# ANALYSIS OF ROOT AND CANAL MORPHOLOGY OF SECOND PERMANENT MOLARS IN A SELECTED KENYAN POPULATION USING CONE BEAM COMPUTED TOMOGRAPHY

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**V60/7157/2017**

**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF DENTAL SURGERY (PROSTHODONTICS) IN THE DEPARTMENT OF CONSERVATIVE AND PROSTHETIC DENTISTRY, SCHOOL OF DENTAL SCIENCES, UNIVERSITY OF NAIROBI.**

**2022**

## DECLARATION

I, Bii Antony Kipkoech, declare that this is my original work and has not been presented, in part or in full for the award of a degree, diploma or certificate in this or any other university.

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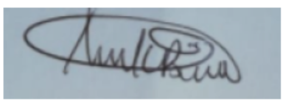
V60/7157/2017

Sign… Date; 24th October 2022

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## DEDICATION

To my family for the continuous support.

And to my teachers, both current and former, for inspiring and always believing in me.

## ACKNOWLEDGEMENT

I would like to express my deep and sincere gratitude to my supervisors Dr. Tom Dienya, Dr. James Nyaga, Dr. Susan Maina and Dr Eunice Kihara for providing invaluable guidance and feedback during this study.

I also wish to greatly appreciate Dr. Joseph Gakonyo and Winnie Atieno of Digital Healthcare Solutions for their assistance in data collection and Desmond K'Owino for his help in data analysis.

Profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis.

Finally to God for His benevolence and strength throughout my study period.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| BDS | : | Bachelor of Dental Surgery |
| CBCT | : | Cone Beam Computed Tomography |
| CT | : | Computed Tomography |
| D | : | Distal |
| DB | : | Distal Buccal |
| DOM | : | Dental Operating Microscope |
| IOPA | : | Intra-Oral Periapical |
| M | : | Mesial |
| MB | : | Mesio-Buccal |
| MDS | : | Master of Dental Surgery |
| P | : | Palatal |
| SPSS | : | Statistical Package for Social Sciences |

## ABSTRACT

***Study background:*** Successful root canal treatment involves proper access, chemico-mechanical preparation and a three-dimensional hermetic obturation. To achieve this, a thorough knowledge of root and canal anatomy is essential, since undetected canals act as a bacterial reservoir leading to post-treatment disease. Therefore, determining root and canal configurations is necessary. More importantly, variations among different study populations in both internal and external root anatomy are known to exist.

***Broad objective:*** To evaluate the internal and external root morphology of second permanent molars in a Kenyan population using CBCT imaging.

***Study design and site:*** This was a retrospective cross-sectional study involving analysis of CBCT images taken at Digital Healthcare Solutions imaging centre located in Kilimani area of Nairobi.

***Materials and methods:*** Previously taken CBCT images of mandibular and maxillary second permanent molars were analysed. External root morphology specifically: number of roots, mean root length, direction of root curvature and presence of root fusion were determined. Internal root morphology was evaluated using Vertucci (1984) classification. The data was entered in a coded form and analysed using Statistical Package for Social Sciences version 24. Descriptive analytical tests, t-test and chi-square tests were carried out to determine the frequency and relationship between various variables. Ethical approval was sought and granted from KNH-UoN Ethical Research Committee (Approval No. P837/19/2019). Additionally, permission to carry out the study at Digital Healthcare Solutions imaging centre was requested from its administration and granted.

***Results:*** One hundred and forty two maxillary second permanent molars examined, out of which three (2.1%) had a single root, nine (6.3%) had two roots and 129 (90.8%) had three roots. Majority

(97.1%) of mandibular second permanent molars had two roots, with only 3 (1.7%) and 2 (1.1%) having one and three roots respectively. Root fusion was more common in the maxillary (29.2%) than mandibular (8%) second permanent molars with the most common fusion occurring between the mesiobuccal and distobuccal roots. Mesiobuccal root of the maxillary second permanent molar was curved in 69 (52.3%) of the images examined with a distal curvature being the commonest (50.5%), while distobuccal and palatal roots were found to be mostly straight. In the mandibular second permanent molars, about half (50.5%) of the mesial roots were curved in the distal direction, while the distal root was majorly (150, 87.2%) straight. Regarding the root length, mesiobuccal, distobuccal and palatal roots of maxillary second permanent molars were found to have a mean root length of 19.67mm (±1.57 SD), 19.29mm (±1.47 SD) and 20.84 mm (+1.69 SD) respectively. Additionally, the mesial and distal roots of mandibular second permanent molars were 21.16 mm (+1.61 SD) and 20.29 mm (+1.58 SD) respectively. Internal morphology/canal configuration was described using Vertucci classification (1984). In the maxillary second permanent molar, the mesiobuccal root presented with the most varied root canal configurations unlike the palatal and distobuccal roots which exhibited only Vertucci type I configuration in all the images examined. Specifically, most (81.8%) of the mesiobuccal roots had Vertucci type I canal configuration followed by type IV seen in 12.2% of the teeth, while type II, III and V appeared in 3%, 1.5% and 1.5% of the images respectively. In the mandibular second permanent molars, Vertucci type IV was the main (58.5%) canal configuration identified in the mesial root while in the distal root type I predominated (93.6%). Other canal configurations found in the mesial root of the mandibular tooth were type I, II, III and V at a frequency of 13.5%, 7.0%, 8.8% and 12.2% respectively.

***Conclusion:*** Maxillary second permanent molars had three roots while mandibular had two roots. Root fusion was found to be more common in the maxillary second permanent molars than in its

mandibular counterpart. Vertucci type I was the commonest canal configuration in both maxillary and mandibular second permanent molars. The mesiobuccal root of the maxillary second permanent molars and mesial root of the mandibular second permanent molars presented with the most varied canal configurations. Cone beam computed tomography is a useful imaging modality in assessment of external and internal root and canal anatomy hence very relevant in endodontic diagnosis, treatment planning and follow-up.

# CHAPTER ONE

# INTRODUCTION AND BACKGROUND OF THE STUDY

## 1.1 Introduction

### Study background

Root canal treatment involves the treatment of a tooth whose pulp has been substantially damaged, by either trauma or infection, therefore necessitating pulp extirpation. It ensures preservation and maintenance of a fully functional dentition, with the associated health benefits that a set of teeth confers. The main goal of root canal treatment is the meticulous mechanical and chemical cleansing of the whole pulp cavity followed by its three dimensional obturation with an inert filling material(1). To achieve this, a detailed understanding of root and canal anatomy is of great significance for the dentist undertaking the treatment. Indeed, lack of a working knowledge of pulp anatomy has been ranked as the second commonest cause of post-treatment disease in endodontics, the first being errors in diagnosis and treatment planning(2).

Root canal systems have been found to be fraught with anatomical variations, which can cause challenges in identification of the canals, chemico-mechanical preparation and obturation, all of which are essential for a successful root canal treatment outcome(3). These anatomical variations include multiple foramina, additional canals, fins, deltas, inter-canal connections, loops, C-shaped canals, furcation and lateral canals(4).

Anatomical variations both in internal and external morphology complicate endodontic treatment and makes it more challenging to undertake. These variations have been associated with age, sex, and ethnic/racial differences of the study populations(5). In addition, differences in study protocols (*in vivo* or *in vitro*); sample size; and techniques employed in identifying canal configurations have also been identified as some of the causes of variations seen in tooth morphology research outcomes(6).

**Techniques of evaluating root and canal morphology**

Several methods have been used to study internal and external root morphology of teeth. These include:- direct visualization, staining and clearing, use of resin polyester casting, plain/digital radiography, computerized tomography, sectioning, clinical *in vivo* studies and lately the cone beam computerized tomography (CBCT)(7).

The commonly used methods are staining and tooth clearing as well as plain radiography. However, the main disadvantage of staining and clearing is that it cannot be used *in vivo* and is not repeatable because of the destruction of internal root canal anatomy during the preparation. On the other hand, periapical radiographs have generally been used in clinical examinations. However, due to its two-dimensionality, tissue superimposition and geometric distortions its application in investigative procedures like research on tooth morphology is limited(8). This has led to increased use of CBCT.

Cone Beam CT has radically transformed diagnosis and treatment planning in dentistry, providing three dimensional images with no tissue superimposition that is seen in plain radiography, while at the same time utilising low dose radiation and giving reasonably high resolution compared to conventional CT(9). Minimal artefact interference has also made CBCT a popular imaging modality in assessment of maxillofacial anatomy. Initially, its use was mainly in dental implantology, but it has expanded to include other fields of dentistry including endodontics.

Previous studies have been done to determine the internal and external root morphology of first and second permanent molars in a Kenyan population. The first permanent molars in a Kenyan population have been investigated in vitro by both clearing and staining(10) as well as CBCT(3). Another study investigated the second permanent molars by clearing and staining(11). There has been no study done on morphology of second permanent molars using CBCT in a Kenyan population. This study therefore seeks to investigate the internal and external root morphology of second permanent molars in a selected Kenyan population using CBCT. The findings will be a source of knowledge for Dentists/Endodontists performing root canal procedures in a Kenyan population as well as providing data for further research.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Preamble

Tooth morphology is described in terms of their internal and external anatomy. External morphology being the outer surfaces of the crown and the root(s) while internal morphology comprises of the pulp cavity which lies within the tooth and is enclosed by dentine(12). Internal morphology is usually similar in shape to the external though it can be modified by factors such as age, pathology and occlusion(3).

The second permanent molars are the 7$^{th}$ teeth from the midline in each quadrant, erupting at the chronological age of 12-13 years among Kenyan Africans(13). Commonly, the maxillary second permanent molars are three rooted while mandibular second permanent molars are two rooted(11). The multi-rooted and multi-canal nature presents challenges in identification, biomechanical preparation and obturation during root canal treatment procedures(14). Therefore, a thorough understanding of both external and internal root morphology is of prime importance in achieving a high level of success in root canal treatment.

## 2.2 External root morphology

### 2.1.1 Number of roots

Mandibular second permanent molars have been found to have two roots; mesial and distal(13). However, there exist a few cases of variations where it presents with either one or more than two roots. A study done to establish root morphology of mandibular second permanent molars in a Kenyan population found that majority (93.12%) had two roots while 4.8% and 2% had three and four roots respectively(11). In another study, Ahmed et al found 88% of Sudanese mandibular second permanent molars had two roots with the remaining 12% having either a single conical root or a third distal-lingual root(5). These studies used direct visual analysis technique while a CBCT study done in Turkey on the morphology of mandibular second permanent molars found that 90% had two roots while 10% had a single root(15). In a study by Feraz J et al(16) using plain radiography (IOPA), the incidence of second permanent mandibular molars with three roots among Mongoloid, Negroid and Caucasian patients was found to be 2.8%, 1.8% and 1.7% respectively.

Radix entomolaris (located disto-lingually) and radix para-molaris (located mesio-buccally) are some of the rare variations in the number of roots of mandibular permanent molars with a predisposition to mongoloid populations(17). A radix entomolaris can be found on all the mandibular molars but occurring least frequently on the second molar while radix paramolaris though a rarer variation is found more in the third mandibular molars than first or second(18).

Maxillary second permanent molars are generally three rooted teeth with the roots being palatal, mesiobuccal and distobuccal roots. A clearing and staining study done in a Kenyan population found 96% of maxillary second permanent molars had three roots(11). Katarzyna et al(6) analysed 207 maxillary second permanent molars from a Polish population using CBCT and found that 91.8% had three roots, 5.8% had two roots and 2.4% had a single root. However, different results were obtained in a Taiwanese CBCT study where 212 maxillary second molars were examined and 67.8%, 24.2%, 7.1% and 0.9% had three, two, one and four roots respectively(19). The differences could be due to racial differences of the study populations.

### 2.2.2 Root fusion

Root fusion is a common phenomenon of multi-rooted teeth especially the molars. It is of clinical relevance because teeth with fused roots may present a complicated root canal system due to merging of canals. Ross et al(20) carried out a study on incidence of root fusion of molars and found that 29% of molars had some form of root fusion, whether it was in the cervical third, mid third or apical third of the roots. They also established that root fusion was most common in third molars, followed by second molars, in both jaws and that it occurred with bilateral symmetry when the left and right sides were compared.

Other studies on external morphology of mandibular second permanent molars found 13% fused roots in a Kenyan population(11) while Ahmed et al(5) reported 8% fusion in a Sudanese population. This is in contrast to  4.97% complete fusion and 0.97% partial fusion reported by Demirbuga et al in a Turkish population which was a radiological study done using CBCT(21). It is notable that in these studies, visual method resulted in higher fused teeth incidences, these differences could be attributed to the methodology for example criteria used to define fusion and also genetic variation between the study populations.

Maxillary molars exhibit a higher tendency and complex form of root fusion due to their nature of being three rooted. Among the maxillary permanent molars, root fusion has been found to occur more frequently on third molars followed by second molars(20). Fusion can occur between any of the three roots or even among all the three roots. The prevalence of root fusion of second permanent molars has been found to range from 5%-42%. Ilich reported 18% root fusion of second permanent molars in a Kenyan population (11) while Yang et al(22) reported a 40% prevalence in a Chinese population in Taiwan. Both studies were done using direct visualization. This difference in the prevalence could be attributed to genetic differences between the two populations studied and the sample size, 121 by Ilich in contrast to 309 by Yang et al. Regarding the pattern of fusion, Yang et al reported fusion of the palatal with the mesiobuccal roots to be the most prevalent, followed by fusion of the mesiobuccal with the distobuccal roots; complete fusion of all the three roots into a cone-shaped root was the least common. Other studies done in different populations have shown different results in the pattern of root fusion in maxillary second permanent molars(23).

### 2.2.3 Size and shape of the roots

Most of mandibular second permanent molars have two roots; mesial and distal with a normal morphological variation of a third disto-lingual root which is considered an Asian/Mongolian trait(15). Morphologically, the mesial root is wider bucco-lingually and narrower mesio-distally and larger in its cross-sectional area than the distal one.

The direction of curvature of roots is fundamentally important because it influences the endodontic treatment procedure more so chemo-mechanical preparation. A curved root may necessitate pre-curving of hand instruments. Lack of appreciation of root curvatures can lead to procedural errors like formation of ledges and perforations.  Prior knowledge of frequent direction of root curvatures is also critical especially in cases where the curvature is in bucco-lingual direction since it does not show in a plain radiograph(24). The mesial root has been found to curve mesially in the cervical third then takes on a distal angulation towards the apex(11). The distal root is straighter but with a slight mesial curvature apically. When present, the disto-lingual root is conical and often curved buccally, and can be completely separate or fused with the distal root in the cervical third(18).

Maxillary second permanent molars exhibit three roots, mesiobuccal, distobuccal and palatal. The palatal root has been reported to be the longest and with the largest cross-sectional area. The mesiobuccal root is wider mesio-distally while distobuccal root is conical(25). The palatal root has been reported as straight in 62% of the cases while it is curved buccally and mesially in 31% and 7% respectively(11). The same study found that 39% of the teeth studied had straight mesiobuccal roots while 59% were curved mostly in a distal direction. The distobuccal root was commonly straight (68%), and when curved, was in a mesial direction.

### 2.2.4 Root length

Analyses of root length have been done previously by either direct measurement of extracted teeth or radiographic methods(10). Direct measurement is considered the gold standard because of elimination of geometric distortion and magnification errors experienced in plain radiography(8). Liang et al(26) did a study on the validity of CBCT compared to direct measurement, and concluded that CBCT was a reliable and accurate method in root length determination. The mean absolute difference of the CBCT-based root canal length from direct measurement was 0.46 mm, which was not statistically significant at 95% confidence interval. When compared to periapical radiographs, CBCT has been found to be more accurate for tooth/root length measurements because of lack of magnification and difficulties with landmark identification present in periapical radiographs(27). Several studies have been done on root lengths of second permanent molars with varying results as presented in the table 2.1.

Table 2. 1 Average root lengths in millimetres of second permanent molars

| **Root** | **Katoto et al**(11) | **Ingle et al**(28) | **Rocha et al**(29) |
|---|---|---|---|
| MB | 21.15 | 20.2 | |
| DB | 21.47 | 19.4 | |
| P | 23.18 | 20.8 | |
| M | 22.19 | 20.9 | 20.87 |
| D | 23.15 | 20.8 | 20.00 |

**2.3 Internal root morphology**

Internal root morphology commonly known as root canal system describes the entire space in the dentine where the pulp is housed.(4) It is divided into two depending on location in the tooth; pulp chamber (in the anatomic crown) and the root canal (found within the anatomic root). Root canals extend the whole length of the root, beginning as a funnel-like orifice and exiting as the apical foramen into the periodontium.

Other minor features of the root canal system include; pulp horns; accessory, lateral, and furcation canals; canal orifices; apical deltas; and apical foramina. Presence/absence of these features and their different configurations is responsible for the variations and anatomical complexities observed in the morphology of root canal systems of different populations.(5) Failure to appreciate possibility of existence of these variations would lead to inadequate cleaning and obturation therefore affecting root canal therapy outcome.

Accessory canals are minute canals that extend in a horizontal, vertical, or lateral direction from the pulp to the periodontium.(4) They may be present anywhere on the root surface with the majority found in the apical third of the root and in posterior dentition.(2). Furcation canals are accessory canals, which are found in the furcation area of multi-rooted teeth. These canals are of clinical significance because they act as conduits for irritants primarily from the pulp to the periodontium, hence they have been associated with pulp disease, primary canal infection, canal re-infection and post-treatment disease.(30) Apical ramifications, isthmuses and lateral canals also acts as areas of bacterial persistence following root canal obturation. Persistence of bacteria after root canal filling has been found to be the main cause of post treatment disease following root canal treatment(31)(32).

Root canal pathway from the orifice at the floor of the pulp chamber to the apical foramen is intricate and full of complexities, with canals branching, dividing and at times re-joining. This has been shown from several studies; Hess and Zurcher(33), Weine et al(34) and Vertucci et al(35).

The variations of root canal configurations have led to development of various classification systems, which are important for diagnosis, treatment planning and communication. An ideal classification should be simple, reliable, accurate and easy to communicate. It should also be able to describe the tooth accurately in relation to number of roots, canals in each root and the entire course of the canal from the orifice to the apical constriction.

Weine et al (1969)(34) classified root canal system configurations within a single root into four categories;

Type I – Single canal from the pulp chamber to the apex.

Type II – Two canals leaving the pulp chamber and merging to form a single canal short of the apex

Type III – Two separate and distinct canals from the pulp chamber to the apex.

Type IV – One canal leaving the pulp chamber and dividing into two separate and distinct canals with two separate apical foramina.

However, Vertucci (1984) studied two thousand four hundred permanent teeth using clearing and staining technique and found eight possible root canal system configurations(35) as follows (Figure 2.1):

Type I: A single canal extends from the pulp chamber to the apex.

Type II: Two separate canals leave the pulp chamber and join short of the apex to form one canal.

Type III: One canal leaves the pulp chamber and divides into two in the root; the two then merge to exit as one canal.

Type IV: Two separate, distinct canals extend from the pulp chamber to the apex.

Type V: One canal leaves the pulp chamber and divides short of the apex into two separated distinct canals with separate apical foramina.

Type VI: Two separate canals leave the chamber, merge in the body of the root, and re-divide short of the apex to exit as two distinct canals

Type VII: One canal leaves the pulp chamber, divides and then re-joins in the body of the root, and finally re-divides into two distinct canals short of the apex.

Type VIII: Three separate, distinct canals leave the pulp chamber to the apex.

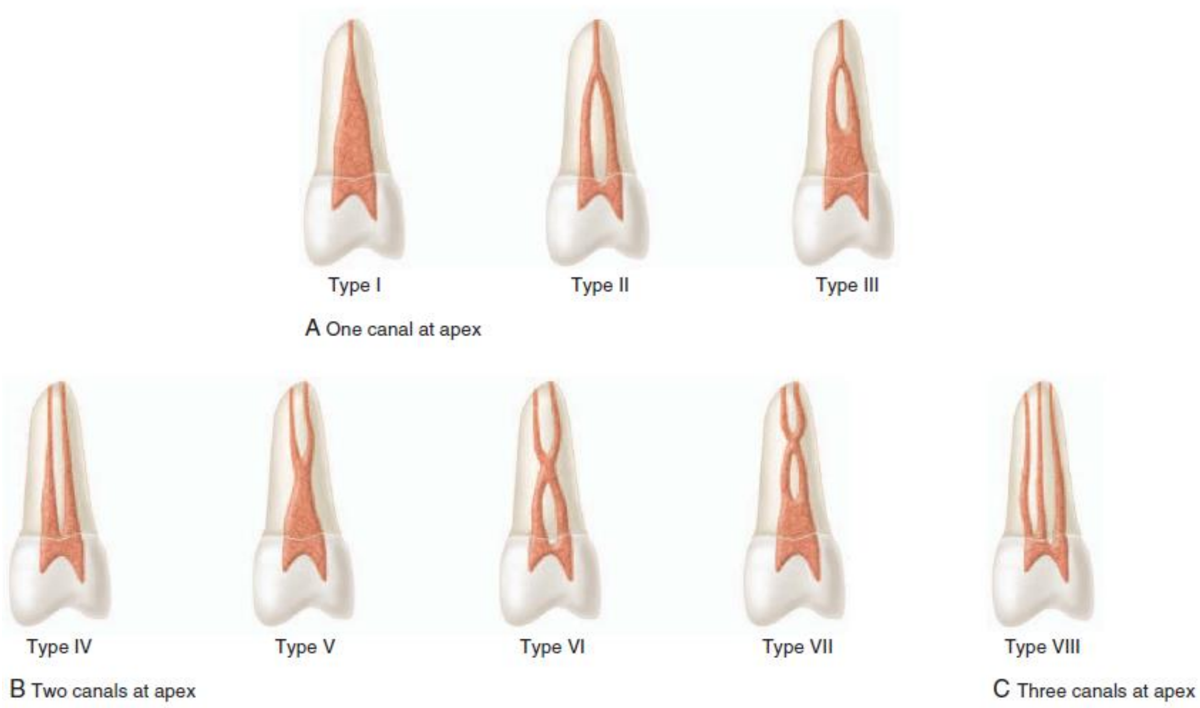


*Figure 2. 1 Vertucci canal configuration illustration* (adapted from Cohen's Pathways of the Pulp 10th Ed.)

This classification is more exhaustive covering most of the possible configurations hence it is popularly used. However, a few variations which do not fall into any of the eight types described above have been reported(36). This has led to some canal configurations being described as "non-classifiable." Gulabivala et al(36) examined mandibular molars in a Burmese population and found seven additional canal configurations (Figure 2.2). Furthermore, Sert and Bayirli(37) reported fourteen new/additional configurations to Vertucci's classification numbering them as type XI to XXII after analysing 2800 maxillary and mandibular teeth from a Turkish population using clearing and staining technique.

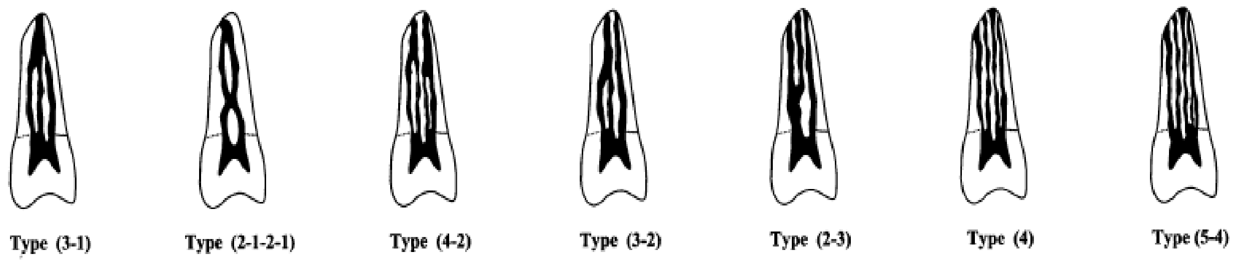


Figure 2. 2 Additional canal configuration modifications by Gulabivala et al(36)

In addition, in an attempt to cater for the inadequacies of Weine and Vertucci classification, Ahmed et al recently came up with a new way of classifying root and root canal configuration(38). The classification provides information on the tooth number, number of roots and canal configuration in each of the roots. The number of roots is added as a superscript before the tooth number whiles the configuration is added as a superscript after the tooth number and defines the continuous course of the root canal system starting from the orifice(s), through the canal to the foramen/foramina (Figure 2.3). Examples of root and canal description using this system.

$^{1}21^{1}$ refers to maxillary left permanent incisor with one root and one canal from the orifice to the foramen.

$^{1}25^{2}$ refers to maxillary left second premolar with one root and two independent canals from orifice to foramen.

$^{1}34^{1-2-3}$ means mandibular left first premolar with one root, one orifice and one canal initially that bifurcates into two independent canals and terminates in three canals and three apical foramina.

$^{2}24\ B^{1-2}\ P^{1}$ describes a maxilla left first premolar with two roots, buccal root having a canal starting as one then diving into two and terminating as two foramina while the palatal has a single canal; one orifice one apical foramen.

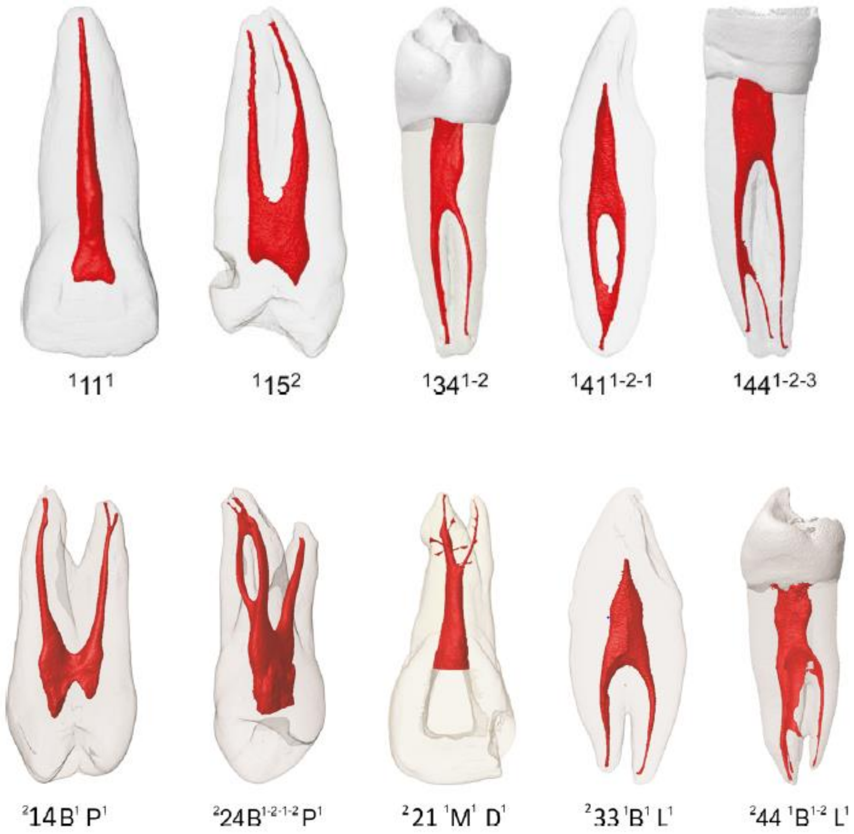


Figure 2. 3 A new system for classifying root and root canal morphology (38)

Although this classification provides more information, like the tooth number, its main disadvantage is that it is complex.

### 2.3.1 Permanent mandibular second molar

Mandibular permanent second molars commonly have two roots: mesial and distal. Various studies have found that in the mesial root, Vertucci type IV canal configuration is the most common while in the distal root Vertucci type I canal configuration predominated(35). A study done by clearing and staining technique in a Kenyan population reported that 88% of the canals in the mesial root had type IV canal configuration while 86% of the canals in the distal root had type I canal configuration with the remaining 14% being type IV(11). Similar results were obtained by Nur BG et al(15) who established that 90% of mesial roots had two canals while 97% of the distal roots had a single canal. A study in a Sudanese population established that most of the distal roots of second mandibular molars (69%) had one canal whereas most mesial roots (83%) had two canals, of which type IV (63%) and type II (18%) canal configurations were most prevalent(5). Variations in the root canal configuration in both the mesial and distal roots have been found to occur. A single canal, two canals, four canals, five canals and the C-shaped canal system are some of the variants observed in permanent mandibular molars(39). Moreover canal configurations type II, III and V have been encountered in permanent mandibular second molars; Subha N et al(40) did a retrospective CBCT study on internal morphology of mandibular second molars and found that 19% of mesial and 3% of distal canals had type II configuration and also 3% of mesial roots had type III canal configuration.

C-shaped canals are one of the important variations seen commonly in permanent mandibular second molars. This anatomic feature was first described by Cooke and Cox in 1979(41). It derived its name from the cross sectional morphology of root and root canal due to presence of a fin connecting two roots leading to fusion either on the buccal or lingual aspect of the tooth between distal and mesial roots(42). This shape of the canals is of clinical significance because it poses a challenge in root canal treatment, specifically debridement and obturation. C-shaped canals have been reported to occur more commonly in Asians as compared to other ethnic groups(43). Several studies have established the prevalence of C shaped canals in mandibular second molars to be about 4%(21)(40). A study from a Kenyan population found slightly higher (6.35%) prevalence of C shaped canals in permanent mandibular second molars(11).

### 2.3.2 Permanent maxillary second molar

The second permanent maxillary molar teeth have been found to present with greater diversity in the number and configuration of root canals(44). Consequently, it is possible to observe three canals, four canals and C-shaped root canals that can be difficult to treat. Typically, this tooth has three roots: mesio-buccal, disto-buccal and palatal. Palatal and disto-buccal roots have been found to exhibit Vertucci type I canal configuration.(45)(8). The mesiobuccal (MB) root of maxillary molars has always been a challenge presenting with many variations, this holds true also for the second molar. Studies have found the presence of a second canal in the mesiobuccal root having type II/IV Vertucci canal configuration. However, the prevalence of MB2/mesio-palatal canal is lower in the maxillary second molar than maxillary first permanent molar(6). In a study on the canal configuration of maxillary second molars, a 31% prevalence of a second MB canal was found(11). Further, other studies have found the second MB canal to be present in 23%-58% of maxillary second permanent molars(46)(47)(45)(48)(49).

### 2.4 Methods used to study root canal systems

Root canal systems/internal morphology of teeth are very intricate and marred with many complexities. Several *in vivo* and *in vitro* methods and techniques have been utilised to study them with varying degrees of accuracy and success attained. An ideal method should be accurate, simple, reliable, non-invasive, non-destructive and possess feasibility for use *in vivo*. The methods previously employed include; resin polyester casting, plain/digital radiography, staining and clearing, radiographic assessment enhanced with contrast media, conventional computerised tomography, sectioning, clinical *in vivo* studies for instance use of dental operating microscope and more recently cone bean computed tomography (CBCT)(7).The most commonly utilised techniques are clearing and staining and use of plain/digital radiography.

#### 2.4.1 Staining and Clearing

Staining and clearing technique has been considered the gold standard in root canal systems analysis due to its reliability and ability to demonstrate the entire root canal system including minute details like the accessory canals(50). This has made it a highly favoured technique used by many researchers. However, its disadvantages are inability to be used *in vivo* and not being repeatable due to destruction of the specimens.

### 2.4.2 Intra-oral periapical radiographs

Intra-oral periapical radiographs are the backbone of dental imaging and consequently have also been used to study the internal root anatomy. It is a simple and economical method that can be applied both in vivo and in vitro. However, plain radiography gives a two dimensional image of a three dimensional object hence has a limitation of superimposition of the teeth with the surrounding dento-alveolar structures(51).This limits its diagnostic performance since relationship of the teeth to surrounding structures cannot be assessed accurately. Most importantly, structures in a buccal lingual plane for example canals and root fractures might not be demonstrated clearly. The other drawback of plain radiography is that image distortion and magnification can occur. Nattress et al(52) investigated the predictability of radiographic diagnosis of variations in root canal anatomy of mandibular incisors and premolars and found that plain radiography failed to diagnose a second canal in 30% of the cases. Also, Ramamurthy et al(53) investigated the ability of plain X-ray radiography to detect presence of a second mesiobuccal canal in maxillary first permanent molar and found a detection rate of only 55%.

### 2.4.3 Orthopantomogram

Orthopantomogram (OPG) is frequently the first diagnostic radiograph taken mostly for screening purposes by clinicians. It provides a panoramic view of the dental hard tissues as well as the jaws including the temporomandibular joints. OPG radiographs are two-dimensional views of three-dimensional structures hence the limitation of superimposition and geometric distortion in form of magnification also occurs. Lien LC et al(54) did a study on the accuracy of OPG in the assessment of tooth length and found elongation of root lengths occured. The results showed that the mean lengths measured from OPG were consistently higher than the actual lengths by 22% ($p < 0.001$) for maxillary teeth and by 1% for mandibular teeth. OPG has also previously been used in studies of the internal root anatomy particularly the presence of C-shaped canals in mandibular molars(55). It was found to have good specificity and sensitivity in diagnosing the C-shaped canals and therefore could be used as a surveying modality to detect C-shaped canals and determine whether further examination is required before endodontic treatment.

### 2.4.4 Computed tomography

CT scans provide three-dimensional imaging and have been in existence since 1970s, however, its cost, access and higher ionizing radiation doses have limited its use. The complexity of oral and maxillofacial anatomy, and the quest to obtain additional information in three dimensions led to the development of CBCT imaging system for maxillofacial imaging in 1995 by Tacconni and Mozzo(56) . Technically, conventional CT scan differs from CBCT in that the former uses fan shaped X-ray beam while the later uses cone shaped X-ray beam in image acquisition capturing a cylindrical or spherical volume of data known as the field of view(57).

### 2.4.5 Cone Beam CT

In endodontics, CBCT has been found to be important in diagnosis, treatment planning and post treatment reviews/outcomes/follow-up. It is used in; diagnosis of periapical lesions caused by inflammation of the pulp, canals visualization, detection of root resorption, root fractures demonstration and planning of periapical surgeries(58).

Many reviews and comparisons on the use of CBCT versus plain radiography in determining morphology of root canal systems have been done with results favouring use of CBCT. Patel et al(59) reviewed literature on use of CBCT in endodontics and reported that it was superior to plain radiography in identification of root canals. CBCT has been found to enhance detection of additional canals in the bucco-lingual plane from 55% seen in plain radiography to 60-93% (60). Metherne et al(61) did an *in vitro* investigation to compare the diagnostic efficacy of contemporary digital imaging modalities with that of CBCT and found CBCT to be superior.

Another study done to compare the accuracy of CBCT to that of staining and clearing in determining root canal morphology found that CBCT provided accurate information but no significant difference between the two methods was established(62). Baratto et al did an analysis of the internal root anatomy using CBCT and dental operating microscope, and established the later to be more optimal in detection of additional canals(63).

However, as an imaging modality, CBCT should only be used when lower dose conventional radiography fails to provide adequate diagnostic information. This is because CBCT radiation exposure is slightly higher than conventional radiography(51). This is in line with the principle of as low as reasonably achievable (ALARA) exposure to ionizing radiation which should always be adhered to. Other limitations of CBCT include; cost, availability/accessibility and image scatter caused by radiopaque restorations in the oral cavity (64). CBCT has been found to produce severe streaking artefacts in presence of metallic dental restorations and implants (65).

### 2.5 Research Problem

Endodontic treatment has become a common treatment modality for various diseases of the pulp. This has been due to better patient awareness and improved success rate of root canal treatments which in many instances, has been found to be more than 90%(4). There has also been marked advances in endodontic diagnostic and treatment methods. Endodontic treatment aims at eradicating disease and restoring function leading to retention of teeth, which would have otherwise been extracted.

A favourable root canal treatment outcome necessitates a deep understanding of the root anatomy and root canal morphology together with its variations from the normal. In routine dental clinical practice, the presence of anatomical aberrations in the root and root canal systems may present a major endodontic challenge to clinicians. It is therefore important to have a thorough knowledge and understanding of their anatomy and possible variations in order to avoid probable complications and unwanted endodontic procedural errors/accidents.

Second permanent molars are multi-rooted teeth exhibiting complex root and root canal anatomy hence making endodontic treatment more challenging. Moreover, studies have shown increased complexities and presence of variations in root and root canal systems, which affects the prognosis and consequently contributes to the overall predictability of endodontic treatment. Therefore, an in-depth comprehension of the internal and external anatomy and any existing variations is of outright significance.

### 2.6 Justification of the Study

It has been shown that root and canal morphologies are genetically determined and varies greatly in different races and even in different individuals within the same race(5). It is important to be familiar with the anatomical variations in root canal systems and characteristic features in various racial groups as it helps in identification, negotiation and management of canals during root canal treatment.

Globally, there are various studies done on internal and external morphology of teeth, and specifically the second permanent molar among different ethnicities/races. However, only a few studies have been conducted to evaluate root and canal morphology in a Kenyan population using staining and clearing for the first(10) and second(11) molar. Only a single study has used CBCT for the first molar(3). These studies have established variations from previously done ones; the difference could be attributed to the research methodology. For instance, Nyaga et al(10) used staining and clearing method and reported one canal in 65.2% and two canals in 29.4% of mesiobuccal root of maxillary first permanent molars. In contrast, Dienya 2008(3) used CBCT and found that 55.4% and 44.5% of mesiobuccal root of the same tooth had one and two canals respectively. It is notable that both studies involved a Kenyan population and had relatively similar sample sizes; 187 versus 160 respectively, therefore, the variance could be due to the difference in method of invstigation.

The aim of this study is therefore to establish the internal and external root morphology of the second permanent molars of a Kenyan population using CBCT. The findings will be used as comparative analysis to a previous study which was done using staining and clearing as well as serve as a reference by dentists in clinical practice leading to improved quality of treatment. Moreover, it will form a basis for further research in the field of endodontics.

## 2.7 Study Objectives

### 2.7.1 Broad Objective

To evaluate the internal and external root morphology of second permanent molars in a Kenyan population using CBCT imaging technique.

### 2.7.2 Specific Objectives

1. To establish the number of roots of the second permanent mandibular and maxillary molars of a Kenyan population using CBCT.
2. To evaluate direction of root curvature of the second permanent mandibular and maxillary molars of a Kenyan population using CBCT.
3. To analyse the pattern of root fusion in the second permanent mandibular and maxillary molars of a Kenyan population using CBCT.

4. To determine the mean root length of second permanent mandibular and maxillary molars of a Kenyan population using CBCT.
5. To evaluate canal configuration in the second permanent mandibular and maxillary molars of a Kenyan population using CBCT.

**2.8 Hypothesis**

**2.8.1 Null hypothesis**

There is no variation in the internal and external root morphology of second permanent molars in a Kenya population.

**2.9 Study Variables**

**Table 2. 2 Variables**

| CLASSIFICATION | VARIABLE | MEASUREMENT |
|---|---|---|
| **Independent** | Type of tooth | Mandibular/maxillary second permanent molar |
| **Dependent** | Root morphology | Number of roots |
| | | Root curvature |
| | | Root fusion |
| | | Root length |
| | Canal morphology | Root canal configuration |

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study design

This study was a retrospective cross-sectional study design involving analysis of CBCT images previously taken.

## 3.2 Study area

Cone beam computed tomography is a fairly new dental imaging modality in Kenya with few Nairobi based privately run imaging centres undertaking it, these are Dental and Maxillofacial Imaging Centre (DAMIC), Digital Healthcare Solutions and Smile Africa Dental Clinic. The study was conducted at Digital Healthcare Solutions. This centre was chosen because of the availability of necessary complete patient records/biodata and adequate sample size. It is located in Kilimani area of Nairobi and offers a variety of dental radiological services including Intra-oral periapical, Bitewings, Panoramic, Cephalometric and CBCT scans.

## 3.3 Study population

The study population included patients who had visited Dental Healthcare Solutions for CBCT images of maxillary and mandibular second permanent molars. The CBCT images had been taken as part of examination, diagnosis and treatment planning for patients in need of various dental treatments including endodontic, orthodontic, surgical and pre-operative assessment for dental implants. The CBCT images of second permanent molars that met the inclusion criteria were investigated.

### 3.3.1 Inclusion criteria

Second permanent molars CBCT images with:

1. Fully formed teeth with closed apices
2. No prior root canal treatment
3. No resorption or calcifications.
4. CBCT images of good quality- clear with no artefacts.

### 3.3.2 Exclusion criteria

1. CBCTs with incomplete biodata/demographic data e.g. gender and age.
2. Poor quality CBCT scans.
3. CBCT scans of second permanent molars of contralateral sides of same patient.

### 3.4 Sample size determination

Betty R. Kirkwood formula(66) was used to calculate the sample size:-

$$n = \frac{\mathrm{Z}^2\mathrm{u}}{\mathrm{e}^2}$$

Where,

n=Desired sample size,

U=Estimated proportion of an attribute in the target population. One of the attributes under study is root length, and for the maxillary second permanent molar MB root has been found to be 21.15mm.(11). This was used as an estimate of one of the characteristics being studied.

e=Maximum possible error in the measurement. It is set as 0.5mm.

z=standard deviation set at 1.96 (95% confidence level).

n=1.96x1.96x21.15/0.5x0.5=325 CBCT images of second permanent molars.

However, a sample of only a sample of 317 was achieved following consecutive sampling of the radiographs obtained, this was less by 8. According to the statistician, this discrepancy was too small to have an effect on the study.

### 3.5 Image acquisition process

The images were taken by a factory level trained radiographer using Orthophos SL 3D® CBCT unit (Sirona Dental Systems Inc., Bensheim, Germany). The CBCT machine image parameters are set according to manufacturer's instructions and are as follows; tube voltage and current fixed at 85kV and 7mA, slice thickness (voxel size) 0.3mm, field of view 15cm and exposure time of 14s. Sidexis XG software (Sirona Dental Systems) is used to capture, process and store as reconstructed 3D data together with the original two-dimensional projection views.

### 3.6 Data Collection instruments and techniques

Cone beam computed tomography images that met the inclusion criteria from the study population were evaluated. The images had been taken as part of patients' diagnosis and treatment planning. Consecutive sampling method was utilised to select the CBCT images that were examined. This was done by visual examination of the images using Sidexis software and every time an image did not meet the inclusion criteria the next image was selected until the sample size was achieved. A data collection form (Appendix 1) was used to collect the data from the previously done CBCT images. All the CBCT images of second permanent molars were assessed by the investigator in three dimensional views and also in axial, sagittal and coronal planes by moving the toolbar from the floor of the pulp chamber to the apex and information on the following were noted;

1. Number of roots and root fusion: roots were considered to be fused if the furcation area was not clearly demarcated. The fusion could therefore be at the cervical, middle or apical parts of the roots.
2. The direction of curvature of the roots: established by anatomically orienting the three-dimensional image of the tooth and observing the direction of curvature of each root. The position of the root apex in relation to the long axis of the tooth determines the direction of root curvature.
3. The root length: measurement tool in the software was used to determine the root length which was measured in millimetres. Mandibular root length was measured from the mesio-lingual and disto-lingual cusps tips for mesial and distal roots respectively. The reference points for the maxillary second molar were mesiobuccal cusp tip for the palatal and mesiobuccal root and distobuccal cusp tip for the distobuccal root. These reference points were chosen because they are the non-working cusps hence less chance of being affected by attrition from opposing dentition.
4. The canal configuration according to Vertucci 1984 classification. This was done by analysis of serial images in coronal, axial and sagittal planes by moving the tool bar from the pulp chamber floor to the apex of each root/root canal.

The data was stored in digital form in compact discs/DVD by the principal investigator for ease of review/retrieval.

### 3.7 Data analysis and presentations

The data was entered in a coded form and analysed using Statistical Package for Social Sciences (SPSS) Version 24. Data analysis for; the number of roots and fusion, root curvatures in different directions, root length, and frequency of various canals configurations based on Vertucci 1984 classification was done. Data entry and analysis was done by a statistician.

The results were presented in bar graphs, pie charts and tables for ease of interpretation and simplicity. Chi square test was used to evaluate the relationship between the various categorical variables while t-test was used to compare the mean root lengths of mandibular and maxillary roots between genders.

### 3.8 Validity and reliability of collected data

The investigator was calibrated by the main supervisor before start of data collection. Twenty randomly selected images were evaluated by the principal investigator and the lead supervisor. Inter-examiner variability test using Cohen's (κ) kappa was run to determine if there was an agreement between the principal investigator and the supervisor's scores. There was a statistically significant almost perfect measure of agreement (0.81 – 1.00) between the principal investigator and supervisor's scores, $\kappa = 0.989$, for root number and root canal configuration. Intra-examiner variability was evaluated by re-examining every tenth tooth image and Cohen's Kappa score used to quantify it. Cohen's (κ) kappa was run to determine if there was an agreement between the first and second measurements of root length. A statistically significant almost perfect measure of agreement (0.81 – 1.00) between the two scores, $\kappa = 0.897$, $p < 0.001$ was found. This confirmed that the results were consistent and had minimal variability.

### 3.9 Ethical considerations

Approval to undertake this research was sought and granted from the Kenyatta National Hospital-University of Nairobi Ethics and Research Committee-Approval No. P837/19/2019 (Appendix II).

Permission to undertake the research at Dental Health Solutions was sought from its management.

Patients' anonymity/confidentiality was maintained by obtaining the necessary demographic data; age and gender only without any form of identification of the patients extracted. Strict confidentiality regarding the patient's data was observed.

### 3.10 Perceived benefits

The results of this study shall be used as reference material for dental practitioners undertaking root canal treatment and as a source of information for teaching at Dental Schools. It will also form a basis for further research and serve as a partial fulfilment for a Master of Dental Surgery degree in Prosthodontics.

### 3.11 Study limitations

The research was carried out in only one centre in Nairobi; hence, results might not be generalizable to the whole Kenyan population.

# CHAPTER FOUR

# RESULTS

## 4.1 Socio-demographic characteristics

Three hundred and seventeen CBCT images of second permanent molars which fulfilled the inclusion criteria were studied. Of these, 175 (55.2%) and 142 (44.8%) were mandibular and maxillary molars respectively. Distribution of teeth according to gender and type is shown in Figure 4.1 while table 4.1 shows their association.

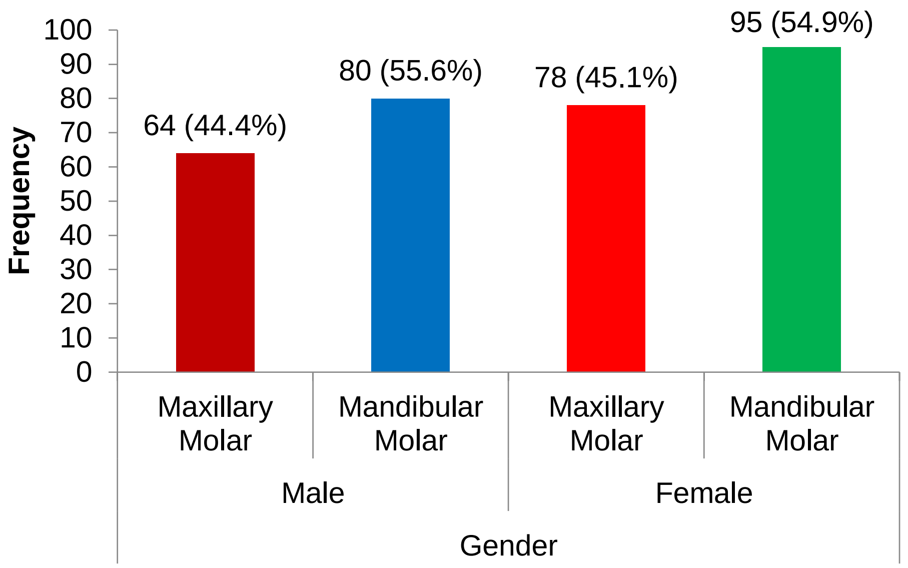


Figure 4. 1 Distribution of second permanent molars by tooth type and gender

The sample age ranged from 16.0 – 65.0 years with a mean age of 38.42 years (+10.41 SD), a median of 39.0 years and a mode of 34.0 years.

Table 4. 1 Distribution of second permanent maxillary and mandibular molars characteristics by gender and tooth type and their association

| Gender | n (%) | Second Maxillary Molar n (%) | Second Mandibular Molar n (%) | Total | $X^2$ | df | p |
|---|---|---|---|---|---|---|---|
| Male | 144 (45.4) | 64 (20.2) | 80 (25.2) | 144 (45.4) | 0.013 | 1 | 0.909 |
| Female | 173 (54.6) | 78 (24.6) | 95 (30.0) | 173 (54.6) | | | |
| Total | 317 (100) | 142 (44.8) | 175 (55.2) | 317 (100) | | | |

Pearson Chi-Square ($\chi^2$) test for association was used for all variables.
df; Degrees of Freedom.

## 4.2 External root morphology

### 4.2.1 Number of roots

Analysis of the number of roots in maxillary and mandibular second permanent molars was done with the summary of the findings shown below in Table 4.2.

Table 4. 2 Number of roots in second permanent maxillary and mandibular molars by gender

| | Number of roots | Gender | | Total |
|---|---|---|---|---|
| | | Male n (%) | Female n (%) | n (%) |
| Maxillary Molars | 1 | 2 (1.4) | 1 (0.7) | 3 (2.1) |
| | 2 | 0 | 9 (6.3) | 9 (6.3) |
| | 3 | 61 (43.0) | 68 (47.9) | 129 (90.8) |
| | 4 | 1 (0.7) | 0 | 1 (0.7) |
| | Total | 64 (45.1) | 78 (54.9) | 142 (100) |
| Mandibular Molars | 1 | 0 | 3 (1.7) | 3 (1.7) |
| | 2 | 79 (45.1) | 91 (52.0) | 170 (97.1) |
| | 3 | 1 (0.6) | 1 (0.6) | 2 (1.1) |
| | Total | 80 (45.7) | 95 (54.3) | 175 (100) |

Majority of maxillary second permanent molars, 129 representing 90.8% had three roots while majority of mandibular second permanent molars had two roots, 170 representing 97.1%.

Of the maxillary second permanent molars, (3)2.1% and (9)6.3% had one and two roots respectively. Figures 4.2 and 4.3 are illustrations of maxillary second permanent molars with one and two roots respectively. All the maxillary molars that had two roots were from females while the single tooth with four roots was from a male.

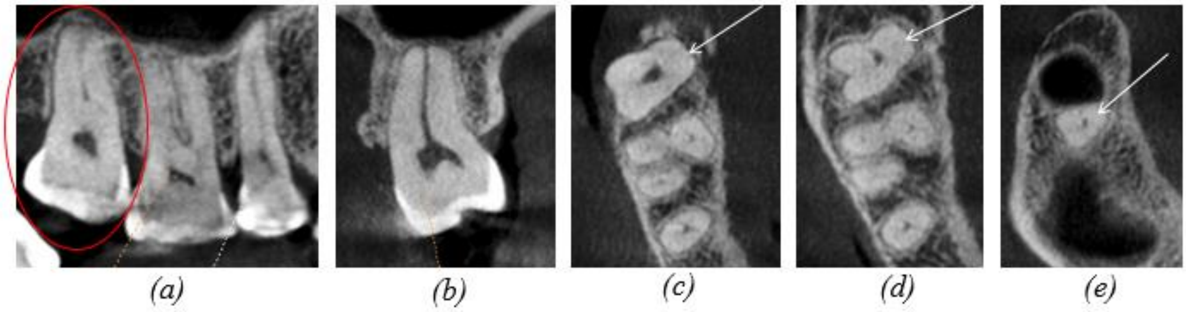

Figure 4. 2 Single rooted right maxillary second permanent molar; (a) sagittal, (b) coronal and axial sections extending from (c) coronal, (d) mid-root and (e) apical regions. Note the single canal from coronal to apex of the root

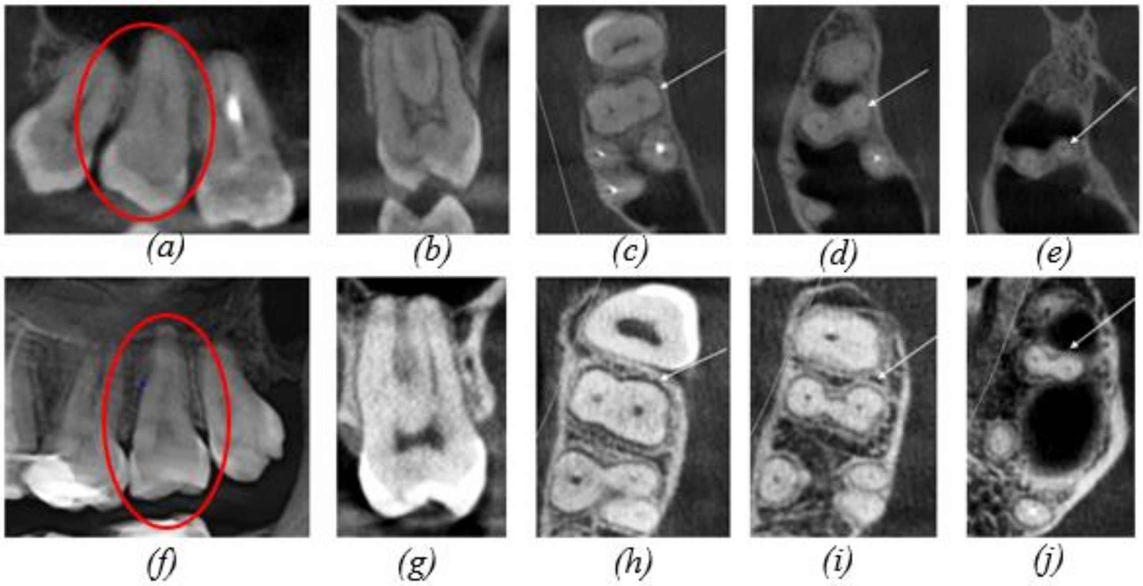

Figure 4. 3 Right and left maxillary second permanent molars with two roots: buccal and palatal. The buccal root is seen in the sagittal sections in (a) and (f), while coronal sections denoted by (b) and (g) clearly illustrates the buccal and palatal roots. (c), (d), (e), (h), (I), and (j) are axial sections from coronal to apical regions showing two fused roots

The mandibular second permanent molars with a single root were 3(1.7%) all of them being females, while 2 (one female and one male) had three roots each. The third root was in a disto-lingual position in one tooth while in another the mesial root split into two from the mid-root position as shown in Figure 4.5.

Figure 4. 4 (a) (b): Two right mandibular second permanent molars with single roots

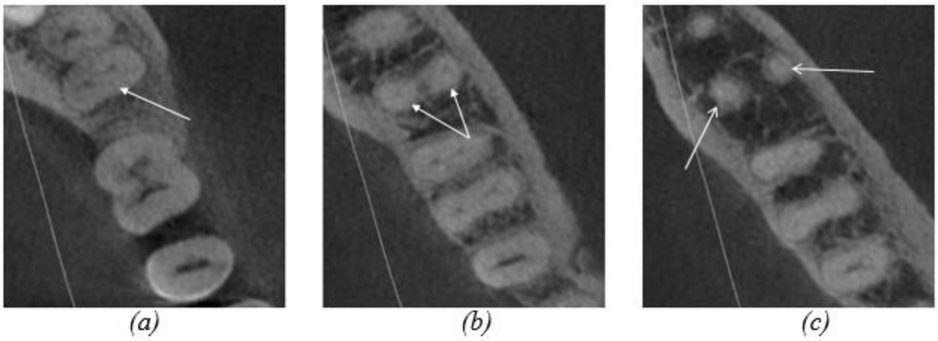

Figure 4. 5 Serial axial sections from (a) coronal, (b) mid-root and (c) apical showing a mandibular second permanent molar mesial root dividing into two from mid-root region. The two arrows in (b) and (c) demonstrates mesiobuccal and mesiolingual roots.

### 4.2.2 Root fusion and pattern of fusion

Majority of the roots of second permanent maxillary (71.8%) and mandibular (92%) molars were not fused. In the second maxillary molar, the commonest fused roots were the mesiobuccal and distobuccal accounting for 67.5% (27) of all the fused roots. All the three roots i.e. mesiobuccal, distobuccal and palatal were fused in 7 (17.5%) teeth. The least common fusion was between the mesiobuccal and palatal root, noted in 3 (7.5%) of the fused maxillary second permanent molar roots. An example of fusion between the mesiobuccal and distobuccal roots is depicted in Figure 4.6 (a) and (b) while Figure 4.6 (c) and (d) shows fusion between mesiobuccal and palatal roots of maxillary second permanent molars.

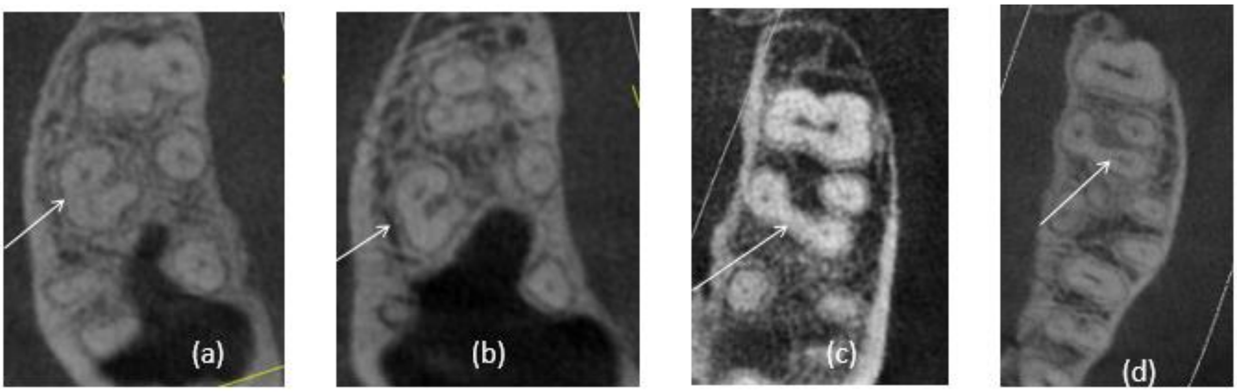


Figure 4. 6 (a), (b) Axial sections of a right maxillary second permanent molar with fusion of mesio-buccal and disto-buccal roots. (c), (d) axial sections of left maxillary second permanent molar with fused mesiobuccal and palatal roots.

Mandibular second permanent molars had 14 (8%) teeth with fused roots, between the mesial and distal roots. Figure 4.7 shows a case of fusion between the mesial and distal roots of right mandibular second permanent molar.

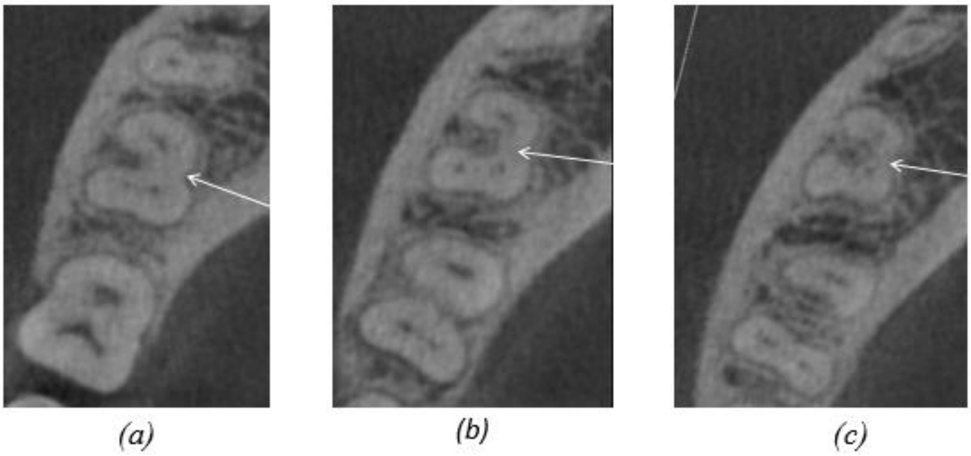


Figure 4. 7 Coronal (a), mid-root (b) and (c) apical axial sections of a right mandibular second permanent molar with root fusion between the mesial and distal roots. The arrow shows the point of fusion.

A summary of the patterns of root fusion in the second permanent molars is presented in Table 4.3.

Table 4. 3 Distribution of fused roots characteristics in second permanent molars by tooth types

| | | Fused roots | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | MB+DB | | | | | | | | |
| Tooth type | n (%) | n (%) | MB+P | MB+DB+P | M+D | Other | Total | Fisher’s | df | p |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | n (%) | n (%) | n (%) | n (%) | | | | |
| Maxillary molars | 40 (74.1) | 27 (67.5) | 3 (7.5) | 7 (17.5) | 0 | 3 (7.5) | 40 (100) | 54.000 | 4 | <0.001*** |
| Mandibular molars | 14 (25.9) | 0 | 0 | 0 | 14 (100) | 0 | 14 (100) | | | |
| Total | 54 (100) | 27 (50.0) | 3 (5.6) | 7 (13.0) | 14 (25.8) | 3 (5.6) | 49 (100) | | | |

Fisher's exact test (Fisher's) for association was used for all variables.
df; Degrees of Freedom.
***p<0.001

### 4.2.3 Root fusion and gender

A Pearson Chi-Square ($X^2$) test showed a non-statistically significant association between root fusion and gender in second permanent molars ($X^2$=1.122, df=1,p=0.290) as presented in Table 4.4.

Table 4. 4 Distribution of root fusion characteristics in second permanent molars by gender.

| | | Root fusion | | | | | |
|---|---|---|---|---|---|---|---|
| | | Absent | Present | | | | |
| Gender | n (%) | n (%) | n (%) | Total | $X^2$ | df | p |
| Male | 144 (45.4) | 123 (38.8) | 21 (6.6) | 144 (45.4) | 1.122 | 1 | 0.290 |
| Female | 173 (54.6) | 140 (44.2) | 33 (10.4) | 173 (54.6) | | | |
| Total | 317 (100) | 263 (83.0) | 54 (17.0) | 317 (100) | | | |

Pearson Chi-Square ($\chi^2$) test for association was used for all variables. df; Degrees of Freedom.

### 4.2.4 Root curvature

Maxillary second permanent molar roots had some form of curvature in 58.5% of the cases while in mandibular, root curvature was present in 56% of the CBCT images examined.

Mesiobuccal root was straight in 47.7% and when the curvature was present, it was mostly in the distal direction (51.5%). The distobuccal root was straight in 75.8% of the cases, with a 10.6% mesial and 13.6% distal curvatures. The palatal root showed the highest (117, 84.2%) occurrence of a straight root. Its most frequent direction of curvature was buccally (19, 13.6%), while only 3(2.2%) had a palatal curvature.

The mandibular second permanent molars mainly (97.1%) had two roots, mesial and distal. The mesial root was curved distally in about half (50.5%) while it was straight in 44.8% of the cases. The distal root was predominantly straight (87.2%) with 7% and 5.8% mesial and distal curvatures respectively. Table 4.5 below summarizes frequency and direction of root curvature in mandibular and maxillary second permanent molars.

Table 4. 5 Frequency of occurrence and direction of root curvature characteristics in second permanent maxillary and mandibular molars

| Tooth type | Root | Straight n (%) | Lingual n (%) | Buccal n (%) | Mesial n (%) | Distal n (%) | Total n (%) |
|---|---|---|---|---|---|---|---|
| Maxillary molars | MB | 63 (47.7) | 0 | 0 | 1 (0.8) | 68 (51.5) | 132 (100) |
| | DB | 100 (75.8) | 0 | 0 | 14 (10.6) | 18 (13.6) | 132 (100) |
| | P | 117 (84.2) | 3 (2.2) | 19 (13.6) | 0 | 0 | 139 (100) |
| | Others | 9 (90.0) | 1 (10.0) | 0 | 0 | 0 | 10 (100) |
| Mandibular molars | M | 77 (44.8) | 0 | 1 (0.6) | 7 (4.1) | 87 (50.5) | 172 (100) |
| | D | 150 (87.2) | 0 | 0 | 12 (7.0) | 10 (5.8) | 172 (100) |
| | Others | 2 (50.0) | 0 | 1 (25.0) | 0 | 1 (25.0) | 4 (100) |
| | Total | 518 (68.1) | 4 (0.5) | 21 (2.8) | 34 (4.4) | 184(24.2) | 761 (100) |

### 4.2.5 Root length

The palatal root had the longest mean root length (20.86mm) among the second permanent maxillary molar roots while the mesial root had the longest mean root length (21.16mm) between the second permanent mandibular molar roots.

**4.2.5.1 Root length in second maxillary permanent molars**

*Mesio-buccal root length*

The mean maxillary second permanent molar mesiobuccal root length was 19.69mm (±1.57 SD) with a median of 19.67mm. The longest root was 22.95mm and the shortest was 16.06mm long.

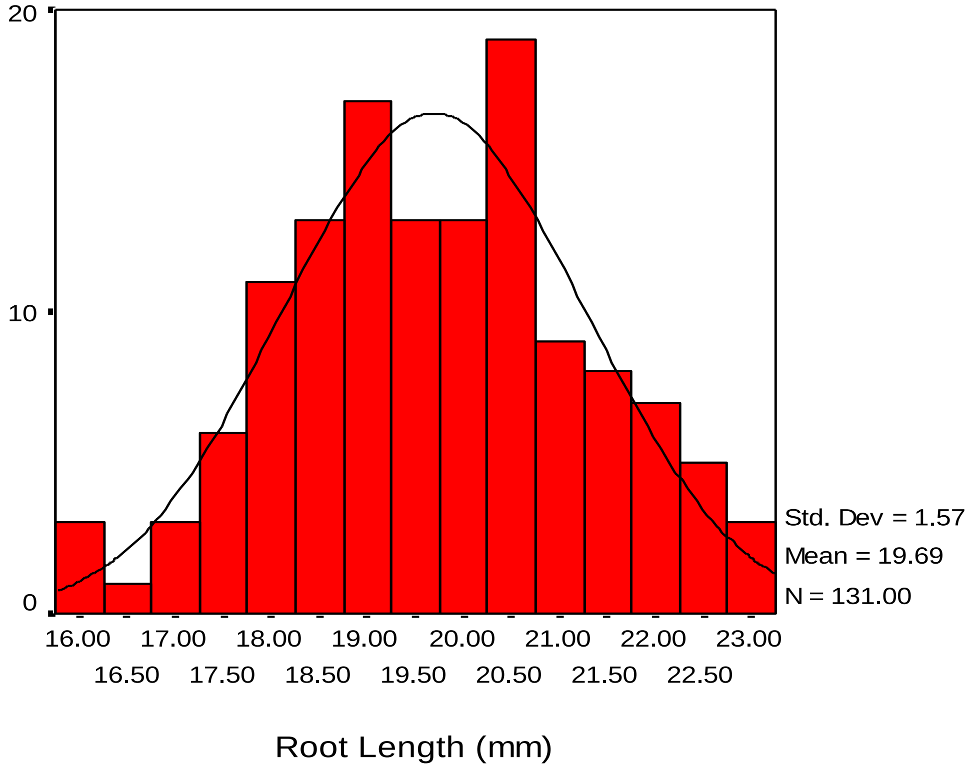


Figure 4. 8 Maxillary second permanent molar mesiobuccal root length

*Distobuccal root length*

The mean maxillary second permanent molar distobuccal root length was 19.30mm (±1.47 SD) with a median of 19.41mm. The longest root was 23.88mm and the shortest was 15.94mm long.

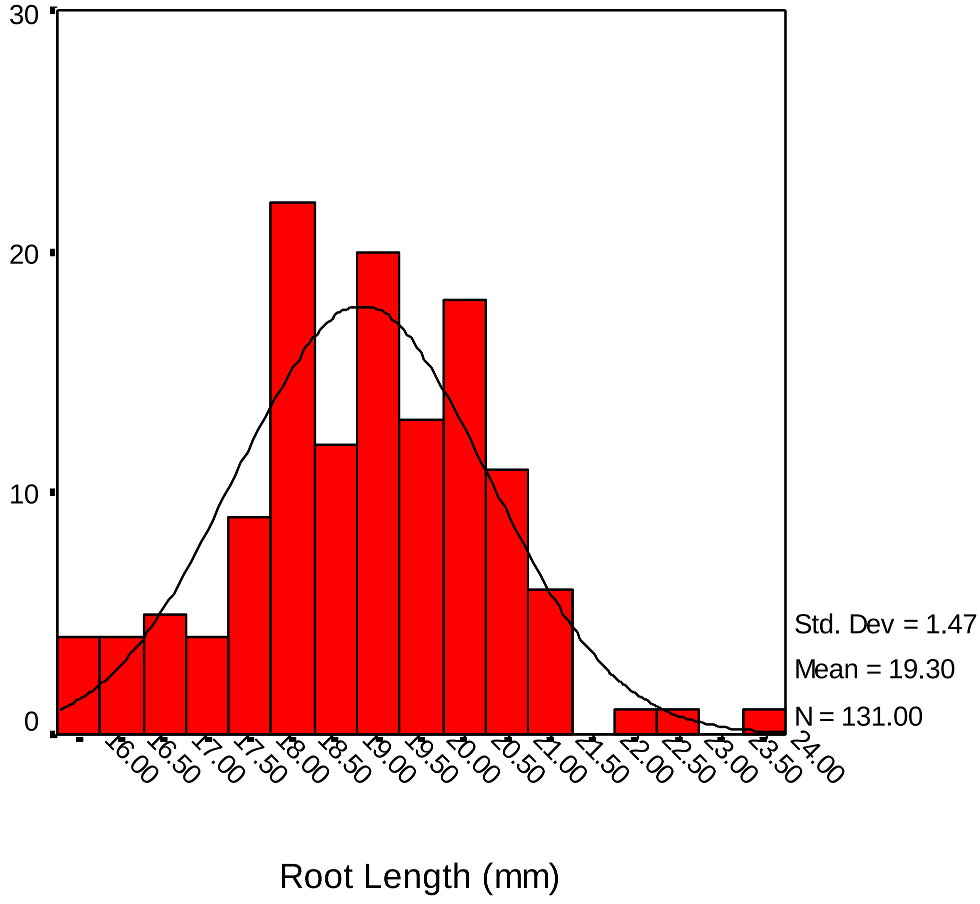


Figure 4. 9 Maxillary second permanent molar distobuccal root length

*Palatal root length*

The mean maxillary second permanent molar palatal root length was 20.86mm (±1.69 SD) with a median of 20.83mm. The longest root was 25.84mm and the shortest was 16.47mm long.

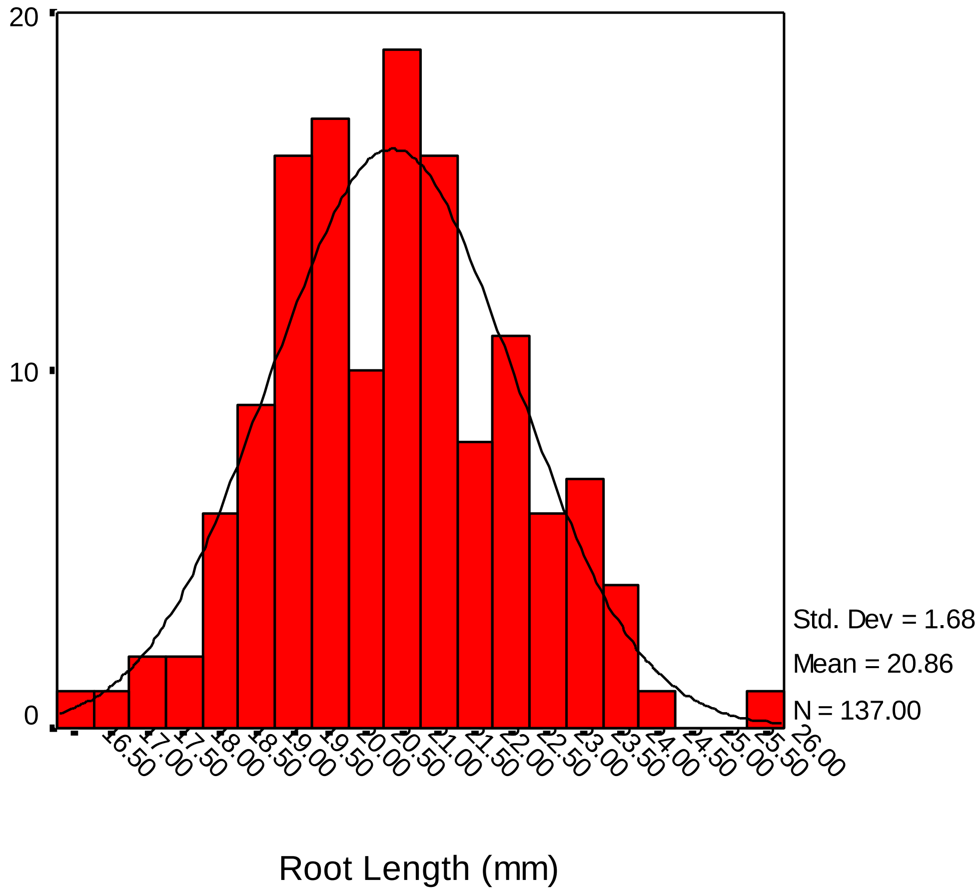


Figure 4. 10 Maxillary second permanent molar palatal root length

#### 4.2.5.2 Root length in mandibular second permanent molars

*Mesial root length*

The mean mandibular second permanent molar mesial root length was 21.16mm (±1.61 SD) with a median of 21.11mm. The longest root was 25.69mm and the shortest was 16.00mm long.

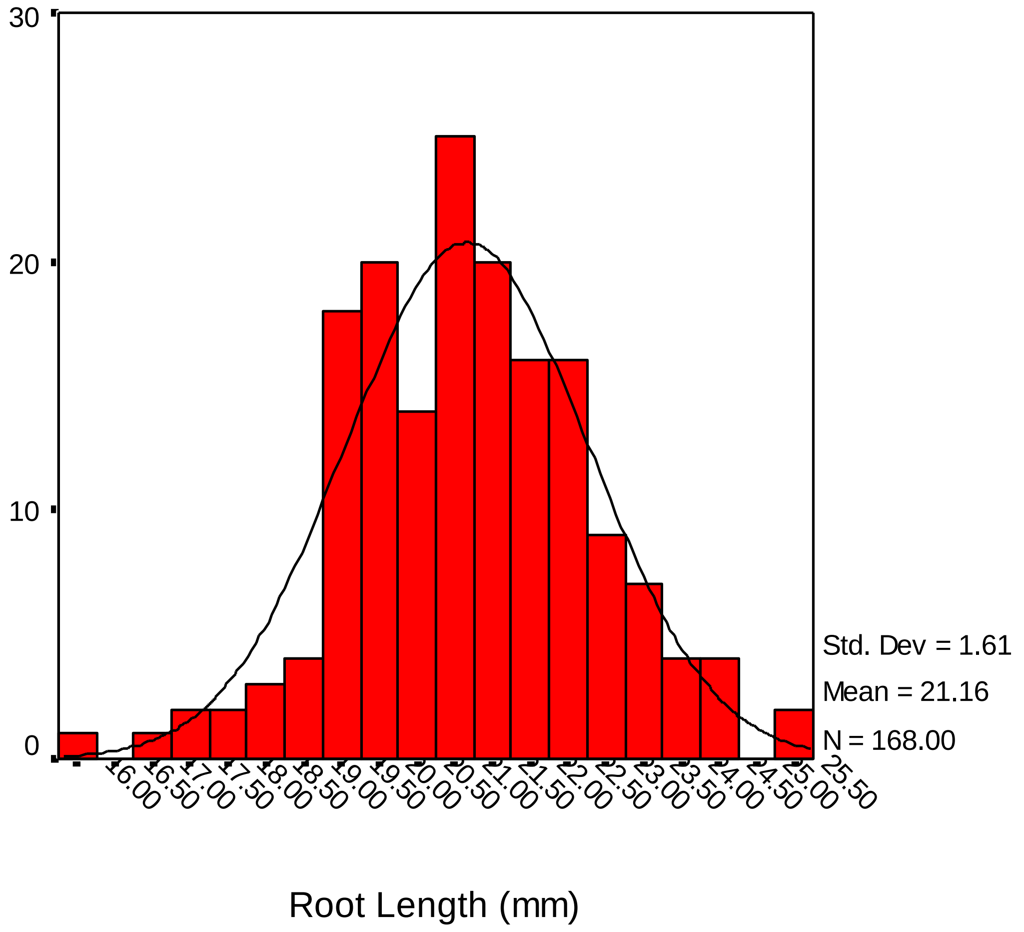


Figure 4. 11 mandibular second mesial root length

*Distal root length*

The mean mandibular second permanent molar distal root length was 20.29mm (±1.58 SD) with a median of 20.26mm. The longest root was 24.21mm and the shortest was 15.29mm long.

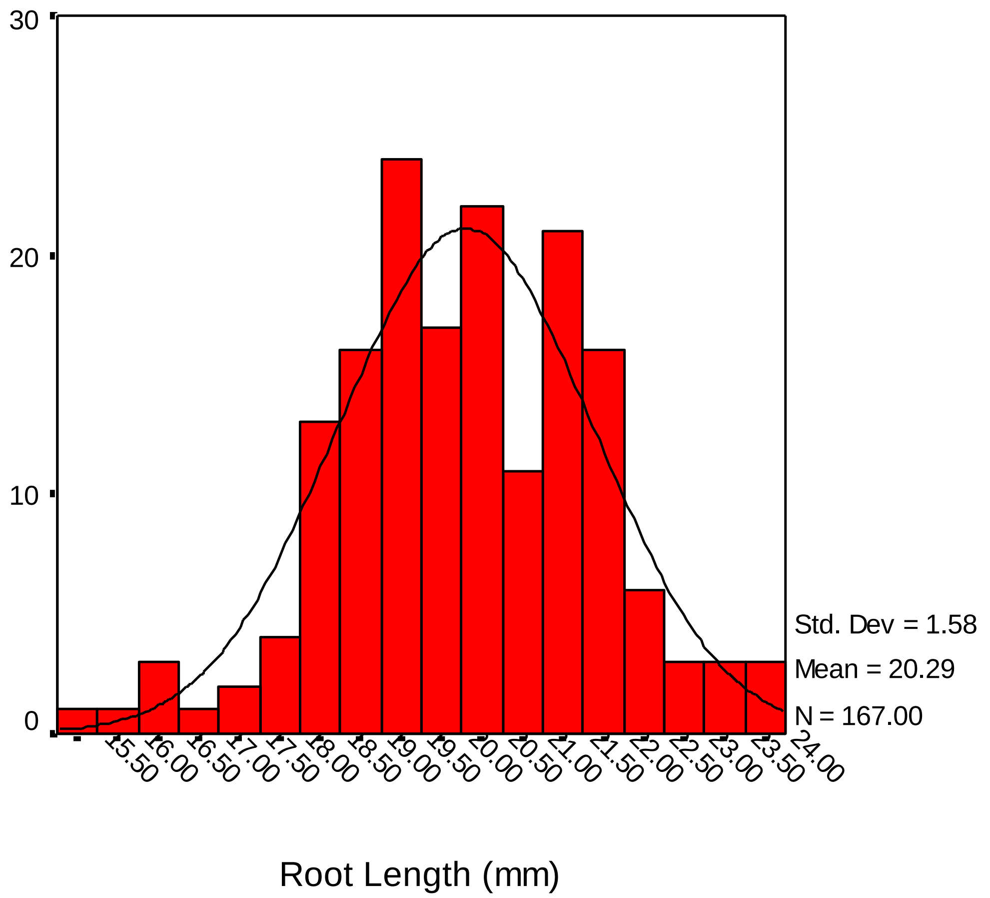


Figure 4. 12 mandibular second distal root length

### 4.2.6 Gender variation in second permanent molars root length

The mean root lengths in all the roots were found to be higher in males than in females. Statistically significant differences (Independent Samples t test) in means of root length between gender groups in MB, DB, P, M and D roots were found as shown in the Table 4.6.

Table 4. 6 Gender variation in mean root length characteristics in the second permanent molars

| Root | Gender | n | M | SD | t | df | p |
|---|---|---|---|---|---|---|---|
| MB | Male | 62 | 20.17 | 1.65 | 3.484 | 131 | <0.001*** |
| | Female | 71 | 19.25 | 1.39 | | | |
| DB | Male | 62 | 19.69 | 1.47 | 3.063 | 131 | 0.003** |
| | Female | 71 | 18.93 | 1.38 | | | |
| P | Male | 62 | 21.29 | 1.75 | 2.857 | 136 | 0.005** |
| | Female | 76 | 20.48 | 1.57 | | | |
| M | Male | 78 | 21.47 | 1.66 | 2.360 | 168 | 0.019* |
| | Female | 92 | 20.90 | 1.52 | | | |
| D | Male | 77 | 20.65 | 1.52 | 2.679 | 166 | 0.008** |
| | Female | 91 | 20.00 | 1.56 | | | |
| Others | Male | 5 | 21.44 | 2.23 | 1.456 | 14 | 0.167 |
| | Female | 11 | 19.86 | 1.91 | | | |

Independent Samples t test (t) was used for all variables.
M; Mean.
SD; Standard Deviation.
df; Degrees of Freedom.
***p<0.001.
**p<0.01.
*p<0.05.

### 4.3 Internal root morphology

#### 4.3.1 Root canal configuration in maxillary second permanent molars

The mesio-buccal root had the most varied canal configurations among the maxillary second permanent molar roots. Five root canal configurations were identified as per Vertucci 1984 classification: type I, II, III, IV, and V with type I being the most predominant (81.8%). Type II, III, IV, and V appeared in 3%, 1.5%, 12.2% and 1.5% in the mesiobuccal roots respectively All the canals in the distobuccal and palatal roots were found to exhibit Vertucci type I canal configuration with one single canal from the orifice to the apex.

#### 4.3.2 Root canal configuration in mandibular second permanent molars

Five canal configurations were also noted in the mesial root with Vertucci type IV (58.5%) being the most common. The other canal configurations occurred at different frequencies with Vertucci type I, II, III, and V being 13.5%, 7.0%, 8.8% and 12.2% respectively.

The distal root had predominantly Vertucci type I canal configuration 160 (93.6%). Two cases each representing 1.2% displayed Vertucci type II and III canal configurations, while 4 (2.2%) and 3(1.8%) had type IV and V respectively.

Figures 4.14 to 4.21 illustrates some of the canal configurations observed.

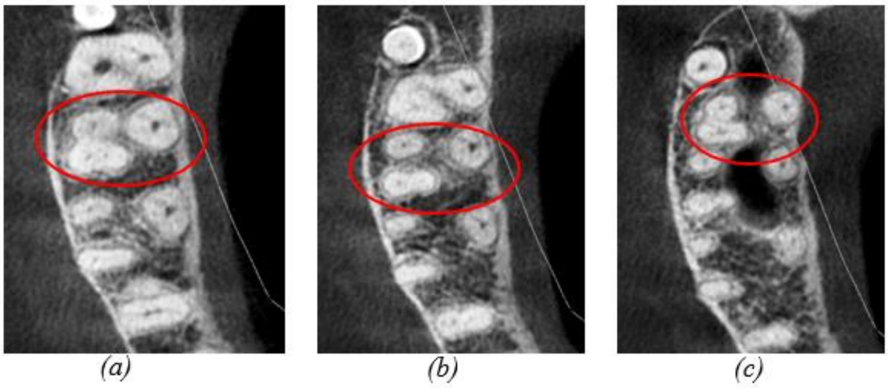


Figure 4. 13 Axial sections (a) coronal, (b) mid-root and (c) apical regions demonstrating Vertucci type I canal configuration in palatal and disto-buccal roots and type II in the mesio-buccal root of a right maxillary second permanent molar.

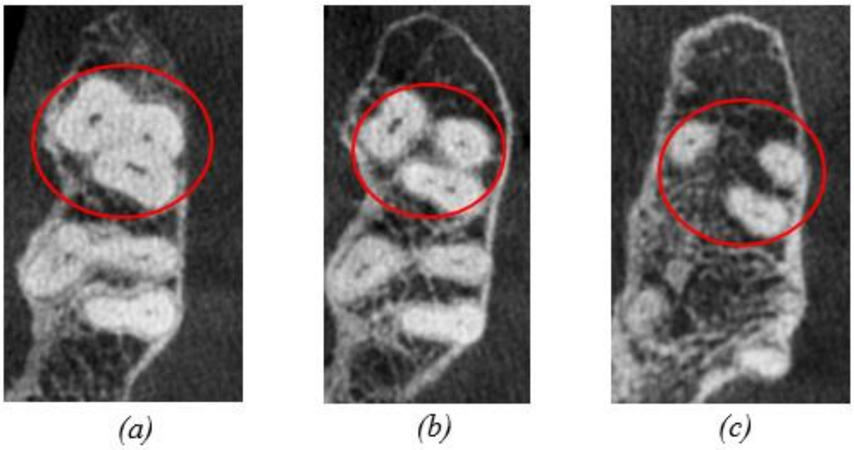


Figure 4. 14 Axial sections from (a) coronal to (c) apical regions showing Vertucci type I (palatal and distobuccal roots) and type III (mesio-buccal root) canal configurations in a left maxillary second permanent molar.

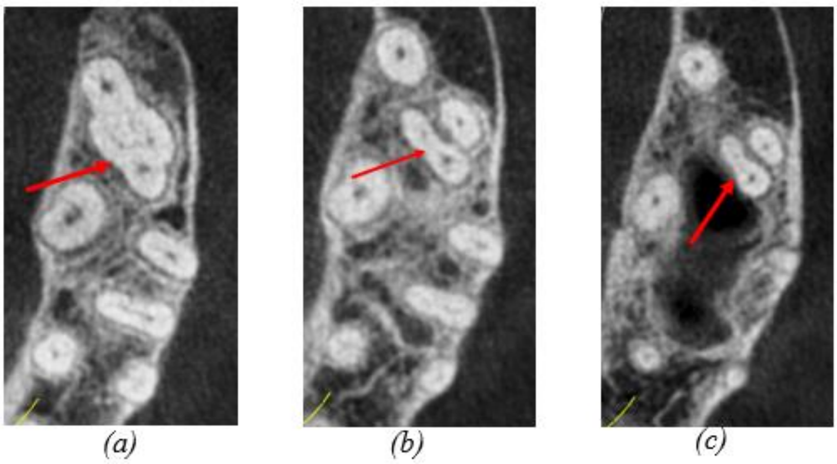


Figure 4. 15 Illustrations of a right maxillary second permanent molar axial sections from (a) coronal to (c) apical demonstrating Vertucci type IV canal configuration in the mesiobuccal root

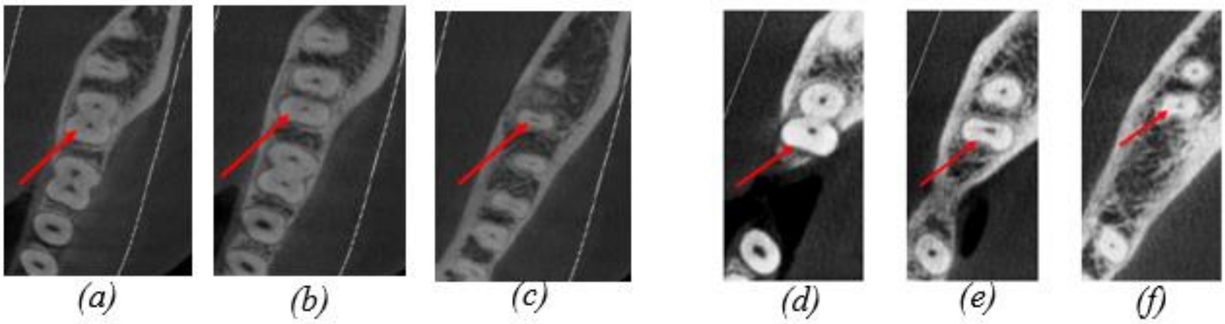

Figure 4. 16 Vertucci type I canal configuration in the mesial roots of two mandibular second permanent molars. Axial sections from (a & d) coronal, (b & e) mid-root and (c & f) apical regions.

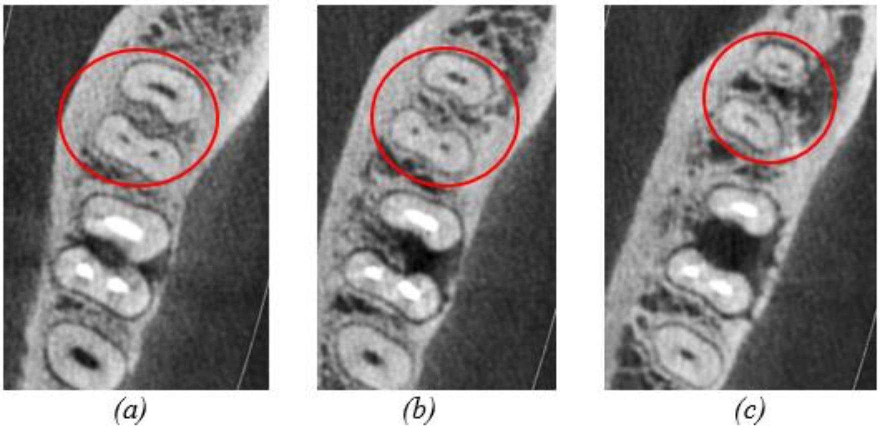

Figure 4. 17 Vertucci type II canal configuration in a mandibular second permanent molar mesial root and type I in the distal root. Axial sections are at (a) coronal, (b) mid-root and (c) apical region

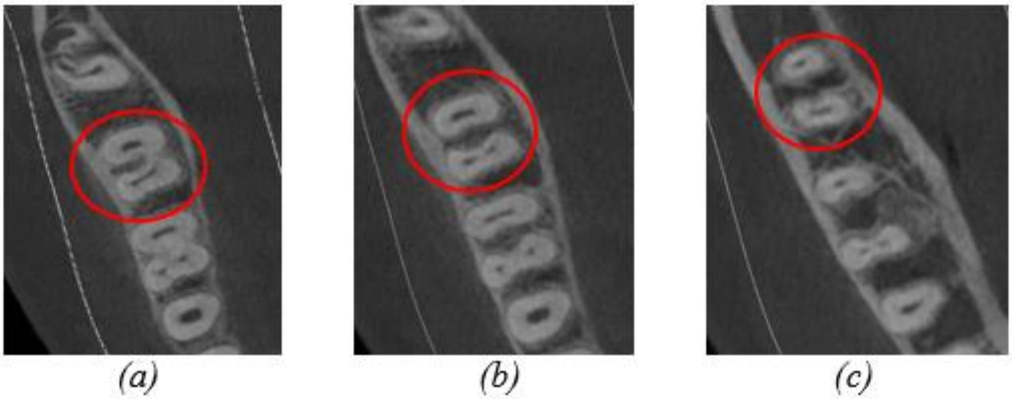

Figure 4. 18 (a) Coronal, (b) mid-root and (c) apical axial sections showing Vertucci type I and III canal configuration in the distal and mesial roots respectively of a mandibular second permanent molar

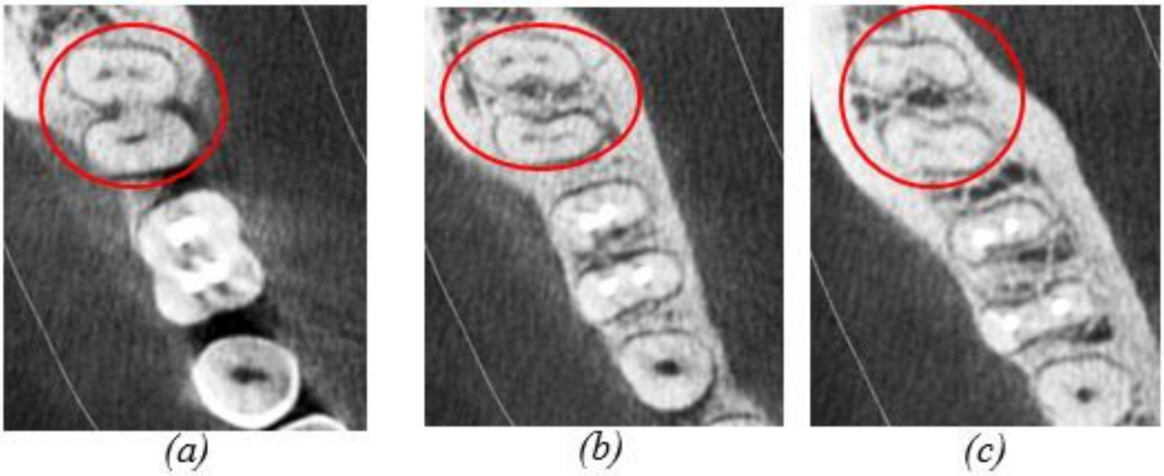


Figure 4. 19 (a) Coronal, (b) mid-root and (c) apical axial sections depicting Vertucci type IV canal configuration in the distal root and type V in the mesial root of a mandibular second permanent molar

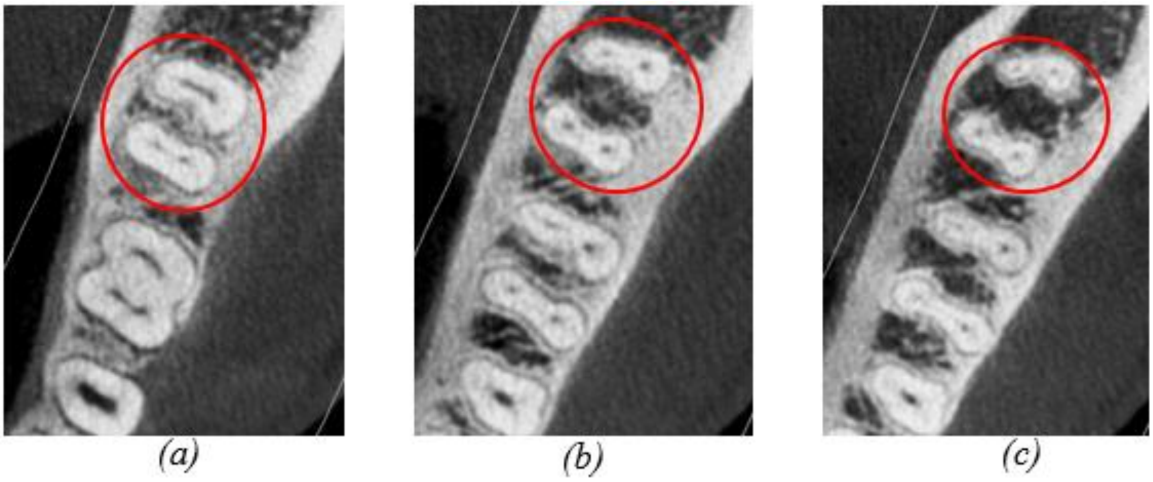


Figure 4. 20 Serial axial sections from (a) coronal, (b) mid-root and (c) apical regions showing Vertucci type IV canal configuration in mesial root and type V in distal root of a mandibular second permanent molar

The table below displays a summary of the canal configurations identified in each of the roots of both maxillary and mandibular second permanent molars.

Table 4. 7 Root canal configuration characteristics in second permanent maxillary and mandibular molars

| Root | Canal configuration (Vertucci 1984 classification) n (%) | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | Others | |
| MB | 108 (81.8) | 4 (3.0) | 2 (1.5) | 16 (12.2) | 2 (1.5) | 0 | 0 | 0 | 0 | 132 (100) |
| DB | 132 (100) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 132 (100) |
| P | 138 (100) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 138 (100) |
| M | 23 (13.5) | 12 (7.0) | 15 (8.8) | 100 (58.5) | 21 (12.2) | 0 | 0 | 0 | 0 | 171 (100) |
| D | 160 (93.6) | 2 (1.2) | 2 (1.2) | 4 (2.2) | 3 (1.8) | 0 | 0 | 0 | 0 | 171 (100) |
| Others | 12 (75.0) | 1 (6.3) | 1 (6.3) | 0 | 2 (12.5) | 0 | 0 | 0 | 0 | 16 (100) |
| Total | 573 (75.4) | 19 (2.5) | 20 (2.6) | 120 (15.8) | 28 (3.7) | 0 | 0 | 0 | 0 | 760 (100) |

# CHAPTER FIVE

## DISCUSSION

A thorough understanding of root and canal morphology ensures adequate cleaning/instrumentation and subsequent obturation of all the root canals leading to reduced chance of post-treatment disease(2).

Several ways of studying root and canal morphology have been used, each with their own merits and demerits. These methods include: sectioning, microscopy, staining and clearing and radiological methods encompassing both conventional and digital radiography(7). The present study used cone beam computed tomography to thoroughly and comprehensively analyse the internal and external root and canal morphology of second permanent molars in a Kenyan population. CBCT is a non-invasive technique allowing three dimensional analysis of both internal and external anatomy of teeth without the limitation of anatomical structural superimposition observed in conventional plain radiography(9).

In this study, a total of 317 CBCT images were analyzed out of which 144 and 173 were male and female respectively. The higher number of females underlines the fact that they have often been found to have better oral health seeking behaviors than their male counterparts(67)(68)(69).

On the tooth type, there were more mandibular (175) than maxillary (142) second permanent molars. This may be because majority of CBCT scans are requested for patients seeking dental implant supported prostheses due to missing tooth/teeth. In addition, given that only specific arch/quadrants of interest are scanned, this may support the findings of the current study of higher number of mandibular scans compared to maxillary. Furthermore, Sanya et al studied the pattern of missing permanent teeth among Kenyans and found the lower molars to be the most commonly missing teeth(70).

### 5.1 External root morphology

Maxillary second permanent molars were found to predominantly (90.8%) possess three roots: MB, DB and P, which was slightly less than the 96% reported by Ilich et al(11). The difference could be attributed to the methodology and difference in the sample size. In the later study, visual analysis was used with a smaller sample size of 121 teeth. However, the results are similar to those obtained by Katarzyna et al (6) in a Polish population using CBCT. They reported 91.8% occurrence of three roots in maxillary second permanent molars. Furthermore, other researchers(71)(72)(73), have reported lower occurrence of three roots in maxillary second permanent molars in different populations using CBCT. Rouhani et al(71) reported 89.6% in an Iranian population, Roserin et al(72) observed 87.1% in a Thai population and a significantly lower percentage of 67.8% was reported by Lin Y et al(73)in Taiwan. The difference could be attributed to racial differences in the study population and sample size. For instance, in the current study the sample size was 142, Rouhani et al (71) had a sample of 125 while Roserin et al (72) and Lin Y et al (73) had higher samples of 457 and 212 respectively.

Moreover, in the present study, 2.1% (3), 6.3% (9), and 0.7% (1) of maxillary second permanent molars were found to have one, two and four roots respectively. This was close to the findings by Katarzyna et al who found that 2.8% and 5.8% had one and two roots respectively(6). Despite studying similar Kenyan population though using visual analysis, Ilich et al obtained slightly different results with 0.83% and 2.48% having one and two roots respectively(11). The disparity from the current study may be attributed to difference in sample size and method of study.

The common finding of two roots, mesial and distal in mandibular second permanent molars was the case in this study where 97.1% were found to have two roots compared to reported 93.13% and 96.8% in a Kenyan(11) and Ugandan(74) populations respectively. Other studies of Sudanese(5), Turkish(15) and Tanzanian(75) populations found 88%, 90% and 100% of mandibular second permanent molars having two roots respectively. All these studies were done using direct visualization, which may explain the slight variation from the current study.

Disto-lingual root known as radix entomolaris is a rare variation in the number of roots of mandibular permanent molars with a predisposition to mongoloid populations(18). In the current study, 1.1% of the mandibular second permanent molar teeth had three roots with the third root being disto-lingual which is in variance with the reported 2.8%, 1.8% and 1.7% in Mongoloid, Negroid and Caucasian patients(16). The difference may be due to genetic variation, sample sizes used, and the use of plain radiography as opposed to CBCT used in current study. When present, appreciation and knowledge of this additional root ensures adequate cleaning and obturation of the canal hence avoiding incidence of post-treatment disease due to it being missed.

Root fusion has been associated with increased complexity of root canal systems. These complexities include existence of additional grooves, isthmuses, or canals that connect some or all of the roots(3). Indeed, Martins JN et al found 10.1% prevalence of merging canals within fused roots in maxillary second permanent molars with the merging occurring mostly between the mesio-buccal and disto-buccal roots canals(76). In the current study, 28.2% of maxillary second permanent molars and 8% of mandibular second permanent molars had some form of root fusion. These results were similar to the ones reported by Ilich et al who established root fusion in 28.1% and 12.2% of maxillary and mandibular second permanent molars respectively(11). Higher incidence of root fusion in maxillary second permanent molars have also been described in Taiwanese, Chinese, Burmese and Latin American populations(73)(22)(77)(78). In one of these studies among Latin Americans, 57.6% root fusion was found using CBCT(78). In contrast, a much lower rate was reported in an Iranian(18.6%) and Saudi (21%) populations(79)(80). The noted contrasts can be ascribed to racial differences in the populations studied and method of evaluation used.

Prior knowledge of these complexities is essential for a favourable outcome of both conventional and surgical endodontic therapy. Fusion of roots can occur anywhere along the length of the roots from cervical, middle and apical thirds. Root fusion is more common in maxillary than mandibular molars because the former have more roots, resulting in a greater possibility of different combinations compared to the lower molars(78).

The commonest pattern of fusion observed in the maxillary second permanent molars was between the disto-buccal and mesio-buccal roots, which was in agreement with a previous study done in a Kenyan population(11). Fusion between the distobuccal and palatal roots occurred with the lowest frequency followed by fusion of all the three roots. This is very different from studies done in Portugal and Korea which reported the highest prevalence of fusion to be between the mesio-buccal and palatal roots(76)(81). The observed dissimilarity could be due to racial differences of the study populations.

As pertains to root curvature, considerable attention should be paid to its presence and direction because it affects instrumentation techniques like pre-curving instruments during root canal treatment(82). This ensures avoidance of procedural errors like ledging and perforations. Caution should also be taken during post space preparation since placement of straight posts into a curved canal runs the risk of weakening or perforating the root.

In the present study, straight roots in maxillary second permanent molars were identified in 47.7%, 75.8% and 84.2% of mesio-buccal, disto-buccal and palatal roots respectively. Slight variation was reported by Ilich et al (11) who found 38.84%, 67.77% and 62% of mesio-buccal, disto-buccal and palatal roots respectively were straight. The difference could be due to the differing study methodology utilized. This could likely occur because positioning of extracted teeth can be confusing especially if they are not labelled well. The most frequent direction of curvature of mesio-buccal root was distal (51.5%) while the disto-buccal root was curved both in distal (13.6%) and mesial (10.6%) directions. The palatal root was mostly straight but when curved, the direction was buccally. The observed directions of curvature in each root were in concurrence with those previously reported(11)(82).

Root curvature in the mandibular permanent teeth was found to occur in slightly more than half (55.2%) of the mesial roots while the distal root was mostly straight (87.2%). The direction of curvature in the mesial root was predominantly in the distal direction. A direct visual analysis study done in a Kenyan population also found a lower percentage of straight roots in the mesial (25.92%) than in the distal (75.66%) roots of second permanent mandibular molars(11). Rocha et al reported 78% of straight distal roots, which was almost similar to the observed in the current study. However, he reported a much higher percentage (83%) of distal curvature in the mesial root. The disparity can be attributed to the racial difference in the study population and methodology.

Root length determination during root canal treatment is aided well when a clinician has an underlying knowledge about the average length of tooth in a particular population. The palatal root was found to be the longest in maxillary second permanent molars with a mean root length of 20.84 mm (+1.69 SD). The mesiobuccal and distobuccal roots were 19.67mm (±1.57 SD) and 19.29mm (±1.47 SD) respectively. These figures are lower than those reported by Ilich et al(11) who established the length of palatal, mesiobuccal and distobuccal roots to be 23.18mm(±1.65), 20.65mm (± I.77 SD) and 21.47mm(± 1.79SD) respectively. The discrepancy could be attributed to the study methodology; the current study used CBCT while Ilich et al used the standard method of direct measurement of extracted teeth. Previous studies on the reliability and accuracy of CBCT on linear measurements, have established that real measurements are always larger than those for the CBCT images(83)(84). Flores-Mir C et al found that in comparison to actual tooth lengths obtained using callipers, CBCT panoramic reconstructions underestimated the lengths by a proportion of 4% and 1.6mm (95% C.I.: 1.1 - 2.0 mm) in actual length(84). Moreover, there was slight disparity of the sample size, 121 versus 142 for the current study. The variation could also be attributed to the intra-population variations. Carrotte P(85) and Naseri et al(79) reported average tooth length in maxillary second permanent molars to be 19.8mm and 20mm respectively. These results were similar to the ones obtained in the current study despite the differences in the study population.

In the mandibular second permanent molars, the mean root length for the mesial root was found to be 21.16 mm (+1.61 SD) while that of the distal root was 20.29 mm (+1.58 SD). This is similar to what was reported by Rocha(29) who established average root length of 20.87mm and 20.00mm for the mesial and distal roots respectively. However, the mean root lengths reported in this study were lower in comparison with that found by Ilich et al(11), who reported mean root lengths of 22.19mm(± 1.71SD) and 23.15mm(± 1.60) for mesial and distal roots respectively. The difference could be related to the method of investigation used as well as the effects of underestimation of lengths found in CBCTs(84).

### 5.2 Internal root morphology

In provision of root canal treatment, the number/configuration of the root canals is of even greater concern to the dentist than the number of roots. This is because root canals which are not chemo-mechanically prepared and subsequently filled during treatment become a reservoir for bacteria, hindering healing and permitting the emergence of new inflammatory lesions and persistent periapical disease. The second canal in the mesiobuccal root of maxillary permanent molars is the most frequently missed canal during root canal treatment(86). Consequently, during treatment or retreatment of maxillary permanent molars, dentists need to be aware of the possible existence of two or more root canals before they commence endodontic treatment. In the current study, root canal configuration in each of the roots of the second permanent molars was described according to Vertucci classification 1984(87).

In the maxillary second permanent molar, the mesiobuccal root presented with the most varied root canal configurations unlike the palatal and distobuccal roots that exhibited only Vertucci type I configuration in all the teeth examined. Specifically, most (81.8%) of the mesiobuccal roots had Vertucci type I canal configuration followed by Type IV configuration which was seen in 12.2% of the teeth. The other canal configurations observed in the mesiobuccal root were Vertucci Type II, III and V appearing in 3%, 1.5% and 1.5% of the teeth respectively. Ilich et al(11) evaluated root canal morphology of maxillary permanent second molars of the Kenyan population by use of staining and clearing. He reported almost similar results as obtained in the current study. He found Vertucci type I canal configuration in 80.16% of the mesiobuccal roots, 100% of distobuccal and 99.2% of palatal roots. A staining and clearing study done in a Ugandan population reported Vertucci type I canal configuration in 86.9%, 99.5% and 99% of mesiobuccal, distobuccal and palatal roots of maxillary permanent second molar(88). Additionally, in the mesiobuccal root, Vertucci type II, IV and V canal configurations were identified at a frequency of 1.8%, 6.7% and 3.2% respectively. Rouhani et al(71) also reported comparable results in the Iranian population with 80.8% of mesiobuccal roots having a single canal from the orifice to the apex (type I Vertucci canal configuration). Other studies have shown a lower prevalence of Vertucci type I canal configuration specifically in the mesiobuccal root. These include a study by Vertucci done by staining and clearing method which found 71% prevalence of type I canal configuration(87). Two radiological studies done using CBCT by Roserin et al(72) and Katarzyna et al(6) reported 70% of mesiobuccal roots in the Thai and Polish populations respectively had Vertucci type I canal configuration. More studies from Brazil(25), USA(89) and Ireland(90) established 58%, 59.7% and 58% of mesiobuccal roots had Vertucci type I canal configuration. In contrast, one study from Taiwan found a higher prevalence (92.3%) of Vertucci type I canal in the mesiobuccal root. The differences observed in all the above studies could be attributed to variation in sample size, evaluation techniques employed in each study as well as racial diversities of the populations studied.

In the mandibular second permanent molar, the mesial root was found to mainly (58.5%) exhibit Vertucci type IV canal configuration. Vertucci Type I, II, III and V canal configurations were seen in 13.5%, 7.0%, 8.8% and 12.2% of the mesial roots respectively. Other previous studies done on mandibular second molars have yielded comparatively similar results with the type IV canal configuration being the most common in the mesial root. For instance, type IV canal configuration was found in 63%, 51.8% and 49.8% of mesial roots of second permanent molars in Sudanese(5), Tanzanian(75) and Ugandan(74) populations. Notably, all these three studies were histological, done by staining and clearing.  In contrast, Gulabivala et al(36) did a study in a Burmese population and found a much lower (26.9%) prevalence of type IV canal configuration in the mesial root with type II being the most common at 35.6%. Additionally, a CBCT study in Turkey by Demirbuga et al(21) reported an almost equal proportion of type II (35.8%) and IV (37.3%) canal configurations in the mesial root of second permanent molars. In the Chinese(91) and Indian(92) populations higher prevalence of type IV canal configuration in the mesial root has been reported at 65% and 75.6% respectively. The noted variations are possibly due to the racial differences of the study populations and the method of analysis used.

On the other hand, the distal root of the mandibular second permanent molars presented less variability than the mesial one, predominantly having Vertucci type I canal configuration, with 93.6% having a single canal from the orifice to the apex. A previous staining and clearing study by Ilich et al (11) in a |Kenyan population reported 85.70% type I canal configuration in the distal root of second permanent molars. The difference could be due to the method of investigation. Several other studies have also established type I canal configuration in the distal root of second permanent molar to occur in more than 90% of the cases(74)(87)(21)(91)(93). In contrast, Madjaba et al(75) did a study on second permanent molars in a Tanzanian population and found a much lower prevalence of 45.9% of distal root had type I canal configuration. The disparity could be due to difference in sample size and method of study. Madjaba et al (75) used staining and clearing technique and had a sample of only 85 as opposed to the current study with 175 mandibular second permanent molars.

### 5.3 Conclusion

Within the limitations of this study, the following conclusions about the external and internal root morphology of second permanent molars in a selected sample Kenyan population were made:

1. Majority of maxillary second permanent molars had three roots while mandibular second permanent molars were predominantly two rooted.
2. Root fusion was more common in maxillary than mandibular second permanent molars with fusion between mesiobuccal and distobuccal roots being the commonest pattern.
3. Mesiobuccal root of maxillary second permanent molars was found to have the highest (47.7%) occurrence of root curvature with the direction being mostly distal. The palatal root of maxillary second permanent molar and distal root of mandibular second permanent molar were found to be predominantly straight, 84.2% and 87.2% of the time respectively.
4. The mean root lengths of second permanent mandibular molars was 21.16 mm (+1.61 SD) and 20.29 mm (+1.58 SD) for the mesial and distal roots respectively. The mesiobuccal, distobuccal and palatal roots of the maxillary second permanent molars

were found to have mean root lengths of 20.84 mm (+1.69 SD), 19.67mm (±1.57 SD) and 19.29mm (±1.47 SD) respectively.

5. The mesial root of the maxillary second permanent molar had the most varied canal configuration ranging from Vertucci type I to V, with the commonest configuration being type I (81.2%) followed by IV (12.2%).
6. In the mandibular second permanent molars, the mesial root had predominantly Vertucci type IV canal configuration while distal root displayed type I in most cases.

### 5.6 Recommendations

CBCT scanning provides additional information and three-dimensional imaging about the internal and external root morphology of second permanent molars. Indeed, there are specific instances both pre- and post-operatively where three-dimensional imaging and understanding of spatial relationships of tissues afforded by CBCT aids in diagnosis and enhances treatment planning.

Due to the anatomical complexity of the mesiobuccal root of second permanent maxillary molars and the frequent occurrence of the MB2 canal, the clinician should consider the presence of two canals in this root during root canal therapy.

Multicentre study involving a larger sample size should be done in various regions of the country to obtain data, which is more representative and generalizable to the Kenyan population.

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## APPENDIX I: Data collection form

1. Age
2. Sex: M …. F ….
3. Tooth type: Mandibular second molar …. Maxillary second molar ….
4. Number of roots: One …. Two …. Three …. Four …. Others ….
5. Root fusion: Absent …. Present ….

   Fused roots: MB+DB ….. MB+P …. DB+P …. MB+DB+P ….

   M+D …. Others ….
6. Root curvature: Absent …. Present ….

   Direction of curvature

| Root | Straight | Lingual | Buccal | Mesial | Distal | Others |
|---|---|---|---|---|---|---|
| MB | | | | | | |
| DB | | | | | | |
| P | | | | | | |
| M | | | | | | |
| D | | | | | | |
| Others | | | | | | |

7. Root length

| Root | Length (mm) |
|---|---|
| MB | |
| DB | |
| P | |
| M | |
| D | |
| Others | |

8. Canal configuration (Vertucci 1984 classification)

| Root | I | II | III | IV | V | VI | VII | VIII | Others |
|---|---|---|---|---|---|---|---|---|---|
| MB | | | | | | | | | |
| DB | | | | | | | | | |
| P | | | | | | | | | |
| M | | | | | | | | | |
| L | | | | | | | | | |
| Others | | | | | | | | | |

## APPENDIX II: Ethical Approval

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23rd December, 2019

KENYATTA NATIONAL HOSPITAL APPROVED 23 DEC 2019 KNH/UoN-ERC P. O. Box 20723 - 00202 NAIROBI

Dr. Bii Antony Kipkoech
Reg. No.V60/7157/2017
Dept. of Conservative and Prosthetic Dentistry
School of Dental Sciences
College of Health Sciences
University of Nairobi

Dear Dr. Kipkoech

**RESEARCH PROPOSAL: ANALYSIS OF ROOT AND CANAL MORPHOLOGY OF SECOND PERMANENT MOLARS IN A SELECTED KENYAN POPULATION USING CBCT (P837/10/2019)**

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 23rd December 2019 – 22nd December 2020.

This approval is subject to compliance with the following requirements:

a. Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
b. All changes (amendments, deviations, violations etc.) are submitted for review and approval by KNH-UoN ERC before implementation.
c. 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.
d. 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.
e. Clearance for export of biological specimens must be obtained from KNH- UoN ERC for each batch of shipment.
f. 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*).
g. Submission of an *executive summary* report within 90 days upon completion of the study.
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.