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Original article

Root and canal configurations of mandibular first molars in a South African subpopulation

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Abstract

Purpose: This study investigated root number and canal configurations, including morphological variations, of mandibular first molars in a subpopulation of South Africans.
Methods: Two calibrated examiners retrospectively evaluated 371 mandibular first molars by using high-resolution cone-beam CT images and the Vertucci classification system with the additions of Sert and Bayirli. Internal and external configurations were recorded, and correlations of sex and age with root number and canal configuration were determined with the chi-square and Fisher exact tests ($P < 0.05$).
Results: Among mandibular first molars, 0.3% were single-rooted, 98.7% were two-rooted, and 1% were three-rooted. The most frequent configuration was Vertucci Type IV in mesial roots and Vertucci Type I in distal roots. Middle mesial canals were found in 20% and middle-distal canals in 7% of samples. The prevalence of third canals increased in mesial and distal roots as age increased ($P > 0.05$). Canal configuration and sex were not correlated ($P > 0.05$).
Conclusion: Mandibular first molars exhibited diverse anatomic characteristics in this subpopulation. Clinicians should be aware of the possibility of additional canals in mandibular first molars, as treatment outcomes may be worse if canals are left untreated.

Keywords; CBCT, cone-beam computed tomography, dental anatomy, endodontics, mandibular first molars

Introduction

An extensive knowledge of dental root and canal anatomy is vital for clinicians performing endodontic treatment, as the internal and external anatomy, especially of mandibular molars, may be complex and exhibit significant variation [1]. Failure to locate all root canals during endodontic treatment decreased the chance of retaining a tooth [2], and the presence of additional untreated root and canal anatomy was reported to be a major cause of endodontic treatment failure in molars [3].

Variation in root number and canal configuration in human dentition is likely attributable to several factors, including hereditary and ethnic differences between populations [4]. Root anatomy was found to be associated with racial, genetic, and external factors [3]. Geographic area may also have a role in dental anatomic variation [5].

Several systems have been used to classify root canal anatomy and root canal morphology of the human dentition. The original Vertucci classification system is one of the most well-known and widely used classifications [6] but is limited when describing teeth with more than two canals per root [5]. In 2004, Sert and Bayirli added 15 configurations to Vertucci's original classification system, to describe increasingly complex root canal anatomy [7]. This expanded classification system has been used in several anatomic studies, especially those describing the anatomy of molar teeth [7-9].

The middle mesial canal—an additional (third) root canal located in the mesial root of human mandibular molars—might be missed during root canal treatment [10]. Middle distal canals (additional root canals in the distal root of molar teeth) have also been observed in mandibular molars [1].

Several studies have used cone-beam computed tomography (CBCT) to characterize root and canal anatomy [11,12]. CBCT was found to be as effective in detecting root canals when compared to clinical troughing and magnification-mediated scouting [10].

A literature search failed to identify any studies of the internal or external dental anatomy of mandibular first molars in a South African subpopulation. The present study thus aimed to determine the root number and canal configuration of mandibular first molars, including morphological variations, in a subpopulation of South Africans presenting for treatment at an academic dental hospital.

Materials and Methods

Ethical approval for this retrospective, cross-sectional, descriptive study was obtained from the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Protocol number: 397/2018). Convenience sampling was used: CBCT scans from the Section of Diagnostic Imaging of the University of Pretoria Oral and Dental Hospital were retrospectively evaluated from the most recently acquired scan until the necessary minimum sample size was reached (time range: September 2016 to November 2018).

Evaluation of CBCT images was based on previously described methods, with modifications [11,13,14], as described below.

Source of CBCT scans

All the present CBCT scans were taken with a CBCT scanner (Planmeca Promax 3D Max, Planmeca Oy, Helsinki, Finland) and retrospectively acquired from an existing database of CBCT scans in the Section of Diagnostic Imaging, Oral and Dental Hospital, University of Pretoria. No new scans were acquired for this study.

The resolution of the CBCT machine ranged from 100 to 600 µm, with 300 to 750 basic frames. The anode current used for acquiring CBCT images was 1 to 14 mA and anode voltage was 54 to 90 kV, with a "focal spot" diameter of 0.6 mm.

The scans included in the study had been obtained for various clinical and diagnostic purposes, including diagnosis and treatment planning for maxillofacial pathology, maxillofacial surgery/trauma, periodontal disease, implantology, orthodontic cases, prosthodontic cases, and advanced endodontics.

Analysis of CBCT scans

Coronal, sagittal, and axial CBCT images of each mandibular first molar were evaluated by two calibrated examiners, each with experience in endodontics and clinical interpretation of CBCT images. Inter-rater calibration was performed by evaluating 92 roots from 46 teeth (18 CBCT scans) before evaluating the study sample. Inter-rater reliability—defined as percentage agreement—was 93.5% (disagreement: $n = 6/92$ samples). CBCT images were examined by scrolling through the slices from coronal to apical, distal to mesial, and buccal to lingual views. Each examiner independently classified each mesial and distal root, and the findings were later compared at a separate meeting. When the two examiners agreed, the classification was accepted. When they disagreed, the samples were re-evaluated by a third independent examiner, also experienced in endodontics and interpretation of CBCT imaging, to determine the final classification.

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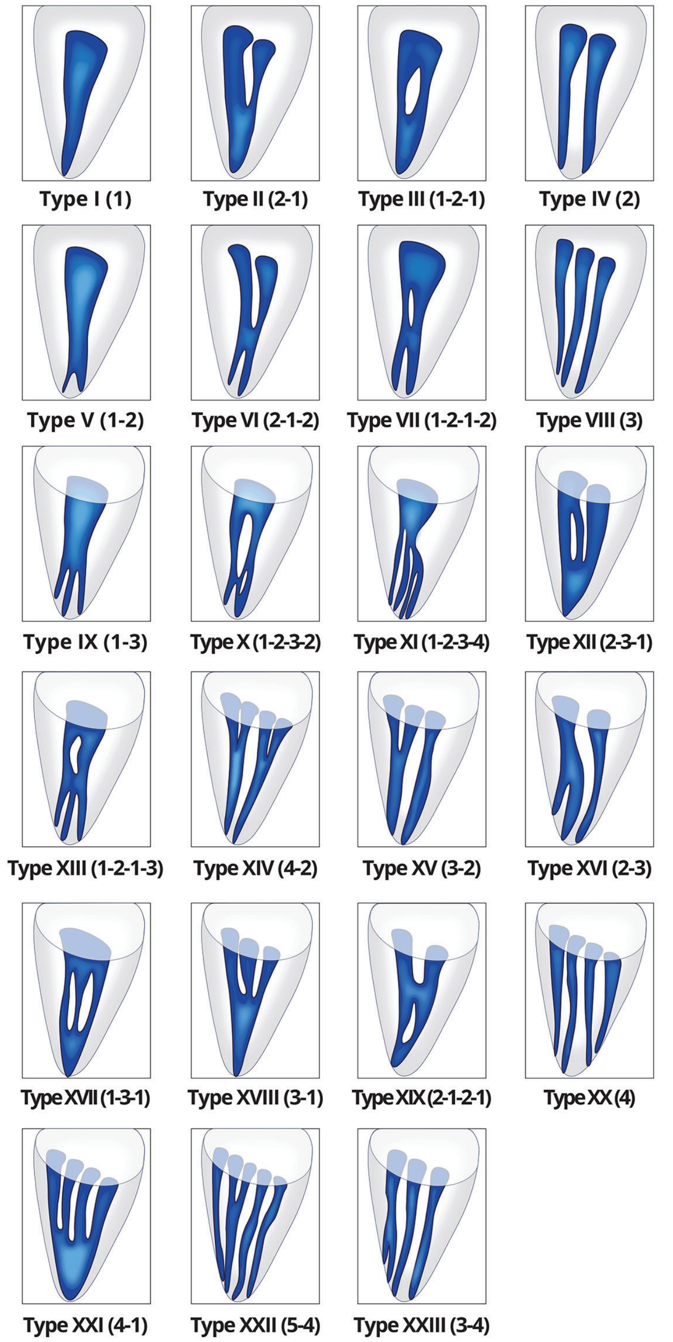

Fig. 1 The canal configuration of each root was classified by using the Vertucci classification system with the modifications proposed by Sert and Bayirli, 2004 [7].

Classification of root number and canal configuration

Teeth were classified as one-, two-, three- or four-rooted and further classified as having a radix entomolaris, radix paramolaris, or two mesial roots.

The mesial and distal canal systems were independently classified with the Vertucci classification system [6], including the modifications proposed by Sert and Bayirli [7]. Figure 1 shows the 23 possible configurations. The prevalence of C-shaped canal systems was recorded, but these teeth were not classified as part of this study. CBCT images were de-identified to ensure patient anonymity.

Participants' age and sex were recorded to identify possible associations of these variables with root number and canal classification. The voxel size of each scan was noted. Participants were grouped by age as younger than 25 years, 25 to 40 years, and older than 40 years. Scans from patients younger than 10 years were not included in the analysis. In accordance with the methodology described by Nosrat et al. [15], age was noted in order to identify significant differences in internal anatomy between older and younger cohorts, as such differences might be relevant clinically.

Inclusion criteria

The present CBCT scans had to include at least one sample (mandibular first molar). The molar had to be fully formed, and the root canal orifices and radicular root canal system had to be visible on the scan. The maximum slice thickness of images included for evaluation was 200 µm.

Exclusion criteria

Samples were excluded if they had any of the following characteristics: root canal orifices that were not clearly visible on the CBCT scan; a radicular root canal system not entirely visualized in the scanned area; any evidence of previous apical surgery; presence of any scatter-producing elements, such as radicular posts, large restorations, metal fixtures, or implants, near roots (thus rendering interpretation unreliable); total canal calcifications/obliterations obscuring the original number of root canals; any signs of root resorption; conical teeth without clearly separate mesial and distal canal systems; and C-shaped teeth (these anatomic variants were noted but excluded from canal classification). Scans with voxel sizes greater than 200 were excluded because of the lack of detail, which makes accurate classification of the canal systems impossible.

Sample size

To achieve a two-sided 95% confidence interval for the prevalence of middle mesial canals within approximately 1% and a total prevalence of 2%, a sample size of 369 teeth was required. The sample size was calculated using nQuery Advanced release 8.0.0.0 (Statistical Solutions Ltd., Cork, Ireland) and was based on the large-sample normal approximation of the binomial distribution.

To reach the minimum number of mandibular molars needed to satisfy the inclusion criteria, at least 92 CBCT scans (assuming four teeth per scan) and at most 369 scans (assuming one tooth per scan) were required.

Statistical analysis

Data were captured by using Microsoft Excel 2003 (Microsoft Corporation, Redmond, WA, USA), and statistical analysis was performed with SAS v9.4 software (SAS Institute Inc., Cary, NC, USA). Root number and root canal configuration are expressed as a percentage of the total number of molars. Categorical variables were compared with significance set at $P < 0.05$ by using the chi-square and Fisher exact tests.

Results

Description of sample

A total of 371 mandibular first molars were evaluated. The distribution of left- and right-sided first molars was approximately even. The male:female distribution of the sample was approximately 50:50. Two mandibular first molars had a C-shaped root and/or canal anatomy and were excluded from further analysis (0.5%, $n = 2/371$), in accordance with the inclusion criteria. The remaining 369 teeth/samples were evaluated.

Root number

Nearly all (98%, $n = 364/369$) mandibular first molars had two roots. Only one single-rooted molar (0.3%, $n = 1/369$) and four three-rooted molars (1%, $n = 4/369$) were observed. No mandibular first molars had four roots (0%, $n = 0/369$).

Canal configurations (modified Vertucci classification)

The distribution of the canal configurations of mandibular first molars is summarized in Table 1. The most common configurations of the mesial roots of mandibular first molars were Type IV (two separate canals, 50.1%, $n = 185/369$) followed by Type II (two canals with separate orifices fusing into one canal and one portal of exit, 21.1%, $n = 78/369$). Most distal roots had a Type I configuration (one single canal, 50.4% $n = 186/369$). The second most common configuration was Type V (two canals with one orifice splitting into two canals, each with its own portal of exit, 19.8% $n = 73/369$). No sample had a Type XIV, XXII, or XXIII configuration. Of the 75 mandibular first molars with three or more mesial canals: 33% ($n = 25/75$) had one distal canal, 56% ($n = 42/75$) had two distal canals, and 10% ($n = 8/75$) had three or more distal canals in their distal roots.

Table 1 Prevalence of canal configurations in first mandibular molars*

Canal classification	Mesial root % (*n*)	Distal root % (*n*)
I	0.54 (2)	50.41 (186)
II	21.14 (78)	3.52 (13)
III	1.90 (7)	12.47 (46)
IV	50.14 (185)	5.15 (19)
V	2.17 (8)	19.78 (73)
VI	2.71 (10)	0.27 (1)
VII	0.54 (2)	0.81 (3)
VIII	1.36 (5)	-
IX	-	0.54 (2)
X	3.79 (14)	0.54 (2)
XI	-	0.27 (1)
XII	3.79 (14)	0.54 (2)
XIII	-	0.27 (1)
XIV	-	-
XV	7.86 (29)	0.81 (3)
XVI	1.08 (4)	1.08 (4)
XVII	-	2.98 (11)
XVIII	2.17 (8)	0.27 (1)
XIX	-	0.27 (1)
XX	0.27 (1)	-
XXI	0.54 (2)	-
XXII	-	-
XXIII	-	-

*as described by Vertucci, including the additions proposed by Sert and Bayirli, 2004 [7]

Table 2 Canal group classifications

Groups	Number of canals	Classifications included in group
1	1	I
2	2	II, III, IV, V, VI, VII, XIX
3	3	VIII, IX, X, XII, XIII, XV, XVI, XVII, XVIII
4	≥4	XI, XIV, XX, XXI, XXII, XXIII

Table 3 Distribution of canal number groups for mandibular first molars

Groups	Mesial root % (*n*)	Distal root % (*n*)
1	0.5 (2)	50.4 (186)
2	78.6 (290)	42.3 (156)
3	20.0 (74)	7.0 (26)
4	0.8 (3)	0.3 (1)

Table 4 Canal anatomy in mandibular first molars by age group

	<25 years		25-40 years		>40 years	
Groups	Mesial % (*n*)	Distal % (*n*)	Mesial % (*n*)	Distal % (*n*)	Mesial % (*n*)	Distal % (*n*)
1	0.89 (1)	54.46 (61)	0.00 (0)	48.55 (67)	0.84 (1)	48.74 (58)
2	82.14 (92)	41.07 (46)	80.43 (111)	44.20 (61)	73.11 (87)	41.18 (49)
3	16.96 (19)	4.46 (5)	18.84 (26)	6.52 (9)	24.37 (29)	10.08 (12)
4	0.00 (0)	0.00 (0)	0.72 (1)	0.72 (1)	1.68 (2)	0.00 (0)

Canal classification in relation to highest canal number

Canals were further classified into four groups according to the highest number of canals present in the canal system (Table 2). Most mesial roots of mandibular first molars had two canals (78.6%, n = 290/369). The second most common number of canals in the mesial roots was three (20.1%, n = 74/369). The two least common numbers of canals were four or more canals (0.8%, n = 3/369) and one canal (0.5%, n = 2/369).

Approximately half of the distal roots of mandibular first molars had only one canal (50.4%, n = 186/369); 42.3% (n = 156/369) had two canals. The prevalence of three canals in distal roots was 7.05% (n = 26/369). In mesial roots, the prevalence of three canals was significantly higher, at 20% (n = 74/369, $P < 0.05$). Only one mandibular first molar had four or more canals in its distal root. Table 3 shows mandibular first molars classified by highest canal number. Canal configurations were not correlated with sex ($P > 0.05$).

Effect of age on canal configuration

The number of root canals was compared in relation to age cohort, as described in the Materials and Methods section. Table 4 shows the number of canals in each age group. The prevalence of third canals in mesial and distal roots of mandibular first molars increased with advancing age, but the difference was not statistically significant ($P > 0.05$).

Discussion

Root number and canal configuration were diverse in the present mandibular first molars. There is no previous study of root number or canal configurations of mandibular first molars in a South African population; thus, this study is likely the first to report the dental anatomy of this tooth type of a subpopulation from this region.

Dental practitioners providing endodontic treatment need a comprehensive understanding of common root numbers and canal configurations, as well as less common anatomic variations, for all tooth types. Extensive knowledge of the internal and external morphology of molar teeth is particularly important, as the success rate for endodontic treatment, particularly for mandibular first molars, was found to be lower [16], which has implications for patients and practicing clinicians.

Failure to locate and treat all root canals during endodontic treatment can result in worse treatment outcomes [2]. Complex anatomic variations, although rare, should routinely be taught at dental schools, to ensure that future clinicians are aware of the existence and relative clinical prevalence of aberrant anatomy. It may be valuable to incorporate these findings into the endodontic training curriculum for undergraduate dental students.

The Vertucci classification system, with the additions of Sert and Bayirli, was used for the present study [7]. The results can therefore be readily compared with those of previous studies. Sert and Bayirli's additions allow for reporting of third and fourth canals, which are often present in mandibular molar teeth. Vertucci's original classification system, consisting of only eight configurations, is limited in its classification of complex root canal systems containing additional canal anatomy. A new root canal classification system was proposed by Ahmed et al. in 2017 [17]. This system was shown to be accurate for the description of root number and canal anatomy, especially in teeth with complex configurations. A recent report comparing the Vertucci classification system to the Ahmed et al. system for maxillary premolar teeth noted that only a small number of teeth could not be adequately classified with the Vertucci system alone [5]. Furthermore, in a large investigation, such as the present study, with many unique root and canal configurations, an excessive number of categories would have been identified if the newer classification system had been used. Meaningful comparison of present and past findings would thus have been challenging, or even impossible. For these reasons, the Ahmed et al. classification system was not considered in the present investigation.

The present study demonstrated prevalences of 0.3% for single-rooted, 98.7% for two-rooted, 1.0% for three-rooted, and 0% for four-rooted mandibular first molars. These values closely correspond with those of previous studies utilizing CBCT [13]. Using the clearing and staining technique, Gulabivala et al. found a high prevalence of three-rooted mandibular first molars in Burmese and Thai populations [18,19], while the present study found only a 1% prevalence of third roots in mandibular first molars. This prevalence is lower than those reported in other studies of African subpopulations [1,20]. A study of the root anatomy of extracted mandibular first molars in a Sudanese population reported a 3% prevalence of three-rooted teeth [1], and Rwenyonyi et al. found no mandibular first or second molars (n = 447) with three roots in a Ugandan population [20].

The present analysis of internal root canal anatomy revealed that most mesial roots of mandibular first molars had two canals and that most distal roots had only one canal. These findings are very similar to those of previous studies [19,21,22].

The location of a middle mesial canal often requires a practitioner to trough (i.e. remove dentin) in the isthmus between the mesiolingual and mesiobuccal canals [23]. This isthmus is the thinnest area of the mesial root of mandibular molars, and troughing of this area may lead to extensive removal of tooth structure, which greatly increases perforation risk [23]. In clinical practice, it would be unnecessary to routinely risk tooth perforation if the prevalence of additional anatomy was known to be low [23]. However, as one-fifth of mandibular first molars in this subpopulation had additional middle mesial canals, it may be advisable to routinely search for this extra canal during endodontic treatment.

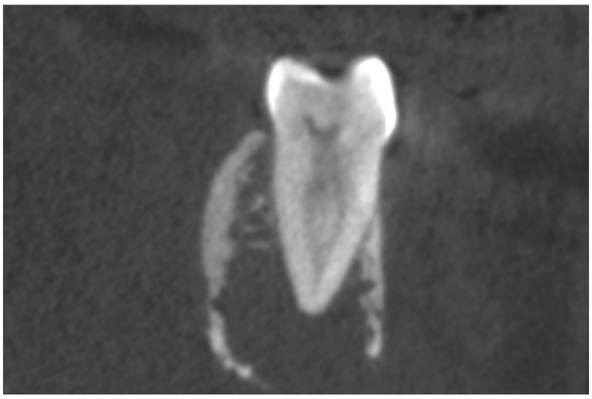

Fig. 2 Coronal CBCT section showing a middle distal canal in a mandibular first molar

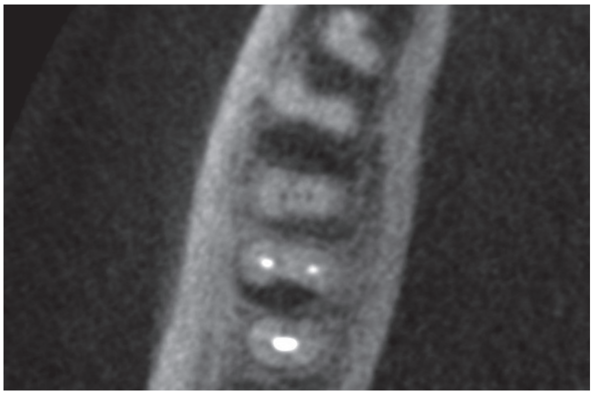

Fig. 3 Axial CBCT section showing a middle distal canal in a mandibular first molar

Table 5 Studies of the prevalence of middle distal canals

Study	Sample size	Subpopulation	Mandibular first molars (%)
Goel et al. 1991 [26]	60	Indian	1.7
Gulabivala et al. 2001 [18]	139	Burmese	0.7
Gulabivala et al. 2002 [19]	103	Thai	1.9
Sert et al. 2004 [28]	200	Turkish	1
Ahmed et al. 2007 [1]	100	Sudanese	3
Al-Qudah and Awawdeh. 2009 [21]	330	Jordanian	1
Present study	369	South African	7.1

Analysis of the association of age with root canal anatomy revealed that the prevalence of middle mesial canals was higher in samples from older age groups than in those from younger age groups, although the difference was not significant. This finding contradicts that of Azim et al. [24], who reported that the prevalence of middle mesial canals was significantly higher in younger persons. A possible explanation for this discrepancy is that the study methodologies differed: Azim et al. [24] used troughing under magnification and the present study analyzed CBCT scans. The higher incidence of middle mesial canals in younger individuals might be attributable to ongoing, lifelong deposition of secondary dentin, which results in obliteration of the additional, smaller middle mesial canals [24]. In contrast to this view, Ballullaya et al. [25] proposed that the same biological process (i.e. lifelong secondary dentin deposition) is responsible for the formation of a vertical groove between the mesiobuccal and mesiolingual canals, creating a middle mesial canal. The present findings seem to support this latter theory.

Middle distal canals (Figs. 2, 3) were present in over 7% of mandibular first molars. This is higher than prevalences reported in Indian, Burmese, Thai, Turkish, Sudanese, and Jordanian populations [1,18,21,26-28]. To the present authors' knowledge, this is the highest prevalence of middle distal canals reported in mandibular first molars. Existing evidence on the prevalence of middle distal canals in first molars is limited, and previous studies reported a prevalence of 0.7% to 3.0% in mandibular first molars (Table 5). An outlying Sudanese study reported a 10% prevalence of middle distal canals; however, this finding was reported in mandibular second molars and not mandibular first molars [1]. A possible explanation for this higher prevalence of middle distal canals in mandibular molars in the Sudanese and current South African studies is that these studies included samples that were mainly African in origin. Future studies of other African populations could clarify whether the higher prevalence of three or more canals in distal root systems is attributable to the origin of populations from this geographic area.

CBCT was selected as the preferred method in the present study because of the large sample size. Other methods for evaluating root and canal anatomy, such as clearing and staining, would likely have been prohibitively time-intensive. CBCT has been shown to be an accurate, reliable method of determining root and canal anatomy and has been used in numerous studies [10,29,30]. The role of CBCT in endodontic diagnosis and treatment planning is well-established. *Ex vivo*, CBCT was demonstrated to be as reliable as physically troughing under magnification [10] and as accurate as clearing and staining [29]. Therefore, CBCT can be reliably used to study root anatomy and root canal configurations in studies of large samples.

A limitation of the present study was that the race of the participants was not recorded. Although dental anatomy might vary in relation to race and ethnicity [3], patients who present to the Pretoria Oral and Dental Hospital self-report their race, which could have led to inaccuracies in the dataset. Furthermore, the complex history surrounding race in South Africa makes data collection on racial lines a sensitive issue. The population of South Africa is racially and ethnically diverse; thus, the present subpopulation should not be considered homogeneous with respect to any specific racial line. Therefore, no assertions can made as to whether the race or ethnicity of individuals affected the present results.

In conclusion, the mandibular first molars of this South African subpopulation exhibited a diverse range of root numbers and canal configurations, although most values for root and canal anatomy were within previously reported ranges. A noteworthy exception to this was the high prevalence of middle distal canals (7%). Middle mesial canals were detected in one of every five mandibular first molars. Because of the relatively high prevalence of additional canals in the mesial and distal roots, clinicians are advised to routinely search for additional canal anatomy when performing endodontic treatment of this tooth type. No correlation of age or sex with root number or canal configuration was found. This study confirms that the Vertucci classification system, with the additions of Sert and Bayirli, is effective in describing root canal configurations in mandibular molars and that CBCT is a viable modality for evaluating root and canal configurations in a large sample of teeth.

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Conflict of interest

All authors have substantially contributed to the study and agree on the final text of the manuscript. This research did not receive any specific funding from agencies in the public, commercial, or not-for-profit sectors. The authors deny any conflicts of interest related to this study.

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