

Morphometric Analysis of the Root Canal System in Three-Rooted Mandibular First Molars: A Micro-CT Study in a Malaysian Subpopulation

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Abstract

Three-rooted mandibular molars show wide variations in the root and canal anatomy. This study aimed to investigate the root canal configuration, the prevalence and location of accessory canals in three-rooted mandibular first molars in the Malaysian subpopulation using micro-computed tomography (micro-CT). A total of 70 extracted three-rooted mandibular first molars were scanned using micro-CT. The segmentation and 3D reconstruction of the acquired images were done using MIMICS software. Vertucci et al. (1974) and Ahmed et al. (2017) systems were used to classify the root canal configuration. The location and type of accessory canals were classified using complementary system introduced by Ahmed et al. (2018). Chi-square test was used for data analysis ($p = 0.05$). Results showed that Vertucci Type I was the most commonly recorded configuration in mesial (12.9%), distal (92.9%) and distolingual (100%) roots, while 50% of the reported configurations in mesial root were non-classifiable by Vertucci system. According to Ahmed et al. coding system, the most recorded code for the mesial, distal and distolingual roots was M^1 , D^1 , and DL^1 , respectively. The most predominantly identified code for the tooth was ${}^3MFM\ M^1\ D^1\ DL^1$ (11.4%), followed by the ${}^3MFM\ M^{1-2}\ D^1\ DL^1$ (7.1%). The Ahmed et al. coding system was able to classify all canals in the mesial root. The chi-square test revealed a significant association between root type and root canal configuration ($p < 0.001$) in both systems. The accessory canals were recorded in 92.9% of the samples, these were predominantly located in the apical third (86.9%), with the patent type being the most frequently encountered (66.3%). Three-rooted mandibular first molars in the studied Malaysian subpopulation demonstrate a wide range of variations in root canal configuration with high prevalence of accessory canals. In comparison to the Vertucci system, the coding system developed by Ahmed et al. provides a precise and practical classification of all canals, irrespective to their complexity.

Introduction

Thorough cleaning of the root canal system is one of the primary objectives of root canal therapy procedures. However, effective debridement can be challenged by the complex anatomical configurations [1]. Endodontic failure can result from untreated canals that harbour persistent microorganisms [2]. Therefore, in order to minimize errors and achieve endodontic success, the clinician must possess a comprehensive understanding of the anatomy of the root canal system and any possible variations [3].

The majority of mandibular first molars have two roots (one mesial and one distal); however, literature shows evidence for different number of roots. The presence of an additional third root in mandibular first molar represents a major variant [4]. In the literature, the mandibular first molar with distolingual root was first reported by Carabelli [5] and subsequently named as radix entomolaris (RE) [6]. This variation is more prevalent and is considered a normal finding in populations of Mongoloid origin, including Native Americans (Indian Americans), Eskimos, and the Chinese [7–10]. The presence of three-rooted mandibular first molar has been considered as a genetic marker [11]. Therefore, this trait extensively employed in the field of anthropology to compare different populations [12].

Micro-computed Tomography (micro-CT) technology is currently acknowledged as the gold standard for the laboratory investigations of root canal anatomy. It provides many qualitative and quantitative presentations that enhance the understanding of the morphological features of the roots and canals. This involves high-resolution 2D and 3D reconstructed images of various parts of the root canal system, along with the measurement of numerous morphological parameters [13].

The Vertucci classification [14] and its supplementary configurations [15] is the most commonly used system for categorising root canal configurations. However, the use of high-resolution methods for identifying root canal configuration (such as micro-CT) revealed complex anatomical features of the root canal system with many canal configurations being defined as 'non-classifiable' Vertucci types [16–19]. Consequently, a novel coding system for classification of root canal configuration was introduced by Ahmed et al. [20]. This system utilises a single code to describe the number of roots, the configuration of the main and accessory canals, as well as the possible anomalies [20–22].

Accessory canals possess a substantial clinical relevance in endodontics, because of their direct contact with the periodontal and periapical tissues. Accessory canals can transmit microbial irritants and induce inflammation to the peri-radicular area, which can negatively impact the results of root canal therapy [23]. A novel coding system for the classification of the morphology of accessory canals has been developed [21] to complement the coding system of the main root canal configuration introduced by Ahmed et al. [20]. The use of complementary codes which describe the distribution and morphologic features of the accessory canals in conjunction with main canal codes provide comprehensive information on the anatomical characteristics of the root canal system [24].

To date, no study has evaluated the root canal anatomy of three-rooted mandibular first molar in the Malaysian subpopulation using micro-CT and Ahmed et al. coding system. Therefore, this study aimed to investigate the root canal configuration of three-rooted mandibular first molar in Malaysian subpopulation using both Vertucci and Ahmed et al. classification systems, and to characterise the accessory canals in this tooth type.

Materials and Methods

Ethical approval

All methods were conducted in compliance with the Declaration of Helsinki. The study was granted approval from the Medical Ethics Committee, Faculty of Dentistry, University of Malaya [Certificate no. DF RD2031/0140 (L)]. Informed consent was obtained from all subjects and/or their legal guardian(s), to utilise their extracted teeth for research purposes.

Sample Size Calculation

The sample size of this study was calculated by using an online sample size calculator (<https://www.calculator.net/sample-size-calculator.html>), in which the confidence level and the margin of

error were set at 90% and 8%, respectively. Malaysia has a population of approximately 32 million individuals, with the incidence of RE in population is about 20% according to the study of Pan et al. [25]. A total of 70 samples were included in this study.

Teeth Selection and Inclusion/Exclusion Criteria

Three-rooted mandibular first molar teeth were obtained from a Malaysian subpopulation and collected from various governmental and private clinics. The reasons for extraction, age, race and gender of the patients were not recorded. Prior to any inspection, the teeth were disinfected by immersion in 5.25 % sodium hypochlorite solution for 30 minutes. Subsequently they were cleaned by an ultrasonic scaler to remove calculus and remaining periodontal tissues. Then the teeth were stored in saline at room temperature until the date of scanning. Only three-rooted mandibular first molar with fully formed apices and intact roots were included in the study, while teeth with previous root canal treatment, access opening, crown restorations or root with open apices were excluded.

Micro-Computed Tomography Scanning and 3D Reconstruction

The samples were scanned using a high-resolution micro-CT system (X-ray microscope (XRM), Xradia 520 Versa, Zeiss, Germany) with a voxel size of 24.14 μm , at 80 kV, 87 μA , LE4 as a source filter, a 360° rotation with a 0.4 rotation step around the vertical axis. The acquired 2D images were converted to DICOM format, then Materialise Interactive Medical Image Control System (Mimics research, version 21.0, Materialise, Leuven, Belgium) was used for segmentation, 3D reconstruction and evaluation.

Root canal configuration classification

The root canal configuration of the mesial, distal, and distolingual roots were classified using Vertucci classification [14], along with 15 supplementary types introduced by Sert and Bayirli ^{[[15]]}. Additionally, Ahmed et al. [20] coding system was employed for classifying the root canal configuration in a single code (Figure 1a). The recorded codes were subsequently categorised on basis of the number of digits they contained. Ahmed et al. coding system employed an 'asterisk' to identify complex canal anatomy (canals with more than four digits) (Figure1b) [26]. Regardless of the classification system used, the canal orifice was determined at 1.5 mm distance from the most apical level (slice) that passes through the cemento-enamel junction (CEJ). The inter-canal communications were regarded as an integral part of the root canal configuration during the classification process. One observer (SKH) was calibrated by an endodontist (HMAA) skilled in using MIMICS software through the evaluation of 10 samples. Two observation sessions were conducted with an interval of one month. Intra- and inter-observer reliability were assessed using Kappa's coefficient.

Classification of accessory canals

Ahmed et al. [21] complementary coding system for accessory canals was used to describe the type and location of the accessory canals. Regarding to the types of accessory canals, four types were recorded: patent (1), blind (1-0), loop (2-1-0), and apical delta (D). The length of each root from the furcation to the

apex was divided into three thirds: coronal (C), middle (M), and apical (A). Based on this system, the location of the accessory canal was described by an abbreviation placed as a superscript within brackets, followed by the configuration that represents the type of accessory canal (Figure 2).

Statistical Analysis

Statistical Analysis was performed by SPSS software version 26 (IBM SPSS Statistics, Armonk, NY, USA). Descriptive statistics, including counts and percentages, were used for representing the distribution of root canal configurations for mesial, distal, and distolingual roots (using the two classification systems). Chi-square tests were used to analyse the association between qualitative variables. The level of significance was set at 0.05 ($p = 0.05$).

Results

The overall Cohen's kappa coefficient values for inter-examiner and intra-examiner reliability were 0.888 and 0.956, respectively, indicating almost perfect agreement.

Root canal configuration classified by Vertucci system

The Vertucci classification was applied to each root individually. Table 1 shows the distribution of root canal configuration across the three roots. In the mesial root, the predominant reported configurations were Type I (12.9%), Type VII (10.0%), and Type V (8.6%), while 50% of the samples were reported as non-classifiable. In the distal root, the most prevalent configuration was Type I (92.9%), with only one sample recorded as non-classifiable. Whereas the configuration of the distolingual root in the entire study sample was identified as Type I (100%). The chi-square test revealed a significant association between root type and root canal configuration ($p < 0.001$).

Root canal configuration classified by Ahmed et al. coding system

In the mesial root, a total of 39 different codes were recorded, with 58.6% of the samples showing codes with four digits or fewer (Supplementary Material A). The most frequently recorded code for the mesial root was M¹, with corresponding percentages of occurrence of (12.9%). The number of the codes recorded in the distal and distolingual roots were 4 and 1, respectively. The most frequently recorded code in distal root was D¹ (92.9%) and only one sample exhibiting a code with more than four digits. The only recorded code in distolingual root was DL¹ (100%). The frequencies of different codes in the mesial, distal and distolingual roots are summarised in Table 2. The results of chi-square test indicated a significant association between root canal configuration codes and the root type. The full codes of the mesial, distal and distolingual roots classified according to the Ahmed et al. system are presented in Supplementary Table S1 and S2, respectively.

In general, the most predominantly identified code for the tooth was ³MFM M¹ D¹ DL¹ (11.4%), followed by the ³MFM M¹⁻² D¹ DL¹ (7.1%). Figure 3 and 4 illustrate several examples of root canal configuration

codes, with the former displaying codes with four digits or fewer, and the latter displaying codes with more than four digits.

After simplifying the configurations that had codes with more than four digits by the replacement of the middle digits with an asterisk, the codes for the mesial root with one orifice and one foramen (M^{1-*1}), and mesial root with one orifice and two foramina (M^{1-*2}) were identified as the most common codes (6), followed by M^{2-*2} (5) and M^{2-*3} (4). In distal root the only recorded code was D^{1-*3} (Table 2).

In the present study, a common canal that joined distobuccal and distolingual canal prior to their separation into two distinct canals was identified in 12.9% of the examined teeth. All of the common canal orifices observed in the current study exhibited long ovoid shape; with the exception of one sample demonstrated a common canal with round orifice and constricted neck (Figure 5).

Accessory canals

The accessory canals were recorded in 65 out of 70 samples (92.9%), a statistically significant difference was observed in the occurrence of accessory canals among the three roots ($p < 0.001$), with the mesial root demonstrating a higher incidence of accessory canals compared to the distal and distolingual root. The most common location of the accessory canals was the apical third (86.9%) in all three roots, followed by the middle third (7.5%). The coronal third comprised just 3.8% of the overall accessory canals. Additionally, the accessory canals extending from the middle to the apical third were 1.8%. Figure 6 shows the percentages of accessory canals in each third of each root. The chi-square analysis indicates no significant association between the root type (mesial, distal and distolingual) and the location of accessory canals (apical, middle and coronal) ($p = 0.424$). In terms of accessory canals types, 66.3% were patent, 19.4% were blind, 3.8% were of loop type, and 10.6% were classified as apical deltas. The percentage of each type of accessory canal within each root is illustrated in Figure 7. There was no significant association between root type and accessory canal type according to the result of chi-square test ($p = 0.467$).

The findings indicated that the code $R^{(A1)}$, which represents one patent accessory canal located in the apical third of the root, was the most prevalent code in all of the three roots, followed by the code $R^{(D)}$ for the apical delta. Table 3 provides detailed descriptions of the distribution of accessory canals in the various roots of three-rooted mandibular first molar, categorised according to the Ahmed et al. coding system. The rare codes of accessory canals in the different roots of three-rooted mandibular first molar classified by Ahmed et al. system are shown in Supplementary Table S3. The various configurations of accessory canals observed in the apical third and the observed apical delta are shown in Figures 8 and 9, respectively. This study indicated a rare occurrence of one loop chamber canal in a three-rooted mandibular first molar (Figure 10).

Discussion

Clinicians usually encounter challenges during root canal treatment of mandibular first molars with a distolingual root. Effective root canal therapy necessitates a thorough awareness of the morphology of roots and canals [12, 27]. Micro-CT investigations have significantly advanced clinical research by enabling the detailed identification of anatomical variations and supporting the development of more refined endodontic treatment protocols [28, 29]. In this study, the classification systems introduced by Vertucci et al. [14] and Ahmed et al. [20] were utilised to categorise the root canal configuration of three-rooted mandibular first molar in a Malaysian subpopulation. One systematic review revealed that most anatomical studies failed to specify the location of the root canal orifice. Consequently, the authors recommended that the position of the root canal orifice should be clearly defined and consistently reported in all studies related to root canal anatomy [30]. Studies showed that the ceiling of the pulp chamber in the majority of molar teeth is at the level of cemento-enamel junction and the approximate distance between the ceiling and the floor of the pulp chamber in mandibular first molar is 1.5 mm [31, 32]. In the current study, a distance of 1.5 mm from the most apical part of cemento-enamel junction was established as the level of canal orifice, marking the start of the root canal.

Regarding the mesial root, only 50% of the samples were classified by Vertucci types, with Type I being the most prevalent at 12.9%. This finding aligns with a study conducted on Brazilian population [9]; however, the distribution pattern of the other types was inconsistent with the current study. Despite being the most recorded configuration within the mesial root, Type I exhibited relatively low percentages, indicating the complexity of configuration in this root. Other micro-CT studies on two-rooted and three-rooted mandibular first molar reported Vertucci Type IV as the most common mesial root configuration, with prevalence of 65% in a Chinese [12], 17.71% in an Egyptian [33], and 46.2% in a Brazilian populations [34]. Such discrepancies can be explained by the population differences in addition to the criteria followed during interpretation [35, 36]. A previous micro-CT study on two-rooted mandibular first molars in a Malaysian subpopulation found that Vertucci Type I was the most common configuration in the mesial root when intercanal communications were included. However, when these communications were excluded, Type IV became the predominant type [35].

In the distal root, the majority of the recorded configuration was Vertucci Type I (92.9%), followed by Type III (5.7%), which is in accordance with other studies in Chinese [12] and Brazilian populations [9]. With regard to the distolingual root, the only recorded configuration was Type I which is consistent with previous studies [12, 37]. In other studies, while the majority of the samples exhibited Type I configuration, but they also record another Vertucci types in a very low frequency [9, 25]. Collectively, these findings indicate that the distolingual root most commonly contains a single canal; however, less frequent variations in canal configuration may occur across different populations.

When the Ahmed et al. coding system was adopted for classification of root canal configuration, the mesial root showed a broad range of anatomical variation, with the root canal systems classified into 39 distinct codes, of which only 10 can be classified by the Vertucci system. In the present study, the most recorded code for mesial root was M¹, which aligns with the findings of a previous micro-CT study conducted in a Malaysian subpopulation [35]. Conversely, other micro-CT studies have reported that the

code M² is the most predominant code in the mesial root [33, 38]. These differences are most likely attributed to variations in the ethnic groups examined, sample size and the methodologies employed including scanning parameters and 3D reconstruction process.

The most commonly recorded code in distal root was D¹, followed by D¹⁻²⁻¹ which is consistent with the findings of Saber et al. [33] and Al-Rammahi et al. [35]. For the distolingual root, the recorded code in this investigation was DL¹. Although a previous study on two-rooted mandibular first molars in a Malaysian subpopulation reported the codes D¹ and D¹⁻²⁻¹ as the most prevalent codes, a more complex configuration in the distal root was also documented [35]. Based on these findings, the presence of a distolingual root seems to be associated with reduced complexity of root canal system in the distal root.

The implementation of 'asterisk' has been suggested to help in simplifying the codes of the canals with complex configuration, especially for those having more than four digits [13, 36, 39]. The current study identified 24 codes in mesial root that have more than four digits, which reflects the complex root canal configuration in this root within the Malaysian subpopulation.

When an 'asterisk' was utilised, these complex codes were reduced to only seven, with the most frequently recorded codes being M^{1*-1} and M^{1*-2}. The configuration with more than four digits in distal root was found only in one sample with the code D^{1*-3}. This facilitates the classification of samples with the same number of canal orifices and apical foramina into a single category. It also informs the clinical identification of the main canals during the initial negotiation and exploration phase, particularly in determining whether the canal(s) merge or remain separate at the canal terminus [24].

Based on the information presented, the coding system introduced by Ahmed et al. [20] is more reliable in the characterization of teeth with complex canal configurations compared to Vertucci classification. Additionally, by using this coding system, it is feasible to document the presence of the common canal within a single code. This anatomic feature cannot be represented using Vertucci classification system. The identification of the common canal in the coronal region of a root, located apical to the pulp chamber, has significant clinical implications for access cavity preparations, detection of root canals, instrumentation and root filling procedures [26, 40]. In the current study, two shapes of common canal orifices were identified, long oval and round orifices. The presence of the common canal coronal to the level of bifurcation of the distobuccal and distolingual canals may pose a challenge to effective detection, instrumentation and filling of both canals. The wide, long oval orifice could be easier to identify and access, whereas the narrow, round orifice may restrict the access to each of the distobuccal and distolingual canals. This may necessitate troughing apically by 1 or 2 mm between distobuccal and distolingual canals in order to locate, instrument and fill them effectively.

Accessory canals serve as routes that may facilitate the spread of bacteria and/or their by-products, which may migrate from the necrotic root canal to the periodontal ligament, resulting in the development of furcation and lateral root lesions [41]. To the best of knowledge, only a few research [9, 12] utilised micro-CT technology to evaluate the incidence of accessory canals in three-rooted mandibular first

molars. The findings of the present study revealed that the prevalence of accessory canals in three-rooted mandibular first molar is 92.9%, with the incidence in mesial, distal and distolingual roots being 53.75%, 26.25%, and 20%, respectively. The mesial root demonstrates a significantly higher prevalence of accessory canals than the distal and distolingual roots. A study of accessory canals in two-rooted mandibular first molar from a Malaysian subpopulation reported a comparable incidence in the mesial root; however, the incidence in the distal root exceeded that of the current study. These findings may imply that the presence of the distolingual root contributes to the simplicity in the anatomy of distal root in terms of main and accessory canals.

The results of this study revealed notable variation in the occurrence of accessory canals within each root in comparison to earlier studies on three-rooted mandibular first molars. While the distal root showed comparable incidence, the incidence in mesial root was lower, and in distolingual root was higher in comparison to a study by Gu et al. [12] on a Chinese population. When compared to the findings of Rodrigues et al. [9] conducted on a Brazilian population, the present study demonstrated a greater prevalence of accessory canals in the mesial root, a lower prevalence in the distal root, and a comparable prevalence in the distolingual root. These inconsistencies in the reported results may be explained by the variations in study population, sample size, and terminology employed to define lateral canals, including primary and secondary canal branches [21, 42].

The majority (86.9%) of the observed accessory canals in the present study were found at the apical third, which is consistent with the findings of several previous investigation [12, 28, 43]. This highlights the importance of proper cleaning and disinfecting of the apical third of the root [44], as well as incorporating accessory canals in root resection procedures to ensure the removal of any microbial remnants that may reside within these canals and adversely affect the success of the treatment outcome [45, 46].

This study recorded different types of accessory canals, including patent, blind, loop and apical delta. The vast majority of observed accessory canals were patent, consistent with the findings of Xu et al. [28] and Al-Rammahi et al. [43]. In this study, 10.6% of the accessory canals were found as apical deltas; this incidence is lower than that observed in three-rooted mandibular first molar in Chinese [12] and Brazilian [9] populations, which reported an incidence of 48.2% and 60%, respectively. The inconsistency in the definition of the apical delta and ethnic diversity of the studied population may be the primary factors for this discrepancy.

This study defines the chamber canal as a small canal originating from the pulp chamber that is usually connected to the external root surface root, including the furcation [21]. This canal may present in several forms (patent, blind or loop). Only one chamber canal of loop type was observed in this study, aligning with the finding of previous research [9]. Investigating the frequency of the chamber canals is clinically important because they can harbour organic material that may disintegrate under certain conditions. This disintegration can result in bacteria and/or toxins that may lead to a periodontal

endodontic lesion. However, these canals can be effectively cleansed chemically and sealed or isolated from the other parts of the root canal system [47].

This micro-CT study of extracted mandibular first molars provides clinically relevant insights for endodontists by detailing root canal configurations, as well as the prevalence and location of accessory canals, thereby providing clinical recommendations for advanced cleaning and root canal filling protocols.

Several limitations were noted in this study. The correlation of different ethnic group in Malaysia (Malay, Indian and Chinese), gender and age on the accessory canals and root canal configuration were not assessed since this information was not recorded. Future studies should therefore investigate the effect of these demographic factors on the root canal anatomy of three-rooted mandibular first molars.

Conclusions

Three-rooted mandibular first molars show wide variation in the root canal configurations in the studied Malaysian subpopulation, with high prevalence of accessory canals, especially in the apical third. While Vertucci classification was unable to classify the configuration of half of mesial root canals, Ahmed et al. coding system was able to classify all canals regardless of their complexity.

Declarations

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Authors' contributions

Conceptualization: [Shatha Khader Hussain], [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed]; Methodology: [Shatha Khader Hussain], [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hijaz Kamal Hasnan], [Hany Mohamed Aly Ahmed]; Formal analysis and investigation: [Shatha Khader Hussain], [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed]; Writing - original draft preparation: [Shatha Khader Hussain]; Writing - review and editing: [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed]; Funding acquisition: [Shatha Khader Hussain], [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed]; Resources: [Shatha Khader Hussain], [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed]; Supervision [Nora Sakina Mohd Noor], [Norliza Ibrahim], [Hany Mohamed Aly Ahmed].

Competing interests

The author(s) declare no competing interests.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1
Root canal configuration classified by Vertucci system

Vertucci classification		Mesial root n (%)	Distal root n (%)	Distolingual root n (%)
Type	Pattern			
Type I	1	9 (12.9)	65 (92.9)	70 (100.0)
Type II	2 – 1	3 (4.3)	-	-
Type III	1-2-1	4 (5.7)	3 (4.3)	-
Type IV	2	1 (1.4)	-	-
Type V	1–2	6 (8.6)	1 (1.4)	-
Type VI	2-1-2	2 (2.9)	-	-
Type VII	1-2-1-2	7 (10.0)	-	-
Type XII	2-3-1	1 (1.4)	-	-
Type XIII	1-2-1-3	1 (1.4)		
Type XIX	2-1-2-1	1 (1.4)	-	-
Non-classifiable		35 (50.0)	1 (1.4)	-
Total		70 (100.0)	70 (100.0)	70 (100.0)

Table 2

Frequencies of different codes in the mesial, distal and distolingual roots, with complex codes (> 4-digits) in the mesial (n = 29) and distal roots (n = 1) simplified by using asterisk.

Mesial root code	n	Distal root code	n	Distolingual root code	n
M ¹	9	D ¹	65	DL ¹	70
M ²	1	D ¹⁻²	1		
M ¹⁻²	6	D ¹⁻²⁻¹	3		
M ²⁻¹	3	D ^{1-*-3}	1		
M ²⁻⁴	1				
M ¹⁻²⁻¹	4				
M ²⁻¹⁻²	2				
M ²⁻³⁻¹	1				
M ²⁻³⁻²	2				
M ¹⁻²⁻¹⁻²	7				
M ¹⁻²⁻¹⁻³	1				
M ¹⁻²⁻³⁻¹	1				
M ¹⁻³⁻²⁻¹	1				
M ²⁻¹⁻²⁻¹	1				
M ²⁻³⁻²⁻³	1				
M ^{1-*-1}	6				
M ^{1-*-2}	6				
M ^{1-*-3}	3				
M ^{2-*-1}	3				
M ^{2-*-2}	5				
M ^{2-*-3}	4				

Mesial root code	n	Distal root code	n	Distolingual root code	n
M ^{2-**-4}	2				
Total	70	Total	70	Total	70

Table 3

The most common Ahmed et al. codes for accessory canals in the different roots of three-rooted mandibular first molar.

Ahmed et al. codes for accessory canals	Root type			Total
	M	D	DL	
R ^(A1)	19 (43.2%)	13 (29.5%)	12 (27.3%)	44 (100.0%)
R ^(A1-0)	2 (22.2%)	6 (66.7%)	1 (11.1%)	9 (100.0%)
R ^(A2)	6 (60.0%)	2 (20.0%)	2 (20.0%)	10 (100.0%)
R ^(A1,1-0)	4 (57.1%)	1 (14.3%)	2 (28.6%)	7 (100.0%)
R ^(D)	3 (25.0%)	4 (33.3%)	5 (41.7%)	12 (100.0%)
R ^(M1)	2 (66.7%)	0 (0.0%)	1 (33.3%)	3 (100.0%)
R ^(M1,A1)	2 (100.0%)	0 (0.0%)	0 (0.0%)	2 (100.0%)
R ^(A1,D)	1 (50.0%)	1 (50.0%)	0 (0.0%)	2 (100.0%)
Other rare codes	12 (57.1%)	6 (28.6%)	3 (14.3%)	21 (100.0%)
Total	51 (46.4%)	33 (30%)	26 (23.6%)	110 (100.0%)

Figures

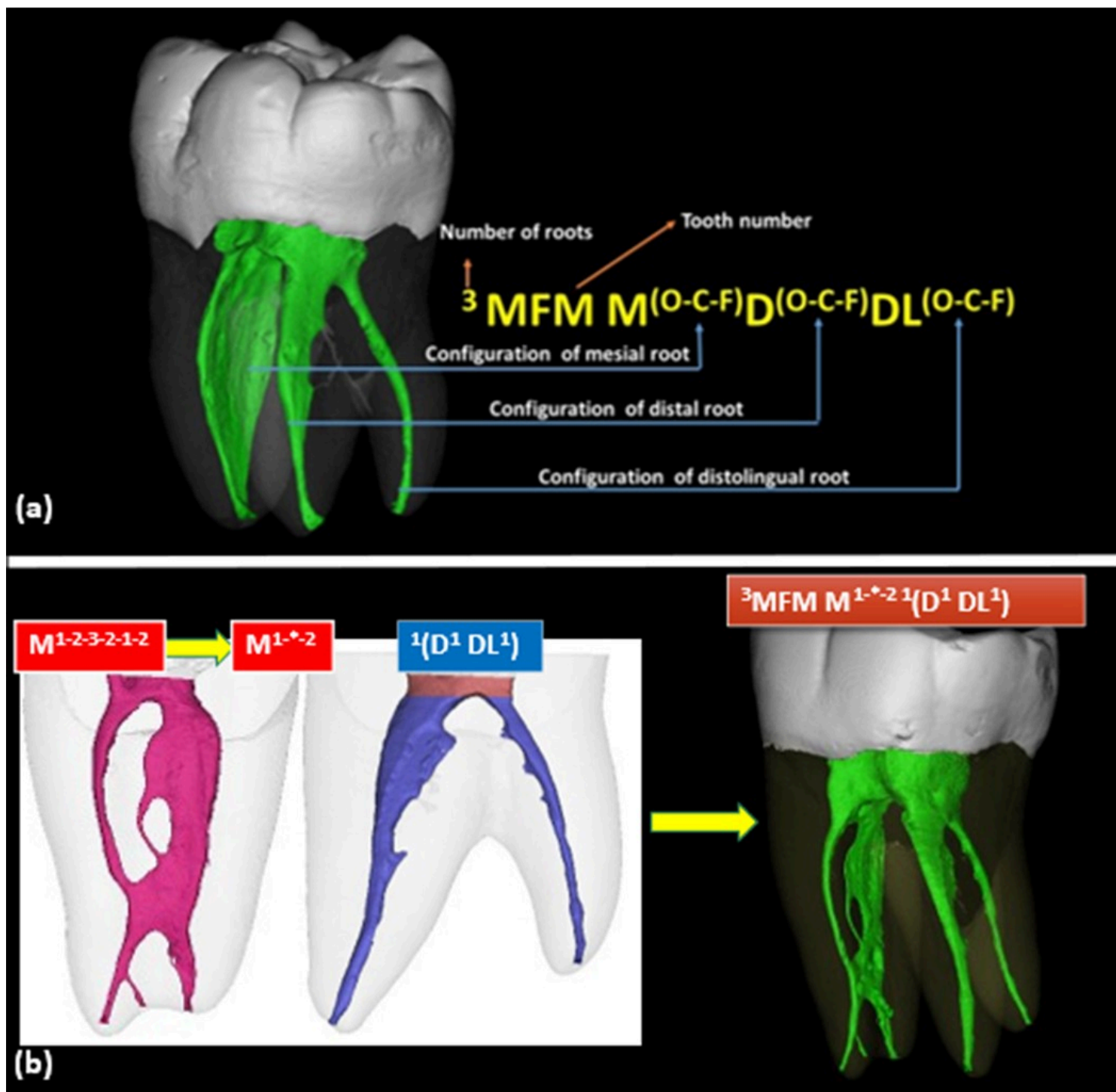


Figure 1

Ahmed et al classification system; (a) three-rooted mandibular first molar with simple configuration classified according to Ahmed et al. coding system, represented by the code $^3\text{MFM M}^1 \text{D}^1 \text{DL}^1$, (b) three-rooted mandibular first molar with complex configuration in mesial root and presence of common canal coronal to bifurcating level of distobuccal and distolingual canals, an asterisk is used to simplify the complex configuration in mesial root.

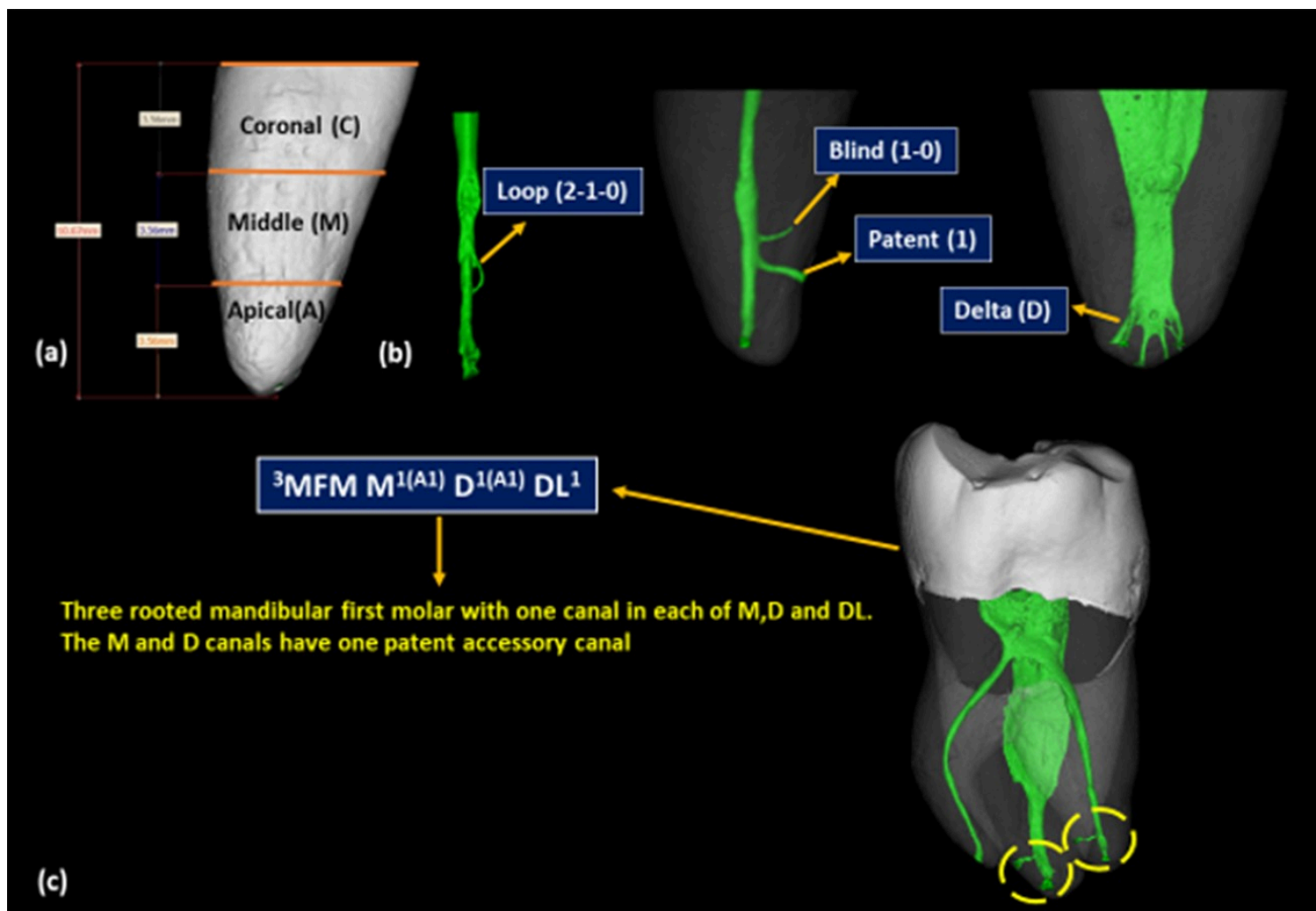


Figure 2

Steps for application of Ahmed et al. classification system for accessory canals;(a) dividing each root into coronal, middle, and apical thirds; (b) determining the type and configuration of accessory canals;(c) example of how to classify accessory canal using Ahmed et al. classification system.

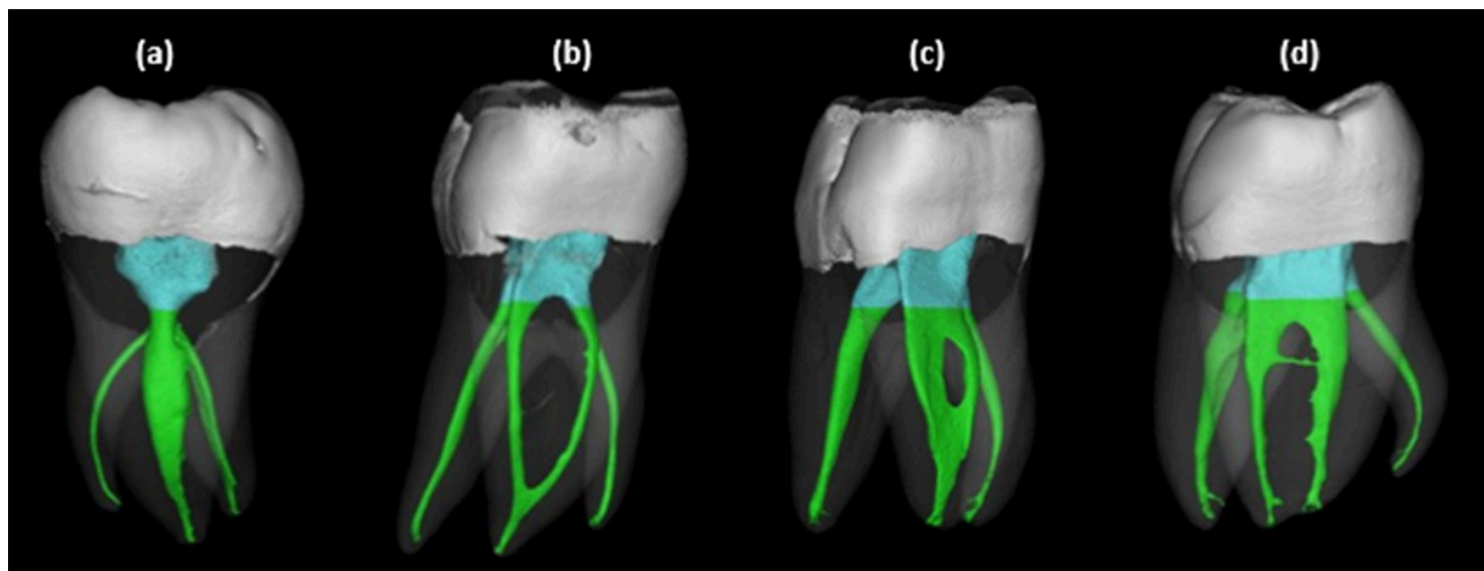


Figure 3

Three-dimensional reconstructed images from micro-CT scans illustrating various root canal configurations (≤ 4 digits) of three-rooted mandibular first molars; (a) ${}^3\text{MFM M}^1 {}^1(\text{D}^1 \text{DL}^1)$, (b) ${}^3\text{MFM M}^{2-1} \text{D}^1 \text{DL}^1$, (c) ${}^3\text{MFM M}^{1-2-1} \text{D}^1$, (d) ${}^3\text{MFM M}^{1-2-1-2} \text{D}^1$.

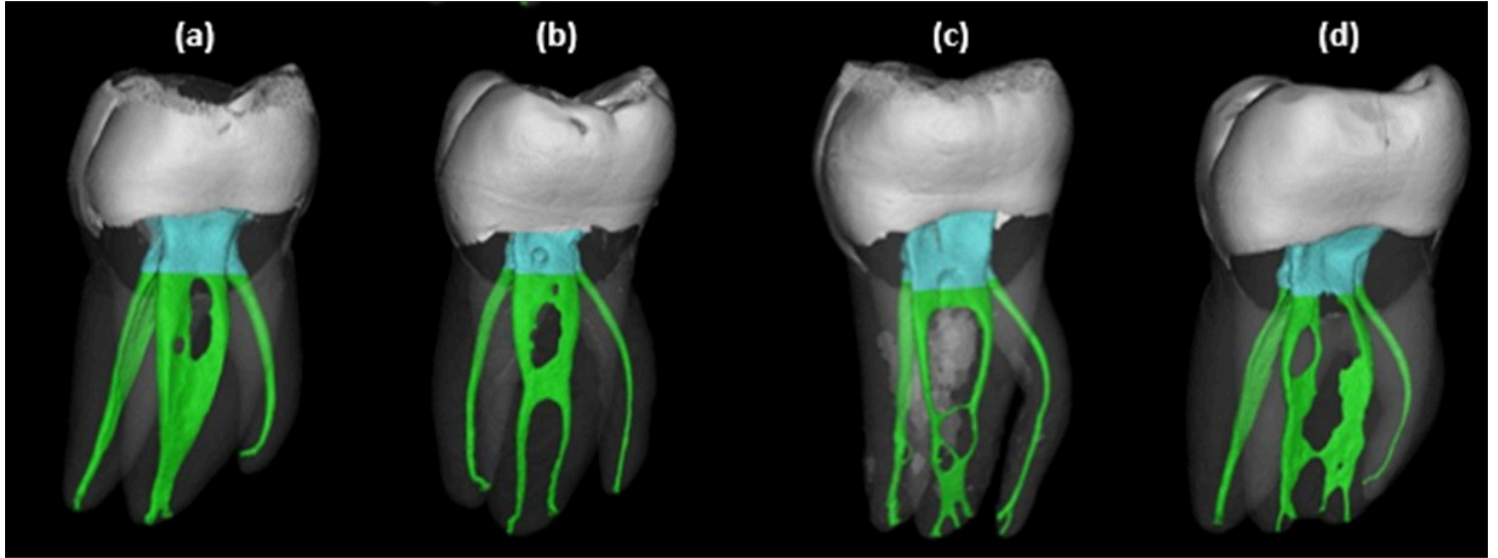


Figure 4

Three-dimensional reconstructed images from micro-CT scans illustrating various root canal configurations (>4 digits) of three-rooted mandibular first molar; (a) ${}^3\text{MFM M}^{1-2-3-1-2} \text{D}^1 \text{DL}^1$, (b) ${}^3\text{MFM M}^{1-2-1-2-1-2} \text{D}^1 \text{DL}^1$, (c) ${}^3\text{MFM M}^{1-2-1-2-3-1-3} \text{D}^1 \text{DL}^1$, (d) ${}^3\text{MFM M}^{2-3-2-1-2-3-2-3} \text{D}^1 \text{DL}^1$.

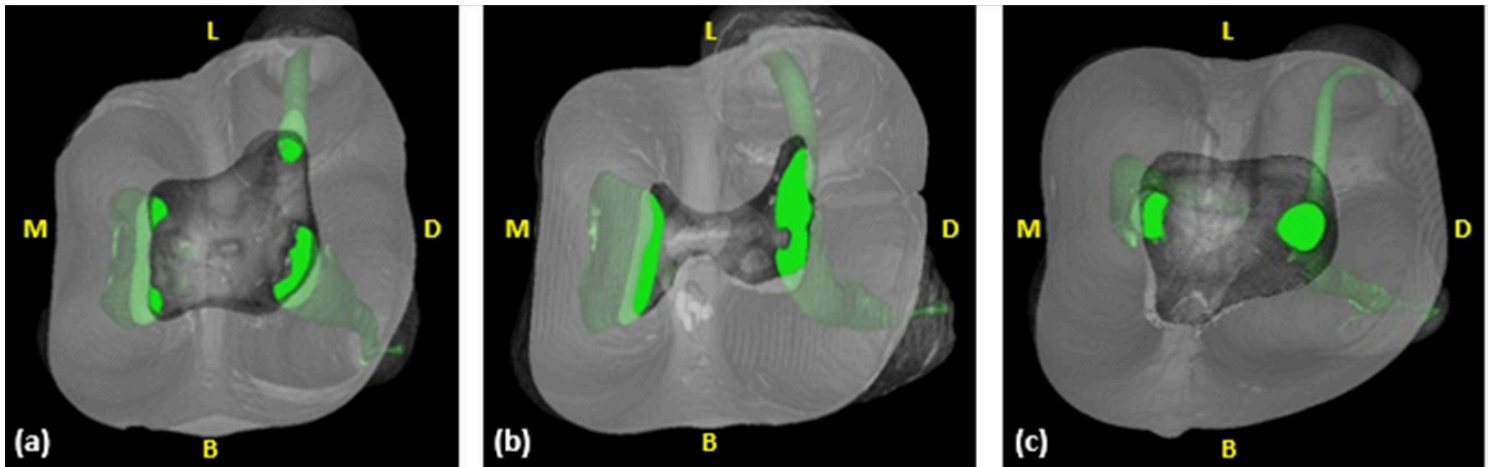


Figure 5

3D reconstructed images of pulp chamber floor of three-rooted mandibular first molars showing different configurations of canal orifices; (a) without common canal, (b) long oval common canal, (c) round common canal.

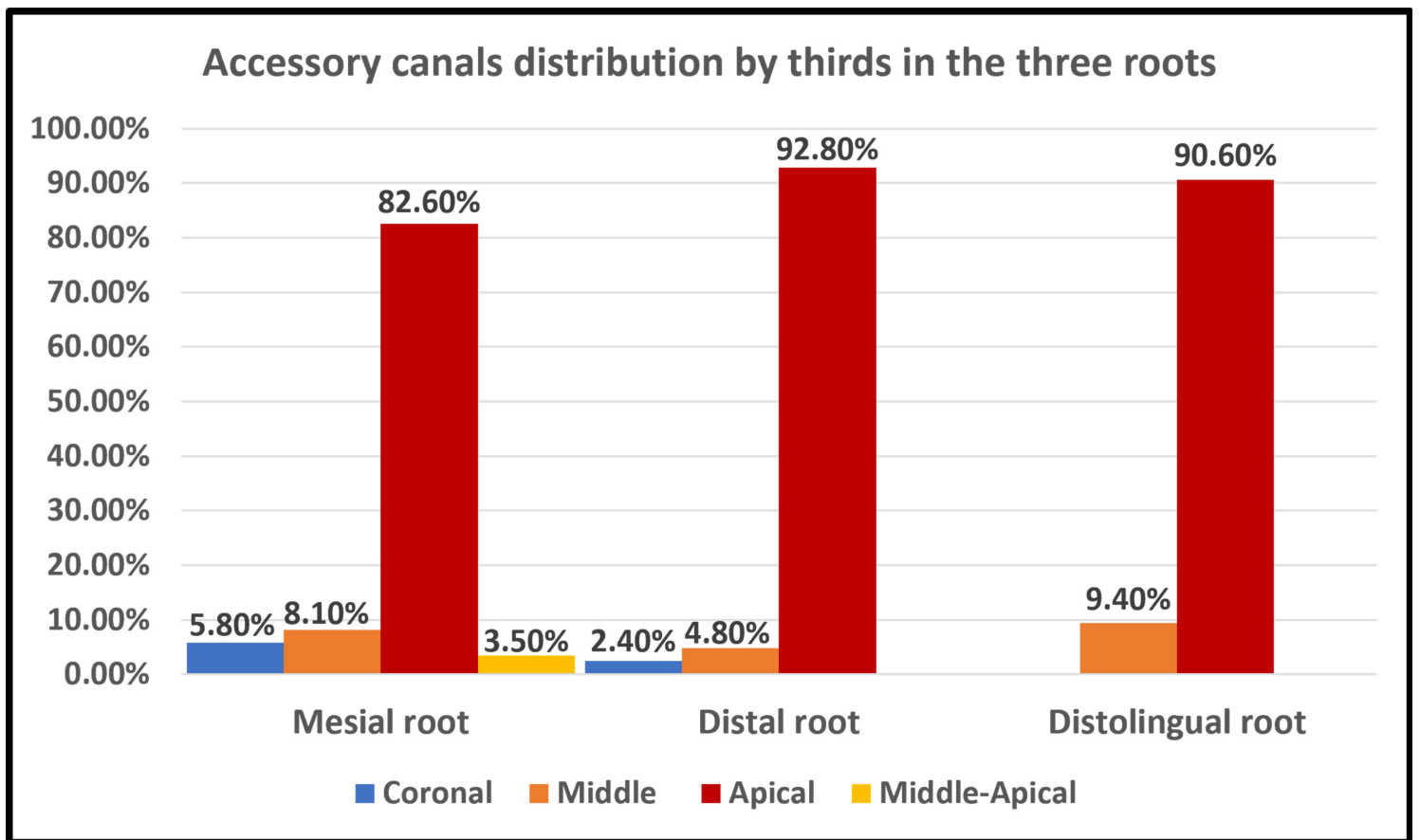


Figure 6

The percentage of accessory canals within coronal, middle and apical thirds for each root type (mesial, distal and distolingual).

Distribution of accessory canal types in the three roots

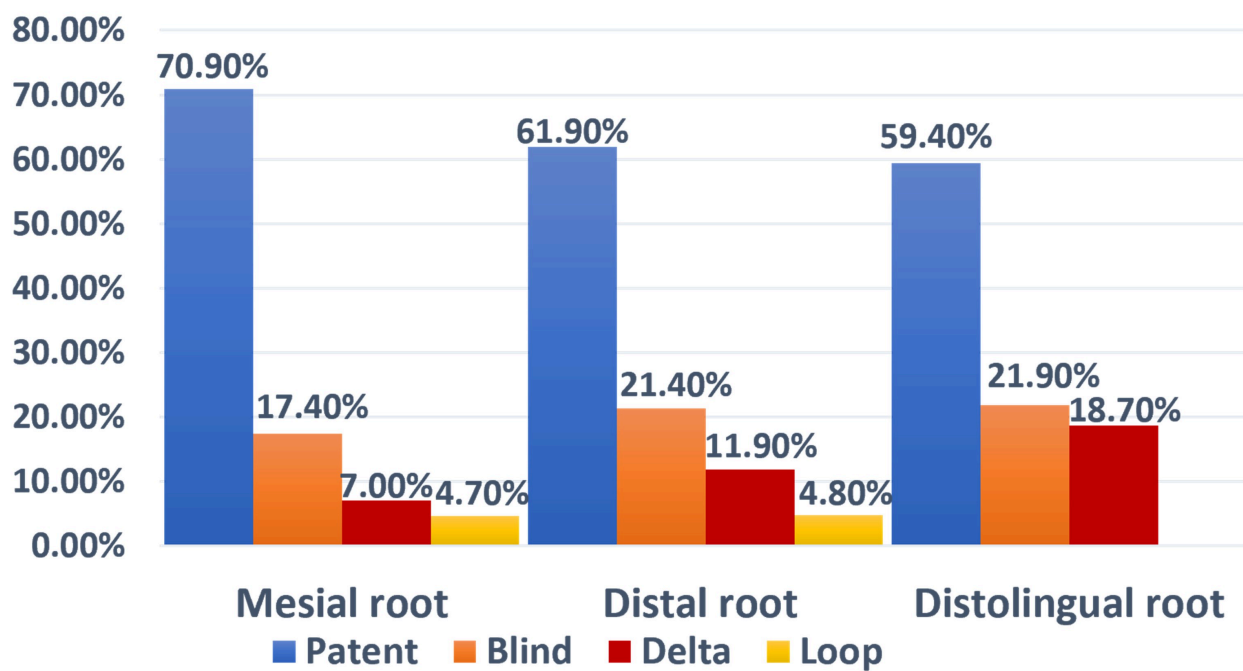


Figure 7

The percentages of accessory canal types within each root (mesial, distal and distolingual).

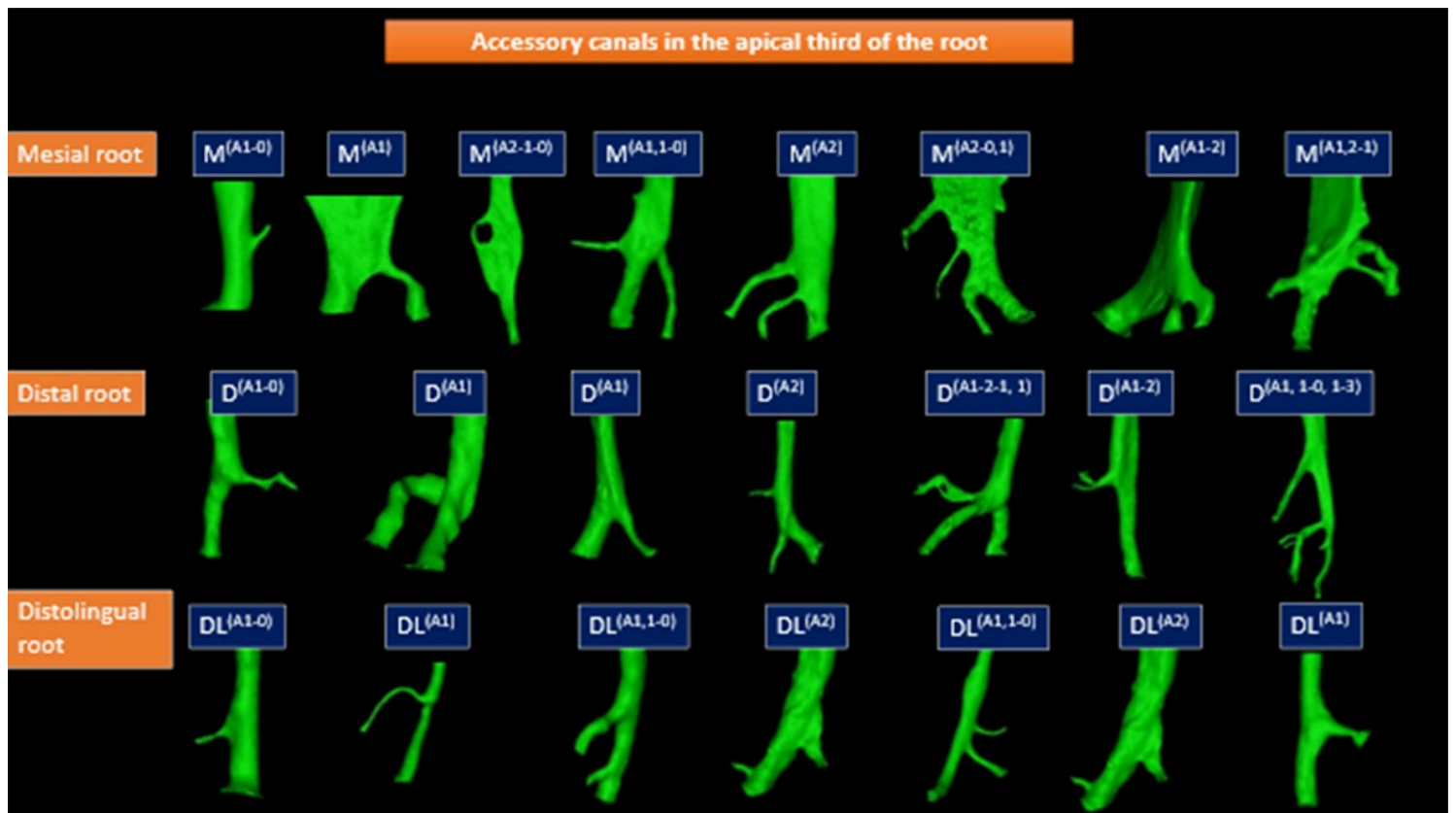


Figure 8

Various configuration of accessory canals identified in the apical third of different roots in three-rooted mandibular first molar.

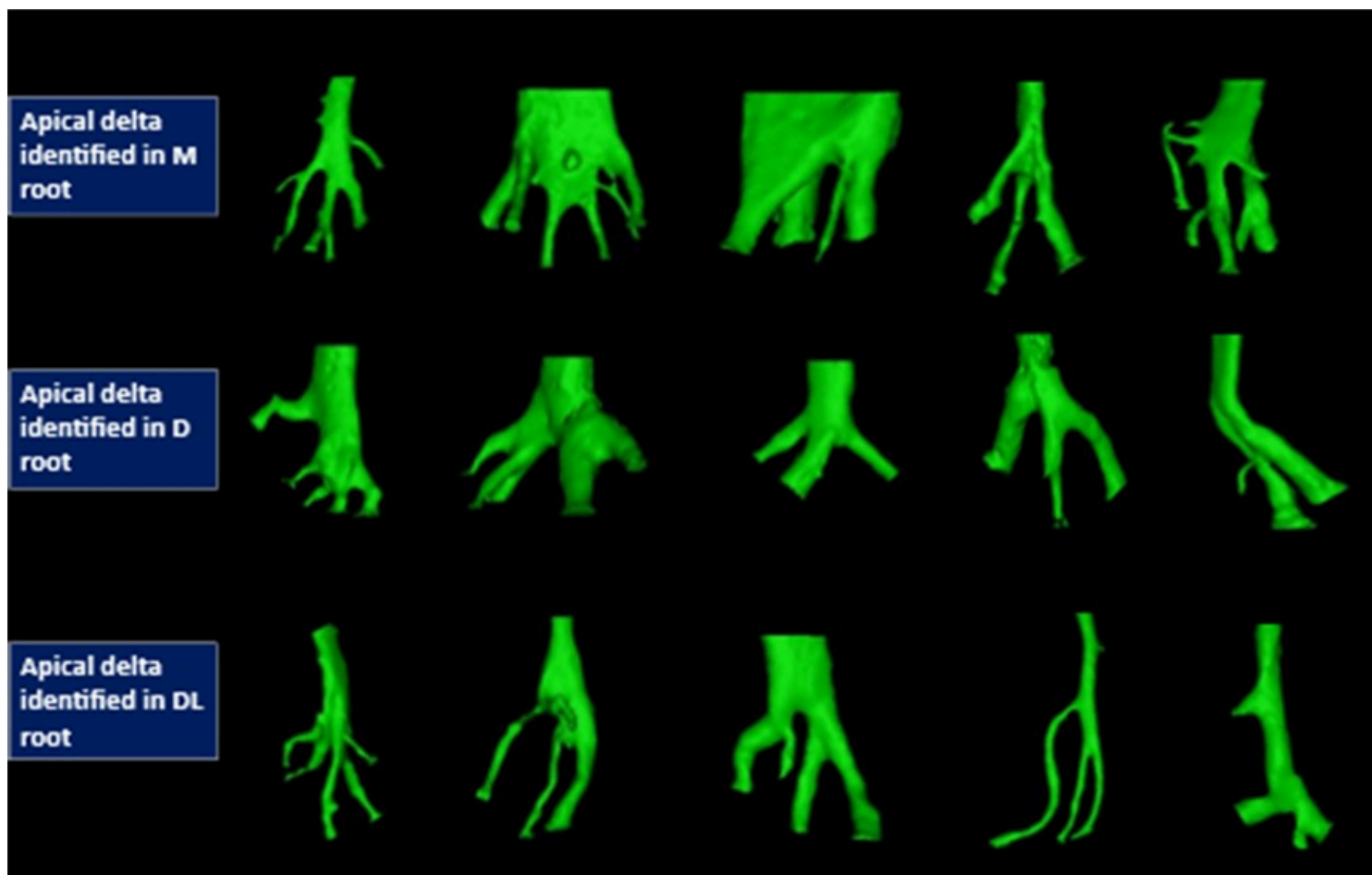


Figure 9

Forms of apical delta identified in three-rooted mandibular first molar.

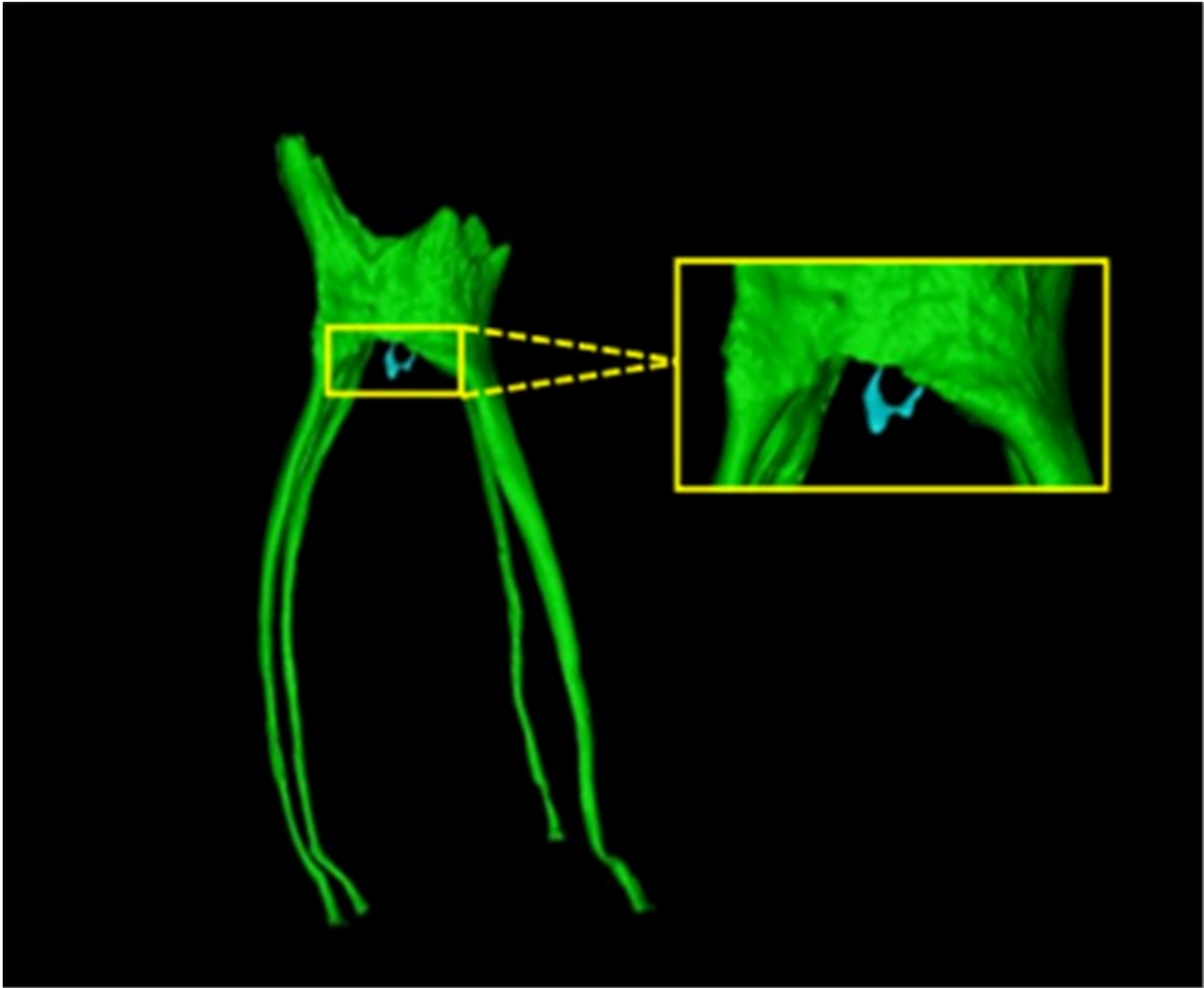


Figure 10

Chamber canals of loop type recorded in three-rooted mandibular first molar.

Supplementary Files

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