‘Prevalence and location of the Secondary Mesiobuccal canal in the maxillary first and second permanent molars using CBCT; in a sample of the Libyan population’

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A mini-thesis submitted in partial fulfilment of the requirements for the degree Magister Scientiae in the Department of Diagnostics and Radiology, Faculty of Dentistry, University of the Western Cape.

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ABSTRACT

Background: Previously, many studies have used cone beam computed tomography (CBCT) to detect and confirm the exact location of the MB2 canal in maxillary molars. It is now considered the gold standard, as it allows clinicians to visualize complex anatomical structures and to perform endodontic treatment safely. However, in the context of this study, the prevalence and location of the MB2 in maxillary first and second permanent molars among the Libyan population is limited. The aim of this *in vivo* study is to describe the prevalence and location of the MB2 in the mesiobuccal root of first and second maxillary molars and to describe a methodology to enable its geometric location in the Libyan population using CBCT imaging.

Material and methods: This study evaluated CBCT images of two hundred sets of a selected Libyan population which were sourced to obtain 378 teeth for analysis. A total of 88 patients' images were examined, of which 175 teeth (90 1MM and 85 2MM) were selected according to the inclusion criteria and established dates. The slice thicknesses were adjusted to 0.5mm to standardize all reconstructions. To detect the location of MB2, the observation and measurements were performed by dividing the roots into equal thirds, and each third was checked for the presence of the MB2 canal (1 mm, 3 mm, and 5 mm) apically to the floor of the pulp chamber. The geometric locations of the MB2 canal were detected in relation to the MB1 and P canals by locating the central points of each canal (MB1 and P) and drawing a line connecting the two points (PMB1 and PP). The association between the MB2 canal, gender and side were determined and evaluated using Pearson's chi-square test. Statistical significance was established at $p < 0.05$.

Results: The MB2 was identified in 48% of the Libyan population, and the distribution of the 1MM was (46.97%). Regarding the distance between points PMB1-PP, the average distance was 8.56 ± 7.8 mm, for PMB1-PMB2 the average distance was 2.4 ± 2.05 mm, and for PMB2-PT the average distance was 1.5 ± 1.2 mm. In the case of the 2MM the prevalence of the MB2 was distributed as (39.4%) and the average distance between points PMB1-PP was 7.8 ± 6.8 mm, while for PMB1-PMB2, the average distance was 2.5 ± 2.00 mm, and for PMB2 and the line projected between the PMB1 and PP canals, the measurement was 1.4 ± 1.0 mm. Concerning the

prevalence of the MB2 according to genders, there was no significant difference between genders in both first and second maxillary molars.

Conclusion: The main goal of the current study was to determine the prevalence and location of the MB2 in the selected sample of the Libyan population. The results of this investigation showed that in 48% the MB2 was present. Furthermore, it has been indicated that CBCT is an accurate and effective diagnostic tool not only for detecting the presence of the MB2, but also to determine the location of the canal *in vivo* in the mesiobuccal root of maxillary molars.

DECLARATION

I, Dr Hoda I Aburgeba declare that this topic titled "Prevalence and location of the Secondary Mesiobuccal canal in the maxillary first and second permanent molars using CBCT; in a sample of Libyan population" is my own work, that this has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Hoda Aburgeba

11 November 2021

QUOTATIONS

"No two things have been combined better than knowledge and patience, A kind word is a form of charity. Also be kind, for whenever kindness becomes part of something, it beautifies it. Whenever it is taken from something, it leaves it tarnished, and the best among you is the one who doesn't harm others with his tongue and hands."

"The Prophet Muhammad" (peace be upon him)

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DEDICATION

This thesis is dedicated to my late father for his total support for me to achieve this dream…..May Allah grant him Jana.

I would like to extend my appreciation to my supportive friend my Husband, Dr Andisha for his constant support, understanding and love. To my wonderful children Maria, Ahmed and Yassen, thank you for being my sources of laughter.

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LIST OF ABBREVIATIONS AND ACRONYMS

	Description
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
1MM	First maxillary molar
2MM	Second maxillary molar
MB	Mesiobuccal root
MB1	Mesiobuccal canal
MB2	Second mesiobuccal canal
PAN	Pantomograph
CBCT	Cone Beam Computer Tomography
CT	Computerized Tomography
MPR	Multi-Planar Reconstruction
SEM	Scanning Electron Microscope
DOM	Dental Operating Microscopy
FPD	Flat Panel Detector
FOV	Field of View
DICOMS	Digital Imaging and Communication in Medicine
P	Palatal canal
PMB1	Central point of the mesiobuccal canal
PMB2	Central point of the MB2 canal

PP	Central point of the palatal canal
PT	Point T (line projected between the PMB1 and PP)
RHS	Right Hand Side
LHS	Left Hand Side
CI	Confidence Interval
At	Apical Third
Mt	Middle Third
Ct	Coronal Third
ALARA	As Low As Reasonably Achievable

KEYWORDS

Second Mesiobuccal canal

Dentistry

Libyan

Cone-beam computed tomography

Radiology

Pantomograph

Maxillary first molar

Maxillary second molar

Location

Root and canal morphology

CHAPTER ONE: INTRODUCTION

Endodontics is the treatment of diseased pulp, root canals and different supporting structures with infections. In endodontics, several factors determine the success or failure of the treatment. One such factor is the variations of the root canal anatomy which has been identified to significantly contribute to the success and failure of endodontic therapy (Betancourt et al., 2017). Root canal morphology must be well understood for successful endodontic treatment, to ensure recognition and identification of canals in the root canal system (Al Shalabi et al., 2000). Furthermore, the mechanical debridement and chemical disinfection of the root canal system and its complete obturation with a specific filling material is of paramount importance in endodontic therapy (Abarca et al., 2015). One of the most common reasons for the failure of root canal treatment is the lack of recognition and treatment of the complete canal system (Karaman et al., 2011). It is therefore important that the clinician is equipped with knowledge of the root canal morphology to successfully complete endodontic treatment (Vertucci, F.J. (1984).

The morphological features of the root canal system involving teeth with more than one root are complex and inconsistent, and a few classifications have been proposed to differentiate between the anatomical variations regarding the shape and number of roots and their canals (Weine et al., (1969); Vertucci, F.J. (1984). It is important to note that the mesiobuccal root has the most variation and therefore the clinician has to be cognizant of the prevalence of extra canals, especially canals located in the mesiobuccal root (Al Shalabi et al., 2000).

The secondary mesiobuccal (MB2) canal is located in the mesiobuccal (MB) root of maxillary molar teeth and is seldomly detected. However, the lack of appropriate detection often prevents proper endodontic treatment during instrumentation, irrigation and obturation (Betancourt et al., 2016).

The application of Computerized Tomography (CT) in endodontics was first reported by Tachibana H and Matsumoto K., (1990). Cone Beam Computed Tomography (CBCT) which is a form of CT has recently been used for the detection of the MB2 canal in maxillary molars *in vivo* and *in vitro*. CBCT is an extra-oral imaging technique that creates 3-dimensional (3D) images of the maxillofacial regions. Compared to conventional radiographic techniques, it provides advanced diagnostic information and enhances the prediction of endodontic management. It also aids the visualization of the root canal anatomy of multi-rooted teeth for better diagnosis. Betancourt et al., (2017)

Consequently, it allows clinicians to visualize complex anatomical structures and to perform endodontic treatment safely. CBCT is one of the best techniques used for confirming and finding the exact location of the MB2 canal in maxillary molars and is now considered the gold standard for examining complex root canal morphology. This imaging modality facilitates planning as well as safe and effective treatment by visualizing and locating any extra canals and complex morphology (Zhang et al., (2011); Betancourt et al., (2016); Studebaker et al., (2017).

The aim of this study was to evaluate the prevalence and location of the MB2 in the maxillary first and second molars using CBCT.

CHAPTER TWO: LITERATURE REVIEW

Endodontic therapy:

In endodontic treatment, the primary goal involves the removal of root canal contents and the elimination of potential and existing infections that could be present. In most cases, the errors associated with endodontic failure are procedural. These procedural failures include inadequate instrumentation, perforations, ledges, inappropriate filling (overfilling or underfilling), and missing canals in the root canal system. Vertucci, F.J. (1984) The above-mentioned errors have been categorized as direct causes of endodontic treatment failure. However, the main factor associated with failed endodontic treatment was the presence of microbial infection in the root canal system or periradicular region. It has been established that procedural errors rarely affect the outcome of endodontic treatment unless superimposed with infection. Siqueira, J.F. (2001).

Knowledge of the presence of an additional canal in the root canal system is important, especially to obtain detailed information of the morphology of the root canals and thus determine the appropriate treatment mechanism Magat, G and Hakbilen, S, (2019). Amongst multi-rooted teeth, the maxillary first and second molars have the greatest variation in terms of the number of roots and number of canals, with indistinct shapes and formations. Likewise, the MB root system has the highest variation and the presence of extra canals in their root system. Al Shalabi et al., (2000).

Root canal morphology:

Overview

In the anatomy of the root canal system, the pulp cavity is housed within the space in the dentine of the tooth as shown in Fig.1. Vertucci, F.J. (2005). The pulp cavity has two distinct features, namely, the pulp chamber and pulp root canal. The pulp chamber and pulp root canal are located in the anatomic crown of the tooth and the anatomic root respectively. As seen in Figure

1, there are other identifiable features such as pulp horns, lateral accessory and furcation canals, canal orifices, intercanal connections, apical deltas and apical foramina Burch, J. and Hulen, S. (1972).

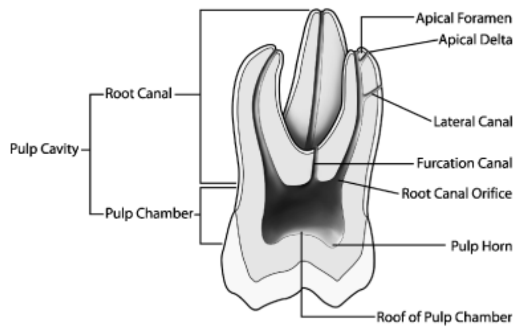


Figure 1: Major anatomic components of the root canal system

The root canal structure emerges as a funnel-shaped canal orifice. It is often present at or slightly apical to the cervical line. The characteristics of the root canal structure are such that it ends at the apical foramen and opens onto the root surface between 0 and 3mm from the centre of the root apex Gutierrez, J. and Aguayo, P. (1995). The hard tissue consists of the human dental pulp and takes on abundant configurations and shapes. It is important to have knowledge of tooth morphology and to visualize the internal anatomy relationship before undertaking endodontic treatment Vertucci, F.J. (2005).

Weine et al., (1969) were the first to categorize root canal configurations in any root into three basic types depending on the pattern of division of the main root canal along its course from the pulp chamber to the root apex. A further type was added later.

For instance, Type I has a single canal heading from the pulp chamber to the apex which implies a 1-1 configuration. As for Type II, the root canal consists of two separate canals which emerge from the chamber but merge at the canal terminus resulting in a single canal called 2-1 configuration. The third, type III, is known to exhibit two distinct canals from the pulp chamber to the canal terminus in a 2-2 configuration. An additional type has been added to the types of root canal system called Type IV. Type IV consists of a single canal that emerges from the chamber and divides into two separate canals at the canal terminus in a 1-2 configuration as shown in Figure. 2 Ahmed et al., (2017).

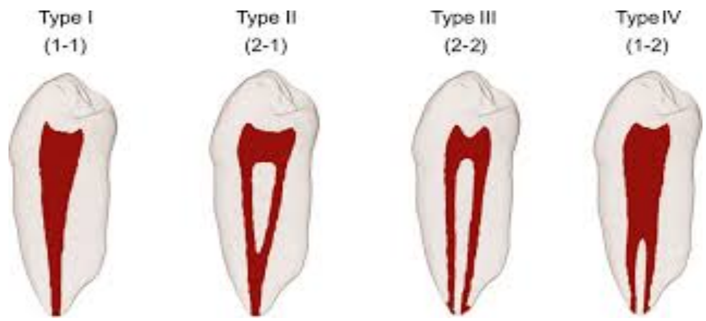


Figure 2: Diagrammatic representations of Weine's classification for root canal morphology Ahmed et al., (2017)

A follow-up with a more comprehensive classification protocol was performed with the use of Hematoxylin dye stain. Vertucci et al., (1974) The classification protocol was based on 200 cleared teeth in which the pulp cavities were stained. The results revealed that root canal systems were more complex than previously described by Weine et al., (1969) and co-workers, and presented an additional 8 configurations. The details of the root canal system are presented in Table 1 below:

Table 1: Types of root canal system classification by Vertucci (1974).

TYPE OF CANAL SYSTEM	DESCRIPTION
I	It has a single canal from the pulp chamber to the canal frontier which implies a 1-1 configuration.

II	This type exits the chamber via two separate canals. However, these two canals merge to form one single short canal at the end of the apex (2-1 configuration)
III	This is a single canal that divides into two and thence merges to exit as one (1-2-1 configuration)
IV	This type is characterised by two separate canals from the pulp chamber to the canal terminals (2-2 configuration)
V	It is a single canal leaving the chamber and dividing into two separate canals at the end of the canal apex (1-2 configuration)
VI	Type VI has two separate canals leaving the pulp chamber. Also, they merge in the body of the root and divide into two distinct canals short of the canal terminus (2-1-2 configuration)
VII	In this type of canal system, a single canal that divides merges and exits into two distinct canals short of the canal terminus (1-2-1-2 configuration)
VIII	Type VIII has three distinct canals from the pulp chamber to the canal terminus (3-3 configuration)

Source: Ahmed et al. (2017)

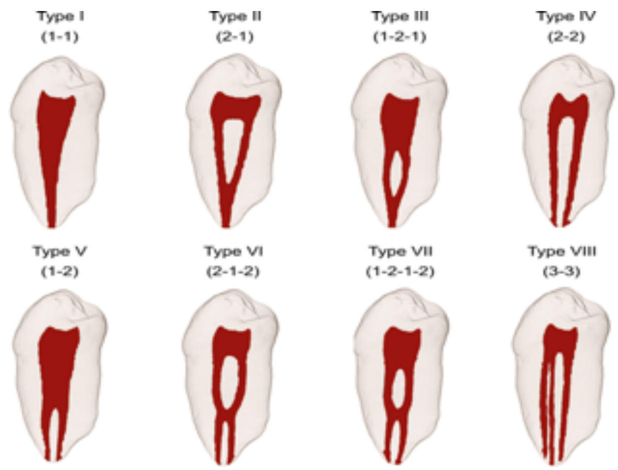


Figure 3: Diagrammatic representations of Vertucci's classification for root canal Morphology. Ahmed et al., (2017).

In terms of canal system classification, the Weine et al., (1969) and Vertucci et al., (1974) classification protocols have been the most commonly used to date. However, these two types of classification protocols have exhibited certain limitations for some canal configurations by not being able to account for maxillary first and second molars Ahmed et al. (2017). The emergence of an updated classification protocol for root canal morphology providing a simple, accurate and practical system has been presented by Ahmed et al., (2017). The concept of the new classification protocol is to ensure that students, dental practitioners and researchers can classify root canal configurations. The benefit of the new classification is that it provides detailed information on the tooth number, the number of roots and root canal configuration types. This new classification excludes developmental anomalies and minor canal anatomy.

Concerning root canal morphology, it was found that type II and IV of Vertucci's method were the most prevalent when the MB2 canal was detected in the Chilean population. Abarca et al., (2015) These results are compatible with the results of the study carried out by Zhang et al., (2011) who reported that after detecting the presence of the MB2 in the MB root of the 1MM, 14%, 69% and 16% of the MB roots had Type II, IV and V canal configurations, respectively, while in the 2MM 18%, 58%, 10% and 3% of the MB roots had type II, IV, V and VI canal configurations, respectively, in the Chinese sub-population. In the case of mesiobuccal roots of the 1MM, type IV accounted for 44.2% of the Thai population. Alavi et al., (2002). A study on an Egyptian population group reported that the highest percentage of canal configurations was in type I and type IV in both first and second maxillary molars. Salem et al., (2018). A recent study carried out in Iraq reported that the most common type was type II (44.58%), followed by type IV (31.30%), and Type I occurred in 18.32% of cases. The other types were less frequent. Al-Saedi et al., (2020). In the Iranian population, the most common type of Vertucci's classification was type II (53.1%), followed by type I. Khademi et al., (2017). Therefore, endodontists, dentists and students require extensive knowledge of root canal anatomy to prevent the possibility of untreated canals that lead to endodontic failure. Al-Saedi et al., (2020).

Secondary Mesiobuccal canal (MB2):

Characteristically, the maxillary molar has three roots; namely palatal, distobuccal and mesiobuccal. These roots can have as many as three mesial canals, two distal canals and two palatal canals. The mesiobuccal root of the maxillary first molar has generated more research and clinical investigation than any root in the mouth. It generally has two canals but a third canal has been reported. When there are two canals in the mesiobuccal root, they are called mesiobuccal canal (MB1) and second mesiobuccal canal (MB2), as shown in Fig. 4. Vertucci, F.J. (2005). The extensive range in the prevalence of MB2 (18% to 95%) has been attributed to ethnic and gender differences across various study populations. Abarca et al., (2015).

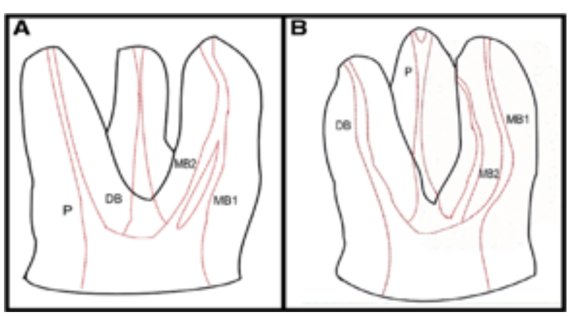


Figure 4: (A) Fusing mesiobuccal canals in mesiobuccal root of maxillary molar, (B) Two

separate mesiobuccal canals of maxillary molar. Betancourt et al., (2016).

The complexity and difficulty of root and canal anatomy vary as first reported by Hess & Zurcher et al., (1925) and extensive studies on the morphology of the root canal system in the MB2 have since been reported by Sert S and Bayirly GS, (2004) and Neelakantan et al., (2010). Similarly, various classifications for root canal morphology have been suggested by Weine et al., (1969) and Vertucci, F.J. (1984) of which the latter suggested that the inability to locate and obturate the MB2 may lead to endodontic failure. The classification of root canal morphology has not adequately enhanced the ease of location and treatment of the MB2 canal due to excessive dentine accumulation in the opening of the canal and difficulty in the visualisation of molar teeth. As a result, it may contribute to continued patient pain or root canal failure. Magat G and Hakbilen S, (2019).

Many obstacles in detecting the MB2 are due to a dentine ledge that covers its orifices. The mesiobuccal inclination of the MB2 orifices on the pulpal floor, as well as the pathway that often takes multiple and abrupt curves in the coronal part of the root impede detection of the MB2 (Fig. 5A). However, these impediments can be eliminated with the use of ultrasonic tips mesially and apically along the path of the mesiobuccal-palatal groove. This process is called troughing and countersinking (Fig. 5B). It is noteworthy to indicate that the process of troughing and countersinking causes the canal to shift mesially, necessitating moving the access wall further mesially. Also, the troughing procedure may have to extend 0.5–3 mm deep. The sensitivity of this procedure requires that care must be taken to avoid furcal wall perforation of this root as a concavity exists on its distal surface. Apical to the troughing level, the canal may be straight or curve sharply to the distobuccal, buccal or palatal plane. Vertucci, F.J. (2005).

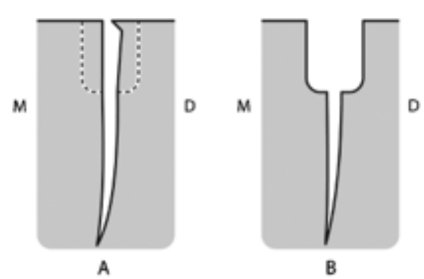


Figure 5: Diagrammatic representation of the orientation of MB2 orifice before (A) and after (B) troughing procedure.

The MB2 detection rates vary considerably with resultant failure mainly due to inadequate clinical identification procedures. Silva et al., (2014). In addition, during endodontic retreatment, the high incidence of locating canals as well as uneventful healing is reduced, hence suggestive that endodontic failure rates may correlate with the inability to detect additional canals at treatment onset. Fernandes et al., (2019).

Prevalence of MB2 in different population groups:

Maxillary molars have the highest number of roots and complex internal anatomy. Previous studies have reported that the maxillary second molar has the most complicated root canal morphology. Zhuk et al., (2020). Furthermore, the prevalence of undetected canal anatomy in the 1MM is between 41.3% and 46.5% and this represents the highest of all other treated teeth. Karabucak et al., (2016). The prevalence of the MB2 in 2MM *in vivo* studies has been reported between 19.7% and 51.1%. Al-Fouzan et al., (2013); Betancourt et al., (2015).

Generally, the high percentage of failure in MB2 treatment is related to the varied location and thus the difficulty in locating and instrumenting MB2 canals which are located in the mesiobuccal root. Other associated factors have been discussed such as age, race, gender and frequency of occurrence of the MB2 canal. However, these aforementioned factors have been reported to be insignificant. Zhuk et al., (2020). In recent years, many studies reported the prevalence of MB2 in the MB root of 1MM & 2MM (Table 2).

Table 2: Summary of literature review comparison of the prevalence of the MB2 Among different populations				
Author	**Years**	**Population**	**Prevalence of MB2 %**	
			1MM	**2MM**
Alavi et al.	2002	Thai	65	55
Smadi et al.	2007	Jordanian	77.32	-
Zheng et al.	2010	Chinese	52.2	-
Zhang et al.	2011	Chinese	52	22
Kim et al.	2012	Korean	63.6	34.4
Al-Fouzanet et al.	2013	Saudi Arabian	51.3	19.7
Silva et al.	2014	Brazilian	42.63	42.63
Betancourt et al.	2016	Chilean	69.82	46.91
(Khademi et al.	2017	Iranian	70.2	43.3
(Salem et al.	2018	Egyptian	65-76	40-59
Fernandes et al.	2019	South African	92-87	69-65
Al-Saedi et al.	2020	Iraqi	81.68	-

Singh S and Pawar M, (2015) focussed on ethnic differences and found a prevalence in the Indian population compared to the Brazilian, Mexican, Ugandan and Kuwaiti populations. The highest figures were reported for the European, Japanese and Thai populations. Therefore, identifying the root canal anatomy of different ethnic populations may be beneficial for successful endodontic treatment Alavi et al., (2002); Weng et al., (2009). This validates the high quantity of research activity on the prevalence of MB2 and its variation among different ethnic populations. It is thus necessary to investigate variations in tooth anatomy and their characteristic features in different racial groups. Zhang et al., (2011).

The distance and location of MB2:

Regarding the investigation of the location and an average distance between MB2 and other canals in the mesiobuccal root, studies have been conducted to explore the location with different techniques both *in vitro* and *in vivo*. These techniques included *ex vivo* sectioning, clearing, staining, magnification, SEM imaging, photomicrography, micro-CT, CBCT among others. Zhuk et al., (2020).

For instance, Gördüysus, M.Ö, et al., (2001) used Dental Operating Microscopy (DOM) to study the location and pathway of the MB2 canal in maxillary first and second molars. The location was observed to vary significantly and consistently located mesial to or directly on a line between the MB1 and the palatal orifices (Fig. 6), which was shown to be within 1.65mm palatally, and 0.69mm mesially from the MB1 orifices. However, not all the MB2 orifices result in a true canal because an 'apparent' MB2 canal was not easily traceable beyond the orifices in 16% of the teeth.

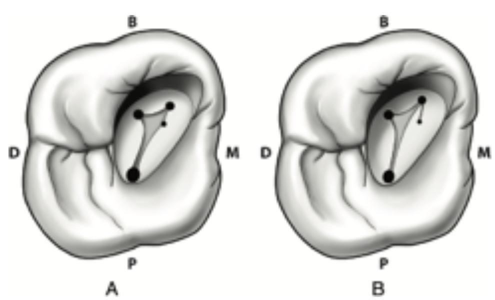


Figure 6: Diagrammatic representation of the position of MB2 canal orifice in maxillary molars.

Betancourt et al., (2015), reported the use of the CBCT technique to measure the MB2 canal location of 1MM. The study showed that the MB2 canal location was 2.2 ± 0.54 mm palatally and 0.98 ± 0.32 mesially to the MB1 canal. In a relative study, MB2 was 2.68 ± 0.49 mm palatally and 1.25 ± 0.34 mesially to the MB1 canal. 2MM was located 2.41 ± 0.64 mm palatally and 0.98 ± 0.33 mm mesially (Betancourt et al., 2016). The study by Görduysus et al., (2001) presented an MB-2 location of 1.65 ± 0.72 mm palatally and 0.69 ± 0.42 mesially to the MB1 canal in a combined study of first and second molars with a different technique, whereas distances reported by Kulid, J.C and Peters, D.D, (1990) showed that there were no statistically significant differences between 1MM and 2MM (1.82 ± 0.71mm). This could be demonstrated by the heightened sensitivity of *in vitro* studies or the use of microscopes with various magnifications that distort the images, whereas with CBCT the resolution of the resulting image is isotropic. A recent study by Zhuk et al., (2020) reported that the distance from MB1 to MB2 was 2.06 0.52 mm. However, one of the drawbacks of studying the MB2 canal morphology is that the variation in the geometric location of the MB2 canal in relation to the MB1 canal palatally or mesially can easily be compromised. This is mostly observed in *in vitro* studies because the anatomical proportion and relation on the arch is not easily accessible for all the axes and planes, which can be done with CBCT. Betancourt et al., (2016).

Different methods to detect MB2:

Many studies used various techniques to detect the MB2 canal in maxillary molars *in vivo* and *in vitro*. These techniques include *ex vivo* sectioning, staining, clearing, micro-computed tomographic scanning, photomicrographs, conventional radiography studies by Pineda F. and Kuttler Y., (1972) and retrospective studies by Gilles J. and Reader R., (1990); Verma P. and Love R., (2011).

In order to enhance the detection of additional canals, studies have suggested the use of techniques such as magnification, localization with burs or ultrasonics, enhanced illumination, the ‘‘Champagne Bubble’’ test, and fibreoptic lighting as tools. Shah et al., (2014); Iqbal M. and Kratchman S., (2004). However, these methods do not enjoy reliability in the detection of the MB2 canal in most cases. Studebaker et al., (2017). These techniques are *ex vivo* methods and synonymous with using extracted teeth and thus might yield unrepresentative samples due to the limited sample size and the inability to detect bilateral and adjacent tooth morphology. It has been reported that conventional intraoral periapical radiographs could evaluate root canal anatomy *in vivo*. However, these techniques are disadvantageous due to overlap, superimposition, or masking of the structures and ultimately result in difficulty in interpreting radiographic images. The existing anatomical structures may be radiolucent, such as the maxillary sinus; or radiopaque such as the zygomatic bone. Pineda F. and Kuttler Y., (1972). In some cases, there may be an anatomical superimposition effect based on several factors such as the degree of bone demineralization, the size of endodontic lesions and the nature of the anatomical structure (thickness, shape and density of the overlying anatomy). In addition, the use of periapical images could provide the clinician with only a 2D image of a 3D structure, whereas CBCT is more useful because this technique of imaging provides visualization of teeth in three dimensions. Limited studies have used this modality to detect the relative location of the MB2 orifice in comparison to the MB1 orifice. Zhuk et al., (2020).

Cone Beam Computed Tomography (CBCT):

Overview

CBCT was originally developed for angiography in the early '80s (Pauwels et al., 2015) and introduced in endodontics in 1990. Zheng et al., (2010). Recently, the inherent characteristics of CBCT have resulted in its preference and popularity in dentistry, especially and its clinical application for studying root canal anatomy before clinical endodontic treatment Zhang et al., (2011); Lee et al., (2011); Kottoor et al., (2010); Patel et al., (2010). The names associated with the imaging modality are attributed to the cone-shaped X-ray beam generated and projected onto a 2D flat panel detector (FPD) array. The arrangement of CBCT is in contrast with traditional CT because it produces a fan-shaped beam onto a 1D arc-shaped curvilinear detector array Boeddinghaus R. and Whyte A., (2018). The guidelines as set by SEDENTEXTCT of 2018 stipulate that: "Limited volume, high-resolution CBCT may be indicated for selected cases where conventional intraoral radiographs provide information on root canal anatomy, which is inadequate for planning treatment, most probably in multi-rooted teeth". Furthermore, for endodontics, if there is no new information, there is no guideline that says you have to do CBCT. CBCT is a cone-shaped or pyramidal X-ray beam and obtains images in 3D using a single revolution of the X-ray detector and source. Depending on the type of CBCT scanner it determines the source of the X-ray and the ability of the detector to rotate between 180˚ to 360˚ around the patient's head. In general, data from CBCT could be spherical or cylindrical volumes of data as described in the figure below (Fig. 7).

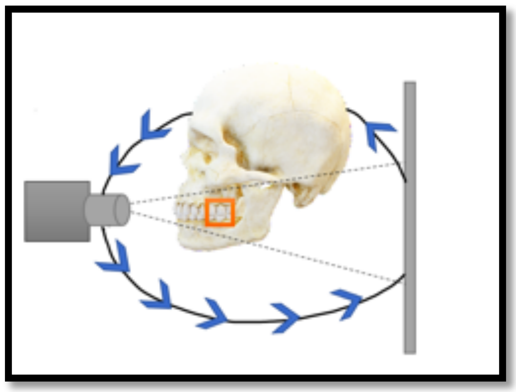


Figure 7: The X-ray source and detector rotate around the head of the patient once. This results in a cylindrical volume of data being captured. Sophisticated software reconstructs the data, which may then be demonstrated in the sagittal, axial and coronal planes.

With regards to volume; digital imaging is made up of pixels, whereas CBCT has a 3-dimensional version of pixels which represents a high spatial resolution because of reconstruction of data consisting of isotropic voxels. Kiljunen et al., (2015). The minimum dimension of voxels can be 0.15 mm × 0.15 mm × 0.15 mm and has a field of view (FOV) that is different among devices. For instance, there are four subcategories for FOV sizes. These include dentoalveolar (<8 cm), maxillomandibular (≤8 cm to 15 cm), skeletal (≤15 cm to 21 cm), and head and neck (> 21 cm). Venskutonis et al., (2014). Furthermore, the voxels are known to be isotropic which implies that the 3D is equal. Also, the CBCT images can be exhibited in 3 orthogonal planes namely, sagittal, axial and coronal as shown (Fig. 8). The orthogonal planes enhance the possibility of producing a 3D image by selecting and moving the indicator and simultaneously changing the other reconstructed slices. Patel et al., (2010).

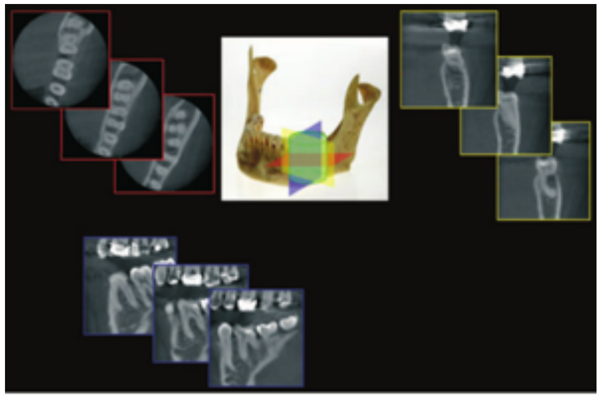


Figure 8: Cross-sectional images in three orthogonal views are generated from the CBCT scan (Patel, S., 2009).

CBCT imaging displays a relatively lower significant radiation dose in comparison to CT in the medical field. Roberts et al., (2009). In addition, the same author stated that an effective dose of CBCT was significantly higher compared to conventional radiography. Previously, it was suggested by certain studies that the CBCT dose could be almost as low as PAN radiography. Ngan et al., (2003); Lofthag-Hansen et al., (2008) In Table 3 below, the effective radiological dose of CBCT and conventional imaging techniques are presented.

Table 3: Comparison of effective doses of various imaging techniques. Patel et al., (2010)

Imaging technique	**Effective doses (micro Sieverts)**
(Panoramic) radiograph	13
(Cephalometric) radiograph	1-3
(Periapical) radiograph	1-8
(Occlusal) radiograph	8
CBCT (6 cm area of view of standard mandible)	75.3

CBCT (6 cm area of view of standard maxilla)	36.5
Conventional CT scan of head	2000

CBCT is invaluable for determining uncommon anatomical variations such as complex root numbers and anatomy, dens in dente (Dens invaginatus (DI) and dilacerated roots. Patel et al., (2010). For this reason, the precise morphology and location of root canals should be detected by using this method rather than conventional radiography which may offer insufficient information. Table 4 shows the distribution and percentages of different uses of CBCT.

Table 4: Percentage and distribution for the usage of CBCT images. Zhang et al., (2011).

(Distribution)		(Percentage)
Ectopic impacted teeth	92	**34.2**
Pre-operative assessment for implant	88	**32.7**
Maxillary sinusitis	22	**8.2**
Facial trauma	20	**7.4**
Odontogenic tumours	19	**7.1**
After root canal treatment	18	**6.7**
Longitudinal root fracture	10	**3.7**
Total	269	**100**

CHAPTER THREE: AIMS & OBJECTIVES

AIM:

The aim of this *in vivo* study is to describe the prevalence and location of the MB2 in the mesiobuccal root of first and second maxillary molars and to describe a methodology to enable its geometric location in a sample of the Libyan population using CBCT imaging.

Objectives:

Primary objectives:

- To determine the prevalence of the MB2 canal in the different root thirds.
- To evaluate and categorize the root canal morphology of the mesiobuccal root.
- To determine the location and distance of the MB2 in relation to the MB and P canals.

Secondary objectives:

- To determine if there is an association between the location and distance of MB2 (in relation to the MB1 and P canals) with the age and gender of the study sample.

Null Hypothesis:

- The second mesiobuccal canal will not be found in the sample of the Libyan population's first and second maxillary molars, whereas the MB2 will not be found in the sample's 1MM and 2MM.
- There will be no variation in the root canal morphology of MB2.

CHAPTER FOUR: MATERIAL & METHODS

Study design:

This is a cross-sectional analytical study. It was conducted on radiographic images that were in the patients' records and were taken for general diagnosis and treatment. The database was analysed and the patients who met the inclusion and exclusion criteria were selected for analysis.

Equipment:

The use of different machines in different dental centres may pose a problem regarding voxel size and resolution. For example, the NewTom® VGi does not provide a reading below 0.3 and when we analyzed the secondary canal, a lower resolution would have been preferable. In addition, there was a difference between the acquisition parameters of different machines. However, we had to include them all due to the limited numbers in Libya and therefore we extracted the DICOM and we opened it in the presence of a third party to standardize the viewing and the evaluation of the data. Furthermore, we used the diagnostic monitor station which contained a PC to evaluate the data in the Department.

Sampling:

The patient records were obtained from four different Dental and Radiology Centres in Libya which serve the broader population of indigenous and foreign residents. Only CBCT images that included the entire maxilla were included. The first and second molars on the right and left sides were analysed. Records dating between January 2016 and December 2017 were assessed. Two hundred sets of DICOMS were sourced to obtain 378 teeth for analysis (regarded as a convenient sample). The patients' identities were anonymized and only age and gender were recorded. The records were taken as part of the diagnosis, examination and planning of surgical, endodontic, periodontal, orthodontic and implantology treatment.

Location of research:

The research study was undertaken in the Department of Diagnostic Radiology.

Inclusion criteria:

- Patients aged between 17 and 65 years at the time of the CBCT scan.
- The maxillary first and second molars had to be present.
- All first and second molars had to be fully erupted with complete root development.
- High-resolution radiographs (CBCT views) of adequate diagnostic quality (sharp and free of distortion).
- CBCT with a voxel size of a minimum of 0.3mm.

Exclusion criteria:

- No previous endodontic treatment of the concerned molars.
- Presence of metallic restoration, intraradicular post or implants in the region of interest.
- Any evidence of canal calcification due to previous trauma, surgery, or systemic pathology that could affect root canal morphology.
- Any anomalies of the pulp chamber related to alteration of structure for eg. pulp stones, internal root resorption, etc.

Ethics clearance:

The research was submitted to the Senate Research Ethics Committee and BMREC of the Faculty of Dentistry at the University of Western Cape for approval and permission to carry out the study (Appendix 1). Permission was obtained from the directors of the Dental and Radiology centres in Libya for access to the patients' records. The records were obtained by means of a consent form that was completed by the patients from the relevant imaging centres (Appendix 2 A, B & C).

All the information obtained during this study was regarded as confidential and no personal identification of the patients was used or disclosed. All the radiographs were documented using allocated numbers.

Data Collection:

The CBCT images from the relevant centres were transported on a dedicated large capacity hard drive in DICOM format. The DICOM files were opened in third party software called OnDemand3D®. The observation was done in batches of 5 -10 cases per day. The maxillary first and second molars were located and isolated to ascertain the presence of MB2 on the right and left sides in the 1MM and 2MM. The location of MB1 and P canals were evaluated and the area between these two canals was assessed for the presence of MB2. Thereafter the prevalence, location and morphology of the canals were recorded in the data capture sheet (Appendix 3).

Observation methodology:

Volumes were opened in the multiplanar reformatting (MPR) window. Slice thicknesses were adjusted to 0.5mm to standardize all reconstructions. The pulp chamber of the molars to be evaluated were located in the axial slice of the MPR window. A corono-apical (axial) exploration was conducted, then the coronal and the sagittal sections were oriented parallel to the long axis of the root to locate the MB1 and P canals on the axial slice (Fig. 9). To detect the location of MB2, the observation and measurements were done according to the protocol described by Abarca et al., (2015). The roots were divided into equal thirds, and each third was checked for the presence of the MB2 canal (1 mm, 3 mm, and 5 mm) apically to the floor of the pulp chamber of the molar being evaluated, to standardize the methodology. The measurement system was used to determine the presence of the second mesiobuccal canal from the pulp chamber to the root apex that was divided into equal thirds and referenced as coronal third, middle third and apical third. Firstly, the coronal cut was used to determine the presence of the MB2 canal in each canal. Secondly, the sagittal cut was used to locate the most apical and most coronal point of the root and to divide it into equidistant thirds. This was also used to leave the canal as vertical as possible. The axial cut was used to corroborate the type of canal which should be as vertical as possible. The floor of the pulp chamber was identified by the slice number in the sequence and noted. Apical slices of the pulp chamber were in increments of 0.5mm as set out in the standardization process. Therefore, two slices down represented 1 mm from the floor of the pulp, a further four slices down represented 3mm from the pulp floor and an additional four slices down represented 5mm from the pulpal floor.

Vertucci's (1974) classification was used to determine the morphology of the mesial root canal system of the maxillary first and second molars.

The reference line was 5mm below the floor of the chamber and the geometric location of the MB2 canal was detected in relation to the MB1 and P canals by locating the central points of each canal (MB1 and P) and drawing a line connecting the two points (PMB1 and PP) (Fig. 10&11). The location of the MB2 was then visualised mesially or distally to the line. After the detection of the MB2, the central point of the canal was located (PMB2) and a straight line was projected between the (PMB2 and PMB1) points. A third line was drawn (PMB2–PT) perpendicular to the PMB1–PP line (PT point), according to the protocol described by Betancourt et al., (2016). The distances between the points were measured in millimetres (Fig. 12).

Figure 9: CBCT images demonstrate Mesiobuccal root with 2 canals as viewed in axial, coronal and sagittal directions.

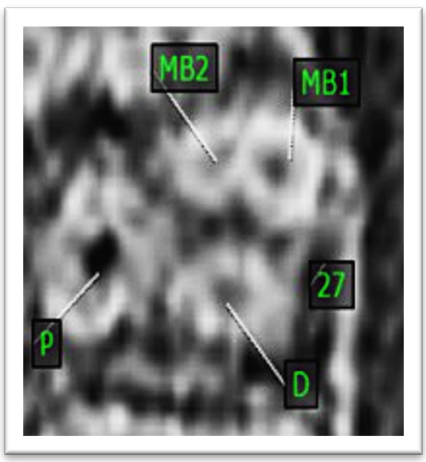
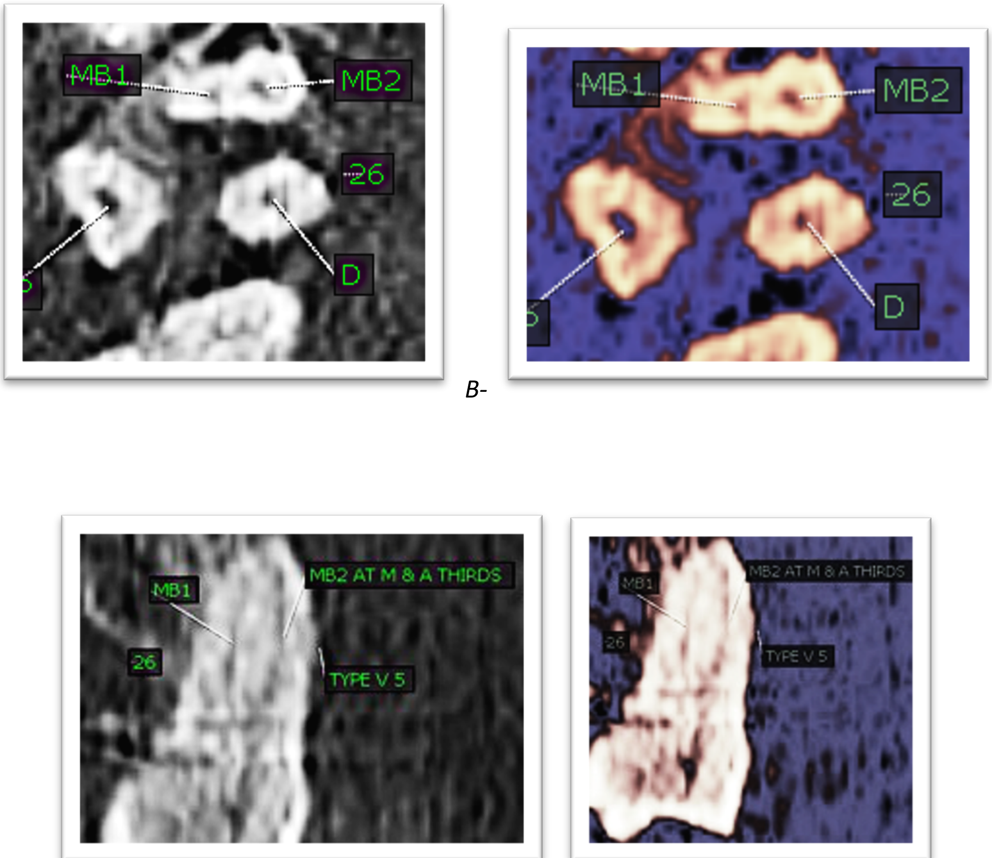


Figure 10: Cross-sectional CBCT image of left maxillary second molar with a clearly distinguished MB2 canal.



A B- C-

Figure 11: Axial (A&B) & Coronal(C) views of left maxillary first molar. PMB1 (centre of mesiobuccal canal.

Furthermore, according to Görduysus, M.Ö, et al., (2001), in his protocol, the line that joins the points (PMB1-PP) demonstrated palatal distance, and the line joining the points (PMB1-PMB2) represented the distance between two mesiobuccal canals, whereas, the third line between (PMB2-PT) demonstrated the mesial distance.

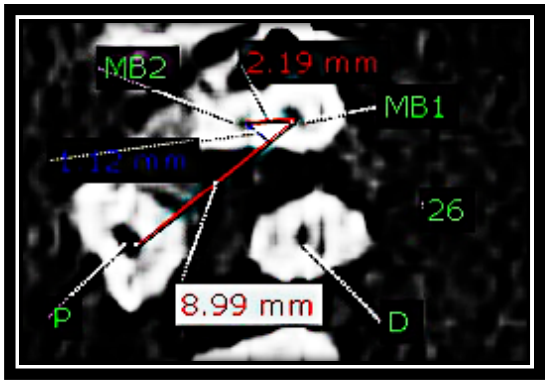


Figure 12: Morphometric measurements applied to characterize the location of MB2 canals.

The observers were allowed to modify brightness and contrast during the study to optimize the view and allow better identification of the anatomic structure on the radiographic modality. The presence and location were recorded in mm in the data capture sheet.

Intra-rater reliability:

Every tenth volume of DICOM was evaluated by the principal researcher with a repeated evaluation after two weeks. Data were captured separately and sent for statistical analysis.

Inter-rater reliability:

A random sample of the data set was evaluated by both the principal researcher and a senior member of the radiology department (gold standard). The data was sent to the statistician for evaluation.

Root morphology evaluation:

The teeth included were radiographically examined by CBCT. The following observations were made:

I.	**The morphology of mesiobuccal roots**
II.	**The number of canals per mesiobuccal root**
III.	**The root canal configuration in mesiobuccal root using Vertucci's (1974) classification and additional modifications (Fig 11).**
IV.	**The variations of the morphology of the mesiobuccal root**
V.	**Frequency of additional canals in the mesiobuccal root by sex, age and tooth position**

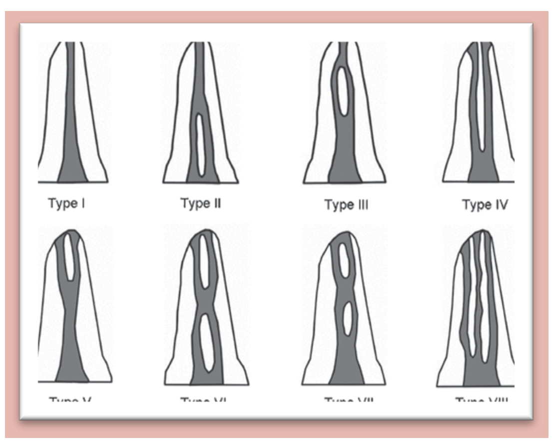


Figure 13: Vertucci's (1974) classification of the root canal system.

Statistical analysis:

The data were analyzed using descriptive statistics (mean ± SD). The association between the MB2 canal, gender and side were determined and evaluated using Pearson's chi-square test. The relation to age was also established using the t-test for independent samples, considering the normality of the data. The statistical significance was established at $p < 0, 05$. Intra-rater reliability was assessed using the Kappa test to determine the prevalence of MB2 and a Bland Altman test to determine the accuracy of distance.

CHAPTER FIVE: RESULTS

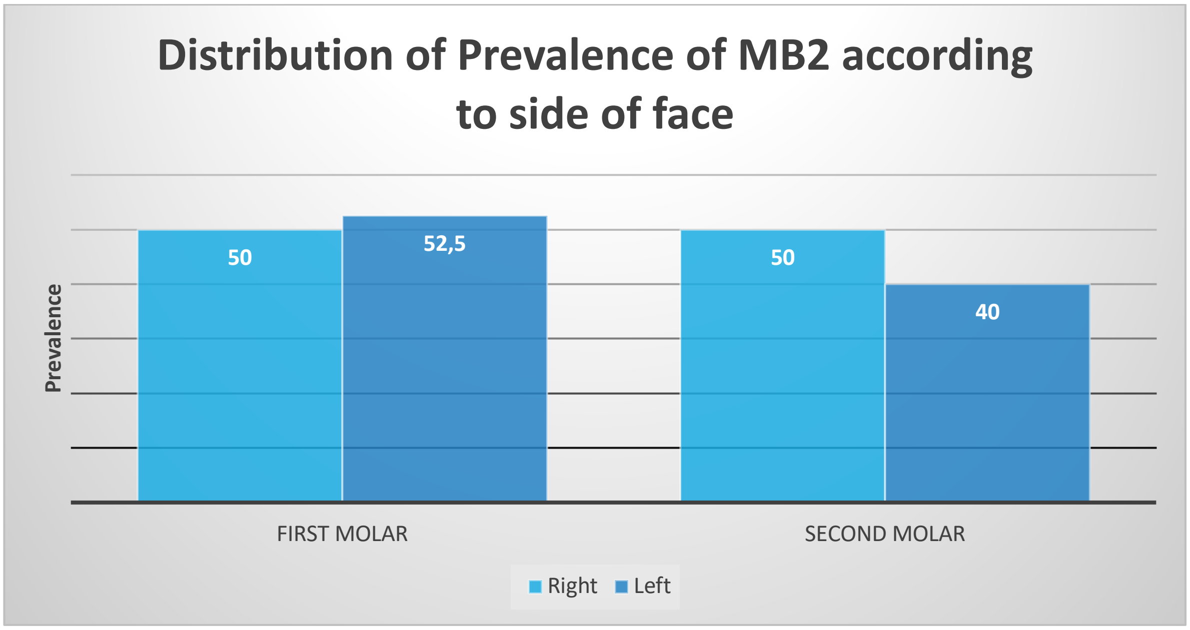
A total of 200 patients' images were selected and examined, of which 66 individuals complied with the inclusion criteria consisting of 175 teeth instead of 378 as mentioned before in the methods section. 90 1MM and 85 2MM were selected according to the inclusion criteria and established dates. They are distributed as follows: fifty of the teeth examined were tooth number 16, forty were tooth number 17, forty were tooth number 26, and forty-five were tooth number 27. In total there were 175 teeth from 66 individuals, with 84 teeth that displayed MB2 (48%) (Table 5). All categorical data were analyzed using a Pearson's Chi Square test.

Table 5: Participants distribution.

Tooth Number	No of teeth	Presence
16	50	25 (50%)
26	40	21 (52.5%)
17	40	20 (50%)
27	45	18 (40%)
TOTAL	175	84 (48%)

The prevalence of the MB2 canal distribution in the Libyan population was (46.97%) of individuals (31/66) in first maxillary molars (Table 6). While the second maxillary molar showed a lower incidence of MB2 (39.4%) of individuals (26/66) (Table 7), the percentage distribution of the MB2 canal according to both sides right and left was 50% on the right and 52.5% on the left of 1MM, whereas the 2MM was identified on both sides as 50% and 40% on the right and the left side, respectively (Table 5) (Fig 12).

Figure 14: the distribution of prevalence of MB2 according to side of face.



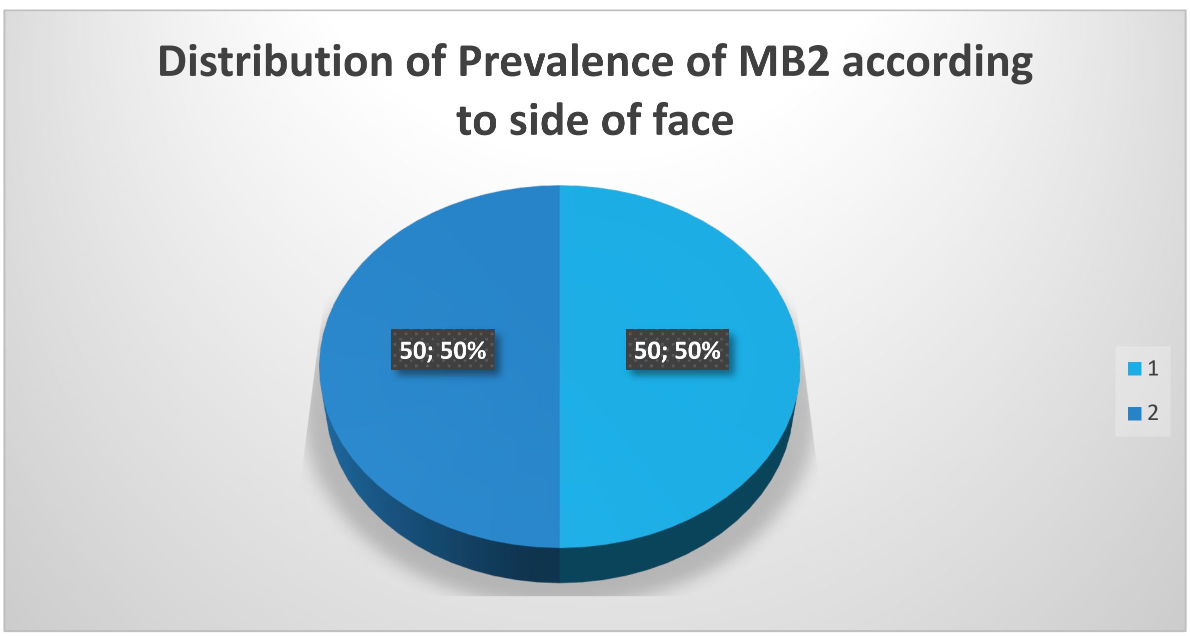


Table 6: Distribution of prevalence of MB2 in first Maxillary Molars.

First Molar	Frequency	Percentage	Cumulative
0	35	53.03	53.03
1	31	46.97	100
Total	**66**	**100.00**	

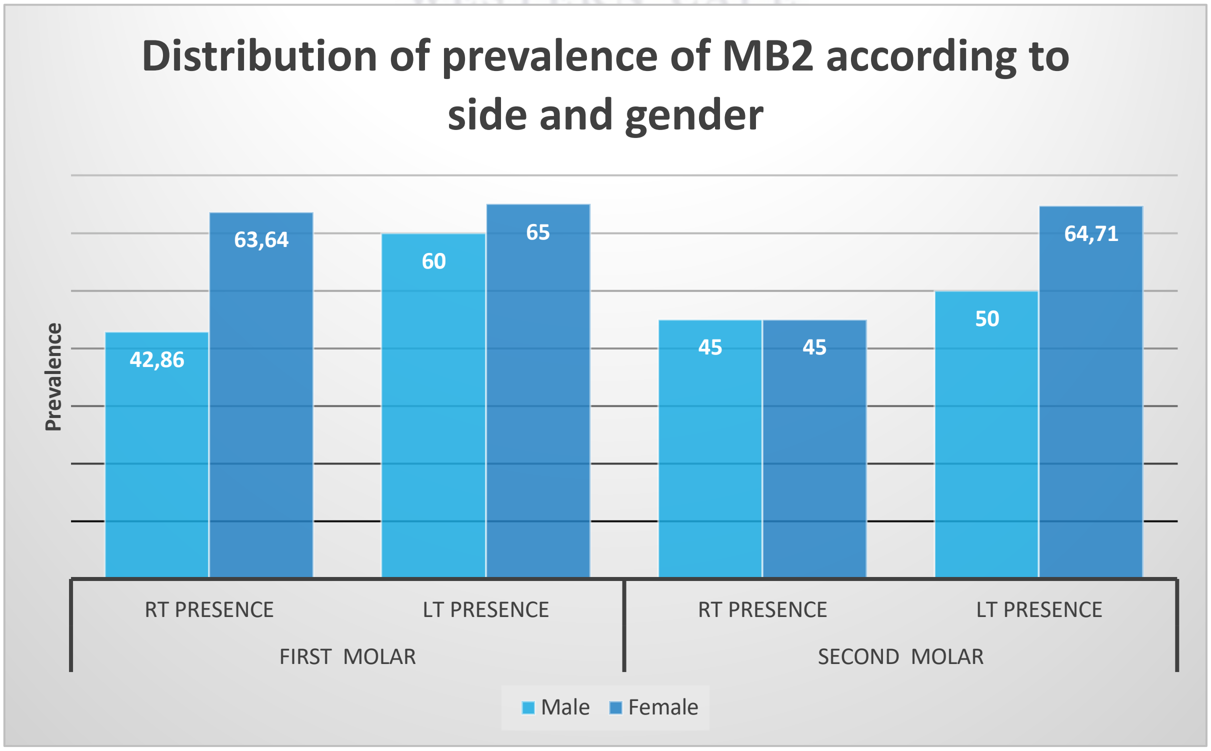
Table 7: Distribution of prevalence of MB2 in second Maxillary Molars.

Secondary Molar	Frequency	Percentage	Cumulative
0	40	60.61	60.61
1	26	39.39	100.00
Total	66	100.00	

Concerning the prevalence of MB2 according to genders, no significant difference between genders was noted. In the first maxillary molars on the RHS, the presence of MB2 was p =0.144 with a more frequent prevalence in women 63.64% than in men 42.86%. There was no significant difference between genders on the LHS and the presence of MB2 was p =0.744, with 65% in women and 60% in men (Fig. 13). The visualization of the MB2 canal between genders in second maxillary molars was quite similar to first maxillary molars with no significant difference on the RHS and the presence of MB2 was p =0.624 with an equal percentage for both sexes (55%). The same results were found for LHS with no significant difference between genders and the presence of MB2 was p =0.336, with 50% in males and

64.71% in females. However, the mean age of participants who had a presence of MB2 in their first molars was 31.58 (the lowest age was 17 and the highest age was 51), while in second molars it was 33.46 (the lowest age was 21 and the highest age was 51) (Tables 8,9).

Figure 15: Distribution of prevalence of MB2 according to side and genders.



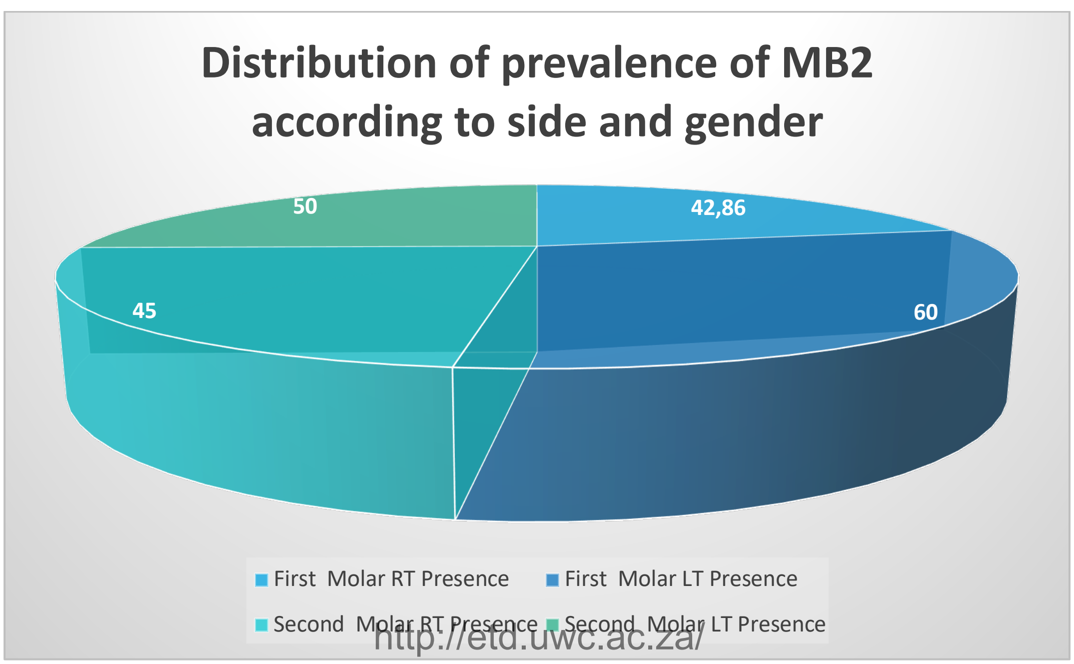


Table 8: Distribution of prevalence of MB2 according to age in 1MM.

Variable	Obs	Mean	Std Dev	Min	Max
Age	31	31.58065	9.200631	17	51

Table 9: Distribution of prevalence of MB2 according to age in 2MM.

Variable	Obs	Mean	Std.Dev	Min	Max
Age	26	33.46154	8.266708	21	51

The distances between the points for both 1MM & 2MM were analyzed with 95% CI. With regards to the distance between points PMB1-PP of the first maxillary molar, the mean was 8.1mm (The average distance was 8.56 ± 7.8 mm), for PMB1-PMB2 the mean was 2.2 mm (The average distance was 2.4 ± 2.05 mm), and for PMB2-PT the mean was 1.3 mm (The average distance was 1.5 ± 1.2 mm) (Table 10). Likewise, for the distance between points PMB1-PP of the second maxillary molars, the mean was 7.3mm (The average distance was 7.8 ± 6.8 mm), for PMB1-PMB2 the mean was 2.2 mm (The average distance was 2.5 ± 2.00 mm), and for PMB2-PT the mean was 1.2 mm (The average distance was 1.4 ± 1.0 mm) (Table 11).

Table 10: The distances between the points for 1MM.

Variable	Obs	Mean	95% conf. interval	
FM_PMB1PP	31	8.185484	7.8049	8.563477
FM_PMB1PMB2	31	2.225161	2.055755	2.394568
FM_PMB2PT	31	1.369677	1.246747	1.492607

Table 11: The distances between the points for 2MM

Variable	Obs	Mean	[95% conf. interval]	
SM_PM1PP	26	7.341865	6.857791	7.82594
SM_PMB1PM2	26	2.216923	1.94237	2.491476
SM_PMB2PT	26	1.239808	1.068153	1.411462

With regards to the morphological classification of the mesiobuccal root, it was observed that the most common type of Vertucci's classification was type II (28.0%) at the middle third in 1MM on the RHS (16), followed by types III, VII & VIII with the same percentage (16%) (Table 12). On the LHS the most common type was type V (28.57%) at the middle and apical thirds, followed by types VIII (14.29%) at the middle and apical thirds (Table 13). Likewise, in 2MM on the RHS (17), types VII, VIII & III were seen in 30.0% (MT & At) and 15% (MT) of teeth, respectively (Table 14), whereas, in 27 LHS, type V (27.78%) was mostly observed at the M & A thirds, followed by type II & type III with the same percentage (11.11%) (Table 15). All types in Vertucci's classification were found in the present study except types I and VI.

Table 12: Morphology of mesiobuccal root in 1MM on the RHS.

MORPHOLOGY OF MESIAL ROOT AND LO	FREQ	PERCENTAGE	CUMULATIVE
II (M)	7	28.00	28.00
III (M)	4	16.00	44.00
IV (M)	1	4.00	48.00
IV (M, A, & C)	1	4.00	52.00
V (M & A)	2	8.00	60.00
VII (M & C)	1	4.00	64.00
VII (M)	4	16.00	80.00
VIII (M&A)	1	4.00	84.00
VIII (M)	4	16.00	100.00
Total	25	100	

Table 13: Morphology of mesiobuccal root in 1MM on the LHS.

MORPHOLOGY OF MESIAL ROOT AND LO	FREQ	PERCENTAGE	CUMULATIVE
II (M)	2	9.52	9.52
III (M&A)	2	9.52	19.05
III (M)	1	4.76	23.81
IV (M & A)	2	9.52	33.33
V (M & A)	6	28.57	61.90
V (M)	1	4.76	66.67
VII (C, M & A)	1	4.76	71.43

VII (M)	2	9.52	80.95
VIII (M & A)	3	14.29	95.24
VIII (M)	1	4.76	100.00
Total	21	100	

Table 14: Morphology of mesiobuccal root in 2MM on the RHS.

MORPHOLOGY OF MESIAL ROOT AND LO	FREQ	PERCENTAGE	CUMULATIVE
II (M &C)	1	5.00	5.00
II (M)	2	10.00	15.00
III (M)	3	15.00	30.00
IV (M & A)	1	5.00	35.00
V (M, C & A)	1	5.00	40.00
VII (M & A)	6	30.00	70.00
VII (M & C)	1	5.00	75.00
VII (M)	2	10.00	85.00
VIII (M)	3	15.00	100.00
Total	20	100	

Table 15: Morphology of mesiobuccal root in 2MM on the LHS.

MORPHOLOGY OF MESIAL ROOT AND LO	FREQ	PERCENTAGE	CUMULATIVE
II (M &C)	2	11.11	11.11
II (M)	2	11.11	22.22
III (M &A)	2	11.11	33.33
V (M & A)	5	27.78	61.11
VII (C & A)	1	5.56	66.67

VII (M & C)	1	5.56	72.22
VII (M)	1	5.56	77.78
VIII (C, M & A)	1	5.56	83.33
VIII (M & A)	1	5.56	88.89
VIII (M)	1	5.56	94.44
VIII (M)	1	5.56	100
Total	18	100	

CHAPTER SIX: DISCUSSION

The current study evaluated the prevalence, location of the MB2 and root morphology of the mesiobuccal root in the MM1 and MM2 in a selected Libyan population. Limitations in the sample collection proved challenging as many patients did not meet the inclusion criteria. The possibility of finding CBCT's of patients with untreated root canals in the upper maxillary molars was low. This situation was exacerbated by the low number of total CBCT exposures in a country with very few machines in circulation. One of the common referrals of small volume CBCT is an endodontic evaluation which ties in with dose reduction and the justification principles of radiation exposure.

The major primary objective sought to determine the prevalence of the MB2 in maxillary molars and to specifically isolate it in one of 3 parts of the root length (thirds). The results showed that the overall prevalence of a MB2 canal was 48%. The prevalence of the secondary canal was 46.9% in the 1MM and 39.4% in the 2MM. These results are consistent with other studies and could imply that the prevalence of undetected canal anatomy in the 1MM is between 41.3% and 46.5% (Karabucak et al., 2016). The prevalence of the MB2 in the 2MM studies have been reported to be between 19.7% and 51.1% (Al-Fouzan et al., (2013) Betancourt et al., (2015).

Prevalence of secondary canal in 1MM:

The comparative studies do not compare like-for-like as some studies only evaluated one of the upper maxillary molars. The frequency of 46.9% in the 1MM is consistent with those reported by Zhang et al., (2011) (52.0%) in a Chilean population. Three studies carried out on a Brazilian population reported frequencies of 44.0%; 48.9% and 46.5% respectively Silva et al. (2014); Candeiro et al., (2019); Caputo et al., (2014). The highest frequencies (73.4%) were noted in a Chilean population as reported by Abarca et al., (2015). In addition, a study conducted on a South African population also reported a high frequency of 89.5% Fernandes et al., 2019). This was also noted by Lee et al., (2011) in a Korean population (71.8%) and by Martins et al., (2018) in a Kuwaiti population (79.8%) (Table 16).

Table 16: Summary of frequencies of secondary canal in MM1

Author	Tooth	Population	Prevalence
Zhang et al., (2011)	1MM	Chinese	**52%**
Silva et al., (2014)	1MM	Brazilian	44%
Candeiro et al., (2019)	1MM	Brazilian	48.9%
Abarca et al., (2015)	1MM	Chilean	73.4%
Caputo et al., (2014)	1MM	Brazilian	46.5%
Fernandes et al., (2019)	1MM	South African	89.5%
Lee et al., (2011)	1MM	Korean	71.8%
Martins et al., (2018)	1MM	Kuwaiti	79.8%

In the investigation of the 2MM, a frequency of 39.4% was observed. These results match those observed in a Chilean study by Abarca et al., (2015) (42.5 %), and Kim et al., (2012) (34.4%) in a Korean population. A slight contrast was noted in the Chilean population (22%) reported by Zhang et al., (2015) and in the Brazilian population (21.9%) reported by Candeiro et al., (2019).

These differences in frequency could be due to the anatomical variability of the mesial root in maxillary molars. This could be explained by the variation in sample sizes between the different studies. The variance in the voxel size of the CBCT modality used could affect the results as the small anatomical dimension of the secondary canal requires a very small voxel size for adequate evaluation. A suspected genetic aspect is postulated for the variability of prevalence as noted in the results from different ethnic groups. This study revealed a similar result when comparing right and left sides. This has clinical relevance in planning endodontic treatment of contralateral sides if one side has had a previous root canal treatment. This was echoed in the results presented by Betancourt et al., (2017), and Lee et al., (2011). These studies were however conducted *in vivo* using CBCT images.

In previous studies regarding canal morphology, different methods of observing the root and canal morphology and configurations, *in vitro*, involved extracted teeth using various methods such as sectioning, clearing and staining, magnification with a microscope, conventional radiographs, and micro-computed tomography. These methods attempted to allow direct observation of the root canal systems but most reported disadvantages, for example, tedious process, time-consuming methods, and limited sample size (Weine et al., 1999).

CBCT has been reported as more effective, accurate, and reliable as a diagnostic tool compared to other imaging modalities and conventional methods Abarca et al., (2015); Betancourt et al., (2016); Magat, G. and Hakbilen S., (2019). In terms of morphology, most of the mesiobuccal roots of maxillary first molars on the RHS had type II (28.0%) at the middle third, followed by types III, VII & VIII with the same percentage (16%). In the 1MM on the LHS, type V was most frequently (28.57%) located at the middle and apical thirds, followed by types VIII (14.29%) located at the middle and apical thirds. These results are consistent with those of other similar studies and suggest that the most prevalent type was type II. Abarca et al., (2015). This was confirmed in a recent study in Iraq that reported the most common type as type II (44.58%). Al-Saedi et al., (2020).

Type II as the most common type was also observed in the United States and Brazilian populations as reported by Ghasemi et al., (2017). However, our results were in contrast to earlier findings by Alavi et al., (2002) who reported type IV (44.2%) as the most common type in a Thai population. A Study in an Egyptian population group reported the highest percentage of type I and type IV in both first and second maxillary molars. Salem et al., (2018). These contrasting results have both treatment and forensic science implications amongst others.

In the result that depicted the 2MM on the RHS, types III, VII & VIII were seen in 30.0% (middle and apical thirds) and 15% (middle third) of teeth respectively. Likewise, in the 2MM on the LHS, type V (27.78%) was mostly observed in the middle and apical thirds, followed by type II & type III with the same percentage (11.11%). All types in Vertucci's classification were found in the present study except types I and VI. This study produced results that corroborate the findings of comparative studies where the dominance of type II morphology was noted as the highest - in the United States and Brazil, as reported by Ghasemi et al., (2017). These results are in contrast to the high percentages of both types II and III in a Chinese population. Khademi et al., (2017).

The clinical application and importance of these results could be applied to the learning and treatment outcomes of root canal therapy. This morphological variation explains why certain canals could be left untreated and harbour micro-organisms that lead to treatment failure. Weine et al., (1999). Clinicians and practitioners need to be aware of the anatomical complexities. A sound knowledge of root canal morphology, the possible variance and the percentage of different types is of paramount importance. The American Association of Endodontics and the American Academy of Oral and Maxillofacial Radiology recently proposed updated guidelines regarding the use of CBCT imaging in endodontics for the preoperative assessment of teeth with suspected complex anatomy and extra canals. Álvarez, J.M. and Macho, Á.Z., (2020).

Clinicians should not use CBCT imaging routinely unless indicated, due to the higher radiation exposure. Ratanajirasut et al., (2018). During this study, it was noted that axial and coronal planes were best suited to visualize the root canal morphology. The anatomical location of the access of the secondary canal was investigated based on an imaginary line connecting the MB1 to P canals, MB1 to MB2 and a perpendicular line to the PMB1–PP line. The MB2 canal location is inconsistent in respect of the palatine canal as noted by Zheng et al., (2010).

In this study, the MB2 was detected mesially to the MB1 and the distance for the 1MM was 2.4 ± 2.05 mm palatally, and 1.5 ± 1.2 mm mesially to the MB1 canal, while the 2MM distance was 2.5 ± 2.00 mm palatally and 1.4 ± 1.0 mm mesially. Betancourt et al., (2015), reported that the location of the MB2 in the 1MM was 2.2 ± 0.54 mm palatally and 0.98 ± 0.32 mesially to the MB1 canal – using the same technique. In a similar study, the MB2 of the 1MM recorded a distance of 2.68 ± 0.49 mm palatally and 1.25 ± 0.34 mesially to the MB1 canal, whereas, the 2MM was located 2.41 ± 0.64 mm palatally and 0.98 ± 0.33 mm mesially. Betancourt et al., (2016). The technique used provided very similar results and will need to be validated in future studies with larger sample sizes.

Previous studies reported variable distances of the MB2 location and showed a wide range of results. The differences were largely dependent on the method of measuring. Görduysus, M.Ö, et al., (2001) used Dental Operating Microscopy (DOM) to study the location and pathway of the MB-2 canal in the 1MM and 2MM and reported the average distance as within 3.5mm palatally and 2 mm mesially from the MB-1 canal. These results were in close comparison to the results of this study. Zhang et al. (2011) reported the distance at 2 mm by using light microscopy. Furthermore, shorter distances (1.82mm) have been presented by Kulid, J.C and Peters, D.D, (1990).

It was noted that not all of the MB2 orifices provided a true canal because an ‘apparent’ MB2 canal was not easily traceable to the orifices in 16% of the teeth. The variation in the geometric location of the MB2 canal, mesially or palatally in relation to the MB1 canal, depends on the type of study. *In vitro* studies do not simulate the anatomical relation and proportion of the dental arch, and the three planes of visualization in a CBCT are superior to normal visualization with the naked eye.

Regarding gender, no significant differences were noted in the prevalence of the MB2 canal, related to the side of the teeth. This was similar to results reported by Abarca et al., (2015), and also previously by Lee et al., (2011); Zhang et al., (2011). The results of this study also revealed that the prevalence of the MB2 was greater in women (63.64%) than in men (42.86 %) in the 1MM on the RHS. On the LHS it was observed as 65% in women, and 60% in men, while in the 2MM on the RHS we found an equal percentage for both sexes (55%). On the LHS, the results were marginally lower in men (50%) and a little higher in women (64.71%). This is in contrast with what was reported by Lee et al., (2011) who found a greater frequency of the MB2 canal in men (48.7%) than in women (30.8%). Many studies have proven that the presence of the MB2 is not affected by sex, which was in agreement with Chinese, Korean, and Egyptian populations. Zhang et al., (2011); Lee et al., (2011); Salem et al., (2018).

Many techniques have been used to study the morphology of the root canal system, including staining and bleaching, conventional and digital x-rays, and most recent studies make use of CBCT. Neelakantan et al., (2010); Betancourt et al., (2015). It is mentioned that CBCT was commonly used to determine the frequency of the MB2 canal because it is a non-invasive method with an effectiveness similar to bleaching and staining. Neelakantan et al., (2010). It is currently considered the gold standard for root canal anatomical studies. Moreover, CBCT is recommended to evaluate age, gender and the side of the tooth. Zheng et al., (2010). Studies using Diaphanization have obtained results similar to this study where Alavi et al., (2002), confirmed that the prevalence of the MB2 was 41.5%, while Ngan et al., (2003) reported 49%. Pécora et al., (1992) reported 42% and Yoshioka et al., (2005) reported 44%. This indicated the procedure to be as effective in the detection of the MB2 as CBCT.

The location of the MB2 canal in the maxillary first molar is complex due to its variable position and narrow foramen. The presence of the MB2 canal was observed *in vivo* using CBCT in 68.3% of cases, similar to those reported by Abarca et al., (2015) (73.44%) and Lee et al., (2011) (71.8%).

CBCT provides better results than other methods such as intraoral radiography, microscopy and visual observation. It is an effective and non-destructive tool to study the presence and location of the MB2 canal *in vivo*. Preoperatively, intraoral X- rays, even when different angles are taken, can only study the morphology of the two-dimensional canals with distortion and overlapping structures. CBCT allows three-dimensional reconstructions and multiplanar measurements of the canal morphology, with a low dose of radiation, limited to the anatomical area investigated, if small field of view modes are selected. High-resolution demands will increase this radiation dosage and should be used not only with caution but with respect for principles of dose reduction. Drawbacks like dispersion due to high-density structures such as enamel, metal posts or restoration imaging affect the quality and diagnostic accuracy. In addition, the patient remains motionless during the exposure, and CBCT is still relatively expensive as it has a high cost-benefit ratio. However, this is negligible.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

This study in a Libyan population revealed a relatively high prevalence of the MB2 in first maxillary molars. Root canal anatomical configuration was examined and variability was expressed for both first and second molars. These important considerations are clinically relevant in a clinical environment where CBCT is a fairly new modality. Therefore, the value of CBCT is highlighted and caution for misuse is emphasized. The clinician should be cautioned and be alert to the following: the possibility of the prevalence of a secondary canal; the value of a low dose; and the use of a small field of view CBCT as per international guidelines, with the motivation to "first do no harm".

We also recommended the use of this modality in endodontics using a small field CBCT according to the European Society of Endodontics and the American Association of Endodontics, because if we reduce the FOV the required effective radiation dose will be lower. Furthermore, other advantages of a small FOV are decreased time to process and read the image, with better ability to avoid metallic structure that could interfere with the quality of the image.

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ADDENDUM

Appendix 01: Ethics clearance letter.

Appendix 02: Letters of request for access to the patients' files (A, B &C).

Appendix 03: Data capturing excel sheet.

Appendix 04: Turnitin Similarity Report.

Appendix 01: Ethics clearance letter.

UNIVERSITY *of the* WESTERN CAPE

60 YEARS *of hope, action & knowledge*

8 November 2021

Dr H Aburgeba
Faculty of Dentistry

Ethics Reference Number: BM19/8/3

Project Title: Prevalence and location of secondary mesiobuccal canal in maxillary first and second molars using CBCT on a Libyan population.

Approval Period: **27 September 2019 – 27 September 2020**

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project and the requested amendment to the project.

Any further amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for the duration of the project.

For permission to conduct research using student and/or staff data or to distribute research surveys/questionnaires please apply via:
https://sites.google.com/uwc.ac.za/permissionresearch/home

The permission letter must then be submitted to BMREC for record keeping purposes.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

NHREC Registration Number: BMREC-130416-050

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 02: Letters of request for access to the patients' files (A, B &C).

Appendix A:

شركة ياسمين العرب
للخدمات الطبية
مستشفى الياسمين
YASMIN HOSPITAI

مستشفى الياسمين
— Yasmin Hospital —

Dear Dr. Hoda Aburgeba
MSc student in oral and maxillofacial radiology
University of Western Cape, South Africa

I acknowledge receipt of your request to access patient's files in my Dental Radiology Center to conduct a research titled: " prevalence and location of MB2 in maxillary first and second molars using CBCT; on a sample of Libyan population.

I accept your request and advice the following provisos:

1. The patient's names will not be noted in the study and all effort for anonymity will be maintained by substituting names for case numbers.
2. All clinical data will be used with discretion and confidentiality.

Looking forward to this collaboration.

Kindest regards

Date: 23/10/2018

مستشفى الياسمين
— Yasmin Hospetal —

Dr: Naji Allolki

Manager of Yasmin Dental center

Signature:

Tel: 051 462 8240 -Mobil: 091 105 9900 - 094 536 1562
Jasmin.clinic.zl@gmail.com

Appendix B:

Almays Co.
Medical Services

شركة الميس
للخدمات الطبية
ترخيص رقم: 47 - 03218
الرقم الإشاري: 227/15

مستشفى الهلال زليتن

التاريخ: 23/10/2018

Dear Dr. Hoda Aburgeba
MSc student in oral and maxillofacial radiology
University of Western Cape, South Africa

I acknowledge receipt of your request to access patient's files in my Dental Radiology Center to conduct a research titled: " prevalence and location of MB2 in maxillary first and second molars using CBCT; on a sample of Libyan population.

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1. The patient's names will not be noted in the study and all effort for anonymity will be maintained by substituting names for case numbers.
2. All clinical data will be used with discretion and confidentiality.

Looking forward to this collaboration.

Kindest regards

Date: 23/10/2018

Dr: Hamza Alshmmam

Manager of Hilal Dental center

Signature:

الإدارة

زليتن: وسط المدينة بالقرب من مصرف الوحدة فرع زليتن
091 480 0700 092 480 0700
alhelal.hospital.zliten@gmail.com

Appendix C:

شركة الحسين لطب الاسنان
Alhussein Dental Company

الرقم الاشاري / ————

Dear Dr.HodaAburgeba
MSc student in oral and maxillofacial radiology
University of Western Cape, South Africa

I acknowledge receipt of your request to access patient's files in my Dental Radiology Center to conduct a research titled: "The prevalence and location of MB2 in maxillary first and second molars using CBCT; on a sample of Libyan population.

I accept your request and advice the following provisos:

1. The patient's names will not be noted in the study and all effort for anonymity will be maintained by substituting names for case numbers.
2. All clinical data will be used with discretion and confidentiality.

Looking forward to this collaboration.

Kindest regards

Date: 25/10/2018

Dr Elhussein gnao

Manager of Alhussein Dental clinic

Signature:

00218 92 2596691
Email : Alhu2012.a2@gmail.com

Ben Ashour street - Tripoli - Libya

218 21 3604660
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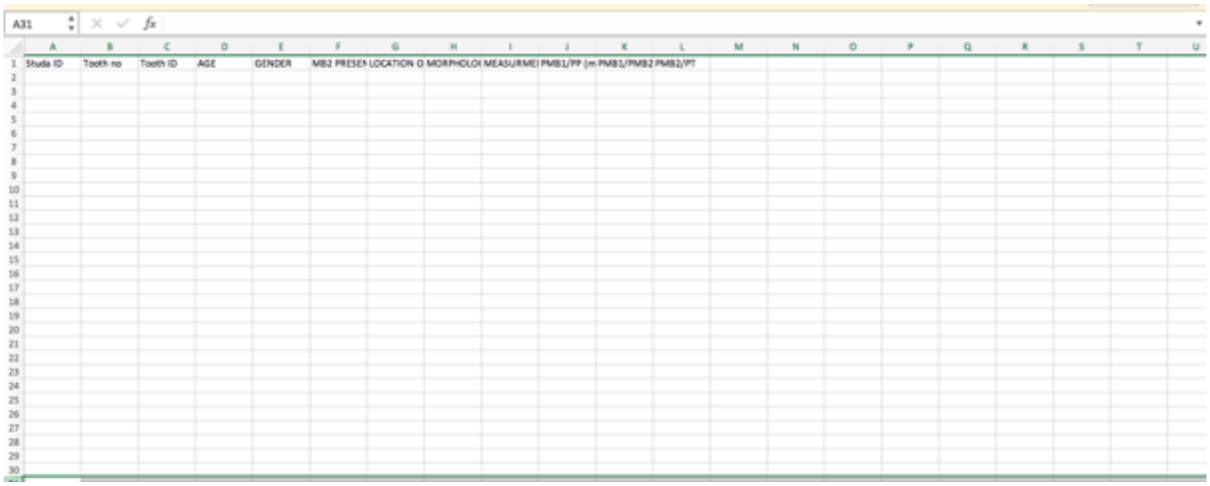
Appendix 03: Data capturing excel sheet



Studa ID	Tooth no	Tooth ID	AGE	GENDER	MB2 PRESEN	LOCATION O	MORPHOLO	MEASURME	PMB1/PP (m	PMB1/PMB2	PMB2/PT

Appendix 04: Turnitin Similarity Report