MORPHOLOGY AND VARIANT ANATOMY OF THE MANDIBULAR CANAL IN A KENYAN POPULATION: A CONE-BEAM COMPUTED TOMOGRAPHY STUDY

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V60/7605/2017

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF DENTAL SURGERY IN ORAL AND MAXILLOFACIAL SURGERY OF THE UNIVERSITY OF NAIROBI

2022

DECLARATION

I do hereby declare that this dissertation is my original work and has not been submitted by any other person(s) in any other institution for the award of a degree or otherwise.

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DEDICATION

To Beldina Machogu, thank you for your unwavering patience, support, and sacrifices.

To Luka Festo, I hope this inspires you to scale even greater heights.

ACKNOWLEDGEMENTS

I would like to thank God for His grace in my life, without which, I would never have come this far. I owe everything to Him.

I am especially grateful to my supervisors, Dr. Fawzia Butt, Dr. Florence Opondo, and Professor Fredrick Onyango. Your wisdom, guidance, and encouragement throughout this project were invaluable. Thank you.

I would also like to acknowledge the efforts of Michael Kimundia and Giovanny Odhiambo, employees of DAMIC Nairobi, for helping me sift through thousands of CBCT scans to come up with a sampling frame for this study. Your contributions have made this project a success and I truly thank you.

Finally, I would like to thank the management at DAMIC Nairobi for allowing me to carry out this study at their facility. You made this study possible.

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LIST OF ABBREVIATIONS

MC	– Mandibular canal
IAN	– Inferior alveolar nerve
2D	– Two-dimension
3D	– Three-dimension
CBCT	– Cone-beam computed tomography
MF	– Mental foramen
WIU	– Weeks of intra-uterine life
CT	– Computed tomography
BMC	– Bifid mandibular canal
TMC	– Trifid mandibular canal
ALMN	– Anterior loop of the mental nerve
mA	– Milliamperes
kV	– Kilovoltage
BSSRO	– Bilateral sagittal split ramus osteotomy
BCP	– Buccal cortical plate
LCP	– Lingual cortical plate
IBM	– Inferior border of mandible
DAMIC	– Dental and Maxillofacial Imaging Centre
MS Excel	– Microsoft Excel
SPSS	– Statistical Product and Service Solutions
ICC	– Intraclass correlation coefficient

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ABSTRACT

BACKGROUND: The mandibular canal (MC) is a bony conduit within the mandible originating from the mandibular foramen and terminating at the ipsilateral mental foramen (MF). It transmits the inferior alveolar neurovascular bundle. It exhibits surgically significant anatomical variations in its course and terminal segment among different ethnic groups. Detailed knowledge of the anatomy of this canal in the local population is important in guiding surgeons to avoid inadvertent injury to the neurovascular bundle during surgical procedures.

STUDY OBJECTIVE: To investigate and document the normal morphology and variant anatomy of the MC in a select Kenyan population using cone-beam computed tomography (CBCT) scans.

METHODOLOGY: This was a retrospective descriptive cross-sectional CBCT study. Quantitative techniques were used to collect morphometric data on the MC and its variants. The study was conducted at a private imaging facility called Dental and Maxillofacial Imaging Centre (DAMIC) in Nairobi, Kenya. The study sample was selected from DAMIC's electronic CBCT database using a non-probability sampling method. Data was collected using a data extraction form in a Microsoft Excel database. It was then exported to Statistical Product and Service Solutions (SPSS) version 24 software for statistical analysis. A p-value <0.05 was considered statistically significant.

RESULTS: 351 hemi mandibular CBCT scans from 202 patients were included in this study. 142 scans were from 81 (40.1%) male and 209 scans were from 121 (59.9%) female patients. The mean age was 40.4±14.2 years. The most frequently encountered course of the MC was the progressive descent type seen in 241 (68.7%) scans. Accessory MC were observed in 15 (4.3%)

scans. Accessory MF were observed in 29 (8.3%) scans. Only one CBCT scan showed both accessory MC and accessory MF in the same patient. The mean diameter of the MC was 3.36±0.39mm. The most frequent position of the main MF in relation to the second premolar was anterior (53.3%). The average distance from the MF to the IBM was 12.17±1.91mm. The anterior loop of mental nerve (ALMN) was observed in 18 (5.1%) scans. The mean length of the ALMN was 4.83±0.89mm.

CONCLUSIONS: The progressive descent and straight projection types were the most and least predominant courses of the MC encountered respectively. The prevalence of accessory MC and accessory MF in this study was relatively low. The presence of accessory MF was not invariably associated with the presence of accessory MC. The orientation of the MC was more lingual towards the angle of the mandible and more buccal towards the MF. The predominant position of the MF was anterior to the second premolar. The prevalence of the ALMN in this study was low but its average length was clinically significant.

RECOMMENDATIONS: To fully understand the anatomic variations of the MC, there is a need for multicentric studies with properly defined anatomical landmarks to quantify and precisely predict these variations.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

The mandibular canal (MC) is a bilateral bony channel originating from the mandibular foramen. It runs longitudinally towards the mental foramen (MF) and serves as a conduit for the inferior alveolar neurovascular bundle [1,2]. In its course, it relates to the roots of the mandibular premolars and molars.

Inadvertent inferior alveolar nerve (IAN) injury has been reported in various fields of dentistry including orthodontics, endodontics, restorative dentistry, and oral and maxillofacial surgery [3]. An in-depth understanding of the course and intraosseous position of the inferior alveolar neurovascular bundle is a prerequisite to performing mandibular dental procedures. These procedures include but are not limited to dental implant placement, third molar surgery, bilateral sagittal split ramus osteotomy (BSSRO), bone grafting, placement of fixation screws, and mandibular jaw resection [4,5].

Significant individual anatomical variations of the course of the MC and the terminal segment of the inferior alveolar nerve (IAN) have been reported to various extents among different ethnic groups and populations. Various studies have tried to map out the course of the MC in their populations [6,7] essentially to form a basis or guide to surgical approaches to the mandible.

Plain and panoramic radiographs are insufficient in the presurgical evaluation of the mandible or variations of the MC. They have magnifications, distortions, limited reproducibility, and only present a two-dimension (2D) position of the MC [8,9]. They fail to show the exact buccal-lingual position of the IAN and there is an inherent risk of inadvertent damage to the contents of the MC and/or excessive removal of cortical bone when they are used solely.

A cone beam computed tomography (CBCT) scan is an accurate three-dimension (3D) imaging modality of dental and maxillofacial structures without magnification or superimposition. The images of maxillofacial structures produced are undistorted and of high resolution. There are many planes for reformatting the images that allow for interactive viewing. Significantly fewer radiation doses are involved in taking CBCT scans, compared to conventional medical-grade computed tomography scans (CT scans) [10].

Hardly any Kenyan studies on CBCT imaging of the MC were found in the literature search. Gakonyo et al [11] carried out a retrospective CBCT study in a private dental clinic in Nairobi, Kenya, and reported on the incidence of double MC and double MF. This represents the extent of available local radiographic data on the subject indicating the imperative need to carry out multicentric studies. This study evaluated the normal morphology and morphometric variations in the course of the MC and terminal segment of the IAN in a select Kenyan population. The knowledge generated from this study is for assisting surgeons in planning the approaches to the mandible and avoiding neurovascular injury during surgery.

1.2 LITERATURE REVIEW

1.2.1 THE MANDIBULAR CANAL

1.2.1.1 Development

At around 8 Weeks of intra-uterine life (WIU), the outer and inner plates of the body of the mandible grow in a vertical direction forming a groove that is open towards the oral cavity. Tooth germs develop in this groove between 8 – 14 WIU [12]. The inferior alveolar neurovascular bundle is also contained in this groove. Gradually, osseous septa form between adjacent tooth germs. Much later a bony horizontal plate separates this rudimentary mandibular canal (MC) from the dental crypts.

Bone is deposited at the fundus of the alveolus and the crest of the alveolar process. The former is incorporated into the body of the mandible. This process determines the position of the MC relative to the apices of the first two molars and premolars. Bone deposition, therefore, contributes to the vertical growth of the body of the mandible.

1.2.1.2 Postnatal changes

At birth, the MC is large and located very close to the inferior border of mandible (IBM). The mental foramen (MF) opening is beneath the socket of the first deciduous molar. The MC is located slightly above the mylohyoid line after secondary dentition develops while the MF is at its usual adult location. In adults, the dentoalveolar and sub-dental parts of the mandible are equidistant and MF opens approximately in the middle of the mandible. MC runs almost in line with the mylohyoid line.

In old age, the mandible is greatly resorbed which results in the main part of the bone lying below the oblique line. The MC and MF are located close to the alveolar border [12].

1.2.1.3 Anatomy

The MC is an intraosseous channel originating from the mandibular foramen of the ramus and terminating at the MF of the body of mandible [1,2]. It transmits the inferior alveolar neurovascular bundle. There are very few studies recording its course [13]. Olivier [14] investigated the intraosseous pathway of the MC and reported its location as lingual to the roots of the third and second molars, below the roots of the first molar, and buccal to the premolar roots. Worthington [15] described three configurations of the MC: 1) a straight projection, 2) a progressive curve, and 3) a catenary-like canal ("curled as hanging between two points") (**Figure 1**). Mirbeigi S et al [6] demonstrated the prevalence of each of these three configuration types to be 33.3% in an Iranian population.

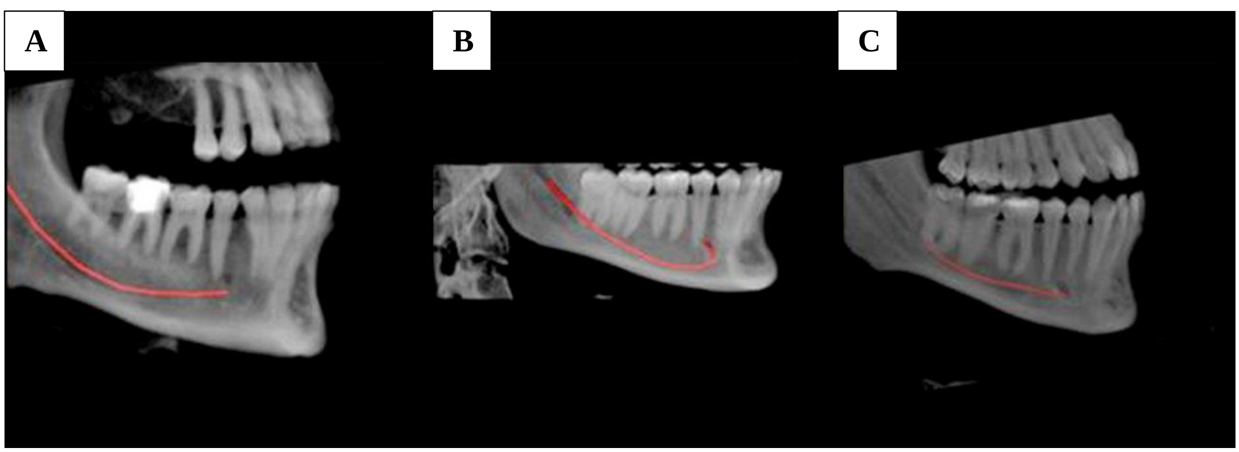

Figure 1: Cone-beam computed tomography (CBCT) scan reconstructions of the mandible with nerve tracings showing variations in the path of MC: **A –** Catenary-like: **B –** Progressive descent: **C –** Straight projection [6,13].

1.2.1.4 The mental foramen

The MF is most commonly found below the second premolar in line with its longitudinal axis. It is less commonly located between the premolars [16]. Moiseiwitsch et al [17] concluded that the MF was generally found on average between premolars in the North American Caucasian population. Shankland [18] showed that the MF on Asian Indian mandibles was located in 75.36% of 138 total mandibular sides directly below the second premolar. Oguz [19] studied a sample of 34 dried Turkish adult (30 – 40 years old) male mandibles and showed that 61.76% on the right and 50% on the left of the MF were directly below the second premolar root. In the remaining mandibles, the MF was between the roots of the premolars. Mbajiorgu [20] presented the most common position of the MF between the lower premolars in black Zimbabwean populations. In an analysis of 79 Kenyan mandibles, Mwaniki D.L. and Hassanali J. [21] indicated that 56.1% of the MF were below the root of the second premolar, 31.1% were behind the root of the second premolar while 12.8% were located between the premolars. These results, as in other similar studies, indicate ethnic and racial differences in the common positions of the MF.

1.2.1.5 Accessory mandibular canals and accessory mental foramina

The presence of accessory mandibular canals has been reported using plain panoramic radiography [22], computed tomography (CT) [23], and CBCT [1] scans. Naitoh et al [24], using CBCT imaging, classified bifid mandibular canals (BMC) into four main patterns: dental, retromolar, buccolingual, and forward types. The prevalence of these variations has been reported to range from 0.08% to 65.0% [22,24] (**Table 1**). Gakonyo et al [11] reported the incidence of BMC to be 26 (3.25%) out of 800 CBCT images in a select Kenyan population.

Table 1: The prevalence of bifid and trifid mandibular canals in literature

Researcher	Study Type	Radiography	BMC	TMC
Gakonyo [11]	Cross-sectional (800 patients)	CBCT	26 cases (3.25%)	0
Auluck [22]	Case report	OPG	5 cases	1 case
Naitoh [24]	Cross-sectional (122 patients)	CBCT	79 cases (65%)	0
Kaufman [29]	Case report	CT	1 case	0
Dario [30]	Case report	OPG	1 case	0
Sanchis [31]	Cross-sectional (2012 patients)	OPG	7 cases (0.35%)	0
Claeys [32]	Case report	CT	1 case	0
Bogdán [33]	Cadaveric study (46 mandibles)	–	8 cases (17.4%)	1 case (2.2%)
Bogdán [33]	Cross-sectional (1000 patients)	OPG	2 cases (0.2%)	
Miloglu [35]	Case report	CT	1 case	0
Karamifar [36]	Case report	OPG	1 case	1 case

BMC – Bifid mandibular canal, TMC – Trifid mandibular canal, CT – Computed tomography scan, OPG – Orthopantomogram, CBCT – Cone-beam computed tomography scan

Any variations noted on two-dimension (2D) imaging need confirmation on three-dimension (3D) imaging as distortions and misinterpretations are common with the former. The mylohyoid nerve imprint on the lingual surface of the mandible, at its point of separation from the inferior alveolar nerve (IAN), is a major factor underlying a false BMC radiograph using conventional 2D imaging. Likewise, the mylohyoid line on the mandibular surface creates a radiologic osteocondensation image in a manner parallel to the MC which can lead to reporting false BMC on 2D images [25,26].

The presence of bifid and trifid MC, especially when two MF are involved, could explain the reason for inadequate anesthesia after an IAN block [27]. The presence of these accessory canals necessitates extra attention when planning for third molar removal. Complications associated with injury to accessory neurovascular bundles include bleeding, paresthesia, or neuroma formation.

An accessory MF was been defined by Naitoh et al [28] as one demonstrating continuity with the MC while other foramina around the MF without continuity with the MC were nutrient foramina. In a Brazilian CBCT study, Oliveira-Santos et al [112] considered additional foramina as 'double MF' when their size was at least half of the main ipsilateral MF and 'accessory MF' when they were smaller than half the size of the main ipsilateral MF. Accessory MF are invariably associated with accessory MC or ramification of the mental nerve before it passes the MF [28]. Gakonyo et al [11] reported the incidence of double MF to be 21 (2.4%) out of 800 CBCT images. Naitoh et al [28] reported 11 (7%) accessory MF out of 157 cases with 2 cases showing bilateral occurrence.

1.2.1.6 Anterior loop of the mental nerve

The anterior loop of the mental nerve (ALMN) [38] also described as the anterior loop of the IAN [37] or the anterior loop of the MC [2] is the anterior and inferior extension beyond the MF of the IAN and its curving back to the MF forming a loop. The identification of this benign anatomical variation is essential for surgical planning, especially for the placement of dental implants in the mental foramen region to prevent iatrogenic injury to the mental nerve and to ensure effective surgery in this region [37, 38].

The prevalence of ALMN has been reported to range from 0% [22] to 88% [39]. A maximum length of 11 mm [39] has been reported. CBCT scans allow for assessment of the mandible with precision and reliability in determining the presence and length of the ALMN [40-43]. In the absence of 3D imaging, Bobat et al [44] proposed observing a 5mm safety zone or using shorter implants as a safer option when placing implants anterior to the MF. Iatrogenic damage to the ALMN can lead to discomfort of unspecified duration in the lower labial gingiva and lip. Damage rates to the ALMN of about 17 – 38% during genioplasty [45,46] and 8.5 – 24% during implant placement [47-50] have been reported.

1.2.2 CONE-BEAM COMPUTED TOMOGRAPHY (CBCT)

1.2.2.1 Development

Computerized transverse axial scanning was introduced in 1972 by G.N. Hounsfield [51]. This technology led to the development of computed tomography (CT) scanning. CT scans were however underutilized in dentistry due to limited access, high radiation exposure, and high cost. CBCT for oral and maxillofacial applications was introduced by Arai [52] in Japan and Mozzo [53] in Italy each working independently. Like CT scans, CBCT offered more accurate imaging and 3D exploration compared to 2D imaging.

1.2.2.2 Mechanism

A CBCT machine uses a cone-shaped beam and a reciprocating solid-state flat panel detector that rotates around the patient once in 180° – 360° covering a defined anatomical volume. One rotation captures 180 – 1024 2D images and conveys them to a computer. The images are reconstructed into the anatomical volume for viewing at a 1:1 ratio in axial, coronal, and sagittal planes using the modified Feldkamp algorithm. The absorbed x-ray dose is reduced by 6 to 15 times in comparison to CT. Depending on the manufacturer, the scanning time range is 5 to 40 seconds. The operating range of a CBCT machine is 1 - 15 mA at 90 - 120 kVp. This compares favorably to 120 - 150 mA and 220 kVp [54], the operating range of a CT scan machine.

1.2.2.3 Applications in maxillofacial surgery

The use of CT scans in dentistry is restricted because of cost, availability, poor resolution, longer scanning time, difficulty in interpretation, and high radiation dose [55]. 2D images are limited by structural superimpositions and imprecise measurement of surface distances [56]. CBCT is an accurate imaging modality of maxillofacial structures that produces undistorted, non-magnified, high-resolution 3D images of the skeletal anatomy that can be reformatted in any plane to allow for image manipulation and interactive viewing [10].

These advantages of CBCT have made it ideal for assessing facial fractures, intraoperative visualization of maxillofacial structures, and navigation during surgical procedures [57,58]. CBCT has also been applied in examining the precise location and extension of tumors and cysts of the jaws and osteomyelitis [59,60]. It is also possible to recognize pathologic jaw calcifications and distinguish them from other calcifications [60,61]. The use of 3D CBCT views for assessment of the relationship between supernumerary, unerupted, or impacted teeth and surrounding vital structures has aided greatly in surgical treatment planning [62,63]. Bone graft receiver sites are evaluated using CBCT images in both the pre-surgical and post-surgical phases of treatment. CBCT scans have been employed in the assessment of osteonecrotic changes of the jaws as seen in bisphosphonate-related osteonecrosis of the jaw [64,65].

1.2.2.4 Application in imaging of the Mandibular canal

The radiation dose associated with CBCT scans is slightly more than panoramic radiography but far less than CT scans [66]. The lack of magnification ensures that measurements obtained from CBCT images are comparable to direct cadaveric measurements [67]. Maloney et al [68], using SimPlant dental CBCT software, demonstrated that the results obtained were accurate and similar to direct cadaveric measurement. He also found the results comparable to measurement using the original i-CAT CBCT software. Various CBCT software employ user-friendly image editing tools that allow nerve tracing and accurate measurement of minute distances. This allows the possibility of color-coded tracking of the MC for easier determination of its course and assessing its relationship with various surrounding structures. CBCT scans are therefore an excellent, low-cost, low radiation, and accurate tool for the evaluation of the MC.

1.2.3 SURGERY AND THE MANDIBULAR CANAL

1.2.3.1 Repositioning of the inferior alveolar neurovascular bundle

Severely resorbed edentulous alveolar ridges in the posterior mandible are not conducive for the placement of long dental implant fixtures due to the increased risk of encroaching into the MC. Management of such cases would involve any one of many surgical procedures including repositioning the IAN [69,70]. Jensen and Nock [71] first described repositioning of the IAN and this technique has been favored when dealing with severely resorbed edentulous mandibular ridge [70,72].

An osteotomy is performed to create a window on the buccal cortex of the body of the mandible that gives access to the inferior alveolar neurovascular bundle. The bundle is repositioned by either lateralization or fenestration to allow insertion of long implant fixtures [72]. The short-term (3 – 6 months) complication of this procedure is neurosensory dysfunction. A pathological fracture to the body of the mandible can occur due to weakening when excessive bone is removed [73].

Distension of the nerve during this surgical procedure or post-surgical compression/distension are the main causes of IAN dysfunction [74]. This surgical procedure is associated with a high percentage of ischemic injury to the IAN. However, it provides a viable surgical option for implant placement in a resorbed mandible with minimal neurosensory deficits developing [74,75]. The use of panoramic radiographs only for presurgical treatment planning will inevitably lead to injury to the neurovascular bundle and excessive cortical bone removal. The buccolingual position of the IAN cannot be assessed on panoramic radiographs [76].

1.2.3.2 Bilateral sagittal split ramus osteotomy

Bilateral sagittal split ramus osteotomy (BSSRO) is used in orthognathic surgery to rotate, set back or advance the distal segment of the mandible. Trauner and Obwegeser [77] in 1957 described the original technique. This was modified by Dal Pont [78] in 1961, and further refined by Hunsuck [79] in 1968 and Epker [80] in 1977.

There is a great risk of injury to the IAN during BSSRO due to the position of the MC [81]. Permanent or temporary neurosensory deficit of the chin and lower lip is the main complication associated with BSSRO or its modifications. Traction on the nerve or incorrect placement of bone screws on the MC during the rigid fixation stage can cause trauma to the IAN resulting in this complication [82]. Direct injury to the nerve may be caused by cutting instruments at the vertical osteotomy stage. Reports in the literature on the frequency of this complication reach up to 85% [83].

There is a need to understand the anatomic location and course of the MC to reduce the chances of IAN injuries during BSSRO [81]. There have been anatomic studies of the MC for the performance of BSSRO [81,82,84] but only Tsuji et al [81] defined the anatomic variability of the MC within the mandibular rami. This enabled surgeons to determine the safest site for splitting the mandible through the buccal plate using a vertical corticotomy. Ahmet et al [85] concluded using CBCT imaging that the safest site for corticotomy in dentate patients was through the body of the mandible, considering the anatomic position of the MC. He recommended a CBCT survey on all patients who are candidates for BSSRO.

1.2.3.3 Osseointegrated dental implant surgery

The position of the MC profoundly influences osseointegrated dental implant surgery [47,86,87]. A 6.5% – 37% incidence of damage to the IAN in the MC is reported in literature with resulting sensory dysfunction. The main cause is a poor assessment of bone length and the use of implant fixtures of excessive lengths [46,47,87,88]. The location of the MC in the mandible should be studied very carefully before implant surgery to prevent inadvertent damage.

Imaging examinations are the most applicable clinical methods for the depiction of the MC when planning for endosseous implant surgeries. They are used to determine the height of bone available for the implant as the distance between the MC and the alveolar ridge [89]. The MC appears as a radiolucent conduit lined by radiodense margins. This cortication is variable, and the MC may not be clear in some cases [89-92]. CBCT is the best imaging modality for examining the MC, but there is significant variability in the visibility of the canal even within the same individual [89,90].

1.2.3.4 Mandibular third molar surgery

Exodontia of the mandibular third molar is the most widely performed oral and maxillofacial surgical procedure. A rare but serious complication associated with this surgery is a neurological injury the incidence of which ranges from 0.4 to 6% [93-95]. Injury to IAN is likely to occur when the mandibular third molar is located very close to the MC [96]. Imaging is the initial step in assessing the risk of IAN injury before surgery. CBCT has been widely adopted for use in this regard due to its 3D capability [97,98].

Precise knowledge of the relationship between the MC and the mandibular third molar roots can be a predictor of nerve injury in third molar surgery. Guang-zhou Xu [99], in a retrospective CBCT study of 537 mandibular third molar extractions in 318 patients in which the affected tooth was intersected by the MC, analyzed the relation between the site of the MC and the likelihood of injury to the IAN after extraction. The conclusion was that the risk of damage to the IAN increases when third molars and the MC intersect, especially on the nerve's buccal side.

1.2.3.5 Bone harvesting from the mandible and bone grafting

Implant site development using bone material is an established pre-prosthetic procedure. It involves bone block onlay graft and sinus lift procedures. For successful biological integration and prosthetic restorations, an implant must be placed in an optimal 3D position [100].

Autologous grafts are generally considered the gold standard among the different types of grafts due to the presence of osteoprogenitor cells along with growth factors, their lack of immunological reactions, and their osteoinductive and osteoconductive properties. Success rates have been reported to be as high as 95%[101,102]. Intraoral donor sites for ridge augmentation include the mandibular body, the ascending ramus, maxillary tuberosity, and the symphysis.

The ramus graft harvest is associated with fewer complications, decreased patient morbidity, and decreased post-operative aesthetic concerns compared to the other intraoral sites. Damage to the

IAN remains the greatest risk in harvesting a ramal graft [103-105]. Surgical access, the coronoid process, the molar teeth, and the MC limit the amount of bone that can be harvested from the ramus. The mandibular foramen is about 20mm from the anterior border of the ramus [106]. CBCT would be the best imaging modality for assessing these structures and establishing their exact locations preoperatively with proper surgical planning due to its 3D capability.

1.2.3.6 Endodontics

Damage or disruption of the IAN after endodontic treatment is possible in any area distal to the MF. The main causes are either overfilling or over instrumentation of the tooth canal and therefore encroachment into the MC. The associated neurosensory disturbances include anesthesia, hypoesthesia, hyperesthesia, paresthesia, and dysesthesia of the chin and lower lip. In a study of 378 CBCT images, Sharma et al [107] reported that the MC was in direct contact with the distal root of the second molar in 22.6% of the cases on the left and 23.5% of the cases on the right side of the mandible. Denio et al [108] showed that the tip of the longest root of the second molar is 3.7 mm from the superior border of the MC and the mesial root apices of the first molar are furthest from the MC by about 6.9 mm. Endodontic treatment of mandibular molars has a high risk of nerve damage, the second molar being most frequently involved. There is also minimal buccolingual mandibular bone width in the premolar region creating an increased risk for IAN damage during endodontic treatment of premolars due to a close relationship with the MC [109].

Incidences of IAN damage in endodontics can be greatly reduced by preprocedural assessment of the apical region and electronic length determination during treatment. CBCT presents an accurate 3D modality for assessment of the relationship between the root apices and the MC before endodontic treatment, especially in cases where plain and panoramic radiographs suggest a close relationship between the two. In cases where a patient presents with symptoms of IAN injury after endodontics, CBCT is the best imaging for diagnosing and assessing the extent of the injury.

1.3 PROBLEM STATEMENT

Iatrogenic injury to the inferior alveolar nerve (IAN) has been reported in oral and maxillofacial surgery, implantology, endodontics, and orthodontics. This occurs either due to variant anatomy or inappropriate surgical approach and/or technique. The result is a temporary loss of sensation in the area of distribution of the IAN. There is a need to have adequate knowledge of the anatomical landmarks around the nerve. These will include the mandibular foramen, mandibular canal (MC) and mental foramen (MF). This will ensure the desired outcome of surgery is obtained with minimal surgical complications.

Cone-beam computed tomography (CBCT) scan studies have shown significant individual anatomical variations of the course and terminal segment of IAN in different populations and ethnic groups. There is limited data on the MC in the Kenyan population. Only one Kenyan CBCT study by Gakonyo et al [11] is found in the literature search. Complex and complicated mandibular surgeries are routinely carried out without well-established basic morphometric reference points for the MC in the local population. This study sought to provide useful information to oral surgeons before commencing mandibular surgeries.

1.4 STUDY JUSTIFICATION

This study aimed to use cone-beam computed tomography (CBCT) scans to present a surgically relevant position of the mandibular canal (MC) in dentate patients from a select Kenyan population by quantifying the morphometric relationship of the MC to the buccal cortical plate (BCP), the lingual cortical plate (LCP), the inferior border of mandible (IBM), and the peri apex of specified teeth. This study also aimed to assess the presence and extent of the ALMN in the MF region in the same population.

The knowledge generated was expected to aid in surgical treatment planning, approaches, and techniques in mandibular surgeries adjacent to or involving the MC. This would enable surgeons to avoid inadvertent nerve injury. This study was also expected to enhance a general understanding of the subject while adding to the body of knowledge available on MC anatomy locally and internationally.

1.5 STUDY OBJECTIVES

1.5.1 BROAD OBJECTIVE

To investigate and document the normal morphology and variant anatomy of the mandibular canal in a select Kenyan population using cone beam computed tomography scans.

1.5.2 SPECIFIC OBJECTIVES

1. To determine the topographical course of the mandibular canal according to the Worthington [15] classification
2. To determine the presence of accessory mandibular canals and accessory mental foramina.

3. To measure the distance between the mandibular canal and the buccal cortical plate, lingual cortical plate, inferior border of mandible, second premolar root apex, first molar distal root apex, and second molar distal root apex.
4. To determine the position of the main mental foramen in relation to the second premolar.
5. To determine the presence and length of the anterior loop of the mental nerve.

1.6 STUDY VARIABLES

Table 2: Variables of the study

	Variable	**Measurement**
Independent variables	Age	Years
	Gender	Male/Female
	Side	Left/Right
Dependent variables	Course of the MC	Straight projection/ Progressive descent/ Catenary-like
	Diameter of MC at the apices of reference teeth	Millimeters
	Distance from MC to the apices of reference teeth	Millimeters
	Distance from MC to the BCP at the apices of reference teeth	Millimeters
	Distance from MC to the LCP at the apices of reference teeth	Millimeters
	Distance from MC to the IBM at the apices of reference teeth	Millimeters
	Position of the MF in relation to the second premolar	Anterior/ Below/ Posterior
	Distance from MF to the IBM	Millimeters
	Presence of the ALMN	Yes/No
	Length of the ALMN	Millimeters
	Presence of accessory MC	Yes/No
	Presence of accessory MF	Yes/No

MC – Mandibular canal, BCP – Buccal cortical plate, LCP – Lingual cortical plate, IBM – Inferior border of mandible, MF – Mental foramen, ALMN – Anterior loop of mental nerve

CHAPTER 2: MATERIALS AND METHODS

2.1 STUDY DESIGN

This was a retrospective descriptive cross-sectional cone-beam computed tomography (CBCT) study using quantitative techniques of data collection. The data included morphometric parameters of the mandibular canal (MC) or its variants.

2.2 STUDY AREA

The study was conducted at a private imaging facility called Dental and Maxillofacial Imaging Centre (DAMIC) located at General Accident House, along Ralph Bunche Road, Upper Hill, Nairobi, Kenya. This imaging facility serves a large number of hospitals and private dental clinics and is one among very few facilities offering CBCT imaging services in Kenya.

2.3 STUDY POPULATION

The sampling frame was approximately 13000 patients who had CBCT scans taken at DAMIC between January 2018 and February 2022.

2.4 SAMPLE SIZE DETERMINATION

Fischer's formular was used to calculate the sample size as follows:

$$n = \frac{Z^2 p\,(1 - p)}{d^2}$$

Where:

n = Sample size

Z = Standard normal deviate set at 1.96 which corresponds to a 95% confidence level

p = Proportion of the population estimated to present with accessory MC

d = Precision level = 0.05

The assumptions for this study were derived from a similar study of 122 implant patients by Naitoh et al [24], who found that 79 (65%) patients had BMC. Therefore:

$$n = \frac{1.96^2 \times 0.65\ (1 - 0.65)}{0.05 \times 0.05}$$

n = 350 hemi mandibular scans

2.5 INCLUSION CRITERIA

1. Age >20 years old.
2. Full mandibular arch CBCT scan.
3. Presence of at least 2 of the following 3 teeth: second premolar, first molar, and second molar.

2.6 EXCLUSION CRITERIA

1. Presence of supernumerary teeth, bone pathology, impacted teeth, or fractures obscuring visualization in the region of interest or changing the position of the MC or mental foramen (MF).

2.7 SAMPLING PROCEDURE

A non-probability sampling method was used. The sampling frame was CBCT images from the DAMIC's electronic database. To select the study images, a consecutive sampling method was used where when a sampled image did not meet the inclusion criteria, the next image in the sampling frame was selected until the calculated sample size was obtained.

2.8 DATA COLLECTION TOOLS

A data extraction form in a 2016 Microsoft Excel workbook was used to collect data (**Appendix 1**).

2.9 IMAGE ACQUISITION TECHNIQUE

A CS 9300® CBCT unit (Carestream Dental, Carestream Health Inc. 150 Verona St. Rochester NY 14608, USA) with a thin film transistor (TFT) sensor and charge-coupled device (CCD) detector technology was used to take all the images. The jaw program pane selected was single jaw full acquisition (10 x 5 cm) for lower jaw exam and voxel size of 180 micrometers. The tube current and voltage were 4 milliamperes (mA) and 85 or 90 kilovoltage (kV) respectively as per the manufacturer's recommendations. The CBCT unit height was adjusted and a chin guide was utilized while scanning to ensure that the occlusal plane was horizontal. The detector completed a full scan of the patient’s head in an average of 8.01 seconds.

CS Imaging software (Carestream Dental, Carestream Health Inc. 150 Verona St. Rochester NY 14608, USA) was used to capture, process, and store the original two-dimension (2D) projection views and the reconstructed three-dimension (3D) data. This data was obtained and used to reconstruct and analyze each jaw in the orthogonal plane using a computer CS 3D visualization and measurement software.

2.10 DATA COLLECTION PROCEDURE

2D images of various orthogonal planes of the mandible were reconstructed to 3D format on a 14-inch HP® (Hewlett-Packard Inc, Palo Alto, CA, USA) computer (diagonal FHD IPS anti-glare LED-backlit and 1920 x 1080 resolution) using CS 3D visualization and measurement software. A dark room was used for viewing to enhance visibility. The variables of the study were assessed, and attention was given to the selected reference points for purposes of standardization. Data collected was entered in the data extraction form. Both sides of the mandible were studied.

2.11 DATA ANALYSIS AND PRESENTATION

Data collected was managed using 2016 Microsoft Excel and analyzed using the Statistical Product and Service Solutions (SPSS) Statistics software version 24. The data was presented in tables. Categorical variables were summarized using percentages and frequencies. Continuous variables were summarized using the mean and standard deviation. Independent samples t-Test and chi-square test were used to analyze the distance between the MC and the buccal cortical plate (BCP), lingual cortical plate (LCP), inferior border of mandible (IBM), root apex of the second premolar, distal root apex of the molar and distal root apex of the second molar to determine whether there was a statistically significant difference between males and females. A p-value <0.05 was considered statistically significant.

2.12 MINIMIZING ERRORS AND BIASES

All measurements on the sampled CBCT images were carried in the orthogonal plane out by the principal investigator after training and familiarization in manipulating the software and taking morphometric measurements. A pilot analysis of 35 CBCT images (10% of the sample size) meeting the inclusion/exclusion criteria was done by the principal investigator for familiarization. The same 35 CBCT images were analyzed by Dr. F. Opondo, a consultant oral and maxillofacial radiologist and lecturer at the University of Nairobi School of Dental Sciences, for calibration of the principal investigator. To assess inter-observer variability, every 35th CBCT image had repeat morphometric measurements done by Dr. F. Opondo. An overall intraclass correlation coefficient (ICC) of 0.989 ($p < 0.001$) demonstrated excellent agreement of the measurements for inter-observer variability.

2.13 STUDY LIMITATIONS

1. The study was carried out in a private CBCT imaging facility. This limited the ability to make inferences in the general population based on the results of this study.
2. Systemic medical conditions afflicting the patients that could have affected the bone quality and quantity were not known.
3. The observational nature of the study could not allow for an objective assessment of age changes in the mandibular canal.
4. Standardization could not be done to the extent of the same radiographer having taken all the CBCT scans.

2.14 ETHICAL CONSIDERATIONS

Ethical approval for this study was sought and obtained from the Kenyatta National Hospital/University of Nairobi Ethics, Research and Standards committee (**Appendix 2**). Permission to carry out the study was sought from DAMIC Nairobi (**Appendix 3**). Patients were not required to participate in this study, rather, only their radiological records were assessed to obtain demographic data and CBCT images. Collected data was captured in a data extraction form with each set of data allocated a serial number. Confidentiality was observed and there was no patient identification information in the data extraction form.

CHAPTER 3: RESULTS

3.1 DEMOGRAPHIC CHARACTERISTICS

A total of 351 hemi mandibular cone-beam computed tomography (CBCT) scans from 202 patients that met the inclusion criteria were retrieved and included in this study. 142 scans were from 81 (40.1%) male and 209 scans were from 121 (59.9%) female patients (**Table 5**). The male to female ratio was 0.7:1. The mean age was 40.4±14.2 years with a minimum age of 20 years and a maximum age of 74 years. The median age was 39 years (IQR 28.0 – 50.0). There were 180 (51.3%) right side and 171 (48.7%) left side scans.

Table 3: Distribution of patients by age group and gender

Age Groups (Years)	**Male**		**Female**		**Total**	
	n	**%**	**N**	**%**	**n**	**%**
20 – 29	21	25.9	35	28.9	56	27.7
30 – 39	19	23.5	30	24.8	49	24.3
40 – 49	16	19.8	27	22.3	43	21.3
50 – 59	12	14.8	17	14.0	29	14.4
≥60	13	16.0	12	9.9	25	12.4
Total	81	100	121	100	202	100

3.2 COURSE OF THE MANDIBULAR CANAL

All 3 variations in the course of the mandibular canal (MC) were observed in this study. The progressive descent type was seen in 241 (68.7%), the catenary-like type in 77 (21.9%), and the straight projection type in 33 (9.4%) scans (**Figure 2**).

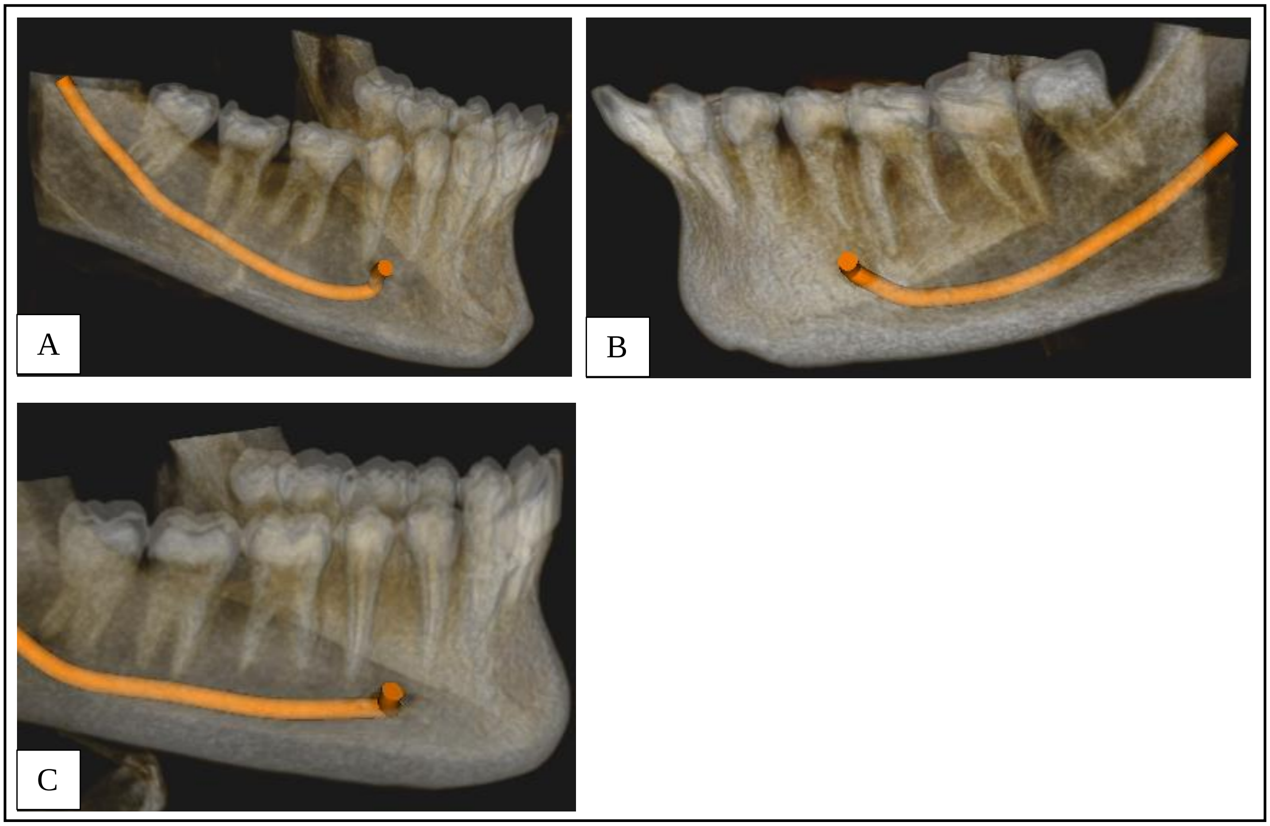

Figure 2: Sample images from the study showing CBCT reconstructions of the mandible with nerve tracings showing variations in the course of MC observed: **A** – Progressive descent, **B** – Catenary-like, **C** – Straight projection

A comparison of the course of the MC between the males and females was done (**Table 6**). Chi-square test showed there was no statistically significant difference in the course of the MC between the genders.

Table 4: Distribution of mandibular canal course according to gender

	Present, *n (%)*	**Absent,** *n (%)*	χ^2**, df, p-value**
Catenary-like			
Male scans	26 (33.8)	116 (42.3)	1.83, 1, **0.176**
Female scans	51 (66.2)	158 (57.7)	
Progressive descent			
Male scans	98 (40.7)	44 (40.0)	0.014, 1, **0.906**
Female scans	143 (59.3)	66 (60.0)	
Straight projection			
Male scans	18 (54.5)	124 (39.0)	3.00, 1, **0.083**
Female scans	15 (45.5)	194 (61.0)	

3.3 OCCURRENCE OF ACCESSORY MANDIBULAR CANALS AND ACCESSORY MENTAL FORAMINA

Accessory MC were observed in 15 (4.3%) out of 351 CBCT scans studied (**Figure 3**). Of these 5 (33.3%) were males and 10 (66.7%) were females. The probability of this observation was assessed using chi-square test and no statistically significant difference was found (χ^2**, df, p** = 0.330, 1, **0.566**).

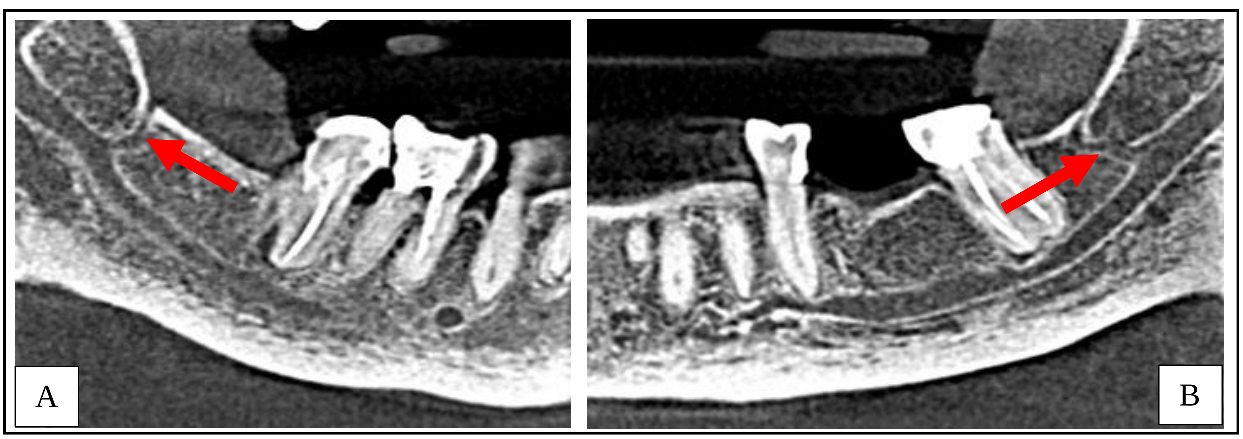

Figure 3: Sample images from the study showing CBCT reconstructions of **A** – Right mandible and **B** – Left mandible demonstrating accessory MCs observed

The main mental foramen (MF) was observed on all 351 CBCT scans studied. Accessory MF were observed in 29 (8.3%) out of the 351 scans (**Figure 4**). Of these, 11 (37.9%) were male and 18 (62.1%) were female. The probability of this observation was assessed using chi-square test and no statistically significant difference was found (**χ^2, df, p** = 0.084, 1, 0.772).

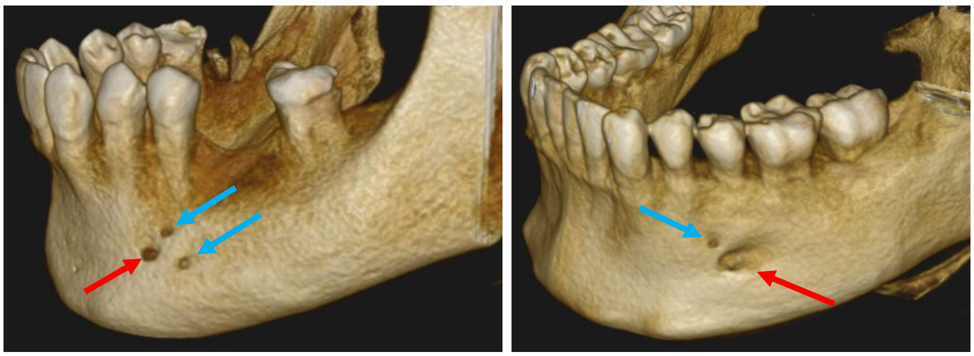

Figure 4: Sample images from the study showing CBCT reconstructions of the mandible demonstrating the main MF and accessory MF observed

Only one CBCT scan showed both accessory MC and accessory MF in the same patient. The relationship between accessory MC and accessory MF was assessed using the chi-square test and no statistically significant difference was found (p = 1.000) (**Table 7**).

Table 5: Presence of accessory Mandibular Canals and accessory Mental Foramina

		Accessory MF		
		Yes, *n (%)*	**No**, *n (%)*	**χ^2, df, p-value**
Accessory MC	**Yes**	1 (3.4)	14 (4.3)	0.053, 1, **1.000**
	No	28 (96.6)	308 (95.7)	

3.4 DIAMETER OF THE MANDIBULAR CANAL

The diameter of the MC was measured at 3 different reference points on both male and female CBCT scans (**Figure 5**). The mean diameter was 3.38±0.39mm at the root apex of the second premolar, 3.33±0.37mm at the distal root apex of the first molar, and 3.37±0.39mm at the distal root apex of the second molar. The overall mean diameter of the MC was 3.36±0.39mm

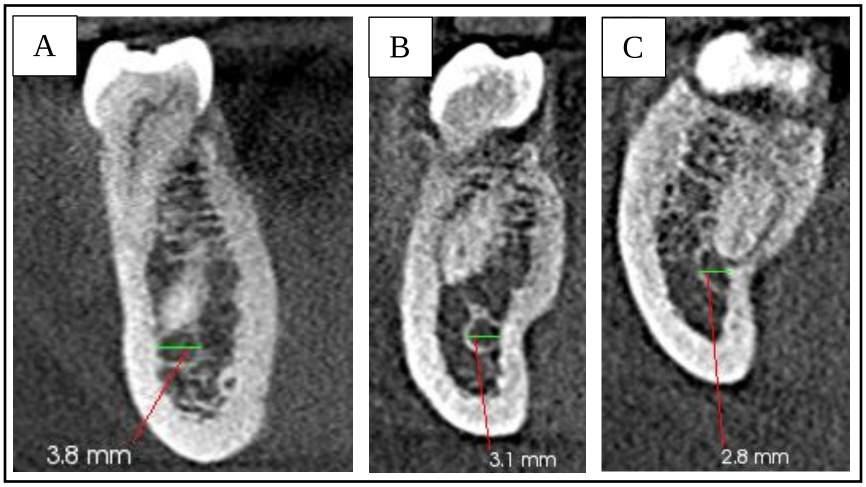

Figure 5: Sample images from the study showing the diameter of the MC as measured at **A** – 2nd premolar root apex, **B** – 1st molar distal root apex, and **C** – 2nd molar distal root apex.

A comparison of the diameter of the MC between males and females was done and found to be greater in males at all reference points (**Table 8**). Independent samples t-Test showed there was a statistically significant difference between the genders at all reference points.

Table 6: Comparison of the diameter of the mandibular canal between males and females

Diameter (mm) of MC at:	**Mean±SD**	**Male±SD**	**n**	**Female±SD**	**n**	**t, df, p**
Root apex of 2nd premolar	3.38±0.39	3.47±0.43	115	3.32±0.36	170	3.25, 283, **0.002**
Distal root apex of 1st molar	3.33±0.37	3.42±0.37	125	3.26±0.35	178	3.86, 301, <**0.001**
Distal root apex of 2nd molar	3.37±0.39	3.48±0.41	136	3.29±0.37	195	4.32, 329, <**0.001**

3.5 DISTANCE BETWEEN THE MANDIBULAR CANAL AND ROOT APICES

The distance between the MC and root apices of reference teeth was measured on both male and female CBCT scans (**Figure 6**). The mean distance to the root apex of the second premolar was 4.05±2.10mm, to the distal root apex of the first molar was 6.00±2.73mm and to the distal root apex of the second molar was 3.20±2.25mm.

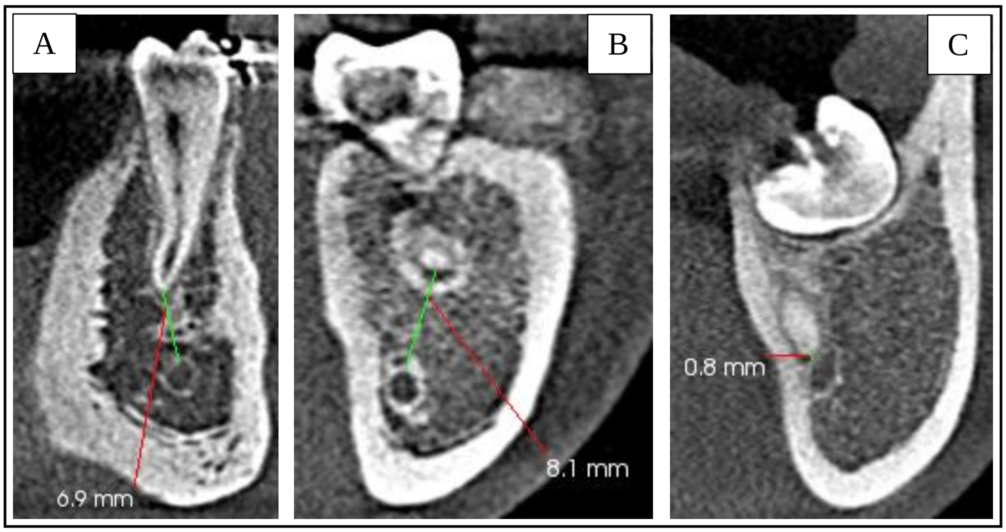

Figure 6: Sample images from the study showing the distance as measured from the MC to **A** – 2nd premolar root apex, **B** – 1st molar distal root apex, and **C** – 2nd molar distal root apex.

A comparison of the distance from the MC to the root apices of reference teeth between males and females was done and found to be longer in males at all points (**Table 12**). Independent samples t-Test showed there was a statistically significant difference in the distance from the MC to the root apex of the 2nd premolar and the distal root apex of the 2nd molar between the genders. There was no statistically significant difference in the distance from the MC to the distal root apex of the 1st molar between the genders.

Table 7: Comparison of the distance from the mandibular canal to the root apices of reference teeth between males and females

Distance (mm) from MC to:	Mean±SD	Male ±SD	n	Female±SD	n	t, df, p
Root apex of 2nd premolar	4.05±2.10	4.44±2.41	115	3.79±1.81	170	2.61, 283, **0.014**
Distal root apex of 1st molar	6.00±2.73	6.19±3.00	125	5.86±2.51	178	1.02, 301, **0.325**
Distal root apex of 2nd molar	3.20±2.25	3.56±2.42	136	2.95±2.10	195	2.46, 329, **0.014**

3.6 DISTANCE FROM THE MANDIBULAR CANAL TO THE BUCCAL CORTICAL PLATE

The distance between the MC and BCP at the root apices region of reference teeth was measured on both male and female CBCT scans (**Figure 7**). The mean distance at the root apex of the second premolar was 4.24±1.51mm, at the distal root apex of the first molar was 6.36±1.75mm and at the distal root apex of the second molar was 5.94±1.84mm.

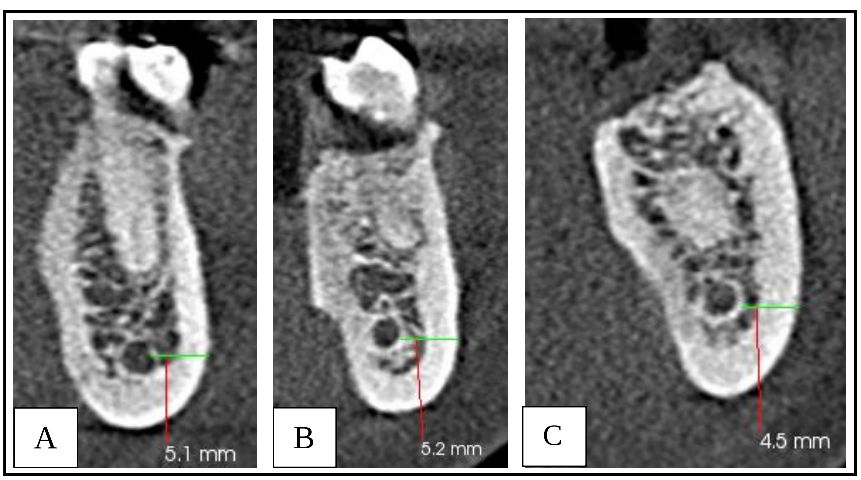

Figure 7: Sample images from the study showing the distance as measured from the MC to BCP at **A** – 2nd premolar root apex, **B** – 1st molar distal root apex, and **C** – 2nd molar distal root apex.

A comparison of the distance from the MC to the BCP at root apices of reference teeth between the genders was done and found to be larger in males than females (**Table 13**). Independent samples t-Test showed there was a statistically significant difference in the distance from the MC to the BCP at the root apex of all the reference teeth.

Table 8: Comparison of the distance from the mandibular canal to the buccal cortical plate between the genders

Distance (mm) from MC to BCP at:	**Mean±SD**	**Male±SD**	**n**	**Female±SD**	**n**	**t, df, p**
Root apex of 2nd premolar	4.24±1.51	4.78±1.56	115	3.88±1.37	170	5.14, 283, **<0.001**
Distal root apex of 1st molar	6.36±1.75	6.75±1.83	125	6.09±1.64	178	3.31, 301, **0.001**
Distal root apex of 2nd molar	5.94±1.84	6.20±1.82	136	5.75±1.84	195	2.20, 329, **0.028**

3.7 DISTANCE FROM THE MANDIBULAR CANAL TO THE LINGUAL CORTICAL PLATE

The distance between the MC and LCP at root apices of reference teeth was measured on both male and female CBCT scans (**Figure 8**). The mean distance at the root apex of the second premolar was 6.44±2.24mm, at the distal root apex of the first molar was 3.34±1.63mm and at the distal root apex of the second molar was 3.23±1.46mm.

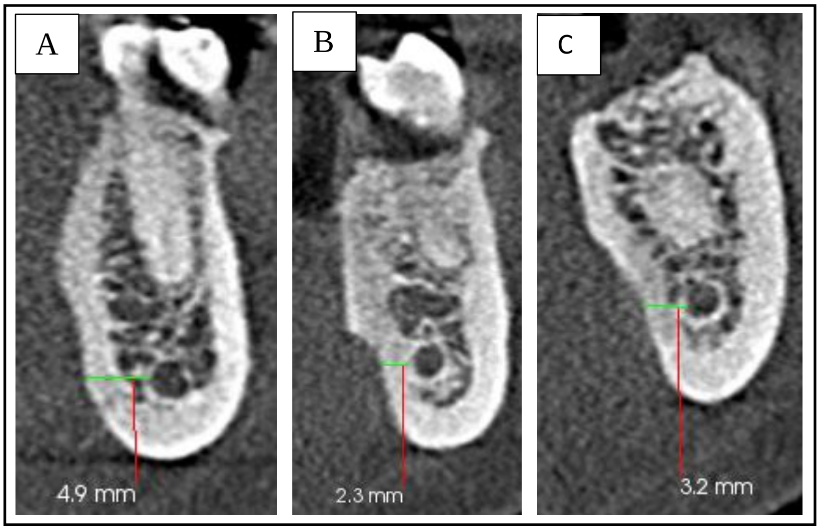

Figure 8: Sample images from the study showing the distance as measured from the MC to LCP at **A** – 2nd premolar root apex, **B** – 1st molar distal root apex, and **C** – 2nd molar distal root apex.

A comparison of the distance from the MC to the LCP at root apices of reference teeth between the genders was done and found to be shorter in males than females except at the distal root apex of the first molar (**Table 14**). Independent samples t-Test showed that this observation at the distal root apex of the first molar was not statistically significant. There was a statistically significant difference in the distance from the MC to the LCP at the distal root apex of the second molar.

Table 9: Comparison of the distance from the mandibular canal to the lingual cortical plate between the genders

Distance (mm) from MC to LCP at:	**Mean±SD**	**Male ±SD**	**n**	**Female±SD**	**n**	**t, df, p**
Root apex of 2nd premolar	6.44±2.24	6.36±2.39	115	6.49±2.13	170	-0.457, 283, **0.648**
Distal root apex of 1st molar	3.34±1.63	3.35±1.80	125	3.33±1.50	178	0.090, 301, **0.928**
Distal root apex of 2nd molar	3.23±1.46	3.04±1.50	136	3.36±1.41	195	-1.99, 329, **0.048**

3.8 DISTANCE FROM THE MANDIBULAR CANAL TO THE INFERIOR BORDER OF MANDIBLE

The distance between the MC and IBM at root apices of reference teeth was measured on both male and female CBCT scans (**Figure 9**). The mean distance at the root apex of the second premolar was 8.31±1.90mm, at the distal root apex of the first molar was 6.78±1.92mm and at the distal root apex of the second molar was 6.88±2.19mm.

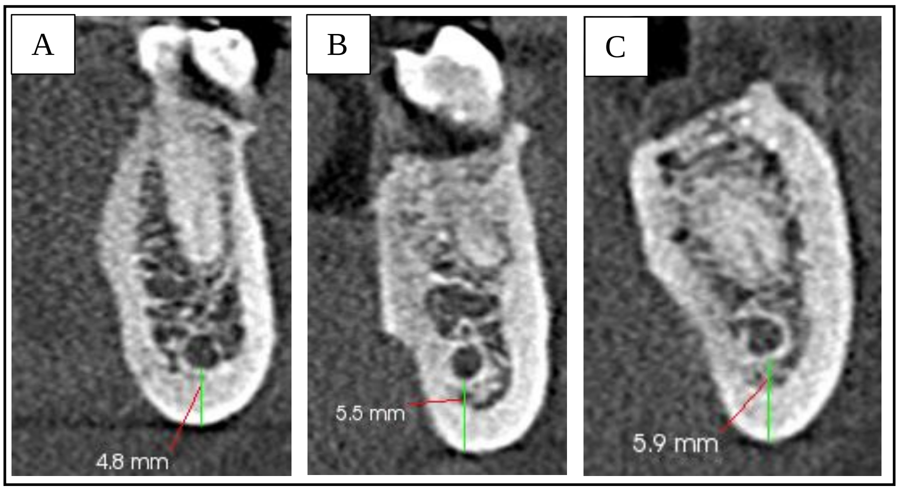

Figure 9: Sample images from the study showing the distance as measured from the MC to IBM at **A** – 2nd premolar root apex. **B** – 1st molar distal root apex and **C** – 2nd molar distal root apex.

A comparison of the distance from the MC to the IBM at root apices of reference teeth between males and females was done and found to be longer in males than females (**Table 15**). Independent samples t-Test showed there was a statistically significant difference in the distance from the MC to the IBM at the root apex of the 2nd premolar between the genders. There was no statistically significant difference in the distance from the MC to the IBM at the distal root apex of the 1st molar and the distal root apex of the 2nd molar.

Table 10: Comparison of the distance from the mandibular canal to the inferior border of mandible between males and females

Distance (mm) from MC to IBM at:	Mean±SD	Male±SD	n	Female±SD	n	t, df, p
Root apex of 2nd premolar	8.31±1.90	8.79±2.00	115	7.98±1.75	170	3.62, 283, **<0.001**
Distal root apex of 1st molar	6.78±1.92	6.99±2.12	125	6.64±1.76	178	1.57, 301, **0.119**
Distal root apex of 2nd molar	6.88±2.19	6.97±2.25	136	6.81±2.14	195	0.63, 329, **0.528**

3.9 POSITION OF THE MAIN MENTAL FORAMEN IN RELATION TO THE SECOND PREMOLAR

The most frequent position of the main MF in relation to the second premolar was anterior (187, 53.3%), followed by below (121, 34.5%) and the least frequent position was posterior (43, 12.3%) (**Figure 10**).

Figure 10: Sample images from the study showing the different positions of the main MF in relation to the second premolar observed: **A** – Anterior, **B** – Below, **C** – Posterior

A comparison of the position of the main MF in relation to the second premolar between males and females was done (**Table 16**). Chi-square test showed there was no statistically significant difference in the position of the MF in relation to the second premolar between the genders.

Table 11: Position of the mental foramen in relation to the second premolar according to gender

	Present, *n (%)*	**Absent,** *n (%)*	χ^2**, df, p**
Anterior			
Male scans	82 (43.9)	60 (36.6)	1.91, 1, **0.166**
Female scans	105 (56.1)	104 (63.4)	
Below			
Male scans	42 (34.7)	100 (43.5)	2.53, 1, **0.112**
Female scans	79 (65.3)	130 (56.5)	
Posterior			
Male scans	18 (41.9)	124 (40.3)	0.04, 1, **0.841**
Female scans	25 (58.1)	184 (59.7)	

3.10 DISTANCE FROM MF TO IBM

The distance between the MF and IBM was measured on both male and female CBCT scans (**Figure 11**). The mean distance from the MF to the IBM was 12.17±1.91mm.

Figure 11: Sample images from the study showing the distance as measured from the MF to the IBM **A** – Right side, **B** – Left side

A comparison of the distance from the MF to the IBM between the genders was done and found to be longer in males than females (**Table 17**). Independent samples t-Test showed there was a statistically significant difference in the distance from the MF to the IBM between the genders.

Table 12: Comparison of the distance from the mental foramen to the inferior border of mandible between the genders

	n	Mean±SD	t, df, p
Male scans	142	13.2±1.8	9.85, 349, **<0.001**
Female scans	209	11.4±1.6	

3.11 PRESENCE AND LENGTH OF THE ANTERIOR LOOP OF THE MENTAL NERVE

The ALMN was observed in 18 (5.1%) out of 351 CBCT scans studied (**Figure 12**). Of these 18 scans, 6 (33.3%) were male patients and 12 (66.7%) were female patients. The probability of this observation was assessed using chi-square test and no statistically significant difference was found (**χ^2, df, p-value** = 0.40, 1, **0.527**).

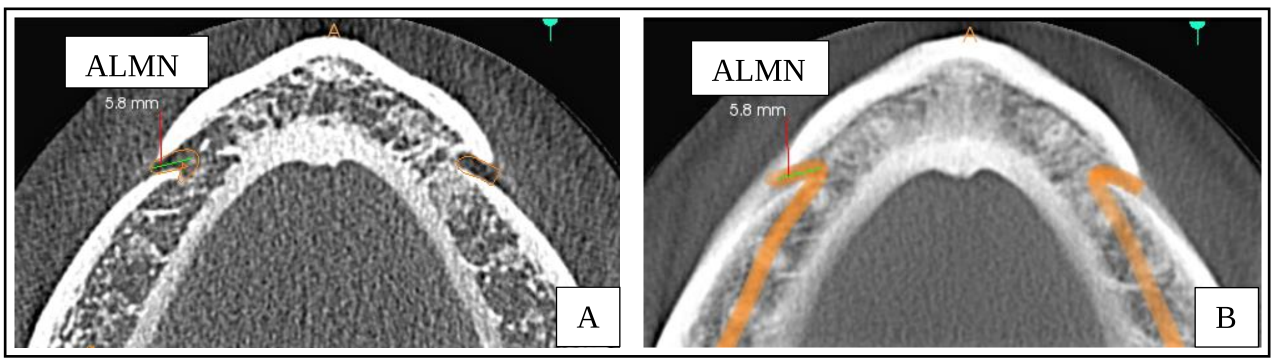

Figure 12: Sample images from the study showing CBCT reconstructions of the mandible demonstrating the anterior loop of the mental nerve (ALMN) **A** – voxel size 180µm, **B** – voxel size 7.7mm

The mean length of the ALMN was measured and found to be 4.83mm ± 0.89. A comparison of the length of the ALMN between the males and females was done (**Table 18**) and independent samples t-Test showed there was no statistically significant difference in the length of the ALMN between the genders.

Table 13: Comparison of the length of the anterior loop of the mental nerve between males and females

	n	**Mean±SD**	**t, df, p**
Male	6	4.6±1.1	-0.76, 16, **0.458**
Female	12	4.9±0.8	

CHAPTER 4

4.1 DISCUSSION

This study sought to use cone-beam computed tomography (CBCT) scans to document a surgically relevant position of the mandibular canal (MC), its variants, and related anatomical structures in dentate patients over 20 years old. It was conducted at Dental and Maxillofacial Imaging Centre (DAMIC), Nairobi, Kenya, and included 351 hemi mandibular CBCT scans taken between January 2018 and February 2022. These CBCT scans had been taken for diagnostic purposes.

4.1.1 COURSE OF THE MANDIBULAR CANAL

The most frequently observed course of the MC was the progressive descent type with a prevalence of 68.7% in the study population. This finding is similar to that from a Nepalese study of 150 CBCT scans that reported the progressive descent type as the most common course of the MC [111]. The progressive descent type is not favorable for placement of implants in the second molar region as the MC is closest to the root apices and at risk of inadvertent encroachment.

The catenary-like type was the second most common course observed with a prevalence of 21.9%. In contrast to this finding, Ozturk et al [13] reported the catenary-like type as the most prevalent course type in an American study of 52 adult dry skulls. The catenary-like type provides the most amount of space for implant placement especially in the first molar region.

The least observed course was the straight projection type with a prevalence of 9.4%. Contrary to this finding, Vieira et al [110], in a Brazilian CBCT study, reported the most frequent MC course to be the straight projection type. It is important to point out that the straight projection type is least favorable for placement of implants posterior to the mental foramen (MF).

These findings demonstrate a clear variation in the prevalence of the courses of the MC based on the population being studied, a fact that should be taken into account by surgeons operating in different geographical areas. There was no statistically significant difference in the occurrence of any of the courses of the MC between males and females. This finding is in line with similar findings by Mirbeigi S et al [6] who found no relationship between gender and the pattern of the MC course.

4.1.2 OCCURRENCE OF ACCESSORY MANDIBULAR CANALS AND ACCESSORY MENTAL FORAMINA

The prevalence of accessory MC in this study was 4.3%. Previous studies have shown the prevalence of accessory MC to range from 0.80% to 65% [22,24] (**Table 1**). Gakonyo et al [11], in a CBCT scan study carried out at a private dental clinic in Kenya, reported the prevalence of bifid mandibular canals (BMC) in 800 scans to be 3.25%. This finding is consistent with the results from this study of a relatively low prevalence of accessory MC in select Kenyan populations.

The presence of accessory MC is potentially a cause of inadequate anesthesia following administration of an inferior alveolar nerve (IAN) block. Third molar disimpaction, bilateral sagittal split ramus osteotomy (BSSRO), and bone harvesting in the ramus are procedures that carry an inherent risk of causing damage to an accessory MC that ends in a retromolar foramen. Iatrogenic injury to these accessory neurovascular structures will often lead to bleeding, paresthesia, and neuroma formation. Knowledge of the prevalence of accessory MC in the local population and their identification using correct imaging modalities is an important component of safe surgical practice.

This study considered all foramina occurring around the main MF to be accessory MF and found their prevalence was 8.3%. In contrast, Sawyer D et al [113] reported a lower prevalence of accessory MF in various ethnic groups as follows: 1.5% among Russians; 3.0% among Hungarians; 2.6% among French; 5.7% among Black Americans; 1.4% among White Americans; 3.3% among Greeks; and 3.6% among Egyptians. Locally, Gakonyo et al [11] in his study of 800 CBCT scans also found a lower prevalence of double MF of 2.4% compared to the current study. Japanese population studies have however showed that accessory MF are more prevalent, ranging from 6.7 to 12.5% [114], findings in keeping with those of this study. Sharma V et al [107] also reported a higher prevalence of accessory MF of 6.46% out of 378 CBCT scans.

The MF is an important anatomical landmark for procedures such as incisive and mental nerve blocks. Locating its precise position is very important when placing endosseous implants in the premolar region. When accessory MF are present, the neurovascular structures that pass through the MF will ramify and follow the alternative courses present. Knowledge of the presence of accessory MF is important when carrying out peripheral neurectomy for neuropathic pain syndromes. Failure to identify and include accessory mental nerves during this procedure is a common cause of persistent pain post-operatively in the area of distribution of the mental nerve. From the findings of this study, it is clear that there are variations in the prevalence of accessory MF in different populations.

4.1.3 MORPHOMETRY OF THE MANDIBULAR CANAL

In the current study, the average diameters of the MC at the root apices regions of the second premolar, first molar, and second molar were 3.38mm, 3.33mm, and 3.37mm respectively. The overall mean diameter of the MC was 3.36mm. These findings are in line with findings by Ikeda et al [115] who reported the average diameter of the MC to be 3.4mm. In contrast, Hamid et al [116] reported smaller diameters of the MC of 2.7mm on CT scan measurement and 2.9mm on electronic digital calipers measurement of sections of five adult Sudanese cadaveric mandibles. The variance from the current study could be attributed to the cadaver mandibles undergoing some degree of shrinkage resulting in the smaller values. Differences in body sizes between the populations considered may also be a contributing factor.

Knowledge of the MC diameter is necessary for avoiding nerve damage during endosseous implant placement, sagittal split ramus osteotomies, and monocortical screw placement. Several diseases of the bone can affect the MC diameter by increasing or decreasing its size as seen in osteolytic malignant diseases and lesions exhibiting perineural spread [117]. Metastasis is an issue of great concern with regards to malignancies and in the mandible, the MC can act as a conduit for malignancy to spread along its course. Any changes in the diameter of the MC in a cancer patient should be taken into account when planning resection margins. Knowledge of the actual diameter of the MC will help in detecting any abnormal changes in its size.

This study found that the MC was closest to the distal root of the second molar and furthest from the distal root of the first molar. This finding suggested a catenary-like course of the MC with the implication that morphometric assessment of the course of the MC may be more objective than the observational assessment that was done. Further inference from this finding is that longer endosseous implants can be placed in the body of the mandible region compared to the mental and angle of mandible areas. Komal A et al [119], in a CBCT study on an Indian population, reported similar findings, noting that mandibular third molar roots bilaterally were in the closest relationship to the MC and the distance gradually increased to a maximum on both sides in the first molar region then tapered anteriorly towards the MF. Sharma V et al [107] on the other hand reported the MC being closest to the roots of the second molar but noted the distance between the MC and periapex of mandibular teeth increased gradually anteriorly with the longest distance being from the periapex of the second premolar to the MC. This is consistent with a progressive descent course and may suggest that the difference from the current study constitutes ethnic differences in anatomical structures between the study populations.

Vazquez et al [118] recommended a minimum 2mm safety margin above the MC during insertion of posterior mandibular endosseous implants to avoid iatrogenic damage to neurovascular structures. Findings from this study concur with this recommendation considering the shortest mean distance measured from the root apex to the MC was 3.20mm. Comparison of the distance from the MC to the peri apex of teeth between males and females showed longer distances in males than females, a finding that was statistically significant at the second premolar and the second molar root apices. This may imply that the masculine mandible is generally larger than the feminine mandible and can therefore accommodate longer endosseous implants.

This study found the buccal cortical plate (BCP) was furthest from the MC at the distal root apex of the first molar and closest at the apex of the second premolar. On the other hand, the lingual cortical plate (LCP) was closest to the MC at the distal root apex of the second molar and furthest at the apex of the second premolar. These findings are in keeping with other studies in the assertion that the MC orientation is more lingual towards the angle of the mandible and more buccal towards the MF [14, 119, 120, 121].

The buccolingual orientation of the MC is an important parameter that requires in-depth analysis before mandibular surgical procedures. In surgical split ramus osteotomy, before the distal vertical osteotomy cut is made in the first molar region, there has to be precise knowledge of the exact distance between the BCP and the outer border of the MC. This knowledge will guide the depth of the osteotomy cut to avoid inadvertent encroachment into the MC and injury to the neurovascular bundle. When using monocortical plates in the mandible, knowledge of the precise distance between the BCP and the MC would be essential in preventing encroachment on the neurovascular structures. Similarly, the decision to orient an endosseous implant either buccally or lingually to avoid encroachment into the canal is largely dependent on knowledge of the buccolingual thickness of the mandible and the position of the MC in relation to the BCP and LCP.

A comparison of the buccolingual orientation of the MC between the genders revealed the distance from the MC to the BCP to be longer in males than females at all reference points, a statistically significant finding. Conversely, the distance from the MC to the LCP was longer in females than males at two out of three reference points. This finding was however not statistically significant. It is therefore not possible to make the definitive conclusion that the MC is oriented closer to one cortex than the other in males compared to females in this study as some of the differences were not statistically significant.

This study found that the distance between the MC and the inferior border of mandible (IBM) progressively increased from posterior to anterior. This finding was consistent between the genders. Males however demonstrated longer distances, a finding that was only statistically significant at the root apex of the second premolar ($p < 0.001$). Similar to this study, Shrestha et al [111] reported the shortest distance between the MC and the IBM was at the second mandibular molar region while Nemati et al [122] reported the longest distance to be at the level of the MF.

For purposes of standardization and reproducibility in this study, the measurement of the distance from the MC to the IBM was done on a perpendicular line from the MC to the nearest cortex below the MC. In some instances, the lower point may not have corresponded with the IBM in that region, therefore, giving a shorter record of the distance. Nonetheless, surgeons must possess a good understanding of the position of the MC relative to the IBM as, during mandibular plating procedures, inappropriate positioning of the plate could lead to encroachment into the MC and neurovascular damage.

4.1.4 MORPHOLOGY OF THE MENTAL FORAMEN

This study found that in 53.3% of the scans, the MF was anterior to the second premolar. 34.5% of the scans showed that the MF was below the second premolar. The least common position of the MF was posterior to the second premolar at 12.3%. There was no statistically significant difference in the position of the MF between males and females. Moiseiwitsch et al [17] in a North American Caucasian population and Mbajiorgu [20] in a black Zimbabwean population concluded that the MF was commonly located anterior to the second premolar, findings in agreement with the current study. On the other hand, Shankland [18] in an Asian Indian population and Oguz [19] in a Turkish population reported that the MF was located most of the time directly below the second premolar. Locally, Mwaniki D [21] and Loyal P et al [123] reported the mental nerve to be directly below the second premolar in contrast to the current study. It is worth noting however that the sample sizes in both studies were significantly smaller than that of the current study and this may have played a role in the varied findings. Nonetheless, these results, as in other similar studies, indicate ethnic and racial differences in the position of the MF.

The tooth position of the MF provides a quick landmark to the surgeon or anesthetist in identifying the mental nerve and administering a mental nerve block. However, aberrant tooth positions do exist and can lead to failed anesthesia when tooth position is used as the only guide in administering a mental block. Surgeons would do well to have epidemiological knowledge of the position of the MF in their local populations. Nonetheless, a radiographic guide remains an important tool in localizing the MF.

The mean distance from the MF to the IBM in this study was 12.17mm. Loyal et al [123] in a Kenyan cadaveric study, Sheikhi et al [124] in a CBCT study on an Iranian population, and Neiva et al [39] in a Caucasian American dry skull all reported distances with minimal variance from that of the current study. The distance was longer in males than in females, a statistically significant finding. This finding of gender dimorphism in the distance between the MF and IBM is in agreement with findings from several other studies [124 – 129].

Knowledge of the morphometric relationship of the MF to surrounding landmarks is important in implant surgery especially when the reference teeth are missing. Other important morphometric parameters that may form a key area of radiographic research in the local population are distances from the MF to the symphysis and the alveolar crest. With average values of these distances, one may not have to rely solely on imaging or reference teeth in planning treatment where these are not available.

4.1.5 THE ANTERIOR LOOP OF THE MENTAL NERVE

The anterior loop of the mental nerve (ALMN) was observed in 5.1% of the CBCT scans studied with an average length of 4.83mm. The prevalence of the ALMN has been reported to range from 0% [130] to 88% [39]. A maximum length of 11mm [39] has been reported. These findings indicate the diversity of the ALMN among different ethnic groups.

Iatrogenic damage to the ALMN can lead to discomfort of unspecified duration in the lower labial gingiva and lip. Damage rates to the ALMN have been reported in the range of 17 – 38% during genioplasty [45,46] and 8.5 – 24% when placing implants [47-50]. A safer option proposed by Muhammad A. Bobat et al [44] is an observance of a 5mm safety zone or use of shorter implants when it comes to implant placement anterior to the MF. Findings from the current study agree with this proposal considering the mean length of the ALMN was 4.83mm. However, observing a fixed distance anterior to the MF is not safe, and the ALMN length should be determined for each individual to avoid injury to the mental nerve. CBCT scans allow for assessment of the mandible with precision and reliability in determining the presence and length of the ALMN [40-43].

4.2 CONCLUSIONS

1. The progressive descent and straight projection types were the most and least common courses of the MC encountered respectively.
2. Accessory MC and accessory MF had a low prevalence and did not invariably occur together.
3. The orientation of the MC was more lingual towards the angle of the mandible and more buccal towards the MF.
4. The predominant position of the MF was anterior to the second premolar.
5. The average length of the ALMN was clinically significant but its occurrence was low.

4.3 RECOMMENDATIONS

1. To fully understand the anatomic variations of the MC, there is a need for multicentric studies with properly defined anatomical landmarks to quantify and precisely predict these variations.

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APPENDICES

APPENDIX 1: DATA EXTRACTION FORM

Serial Number: ___________

Age: ____________

Gender: ___________

SIDE	RIGHT	LEFT
Course of MC (Straight/Progressive descent/Catenary)		
Presence of accessory MC (Yes/No)		
Diameter of MC at root apex of 2nd premolar (mm)		
Diameter of MC at distal root apex of 1st molar (mm)		
Diameter of MC at distal root apex of 2nd molar (mm)		
Distance from MC to 2nd premolar apex (mm)		
Distance from MC to 1st molar distal root apex (mm)		
Distance from MC to 2nd molar distal root apex (mm)		
Distance from MC to BCP at root apex of 2nd premolar (mm)		
Distance from MC to BCP at distal root apex of 1st molar (mm)		
Distance from MC to BCP at distal root apex of 2nd molar (mm)		
Distance from MC to LCP at root of apex 2nd premolar (mm)		
Distance from MC to LCP at distal root apex of 1st molar (mm)		
Distance from MC to LCP at distal root apex of 2nd molar (mm)		
Distance from MC to IBM at root apex of 2nd premolar (mm)		
Distance from MC to IBM at distal root apex of 1st molar (mm)		
Distance from MC to IBM at distal root apex of 2nd molar (mm)		
Presence of accessory MF (Yes/No)		
Position of the MF in relation to the 2nd premolar (Anterior/Below/Posterior)		
Distance from MF to the IBM (mm)		
Presence of ALMN (Yes/No)		
Length of ALMN (mm)		

APPENDIX 2: ETHICS APPROVAL 1

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Ref: KNH-ERC/A/244

8th July, 2021

Dr. Okiriamu Andrew Ideidei
Reg. No.V60/7605/2017
Det. Of Oral and Maxillofacial Surgery
School of Dental Sciences
College of Health Sciences
University of Nairobi

KENYATTA NATIONAL HOSPITAL APPROVED 08 JUL 2021 KNH/UoN-ERC

Dear Dr. Okiriamu

RESEARCH PROPOSAL: MORPHOLOGY AND VARIANT ANATOMY OF THE MANDIBULAR CANAL IN A KENYAN POPULATION: A CONE BEAM COMPUTED TOMOGRAPHY STUDY (P225/04/2021)

This is to inform you that the KNH- UoN Ethics & Research Committee (KNH- UoN ERC) has reviewed and **approved** your above research proposal. The approval period is 8th July, 2021 – 7th July, 2022.

This approval is subject to compliance with the following requirements:

i. Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
ii. All changes (amendments, deviations, violations etc.) are submitted for review and approval by KNH-UoN ERC before implementation.
iii. Death and life threatening problems and serious adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH-UoN ERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH- UoN ERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from KNH- UoN ERC for each batch of shipment.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (Attach a comprehensive progress report to support the renewal).
vii. Submission of an executive summary report within 90 days upon completion of the study.

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APPENDIX 2: ETHICS APPROVAL 2

This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/ or plagiarism.

For more details consult the KNH- UoN ERC website **http://www.erc.uonbi.ac.ke**

Yours sincerely,

PROF. M.L. CHINDIA
SECRETARY, KNH- UoN ERC

c.c. The Principal, College of Health Sciences, UoN
The Senior Director, CS, KNH
The Chair, KNH- UoN ERC
The Dean, School of Dental Sciences, UoN
The Chair, Dept. of Oral and Maxillofacial Surgery, UoN
Supervisors: Dr. Fawzia Butt, Depts. Of Oral and Maxillofacial Surgery, Human Anatomy, UoN
Dr. Florence A. Opondo, Dept. of Oral and Maxillofacial Surgery, UoN
Prof. Fredrick J. Onyango, Dept. of Oral and Maxillofacial Surgery, UoN

Protect to discover

APPENDIX 3: LETTER OF INSTITUTIONAL PERMISSION – DAMIC

DENTAL & MAXILLOFACIAL IMAGING CENTRE LTD (DAMIC)

Dr Tom Ochola
Consultant Dental & Maxillofacial Radiologist

08/02/2021

To whom it may concern,

RE: <u>PERMISSION FOR DR. ANDREW OKIRIAMU IDEIDEI TO CONDUCT A STUDY AT OUR FACILITY</u>

This is to confirm that the above-named dental surgeon has requested to carry out a cone beam computed tomography (CBCT) study at our facility.

The study, titled "Morphology and variant anatomy of the mandibular canal in a Kenyan population: A cone beam computed tomography study", is part of his Master of Dental Surgery in Oral and Maxillofacial Surgery requirements at the University of Nairobi.

He has permission to carry out his study at our facility upon clearance by the Kenyatta National Hospital/University of Nairobi Ethics and Research Committee (KNH/UON – ERC). We wish him the best in his research.

Sincerely,

DR. T. O. OCHOLA
CONSULTANT & SPECIALIST
DENTAL SURGEON

Dr Tom Ochola
Consultant Dental & Maxillofacial Radiologist

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APPENDIX 4: STUDY TIMELINES

	Nov 2020 – Mar 2021	Apr 2021 – Jun 2021	July 2021 – Oct 2021	Nov 2021 – Mar 2022	Apr 2022	May 2022 – Jun 2022
Proposal development	**3 months**					
Ethics consideration		**3 months**				
Sampling			**4 months**			
Data collection				**5 months**		
Data analysis					**1 month**	
Dissertation Writing and submission						**2 months**