Original Article

Investigation of mandibular second molar root and canal morphology in a Black South African population using cone-beam computed tomography and two classification systems

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Abstract

Purpose: To investigate the root and canal morphology of mandibular second molars, including anatomical variations, in a Black South African population using two classification systems.
Methods: Cone-beam computed tomography images of 386 teeth were evaluated. The number of roots and canal configurations were categorized using the classifications of Vertucci (with modifications by Sert and Bayirli) and Ahmed et al. (including the modified Melton classification). Relationships between variables were assessed using Fisher's exact test ($P < 0.05$).
Results: Mandibular second molars were predominantly two-rooted (91.7%). The majority of teeth had three canals including Type IV mesial (41.2%) and Type I (75.1%) distal (Ahmed et al. configuration: ^{2}MDM M^{2}D^1). Three or more canals were present in almost one-fifth of mesial ($n = 72/386$, 18.6%) and a small number of distal ($n = 21/386$, 5.4%) roots. Males displayed additional canals more frequently in the distal root ($P = 0.02$). C-shaped anatomy was found in 5.7%. Among the C-shapes, the most common was Melton's Type III in the coronal (50%), middle (81%) and apical (72%) thirds.
Conclusion: In this population, mandibular second molar teeth exhibited diverse morphology, which would have clinical significance for endodontic practitioners. The Ahmed et al. classification provided a better description than the Vertucci classification.

Keywords: classification, cone-beam computed tomography, dental anatomy, endodontics, mandibular second molar

Introduction

Knowledge of both common and aberrant root and canal anatomy is vital for both nonsurgical and surgical endodontics [1]. Mandibular second molars frequently require endodontic treatment, and commonly display two roots with three canals [2], but several studies have reported deviations from this norm [3-5]. These deviations may include conical roots [5], C-shaped morphology [5], or the presence of additional canals in both the mesial and distal root systems. For this tooth type, C-shaped canals, as well a Vertucci Type IV configuration in the mesial root of two-rooted mandibular second molars, reportedly have a higher prevalence in Asian populations [6]. These anatomical variations may have clinical significance in the context of endodontic treatment. Anatomical differences in dental morphology are known to be influenced by race, age, sex, ethnicity, and even geographical area [7].

Historically, clearing and staining have been widely used to evaluate canal morphology [8]. More recently, cone-beam computed tomography (CBCT) has been successfully applied in studies of dental morphology in the context of endodontics [9]. The non-destructive nature of CBCT facilitates precise three-dimensional (3D) imaging at an acceptable radiation dose, allowing retrospective analysis of dental anatomy in large numbers of samples [10].

The well-known Vertucci classification [1] has been widely used for reporting root canal morphology [10]. However, this system has limitations and is unable to classify all configurations, especially in complex teeth [11]. To aid the description of complex canal configurations, additions to the original classification were proposed [12]. In 2017, the classification system of Ahmed et al. was introduced with the aim of reporting both root number and canal configuration (simple or complex) of any tooth type simultaneously, using a single code denoting the root and canal structure [13]. So far, only a limited number of studies have used this newer classification system to describe root and canal morphology, including dental anomalies, in comparison with more established classifications [14].

The population of South Africa consists mainly of Black Africans [Statistics South Africa, 2011]. Few studies have documented the dental anatomy of this specific population group [11,15], or that of mixed South African population groups [7].

A review of the existing literature found no information on the overall root and canal morphology (including dental anomalies, such as C-shaped anatomy) of mandibular second molars exclusively within a Black South African population. Consequently, no data are available concerning the prevailing root and canal morphology of this population group and region. The aim of the present study was to describe the root and canal morphology, including C-shaped anatomy, of mandibular second molars in this previously unreported population group and region based on CBCT images and two classification systems.

Materials and Methods

Subjects

This descriptive, cross-sectional observational study was approved by the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Protocol number: 331/2021). CBCT images of mandibular second molars were evaluated from patients attending the diagnostic imaging unit at the University of Pretoria Oral Health Center between November 2014 and September 2021. Scans in the existing database were studied retrospectively. No additional subjects were exposed to radiation for this study. The as low as reasonably achievable (ALARA) concept had been used at the time of scan acquisition by experienced radiographers. Scans meeting the following inclusion criteria were assessed:

1. Black South African patients aged 15 years or older, seeking dental treatment at an academic hospital.
2. Mature mandibular second molars demonstrating fully developed apices (i.e., closed roots).
3. No previous treatment that had modified the original root and canal anatomy (i.e., teeth with posts, crowns, previous endodontic treatment and endodontic surgery were excluded).
4. Scans of a quality acceptable for visualization of root and canal anatomy.
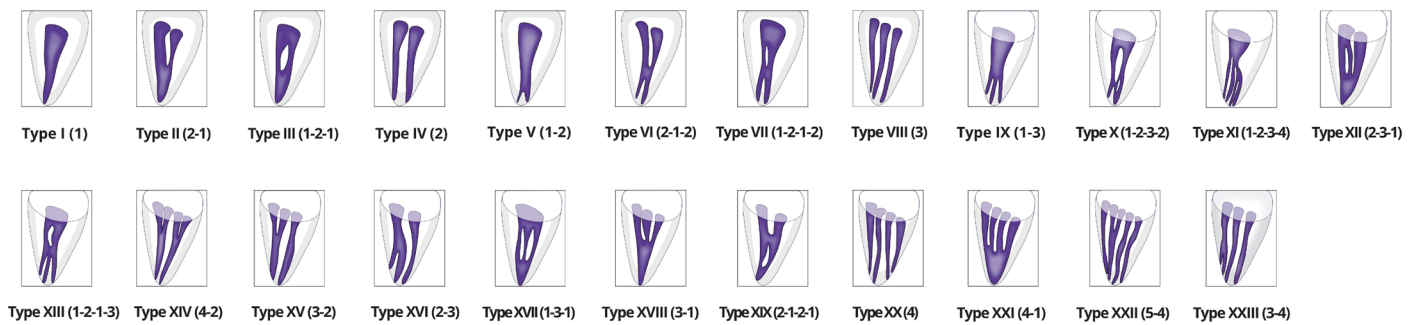5. Voxel size equal to or smaller than 0.2 mm.

Fig. 1 The Vertucci classification system and additions proposed by Sert and Bayirli in 2004 [12]. This classification depicts 23 possible canal configurations.

Convenience sampling was employed, and sample size calculations were determined using statistical software (Epi-Info version 7, Atlanta, GA, USA). Assuming a prevalence of 50% with a 5% margin of error and a 95% confidence interval, the minimum required sample size was determined to be $n = 384$, including both male and female subjects with scans from both sides.

Evaluation of CBCT scans

The methodology employed has been reported previously [15]. The CBCT images included had been acquired using a Planmeca Promax 3D Max CBCT machine (Planmeca OY, Helsingfors, Finland) for a number of reasons, including maxillofacial and oral surgery (for diagnosis and treatment of maxillofacial trauma and pathology), as well as diagnosis and treatment planning in a number of different specialist dental fields. The CBCT machine parameters were adjustable and were varied as needed for each clinical indication. The scanning parameters were variable depending on the scan required, as follows: tube current 1-14 mA, tube voltage 54-90 kV, focal spot diameter 0.6 mm. The resulting voxel size therefore varied from 0.15 to 0.60 mm.

Digital imaging software (Romexis version 6.0, Planmeca, Planmeca OY, Helsingfors, Finland) was used for analysis of the scans. Software settings (e.g., sharpness, brightness and contrast) were optimized by each observer before serial coronal, axial and sagittal sections were viewed. The number of roots and canal morphology were determined. Two observers (previously calibrated through assessment of 50 teeth unrelated to the study) evaluated the samples. In keeping with previously described methodology [16], the first observer (experienced in endodontics) evaluated all of the images and the second observer (both an anatomist and dentist experienced in oral radiology) evaluated one tenth of the sample. Disagreements not resolved by consensus were referred to a third observer for a final opinion regarding the classification. Data were entered into Microsoft Excel 2016 (Microsoft Corp., Redmond, WA, USA).

Classification

The root and canal morphology of the mandibular second molars was classified using the original Vertucci classification [1], including the later additions proposed by Sert et al. [12]. Canal configurations were reported per root (Fig. 1). Classification was additionally performed using the Ahmed et al. system [17], in conjunction with the modified Melton classification for description of C-shaped anatomy where present [18]. A limited description of the Ahmed et al. system, relevant to the present study, is provided in Fig. 2. The code MDM was allocated as a descriptor for mandibular second molars when the Ahmed et al. system was used. As C-shaped canals cannot be described using the Vertucci classification [1], these were reported as unclassified in the present study. Conical roots with non-C-shaped anatomy were, however, described using the Vertucci classification. The Ahmed et al. system does make provision for C-shaped anatomy [17], and this is reported by Fan et al. as part of a single descriptive code based on the modified Melton classification [18]. C-shaped anatomy according to this classification, as used in the present study, was described as follows using the prefix "CSC" for "C-shaped canal", followed by an Arabic numeral indicating the type of C-shape. CSC^1: a continuous C-shaped canal with no separation; CSC^2: a semi-colon shaped canal, with dentin separating the canals from each other; CSC^3: two or three separate canals: CSC^4: a single canal, either oval or round in shape; CSC^5: no observable canal.
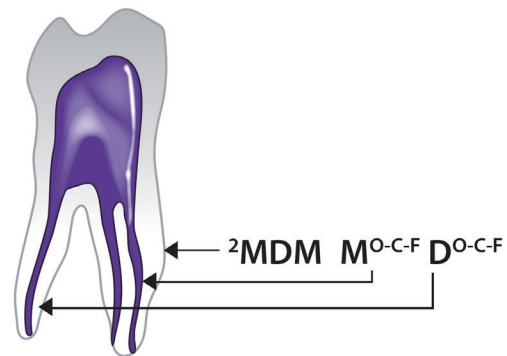

Fig. 2 The Ahmed et al. classification system. The number of roots, canals and anomalies such as C-shaped canal morphology could be reported using a single descriptive code. The tooth itself was assigned the code MDM (mandibular second molar). Root number was indicated by a superscript number directly to the left of the tooth code (e.g. ^{2}MDM for a double-rooted tooth). Directly to the right of the tooth code, the letters O, C and F indicated the number of orifice/s (O), canal/s (C), and foramina (F) per root (e.g. M described the mesial root and D the distal root). Numbers replaced the letters O, C and F when reporting the root and canal configuration (e.g. code ^{2}MDM M^2 D^{1-2-1} indicated a two-rooted tooth, with two orifices, canals and foramina in the mesial root. One orifice with main canal splitting into two but joining again apically into one foramen in the distal root). C-shaped morphology, as described by Melton [24] with modifications by Fan et al. [18], was reported using the prefix CSC in brackets before the root number, with a superscript Arabic number directly adjacent to the CSC code, indicating the type of C-shape [e.g. $(CSC^2)^1MDM^2$ denoted a single-rooted mandibular second molar, with type 2 C-shape morphology and two orifices, canals and foramina in the root]. Double slashes (//) indicated root fusion with shared internal canal anatomy and a single slash (/) indicated fusion of the roots only with no sharing of canal structures between the roots. The superscript prefix BR indicated the presence of a bifid root.

Statistical analysis

To ensure subject anonymity, all scans were de-identified prior to statistical analysis by assigning numbers to the dataset instead of the subjects' hospital file information. Both the age and sex of the subjects were recorded to evaluate differences in root number and/or canal morphology. In keeping with previous methodology [10], three age cohorts were selected in order to evaluate clinically relevant differences in canal morphology: <25 years; 25-40 years; and >40 years. Differences in the prevalence of canal morphology in relation to sex and age were reported using Fisher's Exact test, with corrections for multiple testing where required. Statistical analysis was performed using R Statistical Software version 4.1.1 (R Core Team 2021. R. A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria). The level of significance was set at $P < 0.05$. Simple percentage agreement was used to represent inter- and intra-rater reliability.

Results

Sample description and examiner agreement

In total, 386 mandibular second molar teeth were evaluated from 239 subjects. The subject age range was 15-79 years (mean: 35.4 years). The distribution of left- ($n = 195/386$, 50.5%) and right-sided ($n = 191/386$, 49.5%) samples was approximately even. The sex distribution included slightly fewer teeth from female subjects ($n = 192/386$, 49.7%) than from males ($n = 194/386$, 50.3%). No samples were excluded. The inter- (87.1%)

Table 1 Distribution of C-shaped canal anatomy of mandibular second molars per root third

Type of C-shape	C1 (%)	C2 (%)	C3 (%)	C4 (%)	Total n (%)
Coronal	6 (27.3)	2 (9.1)	11 (50.0)	3 (13.6)	22 (100)
Middle	-	1 (4.6)	18 (81.8)	3 (13.6)	22 (100)
Apical	1 (4.6)	-	16 (72.7)	5 (22.7)	22 (100)

Table 2 Canal configurations per root of mandibular second molars according to the Vertucci classification

Root number	Canal location	I	II	III	IV	V	VI	VII	VIII	IX	X	XII	XIV	XV	XVI	XVII	XVIII	XIX	XXI	Unclassified	Total n of teeth
		1	2-1	1-2-1	2	1-2	2-1-2	1-2-1-2	3	1-3	1-2-3-2	2-3-1	4-2	3-2	2-3	1-3-1	3-1	2-1-2-1	4-1		
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		
One		1 (4.2)	1 (4.2)																	22 (91.6)	24
Two	M	8 (2.3)	43 (12.1)	64 (18.1)	146 (41.2)	17 (4.8)	1 (0.3)	3 (0.8)	1 (0.3)		22 (6.2)	10 (2.8)	3 (0.8)	8 (2.3)	1 (0.3)	17 (4.8)	1 (0.3)	1 (0.3)	1 (0.3)	7 (2.0)	354
	D	265 (74.9)	6 (1.6)	43 (12.1)	1 (0.3)	17 (4.9)	1 (0.3)			3 (0.8)	3 (0.8)					11 (3.1)			2 (0.6)	2 (0.6)	
Three	MB/ML				4 (66.6)									1 (16.7)							6
	M										1 (16.7)										
	D	5 (83.3)				1 (16.7)															
	DL	1 (100)																			
Four	MB/ML				2 (100)																2
	DB/DL				2 (100)																
Total																					386

and intra-observer (84.6%) scores indicated a high degree of examiner agreement.

Root number and C-shaped anatomy

The mandibular second molars evaluated in the present study were predominantly two-rooted (n = 354/386, 91.7%). A smaller number of teeth were single-rooted (n = 24/386, 6.2%), three-rooted (n = 6/386, 1.6%) or four-rooted (n = 2/386, 0.5%).

One tooth demonstrated true fusion of the mesial and distal roots and was not considered C-shaped. C-shaped roots and canals were found in only a small number of teeth (n = 22/386, 5.7%). The most common C-shaped canal morphology in the coronal third was type 3 (n = 11/22, 50.0%), followed by type 1 (n = 6/22, 27.3%), type 2 (n = 2/22, 9.1%) and type 4 (n = 3/22, 13.6%). No type 5 C-shapes were found. The type of C-shape in a given tooth was not necessarily consistent along the root's length, and the morphology varied between the coronal, middle and apical root thirds. These variations are presented in Table 1. Information regarding the number of canals present in C-shaped teeth was reported under the Ahmed et al. classification's findings of the present study (Table 4).

Vertucci canal configurations

For molar teeth, the Vertucci classification is normally applied to roots [1]. Table 2 summarizes the canal configurations of mandibular second molars according to Vertucci.

Twenty-four of the present mandibular second molars were single-rooted. One single-rooted mandibular second molar was classified as Vertucci Type I (n = 1/24, 4.2%) and another as Type II (n = 1/24, 4.2%). The remaining single-rooted teeth were found to be C-shaped (n = 22/24, 91.6%) and were considered unclassifiable by the Vertucci system.

Among two-rooted mandibular second molars, the majority of mesial roots displayed Type IV configurations (n = 146/354, 41.2%), followed by Type III (n = 64/354, 18.1%), Type II (n = 43/354, 12.1%) and Type X (n = 22/354, 6.2%). Several other mesial root configurations were also represented in small numbers. The majority of the distal roots of two-rooted teeth displayed a Type I configuration (n = 265/354, 74.9%), followed by a Type III configuration (n = 43/354, 12.1%).

Among three-rooted mandibular second molars (n = 6/386), five teeth had a mesial root that split into separate mesiobuccal and mesiolingual

roots approximately half way down the root surface. The mesial roots of four of these five teeth were classified as Vertucci Type IV, and one as Type XV. The remaining three-rooted sample (n = 1/386, 0.25%) was observed as a radix entomolaris (with separate mesial, distal and distolingual roots), and displayed a Type XII configuration in the mesial root, Type I in the distal root, and Type I in the separate distolingual root.

Two four-rooted mandibular second molars were observed. Both of these teeth showed a split of the mesial and distal roots about halfway down the root surface (branching into separate mesiobuccal, mesiolingual, distobuccal and distolingual roots). Whilst each root displayed individual canals in the apical half, the mesial roots were classified as Type IV and the distal roots as Type V by the Vertucci classification due to the overall canal morphology.

More than two canals were found in almost one-fifth of mesial roots (n = 72/386, 18.6%) and a smaller number of distal (n = 21/386, 5.4%) roots.

Canal configurations according to the Ahmed et al. classification

Tables 3 and 4 provide a description of mandibular second molar teeth according to the Ahmed et al. classification. Using this classification, mandibular second molars were divided into two groups: conventional teeth (i.e., non-C-shaped anatomy, n = 364/386, 94.3%) and those with C-shaped anatomy (n = 22/386, 5.7%).

In the conventional group, two single-rooted teeth were found. These teeth were coded as ^{1}MDM^1 (n = 1/364, 0.3%) and ^{1}MDM$^{2-1}$ (n = 1/364, 0.3%) respectively.

The most common configuration observed in conventional two-rooted mandibular second molars was ^{2}MDM M^2 D^1 (n = 96/364, 26.3%), followed by ^{2}MDM M^{1-2-1} D^1 (n = 55/364, 15.1%) and ^{2}MDM M$^{2-1}$ D^1 (n = 33/364, 9.1%). The remaining two-rooted mandibular second molars displayed a large number of unique codes, each with a small number of representatives (Table 3).

Among three-rooted mandibular second molars, the most common configuration was ^{3}MDM MB^1 ML^1 D^1 (n = 4/364, 1.2%). The remaining three-rooted tooth was coded as ^{3}MDM MB^1 ML$^{2-1}$ D$^{1-2}$ (n = 1/364, 0.3%).

Two four-rooted mandibular second molars were observed, and both were considered to be ^{4}MDM MB^1 ML^1 DB//DL$^{1-2}$ (n = 2/364, 0.5%).

The mandibular second molars demonstrating C-shaped anatomy according to the Ahmed et al. classification were exclusively single-rooted

Table 3 Root canal configurations of mandibular second molar teeth without C-shaped anatomy according to the Ahmed et al. classification

Configuration	Number ($n =$)	Total percentage (%)	Cumulative total
(RE)^{3}MDM MB^{2-3-1} D^1 L^1	1	0.3	1
^{1}MDM^1	1	0.3	2
^{1}MDM$^{2-1}$	1	0.3	3
^{2}MDM ^{1}M^2 D^1	6	1.6	9
^{2}MDM ^{1}M^2 D^2	1	0.3	10
^{2}MDM ^{BR}M^2 ^{BR}D$^{1-2}$	1	0.3	11
^{2}MDM ^{BR}M^2 D^1	4	1.0	15
^{2}MDM ^{BR}M^2 D$^{1-2}$	1	0.3	16
^{2}MDM ^{BR}M^2 D^{1-2-1}	1	0.3	17
^{2}MDM ^{BR}M^2 D$^{1-3}$	1	0.3	18
^{2}MDM M^1 D^1	8	2.1	26
^{2}MDM M$^{1-2}$ ^{BR}D$^{1-2}$	1	0.3	27
^{2}MDM M$^{1-2}$ D^1	14	3.8	41
^{2}MDM M$^{1-2}$ D^{1-2-1}	2	0.5	43
^{2}MDM M^{1-2-1} D^1	55	15.1	98
^{2}MDM M^{1-2-1} D$^{1-2}$	2	0.5	100
^{2}MDM M^{1-2-1} D^{1-2-1}	6	1.6	106
^{2}MDM M^{1-2-1} D$^{2-1}$	1	0.3	107
^{2}MDM M$^{1-2-1-2}$ D^1	2	0.5	109
^{2}MDM M$^{1-2-1-2}$ D$^{1-2}$	1	0.3	110
^{2}MDM M$^{1-2-3-2}$ D^1	13	3.5	123
^{2}MDM M$^{1-2-3-2}$ D$^{1-2}$	1	0.3	124
^{2}MDM M$^{1-2-3-2}$ D^{1-2-1}	3	0.8	127
^{2}MDM M$^{1-2-3-2}$ D$^{1-3}$	1	0.3	128
^{2}MDM M$^{1-2-3-2}$ D^{1-3-1}	3	0.8	131
^{2}MDM M$^{1-2-3-2}$/D$^{1-2}$	1	0.3	132
^{2}MDM M^{1-3-1} D^1	13	3.5	145
^{2}MDM M^{1-3-1} D^{1-2-1}	2	0.5	147
^{2}MDM M^{1-3-1} D^{1-3-1}	1	0.3	148
^{2}MDM M^{1-3-1}/D^1	1	0.3	149
^{2}MDM M$^{1-3-2-1}$ D^1	1	0.3	150
^{2}MDM M$^{1-3-2-1}$ D^{1-3-1}	1	0.3	151
^{2}MDM M^2 ^{BR}D^1	1	0.3	152
^{2}MDM M^2 D$^{1-3-6-2}$	1	0.3	153
^{2}MDM M^2 D^1	96	26.3	249
^{2}MDM M^2 D$^{1-2}$	8	2.2	257
^{2}MDM M^2 D^{1-2-1}	15	4.1	272
^{2}MDM M^2 D$^{1-2-3-2}$	3	0.8	275
^{2}MDM M^2 D$^{1-3}$	1	0.3	276
^{2}MDM M^2 D^{1-3-1}	7	1.9	283
^{2}MDM M^2 D^2	2	0.5	285
^{2}MDM M$^{2-1}$ D^1	33	9.1	318
^{2}MDM M$^{2-1}$ D^{1-2-1}	3	0.8	321
^{2}MDM M$^{2-1}$ D$^{1-2-3-1}$	1	0.3	322
^{2}MDM M$^{2-1}$ D^{1-3-1}	1	0.3	323
^{2}MDM M$^{2-1}$ D$^{2-1}$	1	0.3	324
^{2}MDM M$^{2-1}$ D$^{4-1}$	1	0.3	325
^{2}MDM M^{2-1-2} D^1	1	0.3	326
^{2}MDM M$^{2-1-2-1}$ D^1	1	0.3	327
^{2}MDM M$^{2-3}$ D^1	1	0.3	328
^{2}MDM M^{2-3-1} D^1	6	1.6	334
^{2}MDM M^{2-3-1} D^{1-2-1}	4	1.2	338
^{2}MDM M^{2-3-2} D^1	2	0.5	340
^{2}MDM M^{2-3-2} D^{1-2-1}	1	0.3	341
^{2}MDM M^{2-4-2} D^1	1	0.3	342
^{2}MDM M^3 D$^{1-2}$	1	0.3	343
^{2}MDM M$^{3-1}$ D^1	1	0.3	344
^{2}MDM M$^{3-2}$ D^1	2	0.5	346
^{2}MDM M$^{3-2}$ D^{1-2-1}	4	1.2	350
^{2}MDM M$^{3-2}$ D$^{2-1}$	2	0.5	352
^{2}MDM M^{3-2-1} D^1	1	0.3	353
^{2}MDM M$^{4-1}$ D$^{4-1}$	1	0.3	354
^{2}MDM M$^{4-2}$ D^1	2	0.5	356
^{2}MDM M$^{4-2}$ D^{1-2-1}	1	0.3	357
^{3}MDM MB^1 ML^1 D^1	4	1.2	361
^{3}MDM MB^1 ML$^{2-1}$ D$^{1-2}$	1	0.3	362
^{4}MDM MB^1 ML^1 DB//DL$^{1-2}$	2	0.5	364
Total	364	100	364

Table 4 Root canal configurations of mandibular second molar teeth with C-shaped anatomy according to the Ahmed et al. classification

Configuration	Number ($n =$)	Total percentage (%)	Cumulative total
(CSC^1)^{1}MDM^1	1	4.5	1
(CSC^1)^{1}MDM$^{1-2}$	3	13.7	4
(CSC^1)^{1}MDM$^{1-2-3-2}$	1	4.5	5
(CSC^1)^{1}MDM^{1-3-1}	1	4.5	6
(CSC^2)^{1}MDM$^{2-3}$	1	4.5	7
(CSC^2)^{1}MDM^{2-3-2}	1	4.5	8
(CSC^3)^{1}MDM^2	1	4.5	9
(CSC^3)^{1}MDM^3	4	18.3	13
(CSC^3)^{1}MDM$^{3-1}$	1	4.5	14
(CSC^3)^{1}MDM$^{3-2}$	4	18.3	18
(CSC^3)^{1}MDM^{3-2-1}	1	4.5	19
(CSC^4)^{1}MDM^1	2	9.2	21
(CSC^4)^{1}MDM^{1-2-3}	1	4.5	22
Total	22	100	22

Table 5 Sex versus Vertucci and Ahmed et al. classification in the distal root canal system of mandibular second molars

Sex	Single canals (n)	Multiple canals (n)
Female	133	31
(z-score)	(0.385)	(0.089)
Male	127	54
(z-score)	(0.368)	(0.156)

Fisher's exact test: $P = 0.02$

(Table 4). The most common configurations observed were (CSC^3)^{1}MDM^3 ($n = 4/22$, 18.3%) and (CSC^3)^{1}MDM$^{3-2}$ ($n = 4/22$, 18.3%), both of which demonstrated type 3 C-shapes in the coronal third. This was followed by (CSC^1)^{1}MDM$^{1-2}$ ($n = 3/22$, 13.7%) and (CSC^4)^{1}MDM^1 ($n = 2/22$, 9.2%). The remainder of the C-shaped teeth demonstrated unique codes when classified using the Ahmed et al. system.

Effect of age and sex on canal configuration

No relationships between age and the Vertucci classification were demonstrated for the mesial root system ($P = 0.49$) or the distal root system ($P = 0.60$) of two-rooted teeth. Furthermore, no relationship was observed between sex and the Vertucci classification for the mesial root system ($P = 0.23$). In the distal root system, however, a relationship was observed between sex and the Vertucci classification ($P = 0.02$), males being more likely to display more than one canal in this root ($P = 0.02$).

With regard to age and the Ahmed et al. classification, no relationships were observed in either the mesial ($P = 0.49$) or distal root canal systems ($P = 0.59$). In the mesial root, no relationship was found between sex and the Ahmed et al. classification ($P = 0.23$). In the distal root system, a relationship between sex and the Ahmed et al. classification was observed ($P = 0.02$, Table 5), males being more likely to display additional canals in this root ($P = 0.02$).

No relationship between sex and the presence of C-shaped morphology was observed ($P = 0.19$).

Discussion

Knowledge of both conventional anatomy as well as anatomical variations is necessary for clinicians to locate, clean and fill entire root canal systems effectively [1,5]. It is well known that missed canals or untreated anatomy may negatively affect endodontic treatment outcomes [10]. Mandibular second molars in particular commonly display aberrations or variations of typical anatomy, and endodontic clinicians should be aware of all possible root and canal configurations in this tooth type in different population groups [5]. The present study confirmed this assertion for mandibular second molars in the Black South African population. As the study design was observational, descriptive and retrospective in nature, it was possible to evaluate a large number of samples, which were found to display both simple and complex morphology. This made it possible to compare the morphology of this tooth type and population group with previously reported populations.

Investigations pertaining to the dental anatomy of South African

Fig. 3 C-shaped morphology was observed in mandibular second molars of the present study. The description of the Melton classification [24] along the length of the root was not necessarily consistent, with changes of this morphology observed between the coronal, middle and apical thirds of the same tooth.

Fig. 4 Additional canals (middle mesial and middle distal canals) were observed in both the mesial (A) as well as distal (B) root canal systems of mandibular second molars.

populations are limited [15], and no studies of mandibular second molars limited specifically to Black South African subjects could be found in the literature. The present study therefore provides new information regarding the dental morphology of the Black South African population living in the Southern African region. A previous study evaluated the root and canal morphology of mandibular first and second molars in a mixed South African population, but the findings were not limited to any particular population [Tredoux S, Root and canal configurations of mandibular molars using CBCT, with an emphasis on middle mesial canals. University of Pretoria (Dissertation): 1-75, 2020].

The mandibular second molars in the present study were predominantly two-rooted, and located mesiodistally. This corresponds with the findings of many others [5], and is historically considered to be a Caucasian trait [5]. However, root number in mandibular second molars may vary, being higher or lower [5], as was the case in the present sample. The prevalence of single-rooted teeth varies, but has been found in up to 41% of mandibular second molars [5]. The number of single-rooted teeth observed here was low, similar to the findings of Plotino et al. [2]. Three-rooted teeth were observed less commonly in the present study (1.6%), and have been reported less frequently than single- or double-rooted mandibular second molars [19]. The prevalence of three-rooted second molars in the present sample was similar to that reported for a Thai population (1.2%) but lower than that for Indian populations (8.9%) [8,20]. In the present investigation, three-rooted teeth were mainly observed as a splitting of the mesial root into separate mesiobuccal and mesiolingual roots with single canals, consistent with the findings of a previous South African study [Tredoux S, Dissertation: 1-75, 2020]. Only one radix entomolaris was observed, and this was considered a rare anatomical variation in this population. Some studies have reported four-rooted mandibular second molars, but this should also be considered uncommon [Tredoux S, Dissertation: 1-75, 2020]. Only two four-rooted teeth were found in the present sample, supporting this assertion.

C-shaped root and canal morphology is an important anatomical variation of mandibular second molars [5]. C-shapes have a wide range of reported prevalence (0-44.5%), but are more commonly found in Asian subjects [21]. C-shaped morphology is thought to be caused by failure of Hertwig's epithelial root sheath to fuse on the buccal or lingual aspect of the root [22]. The presence of C-shape morphology has great clinical significance in endodontics, as these teeth have a complex internal morphology, requiring modification of cleaning, shaping and filling techniques [6], and may be vulnerable to coronal [23] and/or strip perforations [4]. This variation may additionally result in a variety of canal shapes [18], and the morphology may change along the length of the root [24], with no
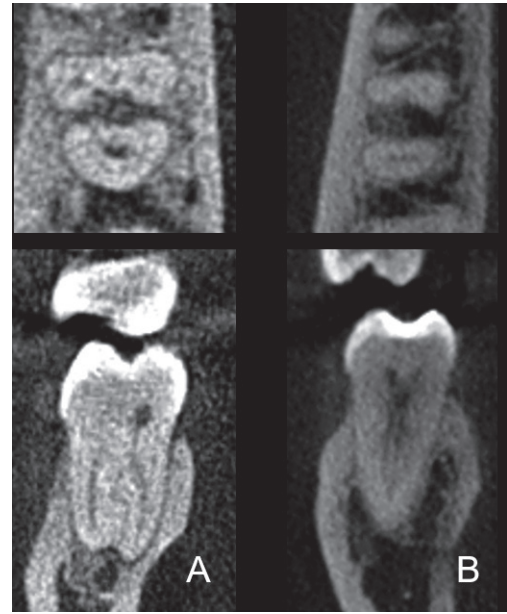
consistency [6]. This phenomenon was also observed in the present study (Fig. 3), and clinicians should be aware that the morphology evident in the coronal third of C-shaped teeth may not necessarily correspond to that found lower down the root [5], and may impact endodontic treatment. The present study reported a relatively low prevalence of C-shaped mandibular second molars (5.7%) in comparison with Korean [4], Saudi Arabian [25] and Sudanese [26] populations, and was similar to that of a White population [2] and another South African population [Tredoux S, Dissertation: 1-75, 2020]. Von Zuben et al. found a 9.3% prevalence of C-shaped mandibular second molars in a mixed South African population [27]. Rwenyonyi observed no C-shaped second molars in a Ugandan population [28]. Variation in the reported prevalence of C-shaped anatomy may be explained by differing study methodologies and sample sizes, population groups and CBCT machine parameters.

Racial and ethnic differences have previously been reported to influence anatomical variations in mandibular second molars [5]. Differing geographic location may also affect anatomical variation [7]. Future research aimed at describing the dental morphology of other Southern African populations would be desirable, as information from this region and the African continent in general is limited [28].

With regard to sex, a higher prevalence of C-shaped roots has been reported in females relative to males [5]. However, other investigations have found an opposite trend [3] or no such relationship [3]. The present study found no relationship between sex and C-shaped morphology. Age and tooth position of mandibular second molars have been reported to show no relationship in terms of anatomical variation [5]. Another South African study similarly found no age or sex correlations with root and canal configuration [Tredoux S, Dissertation: 1-75, 2020]. In the present study, no relationships between age and root canal anatomy were observed. However, males were found to display additional canals in the distal root canal system of mandibular second molars more frequently than females ($P = 0.02$).

The mandibular second molars observed in this Black South African population showed a wide variety of canal morphology. Single-rooted, non-C-shaped teeth had relatively simple single or double canal systems. Among two-rooted teeth, Type IV Vertucci configurations (two canals with two apical foramina) in the mesial root, and Type I (a single canal and foramen) in the distal root (Ahmed code: [2]MDM M[2] D[1]) were the structures most commonly observed. Although suggested by some to be an Asian trait [20], this feature has been reported in other ethnic groups [2]. This differed from American [29], Australian [22] and Turkish [12] studies, which found predominantly Type II (two canals with a single foramen) configurations in the mesial roots. However, Plotino et al. reported Type

IV to be the most common configuration in a White population [2], as was the case in the present Black South African population. Three or more canals were found in almost one-fifth of mesial ($n = 72/386$, 18.6%) and some distal ($n = 21/386$, 5.4%) roots (Fig. 4A, B). This was similar to the findings of a previous study of a mixed South African population, where the prevalence of middle mesial canals was 17% and that of middle distal canals 2% [Tredoux S, Dissertation: 1-75, 2020]. This differed from the findings of Ahmed et al., who reported a 10% prevalence of both middle mesial and middle distal canals in mandibular second molars of a Sudanese population [26].

The present investigation used the classification systems of both Vertucci and Ahmed et al. [1,13]. Over time, the original eight Vertucci configurations were expanded to describe ever-increasing morphologic variations. The additions of Sert and Bayirli list 23 possible configurations [12], and this system has been used for the study of mandibular second molars [10]. Despite these additions, the Vertucci system remains unable to describe either root number or anomalies/variations [13]. Therefore, when using the Vertucci system some teeth invariably remain unclassified, as was confirmed in the present study. This should be considered a significant limitation of the Vertucci system. For this reason, C-shaped morphology has traditionally been described using alternative classifications, such as those originally proposed by Melton [24], and the additions made by Fan et al. [18]. In 2017, a new classification was created by Ahmed et al. to describe root and canal configurations simultaneously using a single descriptive code [13]. This system has the advantage of being able to describe anatomical variations and anomalies (such as C-shaped morphology) in addition to root and canal structures [17], as well as incorporating other classification systems (e.g. Fan et al. [18]) into the descriptive code for root and canal structures [17]. In the present study, this feature was used successfully, allowing all mandibular second molars to be described effectively. This should be considered a significant advantage over previous classification systems. One drawback of the Ahmed et al. system is that it creates several individual configurations, as was evident here. A limited number of investigations have compared the Ahmed et al. classification with other systems [14]. However, no previous attempts have been made to compare the Ahmed et al. system with the Vertucci classification system for description of mandibular second molars. Therefore, the present study may the first to have reported the anatomy of this tooth type with a comparison of these two classifications (including C-shaped morphology as part of the description), thereby improving knowledge and usage of the newer system for complex teeth.

The use of CBCT for the three-dimensional study of structures in the maxillofacial region, including endodontic anatomy, is well established [9]. The non-destructive nature of the technology allows retrospective evaluation of the prevalence of root and canal morphology in large samples [10,30]. The undistorted three-dimensional images of CBCT have been reported to be equal to those obtained by clearing and staining in studies of dental anatomy [31]. This imaging modality has been used by others for the study of mandibular second molars [14]. However, the 200-μm resolution used in the present investigation should be considered a limitation. Micro-CT is also popularly used for the study of root and canal morphology, but this technology cannot be used on living subjects [14].

In conclusion, the present study has revealed the diverse morphology of root and canal structures of mandibular second molars in a Black South African population. Two-rooted mandibular second molars were the type most commonly observed, and the prevalence of C-shaped anatomy was relatively low (5.7%). The most common canal configuration in the mesial roots was Vertucci Type IV (41.2%) and the Type I distal root (75.1%), or ^{2}MDM M^2 D^1 as described by the Ahmed et al. classification. Three or more canals were found in a number of mesial ($n = 72/386$, 18.6%) and distal ($n = 21/386$, 5.4%) roots. Males demonstrated additional canals in the distal root canal system more frequently than females ($P = 0.02$). The use of CBCT, in combination with the Ahmed et al. classification, more effectively described the anatomy of mandibular second molars in comparison with the Vertucci classification. Clinicians must be cognisant of the existence of both normal root and canal morphology, as well as anatomical variations, in order to perform successful endodontic treatment on mandibular second molars.

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