

Evaluation of the root and canal morphology of
permanent maxillary first molars using cone beam
computed tomography in a sample of patients treated
at the Wits Oral Health Centre



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DECLARATION

I, Abdelmenem Ali Irhaim declare that this research report is my own work. It is being submitted for the degree of MSc Dent at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

.....

This is 16th day of November 2016

DEDICATION

To my mother, my father and my brothers.

ABSTRACT

Purpose: To evaluate the root and canal morphology of permanent maxillary first molars using cone beam computed tomography in a sample of patients treated at the Wits Oral Health Centre.

Methods: Two hundred CBCT images with bilateral permanent maxillary first molar were carefully examined by two dentists. Information obtained was on the number and morphology of roots per tooth, the number of canals per root, the root canal configuration in each root using Vertucci's classification, the relationship between MB2, tooth position and different age groups, and the frequency of C-shaped root canals were determined.

Results: The prevalence of three separate roots was 91%. The frequency of three roots where two of them were fused was 8%. Two fused roots were observed in 0.5% of teeth and three fused roots were seen in 0.5% teeth. Regarding the mesiobuccal roots (MBR), the most frequent was Vertucci type IV root canal configuration (42.75%), then type I (39.5%), Type II (15%), type III (1.25%); type V (0.75%), and type VI (0.75%). The occurrence of bilateral MB2 was 65, 75% while the unilateral occurrence of MB2 was 34, 24%. There was no significant difference between 5 age groups ($p=0.759$, and tooth position $p=0.9977$ in regard of presence of MB2. Distobuccal roots (DBR) displayed a type I configuration in 99.5% of teeth, with only 0.5% of teeth displaying a type IV canal configuration. All palatal roots (PR) had type I canal configuration. No C shaped canals were observed in the sample of 400 permanent maxillary first molars teeth.

Conclusion: Cone-beam computed tomography provides valuable information about the anatomy of root and canal morphology which may facilitate root canal therapy.

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My supervisors, Dr. E Patel and Dr. S Tootla.

To Dr. M Slabbert.

To all staff in Radiology Department.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Morphology and development of the permanent maxillary first molar tooth

The maxillary first molars emerge in to the oral cavity posterior to the deciduous molar teeth, and in contact with them, at approximately 6 years of age. Unlike anterior and premolar teeth, molar teeth do not have deciduous predecessors and are therefore not succedaneous teeth. First molars are the strongest teeth in the maxilla, possessing a large crown that has four well-formed cusps. These teeth play an important role in mastication. The radicular portion of these teeth has three roots: a mesio-buccal, a disto-buccal and a large palatal root. In most instances the disto-buccal root (DBR) and palatal roots (PR) have one canal, whereas, the mesio-buccal root (MBR) often presents with either one or two canals (Nelson, 2010).

Once the crown has formed completely, the root begins to develop. The epithelial root sheath of Hertwig is the key to root formation. This sheath is double layered and develops from the inner and outer cells of the enamel epithelium as they proliferate and migrate apically from the cervical loop of the enamel organ. The dental pulp beneath the dental follicle, except its basal portion, becomes encircled by this sheath. The primary apical foramen is enclosed by the rim of the sheath which is known as the epithelial diaphragm. The ectomesenchymal cells of the dental papilla facing the inner epithelial cells begin to differentiate into odontoblasts that create the dentine of root. As the root dentine is formed, the sheath degenerates, allowing the

ectomesenchymal cells of dental follicle to come in to contact with the dentine of the root. This leads to differentiation of the ectomesenchymal cells to become cementoblasts that secrete cementum on the dentine of root. In this way a single-rooted tooth is formed. The number of roots of a tooth is determined by the ingrowth of transverse diaphragm/s from the epithelial root sheath (Allan and Kramer, 2010).

1.2 The significance of root and canal morphology in the success of endodontic treatment

Before undertaking root canal therapy it is important to understand the subtleties of pulp anatomy and canal variations (Weine et al., 1969; Vertucci, 2005). Many studies have shown that the canal morphology of maxillary molars can be unusual and very complicated (Barbizam et al., 2004; Badole et al., 2014).

A permanent molar with an unusual anatomy was detected by Barbizam et al. (2004). The authors reported a maxillary left first molar with four roots in a 35-year-old male patient with leukoderma. This tooth was a candidate for root canal treatment. There was severe periodontal recession on the palatal aspect of the tooth, and clinical examination revealed bifurcation on the palatal root. Following access in to the coronal pulp, the pulpal floor was found to possess four, large, well-defined root canal orifices, that is, one for each root. The four independent roots were confirmed to be present along with the determination of the working length radiographically. These roots were defined as being two buccal and two palatal roots, which were classified as type I according to Christie et al. (1991). All canals were enlarged to size 35.04 taper file and

had their space sealed with lateral condensation of gutta-percha and Top Seal® using finger spreaders.

Badole et al. (2014), using CBCT and a surgical operating microscope, reported an unusual root canal morphology of a maxillary left first molar with 3 roots and 7 root canals. An endodontic treatment of this tooth was successfully completed. At first, CBCT demonstrated the presence of 3 roots and 6 canals (2 mesio-buccal, 2 disto-buccal, and 2 palatal) in the tooth. When the mesio-buccal roots were further examined, a MB3 orifice was found between the centers of the MB1 and MB2 orifices. A radiolucent line extended from the MB3 orifice toward MB1 suggesting the presence of a seventh orifice between MB1 and MB3. As per Vertucci's classification, the canals in this tooth displayed type IV canal patterns in the distal and palatal roots, whereas the mesial root had a type VIII canal pattern. Furthermore, the right maxillary molar had similar canal numbers and configurations as the left maxillary first molars, as confirmed by CBCT imaging.

In some cases, the dentist fails to recognize the presence of unusual canal which may then lead to endodontic flare-ups. Shenoy et al. (2013) reported a maxillary second premolar with three roots. Only two roots were identified at the initial stage with subsequent RCT being performed. Upon treatment failure, a deeper investigation led to the identification of an untreated third root, mesially. This root was evident in the radiograph because the mesio-distal width of the mid root was equal to that of the crown and a double periodontal ligament space was noted. With careful observation, a missed canal was detected and retreatment was then performed. Hence, a lack of knowledge of pulp anatomy is a considerable factor as a cause of treatment failure.

1.3 Techniques used to determine tooth root canal morphology

In order to improve the successful rates of endodontic treatment, dentists should use the appropriate techniques to identify the correct anatomy of the pulp and canal variations. Consequently, many efforts have been made to examine root canal morphology using the following methods:

1.3.1 Plastic resin injection:

Skidmore and Bjordal (1971) evaluated the root canal configuration of 45 extracted human mandibular first molars. The researcher's injected a special type of polyester casting resin into the teeth to construct plastic casts that duplicated the anatomy of the pulpal cavities. A 35 % solution of nitric oxide was used to decalcify the teeth. The number of roots, number of canals and their morphology and the transverse anastomoses between root canals were summarized and tabulated (Skidmore and Bjordal, 1971).

1.3 2 Conventional radiograph:

In an in vitro study by Pineda and Kuttler (1972), 7275 root canals in 4183 extracted teeth were investigated. The teeth were roentgenographed in two directions: mesio-distally and bucco-lingually. The roentgenograms were observed on a negatoscope with the aid of a magnifying glass, and the results were registered on a chart corresponding to each specific tooth (Pineda and Kuttler, 1972).

1.3.3 Root canal staining and tooth clearing:

In 1984, Vertucci investigated the root canal configurations of e human teeth by injecting hematoxylin dye into the pulp cavities of 2400 extracted permanent teeth. Finally, the sample was cleared by using a clear liquid plastic casting resin. The number and configuration of root canals, position of accessory canals and apical foramina were documented and classified into eight types with variations of single, double and triple canals as indicated in Figure 1.

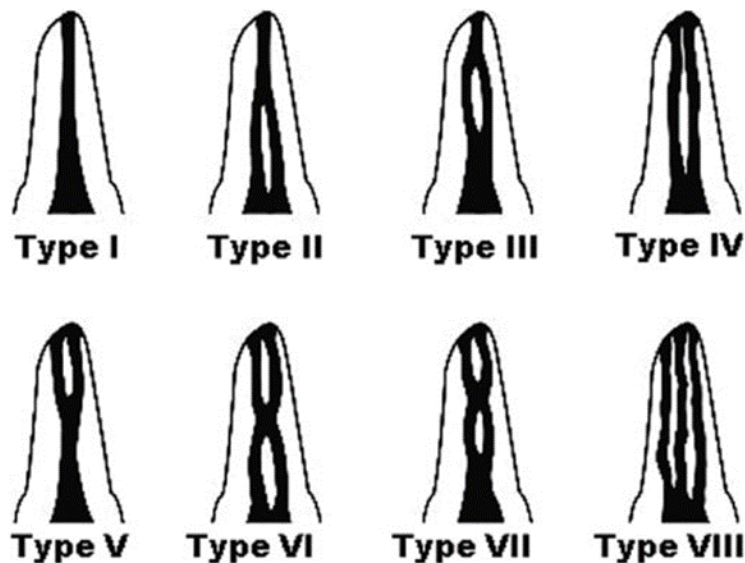


Figure 1: Root canal classification according to Vertucci (1984).

1.3.4 Sectioning:

In 1969, Weine et al studied the canal morphology of the mesio-buccal root of the permanent maxillary first molar by sectioning 208 mesio-buccal roots. The root canals were displayed, and the typical morphology was classified and summarized into four categories as indicating in figure 2.

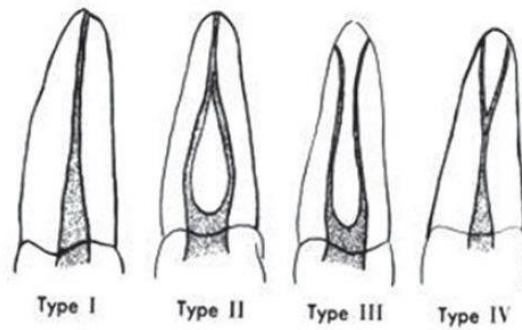


Figure 2: Root canal classification according to Weine (1969).

1.3.5 Computed Tomography (CT) Techniques:

Gopikrishna et al. (2006) used Spiral CT to examine maxillary first molars with a single root and single canal. A 48-year-old female patient presented with pain in the left upper posterior tooth region. The preoperative radiograph showed an abnormal morphology of the upper left first molar tooth with a single root and a single canal. To establish this unusual morphology a multi slice helical imaging was done in the maxilla, and a 3D image of the maxillary teeth was achieved. These images confirmed that the tooth possessed a single root with a single uniformly shaped canal. Similarly, this configuration was noted in the contralateral first molar (Gopikrishna et al., 2006).

1.3.6 Digital and contrast medium-enhanced radiographic technique:

Fan et al. (2008) used a contrast medium to examine 30 extracted mandibular second molars with fused roots and deep lingual longitudinal grooves on the root surfaces. A 76% meglumine diatrizoate compound was injected as a contrast material into the canal space. Radiographs were

taken before and after introducing the contrast medium and with or without the mandible plates. The canal number distribution on the radiographs taken without bone was similar to that from the radiographs taken with both contrast medium and bone. To evaluate the accuracy of the radiographic findings, the researchers used the buccal-lingual and three-dimensional view of the reconstructed canal images based on Micro-computed tomography scan (μ CT) as an index. The results revealed that the bone superimposition can significantly decrease the possibility of canal detection without intra-radicular contrast medium ($P < 0.001$), especially in the apical area. However, the bone superimposition was found not to affect canal reading when contrast medium was injected ($p=0.05$) into the canals. Based on these findings, the author concluded that intra-radicular contrast medium can enhance the detection of C-shaped root canal in mandibular second molars even when the teeth are within bone (Fan et al., 2008).

1.3.7 Micro computed tomography (μ CT):

Verma and Love (2011) used Sky scan micro CT at a thickness of 11.61 mm, to analyze the root canal morphology of twenty restricted mesio-buccal roots which were randomly selected from extracted maxillary first molars teeth. The researchers found that most of the roots had a complex anatomy, where 18 roots showed an additional mesio-buccal canal (MB2). A total of 11 roots had inter canal communications. Three roots presented with single foramens while 4 roots displayed two foramina. Three or more foramina were observed in the remaining 13 roots. Regarding the orifices at the furcation level; 10 roots presented with 2 orifices; 8 had one orifice, and three orifices were observed in 2 roots. Accessory canals were found in 17 roots. The classification of Weine et al. (1969) could be applied to classify up to 60% of root canals, and 70% could be classified according to Vertucci1984 (Verma and Love, 2011).

1.4 The use of CBCT in dentistry

CBCT is a recent technology where a rotating gantry that is fixed to a source for x-ray and a detector is used to accomplish the image. The middle of the area of interest is subjected to an ionizing radiation from one side and these radiations are received on the opposite side by the detector. The x-ray source and detector rotate around a rotation fulcrum fixed within the centre of the region of interest. Projection images of the field of view (FOV) are acquired during the rotation that revolves 150 to more than 600 successive planar images. These images are in a thorough, or occasionally partial, arc. To obtain individual image slices of the FOV in the old medical CT, a fan- shaped x-ray beam that progresses helically is used and then the slices are stacked to acquire a 3D representation. Thus, the procedure in traditional CT differs from that for CBCT. A separate scan and separate 2D reconstruction are required for each slice. The entire FOV is incorporated in case of CBCT exposure. Therefore, only one rotational sequence of the gantry is required to obtain adequate data for image reconstruction (Scarfe & Farman, 2008).

CBCT has been used in the field of dentistry since 2001 (Scarfe et al., 2006). The main use so far has been in oral and maxillofacial surgery (Araki et al., 2007; Tetradis et al., 2010), implant dentistry (Van Assche et al., 2007; Benavides et al., 2012), and Endodontics (Tyndall and Rathore, 2008; Patel, 2009). Additional uses include diagnosis of TMJ disorders (Tsiklakis et al., 2004), Orthodontics (Terakado et al., 2000), Periodontics (Tyndall and Rathore, 2008), Operative dentistry (Tetradis et al., 2010), and in Forensic dentistry (Yang et al., 2006). The uniqueness of CBCT is the ability to create three-dimensional images of anatomic features which can then be displayed in axial, sagittal, and coronal views. Due to the isotropic nature of CBCT, objectives can be accurately measured in different dimensions. In contrast, conventional medical

CT scans are anisotropic in nature, and not as accurate in the different planes and views (Scarfe et al., 2006). Whilst many studies have assessed the anatomic characteristics and types of root canal morphology by conventional techniques, CBCT scans can reduce and eliminate superimposition of surrounding structures, which makes it superior to conventional periapical films (Lofthag et al., 2007). In addition, as a clinical tool CBCT does not damage the tooth structure and saves time during laboratory assessments of root canal morphology when compared to medical CT (Scarfe et al., 2006).

1.5 The use of CBCT to evaluate root and canal morphology of maxillary molars

The accuracy of CBCT in determining the exact internal morphology of the mesiobuccal root of the maxillary molars was studied by Blattner et al. (2010). The authors concluded that CBCT scans show no statistically significant difference when compared with the gold standard clinical sectioning of teeth (Blattner et al., 2010). Several studies have examined the anatomic variations and types of root and canal morphology of permanent maxillary first molar by using CBCT (Zheng et al., 2010; Kim et al., 2012; Guo et al., 2014; Altunsoy et al., 2015).

In China, Zheng et al. (2010) examined 775 CBCTs; to study 627 unilateral and 74 bilateral qualifying maxillary first molars in an attempt to describe root and canal morphology of permanent maxillary first molars. Age of the subjects ranged between 10 and 86 years. Three separate roots were found in most molars (97.3 %), whereas all roots were fused in 0.48% of teeth. In unilateral qualifying molars, about the half of teeth had four canals (50.4%), followed by 47.2% with three canals. The remaining 2.37% were found to possess either two, five, or six

canals. When comparing frequencies of root canal and apical foramen numbers in different roots most teeth had one foramen per root (Mesiobuccal root (MBR) = 87.98%, disto-buccal root (DBR) = 99.04%, and palatal root (PR) = 98.88%). Only one tooth exhibited two canals in the disto-buccal root (DBR) and palatal root (PR). Interestingly, another tooth displayed six canals, with two in each root (MBR, DBR, and PR). The teeth with five canals had two canals in the MBR and an additional canal in either the DBR or PR. In contrast to the MBRs, the most frequent configuration in DBR and PRs was a single canal per root, while only 1.12% of DBRs and 1.76% of PRs presented with additional canals. About 54% of left maxillary molars and 50% of the contralateral first maxillary molars presented with multiple canals in their MBR, with no significant statistical difference between the two. Additional canals in MBR were found to be more prevalent in patients aged 20 to 30 years in comparison to other age groups, with the lowest prevalence seen in patients older than 60 years. The only statistical significant difference ($p < 0.05$) was detected between ages 20 to 30 with regard to the presence of additional canals. Sex and tooth position did not affect the presence of MB2. The bilateral occurrence of an additional mesiobuccal canal (MB2) among patients with bilateral permanent maxillary first molars was 71.11%. However, the prevalence of bilateral distribution of MB2 did not differ with sex and tooth position (Zheng et al., (2010).

Kim et al. (2012) carried out an in vivo study attempting to recognize the root and canal configurations of the upper first and second molars teeth using CBCT scans. A total of 814 maxillary first molars were incorporated in their research creating 415 CBCTs (217 women and 198 men) obtained from the Korean population. The predominant finding was three separate roots in 802 maxillary first molars (97.91%) with no four-rooted first molars observed. Of these

802 teeth with 3 roots, 63.59% had an additional canal in the mesiobuccal root while only 10 of this teeth had additional canals in their DBR. Eleven first maxillary molars presented 5 canals where the distribution of the canals was 2 MB canals, 2 DB canals, and 1P canal for ten of these teeth while one maxillary first molar tooth presented with 3 MB, 1DB canal, and 1p canals. However, 12 teeth with fused roots were excluded due to the difficulty faced in analyzing them. In the MB roots of the maxillary first molars with additional canals, 2 apical foramina (types IV, V and VI and others) were more common than 1 apical foramen (types II and III). The presence of an additional MB canals were not affected by tooth position and age, however they were found to be more predominant in males (0.006). The bilateral occurrence of additional mesio-buccal canals (MB2) was 82.9% in upper first molar teeth while C-shaped root canal patterns were not found in this study (Kim et al., 2012).

Guo et al (2014) conducted a study in a North American population to assess the frequency and number of roots, incidence of (MB2), and canal pattern in every root using the Vertucci classification. A total of 317 cases with bilateral maxillary permanent first molars were included finding that 99.1% had 3 root and 0.9% of teeth had 2-roots. In other results 0.9% had fused roots, 65.6% of cases had bilateral MB2 canals and the total occurrence of MB2 canals in 3-rooted maxillary first molars was 68.2%. Canal morphology in mesio-buccal roots showed 3 types of Vertucci classification, type IV, I and II (41.9%, 28.3% and 26.3% respectively). The highest occurrence of MB2 among the six age groups was in the age group of 60+ years (80.0%), whereas the lowest was in the age group of 30-40 (60.0%). Gender and tooth position did not affect the occurrence of MB2. For disto-buccal and palatal roots, 99.6% and 100% of cases, respectively, were of type I pattern (Guo et al., 2014).

More recently in Turkey, a total of 1158 maxillary first molars were investigated by Altunsoy et al (2015), using CBCT to describe morphology in respect to the number of roots, root canals, and the canal configuration in accordance with the Vertucci classification (1984). The presence of three roots was the most common occurrence (99%) in the maxillary first molar which confirmed the previous results. One or two rooted maxillary first molars were observed in about 1% of teeth. The incidence of additional canals in mesio-buccal roots of permanent maxillary first molars was approximately 62%, with type IV canal configurations being the most frequent in both female (50.5%) and male (47%) patients followed by type I (36.3 and 39.8%) and type II (12.7 and 13%). Type III and type V canal configurations were also observed but in a very small proportion of the sample size. For the DBR of maxillary first molars, more than 99% of the roots were shown to have type I canal configurations (Altunsoy et al., 2015).

Interestingly, CBCT has also been used to evaluate rare root canal configurations. Jo et al. (2016) analysed, C-shaped root canal configurations at Chosun University Dental Hospital in Korea. In this study 1786 of maxillary first molars and 1767 of maxillary second molars teeth were digitized using CBCT and analyzed retrospectively. Axial, coronal, and sagittal views were created by piViewstar and Rapidia MPR software (Infinit Co). The most common cases of root fusion occurred between the mesiobuccal and palatal roots. Generally, 3.2% of the first molar and 19.5% of the second molars had some root fusion and the overall occurrence of the root fusion in both the permanent maxillary first and second molars teeth was 11.3%. Less than 1% of the first molars and 2.7% of the second molars were found to have C-shaped root canal with an overall prevalence of a C-shaped canal configuration in maxillary first and second molars of 1.8%. Root fusion frequency and the occurrence of C-shaped canal configuration in the second

molars was significantly higher than that observed in the first molars ($p < 0.001$). CBCT is therefore considered to be the leading and acceptable technology to be used when evaluating and identifying root canal morphology.

Understanding the internal anatomy of maxillary first molar for root canal therapy as well as its variations in different parts of the world is important. A literature search failed to show up any similar studies in a SA population. The need for accurate anatomical knowledge for undertaking successful endodontic treatment necessitated a CBCT study of the maxillary first molar tooth in South Africa.

CHAPTER 2

AIM AND OBJECTIVES

2.1. Aim

This study aimed to evaluate the root and canal morphology of permanent maxillary first molars using cone beam computed tomography in a sample of patients treated at the Wits Oral Health Centre, Johannesburg South Africa.

2.2. Objectives

1. To assess the number of roots and identify their morphology per tooth.
2. To assess the number of canals per root.
3. To evaluate the canal configuration in each root using Vertucci's classification.
4. To assess the relationship between MB2, tooth position and different age groups.
5. To detect the frequency of C-shaped canals.

CHAPTER 3

METHOD AND MATERIALS

3.1. Sample Size calculation

Sampling procedure involved the screening of 640 CBCT images of which only 200 CBCTs met all the inclusion criteria and thus constituted the sample for study. Given then a sample of 200, the estimated precision level (based on a confidence level of 95%) is 6, 9%.

3.2. Methods and materials

This was a retrospective recorded based study, composed of 200 CBCT images taken between 01 January 2012 and 30 September 2015 for different diagnostic reasons. All CBCT images were selected from radiology department at the Wits Oral Health Centre housed in the Charlotte Maxeke Johannesburg Academic Hospital, Johannesburg, South Africa. Ethical permission was obtained from the Human Research Ethics Committee (M150476) as well as the Hospital Risk Assessment Committee.

The sample was subdivided into five subgroups based on age which included the following (11-20, 21-30, 31-40, 41-50 and 51-60). This was done to assess the relationship between the presence of an additional mesiobuccal root canal (MB2) and patient age.

3.3. Data collection tools

The CBCT system used in this study was run by Sirona Galileos imaging software; all images were obtained using the following parameters as per department protocol: an adult protocol with an exposure at a voltage of 85 KV, an exposure time of 14 seconds with a frequency of 50-60Hz at 5.0 mA. The angle of the cone beam was set at 24 degrees for all exposures.

Axial, coronal, and sagittal three-dimensional section images were displayed on a monitor and inspected by two dentists for their accuracy and candidacy for endodontic purposes. The number and morphology of roots per tooth, the relationship between MB2, tooth position and different age groups, and the number and configurations of canals per root were captured and classified according to the Vertucci's classification. Furthermore, the frequency of C-shaped canals was analyzed and tabulated.

3.4. Statistical analysis

Ratings were first recorded onto data capturing sheets and then captured into IBM SPSS for Windows. Kappa statistic was used to assess inter-rater reliability and intra-rater reliability. Data represented as Frequency (n) and percentage (%) when appropriate. The Chi square test was used to compare between different tooth positions. A comparison between the different test groups passed on patient's age using the Kruskal Wallis test.

3.5 Inclusion criteria

1. Patients between the ages of 11 to 60 years old, because the apices of maxillary first molars are usually complete at age 11 and due to age related changes of the root canal system potentially obliterating additional smaller canals, a maximum age of 60 will be included.
2. Bilateral first maxillary molars.
3. Fully matured and erupted bilateral maxillary first molars.
4. CBCT images with good quality.

3.6 Exclusion criteria

1. Image deformity.
2. Primary teeth.
3. Incomplete root formation.
4. Root canals with open apices, resorption, or calcifications.
5. Molars that have been previously endodontically treated, or that present with posts.

CHAPTER 4

RESULTS

In order to assess inter-rater reliability two dentists independently examined 30 randomly selected CBCT images. Axial, coronal and sagittal three-dimensional section images were displayed on a monitor Phillips 196VL (18.5 inch monitor, 1366 x 768 screen resolution, 60Hz refresh rate) and inspected by two dentists. Disagreement was recorded in two of the images for canal configuration (table 1). However, after deliberation, agreement was reached. The near perfect overall agreement reported is evidence of high levels of inter-rater reliability. For intra-rater reliability 30 randomly selected CBCT records had been scored and rescored by the same examiner on assessment of all study objectives, Kappa statistics was applied and 100% agreement was obtained (table 2).

Table 1. Inter-rater reliability

Parameter	Agreement following examination	% agreement
Number of roots and their morphology	30/30	100.0%
Number of canals per root	30/30	100.0%
Canal configuration in each root	28/30	93.3%
Frequency of C shaped canals	30/30	100.0%

Table 2. Intra-rater reliability

Parameter	% agreement
Number of roots and their morphology	100%
Number of canals per root	100%
Canal configuration in each root	100%
Frequency of C shaped canals	100%

Six hundred and forty CBCT images of patients aged between 11 and 60 years were obtained from the clinic records during the time period selected. After application of inclusion and exclusion criteria two hundred images with bilateral maxillary permanent first molars were included in the study. The mean age of the patients was 28.2 (SD 11, 2) years.

4.1 Number of tooth roots and their morphology

The number of roots most commonly observed in both right and left maxillary molars were three separate roots, 90.5% on the right side and 91.5% on the left side. The incidence of three roots where two of them were fused was similar on right and left sides (8.5% and 7.5% respectively) (Table 3) .Two teeth displayed two fused roots whilst two other teeth had three fused roots. No single or four-rooted maxillary first molars were detected. Examples of different root and canal morphologies of maxillary first molars are shown in Figure 3.

Table 3. Number of roots and root morphology in permanent maxillary first molars

	Right side		Left side	
	<u>Frequency</u> (n)	<u>Percent</u> (%)	<u>Frequency</u> (n)	<u>Percent</u> (%)
Three separate roots	181	90.5	183	91.5
MBR fused with DBR	3	1.5	2	1
MBR fused with PR	4	2	3	1.5
DBR fused with PR	10	5	10	5
Three fused roots	1	0.5	1	0.5
Two fused roots	1	0.5	1	0.5

MBR= Mesiobuccal root, DBR= Distobuccal root, PR= Palatal root

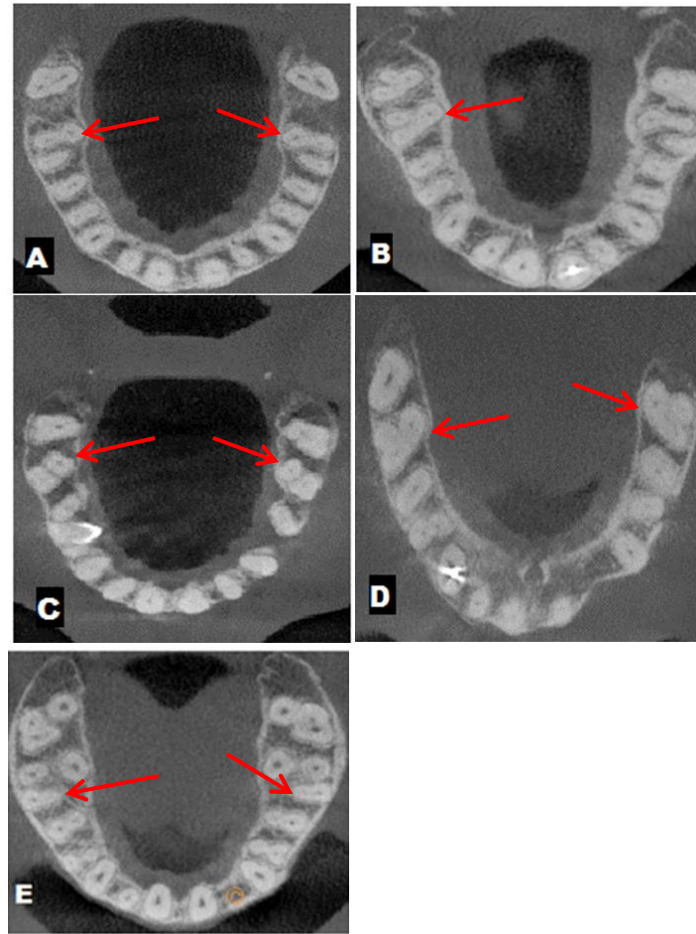


Figure 3: Images of maxillary first molar with root and canal variations in the axial section; the arrows indicate the examined teeth. (A) Bilateral permanent maxillary first molars with fused palatal and distobuccal roots. (B) Right permanent maxillary first molars with fused palatal and mesiobuccal roots. (C) Bilateral permanent maxillary first molars with two roots. (D) Bilateral permanent maxillary first molars with three fused roots. (E) Bilateral maxillary first molar with additional mesiobuccal canals (MB2).

4.2 Frequency of MB2 of permanent maxillary first molars according to age, and tooth position (left and right)

The total percentage of MB2 canals in permanent maxillary first molar was 60.5% (242 of 400).

Table 4 displays the distribution of unilateral and bilateral occurrence of the additional mesiobuccal canal (MB2). All patients (in the sample size of 200) exhibited bilateral permanent maxillary first molars. The occurrence of bilateral MB2 was 65.75% which was much higher than unilateral occurrence of 34.24%. The prevalence distribution of MB2 by 5 age groups (11-20, 21-30, 31-40, 41-50 and 51-60) and by tooth position is displayed in Table 5. The differences between the age groups were not statistically significant ($p=0.759$). Also an insignificant difference existed for differing tooth position ($p=0.9977$).

Table 4. Unilateral and bilateral occurrence of additional mesiobuccal canal (MB2) in CBCT scans at the Wits Oral Health Centre

MB root with additional canal (MB2)			MB with single canal	
Unilateral		Bilateral		
Right	Left			
No. of Patients (%)	No. of Patients (%)	No. of Patients (%)	No. of Patients (%)	Total
27(13.5)	23 (11.5)	96 (48)	54 (27)	200

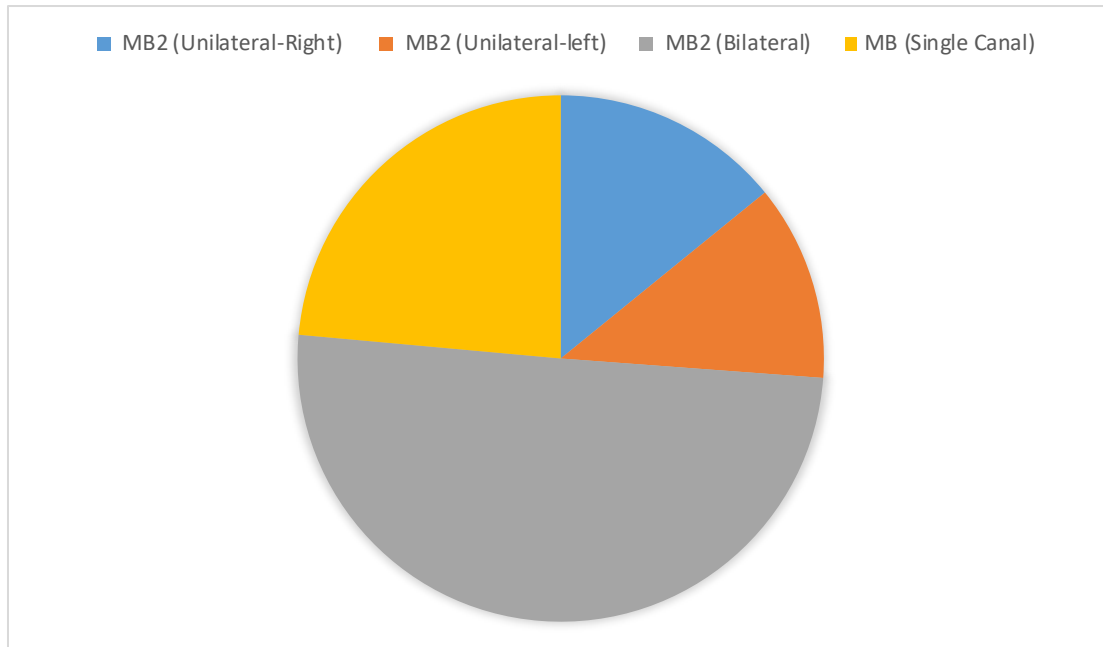


Figure 4: Pie chart showing the distribution of MB canal for the tested population

Table 5. Number and prevalence of MB2 in maxillary first molar by age and tooth position

	Tooth position		Age (Y)				
	Right	Left	11-20	21-30	31-40	41-50	51-60
Total number of teeth	N= 200	N= 200	N= 102	N= 162	N= 82	N= 24	N= 30
Number of teeth with MB2	123	119	63	98	49	14	18
Percentage (%)	61.5	59.5	61.7	60.4	59.7	58.3	60

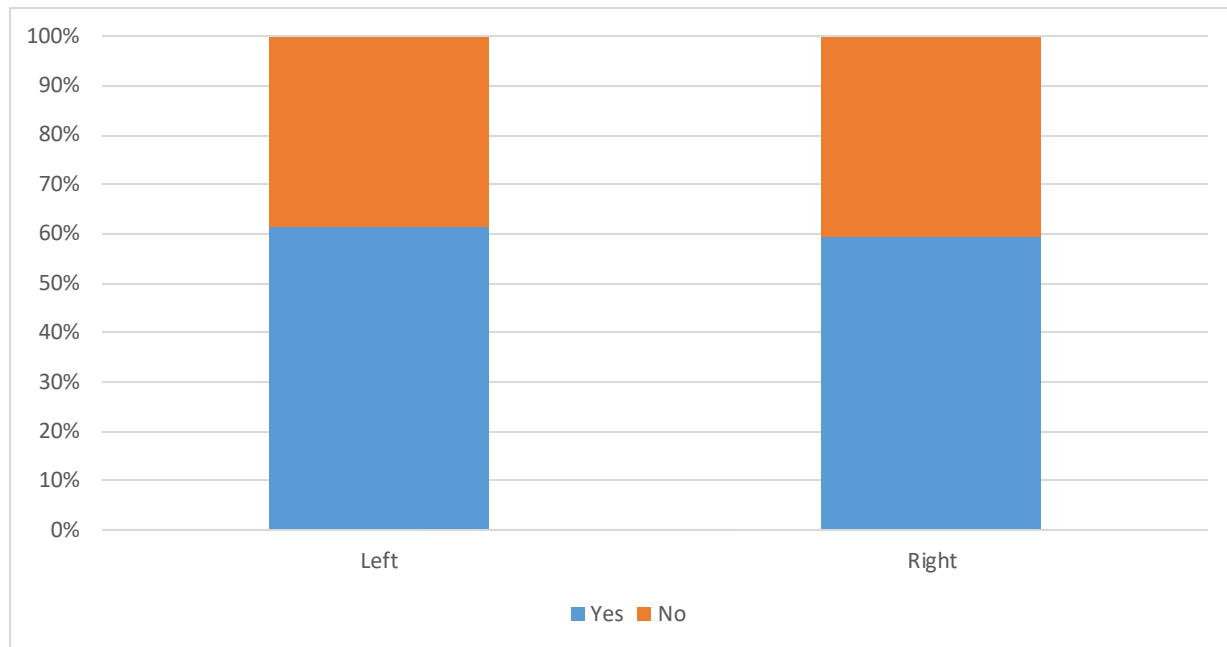


Figure 5: Histogram showing the percentage of MB2 distribution according to tooth position

4.3 Number and configuration of root canals of permanent maxillary first molars according to Vertucci's classification

The types and percentage of root canal configurations in permanent maxillary first molars are indicated in table 6. Distobuccal roots displayed a type I configuration in 99.5% of teeth, with only 0.5% of teeth displaying a type IV canal configuration. All palatal roots (irrespective of position) had a type I canal configuration. In the mesiobuccal roots, type IV canal configuration was the most prevalent, followed by type I configuration and then Type II. Very few teeth had type III type V or type VI configurations.

Table 6: Distribution and percentage of root canal configurations of permanent maxillary first molar according to Vertucci 1984

	Mesiobuccal roots (MBR)	Distobuccal roots (DBR)	Palatal roots (PR)
Type I	(158) 39.5%	(398) 99.5%	(400) 100%
Type II	(60) 15%	0	0
Type III	(5) 1.25%	0	0
Type IV	(171) 42.75%	(2) 0.5%	0
Type V	(3) 0.75%	0	0
Type VI	(3) 0.75%	0	0
Total	(400)100%	(400)100%	(400)100%

4.4 Frequency of C shaped canal

Regarding the presence of C shaped root canals- no C shaped canals were observed in any of the permanent examined maxillary first molar teeth.

CHAPTER 5

DISCUSSION

A sound knowledge of root and canal morphology enables the clinician to adequately assess the anatomy of a tooth during endodontic treatment. Due to the complexity of maxillary first molar morphology, many studies have been performed to evaluate root and canal morphology of this tooth, to facilitate and simplify the endodontic treatment (Alavi et al., 2002; Guo et al., 2014). However, most of the techniques that have been used in these studies are limited in they cannot be used in the clinical setting. The recent use of CBCT has provided noninvasive 3D visualization of external and internal dental anatomy. This retrospective study, which used CBCT scans, provides comprehensive information on the root and canal configurations of permanent maxillary first molars in a South African sample.

In this study, the fusion of roots was found in 36 of 400 (9%) of the maxillary first molars which is in agreement with a study on an Irish population where the authors used a clearing technique on 83 of extracted maxillary first molar teeth, and they found that an 11% of maxillary first molars had fused roots (Al Shalabi et al., 2000). However, in the Irish study the highest occurrence of fusion was between the mesiobuccal and distobuccal roots (5 of 83 or 6%), while in this study the fusion between distobuccal and palatal roots was more frequent (20 of 400 or 5%). Other studies conducted on Chinese and Korean populations (Zheng et al., 2010; Kim et al., 2012) revealed a lower occurrence of root fusion of 2.71% and 0.73% respectively. In this study, the roots were categorized as being fused when they were joined for the entire length of the root. It should be noted that the criteria for fusion might be different from other studies where lesser degree of root fusion was reported. These differences highlight the need to standardize criteria

when assessing root anomalies such as fusion. Furthermore, fused roots pose a challenge for clinicians as they negate the possibility of root resection- which is an option available to extend the function of a molar tooth when there is a persistent endodontic failure (Langer et al, 1981).

In two studies conducted by Ng et al. (2001) on a Burmese population and Alavi et al. (2002) on a Thai population, all maxillary first molars had three roots. However, Al Shalabi et al. (2000) reported that 97.6% of maxillary first molars in the Irish population had three roots and 2.4% had two roots, whilst in an Indian population 96.8% of maxillary first molars had three roots and 1.3% had two roots (Neelakantan et al., 2010) . In the present study, 99.5% of maxillary first molars had three roots whilst only 0.5% had two roots. These findings were similar to those in previous studies. Table 7 compares the differing root numbers of maxillary first molar teeth between this study and previous studies.

The risk of variability in the number of roots present for any maxillary molar requiring root canal treatment necessitates preoperative radiographs. Specific attention to the unusual number and configuration of canals must be given since unusual anatomy would increase the risk of endodontic treatment failure.

In the present study, the prevalence of the second mesiobuccal canal (MB2) was 60.5%. It is the most common variation in the first maxillary molars. This result is in accordance with previous studies that used in Vivo CBCT as an examining tool which were undertaken in populations from Turkey 62% (Altunsoy et al., 2015) using a sample size of 1158, Korea 63.59% (Kim et al., 2012) with a sample size of 814, and North America 68.2% (Guo et al., 2014) where 317 cases

with bilateral maxillary permanent first molars were involved in the study. The high occurrence rate of MB2 suggests that clinicians should pay attention to their presence.

Similar studies using CBCT conducted in India and China had lower rates of MB2 prevalence of 48.27% and 52% respectively.

In this study, the mesiobuccal root expressed a higher frequency of type IV canal configuration (42.75 %), followed by type I configuration (39.5%) and type II configuration (15%). These results are largely in agreement with a study conducted in North America in a sample of 634 maxillary first molar teeth using CBCT as method of examination. In that study 41.9% presented with a type IV configuration, 28.3% with type I canal configuration, and 26.3% with a type II configuration (Guo et al., 2014). Similarly, a Korean CBCT study with a sample size of 814 maxillary first molars described a frequency of 40.65%, 36.41% and 20.45% for the MB2 root canal configuration IV, I and II respectively. However, studies undertaken in India, by Neelakantan et al. (2010), and in Iran by Rouhani et al. (2014) found that type I configuration was more common, in the mesiobuccal root of maxillary first molars. From a clinical perspective, data on the presence of MB2 is of paramount importance because the long term endodontic success of maxillary first molar entails detection, debridement, and filling of the MB2 canal. Failure in doing so results in endodontic failure (Hartwell et al., 2007; Vertucci, 2005; Wolcott et al., 2005). The complex root canal anatomy was suggested as the probable cause for endodontic therapy failure of maxillary molars. For this reason, in addition with other factors, the highest rate of endodontic failure was observed in maxillary molar teeth. (Wolcott et al., 2005; Vertucci et al., 2005).

Table 7: Number of roots found in maxillary first molars in comparison with previous published studies

Reference	Country	Nature of study	No of teeth	Teeth studied	1 root (%)	2 roots (%)	3 roots (%)	4 roots (%)	5 roots (%)
Thomas et al (1993)	Australia	Radiographic analysis with infusion of radiopaque gel.	216	Maxillary First molar	0	5.6%	94.4%	0	0
Al Shalabi et al (2000)	Ireland	Staining and clearing	83	Maxillary First molar	0	2.4%	97.6%	0	0
Ng et al (2001)	Burma	Staining and clearing	90	Maxillary First molar	0	0	100%	0	0
Alavi et al (2002)	Taiwan	Staining and clearing	52	Maxillary First molar	0	0	100%	0	0
Neelakantan et al (2010)	India	CBCT	220	Maxillary First molar	0.9%	1.3%	96.8%	0	0
Faramarzi et al,2015	Iran	CBCT	156	Maxillary First molar	0	0	100%	0	0
Present study	South Africa	CBCT	400	Maxillary First molar	0	0.5%	99.5%	0	0

In the present study: type III, V and VI Vertucci canal configurations were observed in the mesiobuccal root at a frequency of 1.25%; 0.75 % and 0.75% respectively. These results are similar to those conducted in Korea where the prevalence of type III, IV and VI was 0.25%, 2%, and 0.12% respectively (Kim et al, 2012). It is also comparable to a study in North America whereby the prevalence of these configurations in the mesiobuccal root was 1.1%, 2.4% and 0% respectively (Guo et al., 2014). Type VII and VIII canal configurations were not observed in any of the mesiobuccal, distobuccal and palatal roots. This is consistent with studies conducted in Turkish and Indian populations (Altunsoy et al, 2015; Neelakantan et al, 2010). However, a study conducted by Sert and Bayirli (2004) using clearing technique reported a prevalence of type VII and Type VIII canal configurations of the maxillary first molars of 1.82% and 0% respectively in a Turkish population (Sert and Bayirli, 2004). Table 8 outlines the distribution and percentage of root canal configuration of maxillary first molars in several studies.

In this study, there was no substantial statistical difference in the occurrence of MB2 between the different age groups, which differs from other studies (Neaverth et al., 1987; Zheng et al., 2010). Neaverth et al. (1987) examined 228 maxillary permanent first molars at the time of endodontic treatment where the prevalence of MB2 was 77.2%% with a higher frequency of MB2 in the patient group aged 20 – 40 years. In a Chinese population Zheng et al. (2010) reported that the occurrence of the additional mesiobuccal canal (MB2) was significantly higher in the age group of 20 – 30 years. However, another study conducted in a North American population revealed that the highest occurrence of MB2 was among patients over 60 years old (Guo et al, 2014). In light of these findings, the clinician needs to consider the presence of the MB2 canal in all age groups. Furthermore, the results of this study revealed that tooth position, either on the right or

left quadrant of the maxillary jaw, is not a determinant for the number of mesiobuccal root canals, which is in agreement with the Chinese and North American studies (Zheng et al., 2010; Guo et al., 2014).

Bilateral occurrence of MB2 canals were observed in 67.2% of permanent maxillary first molars, which is in accordance with a North American study with a percentage of 65.6% (Guo et al, 2014) and a Korean study of 82.9 % (Kim et al, 2012). This high prevalence rate indicate that the possibility of the presence of additional canal in the molar of opposite side should be considered if patient has been known to have the MB2 in one maxillary first molar.

Table 8. Percentages of root canal configuration found in MB, DB and P roots of maxillary first molars in several studies

Reference	Country	Nature of study	No of teeth	Roots	Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII	Type VIII	Additional types
Pinda and Kutler, 1972	Mexico	In vitro radiographic	262	MB	39.3	12.2	0	23.7	12.8	12	0	0	0
				DB	96.4	0	0	3.6	0	0	0	0	0
				P	100	0	0	0	0	0	0	0	0
Vertucci, 1984	USA	In vitro clearing	100	MB	45	37	0	0	0	0	0	0	0
				DB	100	0	0	0	0	0	0	0	0
				P	100	0	0	0	0	0	0	0	0
Al Shalabi et al (2000)	Ireland	Staining and clearing	83	MB	19.5	15.8	0	36.6	6.09	17	2.4	1.2	0
				DB	97.5	0	0	0	2.46	0	0	0	0
				P	98.7	0	0	0	1.21	0	0	0	0
Alavi et al (2002)	Taiwan	Staining and clearing	52	MB	32.7	17.3	1.9	44.2	1.9	0	0	0	1.9
				DB	98.1	1.9	0	0	0	0	0	0	0
				P	100	0	0	0	0	0	0	0	0
Ng et al (2001)	Burma	Staining and clearing	90	MB	30	25.6	1.1	33.3	6.7	0	0	0	3.3
				DB	94.5	2.2	1.1	1.1	0	0	0	0	1.1
				P	100	0	0	0	0	0	0	0	0
Weng et al, 2009	China	Modified Root Canal Staining	45	MB	66.7	8.9	8.9	8.9	6.6	0	0	0	0
				DB	88.9	6.7	0	0	4.4	0	0	0	0
				P	97.8	0	2.2	0	0	0	0	0	0

Neelekantan et al, 2010	India	CBCT	191	MB DB P	51.5 90.4 88.1	5.5 2.7 1.8	0 1.8 0	38.6 1.8 4	0 0 1.4	0 0 0	0 0 0	0 0 0	0 0 0
Kim et al, 2012	Korea	CBCT	755	MB DB P	36.4 98.8 100	20.5 0.37 0	0.25 0.12 0	40 0.37 0	2 0.37 0	0.12 0 0	0 0 0	0 0 0	0 0 0
Faramarzi et al, 2015	Iran	CBCT	156	MB DB P	0 100 100	71.3 0 0	0 0 0	28.7 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Altunsoy et al, 2015	Turky	CBCT	1157	MB DB P	38.5 99 99.8	13 0 0	0.1 0 0.1	49 0.6 0.1	0.3 0 0	0 0 0	0 0 0	0 0 0	0 0 0
Present study	South Africa	CBCT	400	MB DB P	27 99.5 100	27.5 0 0	1.25 0 0	42.75 0.5 0	0.75 0 0	0.75 0 0	0 0 0	0 0 0	0 0 0

In this study, additional canals were detected in 0.5% of distobuccal roots of maxillary permanent first molars. This result is similar to those stated by Altunsoy et al. (2015), Zheng et al. (2010) and Kim et al. (2012) who found the occurrence of additional canal in the distobuccal roots of permanent maxillary first molars to range between 0.4% and 1.23%. However, some studies found 100% of distobuccal roots of maxillary first molars had a type I Vertucci root canal configuration which were conducted in Thai, Kuwaitis, and Iranian populations (Alavi et al., 2002; Pattanshetti et al., 2008; Faramarzi et al., 2015 respectively).

With regard to previous outcomes, distobuccal roots may present unusual number and morphology of canals that necessitates consideration of these possible variations during root canal therapy.

Many studies, including the North American one by Guo et al. (2014), the Korean study by Kim et al. (2012), and the study done in the Burmese populations by Ng et al. (2001) reported 100% occurrence of type I Vertucci root canal configuration in the palatal root of permanent maxillary first molars. Our result is thus consistent with the aforementioned studies. However, other studies carried out in India by Neelakantan et al. (2010) and in China by Weng et al. (2009) reported 88.1% and 97.8% of maxillary first molar had a type I Vertucci root canal configuration.

None of the maxillary first molars in this study showed C shaped root canals, which is consistent with an earlier study aimed at detecting maxillary first molars with this configuration (Neelakantan et al., 2010; Kim et al., 2012). However, Jo et al. (2016) reported C-shaped root canals in 0.8% of the permanent maxillary first molars in his study in a Korean population. Another study conducted by De Moor (2002) exhibited the presence of C shaped root canal of maxillary first molar in 2 out of 2175 roots in Ghent University (Belgium).

Whilst C-shaped root canals are most commonly seen in the mandibular second molars, they could possibly present in maxillary first molars. The importance of understanding the root canal morphology of a tooth prior to endodontic therapy cannot be over emphasized. The results obtained from this study further support this notion that clinicians must pay attention to the variations that may occur in maxillary first molars.

5.1 Limitations

This study used a limited number of CBCT images, and for this reason cannot be generalized as an evaluation of the general South African population. Unfortunately, the unavailability of gender distribution in our data base negated any kind of the contribution of gender to the root canal morphology.

CHAPTER 6

CONCLUSIONS

AND RECOMMENDATIONS

In a sample of the South African population, the most common root morphology in maxillary first molar was three separate roots. Only 9% of maxillary first molar showed fused roots.

The incidence of additional canals in mesiobuccal roots (MB2) was 60.5%, with no significant statistical difference between age groups and tooth position. In the case of the mesiobuccal root having the MB2 canal, a Vertucci type IV canal pattern was the most frequent, followed by type I. The bilateral occurrence of the MB2 was 67.2%.

Among 400 maxillary first molars examined, a type I Vertucci canal configuration was found in most of the distobuccal roots and in all palatal roots.

This study provides valuable information in the field of endodontics, as prior knowledge of anatomic variations leads to more favourable root canal treatment outcomes. Further study is required to assess the impact of gender as well as to compare the maxillary first and second molar anatomy. A study with a larger sample size is also recommended so that results can be inferred to the general South African population.

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Appendix A



R14/49 Abdelmenem Ali Irhaim

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M150476

NAME: Abdelmenem Ali Irhaim
(Principal Investigator)

DEPARTMENT: School of Oral Health Sciences
University of Witwatersrand Oral Health Centre
Department of Oral Rehabilitation

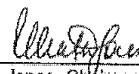
PROJECT TITLE: Evaluation of Root and Canal Morphology of
Permanent Maxillary First and Second Molars
Using Cone Beam Computed Tomography in a
Sample of Patients Treated at Wits Oral Health Centre
(Title Changed 20/05/2015)

DATE CONSIDERED: 24/04/2015

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr S Tootla and Dr E Patel

APPROVED BY: 
Professor P Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 18/05/2015

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and ONE COPY returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. I agree to submit a yearly progress report.


Principal Investigator Signature

Date 16/11/2016

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix B



Private Bag 3 Wits, 2050
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Reference: Ms Thokozile Nhlapo
E-mail: thokozile.nhlapo@wits.ac.za

23 June 2015
Person No: 923342
PAG

Dr A Irhaim
Alkhoms
Libya
0000
Libyan Arab Jamahiriya

Dear Dr Irhaim

Master of Science in Dentistry: Approval of Title

We have pleasure in advising that your proposal entitled *Evaluation of root and canal morphology of permanent maxillary first molars using cone-beam computed tomography in a sample of patients treated at the Wits Oral Health Centre* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely



Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences