Journal of Oral Science, Vol. 64, No. 4, 300-306, 2022

Original Article

A study of mandibular premolar root and canal morphology in a Black South African population using cone-beam computed tomography and two classification systems

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(Received June 20, 2022; Accepted August 23, 2022)

Abstract

Purpose: An investigation of the configurations of mandibular premolar roots and canals in a population of Black South Africans.
Methods: Cone-beam computed tomography analysis of 772 mandibular premolars was performed, and the premolars were classified according to the systems proposed by Vertucci and Ahmed et al. Root number, canal morphology, age, and sex were recorded. Fisher's exact test was used to determine relationships based on age and sex ($P < 0.05$).
Results: Single roots were seen in the majority of mandibular premolars (97.1%). Single canal configurations (i.e., Vertucci Type 1/Ahmed et al. $^{1}MP^{1}$) were observed in 48.5% of first and 81.3% of second mandibular premolars. Mandibular first premolars demonstrated multiple canals in more than half of the sample (51.5%), and C-shaped morphology in more than one-tenth (11.1%). A relationship between sex and the presence of radicular grooves was demonstrated ($P = 0.049$), males being more likely to demonstrate this feature ($P = 0.051$). Multiple canals in mandibular first premolars also showed a relationship with sex ($P = 0.005$), a male predilection being evident ($P = 0.007$). The Ahmed et al. system proved superior to the Vertucci classification for reporting complex configurations and anatomical variations, although a greater number of unique categories were created.
Conclusion: Diverse mandibular premolar root and canal morphology was observed in the studied population. Clinicians must be aware of common morphological features as well as possible anatomical variations in mandibular premolars, as failure to treat complete root canal systems may negatively impact endodontic treatment outcomes.

Keywords: cone-beam computed tomography, endodontics, mandibular premolars, root canal morphology, South African population

Introduction

Both historical as well as modern anatomical studies have shown that root canal structures are elaborate, composed of intricate branching systems which may divide and rejoin at varying positions along the length of the root [1,2]. In order to successfully achieve the goals of endodontic treatment, namely complete debridement, instrumentation and obturation of the root canal system, clinicians must be mindful of both common root and canal configurations, as well as potential anatomical variations [3]. Untreated or missed features of root canal anatomy may lead to adverse endodontic treatment outcomes [4].

Anatomical variation in mandibular premolars has been commonly reported [3,5-7]. Such variation may be related to racial and ethnic differences, genetics, environmental factors and differing geographic distribution [2,8]. Some studies of mandibular premolars have demonstrated the presence of two or more canals [7], and rarely three canals with three separate foramina [3]. The published literature has placed major emphasis on two mandibular premolar variations: the radicular groove [6], and a C-shaped morphology [5]. A good knowledge of population-based anatomy and morphological variations may assist clinicians in locating and negotiating root canal systems, thus potentially improving endodontic outcomes [3].

The South African Government classifies the country's population into several groups, with Black Africans comprising the vast majority (79.0%) [Statistics South Africa, Census 2011, available from: https://www.statssa.gov.za/publications/P03014/P030142011.pdf –last accessed 06-01-2022]. Whilst only a small number of publications have explored the dental anatomy of South African subjects in general [2,4,7,9], none have reported the morphology of mandibular premolars in exclusively Black South African individuals. Information regarding the dental anatomy of South Africa's largest population group is therefore scant.

The Vertucci system [1] is a well-known and widely used classification for the description of dental anatomy [8]. Though elegant and simple to use, an alternative classification system, developed by Ahmed et al. in 2017, was proposed to overcome the limitations inherent to the Vertucci system [10]. These limitations include an inability to describe the number of roots, external root features, complex internal configurations and dental anomalies [10]. A number of studies have compared the newer system to the well-established Vertucci classification [2,8,11].

In recent times, cone-beam computed tomography (CBCT) has been successfully applied to the study of dental anatomy and endodontics [5,12,13], and its role in these disciplines is well established. The present study aimed to describe the root and canal anatomy of permanent mandibular premolars in a Black South African population group using CBCT and the above two classifications.

Materials and Methods

This descriptive study was retrospective and cross-sectional in design. Ethical approval was granted by the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Protocol number: 331/2021). Evaluation of existing high-resolution CBCT scans, acquired between March 2015 and October 2021, was performed until the minimum sample size was achieved. CBCT image evaluation was performed according to the methodology described by Buchanan et al. [2] and Ahmed et al. [10,12]. The precise methodology was as follows:

Inclusion criteria

Only scans of mature mandibular premolars were included. Complete visualization of individual roots and canals was necessary for inclusion. A voxel size of ≤0.2 mm was considered acceptable, as larger voxel sizes could not provide enough detail. Subjects classified as Black African in the existing hospital records were included.

Exclusion criteria

Teeth that were incompletely formed as well as those with existing dental, endodontic or surgical treatment which might potentially have altered the original anatomy were excluded. Scans with artefacts distorting or obscuring visualization, tooth types other than permanent mandibular premolars,

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J-STAGE Advance Publication: September 12, 2022
Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.22-0239
DN/JST.JSTAGE/josnusd/22-0239

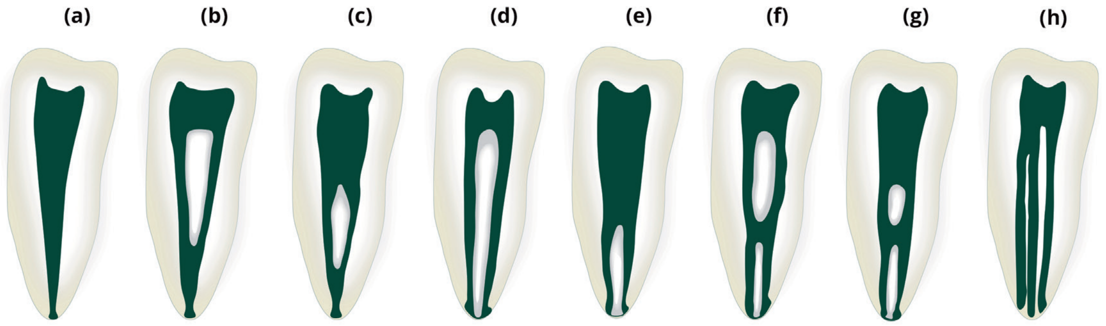

Fig. 1 The Vertucci classification system demonstrating the eight original canal types. Type I (a) displays a single canal with a single foramen. Type II (b) two canals with a single foramen. Type III (c) a single canal splitting into two, then merging to exit as a single foramen, Type IV (d) two canals with two separate foramina, Type V (e) a single canal splitting apically into two foramina, Type VI (f) two canals merging together then diverging into two foramina. Type VII (g) a single canal diverging into two, merging back into a single canal then diverging into two foramina. Type VIII (h) three canals with three separate foramina

and subjects from population groups other than Black African individuals were also excluded.

Sample size

A combined total of 770 teeth (385 mandibular first premolars and 385 mandibular second premolars) was required. The sample size was calculated using Epi-Info version 7 statistical software (Atlanta, GA, USA). For a descriptive, cross-sectional study with unknown prevalence, a 50.0% prevalence was used to maximize the sample size, assuming a 5.0% margin of error and a 95.0% confidence interval, yielding a minimum sample size of $n = 384$ per tooth type.

The sample included left- and right-sided teeth. At least 193 (in the presence of four mandibular premolars) and at most 770 (in the presence of one mandibular premolar) CBCT scans were required. Both male and female subjects were included.

Origin of scans

Scans acquired from a single CBCT unit (Planmeca Promax 3D Max, Planmeca OY, Helsingfors, Finland) in the Section of Diagnostic Imaging, University of Pretoria, were assessed. The existing scans had been acquired for a variety of clinical reasons in various dental disciplines. The specifications of the CBCT unit were as follows: resolution 100-600 µm, tube current 1-14 mA, tube voltage 54-90 kV, focal spot diameter 0.6 mm, field of view variable (depending on area of interest), voxel size range 0.150-0.600 mm.

Scan analysis

Romexis software version 6.0 (Planmeca OY) was used for CBCT evaluation. Two examiners, one with ten years' experience in endodontics and CBCT interpretation and a second, experienced in endodontics and oral radiology, evaluated the sample. The first examiner evaluated all scans, and the second examiner a 10% subset. Calibration was performed before data collection to standardize the examiners by evaluating 50 teeth not included in the study. Then, scans including mandibular premolar teeth were evaluated in the coronal, sagittal, and axial planes.

In a darkened room, included scans were individually adjusted by each examiner to optimise contrast, brightness and sharpness to their preference, to allow for optimal visualization. The long axis of the root of each tooth was positioned parallel to the vertical plane. Each scan was scrolled through a mesial to distal, buccal to lingual and coronal to apical direction. This enabled complete visualization of the number of roots and canal configuration of each tooth. Examiner findings were recorded using Microsoft Excel 2016 (Microsoft Corp., Redmond, WA, USA) and compared. In cases of agreement, the configurations remained unchanged. A third examiner was approached for a definitive opinion in cases of disagreement. Inter- and intra-rater reliability were assessed.

Root and canal configuration

Teeth included in the study were classified using both the Vertucci system [1] and the classification proposed by Ahmed et al. [10]. These systems are described in Fig. 1 (Vertucci) and Fig. 2 (Ahmed et al.).

Mandibular premolars included in the present study were assigned the

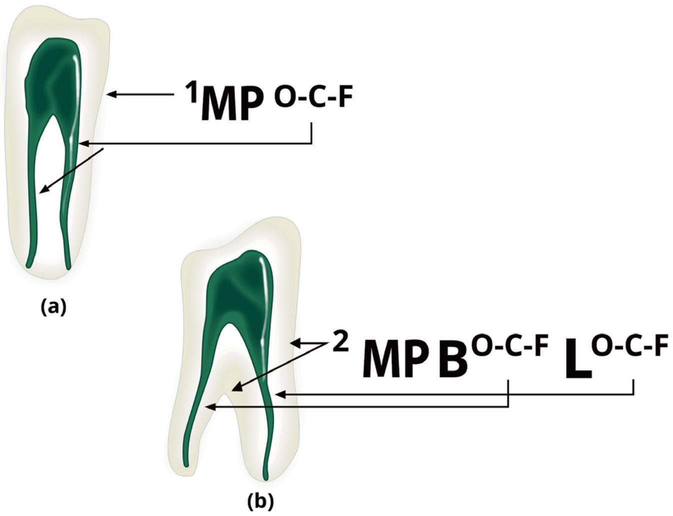

Fig. 2 The Ahmed et al. system demonstrating tooth classification using a single descriptive code indicating both the number of roots and the canal configuration. A code describing the tooth is assigned, in this example MP, indicating a mandibular premolar. The number of roots is indicated by a superscript number before the code (e.g. ^{2}MP for two roots). Letters indicating the number of orifices, canals and foramina follow the MP code (O-C-F). When describing the internal canal configurations, numbers corresponding to the numbers of orifices, canals and foramina present in the root replace the letters O, C and F. A single-rooted tooth with two orifices, two canals and two foramina (Fig. 2a) is therefore described using the code ^{1}MP^{2}. When multiple roots are present, each root is assigned an additional code following the tooth descriptor, in this case B and L, indicating separate buccal and lingual roots (Fig. 2b). When reporting the canal configurations in multi-rooted teeth, each root is independently described according to the number of orifices, canals and foramina (O, C, F) present. The configuration represented in Fig. 2b would therefore be reported using the code ^{2}MP B^{1} L^{1}.

code "MP" when classified using the Ahmed et al. system. This system also allows for description of dental anomalies and external root variations such as proximal gingival grooves (radicular grooves) and a C-shaped morphology [12]. Such variations were allocated the descriptors PGG (as described by Gu et al. [14]) and CSC (as described by Fan et al. [15]), respectively, as proposed by Ahmed et al. [12,16]. Three types of PGG exist according to Gu et al.: Type I describes short grooves not extending beyond the coronal third of the root, Type II shows grooves extending beyond the coronal third of the root, with a simple root canal system, and Type III displays grooves extending beyond the coronal third of the root, which correspond to a complex internal canal structure. The description of C-shaped canal types using Fan's classification is as follows: Type 1 canals are an uninterrupted "C" shape, with no division or separation (CSC^{I}), Type 2 canals are a semi-colon shape (CSC^{II}), Type 3 displays two or three separate canals (CSC^{III}), Type 4 is pyramidal with one large canal (CSC^{IV}) and Type 5 demonstrates no canal (CSC^{V}).

Readers are referred to the relevant source publications for a comprehensive explanation of the Ahmed et al. system [10,12].

In the present study, when classified using the Ahmed et al. system, mandibular premolars were grouped into three categories:

Table 1 Root canal configurations of mandibular premolars according to the Vertucci classification

	Root number	Canal type according to the Vertucci classification									
		I (%)	II (%)	III (%)	IV (%)	V (%)	VI (%)	VII (%)	VIII (%)	Unclassified	Total
First premolar											
	one	187 (49.5)	8 (2.1)	36 (9.6)	11 (2.9)	103 (27.2)	1 (0.3)	2 (0.5)		30 (7.9)	378
	two				1 (14.3)	5 (71.4)				1 (14.3)	7
	three								1 (100)		1
	total	187 (48.5)	8 (2.1)	36 (9.2)	12 (3.1)	108 (28.0)	1 (0.3)	2 (0.5)	1 (0.3)	31 (8.0)	386 (100)
Second premolar											
	one	314 (84.4)	4 (1.1)	23 (6.2)	1 (0.3)	9 (2.4)	1 (0.3)	2 (0.5)		18 (4.8)	372
	two				1 (11.1)	3 (33.3)				5 (55.6)	9
	three								4 (80)	1 (20)	5
	total	314 (81.3)	4 (1.0)	23 (6.1)	2 (0.5)	12 (3.1)	1 (0.3)	2 (0.5)	4 (1.0)	24 (6.2)	386 (100)

- Group 1: demonstrated a normal root anatomy (no radicular grooves) and a normal internal canal system (i.e., non-C-shaped systems).
- Group 2: included teeth displaying radicular grooves (external root surface variation) with a conventional (i.e., non-C-shaped, but additional) canal system internally –indicated by a prefix (e.g., PGG^{III}) before the Ahmed classification.
- Group 3: demonstrated radicular grooves (externally) as well as a C-shaped canal system (internally) –indicated as (PGG^{III}, CSC). A Roman numeral describing the type of C-shape morphology according to Fan et al. [15] followed the CSC abbreviation (e.g., CSC^{III}).

As the clinical relevance of age and sex in dental anatomy has been established [17], the relationships between these variables and root number and canal configuration were evaluated. The following age groups were selected: <25 years, 25-40 years, and >40 years, in line with previous methodology [17]. Scans from subjects <14 years old were excluded as the roots of these teeth were not mature. Anonymity of subjects was ensured by de-identification of the CBCT scans.

Statistical analysis

Data capturing was performed using Microsoft Excel 2016 (Microsoft Corp.). For statistical analysis, R Statistical Software version 4.1.1 (R Development Core Team, Vienna, Austria) was used. The Fisher Exact test was used to test for categorical variables with a significance set at $P < 0.05$. Examiner agreement was determined as the percentage of agreement. Agreement was calculated using a 10.0% subset of samples (of the total number included) evaluated by both examiners.

Results

Sample characteristics and examiner agreement

A total of 772 permanent mandibular premolar teeth in 232 subjects ranging in age from 14 to 88 years (mean: 36.4 years) were evaluated. The distribution of left- (n = 387/772) and right-sided (n = 385/772) teeth was similar. Exactly half (n = 386/772) of the sample were mandibular first premolars and the other half (n = 386/772) were mandibular second premolars. Slightly more male (n = 400/772, 52.0%) than female (n = 372/772, 48.0%) subjects were included. Inter- and intra-rater agreement was found to be high (91.2% and 90.0% respectively).

Number of roots

Mandibular first premolars were mostly single-rooted (n = 378/386, 97.9%). A small number of two-rooted (n = 7/386, 1.8%) and three-rooted (n = 1/386, 0.25%) mandibular first premolars were identified.

Similarly, most mandibular second premolars (n = 372/386, 96.3%) were single-rooted. A small number of two-rooted (n = 9/386, 2.3%) and three-rooted (n = 5/386, 1.3%) mandibular second premolars were, however, identified.

Vertucci configurations

The distribution of the canal configurations of both mandibular first and second premolar teeth according to the Vertucci classification is summarized in Table 1.

All Vertucci types were represented in the mandibular first premolars. The most common configuration amongst mandibular first premolars was Type I (n = 187/386, 48.5%), followed by Type V (n = 108/386, 28.0%). Less commonly, Type III (n = 36/386, 9.2%) and Type IV (n = 12/386, 3.1%) configurations were found. The sample contained a small number of Type II, VI, VII, and VIII configurations. Mandibular first premolars with complex configurations, not described by the original Vertucci system, were reported as unclassified (n = 31/386, 8.0%).

Mandibular second premolars also demonstrated all eight Vertucci configurations. The vast majority of mandibular second premolars displayed a Type I (n = 314/386, 81.3%) configuration, followed in order by Type III (n = 23/386, 6.1%) and Type V (n = 12/386, 3.1%). The remainder of the sample demonstrated Type II, IV, VI, VII, and VIII configurations in small numbers (Table 1). Mandibular second premolars with complex configurations not described by the original Vertucci system were reported as unclassified (n = 24/386, 6.2%). Examples of the Vertucci classification used in the present study are demonstrated in Fig. 3.

Of the mandibular first premolars, 11.1% (n = 43/386) demonstrated a C-shaped canal system. Some C-shaped canals corresponded to a Vertucci classification category and were reported as Type II, III, IV or V. The majority of C-shaped canals were, however, complex and reported as unclassified using the Vertucci classification. Among mandibular second premolars, 4.9% (n = 19/386) displayed C-shaped systems and were classified as either Type III, Type V, or unclassified. Examples of the C-shaped morphology found in the present study are demonstrated in Fig. 4.

Canal configurations according to the Ahmed et al. classification

The canal configurations of both the mandibular first and second premolar teeth according to the Ahmed et al. classification are summarized in Tables 2 and 3, respectively.

Among mandibular first premolars 71.8% (n = 277/386) demonstrated normal roots with normal internal configurations (Group 1), 17.1% (n = 66/386) displayed a radicular groove with normal internal canal configurations (Group 2) and 11.1% (n = 43/386) demonstrated a C-shaped (both external and internal) anatomy (Group 3).

The most common configuration amongst the mandibular first premolars was the $^{1}MP^{1}$ configuration (n = 187/386, 48.5%), i.e., one root and one canal internally, with no radicular groove externally. The second most frequent configuration was the $(PGG^{III})^{1}MP^{1-2}$ (n = 55/386, 14.3%), indicating the presence of a radicular groove externally on the root surface with a deep split of the main root canal into two separate canals. This was followed by the $^{1}MP^{1-2}$ configuration (n = 37/386, 9.6%) and $^{1}MP^{1-2-1}$ (n = 35/386, 9.1%). The most common C-shape configuration was $(PGG^{III}, CSC^{III})^{1}MP^{1-3-2}$ (n = 12/386, 3.1%). The remainder of the mandibular first

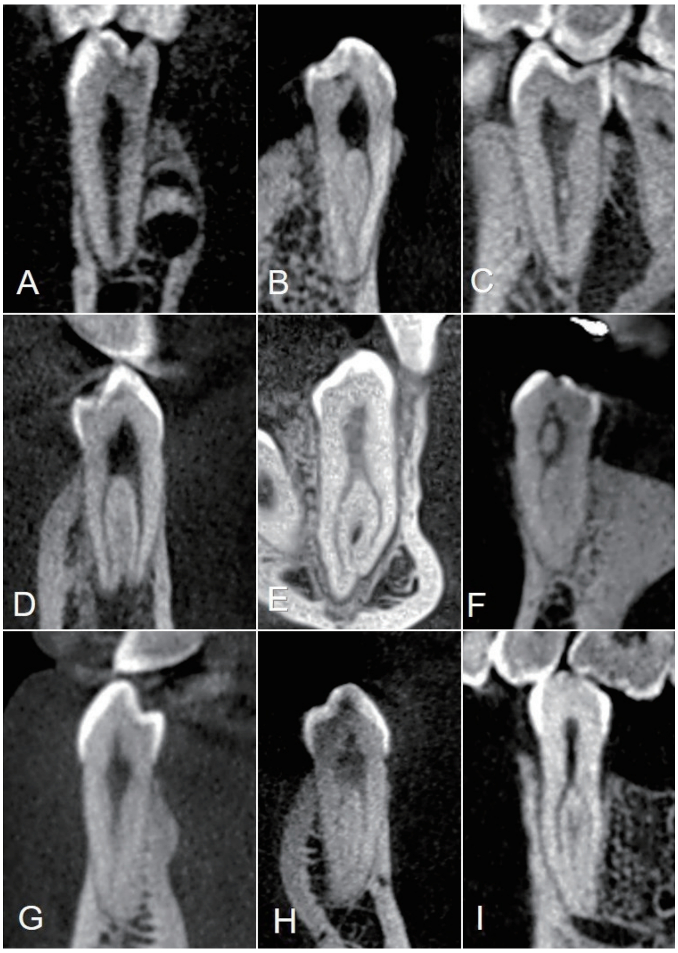

Fig. 3 A selection of mandibular premolar canal configurations observed in the present study. All Vertucci types were represented: Type I (A), Type II (B), Type III (C), Type IV (D), Type V (E), Type VI (F), Type VII (G), Type VIII (H), as well as an unclassified C-shaped configuration (I). The Vertucci classification, however, makes no provision for the number of roots, and the classification does not change even if multiple roots are present as in Fig. 3E.

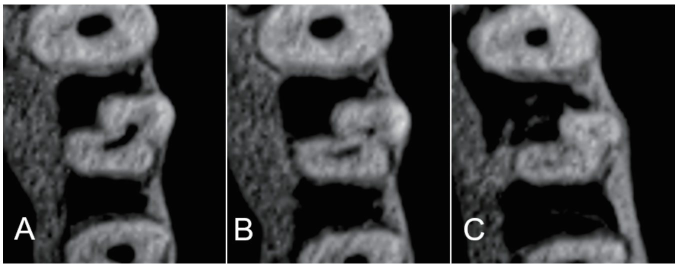

Fig. 4 A C-shaped canal morphology in addition to radicular grooves were observed in both mandibular first and second premolars in the present study, and described according to the Fan et al. classification [15]. Panels A, B and C of Fig. 4 demonstrate a selection of axial slices in examples of teeth where a C-shaped morphology was observed. A Type 1 C-shape (uninterrupted C) is demonstrated in Fig. 4A, Type 2 (semicolon) in Fig. 4B, and Type 3 (two or three separate canals) in Fig. 4C.

premolars had a high number of unique codes, with only small numbers of teeth grouped together (Table 2).

Among the mandibular second premolars, 94.3% (n = 364/386) had normal roots with normal internal configurations, 0.75% (n = 3/386) displayed radicular grooves with normal internal configurations, and 4.9% (n =19/386) had C-shaped external and internal anatomy.

The most common configuration amongst the mandibular second premolars was the $^{1}MP^{1}$ configuration (n = 314/386, 81.3%), i.e., one root and one canal. The second most frequent configuration was $^{1}MP^{1-2-1}$ (n = 21/386, 5.4%), containing one main canal which briefly bifurcated and then rejoined apically. This was followed by the $^{1}MP^{1-2}$ configuration (n = 7/386, 1.8%), i.e., a split of the main canal into two canals apically. The remainder of the mandibular second premolars demonstrated a high number of unique codes with a small number of representatives (Table 3). Examples of the varied description of morphology using the Ahmed et al. system is displayed in Fig. 5.

Table 2 Root canal configurations of mandibular first premolars according to the Ahmed et al. classification

Configuration according to the Ahmed et al. (2017) classification			
Configuration	Number (n)	Total percentage (%)	Cumulative total
Teeth with conventional anatomy			
$^{1}MP^{1}$	187	48.5	185
$^{1}MP^{1-2}$	37	9.6	222
$^{1}MP^{1-2-1}$	35	9.1	257
$^{1}MP^{1-2-1-2}$	2	0.5	259
$^{1}MP^{1-3}$	1	0.25	260
$^{1}MP^{2}$	2	0.5	262
$^{1}MP^{2-1}$	4	1.0	266
$^{1}MP^{2-1-2}$	1	0.25	267
$^{2}MP\ ^{1}B^{1}\ L^{1}$	6	1.6	273
$^{2}MP\ B^{2-1}\ L^{1}$	1	0.25	274
$^{3}MP\ MB^{1}\ DB^{1}\ L^{1}$	1	0.25	275
Teeth with proximal gingival grooves and conventional internal canals			
$(PGG^{III})^{1}MP^{1-2}$	55	14.3	332
$(PGG^{III})^{1}MP^{1-3-2}$	2	0.5	334
$(PGG^{III})^{1}MP^{2}$	6	1.6	340
$(PGG^{III})^{1}MP^{2-1}$	3	0.8	343
Teeth with proximal gingival grooves and C-shaped internal anatomy			
$(PGG^{III}, CSC^{I})^{1}MP^{1-2}$	5	1.3	348
$(PGG^{III}, CSC^{I})^{1}MP^{1-2-3}$	1	0.25	349
$(PGG^{III}, CSC^{I})^{1}MP^{1-3}$	2	0.5	351
$(PGG^{III}, CSC^{I})^{1}MP^{1-3-1}$	2	0.5	353
$(PGG^{III}, CSC^{I})^{1}MP^{1-3-2}$	1	0.25	354
$(PGG^{III}, CSC^{II})^{1}MP^{1-2}$	7	1.8	361
$(PGG^{III}, CSC^{II})^{1}MP^{1-2-1}$	1	0.25	362
$(PGG^{III}, CSC^{II})^{1}MP^{1-3-2}$	5	1.3	367
$(PGG^{III}, CSC^{II})^{1}MP^{2}$	1	0.25	368
$(PGG^{III}, CSC^{III})^{1}MP^{1-2-3}$	1	0.25	369
$(PGG^{III}, CSC^{III})^{1}MP^{1-2-3-2}$	2	0.5	371
$(PGG^{III}, CSC^{III})^{1}MP^{1-3-2}$	12	3.1	383
$(PGG^{III}, CSC^{III})^{1}MP^{2}$	2	0.5	385
$(PGG^{III}, CSC^{III})^{1}MP^{2-1}$	1	0.25	386
Total	386	100	386

Table 3 Root canal configurations of mandibular second premolars according to the Ahmed et al. classification

Configuration according to the Ahmed et al. (2017) classification			
Configuration	Number (n)	Total percentage (%)	Cumulative total
Teeth with conventional anatomy			
$^{1}MP^{1}$	314	81.3	314
$^{1}MP^{1-2}$	7	1.8	321
$^{1}MP^{1-2-1}$	21	5.6	342
$^{1}MP^{1-2-1-2}$	2	0.5	344
$^{1}MP^{2}$	1	0.25	345
$^{1}MP^{2-1}$	4	1.0	349
$^{1}MP^{2-1-2}$	1	0.25	350
$^{2}MP\ ^{1}B^{1}L^{1}$	4	1.0	354
$^{2}MP\ B^{2}L^{1}$	1	0.25	355
$^{2}MP\ M^{1}D^{1-2-1-2}$	1	0.25	356
$^{2}MP\ M^{2}/D^{2}$	2	0.5	358
$^{2}MP\ M^{2}\ D^{2}$	1	0.25	359
3MP $MB//DB^{1-2-1}\ L^{1}$	1	0.25	360
3MP $MB^{1}\ DB^{1}\ L^{1}$	4	1.0	364
Teeth with proximal gingival grooves and conventional internal canals			
$(PGG^{III})^{1}MP^{1-2}$	2	0.5	366
$(PGG^{III})^{1}MP^{1-2-1}$	1	0.25	367
Teeth with proximal gingival grooves and C-shaped internal anatomy			
$(PGG^{III}, CSC^{I})^{1}MP^{1-2}$	1	0.25	368
$(PGG^{III}, CSC^{II})^{1}MP^{1-3}$	1	0.25	369
$(PGG^{III}, CSC^{II})^{1}MP^{1-3-2}$	2	0.5	371
$(PGG^{III}, CSC^{III})^{1}MP^{1-2-1}$	1	0.25	372
$(PGG^{III}, CSC^{III})^{1}MP^{1-2-4-3}$	1	0.25	373
$(PGG^{III}, CSC^{III})^{1}MP^{1-3}$	2	0.5	375
$(PGG^{III}, CSC^{III})^{1}MP^{1-3-1}$	5	1.55	380
$(PGG^{III}, CSC^{III})^{1}MP^{1-3-2}$	4	1.0	384
$(PGG^{III}, CSC^{III})^{1}MP^{1-3-2-1}$	2	0.5	386
Total	386	100	386

Canal configuration in relation to age and sex

Canal configurations were compared among the sex and age groups defined

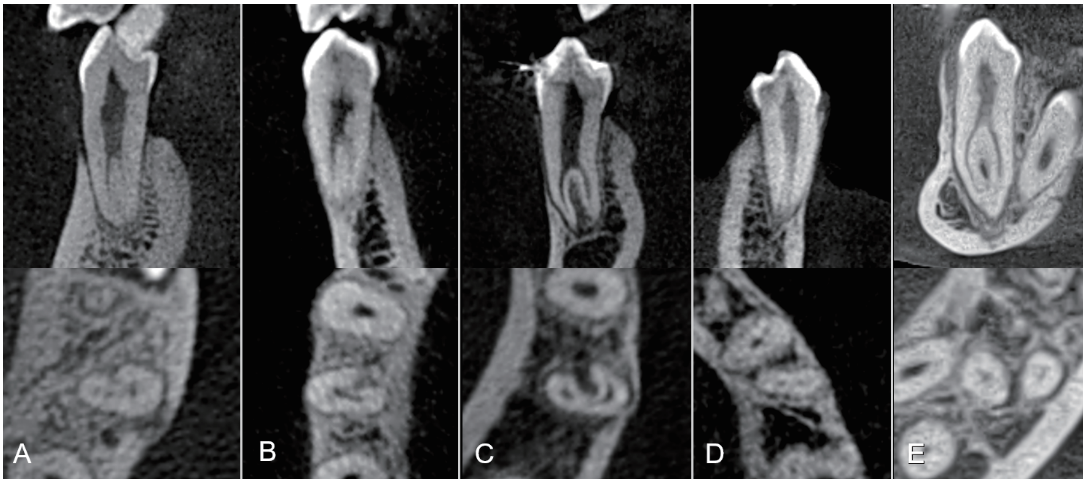

Fig. 5 Examples of five teeth classified as Vertucci Type V configurations, which were assigned a variety of codes when classified using the Ahmed et al. system. The upper panels (displaying coronal CBCT sections) demonstrate the same tooth as the lower panels (axial CBCT sections). Fig. 5A: (PGG^{III})^{1}MP$^{1-2}$, Fig. 5B: (PGG^{III}, CSC^{I})^{1}MP$^{1-2}$, Fig. 5C: (PGG^{III}, CSC^{II})^{1}MP$^{1-2}$, Fig. 5D: ^{1}MP$^{1-2}$, and lastly Fig. 5E: ^{2}MP^{1} B^{1}L^{1}. Description of the root and canal morphology is more accurate using the Ahmed et al. classification, although a larger number of unique categories are created.

Table 4 Vertucci and Ahmed et al. classifications of mandibular first premolars in relation to sex

Sex	Single canals (*n*)	Multiple canals (*n*)
Female	104	82
(z-score)	(0.269)	(0.212)
Male	83	117
(z-score)	(0.215)	(0.303)

Fisher's exact test: $P = 0.005$

Table 5 Radicular grooves (PGG code in Ahmed et al. classification) for mandibular premolars in relation to sex

Sex	Single canals (*n*)	Multiple canals (*n*)
Female	6	180
(z-score)	(0.015)	(0.466)
Male	16	184
(z-score)	(0.041)	(0.476)

Fisher's exact test: $P = 0.049$

in the Materials and Methods section. For mandibular first premolars, no significant relationships were found between age groups and either the Vertucci ($P = 0.585$) or Ahmed et al. ($P = 0.586$) classification. Relationships between sex and the Vertucci ($P = 0.005$) as well as Ahmed et al. ($P = 0.005$) classifications were, however, observed (Table 4), and males were more likely to demonstrate multiple canals in this tooth type in comparison to females ($P = 0.007$).

For mandibular second premolars, no relationships were found between age groups and the Vertucci ($P = 0.054$) or Ahmed et al. ($P = 0.053$) classifications. Furthermore, no relationships between sex and either the Vertucci ($P = 1.000$) or Ahmed et al. ($P = 1.000$) classifications were observed.

A relationship between sex and the presence of radicular grooves (PGG) was observed ($P = 0.049$, Table 5), with males demonstrating this feature more commonly than females ($P = 0.051$). No relationship between sex and C-shaped canal systems (CSC) was found ($P = 0.060$).

Discussion

To ensure good treatment outcomes, endodontic practitioners need to have an excellent knowledge of both common and uncommon mandibular premolar root and canal configurations. Failure to locate, debride and obturate the entire root canal system reduces the likelihood of successful treatment [4].

So far, descriptions of the root and canal morphology of South African populations have been scant [2,4,7,9,18,19]. Only a single worldwide study of lingual canals in mandibular premolars by Martins et al. included any South African data [7]. However, that study included predominantly subjects of Asian and White origin, with only a small number of Black African subjects. As Black Africans constitute nearly 80.0% of the South African population [Statistics South Africa, Census 2011], the findings of Martins et al. [7] are likely not representative of the majority of South Africans. As it appears that no study has yet reported the root and canal morphology in an exclusively Black South African population, the present study is likely the first to have investigated this specific group.

Both the mandibular first and second premolars in the present study demonstrated predominantly single roots, with a small number of two- and three-rooted teeth. This is similar to findings reported for several other populations [3,5,13,20]. The most common canal configuration demonstrated in mandibular first premolars was a single canal (Vertucci Type I or ^{1}MP^{1}). This is in agreement with the findings of a number of other studies of individual populations including; Jordanian [3], Turkish [21], German [22], Portuguese [5], Venezuelan [13], two different Korean [6,23] and Chinese [24] subjects. These findings were also reiterated in a worldwide multicenter study of diverse populations from 23 countries [7].

An interesting finding in the present study was that fewer than half of the mandibular first premolars had single canals (48.5%). This suggests that clinicians could potentially encounter multiple canals in more than half of Black South African patients, and is therefore of clinical significance when considering endodontic treatment in this group. Previous authors have proposed that the larger tooth size of African subjects may be responsible for a higher number of canals when compared to their Asian and European counterparts [25]. The present findings in a population exclusively of African origin may support this possibility. The mandibular premolars of the African cohort investigated by Martins et al. also showed a higher proportion of additional lingual canals, [7] thus further supporting these findings.

The prevalence of single-canal first premolars in the present study (48.5%) was also notably lower than that in the study by Martins et al. (75.0%), which included mainly Indian and White subjects [7]. This is in agreement with Trope et al., who reported a higher frequency of additional canals in mandibular premolars of Black subjects in a North American population [26]. Race and ethnicity [3,7,8,27] along with geographic location [2,7,28] have been reported as factors influencing variation in root canal morphology. This finding highlights the importance of understanding anatomical variations between different population groups, especially in the setting of a country such as South Africa where the population is not necessarily homogeneous.

In agreement with the findings of other studies, mandibular second premolars in the present investigation showed a high prevalence (81.3%) of single-canal configurations [3,6,20]. The worldwide prevalence of lingual canals in mandibular second premolars was reported to be 5.3%, being significantly lower than that for mandibular first premolars [7]. Although the present findings in a Black South African population support this, the prevalence of 18.7% seems notably higher than the worldwide average. As in other investigations, the presence of mandibular premolars with three independent canals (Type VIII) was a rare finding [3,6,20]. A selection of the canal configurations found in the present study can be seen in Fig. 3.

With regard to the relationship between sex and canal configuration, males in the present population had a higher prevalence of multiple canals in mandibular first premolars ($P = 0.007$). This is in partial agreement with Martins et al., who found lingual canals more frequently in both first and second mandibular premolars of males [7]. Although some authors have suggested that this may be due to the larger tooth size in males [25], tooth size was not evaluated in the present study. No relationship between age and canal configuration was observed in the present study. This was in contrast to Martins et al., who found that older subjects (>60 years) had the lowest prevalence of second canals in first premolars [7]. This decrease in the number of canals with age may be a consequence of deposition of secondary and tertiary dentin over time [29]. A further explanation for the discrepancy between the present findings and those of Martins et al. [7] may be methodological differences, as well as the relatively younger present subject sample.

Radicular grooves were found in both mandibular first and second premolars. It has been suggested that such grooves may be caused by incomplete division of a root into two or more roots, creating a depression in the external surface during tooth development [30]. In the present study, radicular grooves were found more frequently in mandibular first premolars (28.2%) than in second premolars (5.7%), with a male predilection. Similarly, a Korean population showed a large difference between first (13.2%) and second (0.5%) premolars and also demonstrated a male predilection for such grooves [6]; such a difference was also reported in a Portuguese population (10.9% first and 1.8% second premolars) [5]. In a Jordanian population, however, the difference between the frequency of radicular grooves in first and second premolars was less pronounced (17.6% and 13.5% respectively) [3].

All radicular grooves in the present study were found in teeth with multiple canals, in line with the findings of a previous study [15]. Mandibular premolars with radicular grooves may be more difficult to treat endodontically, due an increased risk of root perforation and challenges in locating the lingual canal [6]. Such challenges may be alleviated by the use of high magnification and illumination when treating such cases, as well as three-dimensional imaging such as CBCT (Figs. 3-5).

The reported prevalence of a C-shaped morphology has been relatively low in CBCT studies of mandibular premolars in Western European and Asian populations [5,24,31]. No previous CBCT data for African populations appear to be available. The present study found a C-shaped morphology in 11.1% of mandibular first premolars and 4.9% of mandibular second premolars. A study of a Portuguese population found C-shaped canals in 2.3% of first premolars and 0.6% of second premolars. [5] Two studies of Chinese populations found a low prevalence of C-shaped morphology in mandibular premolars; in the first study, the prevalence was 1.1% in mandibular first premolars [24,31], and in the second it was 1.1% of mandibular first premolars and 0.6% of mandibular second premolars [24,31]. However, the prevalence in the present study was significantly lower than that reported in a Venezuelan population (28.9% of first premolars, 7.14% of second premolars) [13].

Whilst studies of extracted teeth have demonstrated that mandibular premolars have a higher prevalence of C-shaped anatomy, these should not be seen as true population prevalences, as teeth with more complex anatomy may have had a greater likelihood of being extracted and included [5]. Such differences in study methodology may explain the variation found in the prevalence of C-shaped anatomy between older studies using extracted teeth and modern studies using CBCT. Martins et al. found a male predilection [5], and Brea et al. a female predilection [13] for C-shaped mandibular premolars. No relationship between sex and C-shaped morphology was observed in the present study.

The present study found radicular grooves, complex internal configurations and multiple canals (Fig. 4) commonly accompanied a C-shaped anatomy. Such a correlation between C-shaped morphology and multiple canals has been reported previously [5,13], supporting the assertion that there is a strong relationship between external root structure and internal canal shape in these teeth [5]. Complex mandibular premolars, such as those with C-shaped morphology, are clinically significant as they have been reported to be more difficult to clean and shape [3,5,13]. Some studies did not classify C-shapes independently and simply referred to such cases as Type I Vertucci configurations [6]. This may explain differences among the overall prevalences reported in different populations [6].

Both the Vertucci and Ahmed et al. classifications were used in the present study [1,10]. The Vertucci classification is well known, and has been widely used for almost four decades [1]. This system is easy to use, but cannot describe root number, complex configurations or dental anomalies [10]. This was also evident in the present study, where a number of complex configurations could not be described (7.1% of all mandibular premolars examined).

The Ahmed et al. system simultaneously provides an accurate description of both internal and external anatomy. Due to the added complexity of the system and its ability to include other classifications, it is capable of describing both anatomical variations and dental anomalies in conjunction with root and canal morphology (e.g., PGG, CSC, Fig. 4) [12,16]. This feature is a major benefit of the newer system, as all tooth types can be accurately described. The Ahmed et al. system has been found to be highly accurate for the description of both simple and complex teeth, and can describe configurations which the Vertucci system cannot [2,10]. The newer system, however, created a larger number of unique categories, many of them applying to only a small number of similar teeth. This limitation was previously alluded to by Tredoux et al. [4], and the sentiment is supported by the findings of the present study. The discrepancy between the classification systems of Vertucci and Ahmed is demonstrated in Fig. 5.

Previous studies comparing the Vertucci and Ahmed et al. classification systems have suggested that the two are largely comparable for description of relatively simple canal configurations [2,8,11]. However, the present study found more variation between the two classifications relative to the findings of previous studies [2,8,11], likely due to the increased number of complex configurations in mandibular premolars.

The simplicity of CBCT compared to other methods (e.g., clearing and staining) is beneficial when a large number of study samples are evaluated [2,6]. CBCT is both accurate and reliable for investigation of dental anatomy [7,32].

The present study had some limitations. One such limitation may be self-reporting of race when creating a hospital file. Another is that the resolution of the CBCT unit employed, with a minimum voxel size of 150 mm, would have limited the amount of detail that could be observed and described. Micro-computed tomography may have yielded a higher resolution and allowed observation of finer details in comparison to CBCT. However, this modality is expensive, time-consuming, and cannot be used on living subjects [33].

In summary, the present study has shown that the mandibular premolars of this Black South African population had primarily single roots with diverse internal canal morphology. Mandibular first premolars demonstrated single canals in less than half the sample (48.5%) and a C-shaped morphology in more than one-tenth (11.1%). This is a departure from classically described anatomy of mandibular premolars. The Ahmed et al. classification system provided a better overall description of root and canal morphology than the Vertucci classification system. Clinicians must be mindful of anatomical variations when performing endodontic treatment on mandibular premolars, as this may impact diagnosis, treatment planning and patient care. The present results support the application of CBCT for large-scale studies of dental anatomy.

Conflict of interest

All authors contributed substantially to this study and agreed on the final text of the manuscript. This research did not receive any specific funding from agencies in the public, commercial, or non- profit sectors. The authors have no conflicts of interest related to this study.

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