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Microcomputed-Tomographic Analysis of the Root Canal Morphology of the Mandibular First Molars in a Malaysian Subpopulation Using Two Classification Systems

Análisis por Tomografía Microcomputada de la Morfología del Conducto Radicular de los Primeros Molares Mandibulares en una Subpoblación de Malasia Utilizando dos Sistemas de Clasificación

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SUMMARY: This work investigated the morphology of the root canal system of the mandibular first molar in a Malaysian subpopulation. Using micro-computed tomography with an isotropic resolution of 22 µm, 140 mandibular first molars were scanned. MIMICS software was used for segmentation, 3-D reconstruction and analysis of the acquired images. The canal configuration was described using Vertucci [supported by the supplementary configurations proposed by Sert & Bayirli (2004)] and Ahmed *et al*. (2027), coding systems. The chi-square test was used to assess the association between qualitative variables. By non-considering intercanal communications, Vertucci types IV (17.1%) and I (76.4%) were the most frequently reported configurations in the mesial and distal roots, respectively. Of the reported configurations, 24.3% and 4.3% were non-classifiable by Vertucci system in the mesial and distal roots, respectively. Up to 63.6% and 9.3% of the reported configurations were non-classifiable, and type I was the most frequent when considering intercanal communications (7.1% and 76.4% in the mesial and distal roots, respectively). According to Ahmed *et al*., system, almost half of the sample had more than four digits (47.9%), followed by the 3-digits category (20.71%). In both systems, a significant association was found between the canal configuration and the root type ($p<0.001$). The mandibular first molar of this Malaysian subpopulation demonstrated a wide range of root canal morphology. When compared to the Vertucci system, the system developed by Ahmed *et al*., successfully classified all molars configurations despite their level of complexity. The complex canal anatomy of mandibular first molars in this subpopulation warrants special attention during root canal treatment procedures.

KEY WORDS: Root canal configuration; Intercanal communication; Anatomy; Micro-computed tomography.

INTRODUCTION

The ultimate aim of root canal treatment (RCT) is to adequately clean, shape, and hermetically seal the root canal system (RCS) while protecting dentine from being unnecessarily weakened (Plotino *et al*., 2013). Due to the complexity and unpredictability of the internal anatomy of human teeth, RCT is not without risk. Thus, a thorough knowledge about the normal and complex root and canal anatomy is a fundamental requirement for a successful RCT (Vertucci, 1984).

Several previous studies have shown many anatomical variations and complexities in the mandibular first molar (MFM) (de Pablo *et al*., 2010; Al-Rammahi *et al*., 2023). Numerous external and internal root and canal morphological characteristics in this tooth type have been studied using a wide range of evaluating modalities, such as two-dimensional (2D) radiographs, stereomicroscopy, clearing and staining, scanning electron microscopy (SEM), and cone-beam computed tomography (CBCT) (de Pablo *et al*., 2010). However, in comparison to the earlier methods, microcomputed tomography (micro-CT) has been the gold standard technology in investigating several morphological aspects (Harris *et al*., 2013; Filpo-Perez *et al*., 2015). Its small voxel size and high resolution

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contribute to its accuracy in depicting the fine details of the root canal configuration (RCC). This has resulted in the reporting of considerable percentages of non-classifiable RCC (Filpo-Perez *et al*., 2015; Al-Rammahi *et al*., 2023) using the existing classification systems, such as Vertucci (Vertucci *et al*., 1974) system. As a result, a new coding classification system was proposed (Ahmed *et al*., 2017), which has the ability to accurately describe the number of roots and RCC in a single code (Ahmed *et al*., 2017).

Various external and internal anatomical features of the MFM were the subject of many micro-CT studies in different populations (Filpo-Perez *et al*., 2015; Al-Rammahi *et al*., 2023). Up to now, no micro-CT anatomical study has been conducted on the MFM in the Malaysian population. Therefore, this micro-CT study aimed to investigate the root canal morphology of the MFM in a Malaysian subpopulation using Vertucci (Vertucci *et al*., 1974) and Ahmed *et al*., (2017) coding systems.

MATERIAL AND METHOD

Ethical approval for the current work has been granted by the Medical Ethics Committee of the Faculty of Dentistry, University of Malaya [protocol number DF RD2208/0042 (L)].

In this study, an online calculator for estimating the sample size was used to calculate the sample size. Malaysia has an estimated population of approximately 32 million citizens. With a 90% confidence level and a 7% marginal error, a sample size of 140 MFM was determined, which were then collected from different governmental and private dental clinics.

The inclusion criteria include sound two-rooted MFM or those with caries that do not mask tooth identification, fully formed apices, absence of root fracture, absence of root resorption, and no previous endodontic filling or access opening. The patient's gender or age and the reason for extraction were unknown.

The selected teeth were soaked in a solution of sodium hypochlorite (2.5%) for thirty minutes to dissolve the soft tissue attachments. The removal of any residual hard and/or soft tissues was then performed using an ultrasonic scaler. Two investigators were then involved in performing a thorough inspection of the teeth based on the inclusion and exclusion criteria to choose the eligible teeth, using a dental loupe (Heine Optotechnik GmbH & Co. KG, Gilching, Germany) with 3.5X magnification power to detect any fractures and/or root resorption. Thymol solution (0.1%) was then used to keep the included teeth until further use after being rinsed for 30 minutes under running water.

Scanning and image analysis. The teeth were scanned with high-resolution 3D X-ray Imaging Systems (Xradia Versa 520; Carl Zeiss Inc. Pleasanton, USA) using a standardised scanning parameters: an isotropic resolution of 22 µm, 80 kV, 88 mA, LE4 as a source filter, 360° rotation around the vertical axis with a step of rotation of 0.4. After importing the acquired 2-D images in DICOM format, Materialise Interactive Medical Image Control System (MIMICS) (Materialise 24.0.0.427, Leuven, Belgium) was used for segmentation, 3-D reconstructionand analysis the acquired images. The RCC was evaluated using Vertucci classification system (Vertucci *et al*., 1974) in addition to the supplementary 15 configurations that were established by Sert & Bayirli (2004). Ahmed *et al*., (2017) coding system was additionally used to describe the RCCs using a single code (Fig. 1).

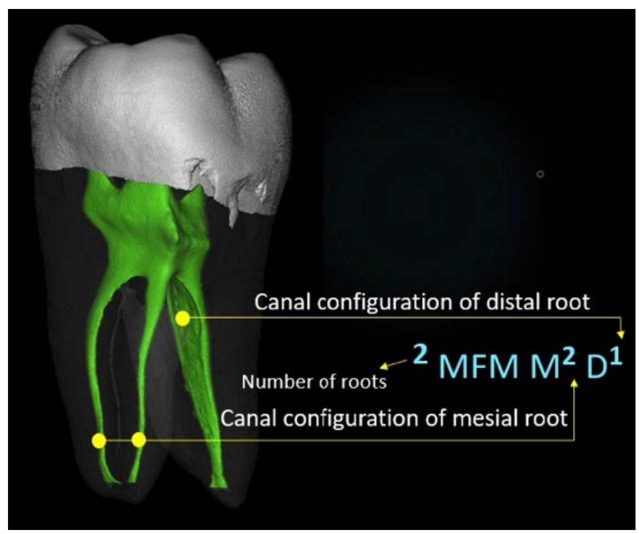

Fig. 1. Ahmed *et al*., coding system. The root number, tooth number, and the RCC are all included in a single code. Root number was reported using a superscript number to the left of the tooth code (e.g., 2 MFM used for two-rooted mandibular first molar). To the right of the tooth code, letters are placed, referring to the root type (M for the mesial root and D for the distal root). To the right of each root letter, superscript letters O, C and F indicated number of orifice/s (O), canal/s (C), and foramina (F) per root. These superscript letters replaced with numbers after reporting the RCC. For instance, in the current case, the code 2MFM M2 D1 indicates two-rooted mandibular first molar with 2 separated canals in the mesial root and single canal in the distal root. Describing the RCC starts from the canal orifice (1 mm apical to the pulp chamber floor) until the canal terminus.

Statistical analysis. The IBM SPSS version 26 was the software utilised for performing the statistical analysis. Using the chi-square test, the association between the qualitative variables was evaluated. The level of significance was set at 0.05 ($P < 0.05$).

RESULTS

Root canal configuration according to Vertucci system. In the MFM, Vertucci system was used per individual root. Table I summarises the distribution of the RCC in the MFMs. As for the first scenario (non-considering intercanal communication (ICC) while describing RCC), in the mesial root (MR), types IV (17.1%) and V (15.7%) were the most commonly identified configurations. In the distal root (DR), type I was the predominant configuration (76.4%). Not considering ICC resulted in lower percentages of non-classifiable configurations in the MR (24.3%) and DR (4.3%).

As for the second scenario (considering the ICC while describing the RCC), in the MR, Vertucci type I was the most frequently reported configuration (7.1%). In DRs, type I was predominant (76.4%). Considering ICC led to a considerably high percentage of non-classifiable configurations in MRs (63.6%) and DRs (9.3%). The chi-square results in both scenarios showed a significant association between the RCC and root type ($p<0.001$).

Root canal configuration according to Ahmed *et al.*, (2017) system. As for the MR (Table II), almost half of the sample had more than four digits (47.9%). Forty-nine varied codes were reported as having >4 digits, with a frequency percentage of 47.85%.

In the DR (Table III), the 1-digit category had the overwhelming majority (76.42%) over the others. Only the D1 code was reported under the 1-digit category. The chi-square test revealed a significant association between the RCC categories and the root type ($p < 0.001$). Overall, the most common code identified for the tooth as a whole was 2MFM M1 D1 (7.2%), followed by 2MFM M1-2-1 D1 (5%) and 2MFM M1-2-1-2 D1 (4.3%). Figure 2 shows several examples of RCC codes with different digits.

Table I. RCCs in the mandibular first molar according to Vertucci system.

Vertucci categories		Mesial root n (%)		Distal root n (%)	
Type	Pattern	Non considering ICC	Considering	Non considering ICC	Considering ICC
I	1-1	10 (7.1)	10 (7.1)	107 (76.4)	107 (76.4)
II	2-1	15 (10.7)	3 (2.1)	1 (0.7)	1 (0.7)
III	1-2-1	13 (9.4)	7 (5)	15 (10.7)	11 (7.9)
IV	2-2	24 (17.1)	7 (5)	-	-
V	1-2	22 (15.7)	5 (3.6)	6 (4.3)	4 (2.9)
VI	2-1-2	2 (1.4)	5 (3.6)	-	-
VII	1-2-1-2	3 (2.1)	6 (4.3)	-	1 (0.7)
IX	1-3	-	-	3 (2.1)	2 (1.4)
X	1-2-3-2	4 (2.9)	2 (1.4)	1 (0.7)	1 (0.7)
XII	2-3-1	2 (1.4)	1 (0.7)	-	-
XV	3-2	3 (2.1)	-	-	-
XVI	2-3	5 (3.6)	1 (0.7)	1 (0.7)	-
XVII	1-3-1	2 (1.4)	2 (1.4)	-	-
XIX	2-1-2-1	-	2 (1.4)	-	-
XXIII	3-4	1 (0.7)	-	-	-
Non classifiable		34 (24.3)	89 (63.6)	6 (4.3)	13 (9.3)
Total		140 (100)		140 (100)	

DISCUSSION

The current investigation evaluated the RCC of the MFM, comparing two classification systems. The occurrence of intercanal communication may result in uncertainty about its characterisation, which can either be classified as a fundamental component of the RCC or as a minor anatomical feature with no effect on its morphological identification (Karobari *et al*., 2019). Given Vertucci had not explicitly addressed the criteria for determining ICC (Vertucci, 1984), the confusion seems to be greatly evident whenever micro-CT investigations present various RCCs as "non-classifiable" (Filpo-Perez *et al*., 2015, Ahmed *et al*., 2017). Consequently, in this micro-CT investigation, the RCC of the MFM was characterised, taking both scenarios into account (i.e., including and excluding inter-canal communications). A comparison of the two scenarios would provide a clear

Table II. RCC in the mesial root of the mandibular first molar according to Ahmed *et al*., system.

								More than 4 digits											
1 digit	**n**	**2 digits**	**n**	**3 digits**	**n**	**4 digits**	**n**	**5 digits**	**n**	**6 digits**	**n**	**7 digits**	**n**	**8 digits**	**n**	**9 digits**	**n**	**≥ 10 digits**	**n**
M^{1}	10	M^{1-2}	4	M^{1-2-1}	7	$M^{1-2-1-2}$	6	$M^{1-2-1-2-1}$	2	$M^{1-2-1-2-1-2}$	3	$M^{1-2-1-2-3-2-1}$	1	$M^{1-2-1-3-1-2-1-3}$	1	$M^{1-2-1-3-2-3-1-2-3}$	1	$M^{1-2-1-2-1-2-1-2-1-2}$	1
M^{2}	7	M^{2-1}	4	M^{1-2-3}	2	$M^{1-2-3-2}$	3	$M^{1-2-1-2-4}$	1	$M^{1-2-1-3-1-4}$	1	$M^{1-2-3-2-1-2-3}$	1	$M^{1-2-3-2-1-2-1-2}$	1	$M^{1-2-3-2-3-2-3-2-1}$	1	$M^{1-2-4-3-2-3-2-3-2-1-2}$	1
		M^{2-3}	1	M^{1-3-1}	2	$M^{1-3-1-2}$	1	$M^{1-2-3-2-1}$	3	$M^{1-2-3-2-1-2}$	1	$M^{1-2-3-2-3-1-2}$	1	$M^{1-2-3-2-1-2-3-2}$	1	$M^{1-2-3-4-3-2-3-1-3}$	1	$M^{2-1-2-1-2-1-2-4-3-1-2}$	1
				M^{1-3-2}	2	$M^{1-3-2-1}$	1	$M^{1-2-3-2-3}$	1	$M^{1-2-3-2-3-2}$	4	$M^{1-2-3-2-3-2-3}$	3	$M^{2-1-2-1-2-1-2-1}$	2	$M^{2-1-2-1-2-1-2-3-2}$	2	$M^{2-1-3-4-3-4-3-2-3-2-3}$	1
				M^{2-1-2}	5	$M^{2-1-2-1}$	2	$M^{1-3-2-1-2}$	1	$M^{1-2-6-4-2-3}$	1	$M^{2-1-3-1-2-1-3}$	1	$M^{2-1-2-1-3-1-3-2}$	1	$M^{2-1-2-3-4-6-3-2-4}$	1	$M^{2-3-2-1-2-3-4-3-2-1}$	1
				M^{2-3-1}	1	$M^{2-3-2-1}$	2	$M^{2-1-2-1-2}$	3	$M^{2-1-2-3-2-1}$	2	$M^{2-3-2-3-2-3-1}$	1	$M^{2-1-3-2-3-2-3-2}$	1			$M^{3-2-3-2-3-2-3-2-3-2}$	1
				M^{2-3-2}	9	$M^{2-3-2-3}$	1	$M^{2-3-2-3-1}$	1	$M^{2-3-1-2-3-2}$	2	$M^{2-3-2-3-2-3-2}$	2	$M^{2-3-2-3-2-3-2-1}$	2				
				M^{3-2-1}	1	$M^{2-3-4-3}$	1	$M^{2-3-2-3-2}$	1	$M^{2-3-2-1-2-1}$	1			$M^{3-2-3-2-3-2-3-2}$	1				
						$M^{2-5-4-2}$	1			$M^{2-3-2-3-2-1}$	1								
										$M^{2-3-2-3-4-2}$	1								
										$M^{2-3-4-3-2-3}$	1								
										$M^{2-3-4-3-4-3}$	1								
										$M^{3-2-3-2-3-2}$	1								
										$M^{3-2-3-2-3-4}$	1								
										$M^{3-2-4-3-2-1}$	1								
17		9		29		18		13		22		10		10		6		6	
73 / 140 (52.14%)								**67 / 140 (47.86%)**											

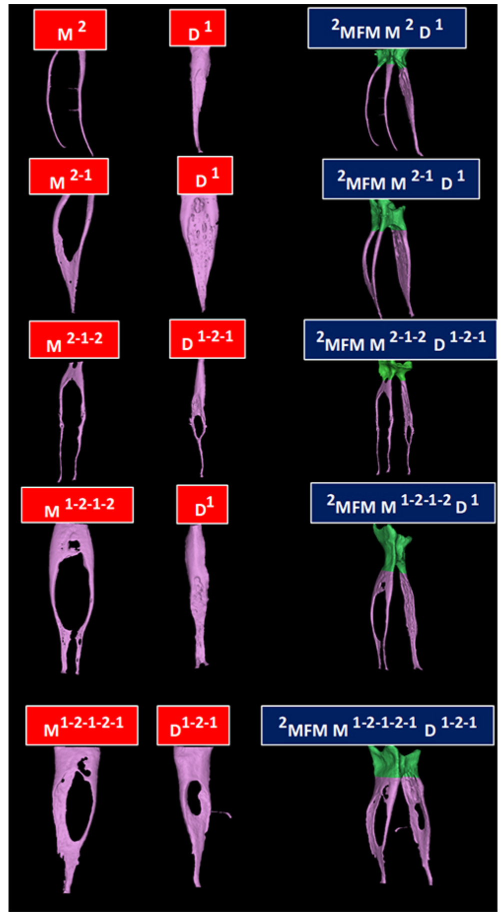

Fig. 2. 3D reconstructed images from micro- CT scans showing different RCCs in the mesial and distal roots of mandibular first molars.

demonstration of how the RCC distribution map could be altered, as well as the influence of such an inclusion on the depiction of more non-classifiable configurations.

As for the first scenario (i.e., not considering intercanal communications), in the MR, the micro-CT-based literature exhibited contradictory findings in different populations regarding the most prevalent configuration type. In the Brazilian population (Marceliano-Alves *et al*., 2019), type IV (46.2%) was the most prevalent configuration. Other micro-CT studies showed types I (16.36%), III (25%), and V (27.27 %) as the most frequent in Brazilian (Rodrigues *et al*., 2016), Turkish (Sallı & Egil 2021), and North American (Harris *et al*., 2013) populations, respectively. In this study, types IV (17.1%) and V (15.7%) were the most commonly reported configurations, followed by type II

Table III. RCC in the distal root of the mandibular first molar according to Ahmed *et al*., system.

Distal root									
1 digit	n	2 digits	n	3 digits	n	4 digits	n	More than 4 digits	n
D^{1}	107	D^{1-2}	4	D^{1-2-1}	11	$D^{1-2-1-2}$	1	$D^{1-2-1-2-1}$	3
		D^{1-3}	2	D^{1-4-2}	1	$D^{1-2-3-2}$	1	$D^{1-2-1-3-1-2-1}$	1
		D^{2-1}	1	D^{1-2-3}	1	$D^{1-3-2-1}$	1	$D^{1-2-3-1-2-1-2}$	1
								$D^{1-2-3-2-3}$	1
								$D^{1-3-2-1-2-3}$	1
								$D^{1-3-4-3-4-3-2-3-2}$	1
								$D^{1-4-3-2-3-2-1-2-1}$	1
								$D^{2-4-3-2-1-2-3}$	1
total	107 76.42 %		7 5 %		13 9.3 %		3 2.14 %		10 7.14 %
140 (100%)									

(10.7%). Albeit they reported noticeably higher incidences of type IV, the findings of the current investigation, however, agree with those of Marceliano-Alves *et al*. (2019) and Wolf *et al*. (2016).

On the other hand, the studies used devices other than micro-CT were split into two groups. The first group of studies revealed that type IV was the most reported configuration, with a prevalence ranging from 50% to 75% in Chinese (Qiao *et al*., 2020), Serbian (Popovic *et al*., 2020), and Indian (Karunakaran *et al*., 2017) populations. However, two other investigations showed a far greater prevalence of type IV in Malaysian (93%) (Pan *et al*., 2019) and southern Chinese subpopulations (93.9%) (Wang *et al*., 2010).

The second group of studies found that type II was the most common configuration in Tanzanian (Madjapa & Minja 2018) and Spanish (Pérez-Heredia *et al*., 2017) populations. The vast majority of the preceding studies were CBCT-based except for two, which were clearing and staining-based studies (Karunakaran *et al*., 2017; Madjapa & Minja 2018). Seemingly, the aforementioned findings were considerably higher than what was reported in the current study.

It is well acknowledged in the literature that age, gender, sample size, population/ethnicity, and tooth side are all factors that might contribute to the high anatomical variability (de Pablo *et al*., 2010; Al-Rammahi *et al*., 2023). Such inconsistencies could also be explained by the difference in the method used (Al-Rammahi *et al*., 2023). Evidently, the CBCT studies present higher percentages of Vertucci types and lower non-classifiable configurations compared to their micro-CT counterparts. This could also be attributed to the higher spatial resolution of micro-CT, which depicts even the finest details and extra canals and consequently provides new configurations not reported by Vertucci. Moreover, intercanal communications, particularly in micro-CT-based images, cause confusion while describing the configuration. This, in turn, could increase inter- and/or intra-observer variability. In this study, of those reported configurations, 24.3% were non-classifiable, even with the inclusion of 15 supplementary types and not considering inter-canal communications.

It is well known that the DR has less anatomical variability than the MR in terms of the number and configuration of canals. Type I was the most commonly reported configuration, with a widely varied prevalence across different populations. The prevalence of type I in CBCT studies ranged from 72.3% to 89.8% in different populations (Pérez-Heredia *et al*., 2017; Popovic *et al*., 2020; Qiao *et al*., 2020). However, another CBCT study on the Malaysian population showed a noticeably higher type I prevalence (96%) (Pan *et al*., 2019).

Similarly, the micro-CT-based literature demonstrated consistent findings with the non-micro-CT studies regarding the prevalence of type I in the DR. It was about 57%, 81.8%, and 76% in the investigations of Marceliano-Alves *et al*. (2022), Harris *et al*. (2013), and Filpo-Perez *et al*, (2015), respectively. In this context, the current study showed a consistent finding compared to the literature. Type I prevailed over the DR (76.4%), followed by type III (10.7%).

One of the salient findings in the micro-CT studies is the depiction of a considerable number of non-classifiable configurations that are outside of Vertucci's system ambit. For instance, Filpo-Perez *et al*. (2015) noticed that 13% of the DRs in their study's sample did not fit Vertucci. Similarly, the current study figured out that 6 (4.3%) were non-classifiable in the DR. These intriguing findings could confirm the internal complexity and variability of the DR of the MFM (Marceliano-Alves *et al*., 2022).

Concerning the second scenario, where inter-canal communications were included, the map of the Vertucci types distribution was comprehensively shifted. Type I has become the most common configuration in the MR (7.1%), followed by type III (5%). This has also resulted in high percentages of non-classifiable configurations in MRs (63.6%) and DRs (9.3%). These findings confirm the existing conclusion based on micro-CT findings that the Vertucci system is unable to represent intricate RCCs. Additionally, inter-canal communication should be considered in the clinical scenario while treating mandibular molars, adopting advanced materials and techniques to minimise the potential failure (Karova & Zongova-Adem 2023).

In both scenarios, this study showed a significant association between the Vertucci configuration types and root type ($p<0.001$), indicating higher variability and complexity of the MR in the MFM in this Malaysian subpopulation. As confirmed before, this should incentivise clinicians to pay more attention to the MR during root canal treatment procedures.

In order to achieve a systematic and accurate anatomical description that enhances RCT, it has recently been advocated to employ the coding system established by Ahmed *et al*. (2017) in research, education, and clinical practice (Ahmed *et al. 2020*, 2023). The current investigation demonstrated that, in the MR, almost half of the sample had more than four digits [67 (47.9%)], followed by the 3-digits category [29 (20.7%)], indicating a higher complexity of the MR internal anatomy. This indicates the accuracy and effectiveness of this system in presenting the actual complexity of the internal anatomy. On the other hand, this also refers to the high variability and the presence of many more codes in the MR.

In the DR, only the D1 code was reported under the 1-digit category [107 (76.42%)]. In contrast to Pan *et al*. (2019), who found only three main Vertucci configurations in the DR of the MFM in the Malaysian population, this study found many more configurations. Ten of these configurations had more than four digits.

Notably, the prevailing single canal in the DR does not necessarily mean that RCT is guaranteed to be easy and successful. The unpredictable 2D parameters and cross-sectional patterns of the distal canals, in addition to the various RCCs reported, are all complexity-assuring factors. As a result of these findings, this study agrees with Marceliano-Alves *et al*. (2022) on the potential anatomical difficulties that may necessitate additional attention in practice.

The main limitation of the current study is that the samples used were fully anonymous; therefore, it was not possible to relate the findings to ethnicity, gender, or age, which is usually provided in CBCT observational clinical studies. Additionally, this study was limited to two-rooted MFMs.

CONCLUSION

The MFM of this Malaysian subpopulation demonstrated a wide range of root canal morphology. When compared to the Vertucci system, the coding system developed by Ahmed *et al*., (2017, 2020), successfully classified the RCCs of all molars despite their level of complexity. Variations in the anatomy of the MFM are commonly seen in this cohort group, posing challenges for clinicians performing endodontic treatment.

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RESUMEN: En este trabajo se investigó la morfología del sistema de conductos radiculares del primer molar mandibular en una subpoblación de Malasia. Utilizando tomografía microcomputada con una resolución isotrópica de 22 µm, se escanearon 140 primeros molares mandibulares. Se utilizó el software MIMICS para segmentar (enmascarar), reconstruir en 3D, visualizar y analizar las imágenes adquiridas. La configuración del canal se describió utilizando Vertucci respaldado por las configuraciones complementarias propuestas por Sert & Bayirli (2004)] y Ahmed *et al*. (2017, 2020), sistemas de codificación. Se utilizó la prueba de chi-cuadrado para evaluar la asociación entre variables cualitativas. Sin considerar las comunicaciones intercanales, los tipos Vertucci IV (17,1%) y I (76,4%) fueron las configuraciones reportadas con mayor frecuencia en las raíces mesiales y distales, respectivamente. De las configuraciones reportadas, el 24,3 % y el 4,3 % fueron no clasificables por el sistema de Vertucci en las raíces mesial y distal, respectivamente. Hasta el 63,6 % y el 9,3 % de las configuraciones reportadas fueron no clasificables, siendo la tipo I la más frecuente al considerar las comunicaciones intercanales (7,1 % y 76,4 % en las raíces mesiales y distales, respectivamente). Según Ahmed *et al*. (2017, 2020) en el sistema, casi la mitad de la muestra tenía más de cuatro dígitos (47,9 %), seguido por la categoría de 3 dígitos (20,71 %). En ambos sistemas se encontró una asociación significativa entre la configuración del canal y el tipo de raíz (p<0,001). El primer molar mandibular de esta subpoblación de Malasia demostró una amplia gama morfológica del conducto radicular. En comparación con el sistema Vertucci, el sistema desarrollado por Ahmed *et al*. (2017, 2020) clasificaron con éxito todas las configuraciones de los molares a pesar de su nivel de complejidad. La compleja anatomía del canal de los primeros molares mandibulares en esta subpoblación merece una atención especial durante los procedimientos de tratamiento de conducto.

PALABRAS CLAVE: Configuración del conducto radicular; Comunicación intercanal; Anatomía; Tomografía microcomputada.

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