External and internal root morphology of premolar teeth in Kenyans of African descent.

Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Dental Surgery (MDS) in Paediatric Dentistry, University of Nairobi.

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DECLARATION

This thesis is my original work and has not been presented nor is it being considered for presentation for the award of a degree at any other university.

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DEDICATION

This thesis is humbly dedicated to my family: my husband Peter Ng'ang'a, my son Sami Ng'ang'a and my daughter Wambui Ng'ang'a. Their unwithering faith in me gave me renewed energy every day during the period in which I was undertaking this work. This enabled me to continue with this task to completion.

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ABSTRACT

Literature review indicates that there are very few studies that have been carried out on the morphology of Kenyan teeth.

***Objective*:** To determine the external and internal root morphology of premolar teeth in Kenyans of African descent.

Design: In vitro descriptive cross-sectional study.

Setting: Faculty of Dental Sciences, University of Nairobi.

Materials: Four hundred and eighty seven premolar teeth (specimens) extracted mainly for orthodontic reasons from Kenyans of African descent. The specimens were obtained from patients aged between 13-30 years attending dental clinics within Nairobi. Only teeth with fully formed roots, intact cusp tips and with no evidence of extensive secondary cementum formation at the apex were included in the study.

Methodology: The teeth were grouped according to gender and according to the four premolar tooth types (maxillary first separately from the second and mandibular first separately from the second). The number of roots and direction of root curvature of the teeth were determined by visual observation. Tooth length was measured using a Boley gauge. After decalcification and clearing the internal root morphology was studied under a microscope at a magnification of either x10 or x40 (magnification varied depending on the complexity of the canal pattern). The number and types of root canals were recorded according to Vertucci and Kartal et al's classifications.

Data analysis: Data analysis was done with the help of SPSS and Epi Info computer packages. Cohen's Kappa and a paired t-test were employed in the assessment of intraexaminer agreement. Descriptive statistics, independent t-test, chi-square test and Fisher's exact tests were applied in statistical evaluation of data.

Results: A total of 487 premolar teeth were studied. There were 155 maxillary first, 114 maxillary second, 108 mandibular first and 110 mandibular second premolars. The different tooth types were distributed evenly between males and females. The external morphology of the maxillary first premolar revealed that 83.2% were two-rooted (mean tooth length: buccal root-22.3 mm; lingual root-21.2 mm) 10.3% one-rooted (mean tooth length-22.6 mm) and 6.5% three-rooted. The maxillary second premolar was double rooted in 56.1% (mean tooth length: buccal root-21.9 mm; lingual root-21.5 mm), single rooted in 41.2% (mean tooth length-22.8 mm) and three rooted in 2.6% of the sample. 98.1% of mandibular first premolars were single rooted (mean tooth length-23.6 mm). 99.0% of mandibular second premolars were single rooted (mean tooth length-23.4 mm). There were no significant gender differences in the distribution of number of roots for the maxillary second, mandibular first and second premolar teeth. However, with respect to the maxillary first premolar tooth, three roots occurred significantly more commonly in males than females *($P<0.05$)*.

Males were found to have larger mean tooth length than females in all the four premolar tooth types except in single-rooted maxillary first and second premolars where there were no significant differences.

Majority of the roots (60.6%) in all the premolars were straight. Distal and "S" curvatures were also common (20.5%, 10.1% respectively) while lingual, buccal and mesial curvatures were rare. There were no significant gender differences in direction of root curvature *($P>0.05$)*.

The internal root morphology revealed that maxillary first and second premolars had two canals in 87.1% and 67.6% of the specimens respectively, while the mandibular first and second premolars had one canal in 63% and 92.7% of the specimens respectively.

The maxillary first and second premolar teeth had eight root canal types each. The mandibular first premolar tooth had the greatest variation with nine canal types while mandibular second premolar had the least variation with seven-canal types.

There were no significant gender differences in number and types of canals.

Conclusions: Maxillary first premolars were mostly two-rooted while the maxillary second premolars had either one or two roots. Mandibular first and second premolars were mostly one-rooted.

Majority of the roots were straight in all the four premolar tooth types and in both gender.

Males had significantly larger mean tooth lengths than females in all the premolar tooth type except in single-rooted maxillary first and second premolars where there were no significant differences.

Mandibular first premolars demonstrated the greatest variation in the root canal pattern while the mandibular second premolars had the least variation.

Recommendations: Clinicians, teachers and researchers should familiarize themselves with the data reported here for external and internal root morphology of premolar teeth in Kenyans of African descent and apply the information appropriately.

Additional studies on external and internal morphology of other tooth types and in specific age groups should be undertaken among Kenyans.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1. General introduction

Anatomy is the scientific study of the structure of animal bodies or plants while morphology is the scientific study of the form and structure of animals and plants.[1] One of the branches of human anatomy is dental anatomy which has clinical applications in most of the different specialties of dentistry: Oral Pathology, Oral Medicine, Oral and Maxillofacial Surgery, Radiology, Orthodontics, Paediatric Dentistry, Prosthodontics and Conservative Dentistry. Endodontics, a sub-specialty of conservative dentistry deals primarily with debridement of infected root canals and their subsequent obturation.

There are two main indications for obturating a root canal. First, to prevent micro-organisms from entering the canal system from the oral cavity or via the blood stream (anachoresis), and secondly, to stop the ingress of tissue fluid which would provide a culture medium for any residual bacteria within the tooth.[2]

Successful endodontic treatment depends on correct biomechanical preparation of a root canal and it's sealing. To achieve this, an understanding of the potential for variation in the root canal system is critical.[3]

In 1976, Ingle and Glick[3] attributed failures of endodontic treatment to lack of adequate knowledge on morphology of teeth, incomplete canal obturation, presence of an untreated canal and inadvertent removal of obturating material.

Pre-operative radiographs are necessary to show the external and internal morphological features of a root before instituting endodontic therapy.[4,5] Adequate knowledge of the external morphology (number of roots, direction of root curvature and tooth length) and internal morphology (number and types of root canals) of teeth are therefore essential for accurate interpretation of radiographs.[3]

An understanding of external morphology is also important in other treatment modalities such as surgical endodontics, periodontal surgery, dental extractions and orthodontic tooth movement. An extraction ("simple" or surgical) tends to be more difficult when the tooth has two or three roots.[6] Orthodontic tooth movement may be more difficult to accomplish in multirooted premolars.[7]

Genetic determination of dental morphology and the anthropological associations of certain dental characteristics with certain racial groups have been reported.[8-13] In 1986, a study carried out by Trope et al.,[12] reported that blacks exhibited a significantly higher number of multiple root canal systems in mandibular first premolars than whites. However, there is no substantial evidence that this claim has subsequently been corroborated or refuted by research on different nationalities of the African racial group.

Several studies on Kenyans of African descent in regard to the different dimensions of the dentition and associated structures have been done.[14-20] However, the literature reviews scanty information on the tooth morphology of Kenyans of African descent. Furthermore, only in a few instances have gender differences been highlighted.

Using dental casts, Hassanali and Odhiambo[18] analyzed the palatal depth, palatal length, maxillary and mandibular arch circumferences, posterior arch circumference, inter-canine and inter-molar distances and mandibular length of Kenyan children. The mean values for all the variables were generally higher in males than in females. Males have also been shown to have larger mesio-distal crown width than females in different racial groups,[21] and amongst the Japanese[22] males have been found to have more number of roots in the maxillary first premolar than females.

The aim of this study therefore, was to determine the external and internal morphology of premolar teeth in Kenyan males and females of African descent with regard to the number of roots, direction of root curvature, tooth length, and number and types of canals.

1.2. Development and eruption of premolars

Premolar teeth are found in the permanent dentition and are important for mastication and aesthetics. The term "bicuspid" is used synonymously because these teeth have two cusps, a larger buccal and a smaller lingual cusp.

Scotts and Simon[23] indicated that in the Caucasians, commencement of calcification in premolars is between $1^1/_2$ and $2^1/_2$ years. Completion of crown calcification is between 5 and 7 years and eruption dates range from 10 to 12 years. Root completion is usually 2-3 years after eruption.

There are no documented data on the timings of crown calcification and root development for Kenyans' teeth. However, the reported range of eruption time for the premolar teeth in Kenyans of African descent is between 9.40 and 10.23 years, with the maxillary premolar erupting earlier than the mandibular premolar by about 0.1 to 0.2 years.[24.25]

There are reported racial and gender differences in the eruption of premolars. Generally female teeth have been found to erupt earlier than those of males.[23-28]

1.3. External root morphology

1.3.1. Number of roots in premolar teeth

Direct visual observation method has been used in determining the number of roots in teeth.[13,29,30] This method is acceptable because it is straight-forward and the roots are large enough to be clearly seen with the naked eye.

1.3.1.1. Maxillary first premolar

The number of roots in this tooth is reported to vary significantly in different individuals and populations. Various studies have reported the occurrence of one root to range from 10% to 60%, two-roots 40% to 72% and three roots 0.0% to 6.0% (Table 1). [13,29-39] One Japanese study[22] found significant gender differences in number of roots in this tooth, where single-rooted teeth were reported in 55.4% of the males and 76.1% of the females whereas two distinct roots occurred in 25.5% of the male and 17.6% of the female teeth.

Table 1. Studies on number of roots in the maxillary first premolar.

Author(s)	Year of report	Country of study	No. of teeth	One root (%)	Two roots (%)	Three roots (%)
Hess[29]	1925	U.S.A	†	19.5	79.3	1.2
Mueller[30]	1933	U.S.A	130	31.5	68.5	0.0
Green[31]	1955	U.S.A	†	30.0	70.0	0.0
Ingle[32]	1965	U.S.A	†	43.0	55.0	2.0
Carns & Skidmore[33]	1973	U.S.A	100	37.0	57.0	6.0
Kerekes & Tronstad [34]	1977	Sweden& Norway	20	20.0	70.0	10.0
Vertucci & Gegauff[35]	1979	U.S.A	400	39.5	56.5	4.0
Woefel[36]	1990	*	200	38.0	61.0	1.0
Pecora et al.[37]	1991	Brazil	240	55.8	41.7	2.5
Walton &Torabinejad[38]	1996	*	†	10.0	85.0	5.0
Loh[13]	1998	Singapore	957	49.4	50.6	0.0
Chaparro et al.[39]	1999	Spain	150	40.0	56.7	3.3

** Caucasians of unspecified nationality*   *† unspecified*

1.3.1.2. Maxillary second premolar

There were fewer studies in the literature on the number of roots in this tooth than those for maxillary first premolar.

The tooth is reported to be mostly single rooted (82.0%-97.7%) as shown in Table 2. However in some cases a slight division of the root at the apex has been found, but distinct divisions are rare.[40] The occurrence of two roots has been reported to range from 2.3% - 18.0%.[30,34,40,41] When two roots occur the outward appearance of this tooth resembles that of the maxillary first premolar.[23] The three-rooted form is rare but has been presented in case reports.[42-44] The presence of a third root is usually noticed on further investigation during re-treatment of failed root canal therapy where the previously unnoticed third canal leads to postoperative discomfort.

Table 2. Studies on number of roots in maxillary second premolar.

Author (s)	Year of report	Country	No. of teeth	One root (%)	Two roots (%)	Three roots (%)
Mueller[30]	1933	U.S.A	128	97.7	2.3	0.0
Kerekes & Tronstad[34]	1977	Sweden & Norway	20	90.0	10.0	0.0
Sikri & Sikri[41]	1991	India	373	81.95	18.05	0.0
Pecora et al.[40]	1992	Brazil	435	90.3	9.7	0.0

1.3.1.3. Mandibular first premolar

There is scanty information in the literature on the number of roots in this tooth. The information available indicates that the tooth is mostly single rooted.[23,34] The external root morphology reveals that the root is conical in length and oval-to-nearly-round in cross section. The mesial surface has been described as more markedly flat than the distal surface. The mesial groove found in the tooth is occasionally so marked as to suggest two roots fused distally with an actual bifurcation close to the apex.[23] Kerekes and Tronstad[34] reported that all the 20 mandibular first premolar teeth in their study were single rooted. It is worthwhile noting that the sample size in Kerekes and Tronstad[34] study is too small for one to draw strong conclusions.

1.3.1.4. Mandibular second premolar

Like in the case of the mandibular first premolar, a search of the literature revealed scanty information on the number of roots in this tooth in different populations. The tooth is reported to be mostly single rooted, oval in cross-section, and somewhat flattened mesially and distally.[23] It also shows vertical grooves on these surfaces. Kerekes and Tronstad [34] observed that all the 20-second mandibular premolar teeth in their study were single rooted. Again it is important for one to be critical of the small sample size used in the study.

1.3.2. Premolar root curvature

Investigators have given the study of premolar root curvature little attention. One study in the literature based on direct visual observation of the external surface of the root have reported the roots of maxillary and mandibular premolar teeth have either straight or exhibit a distal curvature in most of the cases,[32] while two other studies[37,40] indicate that majority of the maxillary first and second premolar roots curve distally.

1.3.2.1. Maxillary first premolar

The roots of this tooth were found to be either straight or curved in variable directions: lingually, buccally, mesially, distally, or to have an "S" curve. A study by Percora et al.[37] found most of the roots of the maxillary first premolar to curve distally while Ingle et al.[32] reported most of the roots as straight.

1.3.2.2. Maxillary second premolar

Pecora et al.[40] observed that most of the maxillary second premolar roots curved distally. However, Ingle et al.[32] have reported the roots of this tooth as either straight or having a distal curvature.

1.3.2.3. Mandibular first premolar

From the literature, there is little information on the root curvature of this tooth. The few studies indicate that most of the roots are straight or have a distal curvature.[23,32]

1.3.2.4. Mandibular second premolar

The available information on root curvature of the mandibular second premolar shows that majority of the roots are either straight or curved distally.[23,32]

Table 3 summarizes previous studies on direction of root curvature for all the four premolar tooth types.

Table 3. Studies on direction of root curvature in premolar teeth.

Author(s)	Year of report	Premolar tooth type	No. of roots	Direction of root curvature					
				Straight (%)	Distal (%)	Mesial (%)	Buccal (%)	Lingual (%)	"S" (%)
Ingle et al.[32]	1976	Max first	One-root	38.0	37.0	0.0	15.0	3.0	0.0
Pecora et al.[37]	1991			8.9	79.9	1.5	2.2	1.5	6.0
Ingle et al.[32]	1976		Two-roots B	28.0	14.0	0.0	14.0	36.0	8.0
Pecora et al.[37]	1991			23.0	33.0	1.0	5.0	27.0	11.0
Ingle et al.[32]	1976		L	45.0	14.0	0.0	28.0	9.0	0.0
Pecora et al.[37]	1991			24.0	38.0	1.0	26.0	3.0	8.0
Ingle et al.[32]	1976	Max second	One-root	37.0	34.0	0.0	16.0	0.0	13.0
Pecora et al.[40]	1992			27.8	67.9	2.0	1.8	0.5	6.8
Pecora et al.[40]	1992		Two-roots B	16.6	57.1	9.5	7.1	2.4	7.2
			L	23.8	57.1	11.9	4.8	2.4	0.0
Ingle et al.[32]	1976	Mand first	One-root	48.0	35.0	0.0	2.0	7.0	7.0
Ingle et al.[32]	1976	Mand second	One-root	39.0	40.0	0.0	10.0	3.0	7.0

Mand –mandibular   Max-maxillary   B-buccal   L-lingual

1.3.3. Premolar tooth length.

Studies on tooth length of the premolar teeth are well documented. Various instruments such as the Boley gauge[45] and digital pakimeter[46] have been used in tooth length measurement. In these methods, most of the authors have used common reference points when taking the measurements (cusp tip to the corresponding root apex). Other methods used have been inserting a file into the root canal and then measuring the inserted portion of the file, and using a graph paper on the external surface of a tooth and measuring the length from the cusp tip to the root apex.[19]

Literature search revealed one study by Maina and Wagaigu[19] (Kenya) and another by Okpo and Akpata[47] (Nigeria) on the tooth length of the African racial group. However, gender differences were not evaluated in the two studies. Data from previous studies on premolar tooth lengths are shown in Tables 4, 5, 6 and 7.

1.3.3.1. Maxillary first premolar

The length of the maxillary first premolar has been reported to range between 15.5 mm-28.9 mm.[20, 36,37,47-49] Table 4 shows previous studies on tooth length in this tooth.

Table 4. Studies on tooth length (mm) of the maxillary first premolar.

Author(s)	Year of *report*	Country	No. of teeth	Mean *length*	Maximum *length*	Minimum *length*
Bjorndal et al.[48]	1974	U.S.A	36	22.3	25.8	18.8
Cohen & Burns[49]	*1976*	*U.S.A*	†	*20.6*	*22.5*	*17.0*
Okpo & Akpata[47]	1986	Nigeria	70	21.9	26.0	19.0
Woefel[36]	1990	*	234	21.5	28.9	15.5
Maina & Wagaiyu[19]	1990	Kenya	30	22.4	26.0	19.0
Pecora et al.[37]	1991	Brazil	240	21.0	27.5	17.1

* *Caucasians of unspecified nationality* † *unspecified*

1.3.3.2. Maxillary second premolar

The length of the maxillary second premolar tooth has been reported to range between 15.2 mm and 30.5 mm[20,36,40,47-49] (Table 5).

Table 5. Studies on tooth length (mm) of maxillary second premolar.

Author(s)	Year of report	Country	No. of teeth	Mean length	Maximum *length*	Minimum length
Bjorndal et al.[48]	1974	U.S.A	46	22.3	26.4	16.7
Cohen & Burns[49]	1976	U.S.A	†	21.5	27.0	16.0
Okpo & Akpata[47]	1986	Nigeria	70	22.5	28.	18.0
Woefel[36]	1990	*	†	21.2	28.4	*15.2*
Maina & Wagaiyu[19]	*1990*	*Kenya*	45	22.6	27.0	18.0
Pecora et al.[40]	1992	Brazil	435	21.5	30.5	15.8

**Caucasians of unspecified nationality* *† Unspecified*

1.3.3.3. Mandibular first premolar

Several studies have been undertaken to determine the tooth length of the mandibular first premolar.[20,45,47-49] The two studies[19,47] on African tooth length have reported similar mean tooth lengths (22.8 mm) for the mandibular first premolar in Kenyans and Nigerians. Data on the length of this tooth are shown in Table 6.

Table 6. Studies on tooth length (mm) of mandibular first premolar.

Author(s)	Year of report	Country	No. of teeth	Mean length	Maximum length	Minimum length
Bjorndal et al.[48]	1974	U.S.A	17	22.9	24.2	21.2
Cohen & Burns[49]	1976	U.S.A	†	21.6	26.0	18.0
Okpo & Akpata[47]	1986	Nigeria	70	22.8	27.0	18.0
Maina & Wagaiyu[19]	1990	Kenya	41	22.8	27.0	19.0
Caliskan et al.[45]	1995	Turkey	100	21.2	†	†

†unspecified

1.3.3.4. Mandibular second premolar

Studies on mandibular second premolar tooth length are relatively few. Maina and Wagaiyu[19] reported a mean tooth length of 22.9 mm for Kenyans, a value which is not very different from that reported from other populations. However differences between genders were not looked into. Findings on mandibular second premolar tooth length are presented in Table 7.

Table 7. Studies on tooth length (mm) of mandibular second premolar.

Author(s)	Year of report	Country	No. of teeth	Mean length	Maximum length	Minimum length
Bjorndal et al.[48]	1974	U.S.A	18	22.3	25.0	19.3
Cohen & Burns[49]	1976	U.S.A	†	22.3	26.0	18.0
Okpo & Akpata[47]	1986	Nigeria	70	22.5	28.0	19.0
Maina & Wagaiyu[19]	1990	Kenya	46	22.9	27.0	19.0
Caliskan et al.[45]	1995	Turkey	100	21.6	†	†

†unspecified

1.4. Internal root morphology

Over the years several methods have been devised to study the internal anatomy of teeth. The history of decalcification technique shows that it was first employed in 1908 in the study of internal tooth morphology. The earlier studies forced materials such as wood, metal, celluloid and vulcanite into the canals before decalcifying the specimens.[50] The disadvantage with these methods was that the materials forced into the canals irreversibly altered the canal patterns and hence the methods had to be abandoned. Other techniques employed in the study of internal root morphology are radiography,[13,30] radiography with metallic endodontic probes inserted into the canals,[51] sectioning and wearing,[34] sectioning and microscopy,[52] and sectioning, microscopy and photography.[53] However, these techniques are relatively tedious and require more sophisticated equipment. A more recent method in the study of internal tooth morphology is the application of micro–Computerized Tomography (micro-CT)[54] which allows a three dimensional observation of the specimens. However, this method also requires sophisticated equipment.

A more ideal technique would be one in which no physical change is introduced to the tooth and does not require prohibitively expensive equipment. Decalcification in combination with a clearing technique provides this alternative model and results in transparent specimens that allow a three-dimensional viewing of the tooth.[55-61] Other advantages of this method are that the procedure is easy to conduct and the specimen retains the original form of the internal root morphology, the canal forms are seen clearly and the prepared specimens can be preserved for a long time.

The studies on internal morphology report a wide variation in number of root canals in the maxillary first and second premolars, and the mandibular first premolar. The mandibular second premolar is reported to have a more consistent number of canals. Although to some extent the different methodologies employed may have contributed to some of the variations observed there is evidence to indicate that there are actual variations in the internal morphology of different specimens of the same tooth type. Variations in the morphology of premolars have also been shown not only within the same population but between racial groups.[22,29,30,33,34,40,41]

1.4.1. Number of canals.

1.4.1.1. Maxillary first premolar

The tooth usually has two canals irrespective of whether it has one or two roots. The occurrence of two canals has been reported in the literature to range between 68.8% and 92.0% (Table 8).[29-31,33,35,52]

Table 8. Studies on the number of root canals of maxillary first premolar.

Author(s)	Year of report	Country	No. of teeth	One canal (%)	Two canals (%)	Three canals (%)
Hess[29]	1925	U.S.A	260	19.5	79.3	1.2
Barrett[52]	1925	U.S.A	32	28.1	68.8	3.1
Mueller[30]	1933	U.S.A	130	8.5	91.5	0.0
Green[31]	1955	U.S.A	50	8.0	92.0	0.0
Pineda & Kuttler[62]	1972	Mexico	259	26.2	73.3	0.5
Carns & Skidmore[33]	1973	U.S.A	100	9.0	85.0	6.0
Vertucci& Gegauff[35]	1979	U.S.A	400	26.0	69.0	5.0

In less than 10% of cases the maxillary first premolar may be three-rooted with three distinct canals, two buccally and one palatally.[30,32] The root canals are normally separate and very rarely blend into the ribbon-like type of canal frequently seen in the second premolar. They are usually straight with a round cross-section. Vertucci and Gegauff[35] indicate that an examination of the floor of the pulp chamber may offer clues as to the number of canals present. When only one canal exists, it is easily probed in the center of the access preparation. If only one orifice is found away from the center of the preparation, another canal may probably be present, located on the opposite side. The two authors elaborated further on the relationship of two orifices to each other. If the canals were more than 3 mm apart, the two canals remained separate throughout their length. If less than 3 mm, the two canals usually joined. The closer the orifices were to each other, the more coronal the union.

1.4.1.2. Maxillary second premolar

The literature varies considerably in the number of canals in this tooth. Some authors have described this tooth as having one canal, with the possibility of two[63-65] while others have described it as having two canals, with the single canal being the exception.[23,66] The occurrence of two canals has been stated to be as low as 28% and as high as 50.6% (Table 9).[45,61,62,67-69] Somer et al.[70] reported the maxillary second premolar as the second most endodontically treated tooth making the study of its internal anatomy crucial.

Table 9. Studies on the number of root canals in maxillary second premolar.

Author(s)	Year of report	Country	No. of teeth	One canal %	Two canals %	Three canals %
Pineda & Kuttler[62]	1972	Mexico	282	55	45	0
Green[67]	1973	U.S.A	50	72	28	0
Vertucci et al.[68]	1974	U.S.A	200	48	51	1
Belizzi & Hartwell[69]	*1985*	*Germany*	630	40.3	58.6	1.1
Caliskan et al.[45]	1995	Turkey	100	44	56	0
Kartal et al.[61]	1998	Turkey	300	48.66	50.64	0.66

1.4.1.3. Mandibular first premolar

Mandibular first premolar has one canal most of the time.[29,68,69] The occurrence of more than one canal has been reported to range between 2.7%-62.5% (Table 10).[29, 30,52-55,62,67,71,72] As mentioned earlier the differences in the number of canals are probably related to the different methodologies used as well as being real indicators of the wide variation in the number of roots that one can expect to find in different specimens of this tooth type.

Table 10. Studies on number of root canals in mandibular first premolar.

Author(s)	Year of report	Country	No. of teeth	one canal %	More than one canal %
Hess[29]	1925	U.S.A	75	97.3	2.7
Barret[52]	1924	U.S.A	32	37.5	62.5
Okumura[55]	1927	Japan	85	76.0	24.0
Mueller[30]	1933	U.S.A	156	95.5	4.5
Amos[71]	1955	U.S.A	1,000	82.1	17.9
Pineda & Kuttler[62]	1972	Mexico	202	74.2	25.8
Green[67]	1973	U.S.A	50	86.0	14.0
Zillich & Dowson[72]	1973	U.S.A	1,393	76.9	23.1
Baisden et al.[53]	1992	U.S.A	106	76.0	24.0

1.4.1.4. Mandibular second premolar

Most studies indicate that the mandibular second premolar usually has one canal.[30,31,66-68] The occurrence of two canals ranges from 0% to 15 % while three canals are rare (Table 11). However, some case reports have shown this tooth to have three or even four canals.[74-77]

Table 11. Studies on number of root canals in the mandibular second premolar.

Author(s)	Year of report	Country	Total No. of teeth	One canal No. of teeth	%	Two canals No. of teeth	%	Three canals No. of teeth	%
Green[67]	1973	U.S.A	50	46	92.00	4	8	0	0.0
Hess[29]	1925	U.S.A	65	60	92.31	5	7.69	0	0.0
Kerekes& Tronstad[34]	1977	Sweden & Norway	20	17	85.00	3	15.0	0	0.0
Mueller[30]	1933	U.S.A	206	206	100.00	0	0.0	0	0.0
Okumura[55]	1926	U.S.A	55	54	98.18	1	1.82	0	0.0
Pineda & Kuttler[62]	1972	Mexico	400	390	97.50	10	2.5	0	0.0
Zillich & Dowson[72]	1973	U.S.A	938	793	84.50	109	11.7	4	0.4

1.4.2. Root canal types

Literature shows only a few studies on root canal types of premolar teeth with the most comprehensive studies being those carried out by Caliskan et al.[45] and Vertucci.[77] However, in terms of classification of canal types, the classifications by Vertuci[77] and Kartal et al.[61] are more conclusive than others. Hence the classification adapted in determination of canal types in the present study was that by Vertucci[77] and Kartal et al.[61] (See diagrammatic presentation of the classification in Appendix 1).

1.4.2.1. Maxillary first premolar

The tooth has been observed to have a variety of canal types. Vertucci and Gegauff[35] studied this tooth and arrived at the opinion that five different canal configurations might be present making it a difficult tooth to root-fill. Caliskan et al.[45] also observed five different canal types in this tooth in a Turkish population. In both studies, type 1V was the most commonly occurring.

1.4.2.2. Maxillary second premolar

Of all the premolar teeth, Vertucci[77] observed the maxillary second premolar to have the greatest variation in canal types, depicting all of the eight classes of canal types. Caliskan et al.[45] observed seven canal types in this tooth. In both studies, type 1 was the most commonly occurring.

1.4.2.3. Mandibular first premolar

In their studies Vertucci[77] observed five canal types while Caliskan et al.[45] observed seven canal types in this tooth. It is important to note that both studies employed a similar classification when grouping the canal types. Canal type 1 was found to be the most commonly occurring in both studies. Another study by Kartal et al.[61] observed all of Vertucci's eight classes of canal types and an additional three aberrant canal types. In total, Kartal et al.[61] observed eleven canal types in the mandibular first premolar of which type 1 was the most commonly occurring. Kartal et al.[61] added the new canal types to Vertucci's classification and named them as type 1X, X, X1.

1.4.2.4. Mandibular second premolar

Among the four premolar tooth types, the mandibular second shows the least variation in canal type. Two studies[45,77] demonstrated the presence of only two canal types (types I and V) in this tooth. In both studies, majority of the teeth had canal type I (93.6%[45] and 97.5%[77] respectively). Table 12 shows the canals types presenting in different premolars as observed by the two authors.[45,77]

Table 12. Distribution of root canal types (%) in premolars as observed by Vertucci [77] and Caliskan et al. [45]

Tooth type	Author(s)	No of teeth	Root canal types.							
			I	II	III	IV	V	VI	VII	VIII
Max 1st	Vertucci[77]	400	8.0	18.0	0.0	62.0	7.0	0.0	0.0	5.0
	Caliskan et al.[45]	100	3.9	5.9	0.0	78.4	5.9	5.9	0.0	0.0
Max 2nd	Vertucci[77]	200	48.0	22.0	5.0	11.0	6.0	5.0	2.0	1.0
	Caliskan et al.[45]	100	44.0	22.0	6.0	12.0	6.0	6.0	4.0	0.0
Mand 1st	Vertucci[77]	400	70.0	0.0	4.0	1.5	24.0	0.0	0.0	0.5
	Caliskan et al.[45]	100	64.1	7.5	3.8	7.6	9.4	1.9	0.0	5.7
Mand 2nd	Vertucci[77]	400	97.5	0.0	0.0	0.0	2.5	0.0	0.0	0.0
	Caliskan et al.[45]	100	93.6	0.0	0.0	0.0	6.4	0.0	0.0	0.0

Max= Maxillary *Mand= Mandibular*

1.5. Summary of literature review

- Literature shows a wide variability in both the external and internal root morphology of premolar teeth not only in the same population but also between different racial groups. Considering the varied design of the studies, one would tend to attribute some of the variability to differences in the methodologies. The other differences would be accounted for by actual variations in the different specimens and by racial factors.
- Most of the studies on number of roots were on the maxillary first premolar. There was relatively less data on the rest of the premolars. Maxillary first premolars have either one or two-roots with three roots being rare. Maxillary first premolars are mostly one-rooted with only a few teeth presenting with two roots. Both the mandibular first and second premolars are one-rooted.
- The studies reported little variability on the mean tooth length for each premolar tooth type.
- There was paucity of information on the direction of root curvature of the premolars. The few studies in the literature found majority of the roots to be either straight or to curve distally.
- Maxillary first premolar mostly presents with two canals while maxillary second premolar presents with either one or two canals. Mandibular first premolar presents with the most varied number of canals with one canal being the most common. However, one, two, three and four canals can also be encountered. Mandibular second premolar has the most consistent internal root morphology. In most cases it shows one canal.

- There were very few studies done on the root canal types in premolar teeth.[35,45,61,77] Mandibular first premolars were reported to have the most variable canal patterns while the mandibular second premolar presented with the least variable canal pattern.
- Most of the studies were on the Caucasian population. Data on external and internal root morphology in Africans was scanty and only two studies on tooth length were found.[19,47]
- Studies highlighting gender differences on external and internal root morphology of premolar teeth were few.

1.6. Research problem

The studies have shown a wide variation in the external and internal root morphology of teeth.[8-13] It has therefore been emphasized that a dentist carrying out endodontic treatment, orthodontic tooth movement or tooth extraction should be aware of the existence of such variations. Since there is paucity of information on the external and internal root morphology of Kenyans of African descent, dentists in this country tend to refer to the data on tooth morphology for Caucasians during clinical procedures. This may not be appropriate because studies have shown genetic and racial differences in dental morphology.[8-13]

The present study was therefore aimed at addressing this problem by providing data on some selected aspects of premolar root morphology for Kenyans of African descent and further determine whether there are significant gender differences.

1.7. Study justification

Knowledge on the anatomy and morphology of teeth is important to a dentist for accurate interpretation of radiographs, correct diagnosis and successful treatment during various clinical procedures.

Some failures in endodontic treatment have been attributed to lack of adequate knowledge on external and internal root morphology of teeth.[3] Orthodontic tooth movement[7] or a dental extraction[6] tends to be more difficult in multi-rooted teeth or in teeth with curved roots.

The findings of this study will be relevant, serving as reference data for morphology of premolars of Kenyans of African descent during clinical procedures, teaching and research.

1.8. Objectives

1.8.1. Broad objectives

To determine the external and internal root morphology of premolar teeth in Kenyans of African descent and evaluate gender differences.

1.8.2. Specific objectives

- To establish number of roots in premolar teeth.
- To assess direction of root curvature in premolar teeth.
- To establish tooth length in premolar teeth
- To describe the number of root canals in premolar teeth.
- To describe the types of root canals in premolar teeth

1.9. Hypothesis

The external and internal root morphology of premolar teeth of Kenyans of African descent is not different in males and females.

CHAPTER 2: MATERIALS AND METHODS

2.1. Study design

This was an in vitro descriptive cross-sectional study where freshly extracted teeth were collected.

2.2. Study population.

The premolar teeth were obtained from Nairobi residents. Nairobi, which is the capital city of Kenya, is a cosmopolitan city with a population of about 2.1 million people.[78] The city residents are migrants from all parts of the country. Although there is no available data to show the ethnic distribution of the residents, one would expect to find a degree of representation of the various ethnic groups that comprise Kenyans of African descent. It is arguable therefore that the specimens were obtained from different ethnic groups of Kenyans of African origin whose proportional representation along ethnic lines was not determined. The minimum and maximum (13-30 years) ages of the patients from whom specimens were collected and the reasons for extraction were noted.

2.3. Sampling procedures

Purposeful sampling (preferential identification and choice) was used to select the hospitals from which to collect specimens. The selected hospitals were all in Nairobi (Kenyatta National Hospital, Social Services League Dental Clinic and University of Nairobi Dental Hospital). These are the main hospitals that cater for the dental needs of the majority of residents in Nairobi and the neighbouring districts. Their strategic locations, wide range of dental services offered and subsidized fees make them accessible, "affordable" and appealing to a large proportion of people in and around Nairobi.

2.4. Sample size determination

With the help of a statistician, the sample size was calculated using Fisher's et al. (1991),[79] formula for populations whereby the number of teeth required in this study was referred to as the "population". The following formula was used:

$$n = \frac{z^2 pq}{d^2}$$

n = the desired sample size

P = proportion in the target population estimated to have a particular characteristic. Since different characteristics of the teeth were being studied, 50% (0.5) was used to estimate the value p, as there is no reasonable available estimate from the previous studies on the characteristics to be studied.

q = 1.0 - p.

d = degree of accuracy desired, set at .05

z = the standard normal deviate, at 1.96, which corresponds to the 95 percent confidence level.

Hence $$n = \frac{1.96 \times 1.96 \times .5 \times .5}{.05 \times .05} = 384$$

The **minimum** sample size was calculated to be 384 teeth. The minimum number of specimens per tooth type in each gender was therefore expected to be 49.

To increase precision and power[80] (from 50% to 80%), a sample size of 487 teeth was used.

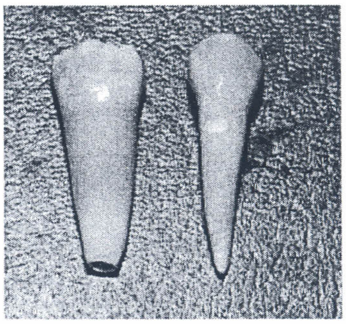
2.5. Data collection, instruments and procedures.

2.5.1. Inclusion criteria

- Premolar teeth extracted from Kenyans of African descent
- Premolar teeth with intact cusps.
- Restored premolar teeth where the restoration did not extend to the cusp tip.
- Premolar teeth with fully formed root(s).

In this study, a root was considered as fully formed when there was tapering of the apex to a pinpoint ending as seen with the naked eye and verified under a magnifying glass at a magnification of x 2½ times (Fig. 1).

Figure 1. Premolar with incomplete root (specimen on the left side) compared to one with completely formed root (specimen on right side). Note the tapering of the root apex to a "pin-point" ending in the fully formed root.

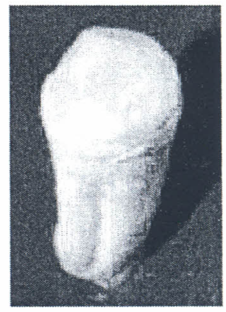


2.5.2. Exclusion criteria

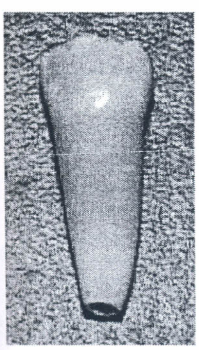
- Premolar teeth from non-Kenyans and Kenyans who were of non-African descent.
- Contra-lateral (antimere) premolar tooth.
- Premolar teeth with developmental abnormalities of the crowns and roots.
- Premolar teeth whose cusps tips were grossly carious [Fig. 2 (a)] or had been restored.
- Premolar teeth whose cusp tips had undergone attrition [Fig. 2 (b)].
- Premolar teeth whose root(s) were not fully formed [Fig. 2 (c)].
- Premolar teeth that had extensive cementum deposition around the root apex [Fig. 2 (d)].
- Premolar teeth whose roots were fractured.
- Premolar teeth that had root-treated canals.
- Premolar teeth from patients who objected to have their teeth studied.

Figure. 2 (a-d): Examples of the kinds of specimens that were excluded from the study.

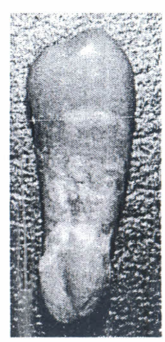
(a)
Premolar with caries involving the cusp tip



(b)
Premolar with attrition of the cusp tips



(c)
Premolar with incomplete root formation



(d)
Premolar with extensive cementum deposition at the apex

2.6. Specimen grouping, handling and examination

Immediately after extraction, the premolar teeth were stored in 5.25% sodium hypochlorite solution in eight plastic containers appropriately labeled in regard to gender and premolar type for at least 30 minutes. The 5.25% sodium hypochlorite disinfected the specimens and also removed organic debris. The specimens were then examined with the help of a magnifying glass (x2½ magnification) and those satisfying the inclusion/exclusion criteria were selected and preserved in 10% formalin as recommended by several authors.[50-53,55-61,77] The specimens remained in the formalin until it was convenient for the investigator to study them.

The parameters studied were: number of roots, root curvature, tooth length and number and types of root canals. The principle investigator (Dr R. Ng'ang'a) carried out all the observations, measurements and recordings. The collected information was entered in pre-prepared data collection charts (Appendix 2,3,4,& 5). The minimum and maximum age of the patients and the reasons for extraction were noted at every occasion that specimens were collected and recorded separately as "other" observations.

The specimens were studied systematically in the following order:

- Determination of number of roots
- Determination of root curvature
- Measurement of tooth length
- Preparation of access cavity to facilitate decalcification and clearing (Note that in the two-rooted fused specimens this step was done together with the

determination of number of roots in order to confirm the presence of two canals from the floor of the pulp chamber).

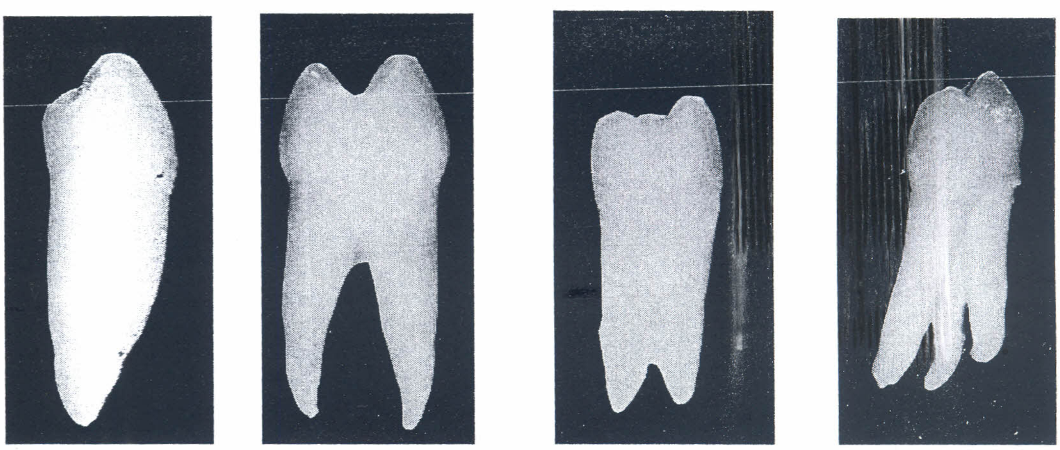
- Staining of the specimens
- Decalcification
- Dehydration
- Clearing
- Examination for number and types of canals
- Photography of typical examples of specimens depicting the eleven canal types.

Each of the above steps is described in detail below.

2.6.1. Number of roots

This was done by counting the number of roots observed visually on each premolar tooth.[13] A root was categorized as one root-form when the tooth showed one root externally (Fig. 3, a). The category of two-root form (distinct) was when the premolar showed two roots that were clearly demarcated immediately from the bifurcation (Fig. 3, b). The fused two-root was considered present when externally two roots were joined almost to the root apices (Fig. 3, c) and in addition, internal examination revealed the presence of two root canals on the pulpal floor. The three-root form was considered present when three external roots were observed (Fig. 3, d).

Figure 3 (a-d): Photographs of premolars depicting one root (a), two distinct roots (b), two fused roots (c), and three roots (d).



(a) (b) (c) (d)

2.6.2. Direction of root curvature

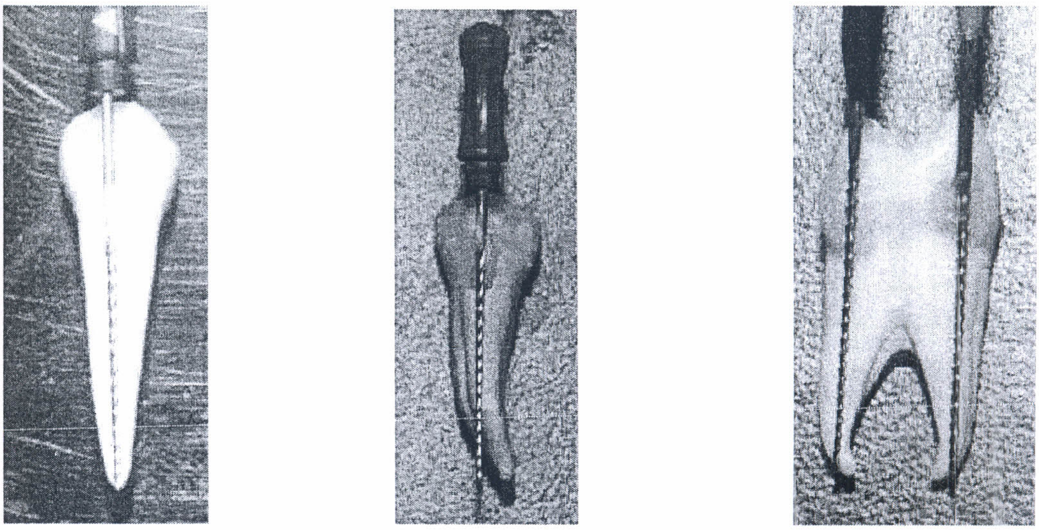
The direction of root curvature was determined by visual examination of the tooth from the facial and proximal aspects.[37] Photographs of premolar specimens depicting a straight root compared with some curved roots are shown in Fig. 4(a-c).

Figure 4 (a-c): Photographs of premolar teeth showing straight root (a), buccal curvature (b), and " S" curvature of buccal root (c).

(a) (b) (c)

In the present study the method of determination of root curvature previously used by Pecora et al.[37] was modified by aligning a reamer perpendicular to the long axis of the premolar from the cusp tip towards the root apex [Fig. 5(a-c)]. The reamer aided in better visualization of the root deviation (curvature). Individual roots were recorded as straight, curving towards the mesial, distal, buccal, lingual or having an "S" curvature.

Figure 5 (a-c): Photographs of premolars showing straight alignment of a reamer with cusp tip and root apex in a straight root (a), and deviation (curvature) of root apex in relation to a reamer aligned perpendicular to the long axis of the tooth from the cusp tip in a one-rooted premolar (b), and two-rooted premolar (c).



(a) (b (c)

2.6.3. Tooth length

The premolar tooth length was measured to the nearest 0.1 millimeters (mm) using a Boley gauge.[45]

Figure 6. Photograph of the Boley gauge and a premolar specimen demonstrating how the tooth length measurement was taken.

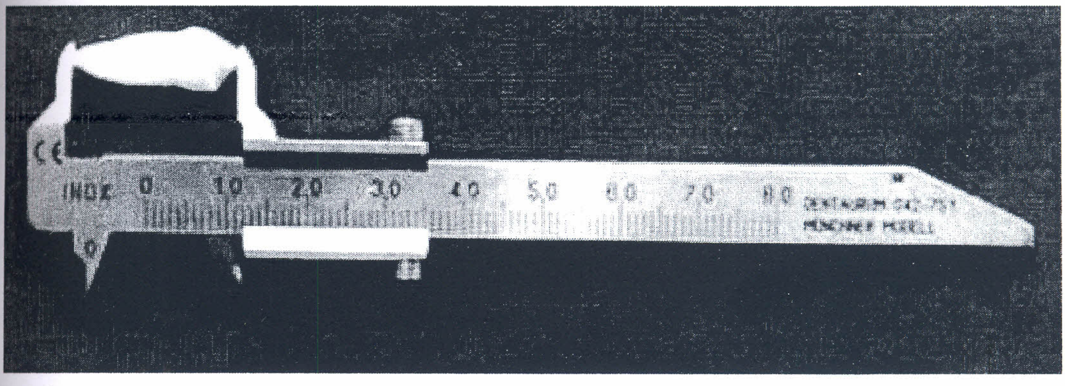
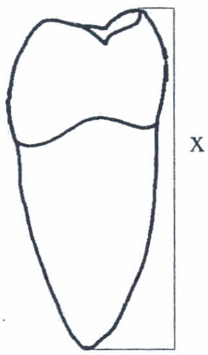


Figure. 7 (a,b) Shows diagrams of premolar teeth indicating the measuring reference points.

In the one rooted tooth, the measurement was taken from the buccal cusp tip to the root apex (Fig. 7a). In the two-rooted tooth the measurements were recorded from the buccal cusp tip to the apex of the buccal root and from the lingual cusp tip to the root apex of the lingual root (Fig. b). In the three-rooted tooth the measurements were from the buccal or lingual (palatal) cusp tip to the corresponding root apex.

Figure 7 (a,b): Diagrams showing the measuring reference points used to determine tooth length for a single-rooted premolar (a), and a two-rooted premolar (b).

cusp tip

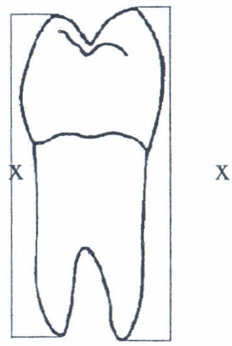


root apex

(a)

A single rooted premolar where the tooth length was measured from the buccal cusp tip to the apex (distance X).

cusp tips



root apices

(b)

Two-rooted premolar showing the buccal and palatal aspects of the tooth lengths that were measured (distance X).

2.6.4. *Number and types of root canals*

In the present study, decalcification and clearing techniques were employed in the preparation of the specimens for the study of the internal root morphology. These techniques have been widely used by several authors to study the internal root morphology.[55-61]

The techniques involved several stages: An access cavity was made on each tooth using a high-speed hand piece and a diamond bur under water spray. The canals were irrigated with 5.25% sodium hypochlorite solution using a 22-gauge syringe for a minimum period of 30 minutes and then dried with paper points. To adequately stain the canal patterns, the specimens were immersed in India ink for a minimum period of 4 days.

Complete decalcification was achieved after soaking the teeth in 5% nitric acid strictly for 4 days. The nitric acid was changed daily and agitated by hand three times each day. After decalcification, the specimens were rinsed in running tap water for a minimum of 4 hours. This was followed by dehydration in successive solutions of ethyl alcohol at concentrations of 70%, 95%, and 100% for a minimum of 5 hours in each concentration. Dehydration was carried out to facilitate clearing with methyl salicylate (oil of wintergreen). The methyl salicylate is not miscible with water. Clearing was completed within 6 hours of immersing the teeth in methyl salicylate. The clearing agent modified the refractive index and eliminated reflection resulting in transparent specimens that revealed the stained pulp canals clearly. Finally, the ink-dyed root canals were examined under a microscope at magnifications of either × 10 or × 40 (depending on the complexity of canal pattern). The canal patterns were recorded according to Vertucci[77] and Kartal et al's.[61] classifications. After assigning each canal pattern to its classification, the specimens were photographed from the view that demonstrated the canal pattern most clearly. The photographs were taken using an SLR single lens reflex - 35mm Olympus camera (OM-1) that was fitted with a 50 mm macro lens onto which a $\times 2$ teleconverter was attached. The magnification in the camera was 1:1. The enlarger magnification was 3.5. The specimens were photographed under transmitted light to show stain intensity in the specimen and instance light to show specimen structure.

2.7. Data validity

The premolar teeth were collected from the main public dental clinics in Nairobi. The main reasons for the selection of the large public clinics was in the expectation of obtaining specimens from the various ethnic groups of Kenyans of African descent. The other reason was to ensure that an adequate study sample of specimens could be obtained. After the extraction, each tooth was placed in one of the eight appropriately labeled containers designating gender and premolar type. Both specimen and data collection progressed concurrently and extended over a period of about 18 months.

The principal investigator was present most of the time during extractions to ascertain that the premolar specimens collected were from Kenyans of African descent and that they were correctly placed in the appropriate male and female containers. Three dentists, one at Kenyatta National hospital and two at Social Services League Dental Clinic had been trained in the details of the protocol of this research and had been mandated to undertake the role of consistently assigning each premolar to its rightful place in the absence of the investigator. The investigator carried out all the critical study procedures (observations with the naked eye, magnifying glass and under the microscope, linear measurements, decalcification and clearing of specimens) and subsequent data recording at the Faculty of Dental Sciences, University of Nairobi. Photography of the decalcified specimens was performed by a professional photographer conversant with the handling of biological specimens at the International Livestock Research Institute (ILRI), Nairobi. Pre-test of all observations and measurements (number of roots, root curvature, tooth length, number and type of root canal) were carried out in order to test and where necessary "fine tune" the methodology. Any problems encountered were addressed and rectified before the actual data collection begun.

2.8. Data reliability

Before commencement of data collection, the investigator was calibrated in regard to all the variables under investigations by one of the supervisors. Any discrepancies were addressed at this point. Cohen's *Kappa* test[81] was employed to test for intraexaminer reliability. The investigator achieved an intra-examiner reproducibility of *Kappa= 0.93* for identification of number of roots and *Kappa=0.91* for identification of direction of root curvature. A paired t-test[82] was used to assess the reliability of tooth length measurements and showed no statistically significant differences between the first and the second measurements ($t= 1.18; p>0.05$). A *kappa of 0.91* was achieved in the identification of number and types of canals.

Continuous monitoring of data for reliability was undertaken. This was done by the investigator making a second observation or taking a second measurement of all parameters under investigation on every tenth specimen at 2 weeks interval for comparison with the first measurement.

2.9. Ethical considerations

- Permission to carry out the research was sought from The Research and Ethics Committee of the Faculty of Dental Sciences, University of Nairobi, and The Research, Ethics and Standards Committee, Kenyatta National Hospital.
- Permission to collect specimens from the various hospitals' dental surgery clinics was sought from the administrators' in-charge of each dental clinic.
- Informed consent was sought from patients and their parents/guardians (Appendix 6).
- Patient's (or their parent(s)/guardian(s) consent to have their teeth included in the study was voluntary and had no financial implications.
- Confidentiality was observed in that during data analysis there was no disclosure of the person whose specimen was collected.
- The benefits of this research are that clinicians, teachers and researchers may use the data in the best interest of the patients. The clinicians will render certain dental procedures to Kenyan patients backed by relevant and appropriate scientific findings.

2.10. Data analysis

Data was entered into a computer and the SPSS (Statistical Package for Social Sciences) and Epi-Info packages were used for analysis. Data "cleaning" was carried out prior to analysis.

The following descriptive statistics were done:

- *Means:* To determine the mean tooth length for each premolar tooth in each gender.
- *Minimum (lowest measurement)/Maximum (highest measurement)* were recorded to show the range in tooth length for each premolar tooth type in each gender.
- *Standard deviations* were determined to show variability in tooth length for each premolar tooth type in each gender.
- *Frequencies for* number of roots, direction of root curvature, number and types of canals were determined for each premolar tooth type in each gender.

The following statistical tests[82] were employed in hypothesis testing and the significance levels tested at $\alpha = 0.05$.

- Independent t- test to assess gender differences in tooth length (continuous parametric data).
- Pearson Chi-square tests were used for non-parametric categorical data whereby gender differences in number of roots, direction of root curvature, number of canals and canal types were assessed.
- Fisher's exact test to assess gender differences in number of roots, direction of root curvature, number of canals and canal types. This was employed in situations where assumptions of Chi-square tests were not met.

CHAPTER 3: RESULTS

3.1. General observations

It was observed that 70% of the selected specimens were extracted for orthodontic reasons. The age of the patients from whom the specimens were obtained ranged from 13 - 30years. No patients objected to having their teeth collected for this study.

3.2. Distribution of premolars.

The total number of premolar teeth examined in this study was 487. Distribution of the four premolar tooth types by gender is shown in Table 13.

Table 13. Distribution of premolar tooth type by gender.

Premolar tooth type	Number of premolars		Total no. of teeth
	Males	Females	
Maxillary first	77	78	155
Maxillary second	57	57	114
Mandibular first	54	54	108
Mandibular second	55	55	110
Total	**243**	**244**	**487**

3.3. External root morphology of premolars

3.3.1. Number of roots

The combined male and female number of roots in all the four premolar tooth types are shown in Table 14 below. A few maxillary first (6.5%) and second (2.6%) premolars were found to have three roots.

Table 14. Distribution of number of roots in premolars (%) for combined gender

Type of premolar	Total no. of teeth	One-rooted %	Two-rooted		Three-rooted %
			Distinct root %	Fused root %	
Max. 1st	155	10.3	61.3	21.9	6.5
Max. 2nd	114	41.2	18.4	37.8	2.6
Mand. 1st	108	98.1	0	1.9	0
Mand. 2nd	110	99.0	1.0	0	0

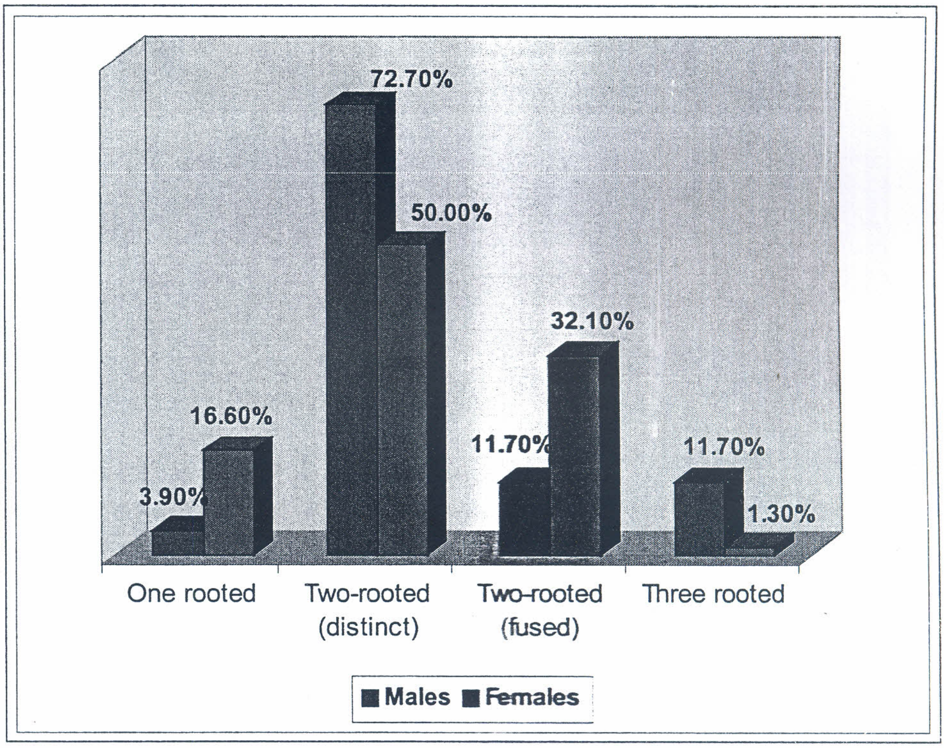
Max= Maxillary *Mand= Mandibular*

3.3.1.1. Maxillary first premolar

The total number of maxillary first premolars examined was 155. There were 77 premolars from males and 78 from females. When the distinct and fused teeth were combined, most of the teeth were two-rooted (83.2%). 10.3% of the teeth were one-rooted and 6.5% three-rooted (Table 14).

In both gender, two-rooted premolars were the most common (Fig. 8). The number of roots differed significantly between males and females *($\chi 2=11.79$; 2df; $P<0.05$ [$p=0.02$])*, with more male teeth (11.7%) presenting with three roots than female teeth (1.3%).

Figure 8. Percentage number of roots in maxillary first premolar (n=155 teeth).

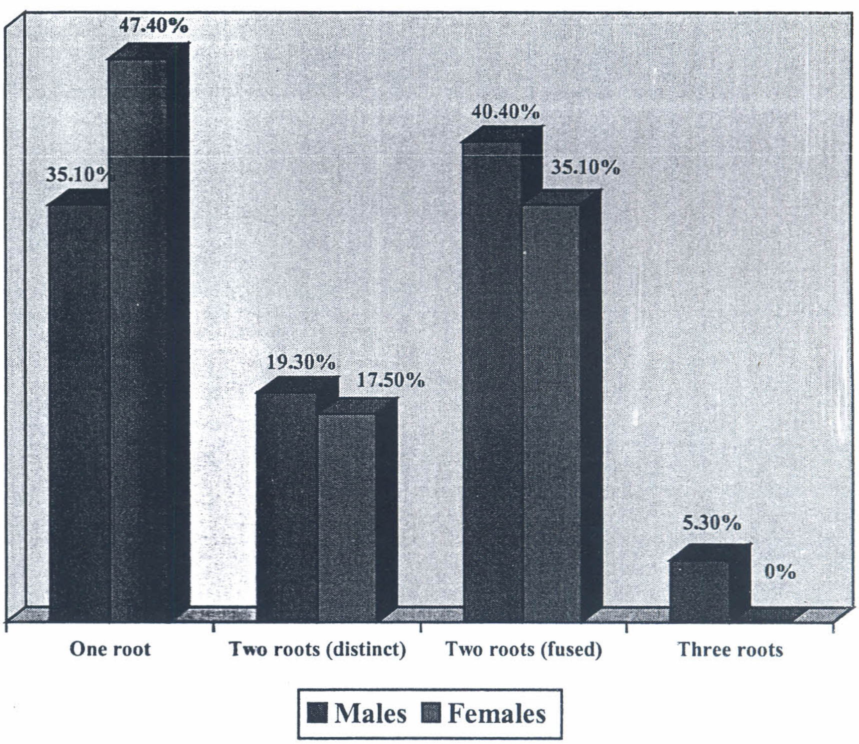


3.3.1.2. Maxillary second premolar

One hundred and fourteen maxillary second premolars were examined, 57 from each gender. There were 56.1% two-rooted (distinct + fused) and 41.2% one-rooted maxillary second premolars (Table 14).

When each gender was considered separately females had more single–rooted teeth than males while males had more two-rooted teeth than females (Fig. 9). Three-rooted teeth (5.3%) were only found in males. The gender differences in one and two-rooted maxillary second premolars were not statistically significant *(Fisher's $\chi 2=2.303$; 1df; $p>0.05$ [$p=0.087$]).*

Figure 9. Percentage number of roots in maxillary second premolar (n=114 teeth)

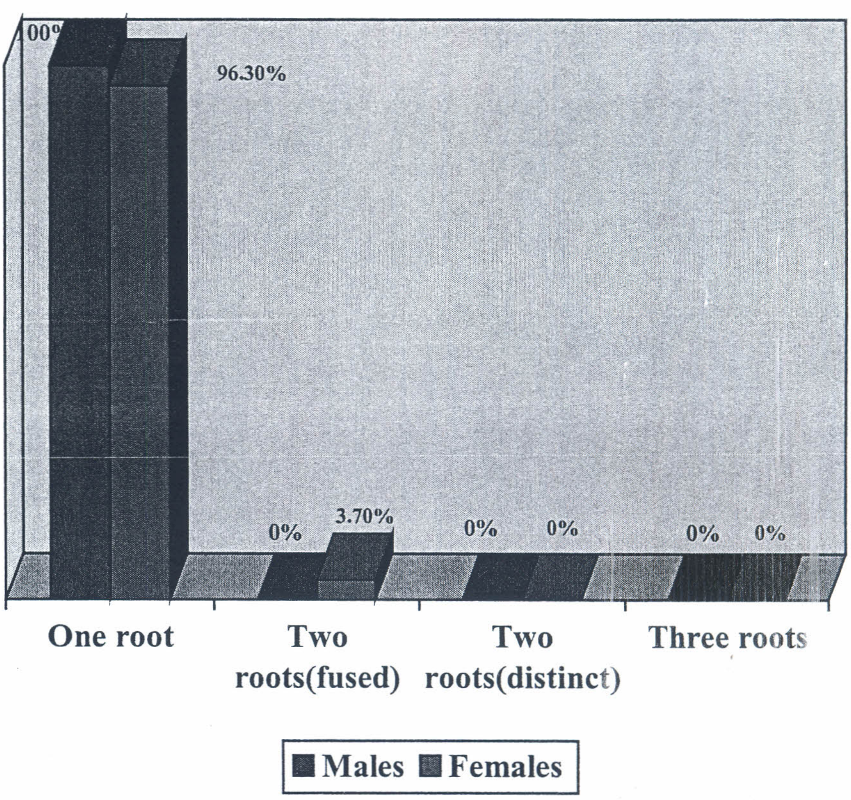


3.3.1.3. Mandibular first premolar

The total number of mandibular first premolars examined was 108. There were 54 premolars from each gender. Nearly all the teeth (98.1%) were one-rooted (Table 14 and Fig. 10).

There were no significant gender differences in the occurrence of one or two-rooted mandibular first premolars *(Fisher's $\chi2$=2.04; 1df; p>0.05 [p=0.086]).*

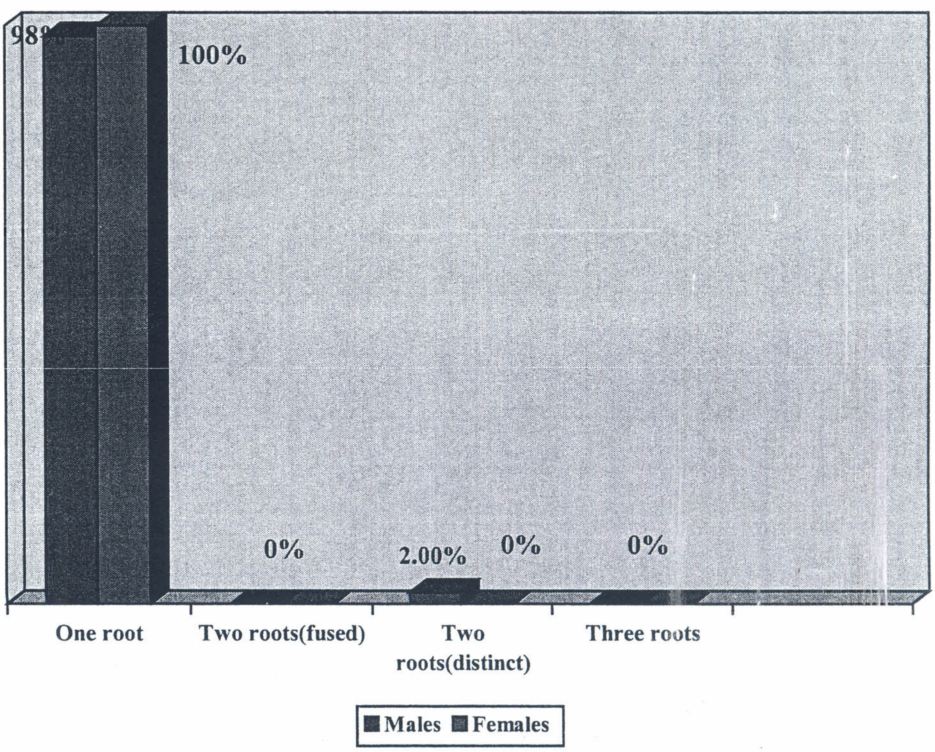
Figure 10. Percentage number of roots in mandibular first premolar (n=108 teeth).



3.3.1.4. Mandibular second premolar

One hundred and ten mandibular second premolars were examined, 55 from each gender. Almost all the teeth (99.1%) presented with one-root (Table 14 and Fig. 11). Gender differences in the occurrence of one and two-rooted mandibular second premolars were not statistically significant *(Fisher's $\chi 2=0.01$; 1df; $p>0.05$ [$p=0.912$])*

Figure 11. Percentage number of roots in mandibular second premolar (n=110 teeth).



3.3.2. Premolar root curvature

3.3.2.1. Maxillary first premolar

In single rooted maxillary first premolars, 81.3% had straight roots, 12.5% distal curvature, and 6.3% had an "S" curvature. In two rooted teeth, the buccal (56.6%) and lingual (55.8%) roots were mostly straight (Table 15).

Gender differences in direction of root curvature (straight versus all other curvatures combined) were not statistically significant *($\chi 2=1.05$; 1df; $p>0.05$ [0.636]).*

Table 15. Distribution of number of roots and their curvatures in maxillary first premolars in males (M) and females (F).

Number of roots	Gender	Direction of root curvature.												Total	
		Straight		Lingual		Buccal		Mesial		Distal		"S"-curve			
		No	%	No	%	No	%	No	%	No	%	No	%	No	%
One-root	M	2	66.6	0	0.0	0	0.0	0	0.0	1	33.3	0	0.0	3	100
	F	11	84.6	0	0.0	0	0.0	0	0.0	1	7.7	1	7.7	13	100
	Total	**13**	**81.3**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**2**	**12.5**	**1**	**6.3**	**16**	**100**
Two-roots B	M	38	58.5	5	7.7	1	1.5	1	1.5	18	27.7	2	3.0	65	100
	F	35	54.7	4	6.3	2	3.1	2	3.1	11	17.2	10	15.6	64	100
	Total	**73**	**56.6**	**9**	**7.0**	**3**	**2.3**	**3**	**2.3**	**29**	**22.5**	**12**	**9.3**	**129**	**100**
L	M	40	61.5	1	1.5	5	7.7	2	3.1	12	18.5	5	7.7	65	100
	F	32	50.0	1	1.6	11	17.2	2	3.1	9	14.1	9	14.1	64	100
	Total	**72**	**55.8**	**2**	**1.6**	**16**	**12.4**	**4**	**3.1**	**21**	**16.3**	**14**	**10.9**	**129**	**100**
Three-roots MB	M	6	60.0	0	0.0	0	0.0	0	0.0	2	20.0	1	10.0	9	100
	F	0	0.0	1	10.0	0	0.0	0	0.0	0	0.0	0	0.0	1	100
	Total	**6**	**60.0**	**1**	**10.0**	**0**	**0.0**	**0**	**0.0**	**2**	**20.0**	**1**	**10.0**	**10**	**100**
DB	M	6	66.7	0	0.0	0	0.0	0	0.0	2	22.2	1	11.1	9	100
	F	0	0.0	1	100	0	0.0	0	0.0	0	0.0	0	0.0	1	100
	Total	**6**	**60.0**	**1**	**10.0**	**0**	**0.0**	**0**	**0.0**	**2**	**20.0**	**1**	**10.0**	**10**	**100**
L	M	4	44.4	0	0.0	0	0.0	1	11.1	2	22.2	2	22.2	9	100
	F	0	0.0	0	0.0	1	100	0	0.0	0	0.0	0	0.0	1	100
	Total	**4**	**44.4**	**0**	**0.0**	**1**	**10.0**	**1**	**10.0**	**2**	**20.0**	**2**	**20.0**	**10**	**100**
Total roots per curvature (No. and %).		**174**	**57.2**	**13**	**4.3**	**20**	**6.6%**	**8**	**2.6**	**58**	**19.1**	**31**	**10.2**	**304**	**100**

B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.3.2.2. Maxillary second premolar

The single rooted maxillary second premolar had straight roots in 55.3%, distal curvature in 31.9% and "S"-curvature in 12.8% of the specimens. In two-rooted teeth, 67.2% of the buccal and 59.4% of the lingual roots were straight. Table 16 shows distribution of number of roots and their curvatures in this tooth.

Gender differences in direction of root curvature (straight versus all other curvatures combined) were not statistically significant *($\chi 2=0.001$; 1df; $p>0.05$ [0.999]).*

Table 16. Distribution of number of roots and their curvatures in maxillary second premolars in males (M) and females (F).

Number of roots	Gender	Direction of root curvature												Total	
		Straight		Lingual		Buccal		Mesial		Distal		"S"-curve			
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
One-root	M	12	60.0	0	0.0	0	0.0	0	0.0	7	35.0	1	5.0	20	100
	F	14	51.9	0	0.0	0	0.0	0	0.0	8	29.6	5	18.5	27	100
	Total	**26**	**55.3**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**15**	**31.9**	**6**	**12.8**	**47**	**100**
Two-roots															
B	M	21	61.8	1	2.9	0	0.0	1	2.9	8	23.5	3	8.8	34	100
	F	22	73.3	0	0.0	1	3.3	0	0.0	5	16.7	2	6.7	30	100
	Total	**43**	**67.2**	**1**	**1.6**	**1**	**1.6**	**1**	**1.6**	**13**	**20.3**	**5**	**7.8**	**64**	**100**
L	M	20	58.8	0	0.0	4	11.8	1	2.9	8	23.5	1	2.9	34	100
	F	18	60.0	0	0.0	1	3.3	0	0.0	4	13.3	7	23.3	30	100
	Total	**38**	**59.4**	**0**	**0.0**	**5**	**7.8**	**1**	**1.6**	**12**	**18.6**	**8**	**12.5**	**64**	**100**
Three-roots															
MB	M	3	100	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	100
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**3**	**100**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**3**	**100**
DB	M	2	66.7	0	0.0	0	0.0	0	0.0	0	0.0	1	33.3	3	100
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**2**	**66.7**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**1**	**33.3**	**3**	**100**
L	M	2	66.7	0	0.0	0	0.0	1	33.3	0	0.0	0	0.0	3	100
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**2**	**66.7**	**0**	**0.0**	**0**	**0.0**	**1**	**33.3**	**0**	**0.0**	**0**	**0.0**	**3**	**100**
Total roots per curvature (No. and %).		**114**	**61.9**	**1**	**0.5**	**6**	**3.3**	**3**	**1.6**	**40**	**21.7**	**20**	**10.9**	**184**	**100**

B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.3.2.3. Mandibular first premolar

Majority of these teeth (98.1%) were single rooted of which 62.3% of the roots were straight, 19.8% had a distal curvature, 11.3% an "S" and 4.7% a mesial curvature. Lingual and buccal curvatures were rare (Table 17).

Gender differences in direction of root curvature (straight versus all other curvatures combined) were not statistically significant *($\chi 2=3.089$; 1df; $p>0.05$ [0.071]).*

Table 17. Distribution of number of roots and their curvatures in mandibular first premolars in males (M) and females (F).

Number of roots	Gender	Straight No.	Straight %	Lingual No.	Lingual %	Buccal No.	Buccal %	Mesial No.	Mesial %	Distal No.	Distal %	"S"-curve No.	"S"-curve %	Total No.	Total %
One-root	M	30	55.6	1	1.9	1	1.9	3	5.6	11	20.4	8	14.8	54	100
	F	36	69.2	0	0.0	0	0.0	2	3.8	10	19.2	4	7.7	52	100
	Total	**66**	**62.3**	**1**	**0.9**	**1**	**0.9**	**5**	**4.7**	**21**	**19.8**	**12**	**11.3**	**106**	**100**
Two-roots															
	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
B	F	2	100	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	100
	Total	**2**	**100**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**2**	**100**
	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
L	F	2	100	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	100
	Total	**2**	**100**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**2**	**100**
Three-roots															
	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
MB	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
DB	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
L	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
Total roots per curvature (No. and %).		**70**	**63.6**	**1**	**0.9**	**1**	**0.9**	**5**	**4.5**	**21**	**19.1**	**12**	**10.9**	**110**	**100**

B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.3.2.4. Mandibular second premolar

Almost all the teeth (99%) were single rooted with 65.3% having a straight root, while 23.8% and 7.9% had distal and "S"-curvatures respectively. None of the single rooted teeth curved buccally (Table 18).

Gender differences in direction of root curvature (straight versus all other curvatures combined) were not statistically significant *($\chi 2=1.786$; 1df; $p>0.05$ [0.761]).*

Table 18. Distribution of number of roots and their curvatures in mandibular second premolars in males (M) and females (F).

Number of roots	Gender	Direction of root curvature: Straight		Lingual		Buccal		Mesial		Distal		"S"-Curve		Total	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
One-root	M	32	58.7	0	0.0	0	0.0	2	4.3	14	26.0	6	10.7	54	100
	F	39	70.9	1	1.8	0	0.0	0	0.0	12	21.8	3	5.5	55	100
	Total	**71**	**65.3**	**1**	**1.0**	**0**	**0.0**	**2**	**2.0**	**26**	**23.8**	**9**	**7.9**	**109**	**100**
Two-roots Buccal	M	1	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	100
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**1**	**100**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**1**	**100**
Lingual	M	0	0.0	0	0.0	1	100	0	0.0	0	0.0	0	0.0	1	100
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**1**	**100**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**1**	**100**
Three-roots MB	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
DB	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
Lingual	M	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Total	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**
Total roots per Curvature (No. and %).		**72**	**65**	**1**	**1.0**	**1**	**1.0**	**2**	**1.9**	**26**	**23.3**	**9**	**7.8**	**111**	**100**

B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

The combined gender findings for the direction of root curvature are shown in Table 19. *In all the four premolar tooth types, most of the roots were straight (60.6%). Distal* (20.5%) curvature was the most frequent followed by "S" (10.1%) curvatures. Lingual, buccal and mesial curvatures rarely occurred.

Table 19. Combined findings for direction of root curvature in the four premolar tooth types in males and females.

Premolar tooth type	Direction of root curvature.													
	Straight		Lingual		Buccal		Mesial		Distal		"S"-curve		Total No. of roots	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Max first	174	57.2	13	4.3	20	6.6	8	2.6	58	19.1	31	10.2	**304**	**100**
Max second	114	62.0	1	0.5	6	3.3	3	1.6	40	21.7	20	10.9	**184**	**100**
Mand first	70	63.6	1	0.9	1	0.9	5	4.5	21	19.1	12	10.9	**110**	**100**
Mand second	72	64.9	1	0.9	1	0.9	2	1.8	26	23.4	9	8.1	**111**	**100**
Total no. of roots	**430**	**60.6**	**16**	**2.3**	**28**	**3.9**	**18**	**2.5**	**145**	**20.5**	**72**	**10.1**	**709**	**100**

Max=Maxillary *Mand=Mandibular*

(Note: The total number of roots in the Table exceeds the number of premolars in the study because some of the teeth were multi-rooted).

3.3.3. Premolar tooth length

The results for the premolar tooth length are presented separately as well as combined for males and females (Tables 20-23).

3.3.3.1. Maxillary first premolar.

In the one-rooted maxillary first premolars the difference in the mean tooth length for males (22.8 mm) and females (22.6 mm) was not statistically significant (P>0.05).

In the two-rooted premolar, both the mean buccal and mean lingual tooth lengths were significantly larger in males than in females (P<0.05). Details of the findings for the maxillary first premolar are presented in Table 20.

Table 20. Maxillary first premolar tooth length (mm) by gender.

Category of premolar	Gender M=male F= female	No. of teeth	Minimum length	Maximum length	Std deviation	Mean tooth length	t- value (Independent t-test)	**P-value**
One-rooted	M	3	22.0	23.5	0.76	22.8		
	F	13	20.0	25.2	1.63	22.6	0.43	0.689^{f}
	Combined	***16***	***20.0***	***25.2***	***1.48***	***22.6***		
	(M+F)							
Two-rooted		65	20.0	27.2	1.51	22.8		
B	M	64	19.0	24.8	1.31	21.7	4.217	0.003*
	F	***129***	***19.0***	***27.2***	***1.50***	***22.3***		
	Combined							
		65	18.5	25.0	1.45	21.6		
L	M	64	18.0	23.2	1.33	20.9	2.809	0.031*
	F	***129***	***18.0***	***25.0***	***1.49***	***21.2***		
Three-rooted	***Combined***							
MB		9	22.2	25.0	0.889	23.3		
DB	M	9	22.2	24.3	0.890	22.8		
L	M	9	21.0	25.0	1.324	23.1		
	M							
MB		1	-	-	-	23.4		
DB	F	1	-	-	-	23.4		
L	F	1	-	-	-	23.2		
	F							

Combined = M+F ^{f} *= not significant* ** =significant difference*
B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.3.3.2. Maxillary second premolar

In the one-rooted maxillary second premolars the difference in the mean tooth length for males (23.0 mm) and females (22.6 mm) was not statistically significant ($P>0.05$).

In the two-rooted premolar, both the mean buccal and mean lingual tooth lengths were larger in males than in females. The differences were found to be statistically significant ($P<0.05$). Details of the findings for the maxillary second premolar are presented in Table 21.

Table 21. Maxillary second premolars tooth lengths (mm) by gender.

Category of premolar	Gender M=male F= female	No. of teeth	Minimum length	Maximum length	Std deviation	Mean tooth length	t- value (Independent t-test)	P-value
One-rooted	M	20	19.8	26.0	1.76	23.0		
	F	27	18.2	25.8	2.01	22.6	1.15	0.456ƒ
	Combined	47	***18.2***	***26.0***	***1.90***	***22.8***		
Two-rooted	M	34	19.0	26.0	1.47	22.4		
B	F	30	18.5	24.2	1.58	21.2	3.149	0.025*
	Combined	64	***18.5***	***26.0***	***1.63***	***21.9***		
	M	34	18.2	26.0	1.66	22.1		
L	F	30	18.0	23.8	1.70	20.7	3.251	0.036*
	Combined	64	***18.0***	***26.0***	***1.80***	***21.5***		
Three-rooted								
MB	M	3	23.0	24.0	0.58	23.3		
DB	M	3	22.5	24.1	0.82	23.2		
L	M	3	21.6	24.0	1.23	23.0		

Combined = M+F   *ƒ = difference not significant*   ** =significant difference*
B=buccal   *L=lingual*   *MB=mesio-buccal*   *DB=disto-buccal*

3.3.3.3. Mandibular first premolar

Mandibular first premolars with single roots comprised 98.1% of the sample. Males had significantly larger mean tooth length than females (Table 22).

Table 22. Mandibular first premolar tooth length (mm) by gender.

Category of premolar	Gender M=male F= female	No. of teeth	Minimum length	Maximum length	Std deviation	Mean tooth length	t- value (Independent t-test)	p-value
One-rooted	M	54	20.2	29.0	1.74	24.3		
	F	52	19.8	26.7	1.44	22.8	4.699	0.012*
	Combined	***106***	***19.8***	***29.0***	***1.75***	***23.6***		
Two-rooted								
B	F	2	20.3	22.0	1.20	21.2		
L	F	2	17.8	19.0	0.85	18.4		

Combined = M+F **Significant difference*
B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.3.3.4. Mandibular second premolar.

Table 23 shows that nearly all (99%) the lower second premolar teeth were one-rooted. Males had statistically significant larger mean tooth length than females ($p<0.05$).

Table 23. Mandibular second premolar tooth length (mm) by gender.

Category of premolar	Gender M=male F= female	No. of teeth	Minimum length	Maximum length	Std deviation	Mean tooth length	t- value (Independent t-test)	P-value
One-rooted	M	54	20.0	30.2	2.29	23.9		
	F	55	20.3	26.3	1.60	23.0	2.298	0.026 *
	Combined	***109***	***20.0***	***30.2***	***1.99***	***23.4***		
Two-rooted								
B	M	1	23.8	23.8	0	23.8		
L	M	1	21.5	21.5	0	21.5		

Combined = M+F **Significant difference*
B=buccal L=lingual MB=mesio-buccal DB=disto-buccal

3.4. Internal root morphology of premolars

3.4.1. Number of root canals.

In both gender most of the maxillary first (87.1%) and second (67.6%) premolars presented with two canals while most of the mandibular first (63%) and second (95.6%) premolars had one canal. Gender differences in number of root canals were not statistically significant for the maxillary second, mandibular first and mandibular second premolars. However, there were significant gender differences in number of canals in the maxillary first premolar where males had a higher percentage (11.7%) of three canals than females (1.3%) as shown in Table 24.

Table 24. Distribution (%) of number of canals by gender in the four premolar tooth types

Premolar tooth type	Gender M=male F=female	No. of teeth	Percentage no. of canals at the apex.				*Statistical tests*
			One %	Two %	Three %	Four %	
Max first	M F **Combined**	77 78 **155**	5.2 7.7 **6.5**	83.1 91.0 **87.1**	11.7 1.3 **6.5**	0.0 0.0 **0.0**	$\chi 2$= 20.14; df 2; p= 0.002* [p<0.05]
Max Second	M F **Combined**	57 57 **114**	24.6 33.4 **29.0**	68.4 66.7 **67.6**	7.0 0.0 **3.5**	0.0 0.0 **0.0**	$\chi 2$= 0.63; df 1; p= 0.683^f [p>0.05]
Mand first	M F **Combined**	54 54 **108**	66.7 59.3 **63.0**	26.0 35.3 **30.7**	7.4 3.7 **5.5**	0.0 1.9 **1.0**	$\chi 2$= 3.16; df 1; p= 0.056^f [p>0.05]
Mand second	M F **Combined**	55 55 **110**	92.7 98.2 **95.6**	7.2 1.8 **4.5**	0.0 0.0 **0.0**	0.0 0.0 **0.0**	$\chi 2$= 1.89; df 1; p= 0.086^f [p>0.05]

Combined = M+F *significant difference ^{f}difference not significant
Max=maxillary *Mand=mandibular*

3.4.1.1. Maxillary first premolar.

The occurrence of two canals at the apex was more common in females than in males, whereas the occurrence of three canals was more common in males than in females. The later occurrence was statistically significant Table 24.

3.4.1.2. Maxillary second premolar

The maxillary second premolar was found to have three canals at the apex in 7% of the male teeth while none of the female teeth had three canals at the apex.

The statistical test for gender differences in the occurrence of one and two canals was not significant (Table 24).

3.4.1.3. Mandibular first premolar

In both males and females, majority of the mandibular first premolars presented with one canal at the apex (males 66.7%, and females 59.3%). A few specimens in both genders were found to have three canals at the apex. One female specimen showed a fourth canal at the apex.

3.4.1.4. Mandibular second premolar

In both gender, nearly all the mandibular second premolars (95.6%) displayed one canal at the apex.

3.4.2. *Root canal types.*

The mandibular first premolar had the most variable root canal pattern compared to other premolars. It was represented in nine of the eleven classifications of Vertucci[77] and Kartal et al.[61] Mandibular second premolar had the least variable pattern with only seven canal types. Both the first and second maxillary premolars demonstrated eight canal types each.

Gender differences in canal types were evaluated in the two canal types that had adequate representation to permit statistical testing. This was done in the maxillary first premolar (Canal type IV/V), maxillary second premolar (Canal type IV/V) and mandibular first premolar (Canal type I/V). The gender differences were not statistically significant in these three tooth types ($P>0.05$) as shown in Table 25. Statistical testing for gender differences in the mandibular second premolar was not done because majority of the teeth in both gender had canal type 1 leaving proportionately very few numbers in the other canal types to permit testing.

Table 25. Percentage of root canal types by premolar tooth type and gender.

Gender M=male Females=F	No. Teeth	Canal types (I-XI) and percentage (%)											
		1 %	11 %	111 %	1V %	V %	V1 %	V11 %	V111 %	1X %	X %	X1 %	χ^2 P-value
M	77	2.6	2.6	0	68.8	14.3	0	0	11.7	0	0	0	$\chi^2 = 3.84$ p= 0.358[f] [p>0.05] (iv/v)
F	78	1.3	2.6	3.8	74.4	11.5	1.3	3.8	1.3	0	0	0	
Total	**155**	**1.9**	**2.6**	**1.9**	**71.6**	**12.9**	**0.7**	**1.9**	**6.5**	**0**	**0**	**0**	
M	57	15.8	5.3	3.5	29.8	22.8	10.5	5.3	7.0	0	0	0	$\chi^2 = 0.02$ 0.934[f] [p>0.05] (iv/v)
F	57	26.3	1.8	5.3	31.6	26.3	3.5	5.3	0	0	0	0	
Total	**114**	**21**	**3.6**	**4.4**	**30.7**	**24.6**	**7.0**	**5.3**	**3.5**	**0**	**0**	**0**	
M	54	53.7	0	13	0	22.2	0	1.9	0	7.4	0	1.9	$\chi^2 = 1.33$ 0.543[f] [p>0.05] (1/v)
F	54	44.4	1.9	13	1.9	31.5	0	0	0	3.7	1.9	1.9	
Total	**108**	**49.1**	**2.0**	**13**	**2.0**	**26.9**	**0**	**2.0**	**0**	**5.6**	**2.0**	**1.9**	
M	55	85.1	5.5	2.1	2.1	3.0	2.1	0	0	0	0	0	∝
F	55	89.1	5.5	3.6	0	0	0	1.8	0	0	0	0	
Total	**110**	**87.1**	**5.5**	**2.9**	**1.1**		**1.1**	**0.9**	**0**	**0**	**0**		

Max=maxillary *Mand=mandibular*

[f] *Difference not significant*

∝= *Statistical test not undertaken because most of the teeth presented with canal type 1, leaving proportionately few numbers in the other canal types to permit statistical testing.*

Photographs showing examples of decalcified and cleared specimens obtained from the present study and which depict the 8 canal patterns according to Vertucci's classification[77] and the 3 canal patterns according to Kartal et al.[61] are shown in Fig. 12.

Figure 12. Photographs of specimens from the present study after decalcification and clearing showing root canal type I- VIII according to Vertucci's[77] and type IX-XI according to Kartal's et al's.[61] classifications.

Type 1. A single canal extends from the pulp chamber to the apex.

Type11. Two separate canals leave the pulp chamber and join short of the apex to form one canal.

Type 111. One canal leaves the pulp chamber, divides into two within the roots, and then merges to exit as one canal.

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

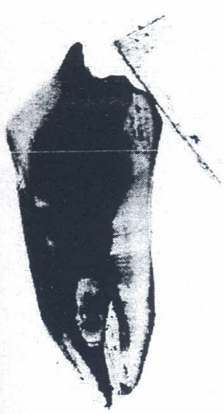
Type V. Only one canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with apical foramina.

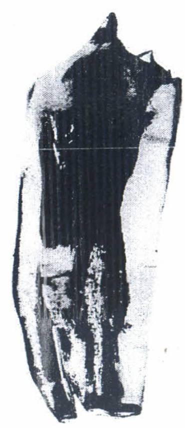
Type V1. Two separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex to exit as two distinct canals.

__Type V11.__ One canal leaves the pulp chamber, divides and then rejoins within the body of the root, and finally redivides into two distinct canals short of the apex.

__Type V111.__ Three separate and distinct canals extend from the pulp chamber to the apex.

__Type IX.__ One wide canal leaves the pulp chamber and separate into three separate canals between the middle and apical third and reaches the apex via three separate foraminae.





__Type X.__ After leaving the pulp chamber as a wide canal, it divides into two canals between the cervical and middle third. This continues into the middle third. In the apical third, the buccal canal first splits into buccal and lingual branches then the lingual canal merges into the lingual branch of the buccal canal. At the apex there are two separate foraminae.

__Type XI.__ A wide canal leaves the pulp chamber and separates into three canals between the cervical and middle third area. These continue as three separate canals along the middle, then, one-canal branches between the middle and apical thirds, resulting in four separate foraminae

CHAPTER 4: DISCUSSION

The broad objective of the present study was to determine the external and internal morphology of premolars in Kenyans of African descent in Nairobi. It is the first prospective study that describes the data for separate gender in regard to the number of roots, direction of root curvature, tooth length, number of root canals and root canal types of premolars in Kenya. The methodologies used and the clinical implications of the results obtained are discussed.

4.1. Methodological considerations

At the outset of this study, the age limit for patients from whom the specimens were to be collected was not strictly set for four reasons. Firstly, there was a need to obtain adequate specimens meeting the strict inclusion /exclusion criteria within the confines of the allocated time for this study. A limitation of specimen collection using age as a criterion would have led to a possible risk of not getting enough study samples. Secondly, the first and second premolar roots develop and become fully formed at different times. These developmental timings have not been determined for Kenyans, hence setting the lower age limit for patients may have been misleading. Thirdly, the premolars in Kenyan females erupt earlier than those of males[24,25] and the teeth would therefore be expected to complete their root formation earlier, but the specific timings for root completion has also not been scientifically documented for Kenyans of African descent. Lastly, setting an age-limit may have excluded suitable specimens that may have been extracted due to diseases or conditions that are mostly encountered in certain age groups (for example, periodontal disease in the elderly and orthodontic reasons in the young) thereby further decreasing the likelihood of reaching the target sample.

Determination of tooth morphology according to patients' age was beyond the scope of this study; hence grouping of each specimen according to age was not done. It is noteworthy, however, that though there was no set age limit, the inclusion/exclusion criteria used in this study was biased towards inclusion of teeth from relatively young patients. Indeed, during specimen collection the minimum age from whom the specimens were obtained in both males and females was noted to be 13 years and the maximum was 30 years. The distribution of the specimens according to age could therefore not be presented in the results.

The study samples were obtained from the large public dental clinics in Nairobi that cater for the majority of residents. This was mainly done in order to get adequate samples. It was also intended to include as many of the Kenyan ethnic groups in the study as possible since Nairobi residents have their origin from all over the republic. However, the proportional representativeness of the study specimens based on the different ethnic groups in Kenya was not established.

To ascertain data validity, the investigator ensured proper procedures for specimen collection were adhered to. Subsequently the investigator performed all the observations, measurements and laboratory procedures. The investigator was calibrated and over 90% intraexaminer agreement achieved prior to starting data collection of all the parameters under investigation. Both specimens and data collection progressed concurrently over a period of about 18 months. This rather long period was due to the fact that availability of suitable specimens took time and was beyond the control of the investigator. The positive side to the long duration was that the many steps in the laboratory procedures were conducted without haste, thereby ensuring consistency and enhancing accuracy.

Identification of number of roots was done by visual observation of the tooth in accordance with Loh's[13] method. However, in the identification of a fused two-rooted tooth this method was modified where internal visual observation of the pulpal floor without instrumentation was done. This approach ensured that there was no interference with canal patterns. On the other hand, this meant that the opportunity to identify a fused two-rooted premolar by verification of the *presence of two canals by instrumentation* might have been missed.

Studies indicate that direction of root curvature can be determined by direct visual observation of the tooth externally[37] or by inserting instruments in the root canal and taking radiographs to observe the curvature.[83] Literature review shows no clear advantages of either method and the choice of approach to be used seems to depend on the objectives and circumstances of the study. However, the disadvantage of using the method where an instrument is inserted into the canal is that, there is interference with the canal patterns, and added cost in terms of radiographs and time.

In order to avoid interference with the canal patterns in the present study, determination of direction of root curvature was by direct visual observation.[37] This method was modified by aligning a reamer along the long axis of the premolar tooth to help enhance the visual appreciation of a curvature [Fig. 5 (a-c)]. To some extent, root curvature determination using this method may introduce some degree of subjectivity because it does not give a strict scientific definition of the point at which a root can be considered to start curving. In situations where curvatures are minor, doubt may arise as to whether or not a root is curved. In the present investigation, instances of doubt in direction of curvature were rarely encountered and in such circumstances, the root was classified as straight.

Tooth length measurement was done using a Boley-gauge in accordance with Caliskan et al's.[45] method (Fig. 6). The Boley gauge has been found to be fairly accurate because it allows direct reading of the measurements. However, even with a Boley-gauge, it is important to note that some inaccuracies may arise when measuring curved roots but such inaccuracies have been shown to be insignificant.[19]

The internal morphology of premolars was studied using Robertson et al's.[58] decalcification and clearing techniques. These authors recommend decalcification for 3 days. However, a pre-test conducted prior to the present study revealed that specimens decalcified for 3 days were unclear when soaked in methyl salicylate. This therefore necessitated modification of the method and the specimens were decalcified for 4 days. This resulted in clearer specimens.

Decalcification and clearing preserves the internal morphology and gives a three dimensional view of the pulp in relation to the exterior of the tooth.[59] This method has been shown to be simple and efficient in the three-dimensional analysis of root canal patterns. Specimens prepared using this clearing technique have been chosen as a standard approach by many researchers for study of internal root morphology as well as in the teaching of preclinical endodontics.[55-61,77]

The methods used to classify canal patterns were those of Vertucci[77] and Kartal et al.[61] because they are very comprehensive. These two methods have been shown to be inclusive such that any canal patterns so far reported in the literature can be classified. Moreover, the two classifications allowed comparison of the findings of the present study with those of Vertucci[77] and Kartal et al.[61]

4.2. External root morphology of premolars.

Number of roots.

Previous studies on number of roots in ***maxillary first*** premolars in different parts of the world have reported different findings. The occurrence of one-rooted premolar has been reported as ranging from 10% - 60%, two-roots 40% - 85% and three-roots 0% - 10%.[13,29-39] In the maxillary first premolars, the present study showed that 83.2% of these teeth in males and females (combined) had two roots, 10.3% one root and 6.5% three-roots. In two rooted maxillary first premolars females had more of the fused-root form while males had more of the distinct-root form (Table 14). Two and three-rooted maxillary first premolars occurred significantly more commonly in males than in females, a finding which was similar to a previous study among the Japanese.[22]

The results closely agree with those of Walton and Torabinejad[38] who found the occurrence of one-root to be 10%, two-roots 85% and three-roots 5% in this tooth in an American sample. Midtdo and Halse[84] also reported a higher number of two and three-rooted maxillary first premolars in subjects with Turner's syndrome. It is unlikely that there would have been a substantial number of specimens from subjects with Turner's syndrome in this study to cause a significant effect on the results. Although reliable data on prevalence of Turner's syndrome among Kenyans is not available, the syndrome has a rare prevalence (1:3,000) among the Caucasians.[85]

Loh[13] studied maxillary first premolar root morphology in a Singaporean population and, like in the present study, differentiated between two-rooted distinct and two-rooted fused roots. The author reported that 50.6% of the teeth in the sample were two-rooted (63.4% fused roots and 36.6% distinct roots). In the present study 83.2% of the teeth were two-rooted (73.7% distinct roots and 26.3% fused roots). The distinct-root form appears to occur more commonly among Kenyans of African descent than among the Singaporeans whereas the fused root form appears to occur more commonly among the Singaporeans than among Kenyans. Identification of distinct-root form was done by the fairly straightforward method of visual inspection of the root in both studies, hence the observed differences may be attributed to racial rather than methodological factors.

The ***maxillary second*** premolar demonstrated the presence of two roots more frequently (56.1%) than one root (41.2%). Only a few teeth had three roots (2.6%) (Table 14). These results contrast those of previous studies where the occurrence of one root in this premolar was reported to range from 82.0% to 97.7% and two roots from 2.3% to 18.0%.[30,34.41] The observed differences could have been due to the criteria used in the identification and classification of number of roots. Unlike in the present study, the previous authors reported on the number of roots in this premolar without making a distinction between fused and distinct root forms. This could have resulted in the findings of more single-rooted maxillary second premolars in the previous findings than in the present finding. It is interesting to note that majority of the two-rooted premolars in the present study had the fused root form (37.7%) more often than the distinct root form (18.4%). However, only 2.6% of the maxillary second premolars in the present study were three-rooted. The three-rooted form is rare and has only been presented as case reports.[42- 44]

There were no statistically significant gender differences in number of roots in maxillary second premolars *($\chi2$=2.303, P>0.05)*.

Nearly all (98.1%) the ***mandibular first*** premolars were one-rooted (Table 14). Identification of the fused root form was by visual observation both externally and internally. This double check was important because the tooth has a mesial groove that occasionally is so marked as to suggest two fused root form.[23] The results of the present study are generally in agreement with the information reported in the literature[23,34] that the mandibular first premolars are mostly single-rooted, but may occasionally present with a division of the root in the apical half.

There were no statistically significant gender differences in the number of roots in this tooth *($\chi 2=2.04$, $P> 0.05$).*

The ***mandibular second*** premolars were one-rooted in 99.1% of the specimens (Table 14). These results are similar to those available in the literature which indicate that this tooth is mostly single-rooted, but may occasionally present with a division of roots in the apical half.[23,34] There were no statistically significant gender differences in the number of roots in the mandibular second premolar *($\chi 2=0.01$, $P>0.05$).*

The current results are useful in a number of clinical situations. A multirooted tooth is more likely to present with multiple canals posing more challenge during endodontic treatment. An extraction may be more difficult and the tooth likely to fracture in multirooted than in single-rooted teeth.[6] The duration of moving a multi-rooted tooth orthodontically may be longer than in a single-rooted tooth. Moreover, a multi-rooted tooth may require higher orthodontic forces than a single-rooted tooth because in general, the larger the area of periodontal attachment the more pressure will be necessary.[7] On the other hand, multi-rooted premolars with separate roots offer better periodontal support for bridge abutments.[86] A multi-rooted tooth is likely to demonstrate more canals than a one-rooted tooth making endodontics more challenging. These results therefore emphasize the importance of knowing the external morphology of premolar teeth and correct radiographic interpretation during clinical procedures. The findings from this study will assist in anticipating likely complications that may arise during clinical procedures.

Root curvature

In the interpretation of the results for root curvature, it is worthwhile noting that there may have been an under-representation of curved roots in the present sample since fractured roots (which occur more frequently in curved roots),[6] were excluded. In addition, it is important to also note that the statistical analysis for gender differences in root curvature was done between "straight" versus all other curvatures combined.

Majority of the roots in all the maxillary and mandibular premolars were straight (60.6%). Distal curvature was the second commonest followed by "S"-curvature. Curvatures towards the buccal, lingual or mesial directions were rare (Table 19). These observations were generally similar in all the four premolar tooth types irrespective of the number of roots and gender.

In the ***maxillary first*** premolar 57.2% of the roots were straight. Some studies in the literature indicate that this tooth is most often encountered with a straight root[32] while others indicate a distal curvature to be the most frequent.[37] These differences are probably related to methodological and racial factors.

Like the maxillary first premolars, most of the ***maxillary second*** premolar roots were straight (62.0%). Ingle et al.[32] have also reported that majority of these teeth have straight roots, but Pecora et al.[40] found distal curvature to be the most frequent.

Mandibular first premolars had 63.6% of the roots straight. This contrasts with the scanty information in the literature that indicates distal curvature to be the most frequent curvature in this tooth.[23]

There is very scanty information in the literature in regard to root curvature in the ***mandibular second*** premolar tooth. Although distal curvature has been reported to be the most commonly occurring,[23] the present study found straight roots in 64.9% of the specimens. As argued out earlier, It is likely that in the current findings, there may have been an under representation of curved roots, because premolars found to have fractured roots were excluded from the study sample.

Direction of root curvature is important in clinical practice for a number of reasons. Failure to detect presence and direction of root curvature may cause perforations during instrumentation of the canals. Abou-Rass[87] has described the inner aspect of the curved root as the "danger zone" and recommended filing away from the zone (anti-curvature filing). Lim and Atock[88] have emphasized the importance of using the circumferential filing technique (filing the buccal, mesial and lingual or palatal walls of the root canal in the ratio of 3:1 with the furcal wall) to avoid endodontic failures due to perforations.

During extraction, curved roots are more likely to lead to complications due to fracture and surgical intervention may sometimes be indicated.[6]

Curved roots have a bearing on the ease and duration of orthodontic tooth movement because tooth movement may be slower in curved as compared to straight roots.[7] Indeed, where the root curvature is highly marked, tooth movement may be difficult or impossible to achieve and an alternative treatment plan may be necessary.[89]

It is important to note that detection of direction of root curvature from radiographs is not always straightforward. This is particularly so in multirooted teeth and when the curvatures are buccal or lingual.[4] Knowledge of the external morphology of roots is therefore necessary in order to help the clinician interpret curvature more confidently. Although in the present study majority of the roots were straight (60.6%), clinicians are encouraged to always be wary of curved roots and to follow the recommended guidelines when treating such roots.

Premolar tooth length

It is important to note that what was measured in the present study was "tooth length" rather than "root length". This was done because in endodontics measuring "tooth length" does the establishment of the working length in the majority of the cases. It was also important to compare the findings of the present study with those of previous studies where "tooth length" was measured.

Results of premolar tooth length in the present study are presented for both combined and separate gender for each premolar tooth type. Generally, the values were found to lie within the range reported by other authors from other parts of the world. However, results on tooth length in the literature have been reported as combined male and female data, making it difficult to compare the present and previous findings along gender lines.

The previous studies indicate that the mean tooth length for the ***maxillary first*** premolar ranges between 21.0 mm to 22.4 mm for different populations.[20,36,37,48] In the present study, the combined mean tooth length for both gender in the one-rooted tooth was 22.6 mm (males 22.8, mm and females 22.6 mm). In the two-rooted premolar the buccal mean tooth length (22.3 mm) was larger than the lingual mean tooth length (21.2 mm).
An earlier study done in Kenya by Maina and Wagaiyu[19] reported the mean lingual tooth length (22.4 mm) to be larger than the buccal (21.8 mm). This was in contrast to the present study and previous studies[37,47,48] that have reported the buccal root to be longer than the lingual root. The reported differences may have arisen as a result of the measuring reference points used. In the present study, the measurements were from the root apex to the corresponding cusp tip. The study by Maina and Wagaiyu[19] used the buccal cusp for both buccal and lingual measurements, which may account for the findings of a longer lingual root than buccal root.

Maxillary second premolar had a combined mean tooth length of 22.8 mm (males 23.0 mm. and females 22.6 mm) in single rooted teeth. In the two-rooted premolar, the mean buccal tooth length was 21.7 mm while the lingual was 21.5 mm. The reported mean tooth length from previous studies ranges from 21.2 mm to 22.6 mm.[19, 34,40,48] The results of this study are therefore in agreement with previous reports.

The combined mean tooth length for both genders in the ***mandibular first*** premolar was 23.6 mm (males 24.3 mm, and females 22.8 mm), a finding that was higher than that previously reported in Kenya (22.8 mm).[19] It is likely that since in the previous study the gender were not separated, there may have been disproportionate representation of specimens from males and females, which may have contributed to the observed differences. Male and female teeth were equally represented and were analyzed separately in the present study.

In the ***mandibular second*** premolar, the combined data for males and females gave a mean tooth length of 23.4 mm (males 23.9 mm, and females 23.0 mm). The combined mean figure is higher than that previously reported by Maina and Wagaiyu for Kenyans (22.9 mm).[19] As pointed out earlier, it is likely that since in the previous study the gender were not separated, there may have been disproportionate representation of specimens from males and females. The subtle differences in the methodologies used may also be a factor.

Males had slightly larger mean tooth length than females in all premolar types and root categories (Table 20-23). The gender differences in tooth length were statistically significant ($P < 0.05$) except in single-rooted maxillary first and second premolars. These results parallel other reports where males have been shown to have larger dental features such as wider mesio-distal crown widths than females,[18,21] findings which are related to genetic factors.

Although radiographs are relied on in the determination of correct working length, some authors have expressed the view that radiographs exaggerate the working length due to distortion. An extracted tooth is on average 1.2 mm shorter than the tooth image in a diagnostic radiograph.[90] Stock and Nehammer[2] have stressed the importance of prior knowledge of average tooth lengths and root anatomy for successful endodontic treatment. Knowing the mean tooth length of a particular tooth type in a specific population and gender may guide the operator in the determination of correct working length and hence correct instrumentation. However, it is equally important for a clinician to appreciate the wide range in tooth length that one is likely to encounter.

Although it is not recommended that a clinician undertake endodontic treatment without the aid of radiographs, most public dental clinics in Kenya are inadequately equipped for intraoral radiography, not to mention the lack of radiographers specially trained for dental radiography in these facilities. Those clinicians who may be compelled to undertake endodontic treatment under these difficult circumstances may find the data for tooth length presented in this study particularly helpful.

From an orthodontic point of view, the root size of the tooth being moved is important in terms of the forces being applied and the anchorage requirements. Higher forces would be necessary to move longer roots and long roots offer better anchorage than short roots.[7] The present results have shown no appreciable differences in mean tooth length between the first and second mandibular premolars suggesting that the orthodontic forces that would be required to move these teeth and the amount of anchorage that they can offer may be similar. Clearly, this comparison (orthodontic forces in relation to tooth length) cannot be done between the maxillary first and second premolars because often these teeth were found to present with different numbers of roots.

4.3. Internal root morphology of premolars.

The results for internal root morphology of premolars discussed in this study comprise number of root canals (Table 24) and types of canals (Table 25).

Number of root canals.

The combined gender data for ***maxillary first*** premolars with one canal, two canals and three canals was comparable to that reported in the literature. Two-canals were the most common (87.7%), a value that is within the range of 73.3% to 98.5% reported in previous studies.[29,30,33,35,69] The occurrence of three canals in this tooth was 6.5%, which is also within the reported range in the literature (0% to 7.5%).[29,33,35,69] When each gender was considered separately, three canals were more commonly occurring in males than females and this was statistically significant ($P<0.05$).

In the ***maxillary second*** premolar, 29% of the specimens had one canal, 67.6% two canals and 3.5% three canals. There is conflicting information in the literature in regard to the number of canals in this tooth. Some authors have described the tooth as having one canal with the possibility of two canals[63-65] and on the other hand, the tooth has been described as having two canals, with the single canal being the exception.[23,66,57] The present results therefore support previous findings that have described this tooth as having two canals most of the time. The data for separate gender showed no statistically significant differences in the distribution of number of canals in the maxillary second premolars ($P>0.05$). The present findings for one and two canals in the maxillary second premolars are similar to those found in a recent study by Mumena et al.[91] in Tanzanian where 63.5% of the specimens had two canals and 36.5% had one canal. Green[67] also found a higher number of teeth with two than with one canal. The present study has reported the highest incidence of three-canaled maxillary second premolars (3.5%) so far in the literature. All the teeth were from males. Clinicians carrying out root canal treatment in Kenyans should therefore be cognizant of the possibilities of a third canal in this premolar and more so if treating a male patient.

One canal was demonstrated in 63.0% of the ***mandibular first*** premolars. The occurrence of mandibular first premolars with more than one canal was higher in the present study (37.2%) than that reported in most studies.[29,30,55,61,67,71,72,77] For instance, Kartal[61], using similar methodology to the one used in this investigation found 27.8% of his sample as having more than one canal. However, Barret[52] using sectioning and microscopy reported an occurrence of more than one canal in 62.5% of the teeth. These large differences may be related to the methodology used by Barret. Although the separate data for number of canals in males and females showed that males had a higher frequency of mandibular first premolars with a single canal (66.7%) than females (59.3%), the differences were not statistically significant *($P>0.05$).*

It is important for clinicians to be aware of this possibility of frequently encountering mandibular first premolars with more than one canal during endodontic treatment among Kenyans.

The ***mandibular second*** premolar demonstrated one canal in 95.5% of the sample. These findings are in accord with those reported by other authors.[29, 30,34, 55,62,67,72] Although none of the mandibular second premolar had three canals in the current findings, clinicians embarking on root canal therapy of this tooth in the general population ought to be aware that three canals have been reported in other populations.[73-76, 92,93] The results of this study indicate that two canals do occur at the apices of mandibular second premolar teeth to a small extent (4.5%). Thorough evaluation of radiographs together with detailed examination of the floor of the pulp chamber is therefore important for correct identification of the root canals and hence proper endodontic treatment.[5, 91,92]

Root canal types.

It was possible to demonstrate all of Vertucci's[77] eight canal types amongst the ***maxillary first*** premolar specimens of Kenyans of African descent. Vertucci[77] reported five canal types in this tooth amongst his specimens. In both studies, type IV canal pattern was the most common (present study-72%, Vertucci's[77] study 62%). None of the Kenyans' maxillary first premolars demonstrated Kartal et al's[61] canal types.

The ***maxillary second*** premolar specimens had all of Vertucci's[77] eight types of canal patterns represented. Type I, IV and V were the most common (Table 25). This was comparable to Vertucci's[77] results where all the eight types were represented. However, majority of the teeth in Vertucci's[77] study depicted type 1, III and IV canal patterns. None of the maxillary second premolars in the current investigation demonstrated Kartal et al.[61] canal types.

The ***mandibular first*** premolar had representation in nine of the eleven possible canal types. It was the only tooth that had specimens exhibiting Kartal et al's.[61] additional three canal types and six of Vertucci's.[77] The current study found a lower occurrence of type 1 canal (49.1%) than that observed by Kartal et al.[61] (72.19%). However, there was a higher percentage of type III (13%) and type V (26.9%) canals than that reported by Kartal et al.[60] (type III-4.3%; type V-5.9%). The occurrence of other root canal types was low.

The ***mandibular second*** premolar had representations in seven of Vertucci's[77] canal types. The majority of the teeth depicted canal type I (87.1%) compared to Vertucci's[77] (97%). There were no specimens that demonstrated any of Kartal et al's.[61] additional three canal types.

The four premolar types demonstrated different degrees of variability in root canal patterns. Mandibular first premolar had the widest variation in root canal pattern with representations in all the eleven canal types. This observation is in agreement with that of Slowey[94] who referred to the mandibular first bicuspid as "probably the most difficult tooth in the mouth to treat endodontically" and associated the difficulty with the complex canal pattern. However, in contrast, Vertucci[77] reported that the maxillary second premolar demonstrated the most complex canal pattern.

The present study found the mandibular second premolar as having the least complex canal pattern. The present study further showed that males and females had similar distribution of canal types in all the four premolar tooth types. There were no statistically significant gender differences in root canal types ($P>0.05$).

The fact that different canal patterns can occur in different premolar tooth types and also within the same premolar tooth type emphasizes the importance of correct radiographic interpretation before embarking on endodontic therapy. It has been observed that premolars with canal bifurcations in the middle or apical third (type V, VI, VII, IX, X, and XI) might present problems during endodontic treatment.[77] There are chances that some of the canals are not always identified and obturated and this may explain some of the endodontic failures associated with these teeth, even though radigraphically and clinically the canal system seems to be obturated.[95] It has therefore been suggested that in addition to taking pretreatment radiographs from a bucco-lingual direction, a second radiograph at 20° angle to the mesial or distal side should be taken because it may give a better view of the bucco-lingual anatomy.[5] A radioluscent line next to the main canal may be observed in the second radiograph, which means that there may be more than one canal in that particular tooth.

The complicated canal patterns found in this study also indicate that complete debridement of the whole canal by mechanical means may be difficult to achieve. This emphasizes the importance of combining chemical and mechanical debridement. When either pain or periapical breakdown is seen after apparently effective nonsurgical endodontic therapy, the possibility of an additional canal should be considered before the tooth is condemned or surgical endodontics is scheduled.[45]

Although the present results do not give the age distribution of the patients from whom the premolars were obtained, the age range of the patients (13-30 years) indicates that the specimens represented a sample of “young” teeth. It is known that the pulp chamber and root canals undergo morphological changes owing to deposition of secondary dentine with age.[96-99] The changes are more marked if the teeth are subjected to external irritation such as attrition, caries or following extensive restorative procedures.[96,97] The degree of mineralization within the pulp, particularly of the amorphous or diffuse type, is also found more frequently in "old" than in "young" teeth.[98,99] The results of number of root canals and canal types described here would therefore likely be appreciably different from those of specimens from an older sample of patients. This should be borne in mind when interpreting the current findings.

4.4. Study limitations.

- At times identification of a fused root was not always straightforward since only visual examination was done. Loh[13] attempted to overcome this problem by using both external visualization and internal instrumentation of the canals to confirm the presence of two root canals in a tooth that externally appeared as two roots joined almost to the apex. In the present study, instrumentation of canals was avoided so as not to interfere with the tooth's internal anatomy (canal patterns) of the teeth since the canal patterns were being studied as well. In the few cases of doubt the root was classified as single-rooted.
- Determination of root curvature was a challenge in a few cases of minor curvature since there are no strict scientific criteria in the literature defining the borderline between a straight and a very minimal root curvature. This limitation may have introduced some degree of subjectivity. In the few instances of doubt the root was classified as straight.
- The sliding portion of the Boley gauge can measure all "full numbers" directly against a graduation on the "fixed" portion of the gauge. The sliding portion was used to estimate the length of the specimen to within 0.1 mm when the measuring tip fell between two full graduations. This estimation was a challenge in terms of consistency. However, any inaccuracies at the "estimation level" of measurement with a Boley gauge have been shown to be insignificant.[45]
- Another challenge was where there were lateral canals in a root that appeared diffuse making clear-cut classification difficult. Such a canal pattern was grouped in the category (classification) of the canal type closely resembling it.

4.5. Conclusions

The present study has provided data on external and internal root morphology of premolar teeth from young Kenyan males and females of African descent that can be used for clinical, teaching, and research purposes.

External root morphology

- Maxillary first premolar was mostly two-rooted with only a few specimens having one and three roots. The three-rooted teeth are more likely to be found in Kenyan males than females. There were statistically significant gender differences in number of roots in this tooth type.
- Maxillary second premolar was mostly two-rooted. The few teeth that were three-rooted were from males. There were no statistically significant gender differences in number of roots in this tooth type.
- Majority of the mandibular first and second premolars had one root. Two-rooted mandibular premolars were rare. There were no statistically significant gender differences in number of roots in the mandibular premolars.
- The mean tooth length in single-rooted maxillary first and second premolars showed no statistically significant gender differences. However, in two-rooted maxillary first and second premolars and in both mandibular first and second premolars, males had statistically significant larger mean tooth length than females.
- In both genders maxillary and mandibular premolar roots followed a similar distribution in the various directions of root curvature. Majority of the teeth had

straight roots. Distal and "S"-curvatures were relatively common while mesial, buccal and lingual curvatures were rare. There were no statistically significant gender differences in direction of root curvature.

- In general the external root morphology of Kenyan teeth has similarities in some parameters (number of roots in the mandibular premolars and in tooth length) and some differences (number of roots in maxillary premolars and direction of root curvature) when compared to Caucasian data.

Internal root morphology

- In the majority of cases, the maxillary first premolars had two canals. A few specimens had either one or three canals.
- Maxillary second premolar showed two canals in most of the specimens. Specimens having one canal were also common but three canals were rare.
- Mandibular first premolar had one canal in majority of the specimens. Specimens having two canals were also common but 3 and 4 canals were rare.
- Most mandibular second premolar teeth presented with one canal with only a few having two canals.
- Mandibular first premolar had the most complex canal pattern while the mandibular second premolar had the least variation.
- There were no significant gender differences in number and types of canals in the maxillary second, mandibular first and mandibular second premolar except for the maxillary first premolar where males presented with three canals more frequently than females.

4.6. Recommendations

- Clinicians, teachers and researchers should familiarize themselves with the data reported here for external and internal root morphology of premolar teeth in Kenyans of African descent. Clinicians should apply the information appropriately by:
  - Carrying out endodontic instrumentation, orthodontic tooth movement and tooth extraction diligently.
  - Undertaking thorough mechanical and chemical debridement of the root canals
  - Considering use of radiographs where justifiable, particularly during endodontic procedures.
- Additional studies on external and internal morphology of other tooth types and in specific age groups should be undertaken among Kenyans.

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APPENDICES

Appendix 1: Diagrammatic representation of root canal types.

(Vertucci (I-VIII)[77] and Kartal et al's. (IX-XI)[61] classifications).

Type 1. A single canal extends from the pulp chamber to the apex.

TypeII. Two separate canals leave the pulp chamber and join short of the apex to form

Type III. One canal leaves the pulp chamber, divides into two within the roots, and then merges to exit as one canal.

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

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

Type VI. Two separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex to exit as two distinct canals.

Type VII. One canal leaves the pulp chamber, divides and then rejoins within the body of the root, and finally redivides into two distinct canals short of the

Type VIII. Three separate and distinct canals extend from the pulp chamber to the apex

Type IX. One wide canal leaves the pulp chamber and separate into three separate canals between the middle and apical third and reaches the apex via three separate

__Type X.__ After leaving the pulp chamber as a wide canal, it divides into two canals between the cervical and middle third. This continues into the middle third. In the apical third, the buccal canal first splits into buccal and lingual branches then the lingual canal merges into the lingual branch of the buccal canal. At the apex there are two separate foraminae.

__Type XI.__ A wide single canal leaves the pulp chamber and separates into three canals between the cervical and the middle third area. This continues as three separate canals along the middle third, then one canal branches between the middle and apical third, resulting in four separate foraminae at the apex.

Appendix 2: Data collection chart (form a) for number of roots.

Tick ( ) the correct information

Gender:	Male	( )	Female	( )
Premolar type.	Upper first	( )	Upper second	( )
	Lower first	( )	Lower second	( )

Tick the number of roots present in the tooth.

One root		( )
Two roots:	*Distinct.*	( )
	Fused.	( )
Three roots		( )

Appendix 3: Data collection chart (form b) for direction of root curvature

Tick ( ) the correct information

Gender: Male ( ) Female ( )

Premolar type. Upper first ( ) Upper second ( )

Lower first ( ) Lower second ( )

Direction of root curvature

No. of roots	Straight	Lingual	Buccal	Mesial	Distal	"S"-curve
One:						
Two: *Buccal* *Lingual*						
Three: *Mesio-buccal* *Disto-buccal* *Lingual*						

Appendix 4: Data collection chart (form c) for tooth length.

Tick ( ) the correct information

Gender:	Male	( )	Female	( )
Premolar type.	Upper first	( )	Upper second	( )
	Lower first	( )	Lower second	( )

Number of roots	root type	Length in mm
One root :		_____
Two roots:	Buccal	_____
	Lingual	_____
Three roots:	Mesio-buccal	_____
	Disto-buccal	_____
	Lingual	_____

Appendix 5: Data collection chart (form d) for number and types of canals

---

Gender: Male ( ) Female ( )

Premolar type: Upper first ( ) upper second ( )
lower first ( ) lower second ( )

Specimen number	**Number of canals at apex**	**Types of canals**										
		Type 1	Type 11	Type 111	Type 1V	Type V	Type V1	Type VI1	Type VII1	Type 1X	Type X	Type X1
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Appendix 6: Consent form

Dear patient/parent/guardian,

I am a postgraduate student, pursuing studies specializing in children's dentistry, at the university of Nairobi, Dental school.

I understand from your dentist that he/she has explained to you the details of your treatment/your child's treatment and that it will involve extraction of a premolar(s) tooth/teeth.

I wish to request your permission to include your extracted tooth/teeth in a study that I am undertaking for my research which requires premolar teeth. All the observations and measurements taken on your tooth will be recorded and analyzed for purposes of this research only.

The results from my study is intended to improve the quality of treatment that dentists will give to their patients.

If you consent, please sign below.

Name of the patient: ______________________________ Sign ________

Name of the Parent/Guardian: ______________________ Sign ________

Relationship to child (Mother, father, others________________)

Thank-you.

Investigator: Dr. RN. Ng'ang'a Sign ________

Date: ___________

Appendix 7: Approval letter from the Ethics and Research Committee

KENYATTA NATIONAL HOSPITAL
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Ref: KNH-ERC/01/1974 **Date: 30 September 2003**

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Faculty of Dental Sciences
University of Nairobi

Dear Dr. Ng'ang'a,

RESEARCH PROPOSAL "EXTERNAL AND INTERNAL ROOT MORPHOLOGY OF PREMOLAR TEETH IN KENYANS OF AFRICAN DESCENT" (P68/7/2003)

This is to inform you that the Kenyatta National Hospital Ethics and Research Committee has reviewed and **approved** the revised version of your above cited research proposal for the period 1 October 2003 – 30 September 2004. You will be required to request for a renewal of the approval if you intend to continue with the study beyond the deadline given.

On behalf of the Committee, I wish you fruitful research and look forward to receiving a summary of the research findings upon completion of the study.

This information will form part of database that will be consulted in future when processing related research study so as to minimize chances of study duplication.

Yours sincerely,

PROF. A N GUANTAI
SECRETARY, KNH-ERC

Cc Prof. K M Bhatt, Chairperson, KNH-ERC
The Deputy Director (C/S), KNH
The Dean, Faculty of Dental Sciences, UON
The Chairman, Dept. of Paediatric Dentistry & Orthodontics, UON
CMRO
Supervisors: Dr. M Masiga, Dept. of Paediatric Dentistry & Orthodontics, UON
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