Journal of Oral Science, Vol. 64, No. 3, 218-223, 2022

Original article

Root and canal morphology of the permanent anterior dentition in a Black South African population using cone-beam computed tomography and two classification systems

Glynn D. Buchanan[1,2], Mohamed Y. Gamieldien[3], Inger Fabris-Rotelli[4], Albert van Schoor[2], and Andre Uys[2]

[1] Department of Odontology, School of Dentistry, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa
[2] Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa
[3] Department of Maxillofacial and Oral Surgery, School of Dentistry, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa
[4] Department of Statistics, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa

(Received January 27, 2022; Accepted April 13, 2022)

Abstract

Purpose: This study investigated the root and canal morphology of the permanent anterior dentition in a Black South African population.
Methods: In total 2,343 permanent anterior teeth were evaluated using cone-beam computed tomography images and described according to the Vertucci and Ahmed et al. classifications. Demographic information, root number and internal canal morphology were recorded. Age and sex associations were made using Fisher's exact test ($P < 0.05$).
Results: All anterior teeth were single-rooted (100%). The most frequent configuration in maxillary anteriors was a single canal (Vertucci Type I/^{1}MXA^{1}). In mandibular anteriors, single canal configurations (Type I/^{1}MDA^{1}) predominated, however 36.6% of mandibular central and 33.9% of lateral incisors displayed two canals. Older subjects (>40 years) demonstrated single canals more than younger subjects ($P = 0.0004$). Females displayed variations more compared to males ($P = 0.002$). The two classifications were found to be comparable for evaluation of permanent anterior teeth. Complex configurations were better described using the newer system.
Conclusion: The permanent anterior teeth of this population exhibited exclusively single roots and diverse internal characteristics. Clinicians should be aware of anatomical variations, particularly in mandibular incisors, as these may result in adverse endodontic outcomes if not taken into consideration by the treating practitioner.

Keywords: anterior teeth, cone-beam computed tomography, endodontics, root canal morphology, South African population

Introduction

As root canal treatment aims to relieve pain and sepsis through cleaning, shaping, and obturation of the entire root canal system, an intimate knowledge of common presentations as well as variations in canal morphology can be considered an absolute requirement to achieve consistently successful outcomes [1]. Failing to detect and manage all canals in a root canal system has been cited as a major cause of endodontic treatment failure and may lead to tooth loss [2].

Though several systems for the classification of the internal and external features of the roots of teeth exist, Vertucci's classification system, first described in 1984 [3], is the most widely used [4]. Though this system is adequate in the description of most root canals [5], it is of little value when describing teeth with complex anatomy and makes no provision for the number of roots [6].

Ahmed et al. proposed a classification to address the shortcomings of existing root canal classifications systems in 2017 [6]. Their system allows for detailed description of both root number and internal canal configurations using a single code regardless of complexity [6]. A limited number of studies have compared Ahmed et al. to the system proposed by Vertucci [4,5,7].

Root and canal morphology has been extensively studied in modern times with the aid of cone-beam computed tomography (CBCT) [4,5,7,8]. The three-dimensional nature of CBCT has allowed for greater preoperative determination of root canal morphology [9] and is superior to periapical radiography in detecting root canals [10,11]. This modality has been found to be as effective as clearing and staining in the identification of root canal anatomy [11].

Several factors may influence root number and canal configuration. Hereditary and/or ethnic differences between population groups may be one reason for such variation [4]. It has further been suggested that race, genetics, environmental factors, as well as geographic distribution, may influence root canal morphology [5,12].

In South Africa, the Government classifies individuals into different population groups, namely: Black African, Coloured (i.e., Mixed-race), Indian/Asian, White, and Other. The vast majority of the population (79%) are, however, classified as Black African individuals (Statistics South Africa, Census 2011, available from: https://www.statssa.gov.za/publications/P03014/P030142011.pdf - 2022-04-13).

No studies regarding the internal or external dental anatomy of permanent maxillary or mandibular anterior teeth in an exclusively Black South African population, or any Sub-Saharan African population, could be found. The present study aimed to describe and classify the root and canal morphology of the permanent anterior dentition in Black South African individuals using two classification systems based on CBCT imaging.

Materials and Methods

Ethical approval for this descriptive, retrospective cross-sectional study was obtained from the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Protocol number: 331/2021). Cone-beam computed tomography scans from the Section of Diagnostic Imaging, Pretoria Oral and Dental Hospital were retrospectively evaluated using a convenient sampling method from June 2021 until the required minimum sample size was achieved. This resulted in an effective date range of scan evaluation from October 2015 to June 2021.

The evaluation of images was based on the methodology previously described by Buchanan et al., with modifications [5]. The exact methodology follows hereafter.

Source of CBCT scans

Existing scans acquired by a single CBCT unit (Planmeca Promax 3D Max, Planmeca OY, Helsingfors, Finland) were assessed. As such, no new scans were taken for the purposes of this study.

The CBCT unit's resolution ranged from 100 to 600 µm, with 300 to 750 basic frames. The anode current used ranged from 1 to 14 mA and anode voltage ranged from 54 to 90 kV, with a focal spot diameter of 0.6 mm.

Scans present in the database were acquired for varying clinical reasons. These included the diagnosis of maxillofacial trauma and pathology, as well as the planning of periodontal, orthodontic, prosthodontic, endodontic and implant treatment.

Correspondence to Dr. Glynn Buchanan, Department of Odontology, University of Pretoria Oral Health Centre, 31 Bophelo Road, Prinshof Campus, Riviera, Pretoria 0002, South Africa
Fax: +27-12-319-2214 E-mail: glynn.buchanan@up.ac.za

J-STAGE Advance Publication: May 30, 2022
Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.22-0027
DN/JST.JSTAGE/josnusd/22-0027

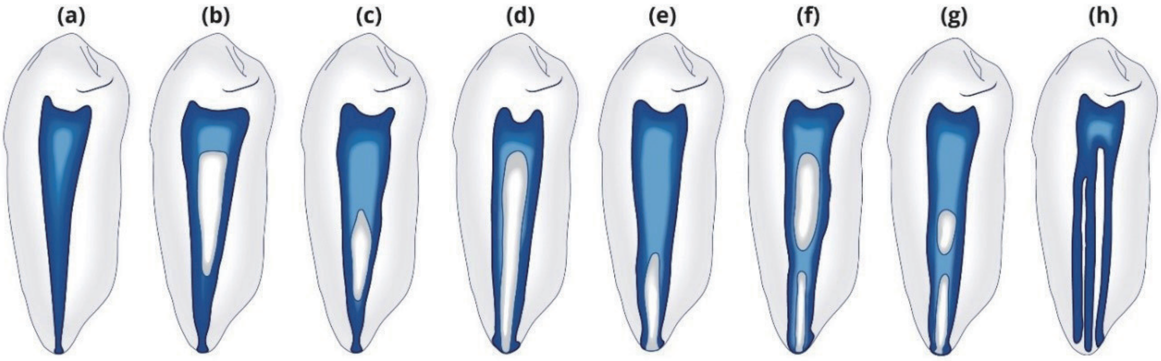

Fig. 1 The original Vertucci classification system with eight configurations. Type I (a) indicates a system consisting of one orifice, one root canal and one apical foramen. Type II (b) demonstrates two orifices with two root canals, exiting as one foramen. Type III (c) displays one orifice with two canals in the mid-root area and one foramen, Type IV (d) includes two orifices, two independent canals with two apical foramina, Type V (e) presents with a single orifice, splitting into two canals and two apical foramina, Type VI (f) has two orifices, two apical foramina but joins with a mid-root communication. Type VII (g) has a similar configuration to Type VI, but begins with a single orifice. Type VIII (h) displays three independent canals.

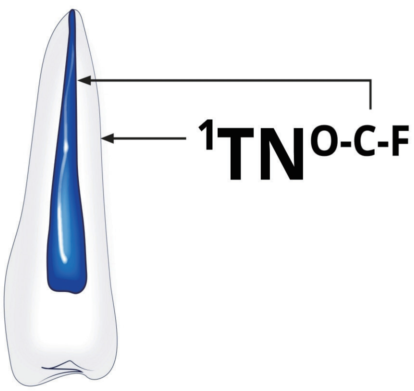

Fig. 2 The Ahmed et al. classification system. Both root number and canal configuration are described. The tooth is assigned a code, indicated as TN in this example. The superscript number preceding the code (TN) indicates the root number. The letters O, C and F follow the tooth number. O = orifice/s, C = canal/s, F = foramina. The letters are replaced with numbers corresponding to the number of orifices, canals and foramina. A single rooted tooth with one orifice, two canals and one foramen is therefore described as $^{1}TN^{1\text{-}2\text{-}1}$.

Analysis of CBCT scans

Coronal, sagittal, and axial images of all maxillary and mandibular permanent anterior teeth were evaluated using Romexis software version 6.0 (Planmeca, Planmeca OY) by an examiner with more than ten years' experience in endodontics and the clinical interpretation of CBCT images. A second examiner with extensive experience in maxillofacial radiology and CBCT interpretation assessed a 10% subset of the sample, in line with methodology described by Fernandes et al. [13].

Calibration of the examiners was achieved by evaluating 50 teeth in a set not included in the study population. This was performed prior to data collection. Following adjustment of contrast, brightness and sharpness filters, each tooth was positioned with the long axis of the root in a vertical plane. The cursor was then moved coronally to apically, mesial to distal, and buccal to lingual to visualise the root/s and root canal system of each tooth in each orthogonal plane. The findings of the examiners were recorded and compared. Where the examiners agreed the classification was accepted. In cases of disagreement, a third examiner was consulted for a final opinion.

Classification of root number and canal configuration

The root number was determined by the methodology attributed to Pecora et al. [14]. Canal configurations were described using the systems developed by both Vertucci in 1984 [3] and Ahmed et al. in 2017 [6].

The Vertucci classification system, with its eight original configurations, is depicted and described in Fig. 1 [3]. The Ahmed et al. classification, using a single descriptive code reporting both root number and canal configuration, is depicted with a brief explanation in Fig. 2 [6]. Using the Ahmed et al. system, samples were assigned with either the code MXA for maxillary anterior teeth or MDA for mandibular anterior teeth. The superscript number preceding the code indicated root number. The superscript numbers following the code indicated the number of orifices (O), canals (C) and foramen (F) present.

All data collected through CBCT evaluation was anonymized. The age and sex of the subjects were recorded to test for associations between these variables and root number/classification. Nosrat et al. suggested the presence of age-related differences in dental morphology [15]. For this reason, the sample was divided into the following age groups: <25 years, 25-40 years, and >40 years, in line with their methodology. Scans from subjects <10 years old were not included.

Inclusion criteria

Scans from the Section of Diagnostic Imaging database containing mature, fully-formed teeth were included. Only scans of acceptable quality to visualise individual roots and canals as well as the entire pulp chamber and apex were included. The voxel size of the scans was 0.2 mm or smaller. Only scans from individuals classified as Black South Africans, as determined by the population classification in the hospital file, were included.

Exclusion criteria

The following factors excluded teeth/scans from this study: immature teeth with open apices, inability to visualise the entire pulp chamber to the apex, previous endodontic treatment, the presence of posts (metal- or fiber-posts), large metal restorations and crowns/bridges/implants obscuring the anatomy, evidence of previous apicectomy or apical/periodontal surgery which altered the original tooth anatomy, extensive resorption fundamentally altering root number or canal configuration, calcification, scatter impeding proper visualisation, scans with voxel sizes exceeding 0.2 mm, tooth types other than permanent maxillary and mandibular anteriors, and scans of subjects not classified as Black South African individuals (according to the hospital file).

Sample size

Evaluation of at least 385 teeth of each tooth type (maxillary central incisors, lateral incisors and canines as well as mandibular central incisors, lateral incisors and canines) were evaluated to determine root and canal morphology. The sample size was calculated using Epi-Info version 7 statistical software (Atlanta, GA, USA). For a cross-sectional study where the prevalence of outcome was unknown, a 50% prevalence was used to maximize the sample size, assuming a 5% margin of error for the 95% confidence interval, yielding a minimum sample size of $n = 384$ per tooth type. Both left- and right-sided samples, as well as male and female subjects were included. A minimum of 193 and maximum of 2,310 CBCT scans were required to complete data collection.

Statistical analysis

Data was captured using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA), and statistical analysis performed using R version 4.1.1 software (R Development Core Team, Vienna, Austria). The Fisher exact test was used to test for categorical variables with a significance set at

Table 1 Root canal configurations according to the Vertucci classification

Tooth type	Root number	I (%)	II (%)	III (%)	IV (%)	V (%)	VI (%)	VII (%)	VIII (%)	Unclassified (%)	Total
Maxillary central incisors	1	387 (100)									387
Maxillary lateral incisors	1	401 (99.5)								2 (0.5)	403
Maxillary canines	1	373 (94.9)	2 (0.5)	12 (3.1)		3 (0.8)	2 (0.5)	1 (0.2)			393
Mandibular central incisors	1	245 (63.4)	9 (2.3)	129 (33.3)		2 (0.5)	1 (0.25)	1 (0.25)			387
Mandibular lateral incisors	1	256 (66.1)	8 (2.1)	115 (29.7)		5 (1.3)		3 (0.8)			387
Mandibular canines	1	362 (93.8)	1 (0.3)	21 (5.4)		2 (0.5)					386

Table 2 Root canal configurations of maxillary teeth according to the Ahmed et al. classification

Tooth type	$^{1}MXA^{1}$ (%)	$^{1}MXA^{1-2}$ (%)	$^{1}MXA^{1-2-1}$ (%)	$^{1}MXA^{1-2-1-2}$ (%)	$^{1}MXA^{2-1}$ (%)	$^{1}MXA^{2-1-2}$ (%)	$(2DI^{III})^{1}MXA^{2}$ (%)	$(DI^{II})^{1}MXA^{1}$ (%)	Total
Maxillary central incisors	387 (100)								387
Maxillary lateral incisors	401 (99.5)						1 (0.25)	1 (0.25)	403
Maxillary canines	373 (94.9)	3 (0.8)	12 (3.1)	1 (0.2)	2 (0.5)	2 (0.5)			393

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

Tooth type	$^{1}MDA^{1}$ (%)	$^{1}MDA^{1-2}$ (%)	$^{1}MDA^{1-2-1}$ (%)	$^{1}MDA^{1-2-1-2}$ (%)	$^{1}MDA^{2-1-2}$ (%)	$^{1}MDA^{2-1}$ (%)	$^{1BR}MDA^{1-2}$ (%)	Total
Mandibular central incisors	245 (63.3)	2 (0.5)	129 (33.3)	1 (0.25)	1 (0.25)	9 (2.4)		387
Mandibular lateral incisors	256 (66.1)	5 (1.3)	115 (29.7)	3 (0.8)		8 (2.1)		387
Mandibular canines	362 (93.8)	1 (0.25)	21 (5.45)			1 (0.25)	1 (0.25)	386

$P < 0.05$. Inter- and intra-examiner agreement was determined as percentages of agreement. The significance level was set at $P < 0.05$.

Results

Description of the sample

A total of 2,343 permanent anterior teeth were evaluated from 334 subjects. The age of the subjects ranged from 10 to 88 years (mean age: 33.6 years). Maxillary teeth accounted for approximately half the sample (n = 1,183/2,343, 50.5%), whilst the remainder were mandibular teeth (n = 1,160/2,343, 49.5%). The distribution of left- (n = 1,190/2,343, 50.8%) and right-sided (n = 1,153/2,343, 49.2%) samples was approximately even. The sex distribution included slightly more teeth from female subjects (n = 1,235/2,343, 52.7%) than male subjects (n = 1,108/2,343, 47.3%). All teeth evaluated met the inclusion criteria and no samples were excluded. Inter- and intra-rater reliability was calculated using percentage agreement and found to be very high (99.5% and 98.3% respectively).

Root number

All permanent maxillary and mandibular anterior teeth were single rooted, i.e., no samples demonstrated multiple roots. One bifid root was demonstrated in a single mandibular canine (n = 1/2, 343, 0.04%).

Canal configurations according to the Vertucci classification

The distribution of the canal configurations of the permanent anterior teeth according to the Vertucci classification is summarized in Table 1. All maxillary central incisors had Type I configuration (n = 387/387, 100%). Maxillary lateral incisors also displayed an almost exclusively Type I configuration (n = 401/403, 99.5%). The two remaining maxillary lateral incisors were examples of dens invaginatus and were not classifiable according to the Vertucci system. Maxillary canines demonstrated predominantly Type I configurations (n = 373/393, 94.9%) with a smaller number of Type III (n = 12/393, 3.1%) and Type V (n = 3/393, 0.8%) canal systems observed. Type II, VI and VII configurations were found in a small number of maxillary canines (Table 1).

The most common configuration found in mandibular central incisors was Type I (n = 245/387, 63.3%), followed by Type III (n = 129/387, 33.3%) and Type II (n = 9/387, 2.3%). Mandibular lateral incisors followed a similar distribution to the central incisors, with the most common configuration reported as Type I (n = 256/387, 66.1%), followed by Type III (n = 115/387, 29.7%) and Type II (n = 8/387, 2.1%). The majority of mandibular canines displayed Type I configurations (n = 362/386, 93.8%), although a minority displayed a Type III configuration (n = 21/386, 5.45%). Type II and Type V configurations were observed in a small number of mandibular canines (Table 1).

Canal configurations according to the Ahmed et al. classification

The distribution of canal configurations of the permanent anterior teeth according to the Ahmed et al. classification is summarized in Tables 2 and 3. Maxillary central incisors demonstrated the $^{1}MXA^{1}$ configuration 100% of the time (n = 387/387). Similarly, maxillary lateral incisors were also most commonly classified as $^{1}MXA^{1}$ (n = 401/403, 99.5%), however using the Ahmed et al. system the two dens invaginatus samples could be classified as $(2DI^{III})^{1}MXA^{2}$ and $(DI^{II})^{1}MXA^{1}$ respectively. Maxillary canines most frequently demonstrated the $^{1}MXA^{1}$ configuration (n = 373/393, 94.9%). The remaining maxillary canines were classified as $^{1}MXA^{1-2-1}$ (n = 12/393, 3.1%), $^{1}MXA^{1-2}$ (n = 3/393, 0.8%), $^{1}MXA^{2-1}$ (n = 2/393, 0.5%), $^{1}MXA^{2-1-2}$ (n = 2/393, 0.5%) and $^{1}MXA^{1-2-1-2}$ (n = 1/393, 0.2%) configurations (Table 2).

The most common configuration found in mandibular central incisors was $^{1}MDA^{1}$ (n = 245/387, 63.3%), followed by $^{1}MDA^{1-2-1}$ (n = 129/387, 33.3%) and $^{1}MDA^{2-1}$ (n = 9/387, 2.4%). Mandibular lateral incisors followed a similar distribution to the central incisors, with the most common configuration reported as $^{1}MDA^{1}$ (n = 256/387, 66.1%), followed by $^{1}MDA^{1-2-1}$ (n = 115/387, 29.7%) and $^{1}MDA^{2-1}$ (n = 8/387, 2.1%). Mandibular canines were predominantly single-rooted with a single canal, coded as $^{1}MDA^{1}$ (n = 362/386, 93.8%), although a minority displayed a $^{1}MDA^{1-2-1}$

Table 4 Age group versus Vertucci classification

Age group	Unclassified	Type I	Type II	Type III	Type V	Type VI	Type VII
1 (<25 years) (z-score)	0 (0.000)	674 (0.287)	6 (0.002)	95 (0.040)	2 (0.000)	0 (0.000)	2 (0.000)
2 (25-40 years) (z-score)	1 (0.000)	790 (0.337)	8 (0.003)	92 (0.039)	5 (0.002)	0 (0.000)	0 (0.000)
3 (>40 years) (z-score)	1 (0.000)	560 (0.239)	6 (0.002)	90 (0.038)	5 (0.002)	3 (0.001)	3 (0.001)

Fisher's exact test: *P*-value = 0.1004

Table 5 Age group versus Ahmed classification

Ahmed configuration	1 (<25 years) (z-score)	2 (25-40 years) (z-score)	3 (>40 years) (z-score)
$(^{2}D^{IIII})^{1}MXA^{2}$	0 (0.000)	1 (0.000)	0 (0.000)
$(D^{II})1MXA^{1}$	0 (0.000)	0 (0.000)	1 (0.000)
$^{1BR}MDA^{1-2}$	0 (0.000)	0 (0.000)	1 (0.000)
$^{1}MDA^{1}$	264 (0.112)	319 (0.136)	280 (0.119)
$^{1}MDA^{1-2}$	2 (0.000)	3 (0.001)	3 (0.001)
$^{1}MDA^{1-2-1}$	93 (0.039)	88 (0.037)	84 (0.035)
$^{1}MDA^{1-2-1-2}$	2 (0.000)	0 (0.000)	2 (0.000)
$^{1}MDA^{2-1}$	6 (0.002)	6 (0.002)	6 (0.002)
$^{1}MDA^{2-1-2}$	0 (0.000)	0 (0.000)	1 (0.000)
$^{1}MXA^{1}$	410 (0.174)	471 (0.201)	280 (0.119)
$^{1}MXA^{1-2}$	0 (0.000)	2 (0.000)	1 (0.000)
$^{1}MXA^{1-2-1}$	2 (0.000)	4 (0.001)	6 (0.002)
$^{1}MXA^{1-2-1-2}$	0 (0.000)	0 (0.000)	1 (0.000)
$^{1}MXA^{2-1}$	0 (0.000)	2 (0.000)	0 (0.000)
$^{1}MXA^{2-1-2}$	0 (0.000)	0 (0.000)	2 (0.000)

Fisher's exact test: *P*-value = 0.0029

configuration ($n = 21/386$, 5.45%). Rarely, $^{1}MDA^{1-2}$, $^{1}MDA^{1-2-1-2}$, $^{1}MDA^{2-1-2}$ and $^{1BR}MDA^{1-2}$ configurations were observed (Table 3).

Effect of age and sex on canal configuration

Canal configurations were compared to the age groups as defined in the Materials and Methods (Tables 4, 5). Using Fisher's exact test, no relationship was found between age versus the Vertucci classification ($P = 0.1004$). A relationship between age and Ahmed et al. classification ($P = 0.0029$) was however observed. Subjects older than 40 years demonstrated a tendency to display single root and canal anatomy more often than younger subjects ($P = 0.0004$).

A relationship between sex and the Vertucci ($P = 0.019$) as well as the Ahmed et al. classification ($P = 0.032$) was furthermore demonstrated (Tables 6, 7). Female subjects displayed Vertucci Type III configurations more often than male subjects ($P = 0.001$) and females were also more likely to have two canals given the classification using the Ahmed et al. system ($P = 0.002$).

Discussion

Knowledge of common root canal morphology is a requirement for clinicians to perform successful endodontic treatment. Dental professionals should, however, maintain a high index of caution when evaluating root canal systems to ensure detection of less common root canal configurations, as failure to locate and treat all canals may adversely influence endodontic treatment success [2].

Limited data exists on root and canal morphology in South African populations [1,5]. No data regarding the anatomy of permanent anterior teeth in a Black South African population could be found in the existing literature. Additionally, no data regarding the anterior dentition from Sub-Saharan African populations could be found in a recent review of CBCT studies of these teeth [12]. Therefore, this study is likely the first to report the anatomy of these tooth types from an exclusively Black South African population group as well as from the Sub-Saharan African geographic region.

Maxillary and mandibular anterior teeth evaluated in this Black South African population were exclusively single-rooted. Whilst maxillary anterior teeth generally display single root and canal systems, they tend to demonstrate a greater number of dental anomalies such as dens invaginatus and palato-gingival grooves when compared to their mandibular counterparts [16]. Rare instances of two-rooted maxillary anterior teeth have been reported [16], although none were found in the present study. Mandibular anteriors more frequently demonstrate additional roots when compared to maxillary anterior teeth. These additional roots are usually in the form of two-rooted canines [4,17].

The present study did not observe any frank multi-rooted mandibular anteriors, although one mandibular canine was described as bifid-rooted in the apical area and described using the code $^{1BR}MDA^{1-2}$ using the Ahmed et al. system (Fig. 3). The Ahmed et al. classification makes provision for the description of dental anomalies, such as bifid roots, which is an advantage of this system over Vertucci's classification [18]. In this instance, a modifier to the descriptive code, written using the letters "BR" in superscript following root number, was used to indicate this anomaly [18].

In the present study all maxillary central incisors demonstrated a single canal (100% $^{1}MXA^{1}$ or Vertucci Type I). This finding is in agreement with previous studies from American, Turkish and Indian population groups [3,19,20]. Almost all maxillary lateral incisors (99.5%) displayed a single canal, which was similar to investigations from Brazilian, Turkish and Malaysian populations [4,8,21]. Two maxillary lateral incisors presented with the dental anomaly dens invaginatus and were considered unclassifiable using the Vertucci system. As the system of Ahmed et al. can be used to describe dental anomalies [18], these teeth were assigned the codes $(2DI^{III})^{1}MXA^{2}$ (Fig. 4) and $(DI^{II})^{1}MXA^{1}$. In these cases, the prefixed letters "DI" indicated the dental anomaly—dens invaginatus—followed by superscript Roman numerals indicating the type of dens invaginatus as described by Oehlers in 1957 [22].

Maxillary canines were also predominantly single canal teeth (94%) in the present study, however several samples demonstrated internal variations with Vertucci Type II, III, V, VI and VII canals represented. This finding is comparable to two previous studies of different Turkish populations [19,21].

The prevalence of internal variation regarding canal morphology is higher in mandibular anterior teeth when compared to their maxillary counterparts [16]. The most common code reported for mandibular central incisors in the present study was $^{1}MDA^{1}$/Vertucci Type I (63%), followed by $^{1}MDA^{1-2-1}$/Vertucci Type III (33%). This finding was similar to that of Brazilian, Portuguese, Israeli, and Malaysian population groups [4,8,23,24].

In the present study, mandibular lateral incisors displayed similar configurations to that of the central incisors, with single canal Vertucci Type I/$^{1}MDA^{1}$ being the dominant canal type (66%), followed by Vertucci Type III/$^{1}MDA^{1-2-1}$ (29%). This finding is similar to those of Portuguese (70% Type I, 23% Type III) [23] and Israeli (62% Type I, 39% Type III) populations [23,24], but lower than that of the Malaysian population (51% Type III, 45% Type I), where Type III configurations were found to be more prevalent than Type I [4]. A Chinese subpopulation demonstrated a lower

Table 6 Sex versus Vertucci classification

Sex	Unclassified	Type I	Type II	Type III	Type V	Type VI	Type VII
Female	1	1092	10	121	8	2	1
(z-score)	(0.000)	(0.466)	(0.004)	(0.051)	(0.003)	(0.000)	(0.000)
Male	1	932	10	156	4	1	4
(z-score)	(0.000)	(0.397)	(0.004)	(0.066)	(0.001)	(0.000)	(0.001)

Fisher's exact test: *P*-value = 0.019

Table 7 Sex versus Ahmed classification

Ahmed configuration	Female (z-score)	Male (z-score)
$(^{2}D^{IIII})^{1}MXA^{2}$	0 (0.000)	1 (0.000)
$(D^{II})^{1}MXA^{1}$	1 (0.000)	0 (0.000)
$^{1BR}MDA^{1\text{-}2}$	0 (0.000)	1 (0.000)
$^{1}MDA^{1}$	455 (0.194)	408 (0.174)
$^{1}MDA^{1\text{-}2}$	5 (0.002)	3 (0.001)
$^{1}MDA^{1\text{-}2\text{-}1}$	114 (0.048)	151 (0.064)
$^{1}MDA^{1\text{-}2\text{-}1\text{-}2}$	1 (0.000)	3 (0.001)
$^{1}MDA^{2\text{-}1}$	9 (0.003)	9 (0.003)
$^{1}MDA^{2\text{-}1\text{-}2}$	1 (0.000)	0 (0.000)
$^{1}MXA^{1}$	637 (0.271)	524 (0.223)
$^{1}MXA^{1\text{-}2}$	3 (0.001)	0 (0.000)
$^{1}MXA^{1\text{-}2\text{-}1}$	7 (0.002)	5 (0.002)
$^{1}MXA^{1\text{-}2\text{-}1\text{-}2}$	0 (0.000)	1 (0.000)
$^{1}MXA^{2\text{-}1}$	1 (0.000)	1 (0.000)
$^{1}MXA^{2\text{-}1\text{-}2}$	1 (0.000)	1 (0.000)

Fisher's exact test: *P*-value = 0.032

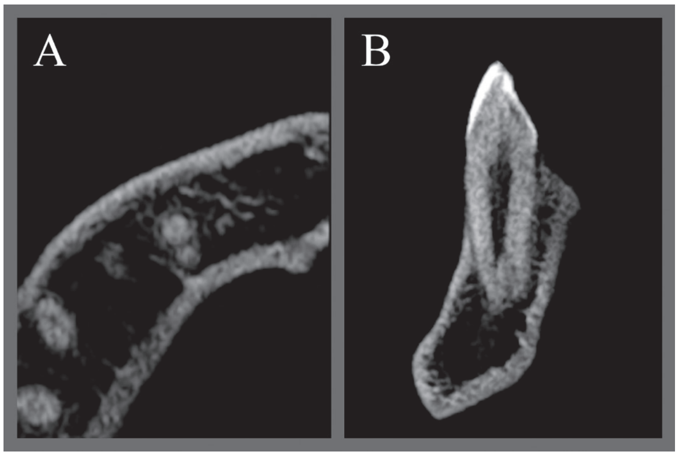

Fig. 3 An uncommon bifid-rooted mandibular canine described as $^{1BR}MDA^{1\text{-}2}$ using the Ahmed et al. system

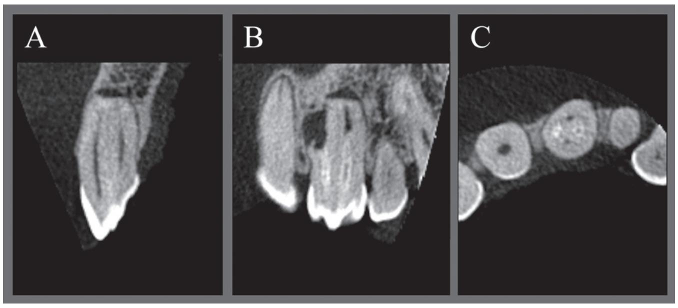

Fig. 4 A maxillary lateral incisor presenting with a double dens invaginatus, assigned the code $(2DI^{III})^{1}MXA^{2}$ using the Ahmed et al. classification system. The code indicates the presence of two invaginations, both Oehlers type III in a single-rooted tooth, as well as two root canals. An advantage of the Ahmed et al. classification is the ability to describe complex dental anomalies in addition to root number and canal morphology using a single descriptive code.

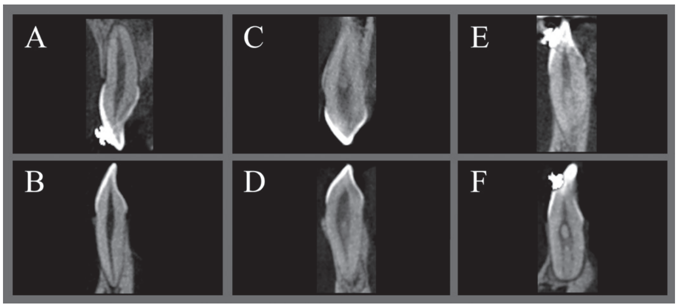

Fig. 5 A selection of sagittal CBCT images demonstrating some of the configurations found in the present study of permanent anterior teeth using the Vertucci and Ahmed et al. systems. A: Vertucci Type I or $^{1}MXA^{1}$, B: Vertucci Type I or $^{1}MDA^{1}$; C: Vertucci Type III or $^{1}MXA^{1\text{-}2\text{-}1}$; D: Vertucci Type III or $^{1}MDA^{1\text{-}2\text{-}1}$; E: Vertucci Type V or $^{1}MDA^{1\text{-}2}$ and F: Vertucci Type VII or $^{1}MDA^{1\text{-}2\text{-}1\text{-}2}$.

prevalence of second canals in mandibular central and lateral incisors [17].

Mandibular canines predominantly demonstrated single canal configurations, Vertucci Type I/ $^{1}MDA^{1}$ (94%), followed by Vertucci Type III/$^{1}MDA^{1\text{-}2\text{-}1}$ (5%). This finding was in line with those of Israeli, Portuguese, Brazilian, and Malaysian populations [4,8,23,24]. A selection of configurations observed in the present study using the Vertucci and Ahmed et al. systems is presented in Fig. 5.

Analysis of the association between age and root canal anatomy revealed a tendency for older subjects (>40 old) to display more simple internal anatomy (single root and canal systems) as compared to younger subjects (P = 0.0004). This is in line with the findings from Turkish [25] and Malaysian populations [4], which showed increased variation in younger subjects. A possible explanation for this phenomenon may be the deposition of secondary and tertiary dentin at specific sites of the root canal system with increasing age, causing the internal structure to change from a complex to simpler configuration [26]. Future studies regarding this topic may be beneficial.

Comparison of canal configuration with sex revealed females to demonstrate two canals more often than males (P = 0.002), with the majority of variation occurring in mandibular incisors. This is in agreement with the findings of an Indian population [27] and in disagreement with those of Malaysian [4] and Turkish populations [20,21], amongst others [12]. Differences between population groups regarding sex and canal configuration may be explained by varying methodology and/or differences in population genetics [4].

Variation in root canal morphology has been attributed to both race and ethnicity [4,19]. Geographic distribution may also influence variation of canal morphology seen in different population groups [5,28]. Future studies of other Southern African and Sub-Saharan populations are needed to document the prevailing dental anatomy from this geographic region, which is still largely unreported and has not been well compared to other population groups.

The original Vertucci classification system, with its eight configurations, was used in the present study in order to compare the findings to previously studied population groups [3]. The classification system proposed by Ahmed et al. in 2017 was additionally used, as it has been shown to be accurate when describing teeth with complex anatomy and those not readily classifiable using the Vertucci classification system [5,6]. The benefit of the newer system is the ability to describe both root and canal morphology using a single code, therefore providing an accurate presentation of the morphology found [6,29]. The Vertucci classification, whilst easy to use and understand, is limited as it makes no provision to describe root number and cannot describe complex anatomy or dental anomalies [6]. However, in the present study, only a small number of anterior teeth could not be readily classified using the Vertucci classification. This finding is in line with a previous investigation which evaluated maxillary premolars [5].

A small number of studies have directly compared the Vertucci classification system to the Ahmed et al. system [4,5,7]. This study therefore contributes to the limited information currently available for comparison between the older and newer systems. The findings of the present study suggest that the two classification systems are comparable for the classification of permanent anterior teeth. Additional studies involving more complex tooth types (i.e. maxillary and mandibular molars) are needed to further compare the two classification systems.

The use of CBCT in endodontics and anatomical studies has been well-established. CBCT was selected as the preferred methodology in the present study due to the large sample size evaluated [4,8]. Alternative methods for the evaluation of root and canal morphology, such as the clearing and staining technique, would have been prohibitively time and labor-intensive [11]. CBCT has been shown to be an accurate, reliable method of determining root and canal morphology and has been used in many previous investigations [1,4,5,7,12]. CBCT has been demonstrated to be as reliable as troughing using magnification [30], clearing and staining [11] and superior to periapical radiography [11] for detecting dental anatomy.

One limitation of the present study was that the race of the subjects was self-reported (as per the Government issue hospital file). The population of South Africa is not homogenous with regards to race and ethnicity, however according to the latest available National Census data, the vast majority of the population are self-classified Black African individuals (Statistics South Africa, Census 2011, available from: https://www.statssa.gov.za/publications/P03014/P030142011.pdf - 2022-04-13).

In conclusion, the permanent anterior dentition of this Black South African population exhibited exclusively single-rooted teeth and a diversity of canal configurations. The findings regarding internal and external morphology largely corresponded to previously reported ranges found in other population groups. Anatomical variations, especially in mandibular anterior teeth, were however not uncommon and clinicians must have a high index of suspicion for the presence of additional anatomy/canals and aberrations when performing endodontic treatment. Older subjects tended to display a single canal system more frequently than younger subjects and females were more likely to demonstrate canal variations than males. This study confirmed that both the Vertucci and Ahmed et al. classification systems are adequate and comparable for the description of dental anatomy in permanent anterior teeth. CBCT is additionally an excellent imaging modality for the evaluation of dental anatomy in a large study sample.

Conflict of interest

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

References

1. Tredoux S, Warren N, Buchanan G (2021) Root and canal configurations of mandibular first molars in a South African subpopulation. J Oral Sci 63, 252-256.
2. Tabassum S, Khan F (2016) Failure of endodontic treatment: the usual suspects. Eur J Dent 10, 144-147.
3. Vertucci F (1984) Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 58, 589-599.
4. Karobari M, Noorani T, Halim M, Ahmed H (2020) Root and canal morphology of the anterior permanent dentition in Malaysian population using two classification systems: a CBCT clinical study. Aust Endod J 47, 202-216.
5. Buchanan GD, Gamieldien M, Tredoux S, Vally Z (2020) Root and canal configurations of maxillary premolars in a South African subpopulation using cone beam computed tomography and two classification systems. J Oral Sci 62, 93-97.
6. Ahmed H, Versiani M, De-Deus G, Dummer P (2017) A new system for classifying root and root canal morphology. Int Endod J 50, 761-770.
7. Saber S, Ahmed M, Obeid M, Ahmed H (2018) Root and canal morphology of maxillary premolar teeth in an Egyptian subpopulation using two classification systems: a cone beam computed tomography study. Int Endod J 52, 267-278.
8. Da Silva E, De Castro R, Nejaim Y, Da Silva A, Haiter-Neto F, Silberman A et al. (2016) Evaluation of root canal configuration of maxillary and mandibular anterior teeth using cone beam computed tomography : an in-vivo study. Quintessence Int 47, 19-25.
9. Patel S, Dawood A, Whaites E, Pitt Ford T (2009) New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. Int Endod J 42, 447-462.
10. Matherne R, Angelopoulos C, Kulild J, Tira D (2008) Use of cone-beam computed tomography to identify root canal systems in vitro. J Endod 34, 87-89.
11. Neelakantan P, Subbarao C, Subbarao C (2010) Comparative evaluation of modified canal staining and clearing technique, cone-beam computed tomography, peripheral quantitative computed tomography, spiral computed tomography, and plain and contrast medium-enhanced digital radiography in studying root canal morhology. J Endod 36, 1547-1551.
12. Martins J, Marques D, João E, Leal N, Caramês J, Mata A et al. (2020) Influence of demographic factors on the prevalence of a second root canal in mandibular anterior teeth – a systematic review and meta-analysis of cross-sectional studies using cone beam computed tomography. Arch Oral Biol 116, 104749.
13. Fernandes N, Herbst D, Postma T, Bunn B (2019) The prevalence of second canals in the mesiobuccal root of maxillary molars: a cone beam computed tomography study. Aust Endod J 45, 46-50.
14. Pecora J, Saquy P, Sousa Neto M, Woelfel J (1991) Root form and canal anatomy of maxillary first premolars. Braz Dent J 2, 87-94.
15. Nosrat A, Deschenes R, Tordik P, Hicks M, Fouad A (2015) Middle mesial canals in mandibular molars: incidence and related factors. J Endod 41, 28-32.
16. Ahmed H, Hashem A (2016) Accessory roots and root canals in human anterior teeth : a review and clinical considerations. Int Endod J 49, 724-736.
17. Han T, Ma Y, Yang L, Chen X, Zhang X, Wang Y (2014) A study of the root canal morphology of mandibular anterior teeth using cone-beam computed tomography in a Chinese subpopulation. J Endod 40, 1309-1314.
18. Ahmed H, Ibrahim N, Mohamad N, Nambiar P, Muhammad R, Yusoff M et al. (2021) Application of a new system for classifying root and canal anatomy in studies involving micro-computed tomography and cone beam computed tomography: explanation and elaboration. Int Endod J 54, 1056-1082.
19. Calişkan MK, Pehlivan Y, Sepetçioğlu F, Türkün M, Tuncer SS (1995) Root canal morphology of human permanent teeth in a Turkish population. J Endod 21, 200-204.
20. Sert S, Bayirli G (2004) Evaluation of the root canal configurations of the mandibular and maxillary permanent teeth by gender in the Turkish population. J Endod 30, 391-398.
21. Altunsoy M, Ok E, Nur B, Aglarci O, Gungor E, Colak M (2014) A cone-beam computed tomography study of the root canal morphology of anterior teeth in a Turkish population. Eur J Dent 8, 302-306.
22. Oehlers FA (1957) Dens invaginatus (dilated composite odontome). I. Variations of the invagination process and associated anterior crown forms. Oral Surg Oral Med Oral Pathol 10, 1204-1218.
23. Martins J, Gu Y, Marques D, Franciso H, Carames J (2018) Differences on the root and root canal morphologies between Asian and white ethnic groups analyzed by cone-beam computed tomography. J Endod 44, 1096-1104.
24. Shemesh A, Kavalerchik E, Levin A, Itzhak J, Levinson O, Lvovsky A et al. (2018) Root anal morphology evaluation of central and lateral mandibular incisors using cone-beam computed tomography in an Israeli population. J Endod 44, 51-55.
25. Kayaoglu G, Peker I, Gumusok M, Kayadugun A, Ucok O (2015) Root and canal symmetry in the mandibular anterior teeth of patients attending a dental clinic: CBCT study. Braz Oral Res 29, 1-7.
26. Tsurumachi T, Huang T, Zhang W, Hayashi M, Ogiso B (2008) Scanning electron microscopic study of dentinal pulpal walls in relation to age and tooth area. J Oral Sci 50, 199-203.
27. Verma G, Bhadage C, Bhoosreddy A, Vedpathak P, Mehrotra G, Nerkar A et al. (2017) Cone beam computed tomography study of root canal morphology of permanent mandibular incisors in Indian subpopulation. Polish J Radiol 82, 371-375.
28. Martins J, Marques D, Silva E, Carames J, Mata A, Versiani M (2019) Prevalence of C-shaped canal morphology using cone beam computed tomography – a systematic review with meta-analysis. Int Endod J 52, 1556-1572.
29. Ahmed H, Dummer P (2018) Advantages and applications of a new system for classifying roots and canal systems in research and clinical practice. Eur Endod J 3, 9-17.
30. Chavda S, Garg S (2016) Advanced methods for identification of middle mesial canal in mandibular molars: an in vitro study. Endodontology 28, 92-96.