

Article

Morphology and Morphometrics of the Mandibular Canal in a Black South African Population

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Abstract

Background/Objectives: Damage to the contents of the mandibular canal is of great concern during endodontological procedures, particularly in the region of the mandibular molar teeth due to their proximity to the mandibular canal. The objectives of this study were to assess variations in the morphology and dimensions of the mandibular canal between the sexes in a Black South African population. **Materials and Methods:** CBCT scans of 30 mandibles were analysed bilaterally to determine the presence of an anterior loop and/or bifid canals in the sagittal view. The distance between the root apices of the first and second mandibular molars and the mandibular canal were determined using the coronal CBCT view. The distance between the mandibular canal and the buccal and lingual cortical plates were also measured. **Results:** Anterior loops were identified in 11.67% of cases, while bifid mandibular canals were present in 5% of cases. The mean distance between the mandibular canal ranged between 5.45 and 6.71 mm for the first molar mesial and distal roots and between 2.37 and 3.62 mm for the second molar roots. The mean distance between the mandibular canal and the lingual cortical plate ranged between 1.75 and 2.84 mm for first molars and 1.40–1.91 mm for second molars. The buccal cortical plate distances ranged from 3.14 to 4.97 mm and 5.21–5.75 mm for the first and second molars, respectively. No statistically significant sex differences were demonstrated for the morphometric measurements. **Conclusions:** The observed mandibular canal variations between populations and sexes highlight the need for patient-specific planning prior to oral dental procedures. Imaging modalities, such as CBCT scans, are essential for accurate measurements between landmarks and the identification of anatomical variations. These findings provide preliminary insights into mandibular canal anatomy in a Black South African sample that should be considered in dental procedures. No significant sex differences were observed; however, these findings should be interpreted with caution given the study's limited statistical power. These findings cannot yet be generalised or extrapolated to the Black South African population.



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1. Introduction

The mandibular canal (MC), or inferior alveolar canal, is a bilateral structure that runs obliquely through the ramus of the mandible from the mandibular foramen through the mandibular body and terminates as the mental foramen (MF) anteriorly. Posteriorly, the MC runs closer to the lingual cortical plate and progressively moves closer to the buccal

cortical plate anteriorly [1]. The MC contains the inferior alveolar nerve (IAN), artery, vein, and lymphatic vessels that provide essential supply and drainage for the mandibular teeth and gingiva. The IAN gives sensory innervation to the mandibular molar and premolar teeth before giving off the incisive and mental nerves [2].

Damage to the IAN is of concern during dental procedures in the region of the mandibular molar teeth due to their proximity to the MC. The root apices of the second mandibular molar teeth are in direct contact with the MC, thus increasing the risk of iatrogenic IAN damage [3]. Root canal treatment has been reported to cause injury to the IAN, leading to complications such as paresthesia, pain and loss of sensation to the ipsilateral mandibular teeth, gingivae, lower lip and chin region. The filling of a root canal may result in perforation of the MC due to its close proximity to the root apices and overfilling of endodontic sealer into the canal [4,5]. Penetration of the MC may cause damage to the inferior alveolar artery and vein, resulting in severe haemorrhaging which may be difficult to control due to the location [6].

Anatomical variations in the MC such as the presence of bifid canals and the formation of an anterior loop may increase the risk of iatrogenic complications. The presence of an anterior loop may result in an inaccurate identification of the MF, which could lead to injury to the mental nerve [7,8]. Failure of mental nerve blocks during anaesthesia administration may occur, resulting in the experience of pain. Identification of bifid canals are imperative in third molar extractions to avoid damage to the inferior alveolar neurovascular structures. The prevalence of these variations differs among different population groups, highlighting the importance of doing extensive research on the anatomy of the MC within specific population groups [9].

A careful evaluation of the morphology and morphometry of the MC relative to surrounding structures is imperative to avoid damage to the neurovascular bundle. Cone beam computed tomography (CBCT) scanning makes it possible to create three-dimensional images of the mandible, thus evaluating the course of the MC [10]. Accurate visualisation of the MC and related structures is important to ensure appropriate dental procedures. Identification of morphological variations is required in the administration of anaesthesia, ensuring that no pain is experienced during dental procedures [11]. It is important to identify population-specific variations as well as differences in the anatomy of the MC between males and females to ensure successful dental procedures. Limited CBCT studies describing the anatomical relationships of the mandibular canal in Black South Africans are available. Despite evidence that craniofacial anatomy varies between population groups, clinicians rely on data generated from other populations that may not be directly applicable to the South African population. Additionally, the size and position of the mandibular canal in the sexes may differ. Sexual dimorphism in the mandible of South Africans has been found [12], and the course and relationships of the mandibular canal may differ between the sexes.

This highlights a need to assess variations in the morphology and dimensions of the MC between the sexes in a Black South African population. Therefore, the aim of this study is to evaluate the morphology and morphometry of the mandibular canal in a Black South African population.

2. Materials and Methods

All data for this quantitative cross-sectional study were collected at the Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria. Retrospectively collected CBCT scans from Black male and female South Africans taken for clinical purposes were evaluated. Scans of 30 dentate mandibles consisting of 15 male and 15 female mandibles were assessed bilaterally, resulting in a sample size of 60 hemi-

mandibles. Ethical approval was granted by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (protocol number: 200/2025).

2.1. Inclusion Criteria

CBCT scans of patients over the age of 18 years were included. The left and right first and second mandibular molar teeth had to be present. Only individuals self-classified as Black South Africans in the existing hospital records were included.

2.2. Exclusion Criteria

Mandibles with evidence of prior dental surgeries, trauma, fractures, pathologies and congenital anomalies were excluded. CBCT scans of mandibles with artefacts, such as movement and those of poor resolution, and mandibles with absent first and second mandibular molar teeth were excluded.

2.3. Methods

Retrospective CBCT scans were acquired using a CBCT machine (Planmeca, Helsinki, Finland) with an isotropic voxel size ranging from 0.20 to 0.40 mm, a field of view (FOV) of 20×15 cm, and operating parameters of 90–110 kV, 8.0–9.0 mA, and a 12–14 s acquisition time. Image reconstruction was performed using the standard algorithm provided by the manufacturer. The mandibular canal (MC), as well as the first and second mandibular molars, were evaluated in the axial, sagittal, and coronal views using Romexis imaging software (version 6.4.5; Planmeca OY, Helsinki, Finland). The sagittal view was analysed to determine the prevalence of bifid canals and/or anterior loops. Measurements were taken in the coronal view after aligning the sagittal and coronal planes with the long axis of each molar root. To ensure measurement standardisation and to eliminate visual bias, the software's standardised brightness and sharpening enhancement tools were applied uniformly to all scans prior to taking measurements.

Measurements for each molar tooth (1st and 2nd) on the left and right sides of the mandible are presented in Figure 1 and were recorded in millimetres as follows:

(A) Minimum distance between both root apices (mesial and distal) and the superior margin of the MC;

(B) Minimum distance between the outer margin of the lingual cortical plate and the lingual margin of the MC;

(C) Minimum distance between the outer margin of the buccal cortical plate and the buccal margin of the MC.

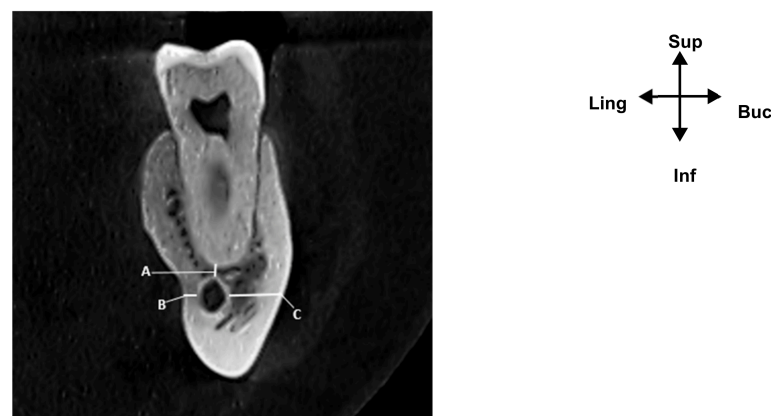


Figure 1. Coronal section of distal root of left second molar illustrating measurements taken: A—distance between root apex and superior margin of MC; B—distance between outer margin of the lingual cortical plate and the lingual margin of the MC; C—distance between the outer margin of the buccal cortical plate and the buccal margin of the MC.

2.4. Statistical Analyses

IBM SPSS Statistics version 30.0.0.0(172) was used to analyse the data. The dataset comprised 30 mandibles which were assessed bilaterally, resulting in 60 hemimandibles; therefore, most individuals contributed paired right/left data. The prevalence of anterior loops and bifid canals was summarised using a frequency table. Descriptive statistics were used to evaluate the morphometric data. The confidence level was set at 95%. Normality was evaluated using the Shapiro–Wilk test, and differences between males and females were analysed using the Mann–Whitney U test. A p -value ≤ 0.05 was considered statistically significant. Interobserver error determination was done by an external examiner for 10% of the sample, and the intraclass correlation coefficient was used to analyse consistency of the results obtained by two observers. Additionally, a post hoc statistical sensitivity power analysis was conducted using G*Power software (version 3.1.9.7 for Windows, Germany) to determine the minimum effect size detectable given our fixed sample size ($n = 15$ per sex; total $N = 30$ mandibles) for the non-parametric independent group comparisons.

To account for non-independence and potential pseudo-replication resulting from bilateral measurements (left and right hemimandibles from the same individual), sex comparisons across continuous distance measurements were additionally evaluated using Linear Mixed-Effects Models (LMMs). Models included sex as a fixed factor and subject ID as a random intercept. To assess the sensitivity of our findings to non-normality, a complementary sensitivity analysis was performed by averaging left and right hemimandibles for each participant ($N = 30$ individuals; 15 males, 15 females) and applying Mann–Whitney U tests on per-individual mean values. Statistical significance was set at $\alpha = 0.05$.

3. Results

3.1. Morphological Data

The incidence of the bifid canals (Figure 2) and anterior loop is shown in Table 1.



Figure 2. Sagittal section of a female mandible with a bifid mandibular canal indicated by the white arrow.

Table 1. Frequency of morphological variations between males and females.

	Bifid Canals (n)		Anterior Loop (n)	
	Left (60)	Right (60)	Left (60)	Right (60)
Male	1 (1.67%)	0	1 (1.67%)	2 (3.33%)
Female	1 (1.67%)	1 (1.67%)	2 (3.33%)	2 (3.33%)
Total	2 (3.33%)	1 (1.67%)	3 (5.00%)	4 (6.67%)

The frequencies for the bifid canals and anterior loops were calculated using the entire sample size (60).

3.2. Morphometrics

Morphometric data are presented in Tables 2–8 and Figures 3–8. The data are presented for each hemimandible and for each of the sexes.

Table 2. Distance between mandibular first molar root apices and the superior margin of the mandibular canal.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	6.58 (5.41, 7.75)	6.71 (5.29, 8.13)	6.11 (4.95, 7.27)	5.45 (4.19, 6.71)	6.32 (5.17, 7.47)	6.30 (5.00, 7.60)	6.00 (4.84, 7.16)	5.70 (4.10, 7.30)
SD (mm)	±2.11	±2.56	±2.29	±2.32	±2.64	±2.43	±2.68	±3.06
Minimum (mm)	1.60	3.60	2.91	2.88	2.00	2.80	2.40	2.53
Maximum (mm)	9.51	11.61	10.41	10.47	10.63	10.41	10.01	11.60
p-value	0.806		0.367		0.967		0.775	

mm: millimetres; F: female; M: male; SD: standard deviation.

Table 3. Distance between mandibular second molar root apices and the superior margin of the mandibular canal.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	3.19 (1.73, 4.65)	3.10 (1.64, 4.56)	2.37 (0.96, 3.78)	2.42 (1.29, 3.55)	3.62 (2.15, 5.09)	3.07 (1.29, 4.85)	2.91 (1.51, 4.31)	2.37 (0.91, 3.83)
SD (mm)	±2.62	±2.56	±2.49	±2.12	±2.58	±3.21	±2.47	±2.63
Minimum (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum (mm)	8.01	7.60	7.65	6.40	8.81	9.60	7.61	8.01
p-value	0.935		0.935		0.461		0.389	

mm: millimetres; F: female; M: male; SD: standard deviation.

Table 4. Mean distance between the lingual margin of the mandibular canal and lingual cortical plate in relation to first molar roots.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	2.60 (2.00, 3.20)	2.64 (2.00, 3.28)	2.04 (1.72, 2.36)	1.93 (1.29, 2.57)	2.48 (1.84, 3.12)	2.84 (2.19, 3.49)	1.75 (1.41, 2.09)	2.13 (1.49, 2.77)
SD (mm)	±1.07	±1.24	±0.57	±1.14	±1.16	±1.28	±0.61	±1.17
Minimum (mm)	0.80	1.20	0.80	0.80	1.40	1.20	0.80	0.80
Maximum (mm)	4.40	5.20	2.80	5.20	5.59	4.80	2.80	4.40
p-value	0.838		0.267		0.567		0.595	

mm: millimetres; F: female; M: male; SD: standard deviation.

Table 5. Mean distance between the lingual margin of the mandibular canal and lingual cortical plate in relation to second molar roots.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	1.48 (1.27, 1.69)	1.85 (1.26, 2.44)	1.59 (1.27, 1.91)	1.76 (1.26, 2.26)	1.40 (1.19, 1.61)	1.85 (1.26, 2.44)	1.53 (1.32, 1.74)	1.91 (1.37, 2.45)
SD (mm)	±0.38	±1.06	±0.58	±0.91	±0.36	±1.06	±0.38	±1.01
Minimum (mm)	0.80	0.80	0.80	0.40	0.80	0.80	0.80	0.80
Maximum (mm)	2.00	4.40	3.20	3.60	2.00	4.40	2.00	4.40
<i>p</i> -value	0.624		0.902		0.345		0.412	

mm: millimetres; F: female; M: male; SD: standard deviation.

Table 6. Mean distance between the buccal margin of the mandibular canal and buccal cortical plate in relation to first molar roots.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	3.32 (2.52, 4.12)	3.75 (2.99, 4.51)	4.36 (3.56, 5.16)	4.97 (4.18, 5.76)	3.64 (2.87, 4.41)	3.14 (2.27, 4.01)	4.83 (4.09, 5.57)	4.83 (4.05, 5.61)
SD (mm)	±1.44	±1.36	±1.43	±1.49	±1.38	±1.58	±1.34	±1.52
Minimum (mm)	1.20	1.60	2.40	2.00	1.20	0.00	2.40	2.40
Maximum (mm)	6.00	7.60	8.40	8.40	6.40	5.60	8.00	7.20
<i>p</i> -value	0.595		0.126		0.713		0.935	

mm: millimetres; F: female; M: male; SD: standard deviation.

Table 7. Mean distance between the buccal margin of the mandibular canal and buccal cortical plate in relation to second molar roots.

Root Type	Left				Right			
	Mesial		Distal		Mesial		Distal	
Sex	F	M	F	M	F	M	F	M
Mean (95% CI) (mm)	5.35 (4.56, 6.14)	5.23 (4.43, 6.03)	5.21 (4.41, 6.01)	5.49 (4.70, 6.28)	5.55 (4.79, 6.31)	5.48 (4.72, 6.24)	5.40 (4.62, 6.18)	5.75 (5.00, 6.50)
SD (mm)	±1.59	±1.81	±1.81	±1.65	±1.38	±1.51	±1.55	±1.48
Minimum (mm)	2.40	2.00	2.00	2.40	2.80	2.80	2.00	2.80
Maximum (mm)	9.20	8.80	9.20	9.20	8.40	8.00	8.80	8.40
<i>p</i> -value	0.806		0.806		0.838		0.539	

mm: millimetres; F: female; M: male; SD: standard deviation.

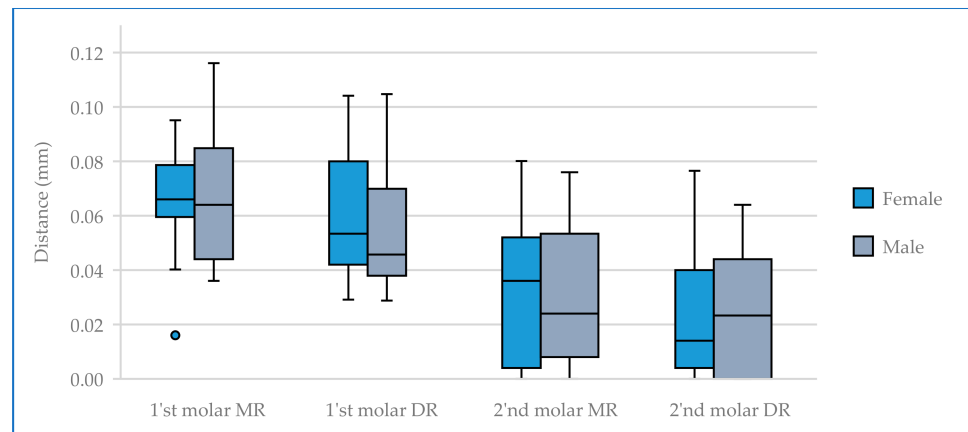


Figure 3. Average distance between the MC and the first and second molar root apices on the left side. MR—mesial root; DR—distal root.

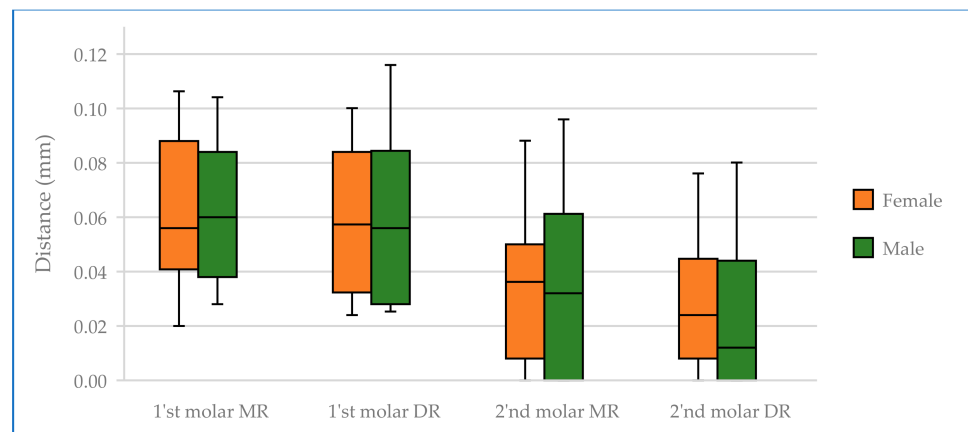


Figure 4. Average distance between the MC and the first and second molar root apices on the right side. MR—mesial root; DR—distal root.

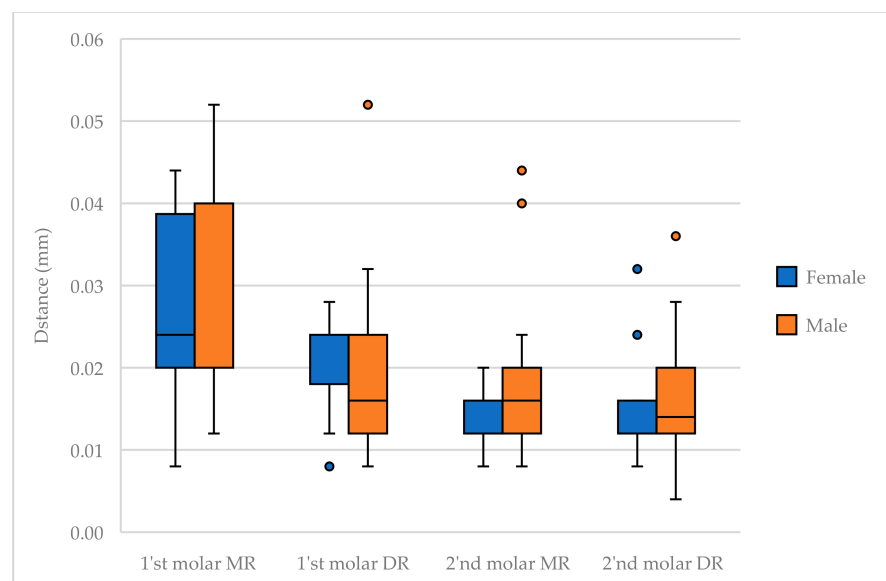


Figure 5. Average distance between the lingual margin of the MC and lingual cortical plate in relation to first and second molar roots on the left side. MR—mesial root; DR—distal root.

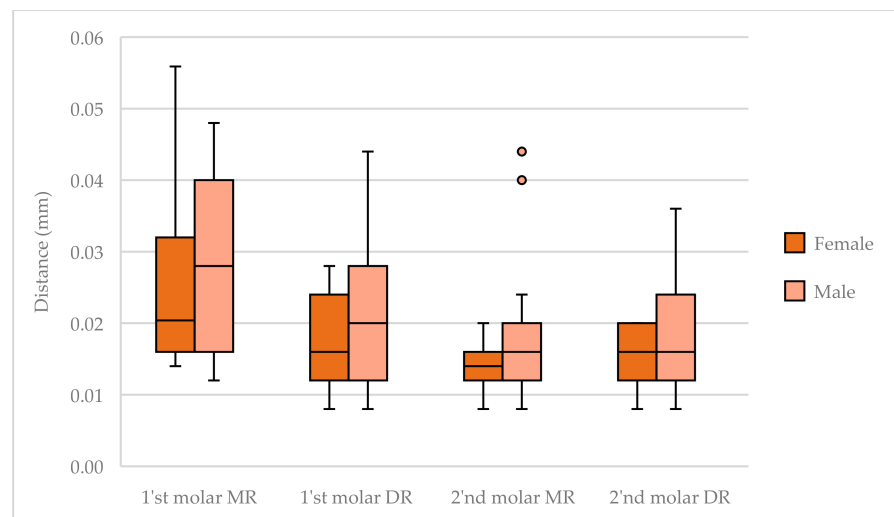


Figure 6. Average distance between the lingual margin of the MC and lingual cortical plate in relation to first and second molar roots on the right side. MR—mesial root; DR—distal root.

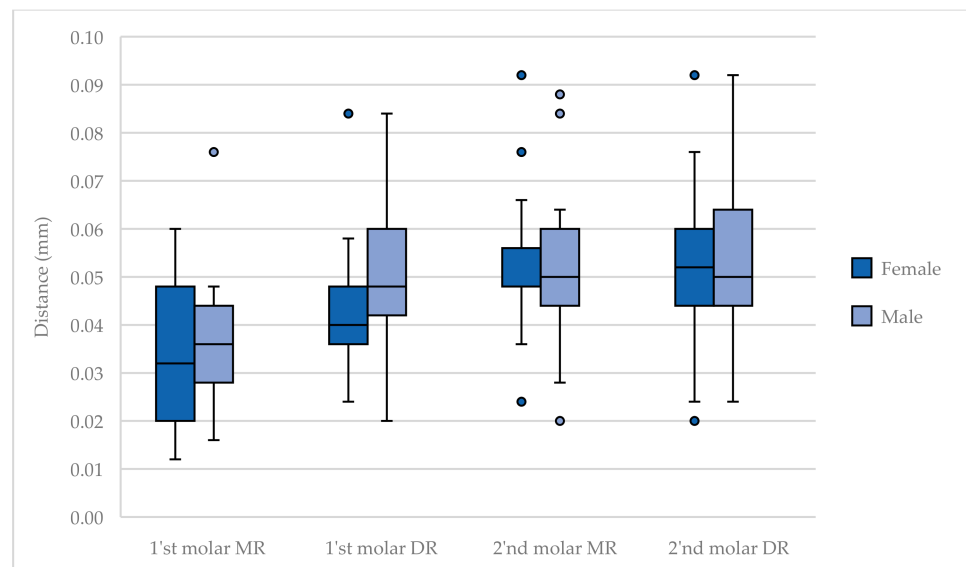


Figure 7. Average distance between the buccal margin of the MC and buccal cortical plate in relation to first and second molar roots on the left side. MR—mesial root; DR—distal root.

Table 8. Effect sizes for sex differences (Cohen's d).

Measurement Variable	Tooth	Left		Right	
		Mesial	Distal	Mesial	Distal
Root apex → MC distance	First molar	0.06	−0.29	−0.01	−0.10
	Second molar	−0.03	0.02	−0.19	−0.21
MC → Lingual cortical plate	First molar	0.03	−0.12	0.29	0.41
	Second molar	0.48	0.22	0.59	0.52
MC → Buccal cortical plate	First molar	0.31	0.42	−0.34	0
	Second molar	−0.07	0.16	−0.05	0.23

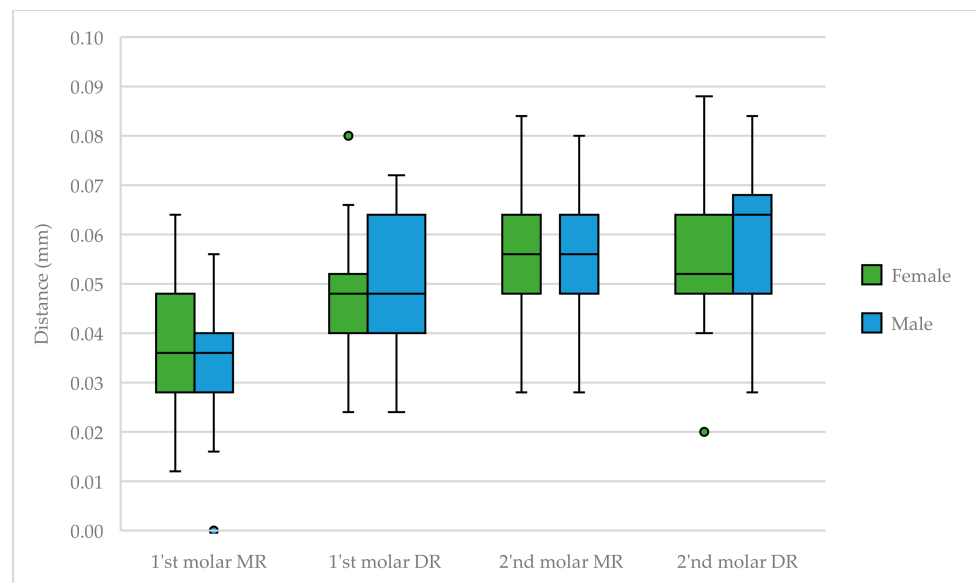


Figure 8. Average distance between the buccal margin of the MC and buccal cortical plate in relation to first and second molar roots on the right side. MR—mesial root; DR—distal root.

To confirm the absence of nonsignificant sex differences, a Mixed-Effects Model was used as given in Table 9.

Table 9. The computed statistical values comparing the Linear Mixed-Effects Model (N = 60 hemi-mandibles clustered within N = 30 individuals) and the sensitivity analysis (N = 30 per-individual averaged values).

Anatomical Measurement	Male Mean $\pm$ SD (mm)	Female Mean $\pm$ SD (mm)	Linear Mixed Model (<i>p</i> -Value)	Averaged Sensitivity (<i>p</i> -Value)	Original Uncorrected (<i>p</i> -Value)
1st Molar Mesial Root—Apex	6.50 $\pm$ 2.40	6.45 $\pm$ 2.17	0.951	0.803	0.806
1st Molar Mesial Root—Lingual	2.74 $\pm$ 1.17	2.54 $\pm$ 0.88	0.602	0.708	0.838
1st Molar Mesial Root—Buccal	3.44 $\pm$ 1.33	3.48 $\pm$ 1.26	0.939	0.950	0.595
1st Molar Distal Root—Apex	5.57 $\pm$ 2.55	6.06 $\pm$ 2.30	0.584	0.481	0.367
1st Molar Distal Root—Lingual	2.03 $\pm$ 1.02	1.89 $\pm$ 0.52	0.637	0.901	0.267
1st Molar Distal Root—Buccal	4.90 $\pm$ 1.40	4.59 $\pm$ 1.31	0.535	0.454	0.838
2nd Molar Mesial Root—Apex	3.09 $\pm$ 2.81	3.40 $\pm$ 2.28	0.737	0.618	0.513
2nd Molar Mesial Root—Lingual	1.85 $\pm$ 0.96	1.44 $\pm$ 0.33	0.115	0.546	0.245
2nd Molar Mesial Root—Buccal	5.35 $\pm$ 1.56	5.45 $\pm$ 1.36	0.856	1.000	0.967

Table 9. Cont.

Anatomical Measurement	Male Mean $\pm$ SD (mm)	Female Mean $\pm$ SD (mm)	Linear Mixed Model (<i>p</i> -Value)	Averaged Sensitivity (<i>p</i> -Value)	Original Uncorrected (<i>p</i> -Value)
2nd Molar Distal Root—Apex	2.40 $\pm$ 2.15	2.64 $\pm$ 2.00	0.749	0.740	0.838
2nd Molar Distal Root—Lingual	1.83 $\pm$ 0.85	1.56 $\pm$ 0.41	0.261	0.833	0.567
2nd Molar Distal Root—Buccal	5.62 $\pm$ 1.39	5.31 $\pm$ 1.54	0.557	0.395	0.481

No statistically significant sex differences were observed across any of the 12 distance variables in either the Linear Mixed-Effects Models (all $p \geq 0.115$) or the per-individual sensitivity analysis (all $p \geq 0.395$). This confirms that the absence of significant sex differences was not an artefact of pseudo-replication (Table 9).

Interobserver reliability was assessed on 10% of the sample. An ICC value of 0.994 (95% CI: 0.987–0.998) was obtained for the intraobserver error, while a value of 0.990 (95% CI: 0.976–0.996) was obtained for the interobserver error.

4. Discussion

This study assessed the prevalence of key morphological and morphometric variations in the MC to the mandibular cortical plates and the molar teeth in a Black South African population.

The results for this study showed an overall prevalence of 11.67% for anterior loops, with a prevalence of 6.67% in females and 5.00% in males. A CBCT study conducted by Rahim et al. [13] similarly reported a higher prevalence in females (15.07%) compared to males (3.96%). This apparent sex-related difference may be attributed to the disproportionate representation of females in their sample, comprising 58.7% of the study population. In a study by Nascimento et al. [9] in a Brazilian population using CBCT scans, a higher prevalence of 41.6% was observed. The sample was mainly composed of females (62.4%), but the anterior loop was more prevalent in males. The researchers hypothesised, but did not investigate, that hormonal influences may contribute to greater cortical bone density in males, leading to increased MC cortication and, consequently, enhanced visibility of the anterior loop compared to females [14]. A study by Sinha et al. [15] on an Eastern Indian population identified anterior loops in 9.7% (97 out of 1000) of the CBCT scans. An anterior loop was found in 39 females and 58 males. The aforementioned studies demonstrate varying prevalences of anterior loops between males and females across different populations. This may suggest that anterior loops may not be a sex-specific trait but rather an individual anatomical variation. Identification of the anterior loop is important in dental procedures to ensure accurate localisation of the MF to avoid injury to the mental neurovascular structures.

In the present study, the prevalence of bifid canals was five percent. The bifid canal was more commonly observed on the left side than the right (3.33% vs. 1.67%). A bilateral bifid canal was present in one female, while one male presented with a bifid canal on the left side only. A study in a Turkish population reported a prevalence of bifid canals in 66.5% of patients, with more being observed in females (54.7%) than males (45.3%) [16]. A possible reason for the difference in the prevalence between the present study and the study by Orhan et al. [16] may be due to their large sample size of 242 scans. Another reason may be due to the criteria used to identify the bifid canals. Orhan et al. [16] used the Naitoh et al. [17] classification system, while the present study only regarded distinct and complete separations as bifid. A study by Fu et al. [18] observed bifid canals in 30.64% of subjects from a total sample of 173 patient computed tomography (CT) scans in a Taiwanese population. Contrary to the study by Orhan et al. [16], bifid canals were observed more

frequently in males than females (38.2% vs 24.7%). The higher frequency observed in the study by Orhan et al. [16] compared to Fu et al. [18] may be attributed to the different imaging modalities used in the studies. CBCT scans have proven to be valuable in detecting bifid mandibular canals and have been reported to present with more accurate and higher quality images than CT scans, resulting in more accurate and reliable observations of bifid canals [10,19]. Safi et al. [14] evaluated bifid canals in CBCT scans of 384 fully edentulous hemimandibles in an Iranian subpopulation. A bifid canal was observed in 9.9% of the sample. The lower prevalence may hypothetically be due to the occurrence of bone atrophy and resorption attributed to the absence of the mandibular teeth. This indicates a need to compare morphological variations between edentulous and dentate individuals [14]. Identification of bifid canals is important as they may contain accessory branches of the inferior alveolar neurovascular bundle, which may be at risk of damage in procedures such as third molar extractions.

The present study analysed the proximity of the MC to the root apices of the first and second molar teeth. The distance between the MC and root apices increased from posterior to anterior, with the distal roots of the second molar having the shortest average distance and the mesial roots of the first molar having the longest average distance. The mesial roots had larger average distances compared to the distal roots for both males and females (Tables 2 and 3). Hiremath et al. [20] used CBCT scans of Central Indian individuals and found shorter average distances for females. The average distance between the MC and the mesial root apex of the first molar was 0.93–8.03 mm for females and 1.46–13.23 mm for males. The mean distance between the MC and mesial root apex for the second molar was 0.00–6.91 mm and 1.31–14.71 mm for females and males, respectively [20].

Oluwafemi et al. [21] investigated the proximity of the molar roots to the MC in Black South African individuals. Using only the left side mesial roots of the molars, the investigators compared differences between females and males. The first molar region had statistically significant mean distances of 4.57 mm and 5.61 mm in males and females, respectively. These values are lower than those found in the present study. The mean distances for the second molar mesial roots were smaller when compared to the present study (2.23 mm vs. 3.19 mm for females; and 2.88 mm vs 3.10 mm for males). A possible reason for these differences may be the use of different imaging modalities. Oluwafemi [21] used digital panoramic radiographs, and while this modality is popular in treatment planning for dental procedures, studies have reported inaccuracies in measurements taken using these radiographs. A key disadvantage of using panoramic radiographs for measurements is their inherent distortion and magnification errors, which can vary across different regions of the image. Bertram et al. [22] found that panoramic radiographs underestimate vertical bone dimensions when selecting implant sites in the region of the second molars. A study by Beshtawi et al. [23] investigated the accuracy of measurements from CBCT scans and panoramic radiographs compared to physical human skulls. The researchers found that CBCT measurements have the most accurate overall mean dimensions and further recommended CBCT imaging to be used for implant planning after verifying its dimensional accuracy and superiority over panoramic radiographs [23].

The mean distances showed that the second molar root apices were closer to the superior margin of the MC than the first molar root apices, regardless of sex or side. The first molar root apices were consistently farther from the MC. The root apices of the second molar, however, were substantially closer to the MC. This is similar to the results obtained by Aljarbou et al. [3], who found that the second molar roots lie closer to the MC compared to the first molar within a Saudi population. Razumova et al. [24] investigated root apex proximity to the MC in patients from Moscow and reported lower mean distances for the first molars when compared to the present study. The distances to the first molar

ranged from 4.46 mm to 4.92 mm, while the mean distances for the second molars ranged from 2.64 mm to 2.85 mm. In the present study, at least one minimum distance of 0.00 mm was recorded for all eight measured categories in the second molars (female/male, left/right, mesial/distal). The results demonstrate direct contact between the root apices and the superior margin of the MC, with 16.67% of mesial roots and 21.67% of distal roots exhibiting such contact. A higher number of males showed direct contact compared to females (14 cases versus 9 cases). Aljarbou et al. [3] found that the mesial root of the second molar was in contact with the MC in 25% of cases and in 38.3% of cases for the distal root. The researchers found that the second molar lies significantly closer to the MC than the first molar and premolars in their sample. These findings may suggest that there may be an elevated risk of injury to the neurovascular bundle in the region of the second molar, indicating that clinicians may need to exercise heightened caution when performing root canal treatment on this tooth. If precautions are not considered during procedures such as endodontic length determination, complications such as perforation and overfilling of the canal during root canal treatment may occur [5]. Underfilling of root canals may also occur due to the use of an incorrect file size, leading to possible treatment failure. Clinicians may need to exercise caution when selecting instrumentation, such as the length and size of the file [25].

Distances between the MC and the buccal and lingual cortical plates were measured to determine the thickness of the mandible in relation to the MC, as seen in Tables 4–7. The distances from the MC to the lingual cortical plate were smaller compared to the buccal cortical plate distances in the region of the first and second molar roots. The lingual distances in relation to the second molar roots were smaller, although not statistically significantly different when compared to the first molar, while the buccal distances for the second molar were larger but not statistically significantly different from the distance for the first molar. The minimal thickness of the lingual cortical plate in relation to the MC, emphasised by the smallest minimum distance of 0.40 mm in the second molar region, may indicate a higher risk of IAN damage during procedures performed on the lingual side of the mandible. These results are supported by a CBCT study that found the MC running closest to or in contact with the lingual cortical plate in the molar region [26]. In this study, the mean distance from the MC to the lingual cortical plate ranged from 2.24 mm to 3.67 mm for the first molar region. The buccal distances, on the other hand, were significantly greater than the lingual distances, with the mean distance ranging from 4.09 mm to 5.34 mm. The lingual distances in relation to the second molar roots were smaller when compared to the first molar. The buccal distances, however, were significantly larger.

Regarding sex differences in the present study, males showed numerically higher mean cortical bone thickness values in most, but not all, measurements. However, these were not statistically significant. In two males, the buccal cortical plate distance in the mesial root region of the second molar was 0.00 mm, indicating termination of the MC and the opening of the MF. This may indicate a posterior location of the MF [1]. An atypical positioning of the foramen may place the mental nerve at risk of iatrogenic damage. The position of the MF may need to be considered during procedures that require mental nerve blocks to ensure successful anaesthesia [8].

It is important to note that no statistically significant differences in the morphology and morphometry of the MC were found, and a clinically meaningful sexual dimorphism could not be demonstrated. Although differences between the sexes were found in this study, there is not sufficient evidence to support sex-specific differences in the mandibular canal of Black South Africans.

A limitation of this study is the relatively small sample size ($n = 30$ individuals, 60 hemimandibles) and the absence of an a priori sample size calculation. Because the study

sample was constrained by the retrospective nature of the archive and strict inclusion criteria within a specific population subset, a post hoc power analysis revealed that our design was inherently underpowered to detect minor or moderate sexual dimorphism. Specifically, for independent non-parametric comparisons ($n = 15$ per group, $\alpha = 0.05$), our sample possessed approximately 26% power to detect a medium effect size ($d = 0.50$) and 57% power to detect a large effect size ($d = 0.80$), only achieving the standard 80% power threshold for very large anatomical variations ($d \geq 1.15$). Therefore, the consistently non-significant p -values reported throughout our morphometric results should be interpreted with caution, as they may reflect a lack of statistical power to capture subtle metric variations rather than definitive anatomical similarity between sexes. Future multi-centre prospective studies with expanded cohorts are required to definitively map these metrics. Although our study possessed limited power for detecting small effect sizes ($d = 0.50$), analytical modelling using Linear Mixed-Effects Models and per-individual sensitivity analyses confirmed that within-subject clustering of bilateral hemimandibles did not confound our results.

5. Conclusions

The differences reported in the frequencies of the presented anatomical variations between different population groups as well as between males and females emphasise the importance of patient-specific planning prior to dental procedures. It is imperative that the correct imaging modality is utilised to accurately identify any variations in the MC. The differences in the morphometric data amongst the different populations indicate a need to establish population-specific dimensions. In conclusion, no significant sex differences were observed; however, these findings should be viewed as preliminary and interpreted with care given the study's limited statistical power.

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