*.[25] No gender difference was found in the number of roots in the current study. However, MB2 was shown to be predominant in males, consistent with previous studies.[7,9,45]

In the present study, patient age influenced the number of canals, especially in the MBR. Age Group "A" (16–25 years) had a higher frequency of additional canals in the MBR (31%) compared to the other age groups although the differences between age groups were not statistically significant ($P = 0.500$). This result agrees with those of Kim *et al*.,[9] Neaverth *et al*.,[10] Thomas *et al*.,[29] Zheng *et al*.,[30] and Lee *et al*.[34] With increasing age, caries, and greater exposure of the tooth to restorative procedures, increase the likelihood of MB2 canal calcification, resulting in difficulties in locating the canal. In the present study, it was noted that some MB2 orifices were covered by dentin, concealing the funnel-shaped structure of the root canal. Such "rounded" dentinal growth needs to be removed during root canal treatment so that the mesiocentral area of the pulp chamber can be viewed to negotiate the MB2 canal. This observation is in agreement with the studies of Acosta Vigouroux and Trugeda Bosaans[46] and Görduysus *et al*.[47]

In the present study, there were no statistically significant relationships between age and bilateral canals or gender and bilateral canals. This is in agreement with the studies of Neaverth *et al*.[10] and Fogel *et al*.[45] The incidence of additional canals in subjects with bilateral maxillary first molars was reported by Zhang *et al*.[25] to be higher than that of subjects with unilateral maxillary first molars, in contrast to the findings of the present study. This may be due to differences in sample size and the higher incidence of bilaterally distributed additional canals.

CONCLUSIONS

The majority of the Saudi subpopulation included in this study had three roots and four canals in the maxillary first molar. The additional fourth canal was located in the MBR and Type IV (two canals with two apical foramina) was the most prevalent. The proportion was higher in males than females of a young age. Prior knowledge of anatomic variations of the teeth before starting root canal treatment can help dentists locate and treat all the canals.

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Conflicts of interest

There are no conflicts of interest.

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