VARIATIONS IN THE HUMAN MANDIBULAR CANAL AND FORAMINA: A CBCT STUDY

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ABSTRACT

Introduction: The increased neurological clinical complications after surgical intervention in the mandible necessitate the demand for precise detection of the mandibular canal and its foramina variations prior to any surgical intervention.

Aims: To identify and classify variations of the mandibular canal and foramina in dentate Malaysian using Cone-Beam Computed Tomography (CBCT).

Materials and Methods: The subjects for this study were 202 who had attended the Oral Radiology Division, Faculty of Dentistry, University of Malaya for CBCT screening. Using the dataset generated, bifid/trifid mandibular canals were identified and classified. Their vertical location, diameter, lumen shape were studied. The location of the mental foramen, mental foramen opening distance, orientation of the opening, the location of the mandibular foramen, the prevalence of accessory mental and mandibluar foramina and retromolar foramen were studied in detail. To enhance the quality of images studied, SimPlant software was employed and the findings analysed using statistical software (SPSS v.12).

Results: In the present study, bifid mandibular canal were observed in 46 (22.77%) patients with the retromolar canal being the most numerous. The mean length of the bifid mandibular canals was 32.33mm ±19.96 (range: 7.20-86.33mm). The mean diameter of the bifid mandibular canal was 1.42 mm (SD ±0.32). Fifty-six percent of bifid mandibular canals were below the main mandibular canal. Trifid mandibular canals were observed in 12 (5.9%) of the 202 patients and retromolar canal was again the most frequent type recorded. The mean diameter of the trifid mandibular canal was 1.29 mm (SD ± 0.23) (range: 0.93-1.89 mm) and the mean length was 20.75 mm ± 14.43 (range: 5-52mm). Forward canal type has the longest trifid mandibular canal length while the retromolar canal was the shortest. With regards to the mental foramina, they were located 10.9 mm from the lingual cortex and 14 mm above the lower edge of the mandible while the mandibular foramen was 5.89 mm from the buccal edge of the mandibular foramen perpendicularly to the buccal cortical margin of the ramus and 23.26 mm above the lower edge of the mandible. Accessory mental foramina were observed in 5 (1.2%), accessory mandibular foramina were observed in 19 (4.9%) and retromolar foramina were observed in 28 (7.2%) of the 388 hemi-mandibles studied.

Conclusion: This study revealed that there is a high prevelance of variations in the number of mandibular canal among Malaysians and that the “retromolar canal” type is the most common type of the mandibular canal variation in this population. The ability to visualise and quantify precisely these complicated variations using CBCT provides support for the view that this imaging modality should become the recognised standard of care before any mandibular surgery.

Keywords: Bifid mandibular canal, Trifid mandibular canal, mental foramen, mandibular foramen, Accessory mental foramen, Accessory mandibular foramen, Cone Beam Computed Tomography (CBCT), Mandibular Canal, Simplant Software, Malaysian Population, Indian, Chinese, Malays.

ABSTRAK

Pengenalan: Komplikasi klinikal akan meningkat selepas pembedahan di rahang bawah jika tidak mengesanan dengan tepat variasi kanal mandibel dan foramina sebelum pembedahan tersebut.

Bertujuan: Untuk mengenal pasti dan mengelaskan variasi kanal mandibel dan foramina dikalangan pesakit-pesakit Malaysia yang bergigi dengan menggunakan Cone-Beam Computed Tomography (CBCT).

Bahan dan Kaedah: Subjek kajian adalah data CBCT daripada 202 pesakit dari Bahagian Radiologi Pergigian, Fakulti Pergigian. Kanal bifid / trifid dikenalpasti dan dikelaskan. Lokasi menegak kanal, garis pusat, bentuk lumen dikaji. Lokasi foramina mental, jarak pembukaan foramina mental, orientasi pembukaan, lokasi foramen dirahang, kehadiran foramina mental dan mandibel dan foramina retromolar aksesori dikaji secara terperinci. Untuk meningkatkan kualiti imej yang dikaji, perisian SimPlant telah digunakan dan hasil kajian dianalisis menggunakan perisian statistik SPSS (V.12).

Keputusan: Dalam kajian ini, kehadiran kanal bifid adalah 22.77% dengan kanal retromolar yang paling banyak. Panjang minima kanal bifid adalah 32.33mm ± 19.96 (julat: 7.20-86.33mm). Garis pusat minima kanal bifid adalah 1.42 mm (SD ± 0.32). Lima puluh enam peratus daripada kanal bifid adalah di bawah kanal mandibel utama. Kanal trifid diperhatikan dalam 12 (5.9%) daripada 202 pesakit dan kanal retromolar sekali lagi adalah jenis yang paling kerap direkodkan. Garis pusat minima kanal trifid adalah 1.29 mm (SD ± 0.23) (julat: 0,93-1,89 mm) dan panjang minima adalah 20.75 mm ± 14.43 (julat: 5-52mm). Jenis kanal kehadapan mempunyai kanal yang paling panjang manakala kanal retromolar adalah yang singkat. Merujuk kepada foramina mental, ia terletak 10.9 mm dari korteks lingual dan 14 mm dari tepi bawah mandibel manakala foramina mandibel adalah 5.89 mm dari tepi bukal foramina mandibel serenjang kepada margin kortikal bukal ramus dan 23.26 mm dari tepi bawah mandibel. Foramina mental aksesori diperhatikan dalam 5 (1.2%), foramina mandibel aksesori diperhatikan dalam 19 (4.9%) dan foramina retromolar diperhatikan dalam 28 (7.2%) daripada 388 separuh rahang yang dikaji.

Kesimpulan: Kajian ini mendedahkan bahawa terdapat kadar kekerapan yang agak tinggi variasi dalam bilangan kanal mandibel dikalangan rakyat Malaysia dan jenis "kanal retromolar" adalah jenis yang paling biasa bervariasi di kalangan penduduk ini. Variasi-variasi yang terdapat memberi sokongan untuk penggunaan CBCT secara rutin untuk penilaian terperinci dan ia mesti menjadi satu standard sebelum apa-apa pembedahan mandibel dilakuakan.

Kata kunci: kanal bifid, kanal trifid, foramina mental, foramina mandibel, foramina mental aksesori, foramen mnadibel aksesori, Cone Beam Computed Tomography (CBCT), Perisian Simplant, Penduduk Malaysia, India, Cina, Melayu

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Saif Yousif Abdullah
22 May 2017

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LIST OF SYMBOLS AND ABBREVIATIONS

IAN	Inferior alveolar nerve.
CBCT	Cone-Beam CT.
MC	Mandibular canal.
MnF	Mandibular foramen.
MF	Mental foramen.
B	Buccal.
L	Lingual.
I	Inferior.
S	Superior.
BSSO	Bilateral sagital split osteotomy.
CT	Computed Tomography.
MPR	Multiplanar Reconstruction.
2D	Two dimensional.
3D	Three dimensional.
SCT	Spiral computerized tomography.
HR-CT	High resolution computed tomography.
HR-MRI	High resolution magnetic resonance imaging.
IMB	Inferior mandibular border.
RMC	Retromolar canal.
RMF	Retromolar foramen.
DMandF	Double mandibular foramen.
AMF	Accessory mental foramen.
BMC	Bifid mandibular canal.
TMC	Trifid mandibular canal.
AmandF	Accessory mandibular foramen.
LA	Local anaesthesia.
MF-I	Distance from the lower edge of the mental foramen perpendicularly to the most inferior point of the lower border of the mandible.
MF-L	Distance from the lingual edge of the mental foramen to the lingual cortical margin of the mandible.
MF-D	Distance between upper edge and lower edge of the mental foramen opening.
MF-Direction	Mandibular anterior loop opening direction.
MandF-I	Vertical distance from the lower edge of the mandibular foramen perpendicularly to the most inferior point of the lower border of the mandible.
MandF-B	Horizontal distance from the buccal edge of the mandibular foramen perpendicularly to the buccal cortical margin of the ramus.
IsBifid	A bifid mandibular canal indicator.
IsTrifid	A trifid mandibular canal indicator.
IsAMF	Accessory mental foramen indicator
IsAmandF	Accessory mandibular foramen indicator
IsRMF	Retromolar foramen indicator.
MSCT	Multislice CT

CHAPTER 1: INTRODUCTION

1.1 Aim of the study

The main aim of the current study is to identify and classify variations of the mandibular canal and its foramina in dentate Malaysian using Cone Beam Computed Tomography (CBCT).

1.2 Statement of problem

It is crucial to determine the anatomic location and also variations of the mandibular canal before any surgical procedure in the mandible. The Mandibular canal or the inferior alveolar canal is a conduit for the inferior alveolar nerve (IAN), the inferior alveolar artery and the inferior alveolar vein that extends from the mandibular foramen to the mental foramen (Sanchis et al., 2003). Although the canal has generally been known to be a single structure, variations such as bifid and trifid canals have been reported since 1973 (Kiersch & Jordan, 1973; Patterson & Funke, 1973). This implies that the mandibular canal is divided into two or three branches, each of these separated branches might contain a neurovascular bundle that can be observed in different forms (Langlais et al., 1985). These variations are often unrecognized and its detection is important because of its clinical implications.

Many surgical procedures in the mandibular segment may lead to inferior alveolar nerve injury so special attention must be considered in surgical procedures involving the mandible. This includes extraction of an impacted third molar (Kipp et al., 1980), dental implant treatment (Smiler, 1993), sagittal split ramus osteotomy (Tamas, 1987; Ylikontiola et al., 2000), preprosthetic operations, during the planning of removable partial dentures and preparing cases involving extensively atrophied mandibles (Bogdan et al., 2006; Karamifar et al., 2009) and block injection of local anesthetics to the inferior alveolar nerve (Jones & Thrash, 1992).

Nerve injury not only gives rise to unpleasant sensations, but may also affect the ability to talk and masticate effectively (Neugebauer et al., 2008). Nerve disability may give rise to continuous aching in the lower face (hyperalgesia, neuralgia) and social suffering. Some patients complain of strange sensations (allodynia, dysesthesia, paraesthesia) when touching the area in the lower lip. In addition, damage of related blood vessels (e.g., inferior alveolar or lingual artery) may cause excessive bleeding.

Recently, more practitioners are localizing the path of the mandibular canal and its anatomical variation using the volumetric imaging. Interestingly, this anatomical variation and its presence can only be confirmed with certainty by volumetric imaging (Claeys & Wackens, 2005). This technology which uses only 3-5% of the radiation dose of the conventional computed tomography might mitigate the injuries to neurovascular bundle and thus avoiding paralysis and hemorrhage in the mental and cheek regions. Damage to these vital structures can also arise from clinicians' surgical mistakes as well as failure to identify these structures (Kim et al., 2006). Hence, it is essential to determine the location and the configuration of the mandibular canal and the related anatomical structures to minimize these types of damages (Rueda et al., 2006).

1.3 Objectives of the study

The overall purpose of this research is to identify and classify bifid/trifid mandibular canals in the Malaysian population. This study also identifies the presence of extra mandibular and/or mental foramina that are associated with the nerve bifidity or trifidity.

Specifically, the study will focus on 9 objectives.

(I) Set criteria for identification of bifid/trifid mandibular canal in human mandibles using the CBCT imaging technique and the SimPlant software.

(II) Indicate the prevalence of the bifid/trifid mandibular canal using CBCT imaging technique and SimPlant software among the Malaysian population.

(III) Classify bifid/trifid mandibular canal in human mandibles among the Malaysian population.

(IV) To determine any racial, gender and age group differences among the Malaysian population.

(V) Determine the bifid/trifid mandibular canal length, diameter, vertical position among the Malaysian population.

(VI) Determine any other mandibular variation in Malaysian mandible that can be detected using CBCT scans.

(VII) Localize position of the normal mental foramen and normal mandibular foramen, and the presence of the accessory mental foramen and accessory mandibular foramen among the Malaysian population.

(VIII) To determine the possible clinical implications of bifid/trifid mandibular canal, mandibular foramina, mental foramina and its accessory foramen.

(IX) To develop a diagnostic algorithm for multiple mandibular canals with treatment planning implications that will provide normative information to assist surgeons in avoiding injury to the nerve during any surgical procedure in mandible.

1.4 Significance of the study

This study is the first local study to be carried out on three major races of the Malaysian population on mandibular canal variations such as bifid or trifid mandibular canal. These unrecognized anatomical variations are considered unusual since mandibular canal has generally been known to be a single conduit in the mandible that carries neurovascular bundles from mandibular to mental foramen. The mandibular canal can be divided into two branches, each separate canal might contain a neurovascular bundle (Langlais et al., 1985). Special attention has to be considered in surgical procedures involving the mandible.

These results may be used as a safety guide during surgical procedures in oral implantology cases and oral and maxillofacial surgery to prevent intraoperative and postoperative complications. This is a landmark study done on the scanned CBCT images of life patients and 3D simulation which must be very precise.

1.5 Choice of the study topic

There are four main reasons behind choosing the topic of this study which are, firstly, no such studies had previously been done in a Malaysian population. Secondly, the number of practitioners performing implant surgery has increased dramatically over the last fifteen years, thus there is a need to understand the relevant anatomy more precisely. Thirdly, studies have shown that the IAN is the most commonly injured nerve in the mandible and recent evidence suggests that this injury can be related to a bifid or trifid mandibular canal.

Lastly, the use of CBCT as the imaging technique was chosen as it is non-invasive and emits low radiation onto the patient.

1.6 Research Scope

This thesis reports on the variations of the mandibular canal and its related structure amongst Malaysian population using CBCT imaging technique and Simplant (SimPlant 3D Pro version 13.1; Materialise Inc., Leuven, Belgium) interactive software. Normal mandibular canal was surveyed with most recent literature that highlight metrical analysis of its location, especially its vertical and horizontal location, diameter, and its opening foramen. All mandibular canals related variations are studies like bifid mandibular canal, trifid mandibular canal, accessory mental foramen and accessory mandibular foramen or double mandibular foramen.

1.7 Organization of Thesis

There are 7 chapters in this thesis. A short introduction on the background study is given in the opening chapter.

Chapter 2 is a literature review chapter which is more specified to the objectives of this study. It highlights branching of the mandibular canal namely bifid and trifid mandibular canal using different imaging modality with detailed clinical significant. Anatomical and radiographic consideration of mandibular and mental foramen with its abnormalities was also reviewed.

Chapter 3 presents a general research methodology used in this study which includes sample selection according to the inclusion and exclusion criteria, followed by the image acquisition employed for the measurement of each anatomical structure aimed in this study.

Chapter 4 is a specified chapter for the bifid mandibular canal with a detailed methodology used for the detection of mandibular canal bifidity. A detailed description for the dependent variables used to measure with its results. The significance of the findings is discussed in this chapter.

Chapter 5 is a specified chapter for trifid mandibular canal which include the detection method of trifidity case, variables employed, methods used to measure these variables and the reported results. The significance of the findings is discussed in this chapter.

Chapter 6 is a specified chapter for mental and mandibular foramen with its variants. A full detailed methodology for measuring these anatomical structures with its variant is described in this chapter. The significance of the findings is discussed in this chapter.

Chapter 7 provides an overview of the findings of this study. It starts with the rationale for choice of the study topic and then elaborates on discussing each important section in detail. The results were further compared with the results of other similar studies. Lastly, it presents conclusions for the research objectives which have been achieved related to the problem statements and the research contributions.

1.8 Summary

This chapter first states clearly the aim of this study which is to identify and classify specific anatomic variations of the mandibular canal and its foramen amongst the Malaysian population.

The problem statement explains briefly about the mandibular canal variations which are often unrecognized and its detection is crucial due to its clinical implications. In addition, mental and mandibular foramen and its variant is also considered as important as the canal itself.

The significance of the study is stated in detail. Furthermore, research objectives and research questions are also explained in this chapter. Moreover, the extent and constraints of this study are further made clear. The chapter presents a general summary of the other chapters of this thesis.

CHAPTER 2: LITERTURE REVIEW

2.1 Introduction

The mandibular canal is a hollow space surrounded by bony tissue extending from the mandibular foramen posteriorly toward the mental foramen anteriorly through which inferior alveolar nerve and vessels passes to supply the mandibular teeth and adjacent structures (Sanchis et al., 2003). Studying the accurate position and course of the mandibular canal within the mandible and identifying the anatomical variations is very important for preventing clinical complications during dental surgical procedures.

Although the canal has generally been known to be a single structure, variations such as bifid and trifid canals have been reported since 1973 (Kiersch & Jordan, 1973; Patterson & Funke, 1973). The term “bifid” is derived from the Latin word which means “cleft into two parts or branches”. Researchers have stated that usually the bifid canals originate at the mandibular foramen and each contain a neurovascular bundle (Langlais et al., 1985). Bifid mandibular canals are often unrecognized and its detection is important when performing surgical procedures. Inadequate anesthesia may be possible with any bifurcation type, especially if the variation includes two mandibular foramina causing standard injection techniques to be ineffective in some patients. To compensate for this anomalous canals and foramina, alternate anesthetic injection techniques may have to be considered in these cases. Rare trifid mandibular canal has also been reported adding further difficulties during dental clinical procedures (Auluck & Pai, 2005; Auluck et al., 2007; Mizbah et al., 2011, 2012; Rashsuren et al.; Wadhwani et al., 2008).

It is acknowledged that these branching canals may contain nerve bundles and arteries, indicating their potential significance in providing innervation and blood supply to the mandible (E. Kaufman et al., 2000). Worse, it has been reported that while 60% of mandibular canal contain the entire inferior alveolar nerve, the remaining 40% of branches may be distributed inside canals that might be indistinct canal (Carter & Keen, 1971). Thus, iatrogenic injury may result from the failure to detect them, both radiographically and clinically. Injury to any of these branches may results in bleeding and worse, traumatic neuroma although such case reports have yet to be communicated (Kieser et al., 2005). A search of the literature regarding injuries to the accessory branches of the mandibular canal found only one case report with neurosensory disturbance that followed a lower left third molar surgery (Wyatt, 1996) and another case of neurosensory disturbance that resulted from the impingement of a bifid canal by a dental implant fixture (Maqbool et al., 2013). In both cases, the neurosensory disturbances resolved once the source of this problem was identified and was dealt with accordingly. These two cases show that iatrogenic injury to a smaller branch of the main nerve can result in an equally dire consequence, similar to the extent as if the main nerve was affected.

2.2 Bifid mandibular canal detection

Mandibular canals can often be detected on panoramic radiographs, although this two-dimensional images have their obvious limitations (Antoniades et al., 2004; Auluck et al., 2007; Karamifar et al., 2009; Langlais et al., 1985). A more accurate information about the course of these canals was noticed when performing cross-sectional Cone-Beam Computed tomography (CBCT) images perpendicular to the alveolar ridge (Claeys & Wackens, 2005; Karamifar et al., 2009; Miloglu et al., 2009; M. Naitoh et al., 2009; Naitoh et al., 2007; Rouas et al., 2007). The prevalence of bifid mandibular canals has been reported to be in the range of 0.08-0.95% using the panoramic radiographs (Grover & Lorton, 1983; Langlais et al., 1985; Nortje et al., 1977; Sanchis et al., 2003; Zografos et al., 1990) while the prevalence was in the range of 15.6-64.8% (de Oliveira-Santos et al., 2012; Kuribayashi et al.; M. Naitoh et al., 2009; Naitoh et al., 2010; Orhan et al., 2011) using CBCT images. It is therefore evident that this anatomical structure and its variation can be detected with somewhat greater certainty employing volumetric scanning technology (Claeys & Wackens, 2005).

Surveying the literature showed that bifid mandibular canals have been detecteded using four different methods namely: radiographic studies, anatomical studies (dry mandibles and dissection), combination of two, and case studies.

2.2.1 Bifid mandibular canal detection through panoramic radiographs

A list of studies has been conducted from 1973 till 2015 using panoramic radiographs to detect bifid mandibular canal. One of the earliest studies made to detect the presence of bifid mandibular canal was reported in 1973 (Kiersch & Jordan, 1973; Patterson & Funke, 1973) that disclosed a unilateral bifid mandibular canal case using dry mandibles. Patterson (1973) identified two mental foramina with two branches which occurred in the ramus and the body of the lower jaw. Lateral projection radiograph of the skull was conducted to confirm their findings.

Four years later a retrospective study of panoramic radiographs conducted by Nortje et al. (1977) and reported bifid mandibular canal to be 0.9% (33 cases out of 3612 patients), The bifidity was noticed in 3 configurations, mostly; duplicate canals commencing from a single mandibular foramen and the least find was arising from two distinctly separate foramina. He further added fourth new variation in the same year (Nortjé et al., 1977) where the position of the entrance of this new variant into the mandible was through an accessory foramen remote from the lingula.

The three studies including the largest sample size were conducted by Groover et al. (1983), Langlais et al. (Langlais et al., 1985) and Kalantar et al. (2015) with 5000, 6000 and 5000 sample size respectively that confirmed this mandibular canal variant. The first group of authors surveyed 5000 United States Army recruits, ages 17-26. It was found that four radiographs were highly suggestive of bifurcation of the inferior alveolar nerves (a prevalence of 0.08%). In one case, the bifurcation seemed to be bilateral. The second group of authors evaluated a total of 6000 patients and found that 57 of them demonstrated bifid mandibular canals (0.95%) with no gender differences. The third group of authors conducted their retrospective study on 5000 panoramic radiographs of patients aged 18 to 80 years (2,783 women and 2,217 men) and found that 61 records (1.2%) indicating a bifid mandibular canal and no statistically significant correlations were found regarding age or gender.

Durst and Snow (1980) acknowledged that these variations in the mandibular canal are not rare but can be considered as common anomalies since they have reviewed 1024 panoramic radiographs and found multiple canals exist in 85 cases (8.3%). Furthermore, another study conducted in Turkey confirmed that bifid mandibular canal is not a rare occurrence since Siniflandirilmasi and Kanallarin (2000) localized and classified bifid mandibular canals on 1507 panoramic radiographs. Twenty-eight radiographs out of 1507 panoramic radiographs (1.85%) was presenting bifid mandibular canal. It was then classified according to the age and gender of the patient and the location of the bifid canals. Four types of bifid mandibular canals were found. Bifid mandibular canal percentage according to gender of the patient was 59.22% for women and 40.5% for men

Although many studies reported its detection in both genders; Sanchis et al.(2003) reported that it was found only in 7 woman (0.35%) after evaluated 2012 patients using panoramic radiographs, 4 cases were bilateral and 3 cases was unilateral.

Among Iraqis, the prevalence of bifid mandibular canal detection was from 1.88% to 5.95% using panoramic imaging. Rashid et al. (2011) analyzed data of 319 panoramic images of Iraqi subjects (159 male and 160 female) and found 6 images (1.88%) of cases with bifid mandibular canal. In another study of similar sample size, Lara et al. (2010) analyzed 350 panoramic images and found that 35 cases of bifurcations to the mandibular canal, corresponding to 5 % of the sample in the study (Figure 2.1). In a different study one year later, the same first author (Rashid, 2012) conducted a research on 319 panoramic images of Iraqi subjects and demonstrated that 5.95% of the sample size were with mandibular canal variations. The distribution of variations found was 1.88% for bifid mandibular canal, 1.57% for indistinct mental foramen, 1.25% for indistinct mandibular canal walls, 1.25% for indistinct mandibular foramen.

Figure 2.1: Unilateral bifid mandibular canal that extends to the right third molar area (left circle) (Lara et al., 2010).

Three main studies conducted in Brazil reported different prevalence of bifid mandibular canal using panoramic imaging. Valarelli et al. (2007) studied 400 mandibles and found that 12.75% of the observed images was with some bifurcation type in the mandibular canal. Regarding the position of the mandibular canal in relation to the mandibular base and the radicular apices of the lower teeth, it was found that high bilateral canal in 32.5%

of the images, 28.25% of intermediate canal, 0.25% of low bilateral canal and 27.25% with some variation. The second study was conducted by Kuczynski et al. (2014) on 3,024 panoramic radiographs from male (n = 1,155) and female (n = 1,869) patients (mean age 30 years) found that 60 radiographs (1.98%) presented unilateral bifid mandibular canals. A recent third study employed 500 patients using panoramic radiographs and found that 5.3% was with bifid mandibular canal, 47.5% of high canals, 16.8% of intermediate canals, 27.1% was lower canals and 8.6% canals with other variations. Based on the height, the bifid mandibular canal was more prevalent among higher canals than other. There were no gender differences with respect to other types and affected sides. In the classification of bifid canals there was no statistically significant difference between men and women (Andrade et al., 2015).

2.2.2 Bifid mandibular canal detection through CBCT

Bifid mandibular canal detection using volumetric imaging is the most common variant in Latin Americans (López-Videla Montaño et al., 2010), Japan (2009) and Turkey (Orhan et al., 2011) making up between 69%, 65% and 46.5% of the sample size studied. It is the second most common variant in Taiwanese making up between 30.6%~41.2% (Fu et al., 2014; Shen et al., 2014), but is the least common variant in Korean (10.2%) (Kang et al., 2014).

Lastly, many studies have reported that the bifid mandibular canal was more frequent unilaterally than bilaterally (Alves & Deana, 2015; Bilecenoglu & Tuncer, 2006; Bilodi et al., 2013; Correr et al., 2013; Han & Hwang, 2014; Lizio et al., 2013; Motta-Junior et al., 2012; Narayana et al., 2002; Ossenberg, 1986; Priya et al., 2005; Rossi, Freire, Prado, Prado, Botacin, & Caria, 2012; Schejtman et al., 1967; Suazo Galdámes et al., 2008; von Arx et al., 2011).

Surveying the literatures revealed that the prevalence of bifid mandibular canal in male was higher than female (Fu et al., 2014). However Akhtar et al. (2014) reported a female predilection. Significant association was found between length of bifid canals and gender, side of hemi-mandible, and cross-sectional bony area of the mandibular canal (Fu et al., 2014).

Other studies found that the rate of bifid mandibular canal corticalization was approximately half~~,~~ (44.7%) with complete corticalization. (Shen et al., 2014). In some studies reported no significant different was found between gender and age (Kang et al., 2014; M. Naitoh et al., 2009; Orhan et al., 2011) while in other study significant difference was found among gender (López-Videla Montaño et al., 2010).

Claeys (2005) reported a rare case of two mandibular canals originating from two separated foramina extending to two other separated mental foramina using CT scan (Figure 2.2). This case couldn’t fit into any suggested classifications by other authors since none of them described an extension to the mentalis area with separated mental foramina. The authors claimed that this a new type or subdivision and could be considered in later studies.

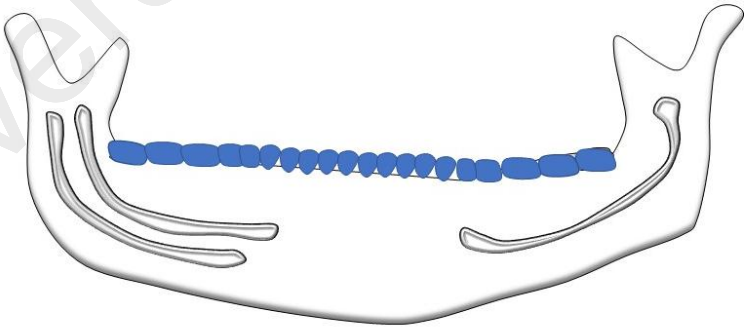

Figure 2.2: Illustrative image of 2 mandibular canals having isolated foramina. adapted and modified from (Claeys & Wackens, 2005).

The prevalence of bifid mandibular canal reported in each geographical location is summarized in Table 2.1 while the number of case studies and full research study reported from different countries using different imaging modalities has been summarized in Table 2.2. and Table 2.3

Rashsuren et al. (2014) conducted their research on 500 patients and found that mandibular canal variation were found in 22.6% of the 500 patients and 16.2% of the 755 hemi-mandibles considered in their study. The type of bifidity were considered according to Naitoh et al. (2009) modified classification. Prevalence rates were evaluated according to bifidity type, gender and age group. Accessory canal diameter, length, and angles were also measured. The retromolar canal type (Figure 2.3) accounted for 71.3% of the identified canals; the dental canal type, 18.8%; the forward canal type, 4.1%; and the trifid canal type, 5.8%. The authors claimed that they have found 7 trifid mandibular canals. The mean diameter of the bifid and trifid mandibular canals was 2.2 mm and that of the main mandibular canal was 4.3mm. Their mean length was 16.9 mm; the mean superior angle was 149.2 degree, and the mean inferior angle was 37.7 degree.

Figure 2.3 : CBCT image shows canal type 1 (retromolar canal type) (Rashsuren et al., 2014).

Based on 100 patients (200 hemi-mandibles), de Oliveira-Santos et al. (2012) assessed the mandibular canal variation and found that 19% of the cases showed bifidity and mostly associated with additional mental foramina.

Kuribayashi et al. (2010) analyzed data of 252 patients (301 mandible sides) using CBCT. The type of bifidity were classified according to Nortje´ et al. (Nortje et al., 1977). The diameter of the accessory canal was classified into two categories: 50% or more and less than 50% of the diameter of the main mandibular canal. Of the 301 subjects, 47 (15.6%) demonstrated a bifid mandibular canal. They were Type I in 2, Type II in 40, Type III in 0, and Type IV in 5 cases. The diameter of the accessory canal was greater than or equal to 50% of the main canal in 23, and less than 50% in 24 cases. Based on the Cone-Beam CT, a bifid mandibular canal was found in 15.6% of cases.

Rossi et al. (2009) analyzed and classified 500 panoramic radiographs of male and female patients to verify the evidence that claims mandibular canal variations do exist. Langlais et al. (1985) classification was used in this study. Bifid mandibular canals were found in 43 (8.6%) radiographs. Of these, 18 (41.9%) canals were classified as type 1; 10 (23.3%) as type 2, none as type 3 and 15 (34.9%) as type 4. Bifid mandibular canals occurred unilaterally and bilaterally but their presence did not differ statistically between the right or left sides. The authors revealed that there is no statistical significance between prevalence of canal types or gender.

Fu et al. (2014) conducted their research in a Taiwanese population to examine distribution of bifid mandibular canal and to evaluate etiological factors for this variations. The sample size included in this study was 173 subjects (97 females and 76 males) using a 64-slice multidetector computerized tomography system. Computed tomographic images were evaluated and the presence of bifid mandibular canals, as well as their widths and lengths, were examined. The authors found that mandibular canal variations exist in 53 (30.6%) of 173 patients and 64 (18.5%) of 346 hemi-mandibles of the total sample size. The mean length and width values of the bifid mandibular canals were 10.1 and 0.9 mm, respectively. The study also revealed that the prevalence of bifid mandibular canal in male was larger than female. Significant association was found between length of bifid canals and gender, side of hemi-mandible, and cross-sectional bony area of the mandibular canal. In the same year Shen et al. (2014) conducted their study in another group of Taiwanese population, they found 170 hemimandibles having bifid mandibular canal obtained from 308 Taiwanese adults. The distribution of the bifidity was 47 (27.7%) cases in the area of ramus; 68 (40.0%), cases located in retromolar area; 29 (17.1%) cases in molar area; 20 (11.8%) cases in premolar area; and 6 (3.5%) cases located in mental foramen area. Another reported result was that 95.9% of bifid canals showed an anterior course and were located superior to the main mandibular canal. Ninety-one percent of bifid canals did not rejoin the main mandibular canal, and 83.5% of the total examined canals diminished inside the mandible without joining and forming a confluence with the mandibular canal. Rate of bifid mandibular canal corticalization was also studied and found that approximately half of the bifid canals (44.7%) were with complete corticalization.

Correr et al. (2013) conducted their research in Brazil on 75 CBCT scans previously diagnosed with bifurcation of the mandibular canal to assess the morphology of bifid mandibular canals and to evaluate their relationship with third molars roots. The samples were divided into 3 groups according to the bifurcation relationship to third molars: class A - uninvolved, class B - close relationship, class C - intimate relationship and class D - absence of third molars. Furthermore, the whole sample was classified according to Langlais et al. (1985). The authors found that unilateral bifurcation (Type 1) was the most frequent type (72.6%), followed by unilateral Type 2 (19.3%). Class D was the most frequent (57.33%), followed by class C (21.33%), class B (13.33%) and class A (8%). The author postulated that most cases were unilateral bifid mandibular canals extending to the third molar or adjacent regions.

Orhan et al. (2011) evaluated 484 hemimandiles in a Turkish population using CBCT imaging and found that 225 (46.5%) sides were with bifid mandibular canal. Forward canal (29.80%) was the most frequent type, followed by the retromolar (28.10%), the buccolingual (14.50%) and the dental canal type (8.30%). Mean lengths of bifid canals were 13.6mm (right side) and 14.1mm (left side). Mean superior angles were 139 degree (right side) and 141 degree (left side), whereas mean inferior angles were 38 degree on the right side and 32 degree on the left side (Figure 2.4). No significant differences were found in relation to gender, length or angle between right and left side.

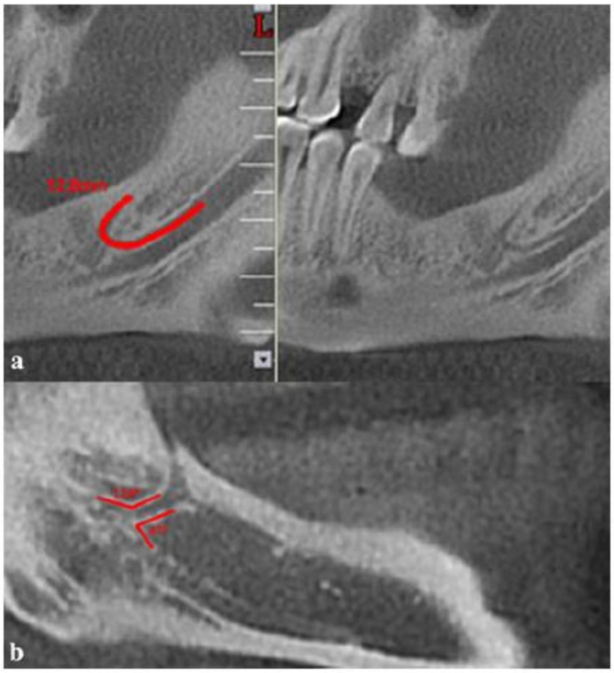

Figure 2.4: Bifid mandibular canal A.Bifid mandibular canal with and without measurement of the canal in the same patient (Sagittal view). B.Measurement of superior and inferior angle of the bifid mandibular canal (Orhan et al., 2011).

Naitoh et al. (2009) utilized CBCT reconstructed images of 122 patients who had undergone preoperative imaging for dental implant treatment. The course of the main MC was observed and the length of the bifid mandibular canal was evaluated and measured. Statistics showed that 65% (55 women and 24 men) of patients had bifid mandibular canal in the mandibular ramus region and 43% of sides were affected by this variation. There was no significant difference between genders. Bifid canal was observed in 96 sides, and trifid were seen in nine sides.

According to the report by López-Videla Montaño et al. (2010), 69% of the 84 subjects studied (52 women, 32 men) were with at least one variation in the pathway of the inferior alveolar canal. According to Naitoh et al. (2009) classification, anterior elongation with confluence was the highest frequency (39.28%) and, retromolar canal was the second most popular variations (23.80%). Statistically significant difference was found when comparing the sagittal slices with the coronal slices of the volumetric study through high resolution tomography in relation with the panoramic reconstruction. The latter suggests that the panoramic images were not sufficient to look for variables in the pathway of the inferior dental canal. It was also found that there was a statistically significant difference (p = 0.02) amongst the gender for the variable classified as lingual canal**.**

In another larger study conducted in Korea (Kang et al., 2014), the existence of the bifid mandibular canal was evaluated in 1933 Korean patients (884 male and 1049 female) using CBCT technologies. The bifid mandibular canal was identified and classified into four types, namely, the forward canal, buccolingual canal, dental canal, and retromolar canal. Bifid mandibular canals were observed in 198 (10.2%) of the sample size. The most frequently observed type of bifid mandibular canal was the retromolar canal (n=104, rate: 52.5%) without any significant difference with regards to age and gender. The authors revealed that the mean diameter of the accessory canal was 1.27 mm (range: 0.27-3.29 mm). The mean length of the bifid mandibular canal (BMC) was 14.97mm (range: 2.17-38.8 mm) with only a significant difference between the dental canal type and the rest types.

Table 2.1: Prevelance of bifid mandibular canal by geographical location

Study	**Country**	**prevalence rate**
Orhan et al. (2011) Siniflandirilmasi and Kanallarin (2000)	Turkey	1.85% ~ 46.5%
De Oliveira-Santos et al. (2012)	Belgium	19%
Fu et al. (2014) Shen et al. (2014)	Taiwan	30.6% ~ 44.7%
Kuribayashi et al. (2010) Naitoh et al. (2009)	Japan	15.6% ~ 65%
Kang et al. (2014) Rashsuren et al. (2014)	Korea	10.2% ~ 22.6%
Lara et al. (2010) Rashid et al. (2011)	Iraq	1.88% ~ 5.95%
Kalantar Motamedi et al. (2015)	Iran	1.2%
Bogdan et al. (2006)	Hungary	Panoramic : 0.2% Dry mandible study :17.4
Sanchis et al. (2003)	Spain	0.35%
Grover & Lorton (1983)	USA	0.08%
Kasabah & Modelle (2013)	Syria	0.98%
Valarelli et al. (2007) Kuczynski et al.(2014) Andrade et al. (2015) Rossi et al. (2009)	Brazil	1.98% ~ 12.75%
López-Videla Montaño et al.(2010)	Colombia	69%

Table 2.2: Prevelance of bifid mandibular canal obtained using different detection methods.

Authors	**Prevalence**	**Radiographic Technology**
Bogdán et al. (2006)	17.4% 0.2%	Dry mandible study Panoramic
Nortje et al. (1977)	0.9%	Panoramic
Durst and Snow (1980)	8.3%	Panoramic
Grover and Lorton (1983)	0.08%	Panoramic
Langlais et al. (1985)	0.95%	Panoramic
Zografos et al. (1990)	0.4%	Panoramic
Akgunlu and Kansu (2000)	17.8%	Panoramic
KL and JR (2001)	7.85%	panoramic
Sanchis et al. (2003)	0.35%	panoramic
Valarelli (2007)	12.07%	panoramic
Rossi et al. (2009)	8.6%	panoramic
Salvador et al. (2010)	30.6%	Panoramic
Lara et al. (2010)	5.0%	panoramic
Kim et al. (2011)	0.038%	panoramic
Rashid et al. (2011)	1.88%	panoramic
Kasabah and Modellel (2013)	0.98%	panoramic
Kuczynski et al. (2014)	1.98%	panoramic
F. S. Neves et al. (2014)	7.4% 9.8%	panoramic CBCT
Andrade et al. (2015)	5.3%	panoramic
Kalantar Motamedi et al. (2015)	1.2%	panoramic
Rouas et al. (2007)	<0.05%	CT & CBCT
M. Naitoh et al. (2009)	64.8%	CBCT
Kuribayashi et al. (2010)	15.6%	CBCT
López-Videla Montaño et al. (2010)	8.3% 69.0%	Panoramic CBCT Note: inclusive of lingual canal, buccal canal and trifid canal
Orhan et al. (2011)	66.5%	CBCT
de Oliveira-Santos et al. (2012)	19.0%	CBCT Only bifid MC with diameter bigger than 1 mm were included
Muinelo-Lorenzo et al. (2014)	16.8% 36.8%	Panoramic CBCT
Kang et al. (2014)	10.2%	CBCT
Rashsuren et al. (2014)	22.6%	CBCT Note: Added a Type V which involved trifid canals.

Table 2.2 (continued): Prevelance of bifid mandibular canal obtained using different detection methods

Authors	**Prevalence**	**Radiographic Technology**
Shen et al. (2014)	41.2%	CBCT & Multislice CT
Fu et al. (2014)	30.6%	CT
Yi et al. (2015)	18.06%	CBCT
Lins et al. (2015)	16.7%	CT

Table 2.3: Case studies reported using different imaging modalities.

Author	**No. of Cases**	**Unilateral (U)/ Bilateral (B)**	**Detection methods**	**Further Enhancement**
Kiersch and Jordan (1973)	1	1/U	Panoramic	None
Patterson and Funke (1973)	1	1/U	Panoramic	Lateral projection
Nortje et al. (1977)	33	13/U 20/B	Panoramic	None
Mader and Konzelman (1981)	1	1/U	Panoramic	Panoramic + lateral projection
Strider (1988)	1	1/B	Lateral projection	Vertical ramus
Quattrone et al. (1989)	1	2/B	Axial tomodensitometry	Osteotomy
Driscoll (1990)	2	2/U	Panoramic	None
Meoli et al. (1993)	1	1/U near double mental foramen	Para-axial Tomography	None
Berberi et al. (1994)	2	1/U near double mental foramen	Different Tomodensitometric cuts	None
E Kaufman et al. (2000)	1	1/short B	Panoramic	None
Auluck et al. (2005)	1	Triple	Panoramic	None
Wyatt (1996)	1	1/U	Panoramic	None
Guimarães et al. (2014)	1	1/U	CT	None

Table 2.3(continued): Case studies reported using different imaging modalities.

Author	**No. of Cases**	**Unilateral (U)/ Bilateral (B)**	**Detection method**	**Further Enhancement**
Devito and Tamburus (2012)	1	1/U	OPG - Panoramic	None
Bhateja et al. (2014)	1	1/B	OPG - Panoramic	None
Naitoh et al. (2007)	3	1/U 2/B	Panoramic	multislice helical CT
Sanchis et al. (2003)	7	3/U 4/B	Panoramic	computed axial tomography
Patel and Andresen (2013)	1	1/U	Panoramic	None
Grover and Lorton (1983)	4	1/U 3/B	Panoramic	None
Miloglu et al. (2009)	1	1/B	Panoramic	None
Claeys and Wackens (2005)	1	1/U	Panoramic	CT
Mizbah et al. (2011)	1	1/B	Panoramic	CBCT revealed BMC at the left side and a trifid mandibular canal at the right side
Khairallah (2015)	1	1/B	CBCT	None
Fredekind et al. (1995)	1	1/B	Panoramic	None
Nikzad et al. (2008)	1	1/U	CT	Double mandibular foramina
Berberi et al. (1994)	1	1/U	Panoramic	CT
Lew and Townsend (2006)	1	1/B	Panoramic	Lateral oblique radiographs
Rouas et al. (2007)	3	2/U 1/B	CT	CBCT
Wadhwani et al. (2008)	1	1/B	Panoramic	Right : bifid Left : trifid
Eliades et al. (2015)	3 1 1	3/U 1/U 1/U	panoramic CT CBCT	None
Auluck et al. (2007)	6	3/U 1/B 1/U	panoramic panoramic CT	1 case trifid using panoramic radiograph

Table 2.3(continued): Case studies reported using different imaging modalities.

Author	**No. of Cases**	**Unilateral (U)/ Bilateral (B)**	**Detection methods**	**Further Enhancement**
Maqbool et al. (2013)	1	1/U	CBCT	None
Mizbah et al. (2012)	2	1/B 1/U other side is trifid	panoramic panoramic	CBCT CBCT discovered trifid

3.2.3 False detection in panoramic images

On a panoramic radiograph, it might be difficult to identify a mandibular canal and its variations. This may be due to the ghost shadow created by the opposing semi-mandible and the overlapping of the pharyngeal airway, soft palate, and uvula (M. Naitoh et al., 2009; Orhan et al., 2011). In addition thin radiopaque lines might be formed by the bony imprint of the mylohyoid nerve, which separated from the inferior alveolar nerve and travelled to the floor of the mouth on the lingual surface of the mandible (Wilson et al., 1984). Moreover, a false appearance could be observed due to sclerotic lines adjacent to the mylohyoid muscle insertion on the lingual surface of the mandible, with a distribution parallel to the mandibular canal (Claeys & Wackens, 2005). Some studies have reported that the prevalence of the bifid mandibular canal might be inaccurate and underestimated using panoramic radiography. Klinge et al. (1989) reported that the mandibular canal could be identified in only 63.9% known cases from panoramic radiographs. Lindh et al. (1992) also reported that the mandibular canals was clearly visible in only 25% of the panoramic radiographs.

One of the most popular study conducted by Kim et al. (2011) was to confirm presence of false bifid mandibular canals. After investigating 1000 panoramic radiographs and 40 dry mandibles, they reported the prevalence was 0.038 amongst the Korean population. Stereoscopic and histological examination of a cross-section of the mandible showed that only one canal was a true canal containing neurovascular bundles: the other was false, reflecting only a bony trabecular pattern.

Serman (2012) suggested that the mylohyoid groove must be taken into consideration when discussing bifid mandibular canals . The mylohyoid groove commences in the region of the inferior margin of the mandibular foramen, runs downwards and forwards and fades away in the submandibular salivary gland fossa.

Arensburg and Nathan (1979) found that in approximately 16% of cases, the mylohyoid groove is partially or totally converted into a bony canal by ossification of the covering membrane; the opening of the canal being seen on a mandible, proximal to the mandibular foramen, while a second opening is present at the distal end of the main mandibular canal. The mylohyoid groove may then give the impression on a panoramic radiograph that there is a bifid mandibular canal.

Although CBCT provides better viewing of anatomical structures, including location, shape, and relationship with the surrounding area, panoramic radiography is a conventional imaging modality that can be used in the study of the bifid mandibular canals. In a recent research Neves et al. (2014) stated that there is no significant difference between CBCT and panoramic images.

All in all, diagnostic errors or erroneous detection in interpreting a bifid mandibular canal in a panoramic radiograph may be attributed to superimposition of structures, inadequate positioning of the patient, bone condensation produced by the mylohyoid muscle in the floor of the mouth, distortion of the radiography and magnification of the device (Correr et al., 2013; Kalantar Motamedi et al., 2014; Sanchis et al., 2003).

In a rare case reported by Guimarães et al. (2014) they mentioned an anatomical variation of inferior alveolar nerve in a 14-year-old child mimicking a recurrence of keratocystic odontogenic tumor, there after further investigation it was found to be a bifid mandibular canal case. Evidently the presence of bifid mandibular canal can be misdiagnosed for a mandibular lesion.

2.2.4 CBCT reliability in detecting BMC

A study was conducted by Kukami (2012) to assess the validity of limited (small field of view) Cone-Beam CT (CBCT) in detecting the distribution of bifid mandibular canals in the retromolar region. He compared the findings with those of panoramic radiography and spiral CT imaging. Subsequently he confirmed the contents of such canals depicted on limited CBCT images by using gross anatomical and histological methods. The spiral CT and limited CBCT images showed the bilateral bifid mandibular canals in the retromolar region, whereas the panoramic radiographs indicated the presence of only the left bifid mandibular canal. The canal distribution was more distinct in the limited CBCT images than in the spiral CT images and the cross-sectional limited CBCT images were consistent with the gross anatomical sections. Histologically, the canals contained several nerve bundles and arteries among which the largest nerve and artery were of a similar size. The authors claimed that limited CBCT is valuable for assessing the distribution of bifid mandibular canals. It is clinically significant to accurately localize a bifid mandibular canal of the retromolar region because it contains a nerve bundle and artery.

Another study conducted by Naitoh et al. (2010) was to compare Cone-Beam Computed Tomography (CBCT) and multislice CT (MSCT). However, clinical differences between CBCT and MSCT in this task have not been fully clarified. In this investigation, the detection of fine anatomical structures in the mandible was assessed and compared between CBCT and MSCT images. The sample consisted of 28 patients who had undergone CBCT and MSCT. The bifid mandibular canal in the mandibular ramus, accessory mental and buccal foramina, and median and lateral lingual bony canals were observed in 2-D images, and the findings were compared between CBCT and MSCT. Four of 19 canals observed in CBCT were not observed in MSCT images. Three accessory mental foramina in 2 patients and 28 lateral lingual bony canals in 18 patients were observed consistently using the two methods. The authors claimed that depiction of fine anatomic features in the mandible associated with neurovascular structures is consistent between CBCT and MSCT images.

A study by Muinelo-Lorenzo et al. (2014) compared cone beam CT versus panoramic radiography in the detection of bifid mandibular canals and retromolar foramina. They found that panoramic radiograph was unable to sufficiently identify BMCs and RFs. The diameter of these anatomical landmarks represents a relevant factor for visualization on panoramic radiograph. Pre-operative images using only panoramic radiography may lead to underestimation of the presence of BMCs and this may lead to surgical complications and anesthetic failures, which could have been avoided using a CBCT device to have a premium detection.

2.3 Bifid mandibular canal development

The most accepted theory that explains the occurrence of bifid and trifid mandibular canals in some patients has been reported by Chavez-Lomeli et al. (1996). The authors claimed that during the intrauterine development of the hemi-mandible, the mandibular canal encloses three individual nerve branches with different origins. It has been suggested there might be three inferior dental nerves innervating three groups of mandibular teeth. The canal to the incisors appeared first followed by the canal to the primary molars and subsequently canal to the permanent molars. These canals are directed from the lingual surface of mandibular ramus towards different tooth groups. During rapid prenatal growth and remodeling in the ramus region there is coalescence of canal entrances that are obvious at birth and they subsequently fuse together to form a single nerve. Bifid and trifid mandibular canal occur as a result of incomplete fusion of these nerves (Figure 2.5).

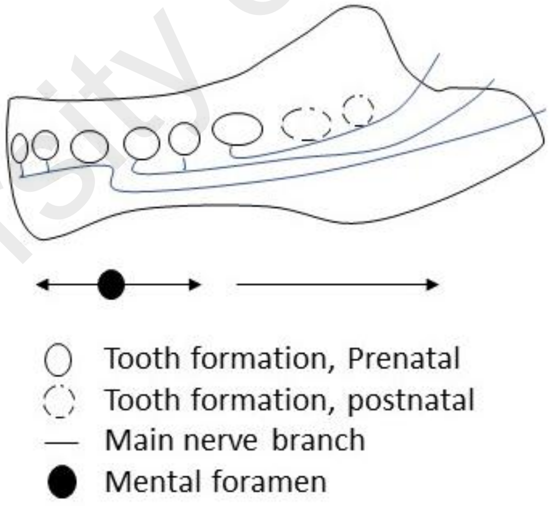

Figure 2.5: Schematic drawing of a human fetal mandible in the lateral view in the latter part of the prenatal period. The pattern of innervation of the dentition from three separate nerve branches is indicated. The arrows indicate the sequence in which the teeth within each group are innervated. Based on the appearance of three separate canals in the prenatal mandible, three areas of innervation in the mandible are suggested, one for the incisors and canines, one for the premolars, and one for the molars. Adapted and modified from (M. E. Chavez-Lomeli et al., 1996).

In another research study done by Mader and Konzelman (1981) they claimed that the cause of bifid mandibular canal may be due to a possible relationship with a general pathology, a case associated with Down's syndrome was observed in a 29-year old patient.

2.4 Bifid mandibular canal classification

Some researchers have tried to classify the bifid mandibular canals that were detected using different imaging technologies. Nortje et al. (1977) published two articles following a retrospective study of 3612 panoramic radiographs of clinical patients in South Africa. Three main patterns of duplication were found: Type 1 (the most common) - duplicate canals originating from a single mandibular foramen, Type 2 - a short upper canal extending to the second or the third molar area, and Type 3 (the least common) - two canals of equal size, arising from separate foramina that join in the molar area. In their second article, they reported a new variation. Type 4 is a double-canal variation in which the supplemental canals arise from the retromolar area and join the main canals in the retromolar area (Nortjé et al., 1977).

On the basis of panoramic radiography, Langlais et al. (1985) have classified the bifid mandibular canal into four types according to anatomical location and configuration. Type 1 consists of unilateral or bilateral bifid mandibular canals extending to the third molar or the immediate surrounding area. Type 2 consists of unilateral or bilateral bifid mandibular canals that extend along the course of the main canal and rejoin it within the ramus or the body of the mandible. Type 3 is a combination of the first two categories. Type 4 consists of two canals, each of which originates from a separate mandibular foramen and then joins to form a larger canal. Both classification mentioned above were based on the findings using the panoramic radiography.

A number of other research groups (Kang et al., 2014; M. Naitoh et al., 2009; Orhan et al., 2011) employed CBCT imaging to classify the bifid mandibular canal according to the origin site and the direction of the bifurcated canal from the mandibular canal as 4 types: i) forward canal: the branch arising from the superior wall of the main canal; ii) buccolingual canal: the branch arising from the buccal or the lingual wall of the main canal; iii) dental canal: in this case, the end of the bifurcated canal reached the root apex of the molars; iv) retromolar canal: the branch arising from the main canal, opening at the retromolar foramen (Table 2.4).

Table 2.4: Summary of the type of the bifid mandibular canal reported by previous research groups.

Classification type	**Rate of each type of the bifid mandibular canal**		
	Naitoh et al. (2009)	**Orhan et al. (2010)**	**Kang et al. (2004)**
Forward canal	60%	38%	40.90%
Buccolingual canal	1.8%	17.80%	2.0%
Dental canal	8.8%	9.3%	4.5%
Retromolar canal	29.8%	34.7%	52.5%

The length and the diameter of the bifid mandibular canal were studied previously. Naitoh et al. (M. Naitoh et al., 2009) reported that the mean length of the bifid canal was 9.6mm (range: 1.4-25mm) in the case of the forward canal; 1.6mm (range: 1.5-1.7 mm) in the case of the buccolingual canal; 8.9mm (range: 1.6-23.0 mm) in the case of the dental canal; and 14.8mm (range: 7.2-24.5 mm) in the case of the retromolar canal. Kuribayashi et al. , 2010) reported that the diameter of the accessory canal was greater than or equal to 50% of the main canal in 23 (49%) cases and less than 50% in 24 (51%) cases. A list of bifid mandibular canal classifications by different authors are summarized in Table 2.5.

Table 2.5: Classifications of mandibular canal branching (1971-2010).

Study	**Methodology**	**Sample size**	**BMC prevalence**	**Classification**	**Frequency of the types**	**Extend from**	**Note**	**Direction**	**End of termination**
Carter and Keen (1971)	Unilateral radiographs and dissection	80	38.75%	Type I	61.25%	Extended from single mandibular foramen in the Ramus region	Single large structure with very short dental branches	Superior to the tips of molars roots	Mental branching
				Type II	13.75% (types 1 or 2)	Extended from single mandibular foramen in the Ramus region	Substantially lower down, with dental branches given off more posteriorly, longer and oblique	Oblique, toward the tips of molars roots	Mental branching
				Type III	25% (types 2 or 3)	Extended from single mandibular foramen in the Ramus region	Two large branches initiated posteriorly	Uppers like alveolar branches	Upper to the tips of the roots; Lower to mental foramen

Table 2.5(continued): Classifications of mandibular canal branching (1971-2010).

Nortje et al. (1977)	Panoramic radiographs	3612	0.9	Type Ia	30.3% of duplication cases	Extended from single mandibular foramen in the Ramus region	Two canals of a similar width (lower slightly narrower)	Inferior narrower	
				Type Ib		Extended from single mandibular foramen in the Ramus region	Double (Superior narrower)	Anterior	
				Type 2		Extended from single mandibular foramen in the Ramus region	Double (Superior shorter)	Anterior	Superior: toward 2nd and 3rd molars and inferior: toward mental foramen
				Type 3		Extended from separated mandibular foramen in the Ramus region	Double (Join in the molars region)	Anterior	Molars region

Table 2.5(continued): Classifications of mandibular canal branching (1971-2010).

Study	**Methodology**	**SZ**	**BMC prevalence**	**Classification**	**Frequency of the types**	**Extend from**	**Note**	**Direction**	**End of termination**
Nortjé et al. (1977)		3612		Type IV		Extended from single mandibular foramen in the Ramus region	Double (Superior narrower than the main canal)	Anterior	Ramus region
Langlais et al. (1985)	Panoramic Radiographs Conventional	6000	0.95	Type I	38.6%	Extended from single mandibular foramen in the Ramus region	Double (Superior shorter)	Anterior	3rd molar and adjacent region
				Type 2	54.4%	Extended from single mandibular foramen in the Ramus region	Double (Joining anteriorly)	Anterior	Ramus or mandibular body regions
				Type 3	3.5%	Extended from single mandibular foramen in the Ramus region	Double (Combination of types II and III)	Anterior	Ramus, retromolar on 3rd molar regions
				Type 4	3.5%	Extended from separate mandibular foramen in the Ramus region	Double (Joining anteriorly)	Inferior	Ramus region

Table 2.5(continued): Classifications of mandibular canal branching (1971-2010).

Study	**Methodology**	**SZ**	**BMC prevalence**	**Classification**	**Frequency of the types**	**Extend from**	**Note**	**Direction**	**End of termination**
Kieser et al. (2005)	Occlusal and unilateral radiographs and dissection	107 mandibles (25 radiographic exams)	0%	Type I (detected by mean of dissections and radiographs)		Extended from single mandibular foramen in the Ramus region	Single, without branches		Mental foramen region
				Type II (detected by mean of dissections and radiographs)		Mandibular body region	Series of individual branches	Superior	Alveolar process (Edentulous mandibles)
				Type III (detected by mean of dissections and radiographs)		Molars region		Superior	Molar region (Edentulous mandibles)
				Type IV (Dissections,radiographs)		Distal and proximal regions		Distal plexus forward. Proximal plexus toward superior	Alveolar process (Edentulous mandibles)

Table 2.5(continued): Classifications of mandibular canal branching (1971-2010).

Study	**Methodology**	**SZ**	**BMC prevalence**	**Classification**	**Frequency of the types**	**Extend from**	**Note**	**Direction**	**End of termination**
Munetaka Naitoh, Kino Nakahara, et al. (2009)	CBCT	122	65%	Type I Retromolar	29.8%	Ramus region	Superior	Superior	Retromolar region
				Type II Dental Canal (3º molar)	7%	Ramus region	Superior	Anterior	Root Apex of the third molar
				Type II Dental Canal (2º molar)	1.8%	Ramus region	Superior	Anterior	Root Apex of the second molar
				Type III Forward Canal (with confluence)	4.5%	Ramus region	Superior (Joining to the main canal)	Anterior	Mandibular body
				Type III Forward Canal (without confluence)	55.3%	Ramus region	Superior	Anterior	Mandibular body
				Type IV Buccal or lingual canal	1.8%	Ramus region	Lateral	Inferior (Buccal or lingual)	Ramus region

3.5 Trifid mandibular canal

Studying the mandibular canal variations is of utmost importance prior to any surgical procedure in the mandible. One of these variations are trifid mandibular canal which has been reported by different studies (Adisen et al., 2013; Auluck et al., 2005; Auluck & Pai, 2005; Auluck et al., 2007; Bogdán et al., 2006; Karamifar et al., 2009; Mizbah et al., 2012; Rashsuren et al., 2014; Wadhwani et al., 2008). Trifid mandibular canal is defined as the identification of three connected mandibular canal in the mandible, one considered as main canal and the other two are abnormal variations. The main mandibular canal is a single tunnel bilaterally through which neurovascular bundles passes to supply mandibular teeth and adjacent structures. It is bounded by bony tissue and extend from mandibular foramen posteriorly to mental foramen anteriorly (Sanchis et al., 2003). Studying the accurate location of the mandibular canal and its variations is very important prior to any surgical intervention in this area to avoid post-operative complications such as impacted third molar extraction (Kipp et al., 1980), implant treatment (Smiler, 1993), sagittal split osteotomy (Tamas, 1987; Ylikontiola et al., 2000), local anesthesia injection into the inferior alveolar nerve (Jones & Thrash, 1992), preprosthetic surgeries due to removable denture planning (Bogdan et al., 2006; Karamifar et al., 2009).

The reported frequency rate of the trifid mandibular canal was 5.8% among Korean population (Rashsuren et al., 2014) while with a lower frequency rate (2.2%) among Hungarian population (Bogdán et al., 2006). Several previous studies have reported case studies about trifid mandibular canal detected using panoramic and CBCT images (Table 2.6). The first established case of a trifid mandibular canal was presented in a study on dry mandibles (Bogdán et al., 2006).

The trifid canals were more easily noticed in CBCT scans than only employing panoramic images (de Oliveira-Santos et al., 2012; Kuribayashi et al.; M. Naitoh et al., 2009; Naitoh et al., 2010; Orhan et al., 2011).

Table 2.6: The prevalance of trifid mandibular canal reported by different studies.

Author	**Type of study**	**Detection methods**	**No. of cases**
Auluck et al. (2005)	Case study	Panoramic	1
Auluck and Pai (2005)	Case study	Panoramic	1
Auluck et al. (2007)	Case study	Panoramic	1
Bogdán et al. (2006)	Cadaver study	Direct assessment	1
Karamifar et al. (2009)	Case study	Panoramic	1
Mizbah et al. (2012)	Case study	CBCT	2
Rashsuren et al. (2014)	Cross-sectional (500 patients)	CBCT	7 trifid (5.8%)
Adisen et al. (2013)	Case study	CBCT	1
Wadhwani et al. (2008)	Case study	Panoramic	1
Bogdán et al. (2006)	Anatomical dissection of dry skull (60 dry mandibles)	Direct assessment	1 (2.2%)

2.6 Retromolar canal

2.6.1 Introduction

The retromolar canal (RMC) and foramen, is an anatomical variation of the mandibular canal in the mandibular retromolar area, houses and transmits neurovascular elements that may innervate the mandibular third molar and associated tissues. which has gained only occasional attention in the literature and is not described in most anatomical textbooks (von Arx et al., 2013).

The retromolar foramen is located posteriorly in the mandible, precisely in the retromolar area. It is considered as an anatomical variation outlined by the external oblique ridge, the attachment of the ptery-gomandibular raphe, and the last mandibular molar. The retromolar canal maybe found between the inferior alveolar canal and the surface of the mandibular retromolar area carrying a neurovascular bundle (Gamieldien & Van Schoor). This area is important as it often entered during mandibular third molar surgery.

A number of studies have confirmed RMC clinical significance since 1960s by reporting its content which is comprised of nerve fibers and blood vessels. (Reich, 1980; Schejtman et al., 1967; Singh, 1981).

2.6.2 The prevalence of retromolar canal

The retromolar canal is considered as one of the types of the bifid mandibular canal (BMC) classification. It is Type1 in Naitoh et al.'s classification (M. Naitoh et al., 2009) and Langlais et al.'s classification (Langlais et al., 1985). It is Type 4 in Nortje et al.'s classification (Nortje et al., 1977). RMC has been observed in studies that determined the prevalence of BMC using previous classifications. Based on Naitoh et al.'s classification, retromolar canal made up between 4% and 75.7% of BMC in different studies (Table 3.7). It is also the least common variant in 2 studies that assessed BMC using Nortje et al.'s classification (Nortje et al., 1977). However, when the retromolar canals were defined as Type I variant using Langlais et al.'s classification (Langlais et al., 1985), it makes up between 1.6% and 84.0% of BMC. It is the most common variant in 7 studies (Correr et al., 2013; Kasabah & Modellel, 2013; KL & JR, 2001; Kuczynski et al., 2014; Langlais et al., 1985; Lara et al., 2010; Rossi, Freire, Prado, Prado, Botacin, & Caria, 2012) and the second most common variant in another 3 studies (Akgunlu & Kansu, 2000; Salvador et al., 2010; Valarelli et al., 2007).

2.6.3 Racial differences

RMC is the most common variant in Korean and Turkish, making up between 52.2% and 75.7% of BMC (Kang et al., 2014; Rashsuren et al., 2014). It is the second most common variant in Japanese, Turkish and Latin Americans (López-Videla Montaño et al., 2010; Muinelo-Lorenzo et al., 2014; M. Naitoh et al., 2009), but is the least common variant in Han Chinese (Yi et al., 2015). Difference in ranking is seen in the Turkish, where it was the most common variant in children (Orhan et al., 2013) but is the second most common variant in adults (Orhan et al., 2011).

2.6.4 Retromolar canal detection

Retromolar canals (RMC) have been reported by different studies using panoramic radiographs and 3D imaging. Panoramic radiographs have their obvious limitations and is considered to have restricted ability in retromolar foramen (RMF) detection (Sisman et al., 2015; von Arx et al., 2011). A more accurate information about RMF was noticed when performing cross-sectional Cone-Beam Computed tomography (CBCT) images. Von Arx et al. (2011) reported that of the 31 RMC observed with CBCT scan, only seven RMC were visible on corresponding panoramic radiographs of 100 patients. Similarly, Sisman et al. (2015) reported that of the 253 RMC observed with CBCT scan, only 29 were visible on corresponding panoramic radiographs of 632 patients. This inadequacy possibly happened due to the inability of panoramic radiographs to detect retromolar canal that was too thin.

2.6.5 Anatomical consideration

Anatomically, the RMC runs from the distal wall of the third molar then ascends in an anteroposterior direction to exit the bone through retro molar formaen (RMF) in the retromolar area (fossa/trigone) (Ossenberg, 1986) (Figure 2.6). Schejtman et al. (1967) reported that the accessory branches were distributed upon the tendon of the temporal muscle, the buccinator, the most posterior region of the alveolar process, and the third mandibular molar. Kodera and Hashimoto (1995) also reported that the retromolar nerve branched off to the buccal mucosa and the buccal gingiva of the mandibular premolar and molar regions in a Japanese cadaver. In contrast, Singh (1981) reported observing a variant of the buccal nerve at the retromolar fossa area that innervated the buccal sulcus and gingivae in a third molar surgical patient. Jablonski et al. (1985) had reported an abnormal buccal nerve originating from the IAN within the ramus of the mandible, traversing through the RMC to emerge through the RMF and then passed forward and upward to penetrate the buccinator muscle. A list of studies with prevalence rate of retromolar canal is summarized in Table 2.7, Table 2.8 and Table 2.9.

There has been a debate over the content and direction of the retromolar canal, although most studies agreed that it contained neurovascular bundles (Bilecenoglu & Tuncer, 2006; Carter & Keen, 1971; Kawai et al., 2012; Kodera & Hashimoto, 1995; Schejtman et al., 1967). Some researchers suggest that the contents of this canal originate from the mandibular neurovascular bundle before it enters the mandibular canal (E Kaufman et al., 2000) while others suggested that these elements arise from the neurovascular bundle in the mandibular canal to later lie in the buccal region (Kodera & Hashimoto, 1995; Ossenberg, 1986; Schejtman et al., 1967).

Many studies have reported that the RMF was more frequent unilaterally than bilaterally (Alves & Deana, 2015; Bilecenoglu & Tuncer, 2006; Bilodi et al., 2013; Han & Hwang, 2014; Lizio et al., 2013; Motta-Junior et al., 2012; Narayana et al., 2002; Ossenberg, 1986; Priya et al., 2005; Rossi, Freire, Prado, Prado, Botacin, & Caria, 2012; Schejtman et al., 1967; Suazo Galdámes et al., 2008; von Arx et al., 2011) and with no preferred side (Ossenberg, 1986),

2.6.6 Factors influencing the retromolar canal

Many studies reported that the RMF is a frequent anatomical variant and shows no differences between gender (Alves & Deana, 2015; Han & Hwang, 2014; Kodera & Hashimoto, 1995; Ossenberg, 1986; Patil, Matsuda, Nakajima, et al., 2013; Pyle et al., 1998; Sawyer & Kiely, 1991; von Arx et al., 2011) and can be unilateral or bilateral (Alves & Deana, 2015; Bilecenoglu & Tuncer, 2006; Ossenberg, 1986; Patil, Matsuda, Nakajima, et al., 2013; Sawyer & Kiely, 1991; Suazo Galdámes et al., 2008; von Arx et al., 2011). However Akhtar et al. (2014) reported a female predilection. Several authors (Han & Hwang, 2014; Narayana et al., 2002) reported greater frequency on the right side, while Motta-Junior et al. (2012) and Priya et al.(2005) reported greater frequency on the left side.

Table 2.7: The prevalence of retromolar canal as reported in the literature.

Authors	**Population**	**Prevalence**	**Assessment method**
Schejtman et al. (1967)	Argentine aborigines	72%	Wet human mandible
Patil, Matsuda, Nakajima, et al. (2013)	Japanese	75.4%	Cone Beam Computed Tomography of live patients
Capote et al. (2015)	Brazilian	8.8%	Panoramic radiography Note: The prevalence reported included only retromolar canal
Sisman et al. (2015)	Turkey	3.06% 26.7%	Panoramic radiography Cone Beam Computed Tomography

Table 2.8 : The prevalence of retromolar foramen as reported in the literature.

Authors	**Population**	**Prevalence**	**Assessment method**
Azaz and Lustmann (1973)	Israeli	12.8%	Dry human mandible
Sagne et al. (1977)	Ancient Swedish	20%	Dry human mandible
Sawyer and Kiely (1991)	[American	7.7%	Dry human mandible
Pyle et al. (1998)	Afro American & Caucasians	7.8%	Dry human mandible
Priya et al. (2005)	Indian	12.7%	Dry human mandible
Bilecenoglu and Tuncer (2006)[§]	Turkish	25.0%	Dry human mandible
[¤]Kawai et al. (2012)	Japanese	52.0%	Cone Beam Computed Tomography of cadavers
Motta-Junior et al. (2012)	Brazilian	17.1%	Dry human mandible
Rossi, Freire, Prado, Prado, Botacin, and Caria (2012)	Brazilian	26.58%	Dry human mandible
Athavale et al. (2013)	Indian	*14.08%	Dry & wet human mandible Note: *The prevalence quoted is for retromolar foramen in dry mandibles. No retromolar foramen was observed in the cadaveric study.
Bilodi et al. (2013)	Indian	12.19%	Dry human mandible
Gupta et al. (2013)	Indian	18.0%	Dry human mandible
Ashraf khanA et al. (2013)	Indian	13.23%	Dry human mandible
Shantharam et al. (2013)	Indian	3.48%	Dry human mandible Note: The prevalence reported included only retromolar foramen
Soman (2014)	Indian	12.5%	Dry human mandible Note: The prevalence reported included only retromolar foramen
Park et al. (2014)	Korean	46.8%	Dry human mandible Note: The prevalence reported included only retromolar foramen
Potu et al. (2013)	Indian	11.7%	Dry human mandible Note: The prevalence reported included only retromolar foramen

Table 2.8(continued): The prevalence of retromolar foramen as reported in the literature.

Poornima et al. (2015)	Indian	9.81%	Dry human mandible Note: The prevalence reported included only retromolar foramen
Tiwari and Roopashree Ramakrishna (2015)	Indian	16.0%	Dry human mandible Note: The prevalence reported included only retromolar foramen
Motamedi et al. (2015)	Iranian	40.4%	Wet human mandible (cadaver)

Table 2.9: The prevalence of retromolar canal and foramen as reported in the literature.

Authors	**Population**	**Prevalence**	**Assessment method**
Kodera and Hashimoto (1995)	[Japanese]	19.5%	Dry human mandible
Narayana et al. (2002)	[Indian]	21.9%	Dry human mandible
Ossenberg (1986) [§]	[Various ethnics]	3.2 – 9.1%	Dry human mandibles Note: This range was noticed in 4 ethnic groups, Italian (8.1%), Japanese (3.2%), Eskimos (8.2%), Canadian White (9.1%)
Suazo Galdámes et al. (2008)	[Brazilian]	12.9%	Dry human mandible
Senthil Kumar and Kesavi (2010)	[Indian]	17.3%	Dry human mandible
von Arx et al. (2011)	[Swiss]	5.8% 25.6%	Panoramic radiography Cone Beam Computed Tomography
Lizio et al. (2013) [#]	[Italian]	16.0%	Cone Beam Computed Tomography
Akhtar et al. (2014) [Indian]	[Indian]	14.7%	Dry human mandible Note: The prevalence reported is a combination that included retromandibular canal and foramen
Alves and Deana (2015)	[Chilean]	18.6%	Dry human mandible for RMF, supported by periapical radiograph in selected cases for assessment of RMC
Han and Hwang (2014)	[Korean]	8.5%	Cone Beam Computed Tomography
Filo et al. (2014)	[Swiss]	16.12%	Cone Beam Computed Tomography
Pimkhaokham et al. (2015)	[Thai]	12.5%	Cone Beam Computed Tomography

[§] Only retromolar foramen >0.5 mm were included, [¤] CBCT scan of cadavers [#] Only retromolars canal with foramen >1mm were included

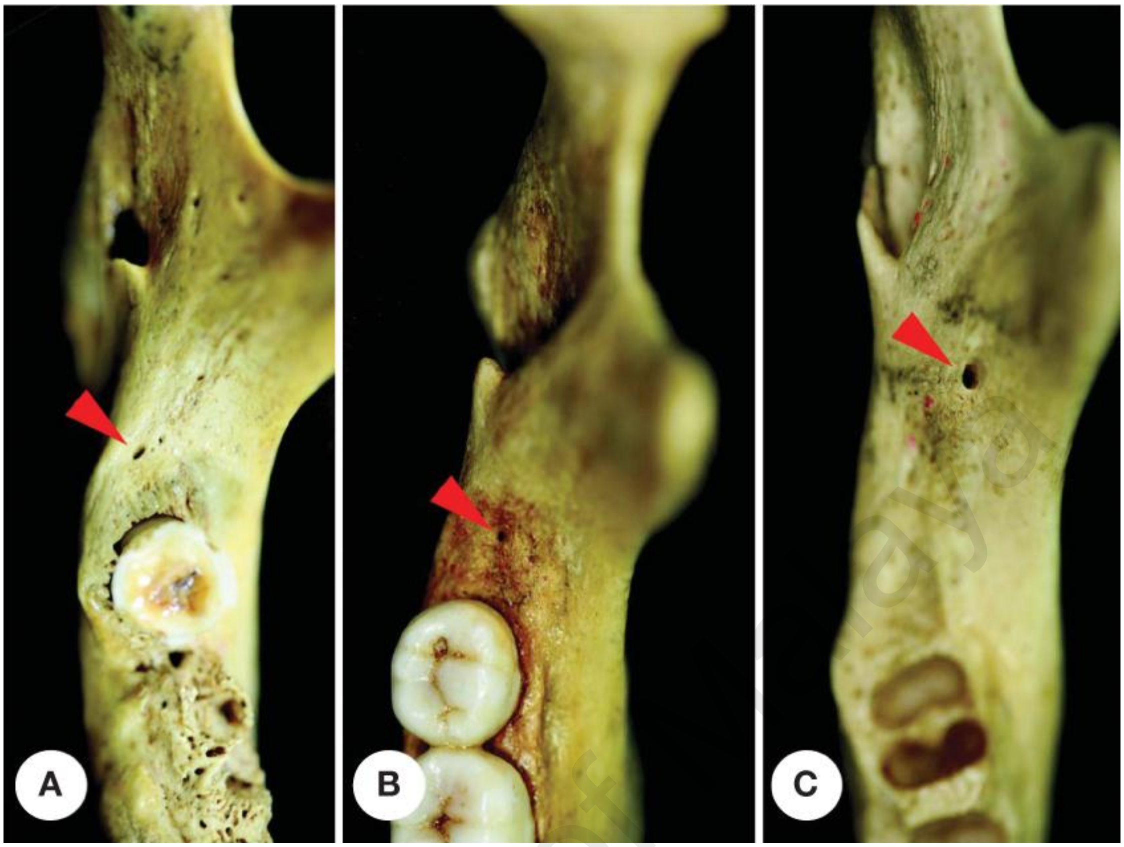

Figure 2.6 Photographs of dry skull in the retromolar trigone zone, showing RMF (arrowheads). (A) RMF located in the RMT and on the lingual side of the midsagittal line of RMT, (B) RMF located in the RMT and on the midsagittal line of RMT, and (C) RMF located out of the RMT and on the buccal side of the midsagittal line of RMT (Park et al., 2014).

2.7 Clinical significance

Irrespective of the type of the mandibular canal variations studied earlier, the presence of these variations can cause some complications. The 2 major clinical implications of the presence of accessory mandibular canals and foramina is: firstly, inadequate local anesthesia, secondly surgical injuries to neurovascular bundles if these canals were undetected preoperatively. For the latter, unexpected intra-operative hemorrhage or postoperative paresthesia to the area of innervations may complicate the surgical procedures being undertaken (Azaz & Lustmann, 1973; Eliades et al., 2015). Other complications such as traumatic neuroma, paresthesia and bleeding can occur during oral and maxillofacial surgery because of possible damage to an unidentified mandibular canal variant. In particular, this should be considered during extraction of an impacted third molar, dental implant treatment, traumatology and reconstructive surgery, and orthognathic surgery (bilateral sagittal split ramus osteotomy technique) (Dario, 2002; Quattrone et al., 1989; Singh et al., 2010).

2.7.1 Local anesthesia

Inadequate anesthesia in the mandible is the most common problem encountered in patients with a bifid or trifid mandibular canal, and it is often due to the conflict between the location of bifurcation and the injection point (Auluck et al., 2007). The position of bifurcation in the mandibular ramus is often superior to the most commonly administered injection point (H. Lee et al., 2009). A number of studies have reported the possibility of local anesthesia failure due to accessory canal presence since 1960s. The cause of failure was especially noticed in the variations that includes two mandibular foramina (Grover & Lorton, 1983; Lew & Townsend, 2006; Rood, 1977; Schejtman et al., 1967; Wadhwani et al., 2008). In reviewing 6 cases of failed inferior alveolar nerve block, Auluck et al.(2007) reported the presence of BMC in 5 cases, and a trifid mandibular canal in the sixth case. Karamifar et al.(2009) reported 2 cases of BMC highlighted that one of the patient had difficulty achieving anesthesia when he had his lower left molar removed. Similarly, Wadhwani et al. (2008) reported that they were able to achieve some soft tissue anesthesia including the lip and tongue, after an inferior alveolar block, but the periodontal tissues surrounding the lower left first molar remained sensitive. Panoramic radiograph showed that the bifid canal apparently had 2 mandibular foramina. Schejtman et al. (1967) informed that local anesthesia failure to the third molar may be caused by presence of retromolar canal.

Clinically this cause of incomplete local anesthesia may remain undetected as accessory canals are often unrecognized since they cannot be seen in the oral cavity. In addition, most dentists do not routinely take radiograph to determine the cause of failure to achieve complete local anesthesia. Somehow, the presence of anatomical variations explain why standard injection techniques are ineffective in some patients, as this accessory branch provides “escape” routes that allow pain impulses to be transmitted continuously (Jeyaseelan & Sharma, 1984; Rood, 1977).

The traditional method of achieving anesthesia is to block the inferior alveolar nerve by depositing the anesthetic solution in the pterygomandibular space at a level slightly above the mandibular foramen before it enters the mandible may not be suitable (Auluck et al., 2007; Lew & Townsen, 2006). Thus, in the case of the bifid mandibular canal, a high inferior alveolar nerve block such as the Gow-Gates technique or the Akinosi technique should be used to perform local anesthesia (Auluck et al., 2007; Meechan, 2002; Miloglu et al., 2009; Rashid et al., 2011). However, these techniques should be used only when there is definitive imaging evidence of multiple mandibular canals and failure of the conventional inferior alveolar nerve block (Kang et al., 2014).

Although these accessory canals and their accompanying foramina have been suggested to cause local anesthetic block failure, one group of investigators suggested that they can be made used to achieve local anesthesia, provided the clinician understand the anatomy of the region. This is particularly possible at the retromolar triangle region. Suazo et al. (2008) reported that this technique was able to achieve 72.5% anesthesia with a latency of 10 minutes, which was sufficient for restorative work to be undertaken at posterior teeth. They claimed that this technique provides the ease of tracing the site of puncture, which could be observed at all times while depositing the anesthetic, with no bleeding as this area has limited vascularisation and a very well adhered mucoperiostium.

However, caution must be expressed as it is not always mandibular canal variations being the causes of failure in achieving sufficient anesthetic result of inferior alveolar nerve block.

1- Various anatomical reasons are;
- Type, shape and morphology of the mandibule.
- Location of the mandibular foramen (E. Kaufman et al., 2000; Keetley & Moles, 2001; Malamed, 2014; Meechan, 2002; Nicholson, 1985).

2- Accessory innervations (communication with inferior alveolar nerve)
- Mylohyoid nerve (Bennett & Townsend, 2001; Blanton & Jeske, 2003; DeSantis & Liebow, 1996; Frommer et al., 1972; Lew & Townsend, 2006; López & Diago, 2006; Madeira et al., 1978; Malamed, 2014; Sillanpää et al., 1988; Stein et al., 2007).
- First cervical branches (C1, C2, C3) (Cruz et al., 1988; Lin et al., 2013).

3- Long buccal nerve (through a retromolar foramen) (Carter & Keen, 1971; Lew & Townsend, 2006; Loizeaux & Devos, 1980; López & Diago, 2006).

4- Increased bone density (E. Kaufman et al., 2000; López & Diago, 2006; Malamed, 2014).

5- Accidentally intravenous injection of the anesthetic solution during the block anesthesia procedure.

6- Unanaesthetised central fibers of the inferior alveolar nerve.

7- Inflammation and infection (i.e. pulpitis or apical periodontitis)(DeSantis & Liebow, 1996; López & Diago, 2006; Meechan, 2002).

8- Incorrect technique performance(iatrogenic error) (Lew & Townsend, 2006).

9- Inappropriate administered dose of anesthetic solution.

10- Ineffective anesthetic solution (i.e. wrong storage of anesthetic solutions) (López & Diago, 2006).

11- Anxious patients (López & Diago, 2006).

12- Reduced pain threshold (Lew & Townsend, 2006).

2.7.2 Orthognathic surgery

The second major clinical implications of the presence of accessory mandibular canals and foramina is the injuries to neurovascular bundles which is caused by orthognathic surgeries. There were 2 cases reported on the presence of BMC in patients undergoing orthognathic surgery. Strider (1988) reported a case of a patient needing an intraoral vertical ramus osteotomy who presented with bilateral BMC identified in panoramic and lateral oblique radiographs. This branching, however did not affect the outcome of the surgery, where the patient did not suffer from post-operative paresthesia. On the other hand, Goodday et al. (1988) reported how the presence of BMC leading to two mental foramina on a patient's right mandible caused him to suffer post-operative paresthesia as the surgeons had to sacrifice the inferior branch of this BMC during anterior horizontal mandibular ostectomy. Saiman et al. (2010) presented 2 cases that were surgically challenging because they discovered the presence of BMC intraoperatively during bilateral sagittal split osteotomy. They found that the complexity of the surgery increased with the addition of a second neurovascular bundle. As a result, one of their patients suffered from post-operative paresthesia. They recommended that CBCT be used as a standard of care for patients undergoing orthognathic surgery.

2.7.3 Third molar removal

Langlais et al. (1985) cautioned that extreme care must be used when a Type 1 or Type 3 BMC is present in cases of third molar removal. They claimed that the tooth may infringe on or be within the canal itself and complications such as traumatic neuroma, paraesthesia, and haemorrhage could arise because of a failure to recognize the presence of this anomaly and appreciate its implications. In fact, Correr et al. (2013) had shown that when the third molars were present, half of the cases showed an intimate relationship, and almost another one-third of cases showed a close relationship between the roots of the third molars and the bifurcation of the mandibular canal. Having said so, some of the branch may not cause local anesthetic or postoperative problem, as described by Eliades et al. (2015) of a case of a supplementary canal that coursed towards the periapical lesion of a third molar, with the tooth successfully removed. They also reported a case of third molar surgery that was performed successfully despite the presence of a retromolar canal immediately distal to a mandibular third molar. This may be because of the fact that the retromolar foramina have been reported to be located between 4 and 4.5 mm from the third molar (Senthil Kumar & Kesavi, 2010). In contrast, one study reported that 30 out of 44 individuals who presented RMC had its final extremity in contact with the root of the mandibular third molars (Capote et al., 2015). However, its implication is not known.

Mizbah et al.(2012) however, adopted a different surgical approach when a bifurcation was observed. They reported how the presence of a retromolar-like BMC adjacent to the mandibular right third molar in a 22-year-old female led them to section the tooth, with the segments subsequently individually mobilized in a strict buccal direction to avoid pressuring onto the inferior alveolar nerve and its accessory branch (Mizbah et al., 2012).

There has been three cases of neurosensory disturbance arising following lower third molar removal being reported (Maqbool et al., 2013; Wyatt, 1996). One of it is related to the BMC, while the other was related to the RMC. On the third case, Singh (1981) reported the presence of unilateral paresthesia of the buccal sulcus and gingivae from the retromolar to the canine region in a patient who undergone a third molar extraction. Wyaat (Wyatt, 1996) reported a case of 23 years old black man who was referred for 3rd molar removal. Panoramic imaging revelead an unusual canal near in the retromolar area. Postoperaively, the patient experienced a short period of partial paraesthesia as expected earlier

2.7.4 Implant surgery

Dental implant was formally introduced in 1982. It is widely used now in routine treatment planning for replacement of missing dentition (Attard & Zarb, 2003). Persistent pain could be reported after dental implant surgery indicating its neural impingement.

The prevalence of IAN injury following implant surgery in the mandible has been reported to be as high as 13% (Ellies, 1992). As a result of enhancing imaging technology these prevalences are now reduced. So far, one case of neurosensory disturbance arising from impingement of a BMC by dental implant fixture has been reported (Maqbool et al., 2013; Wyatt, 1996). Maqbool et al. (2013) reported a case of 51 women who was suffering from burning pain in the mandibular left molar. Clinical examination revealed that three implants were installed in her posterior part of the mandible and the third most distal implant was impinging on a secondary mandibular canal causing this pain. The pain resolved after implant removal..Altered lip sensation has been reported after implant insertion by several studies (Bartling et al., 1999; Walton, 2000; Wismeijer et al., 1997).

2.7.5 Mandibular fracture

The mandible can be fractured following trauma to the lower face. There are five common areas of mandibular fracture that was listed in dental anatomy books (Hollins, 2012). Alveolar fracture which involve the anterior mandibular alveolus may occur during tooth extraction. Canine region fracture that occur in the body of mandible and probably due to relative bony weakness produced by large canine tooth socket. Midline fracture that may occur in the mental symphysis and often following a blow to the chin. Angle fracture that may occur at the separation of the ramus of the mandible from the body on the side of the trauma. Condylar fracture that may occur in one or both of the condyles, following a blow to the opposite side of the jaw or to the chin with the mouth open.

Mandibular fractures should be handled with care to ensure precise alignment of the neurovascular bundle in order to avoid impingement of any extra nerves. Surgeons have stated that alignment of these fragments becomes considerably more difficult in the case when a second neurovascular bundle is located in a different plane (Auluck et al., 2007) and not detected with plain radiographs.

2.7.6 Donor site

The retromolar region is an important donor site for autogenous bone block (Khoury & Hanser, 2015; E. Nkenke et al., 2002; Emeka Nkenke et al., 2002; Yildirim et al., 2000; Yildirim et al., 2001). As the retromolar canal and foramina have often been reported in this region, it has been suggested that their identification is important to ensure a safe harvesting procedure. Unlike the mandibular foramen, the position of the RMF is not constant, hence its location cannot be predicted using landmarks at the retromolar triangle. Some investigators suggested that the retromolar region should be scanned preoperatively using CBCT (Bilecenoglu & Tuncer, 2006; Jablonski et al., 1985; Kawai et al., 2012; M. Naitoh et al., 2009; Singh, 1981). Silva et al.(2006) reported that 8.3% of their patients complained of numbness of the lower lip and the mental area following bone harvesting from the ramus area. Azaz & Lustmann (1973) were concerned of the haemorrhage that may arise when performing surgical procedures at the retromolar region. Khoury and Hanser reported that 1.44% of their patients suffered from heavy bleeding at this donor site (Khoury & Hanser, 2015). Fortunately, this bleeding can be locally managed by crushing the bone in the area occupied by the canal or filling the opening with bone wax, packing the donor site with bone chips or performing electrocautery (Azaz & Lustmann, 1973).

2.7.7 The fabrication of dental prosthesis

In patients wearing prostheses, pain and discomfort can happen to the inferior alveolar nerve due to bone resorption (Claeys & Wackens, 2005). Thus the appreciation of an accessory canal becomes even more important when planning for the construction of removable dentures involving cases of severely atrophied mandibles (Bogdán et al., 2006). As alveolar bone resorbs to as low as the mental foramen level, patients with mandibular prostheses may experience discomfort because of the pressure placed on the neurovascular bundle (A. Gershenson et al., 1986; Ulm et al., 1993). This may also be a problem in the third molar and retromolar pad areas as in the cases where type 1 or type 3 BMC is present. Therefore, recognition of this possibility with subsequent modification of the prosthesis may be necessary (Langlais et al., 1985).

2.7.8 Preoperative assessment

Among the good example of the benefit of detecting branches of the mandibular canal radiographically was the case of placing dental implant above a bifurcated canal by Dario (2002). He described how the use of CT helped him avoid causing iatrogenic injury to a bifurcated branch which was not detected using panoramic radiograph. Similarly, Eliades et al. (2015) reported how they reduced the length of an implant from 11.5 mm to 10 mm due to the presence of a bifid canal detected using CT preoperatively.

It has been suggested that injury to the mandibular canal and it is variant may results in hemorrhage and worse, traumatic neuroma although such case reports have yet to be communicated (Langlais et al., 1985; Patel & Andresen, 2013).

2.7.9 Other related variations

The anatomical variation of the mandibular canal can lead to clinical misdiagnosis. Rouas et al. (2006) had shown how a pseudo enlarged mandibular canal seen on panoramic radiograph was found to be the result of superimposition from a deep mylohyoid groove when viewed using CBCT. There has been a case of misdiagnosis of a recurrent tumor in the vicinity of the mandibular canal, so one to be extra careful when dealing with clinical uncertainty (Guimarães et al., 2014) Lastly, Pinsolle et al. (1997) suggested that because the retromolar canal also allows the passage of vascular components, it may facilitate the spread of infection (the so-called Chompret-L' Hirondel abscess) and metastases of tumors from the oropharynx.

2.8 Mandibular foramen

2.8.1 Anatomical Consideration

Anatomically, the mandibular foramen (MandF) is an orifice located on the medial aspect of the ramus, and serve as a passageway through which the inferior alveolar nerve (IAN) and vessels enter the mandible to supply vital structures in the mandible such as the mandibular teeth, gums and the lower lip through the mandibular canal which curves downwards and forwards into the body of the mandible up to the mental foramen (Standring, 2015).

Radiographically, the mandibular foramen appears bilaterally as a round or ovoid radiolucency centered within the ramus of the mandible as seen using panoramic or CT technologies while it is not seen on periapical radiograph (Karjodkar, 2011). Anterior to the mandibular foramen there is a small bony tongue-shaped projection named lingula. On a panoramic image, the lingual appears as an indistinct radiopacity and it is also not seen on periapical images (Freny & Jaypee, 2009; Iannucci & Howerton, 2013).

2.8.2 Mandibular foramen position

The position of the mandibular foramen (MandF) has been a controversial and much disputed subject among many authors including anatomy text books and published papers. A number of authors described its position as a halfway between the anterior and posterior borders of the ramus (Basmajian & Grant, 1972; Ferris, 1929). Williams and Warwick (1980) described the position of the mandibular foramen in their popular "Gray's Anatomy" as "a little above the center of the ramus"; however its position with respect to the lower dentition was reported as above the occlusal plane (Grant & Basmajian, 1980; Hamilton, 1976) or at the same level of the occlusal plane (Last, 1978).

Fabian (2005) reported that mandibular foramen was located on the medial surface of the ramus of the mandible above its center (upper half). This controversy in the literature is due to lack of consistency in the determination of this reference on the occlusal plane.

Concerning bilateral symmetry; a number of published research confirmed the symmetry of the mandibular foramen and reported no significant difference between the right and left side. (Kilarkaje et al., 2005; Lima et al., 2011; Varma & Haq, 2011).

2.8.2.1 Age-group differences

It has been reported that the distance and position of the mandibular foramen changes amongst age groups from below the occlusal plane in childhood to the level of the occlusal plane at about one decade later and at the occlusal plane in adults (Kilarkaje et al., 2005). These reports; therefore, emphasize that there are contradicting results with regard to the anatomical localization of the mandibular foramen in relation to important landmarks on the mandible among different populations and age groups. This makes determining the exact position of the mandibular foramen is more difficult. Roberts and Sowray (1987) suggests that a reference must be made to the occlusal plane, and the needle has to pass 1cm above the occlusal plane.

The distance from mandibular foramen to other anatomical structure in the mandible increase with age too. Byun et al. (2013) studied 108 patients; with 49 patients aged 8-16 years (growth group) and 59 patients aged 18-25 years (adult group). He found that in the growth group, the distance from the mandibular foramen to the anterior ramus increased with age, as did distance from the gonion to mandibular foramen increased as well.

Bone remodeling occurs from deciduous to early permanent dentition and this alters the position of the mandibular foramen as reported by Tsai (2004). The researcher investigated 311 Taiwanese children through panoramic radiographs and reported statistically significant differences in distances between the mandibular foramen and the anterior and posterior borders of ramus in all dental stages from deciduous to early permanent dentition.

2.8.2.2 Race difference

A review of literature revealed a racial difference in the anatomy of the mandible and those differences which includes metric, morphological and biological differences are present among the three major racial phenotypes, Caucasoid, Mongoloid & Negroid. The mandibular and mental foramina are stable in relation with the base of the mandible and that’s the reason those two anatomic location are used as a reference point in paleoanthropological studies of the facial skeleton in different populations and for identification of the human remains (Komar & Lathrop, 2006; Rodrigo F Neiva et al., 2004).

Several studies were performed on the black African population to detect the location of the mandibular foramen. In a recent study on an adult black Tanzanian, it was found that the vertical position of the mandibular foramen to be above the occlusal plane at the 1st molar and 2nd premolar reference points, while horizontally it was 20 mm and 12 mm from the anterior and posterior borders of the ramus respectively (Russa & Fabian, 2014).

In another study on Zimbabweans, Mbarjiogu (2000) demonstrated that the position of the mandibular foramen was at the same level as the occlusal plane in about 47% of the study population, above the occlusal plane in about 29% and below that plane in about 24%, without bilateral variations. In another study among adult Kenyan Africans, it was reported that the mandibular foramen was below the occlusal plane in about 64.6% and at the level of the occlusal plane in about 31.1% (Mwaniki & Hassanali, 1992). These reports indicated great variation of the mandibular foramen exist among African black groups. A list of studies to locate the position of the mandibular foramen has been summarized Table 2.10.

Table 2.10: Comparison of the mandibular foramen location among different research studies.

Study	**SZ**	**Country**	**Method**	**Result (Location)**	**Remarks**
(Russa & Fabian, 2014)	44	Tanzania	DM	***Vertically:*** MnF above the OP at the 1M and 2PM reference points. ***Horizontally:*** MnF 20mm from anterior border of the ramus and 12 mm from posterior borders of the ramus.	black male Tanzanians age group 30-45 years
(G et al., 2014)	65	India	DM	MnF-mandibular notch: 22.1±3.2mm. MnF-anterior border of ramus:16.9±2.7mm. MnF-posterior border of the ramus: 11.9 ±2.2mm. MnF-base of the mandible :24.9 ± 3.3mm. MNF-gonion : 22.4± 3.2mm.	Accessory mandibular foramen was noted in 41.5% of the mandibles.
(Nicholson, 1985)	8	India	DM	MnF to third molar: 19.6mm +_3.8mm (Right) 19.3mm +_3.6mm (Left)	MnF located at the anteroposterior midpoint of the ramus halfway between the mandibular notch and the lower surface of the mandible and two thirds of the way down a line joining the coronoid process to the angle of the mandible.
(Kang et al., 2013)	108	South Korea	CT	In the growth group, the distance from the MnF to the anterior ramus increased with age, as did distance from the gonion to MnF.	49 patients aged 8-16 years (growth group) 59 patients aged 18-25 years (adult group)
(Sandhya et al., 2015)	30	India	DM	MnF distance (right side) MnF-anterior border: 16.00 ± 3.50 mm MnF-posterior border :10.21 ± 2.34 mm MnF-superior border :20.48 ± 3.89 mm MnF-inferior border: 24.15 ± 4.97 mm MnF-condyle: 33.46 ± 6.08 mm MnF-internal oblique ridge (right side): 12.31 ± 4.88 mm MnF distance (left side) MnF-anterior border :16.27 ± 3.9 MnF-posterior border: 10.28 ± 5.24 MnF-superior border :20.15 ± 3.8 MnF-inferior border :24.86 ± 4.04 MnF-condyle: 32.48 ± 4.73 MnF-internal oblique ridge :10.93 ± 4.06	
(SW et al., 2012)	104	Korea	DM	MnF was located posteriorly to the midpoint of the AP width of the ramus. It was located at 57.3% of the AP width of the anterior border.	

DM: Direct measurement, SZ: Sample size, OP: Occlusal plane, MnF: Mandibular foramen, MnL: Mandibular linguli

Table 2.10 (continued): Comparison of the mandibular foramen location among different research studies.

Study	**SZ**	**Country**	**Method**	**Result (Location)**	**Remarks**
Thangavelu et al. (2012)	102	India	DM	MnF always at the level of the OP or below it. mean distance of 19 mm (with SD 2.34 mm) from the coronoid notch of anterior border of ramus.	
Varma and Haq (2011)	92	India	DM	MnF-mandibular notch :20–25 mm MnF-anterior border of ramus :16 mm MnF-posterior border of ramus :13 mm MnF-third molar tooth : 15–17 mm.	Bilateral symmery
Kilarkaje et al. (2005)	132	Hong Kong	DM	MnF located above the center of the ramus on the medial surface. In children aged 3 years, the MnF has been located 4.12 mm below the OP. 9-year-old children it has reached the OP. Adults it is 4.16 mm above the OP.	Bilateral symmetry 8 young 93 adult 31 old dry mandibles
Hong et al. (2011)	240	Korea	PA	MnF vertical position did not change with age. MnF moved upward in relation to the OP with age. MnF of boys located more superiorly as compared to girls in relation to the OP and more superiorly and posteriorly in the ramus of mandible.	Children 7 to 15-year-old boys and girls.
Trost et al. (2010)	46	France	PA DM	Vertically, MnF located at the midpoint of the inferior two-thirds and the superior third of the ramus. Horizontally, MnF located at the midpoint of the anterior 2/3 and the posterior 1/3 of the ramus, preferentially in front of this point.	
Jerolimov and Kobler (1998)	100	Croatia	DM	Horizontally, MnF 15 mm in front of posterior border of the ramus MnF 17 mm behind anterior border of the ramus. Vertically, MnF was 21 mm below mandibular angle.	

DM: Direct measurement, SZ: Sample size, OP: Occlusal plane, MnF: Mandibular foramen, MnL: Mandibular linguli

Table 2.10 (continued): Comparison of the mandibular foramen location among different research studies.

Study	SZ	Country	Method	Result (Location)	Remarks
F. B. Prado et al. (2010)	87	Brazil	DM	Horizontally: MnF-anterior border of the mandibular ramus edentate right (ER): 17.5 (63.2) mm edentate left (EL): 17.4 (63.4) mm, dentate right (DR): 19.2 (63.6) mm dentate left (DL): 18.8 (63.8) mm MnF-posterior border of the mandibular ramus edentate right (ER): 12.8 (62.4) mm edentate left (EL): 12.9 (62.3) mm dentate right (DR): 14.2 (62.4) mm dentate left (DL):13.9 (62.6) mm Vertically: MnF-inferior point of the mandibular notch edentate right (ER): 23.4 (63.8) mm edentate left (EL): 22.9 (63.7) mm dentate right (DR): 23.6 (63.1) mm dentate left (DL): 23.1 (63) mm MnF-inferior border of the mandibular ramus edentate right (ER): 26.4 (64.2) mm edentate left (EL): 26.4 (64) mm dentate right (DR): 28.3 (63.9) mm dentate left (DL): 28 (63.8) mm	8 dentate mandibles 79 edentate mandibles

DM: Direct measurement, SZ: Sample size, OP: Occlusal plane, MnF: Mandibular foramen, MnL: Mandibular linguli

Table 2.10 (continued): Comparison of the mandibular foramen location among different research studies.

Study	**SZ**	**Country**	**Method**	**Result (Location)**	**Remarks**
Alves and Figueiredo Deana (2014)	185	Brazil		MnF, the lowest point of the mandibular foramen; S, greatest concavity of the mandibular notch; A, anterior margin of the ramus of mandible; P, posterior margin of the ramus of mandible; and Go, gonion MnF-S: 21.02 mm for white females (WF) and 22.00 mm for black females (BF); 24.40 mm for white males (WM) and 24.35 mm for black males (BM); MNF-A: 17.05 mm for WF and 18.09 mm for BF; 17.18 mm for WM and 18.11 mm for BM; MnF-P: 11.11 mm for WF and 12.24 mm for BF; 13.10 mm for WM and 14.15 mm for BM; MnF-Go: 19.00 mm for WF and 19.44 mm for BF; 23.13 mm for WM and 22.12 mm for BM.	
da Fontoura et al. (2002)	280	Brazil	PA DM	vertically & horizontally, MnF located at the posterior third of the ramus directions.	
Mbajiorgu (2000)	38	Zimbabwe	DM	Horizontally, MnF 2.56 mm (right) and 2.08 mm (left) behind the midpoint of ramus. Vertically,3 mm superior to the midpoint of ramus. MnF 47.1% at the same level with OP, 29.4% above, and 23.5% below.	
Lima et al. (2016)	30	Brazil	DM	MnF & MnL located more superior and posterior from the center in relation to the medial surface of the ramus	

DM: Direct measurement, SZ: Sample size, OP: Occlusal plane, MnF: Mandibular foramen, MnL: Mandibular lingul

2.8.3 Clinical significance

A common anesthetic technique used during various surgical procedure and dental operations is an inferior alveolar nerve block, which depends on the accurate placement of local anesthetic fluid in the pterygomandibular space. The inferior alveolar nerve enters the mandibular foramen on the medial aspect of the mandibular ramus. Surgical procedures performed on this part of the mandible includes the reductions of fractures, mandibular osteotomies and jaw resection of tumour. However, with regards to the IAN block, failure has been reported to be as high as 45% and it happens even with skillful surgeon (Goldberg et al., 2008; Madan et al., 2002; Potočnik & Bajrović, 1999; Vinckier, 1999). The success of this procedure mainly depends on positioning the needle tip close to the mandibular foramen.

A review of literature has revealed several factors that are responsible for the local anaesthetic block failure, including presence of accessory mandibular foramina (Cvetko, 2014), the presence of accessory nerves to the mandibular teeth as observed with bifid and trifid canals (Clark et al., 1999), variations in the position of the mandibular foramen (Devi et al., 2002; Keros et al., 2001; Nicholson, 1985; Vinckier, 1999) including bilateral variations (Mbajiorgu, 2000; Oguz & Bozkir, 2002), alterations in the mandibular foramen position during skull growth (H. H. Tsai, 2004), inappropriate positioning of the needle (Hetson et al., 1988) or because the anaesthetic drug is deposited too high, too deep or superficial (Devi et al., 2002). Furthermore, the lack of a certain anatomic bony landmark, in conjunction with variations in the ramus width and height and the inferior alveolar nerve foramen position, is the cause of failure to achieve anesthesia. Mandibular foramen position may appear as an anomalous high position in the ramus as observed in a case reported by

Cvetko (2014) where mandibular foramen was identified from the panoramic radiograph, and Vazirani-Akinosi anesthetic technique was used to perform effective local anesthesia before the extraction of a lower second molar following a failed conventional indirect technique with a higher entry point.

The success of surgery at the ramus of the mandible entails not injuring the inferior alveolar nerve at its entry point into the mandible. Thus, special attention should be taken into consideration when performing surgical procedure as the mandibular foramen and the mandibular lingula are frequently chosen as a reference to perform open surgeries in this area and often present variations in shape, location or even number (Murlimanju et al., 2012; Smith et al., 1991; Tom et al., 1997).

Sagittal split osteotomies are one surgical procedure done on the mandible to reposition it in prognathism and retrognathia with the mandibular foramen being referred to as the anatomical landmark. The main complications encountered during this technique are hemorrhage, injury to the neurovascular bundle, undesired fractures and bone necrosis, therefore a thorough knowledge of the mandibular ramus is very essential (Daw et al., 1999). Furthermore, Salignon et al. (2010) defined a superior and posterior thirds of the ramus to be a “safety zone” to perform vertical ramus osteotomies of the mandible with statistically low risk of inferior alveolar nerve injury.

A number of factors have been reported for the cause of morphological variation of the mandible and mandibular foramen, such factors as bone remodeling, lack of mechanical stimulation, occlusal alterations, changes in muscular activity, and especially the loss of teeth (Dutra et al., 2014; Merrot et al., 2005; F. B. Prado et al., 2010).

2.8.4 Accessory mandibular foramen

Double mandibular foramen (DMandF) is a rare anatomical structure located near the mandibular foramen and leads to a separate structure through which a bifid mandibular canal runs forward and lateral to the main mandibular canal and either connect to it or terminate at a level of the mandibular molar area (Das & Suri, 2004; Manikandhan et al., 2010; Narayana & Prashanthi, 2003). This variation has been reported in the literature as a subtype of bifid mandibular canal (Kuribayashi et al., 2014; Langlais et al., 1985; Nortje et al., 1977).

One of the earliest study that highlighted the vast number of accessory foramen medially and laterally posterior to the lower second premolar found that the mandible was pierced with numerous accessory foramina, amounting to 36 foramina per mandible (Haveman & Tebo, 1976). The mean diameter of these foramina was 0.4 mm. This finding suggested the mandible and posterior teeth can receive their neurovascular supply from both the periphery and central bundles. In the case of peripheral innervations, they may originate from a supplementary branch of a mandibular sensory nerve, such as the auriculotemporal and mylohyoid nerves (Haveman & Tebo, 1976).

Previous studies have reported the prevalence of accessory mandibular foreman and it was ranging from 0.06 to 35% (Table 2.11). It has been found to be mostly on the medial surface than on the lateral surface (Das & Suri, 2004; Haveman & Tebo, 1976). Its clinical significance comes when these foramen are proven to contain neurovascular bundle and that was confirmed by Przystanska and Bruska (2010) as they studied these foramina immunohistochemically and reported that their contents included a neurovascular bundle.

Embryologically, the nerve has been assumed as mandatorily present for inducing osteogenesis and the formation of the mandibular foramen and canal developement. During normal mandibular formation, the accessory nerve was placed on the inner aspect of the newly forming mandible accompanying the Meckel's cartilage (Manikandhan et al., 2010)

Table 2.11: Research studies reporting mandibular foramen variations using different assessment methods.

Study	**SZ**	**Country**	**Assessment method**	**Result**	**Remarks**
Murlimanju et al. (2011)	67	India	Dry mandibles	16.4% (unilaterally in 6 mandibles (3 on the right side and 3 on the left side) and bilaterally in 5 mandibles)	
Choi and Han (2014)	446	Korea	CBCT	8 double mandibular foramina leading to the accessory canals were observed in 6 patients 446 patients (1.35 % of Korean population).	
Patil, Matsuda, and Okano (2013)	300	Japan	CT	26 accessory foramina on buccal posterior aspect. 70 accessory foramina on buccal anterior aspect. 32 accessory foramina on lingual posterior aspect. 59 accessory foramina on lingual anterior aspect.	often bilateral The authors named it as accessory mandibular foramen but all foramen was around mental buccally and lingually

Another reported variation is the temporal crest canal through which the accessory canal passing through double mandibular foramen (DMnF) and reach to the accessory foramen in the antero-inferior region of the coronoid process, approximately in the retromolar fossa. This canal has been considered as a subtype of retromolar canal (Han & Hwang, 2014; Ossenberg, 1987).

Choi and Han (2014) reported that forward type canals were observed in 0.45 % of 446 patients, and the canals which ran forward terminated at the root of the mandibular third molar. They further classified the accessory canals through double mandibular foramen (DMnF) into two groups according to their configuration (Figure. 2.7).

1. Forward type: the canal entering the mandible through DMnF, running forward and lateral to the mandibular canal, and terminating close to the root of the mandibular molars (Figure 2.8A).

2. Retromolar type: the canal entering the mandible through DMnF, running antero-inferiorly, and ending up at the accessory foramen in the antero-inferior region of coronoid process, approximately in the retromolar fossa (Figure 2.8B).

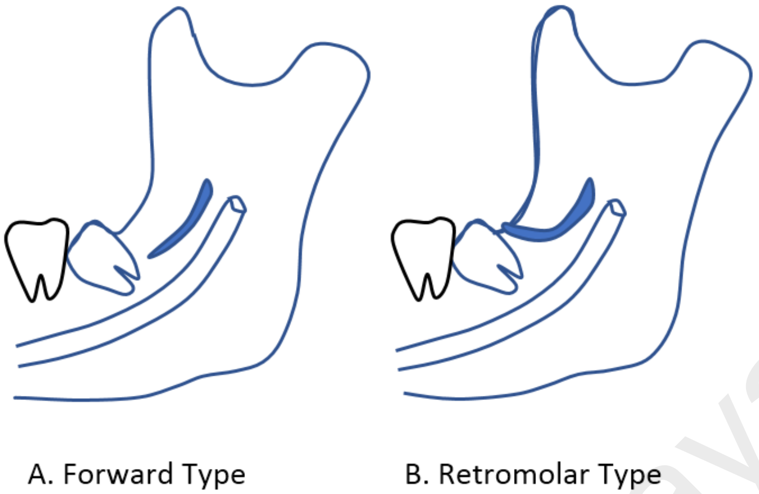

Figure 2.7 Classification of an accessory canal from DMnF. A. Forward type canal (b) ran forward and lateral to the mandibular canal (d) from the mandibular foramen (c), and joined the latter or terminated at the root of the mandibular molars. B.Retromolar type (b′) passing antero-inferiorly through DMnF (a) ended up at the accessory foramen (a′) in the retromolar fossa. Adapted and modified from (Choi & Han, 2014).

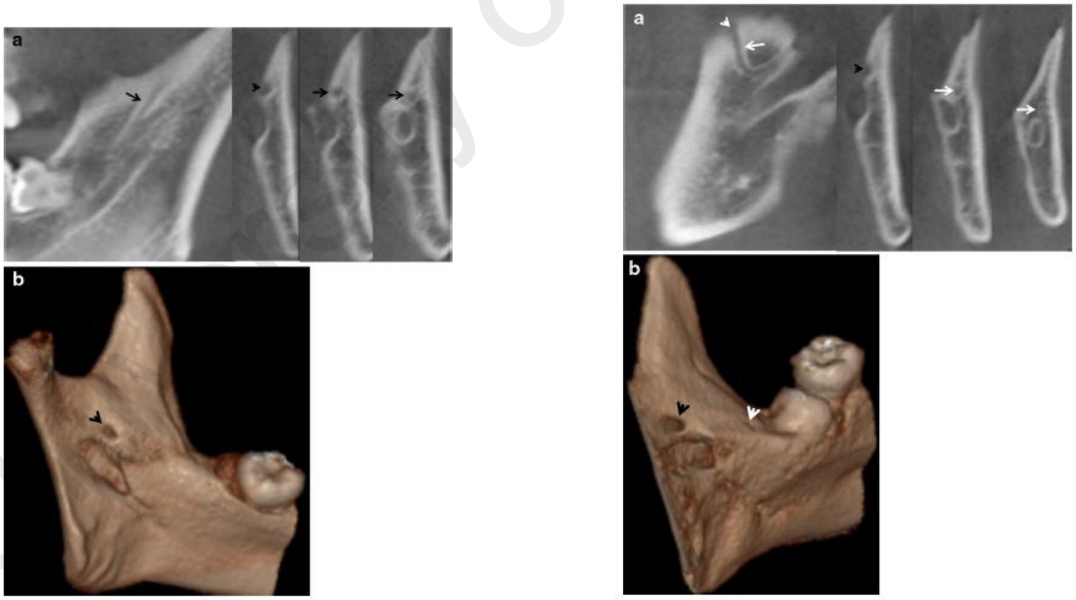

Figure 2.8 CBCT images of forward and retromolar canal type from DMnF (Choi & Han, 2014)

A : CBCT images of forward type canal from DMnF. a Sagittal and cross-sectional image, b three-dimensional image. Forward type canal (black arrow) which ran independently of the mandibular canal, exited at the root of the mandibular third molar. DMnF (black arrowhead) was located vertically above the left mandibular foramen

B : CBCT images of retromolar type canal from DMnF. a Sagittal and cross-sectional image, b three-dimensional image. Retromolar type canal (white arrow) ran antero-inferiorly and reached to the accessory foramen (white arrowhead) on the retromolar fossa. DMnF (black arrowhead) was located vertically above the left mandibular foramen

Even among mandibular foramen variation there are some reported rare variations; like large accessory mandibular canal which was reported by Narayana and Prashanthi (2003). They conclusively showed that a large accessory mandibular foramen was present in 0.3 % of 335 dry mandibles, and the canal that delivered through it moves obliquely forward and lateral to the mandibular canal and joined the latter close to the third molar (Figure 2.9). Another variation was reported by Das and Suri (2004), where they described an unnamed foramen that was located vertically above the lingula on the medial aspect of the ramus. They reported that the accessory canal through the foramen joined the latter or terminated close to the root of the third molar.

A review of literature identified an increased concern regarding the role of accessory mandibular foramen in spreading of tumor cells following the radiation therapy as the barrier mechanisms of the periosteum is reduced in irradiated mandibles and this provide an easy route of perineural spread of the tumor cells from the cortical to the cancellous part of the bone (Das & Suri, 2004; Fanibunda & Matthews, 1999, 2000; Mc GreGon & Mac Donald, 1988; Trikeriotis et al., 2014). Therefore, special attention should be paid for the presence of double mandibular foramen on the mandibular ramus in view of post-radiation recurrence and tumor spread.

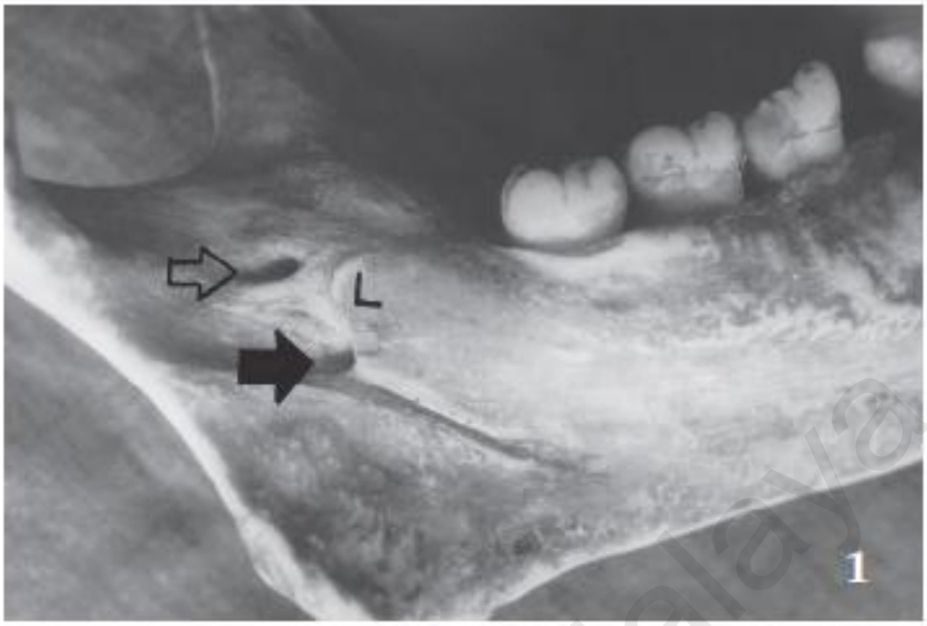

Figure: 2.9: Photograph & illustration of a mandible showing an accessory mandibular foramen. 1- Photograph of a mandible showing an AMandF (open arrow) on the left side. Note that the normal MandF (arrow) is located antero-inferior to it. The typical tongue-shaped lingula (L) is indicated (Narayana & Prashanthi, 2003).

2.9 Mental foramen

2.9.1 Anatomical consideration

Anatomically, the mental foramen is usually an orifice located bilaterally on the lateral surface of the mandible through which mental nerve emerges. It appears as a single structure in the hemi-mandible (Figure 2.10), However there are several variations exist which may include accessory foramina (Imada et al., 2014) or absence of mental foramen (Lauhr et al., 2015).

The mental foramen allows the passage of arteries, viens and nerves from mandibular canal to the lateral surface of the mandible and divides beneath the depressor anguli oris muscle into three sensory branches: one innervates the skin of the chin, the other two innervates the skin and mucous membrane of the lower lip (Alantar et al., 2000; Clemente, 1985; Greenstein & Tarnow, 2006).

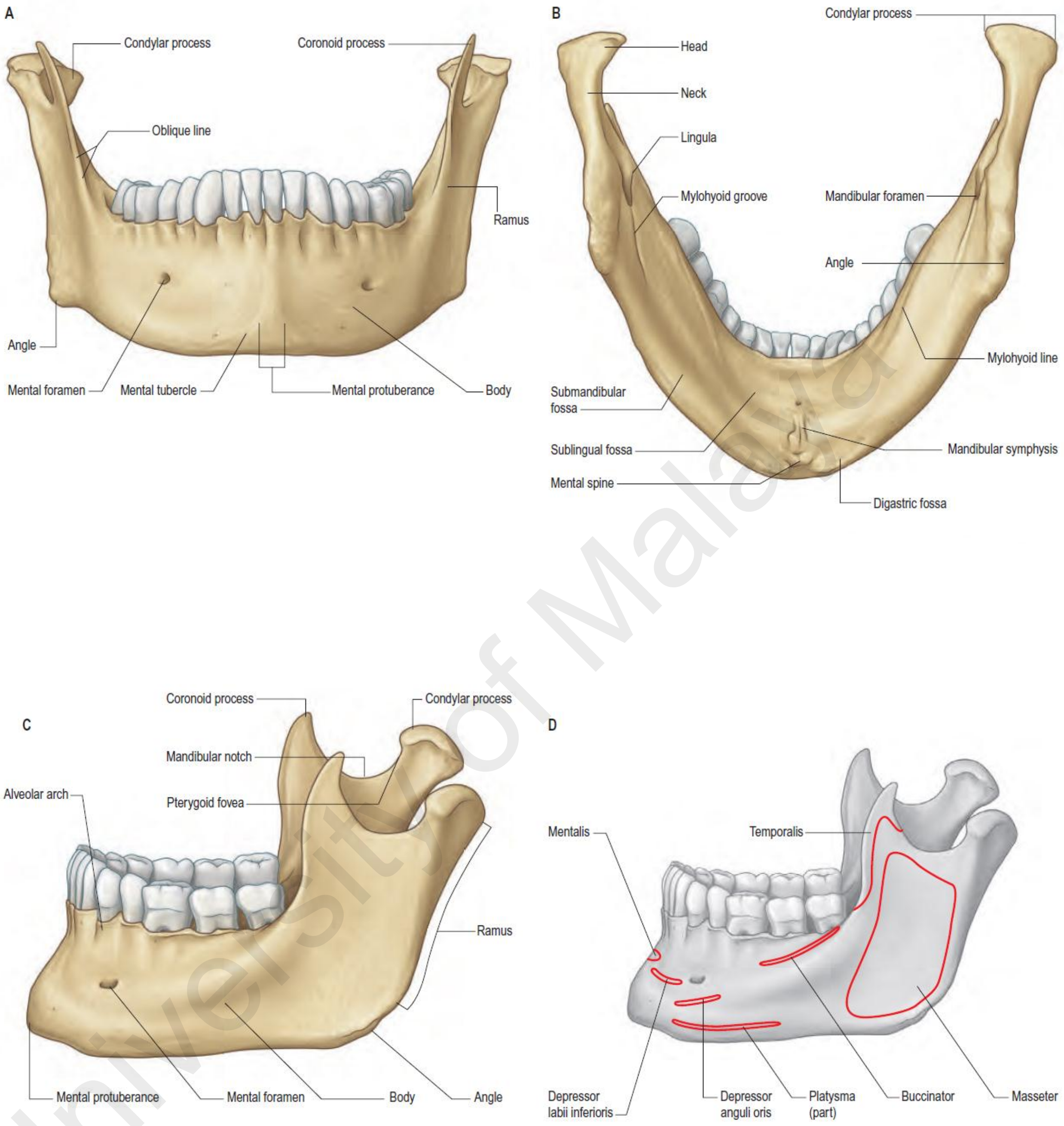

Figure 2.10: The adult mandible. A, Anterior view. B, Medial aspect of mandible (Inferior view). C, Lateral view (with muscle attachments in D) (Standring, 2015).

Radiographically, mental foramen is defined as an opening in the external surface of the mandible in the region of mandibular premolars that manifest the anterior limit of the mandibular canal. Its cortical wall opening is directed superiorly and posteriorly. The mental foramen exhibits a variety in its density, definition of its border and shape which may be round, oblong, slit-like, irregular, partially or completely corticated (Chaurasia, 2014a, 2014b).

Vertically, it is located half way between lower border of mandible and alveolar crest usually at the apex of 2nd premolar in adult mandible (White & Pharoah, 2014) (Figure 2.11). On a panoramic image, the mental foramen reported as being small, ovoid or circular radiolucency found in the apical region of the mandibular premolars (Freny & Jaypee, 2009).

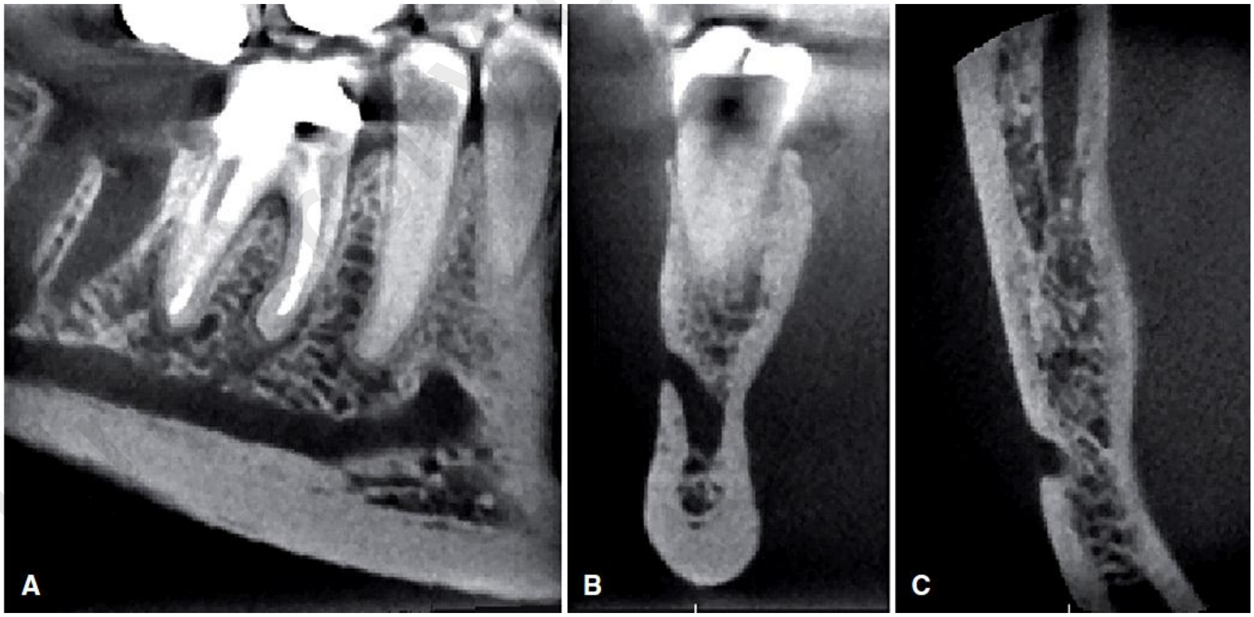

Figure 2.11: CBCT images showing mental foramen from different views. A,Sagittal section of mandible showing mandibular canal rising toward mental foramen which lies anterior to the apex of 2nd premolar. B, coronal section through mental formaen showing mandibular canal ascends to exit through mental foramen (Buccal cortex). C, axial aspect of mandible showing mental foramen opening is posteriorly inclined on buccal cortex. (images enhanced with third part image editing software) (White & Pharoah, 2014).

Awarness about exact location of the mental foramen is of utmost important to surgeon performing surgical procedures, for appropriate delivery of local anesthesia and also in interpreting anatomical landmarks in forensic science (Chkoura & Wady, 2013).

3.9.2 Mental foramen shape

A number of studies have reported two types of mental foramen shape, oval and round; they have demonstrated differences between races (Al-Juboori et al., 2014; Fabian, 2006; 2014; Sheikhi et al., 2015). The majority of Indians were reported to have round mental foramen while Malawians have mostly oval one. Round and oval shapes were reported to gain approximately equal percentage in Tanzanian and Zimbabwean populations (Al-Juboori et al., 2014; Fabian, 2006). A study done in Iran found that the most common variation of mental foramen in Iranian population was oval, superior- posterior opening, apical to the apex, and in line with second premolar. However, other types of mental foramen variables exist, reflecting the significance of preoperative radiographic examinations, especially 3D images (CBCT). A study done by Fabian et al. (2006) reported that the shape of the mental foramen was found to be oval in 54% and round in 46% of cases observed amongst Tanzanian adult black males. Fujita and Suzuki (2014) reported it was oval in japanese population. Among Iraqis, Alsoleihat et al. (2015) reported that the shape of mental foramen was found to be round (51%) and oval (41%). These findings can help in safe implant surgery and administration of successful local anesthesia (Sheikhi et al., 2015).

3.9.3 Variation in the pattern of mental foramen

The determination of the location of mental foramen in human mandible is clinically challenging as has been reported by a number of studies since 1950 (J. Phillips et al., 1992; John L Phillips et al., 1990; J. L. Phillips et al., 1992; Tebo & Telford, 1950).

Direction of opening of the mental foramen has been studied by Fabian (2006) and it was reported to be superiolateral in 44%, posteriorly in 40%, labially in 0% and mesially in 3%. The mental nerve was categorised according to the shape of anterior loop into loop shape (61.50%), straight shape (23.1%) and vertical shape (15.4%). Hu et al. (2007) described four branches of the mental nerve which wre : the angular, medial inferior labial, lateral inferior labial, and mental branches. These types of nerve branches were categorized into 5 types based on their distribution patterns (Figure 2.12). Won et la. (2014) explored the distribution patterns of the branches of the mental nerve and described several branches, among them the inferior labial branches that innervated most of the lower lip.

Alsaad et al. (2003) explained the cutaneous branches from the mental nerve and noticed three distribution patterns simply by dissection under a surgical microscope or by serial sectioning and 3D imaging technique reconstruction. According to their particular nomenclature, three branches of the mental nerve had been discovered as the vertical, the horizontal, as well as, the oblique branch.

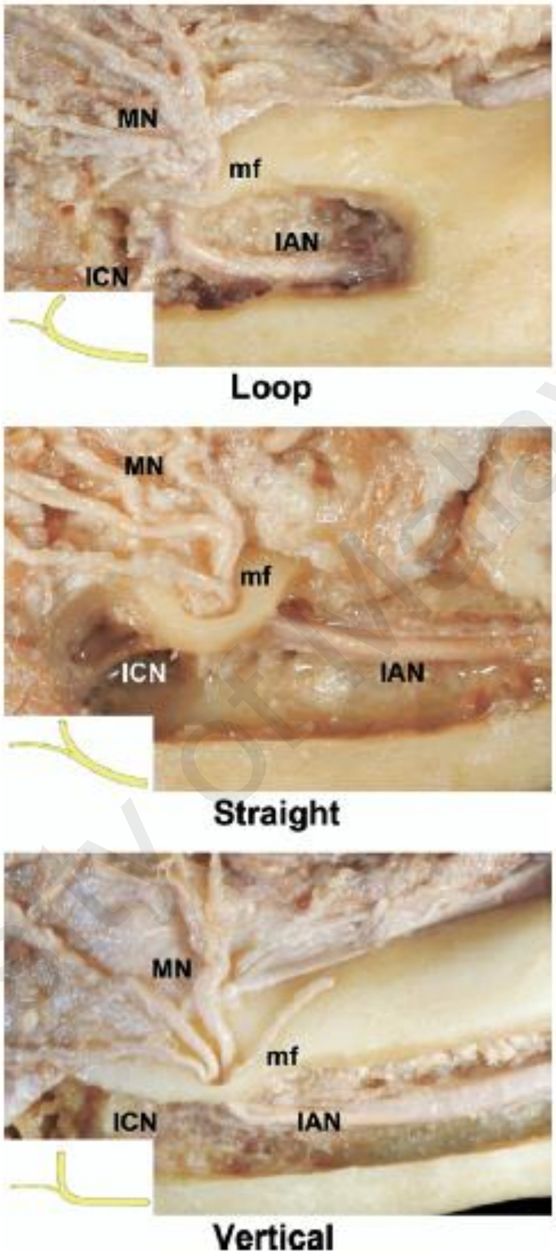

Figure 2.12: The anterior loop configuration of the mental nerve; mental foramen, mental foramen (Hu et al., 2007).

3.9.4 Locating and identifying the mental foramen

Locating the precise location of the mental foramen is of great clinical importance, especially in surgical procedure performed in mental area, to prevent damage to these tissues during nonsurgical and surgical interventions, such as periapical endodontic surgery (J. R. D. Moiseiwitsch, 1995), incision and mucoperiosteal flap reflection (Moiseiwitsch, 1998), infiltration technique when administering local anesthetic in mental area (Loudon, 2011), sagittal split ramus osteotomy (Hashiba et al., 2008), or during dental implant surgery (Greenstein & Tarnow, 2006).

Previously, surgeons used to locate the position of the mental foramen during surgery after raising a mucoperiosteal flap as the foramen is directly uncovered and easily noticed. This method is not consistent nowadays as this method may traumatize the nerve and other vessels resulting in neurosensory disturbance to the patient.

Although there are many reports in the literature on the location of mental foramen using different techniques, most are with shortcoming or risks to the patient. Those techniques can be categorized into non-radiological techniques (palpation, presurgical anatomic landmark, direct visualization) and radiological techniques (periapical radiograph, panoramic radiograph, CT, CBCT, MRI and Ultrasound) as summarized in Table 2.12.

Table 2.12 Mental foramen position as reported by different studies.

Study	**Population**	**Assessment**	**N**	**Result**
Fishel et al. (1976)	Caucasian	Intraoral periapical radiograph	1000	Horizontally, Apical to 2nd premolar: 18.9% Between apices of premolars: 70.4% Apical to 1st premolar: 3.3% Mesial to 1st premolar: 1.5% Between premolar/molar: 6.6 % Apical to the molar: 1% Vertically, Higher than apices of premolars
Wang et al. (1986)	Chinese	Cadaver (Direct measurement)	100	Horizontally, Apical to 2nd premolar: 59% Between apices of premolars: 21% Between premolars/molars: 19% By the molar: 1% Vertically, Distance between superior border from the mental foramen and the base of the lower second premolar socket: 2.50mm
Kekere-Ekun (1989)	Nigerian	Oblique lateral radiography	604	Horizontally, Apical to 2nd premolar: 55.63% Between apices of premolars: 26.99% Mesial to first premolar: 0.17% Apex first premolar: 1.66% Between premolar/molars: 12.3% Apical to the molar: 3.3%
Shankland 2nd (1993)	Indians		138	Horizontally, Apical to 2nd premolar: 75.4% Between apices of premolars: 5.8% Between premolar/molars: 14.5% Apical to themolar: 4.3%
AlJasser and Nwoku (1996)	Saudi	Panoramic	414	Horizontally, Apical to 2nd premolar: 45.3% Between apices of premolars:42.7%
Ngeow and Yuzawati (2003)	Malay	Panoramic	169	Horizontally, Apical to 2nd premolar: 69.2% Between apices of premolars:19.6% Apex first premolar: 3.4% Between premolar/molar: 6.6% Apical to the molar: 1%
R. F. Neiva et al. (2004)	Caucasian	Direct measurement	22	Vertically, Distance between mental foramen and cementoenamel junction of teeth: 15.52 ± 2.37mm
Apinhasmit et al. (2006)	Thai	Direct measurement	106	Horizontally, Apical to 2nd premolar: 56.9% Between apices of premolars:28.7% Between premolar/molar: 10.2% Apex first premolar: 3% Apical to the molar: 1.2%

Table 2.12 (continued): Mental foramen position as reported by different studies.

Study	Population	Assessment	N	Locations
Kim et al. (2006)	Korean	Panoramic Direct assessment	72	Horizontally, Apical to 2nd premolar: 64.3% Between apices of premolars:26.8% Apex first premolar: 8.9% Distance between the cusp tip and the superior border of the mental foramen: 23.42 mm
Fabian (2006)	Tanzanian	Direct measurement	100	Horizontally, Apical to 2nd premolar: 45% Between apices of premolars:12% Between premolar/molar: 35% Apical to the molar: 8%
Haghanifar and Rokouei (2009)	Iranian	PA	400	Horizontally, Apical to 2nd premolar: 46% Between apices of premolars:47.2% Between premolar/molar: 5.3% Apical to the molar: 1.5%
Fujita and Suzuki (2014)	Japanese	CT	100	Horizontally, Apical to 2nd premolar: 55.17% (male) Apical to 2nd premolar:40.56% (female) Between premolar/molar: 38.46% (female)
Al-Shayyab et al. (2015)	Iraqis	PA	518	Horizontally, Between apices of premolars:48.6% Apical to 2nd premolar:43.7%
A. Kalender et al. (2012)	Turkey	CBCT	193	Horizontally, Apical to 2nd premolar: Right 29.5%, Left 33.1% Apical to 1st premolar: Right 5.5%, Left 3.6% Between apices of premolars: Right 61.5%, Left 57.5% By the molar : Right 3%, Left 5.1%
Kqiku et al. (2011)	Austria	Direct measurement	200	Horizontally, Apical to 2nd premolar: 27.5% Apical to 1st premolar: 1.5% Between apices of premolars: 37.75% Apical to the molar: 5% Mesial to 1st premolar :0.25%
Haghanifar and Rokouei (2009)	Iran	Panoramic	400	Horizontally, Apical to 2nd premolar: 46% Apical to 1st premolar: 1.6% Between premolars: 47.2% Apical to the molar: 5.1%
Saito et al. (2015)	Brazil	CT	100	Horizontally, Apical to 2nd premolar: 42% Apical to 1st premolar: 7% Between premolars: 36% between 2nd premolar and 1st molar :14% Apical to the molar: 1%
Dehghani and Ghanea (2016)	Iran	PA	300	Horizontally: Between premolars: 41.5% Apex of the second premolars:31.7% Posterior area of the second premolars :19.2% Anterior area of the first premolars :4.3% Apex of the first premolars :3.3% Vertically: Below apices of the premolars in 78.8% Above apices of the premolars in 2.5%, At the level of apices of the premolars in 18.7%

2.9.4.1 Non radiological techniques

One of the simplest way to locate the position of the mental foramen was by anatomic landmark of the origin of mentalis muscle and also by the feeling of a raised area near the apices of premolars which will indicate the exit of neurovascular bundle. The authors claimed at that time that they have set a safe zone for mental foramen location, but which may not be accurate to determine the exact location (Hazani et al., 2013; Igbigbi & Lebona, 2006).

Guo et al. (2009) conducted their study on a cadaver study based on the hard tissue landmarks and found that the mental foramen is located inferior to the 2nd premolar in 73.8% of cases and 23.34 ±2.39 mm below 2nd molar cusp tip, while in another anatomic study, the location of the mental foramen was found to be located in the middle third from the angle of the mouth (cheilion) to the mandibular border in 90.30% of cases studied (Hur et al., 2008). Another interesting study that used topography to locate mental foramen was performed by Gawlikowska-Sroka et al. (2013); the authors reported that mental foramen was located between first and second premolars regardless of the side of jaw or population groups. These landmarks are inaccurate because of changes that occur in bone morphology during growth of the mandible in children or changes that occur due to resorption after tooth loss.

Direct visualization was considered as one of the method used to study the location of the mental foramen (Hazani et al., 2013; Kqiku et al., 2011). Fourteen fresh cadavers were dissected and measurements were performed from the mandibular border to the origin of mentalis muscle (inferior aspect). It was found that the mental foramen was located below the root of 1st and 2nd premolars or in between then. The distance from the mentalis origin to the mental foramen was 1.8±3 cm and 1.5±0.2 cm vertically to the inferior edge of the mandible (Hazani et al., 2013). In another study which used the same technique, after dissecting 30 cadavers it was found that mental foramen was also located between the first and second mandibular premolars (Kqiku et al., 2011).

2.9.4.2 Radiological technique

Fishel et al. (1976) employed periapical radiographs to detect the location of the mental foramen in 1000 specimen and the mental foramen was detected in 46.8% of them. Moiseiwitsch (1995) also used periapical technique that includes what they termed as “multiple periapical radiography” to locate mental foramen and suggested to use a vertical bitewing and a panoramic film be taken together with a horizontal periapical film to enhance mental foramen detection. Weller et al. (1990) using 75 dry, adult, human mandibles reported that the most common position of the mental foramen was between the apices of the premolars and mental foramen position was 3.8 mm mesial to the apex of the second premolar.

Many researchers have utilized panoramic radiographs to detect the location of the mental foramen, but it was not always possible. Mraiwa et al. (2004) used panoramic radiographs in detecting mental foramen location in 94% of the 545 sample size, but it was distinct in only 49%. Ngeow and Yuzawati (2003) reported that most of the mental foramen were found in a Malay population to be located inferior to the apex of the 2nd premolar, and they also reported that invisibility of the mental foramen was greatly increased in patients above 50 years and older using panoramic method.. Other group of studies suggested to use this technology in conjunction with periapical radiograph to get the actual position of the mental foramen in the mandible (Chkoura & Wady, 2013; Haghanifar & Rokouei, 2009; Yosue & Brooks, 1989).

Chkoura and Wady (2013) examined 794 panoramic radiographs with regard to the location and symmetry of the mental foramen among gender in an in clinical study amongst Moroccan population. The authors reported that the mental foramen was located exactly below the apex of the 2nd premolar in 62.7% of the patients and was located between the first and second premolars in 30% and no significant gender differences were found. Interestingly, it was symmetrically located between both premolars roots in 79% of the samples. while Bharathi et al. (2016) and Al-Shayyab et al. (2015) reported that the mental foramen is not always symmetrical in the same patient.

It has been reported by some authors that the most common location of the mental foramen was between the 1st and the 2nd premolars (Al-Khateeb et al., 2007; al-Khateeb et al., 1993; Haghanifar & Rokouei, 2009; Pria et al., 2011). A significant drawback of using panoramic imaging technology is the routine 20%–36% magnification factor, which makes the location of the mental foramen on the radiograph different than its true clinical location (Batenburg et al., 1997; Choi et al., 2004; Forni et al., 2012; Hayakawa et al., 1993; J. L. Phillips et al., 1992; Serman & Buch, 1991).

Computed tomography (CT) imaging considered as one of the technologies used to locate mental foramen with more accuracy as it provides high-resolution 3-dimensional visualization of skull and surrounding structures. Mraiwa et al. (2002) identified 100% of mental foramen with CT imaging. Lim et al. (2013) examined the buccolingual course of the mandibular canal and mental foramen through spiral CT imaging and panoramic radiographs and reported that in 67% of the specimens that mental foramen was located mesial to the root of mandibular 2nd premolars. In another study of 68 Chinese patients conducted by Jin et al. (2013) using spiral CT imaging, he reported that the mean distance from the superior border of the mental foramen to the alveolar crest was 13.00 mm, and the mean distance from the superior border of the anterior loop to the alveolar crest was 17.83 mm.

One of the common imaging technology that is used to study mental foramen and the surrounding structures is the Cone-Beam Computed Tomographic (CBCT) which employs x-ray generator to radiate in a cone shape pattern including a large volume with a single rotation around the object (Machin & Webb, 1994). Images are then reconstructed using algorithms to produce 3D images at high resolution (Zeng & Gullberg, 1992) and can be enhanced using third party software like Simplant, Dolphin or I-Cat.

One of the latest study conducted by Paul (2015), studied the location of mental foramen in 106 patients using CBCT and found that 53.7% of the mental foramen was located mesially, 45.3% distally, and 1% coincident with the apex of the mandibular second premolar. Furthermore, men had a substantially greater coronal height and tangential height measurement than women as well as black patients had a substantially greater distal horizontal distance from the cementoenamel junction than white patients.

Parnia (2012) reported that mental foramen location was detected clearly in 100% (n = 96) of the sample size using CBCT technology. However, the authors reported that only 68.8% of the right mental foramen and 67.7% of the left mental foramen were distinctly visible. In a study investigating mental foramen location using CBCT, (Ozturk et al., 2012) reported that the mental foramen is located 16 mm above the inferior border of the mandible. In another retrospective study (Chen et al., 2013), they compared the measurements of the location and size of the mandibular canal at the mental foramen between two different population of Taiwanese and Americans using CBCT imaging and reported that there was no statistically significant difference in the distance from the mental foramen to the inferior border of the mandible between those two population. The anatomical study of the location of the mandibular canal, mental foramen, and the accessory mental foramen were clearly determined using different studies employed CBCT imaging (Al-Ani et al., 2013; Angel et al., 2011; Chen et al., 2013; Imada et al., 2014; A. Kalender et al., 2012; Katakami et al., 2008; F. S. Neves et al., 2014; Parnia et al., 2012; Ritter et al., 2012; Rosa et al., 2013).

To determine the ability and accuracy of CBCT technology in detecting mental foramen, Neves et al. (2014) compared panoramic radiography and CBCT imaging and reported that CBCT imaging allowed for greater detectability of the mental foramen and this was in agreement at Naitoh et al.’s (2011a) study where the accessory mental foramen was detected with more accuracy using CBCT imaging as compared to panoramic radiography. Angel et al. (2011) in a CBCT study compared the relative position of the mandibular canal and the mental foramen in adults with different age and gender.

2.9.5 Accessory mental foramen

The definition of accessory mental foramen has been a controversial and is a much-disputed subject amongst researchers as there seems to be no standardized clear definition for it. However, all reported terms in the literature were based on anatomical, radiological and clinical observations ranging from double mental foramina (Arx et al., 2014; Igarashi et al., 2004), additional mental foramina (Santos Junior et al., 2013), multiple mental foramina (Ilayperuma et al., 2009), accessory mental foramina (Patil, Matsuda, & Okano, 2013) and accessory buccal foramina (Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009).

Accessory mental foramen was defined by different groups of researchers as any foramen in addition to the mental foramen in the lateral body of mandible (Ahmed et al., 2015; Cağirankaya & Kansu, 2008; Gupta & Soni, 2012; Jha & Kumar, 2012; Nuri Mraiwa et al., 2003; Paraskevas et al., 2015; Prabodha & Nanayakkara, 2006; Rai et al., 2014; Singh & Srivastav, 2010; Thakur et al., 2011); others defined it as a small foramen in the area surrounding the mental foramen (Riesenfeld, 1956; Sutton, 1974), while a third group defined it as a foramen which is continuous with the mandibular canal, smaller than the mental foramen on each side in Cone-Beam Computed Tomographic (CBCT) images

(Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Naitoh et al., 2011b; Sisman et al., 2012).

A further definition is given by Pancer et al.(2014) who described accessory mental foramen in clinical terms as being continuous both with the inferior alveolar canal on CBCT and also with the inferior alveolar nerve. According to a definition provided by (Arx et al., 2014; Oliveira-Santos et al., 2011) , accessory mental foramen must be less than or equal to 50% of the size of ipsilateral mental foramen while double mental foramina is more than or equal to 50% of the size of ipsilateral mental foramen.

An interesting case was reported by Fuakami et al. (2011), where an accessory mental foramen with no connection to the mandibular canal was detected using CBCT imaging, but after gross anatomical observation it was found that an artery arised from this foramen with no mental nerve branch; therefore, the definition discussed by Pancer et al. (2014) seems to be the most correct from the clinical point of view, but needs to be confirmed by surgical or gross anatomical procedures. Preoperatively, to confirm the existence of accessory mental foramen, surgeon must consider clinical, radiological and anatomical findings as then only they can affirm the nerves. According to Toh et al. (1992), the nerve fibers that emerge from mental foramen with ipsilateral AMF is fewer than nerve fibers with mental foramen alone. This is because the nerve bundles emerging from AMF are among the fibers of the mental foramen.

While a variety of definitions of the term ‘accessory mental foramen’ have been suggested, this study will use the definition of accessory mental foramen as a foramen detected by CBCT, appears smaller than the mental foramen and continuous with the mandibular canal, regardless of it having a nerve or vessels exiting from it. The connectivity of any observed BMC and/or TMC with this accessory foramen is studied in detail.

In endodontics, Concepcion and Rankow (2000) and Von Arx et al. (2011) reported about observing an accessory mental foramen and nerve during the periapical surgery on mandibular second premolar. In comparison, Von Arx et al. (2011) were prepared to expect the presence of accessory mental foramina due to the fact that they scanned the mental region in 3 out of 4 of the apical surgical cases. In one of these cases, their patient reportedly suffered from temporary post-operative paresthesia although all the accessory branches were severed.

2.9.5.1 The prevalence of AMF determined using different observation methods

A considerable amount of literature has been published on accessory mental foramen. These studies reported that the prevalence of accessory mental foramen range from 0.8%-40% using different observation methods (Table 2.13 and Table 2.14) with some reported no significant difference among gender (A. Kalender et al., 2012; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Oliveira-Santos et al., 2011; Sisman et al., 2012).

Various methods have been employed to detect the accessory mental foramen. The first classical method was through gross anatomical observation of dry skull, in which the reported prevalence was 5.5–13% (Budhiraja et al., 2012; Gupta & Soni, 2012; Prabodha & Nanayakkara, 2006; Shukla et al., 2015; Singh & Srivastav, 2010; Udhaya et al., 2013; Zarei et al., 2013).

Panoramic imaging was used by some studies and reported a lower detection rate as compared with other assessment methods (Al-Khateeb et al., 2007; Naitoh et al., 2011b).
A number of studies was using CT to detect accessory mental foramen with a reported prevalence of 2.0–11.9% (Garay & Cantín, 2013; Göregen, Miloğlu, et al., 2013; Haktanır et al., 2010; Imada et al., 2014; A. Kalender et al., 2012; Katakami et al., 2008; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Oliveira-Santos et al., 2011; Orhan et al., 2013).

Orhan et al. (2013) reported that the prevalence of accessory mental foramen in children using CBCT imaging was 6.34%. In addition, two studies compared CBCT and panoramic radiography (Naitoh et al., 2011b; F. S. Neves et al., 2014) and according to Naitoh et al. (2011b), approximately half of the accessory mental foramen or bifurcations of it could be detected on panoramic radiography. However, Neves et al. (2014) reported that the accessory mental foramina were detected in 1.2% of panoramic radiographs and 7.4% of CBCT images, and that the prevalence was significantly different between these two imaging modalities. It is a widely-held view that no difference exists between anatomical studies and CBCT observations in the prevalence of accessory mental foramen.

A number of studies reported that unilateral accessory mental foramen was more often than bilateral accessory mental foramen (Gupta & Soni, 2012; Imada et al., 2014; Jaju et al., 2013; A. Kalender et al., 2012; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Oliveira-Santos et al., 2011; Prabodha & Nanayakkara, 2006; Sisman et al., 2012; Zarei et al., 2013). Bilateral accessory mental foramina are considered rare and were found in only 6–

8% of accessory mental foramen cases, corresponding to approximately 0.53% of the total population (A. Kalender et al., 2012; Oliveira-Santos et al., 2011; Sisman et al., 2012). Furthermore, another very rare finding of accessory mental foramen was a mandible with triple accessory mental foramina (A. Kalender et al., 2012; Sisman et al., 2012). In addition, very few cases of bilateral agenesis of the mental foramen that have been reported (Hasan et al., 2010; Hu et al., 2007; Lauhr et al., 2015).

A false detection of accessory mental foramen has been reported by some studies as some nutrient foramina might be considered as accessory mental foramen if it is detected anatomically by examination of dry skulls alone. Additionally, when there is periapical fistula, they could be counted as accessory mental foramen (Iwanaga et al., 2015).

Table 2.13: Prevalance of accessory mental foramina (AMF)

Study	**Country**	**Assessment method**	**Sample size**	**Prevalence %**
A. Gershenson et al. (1986)	Israel	Cadeveric and dry skull study	575	5.3
Roopa et al. (2002)	India	Dry skull	148	10.1
Prabodha and Nanayakkara (2006)	Sri Lanka	Dry Skull	24	8.3
Al-Khateeb et al. (2007)	Jordan	PA	860	10
Katakami et al. (2008)	Japan	CBCT	150	10.7
Munetaka Naitoh, Yuichiro Hiraiwa, et al. (2009)	Japan	CBCT	157	7
Haktanır et al. (2010)	Turkey	MDCT	100	4
Singh and Srivastav (2010)	India	Dry Skull	100	13.0
Naitoh et al. (2011b)	Japan	CBCT & PA	365	7.7
Oliveira-Santos et al. (2011)	Brazil	CBCT	285	9.4
Singh and Srivastav (2011)	India	Dry Skull	100	13.0
A. Kalender et al. (2012)	Turkey	CBCT	193	11.90
Gupta and Soni (2012)	India	Dry Skull	120	6.6
Orhan et al. (2013)	Turkey	CBCT	63	6.3
F. S. Neves et al. (2014)	Brazil	CBCT & PA	127	7.4
Zarei et al. (2013)	Iran	Dry Skull	50	10
Hoque et al. (2014)	Bangladesh	Dry Skull	185	2.2
Udhaya et al. (2013)	India	Dry Skull	90	5.5
GÖREGEN, MİLOĞLU, et al. (2013)	Turkey	CBCT	315	6.3
Sisman et al. (2012)	Turkey	CT	504	2
Imada et al. (2014)	Brazil	CBCT	100	3.0
Shukla et al. (2015)	India	Dry Skull	70	7.2
Serman (1989)	African American, Caucasian	Dissection of mandible	508	0.88
Zografos and Mutzuri (1989)	Greek	Dissection of mandible	464	6.68

Table 2.13(continued): Frequency of accessory mental foramina (AMF).

Study	**Country**	**Assessment method**	**Sample size**	**Prevalence %**
Roopa et al. (2002)	Indian	Dissection	142	7.74
Oliveira-Santos et al. (2011)	Caucasian, Brazilian	CBCT	285	9.40
Sawyer et al. (1998)	Asian Indian Nazea Indian African American American White	Visual Examination	705	10.50
Naitoh et al. (2010)	Japan	CBCT	28	7
Al-Khateeb et al. (2007)	Jordan	Panoramic	860	10

Table: 2.14 Reported AMF by different case reports.

Study	**Population**	**Age**	**Sex**	**Side**	**Ass.**	**Remarks**
Byers and Ratcliff (1983)	Caucasian	54	M	R	PA	Bifurcated IAC
Meoli et al. (1993)	Italian	41	F	L	CT	Double mental foramen
Dario (2002)	Caucasian	52	M	R	CT	Bifurcated IAC
Cağirankaya and Kansu (2008)	Turkish	62	F	L	Pan and PA	accessory mental foramen
Wyatt (1996)	African American	23	M	L	Pan	Bifurcated IAC
Balcioglu and Kocaelli (2009)	Turkish	48	F	R	CT	Double mental foramen,accessory mental foramen
Kulkarni et al. (2011)	Indian	25	M	R	Flap	accessory mental foramen
Thakur et al. (2011)	Indian	40	M	R	Dissection	accessory mental foramen
Pancer, Garaicoa-Pazmino, et al. (2014)	Caucasian	84	M	R	flap	accessory mental foramen
Frederico S Neves et al. (2010)	Brazil	47	M	L	CT	Lingual accessory mental foramen
Frederico Sampaio Neves et al. (2010)	Brazil	14	F	L	CT	accessory mental foramen

2.9.5.2 Location of the mental foramen and accessory mental foramina

Studies differed as to whether accessory mental foramen is located posteroinferior, posterior or anteroinferior to the mental foramen. The findings are summarized in Table 2.15.

Table 2.15: Location of accessory mental foramen with respect to mental foramen

Study	N	Anterior			Posterior			Superior	Inferior
		Anterosuperior	Anterior	Anteroinferior	Posterosuperior	Posterior	Posteroinferior		
Munetaka Naitoh, Yuichiro Hiraiwa, et al. (2009)	15	20%	0.0%	0.0%	20.%	0.0%	60%	0.0%	0.0%
Katakami et al. (2008)	17	0.0%	0.0%	5.8%	5.8%	41.2%	11.8%	5.8%	29.4%
A. Kalender et al. (2012)	27	0.0%	3.7%	37%	11.1%	0.0%	22.2%	0.0%	11.1%
Sisman et al. (2012)	14	7.1%	7.1%	28.6%	21.4%	0.0%	18.8%	0.0%	0.0%
Oliveira-Santos et al. (2011)	32	18.8%	6.3%	3.1%	15.6%	21.9%	18.8%	12.5%	3.1%
Orhan et al. (2013)	4	0.0%	0.0%	0.0%	25.%	25%	60%	0.0%	0.0%
F. S. Neves et al. (2014)	19	5.3%	0.0%	0.0%	10.5%	10.5%	42.1%	10.5%	21.1%
Göregen, Miloğlu, et al. (2013)	22		45%			54.6%		0.0%	0.0%
Jaju et al. (2013)	9	0.0%	0.0%	22.2%	11.1%	0.0%	66.7%	0.0%	0.0%

2.9.5.3 The distance between the mental foramen and accessory mental foramen

The mean distance between the mental foramen and accessory mental foramen ranges from 0.67 mm to 6.3 mm (Göregen, Miloğlu, et al., 2013; Gupta & Soni, 2012; Jaju et al., 2013; A. Kalender et al., 2012; Katakami et al., 2008; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Prabodha & Nanayakkara, 2006; Sisman et al., 2012).

3.9.5.6 Size of the mental foramen and accessory mental foramen

A number of studies have measured the size of the mental foramen vertically and horizontally (2012; 2009). Naitoh et al. (2009) was the only study to measure the mental foramen area with its accessory mental foramen. The reported area was 1.7mm^2 and the ipsilateral accessory mental foramen was 7.5 mm^2. However, the mean area of the mental foramen alone without AMF was 9.4 mm^2. Therefore, mental foramen size is considered larger than the one with accessory mental foramen. The authors reported no significant difference in the area of the mental foramen between cases in which accessory mental foramina were existed or were absent.

A study conducted by Kalender et al. (2012) after scanning 386 patients using CBCT found that the mean vertical and horizontal dimensions of the accessory mental foramen (AMF) were 1.4 mm (range: 0.8–2.4 mm) and 1.6 mm (range: 0.8–3 mm), respectively while the vertical and horizontal sizes of the mental foramen (MF) were 3.7 mm (range: 1.0–7.0 mm) and 3.4 mm (range:0.8–7 mm), respectively. The mean of accessory mental foramen size does not differ significantly with gender or side.

2.9.5.4 Clinical significance of AMF

Identification of mental foramen variant is of utmost importance in many oral surgical procedure around the mental foramen (Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Sisman et al., 2014) and also in endodontic surgeries (Concepcion & Rankow, 2000; Katakami et al., 2008) . Further, if the accessory mental foramen is not identified and excised during neurectomy procedures in cases of trigeminal neuralgia, it may cause failure of the procedure (Jha & Kumar, 2012).

Accessory mental foramen can be exposed through mucoperiosteal flap to examine it directly. Some complications happen during the surgery or after it and suitable management is of utmost importance to save the nerve and vessels. Rapid action for repair of nerve injuries is of great importance for fruitful recovery of nerve function.

If nerve damage occurred, then patient must be referred immediately for evaluation and surgical correction by neurologist, neurosurgeon, or oral maxillofacial surgeon. If no immediate action is taken and too much time passes, surgical correction may become useless and pharmacologic treatment of chronic pain may be chosen.

If patient complained of an altered nerve sensation, then a proper diagnosis must be obtained through the use of advanced imaging. It is important to recognize whether the paresthesia, or dysesthesia is a result of hitting, compressing, or administrating local anesthetic in close immediacy to the nerve. If the radiograph demonstrates that the dental implant is impinging on the nerve, it should be repositioned or removed, and consideration may be given for administering analgesic, steroid, and antibiotic.

If persistent numbness is still experienced, again a steroid, antibiotic, and analgesic may be considered. If symptoms do not resolve with all mentioned modalities, then neurosurgical modalities may need to require which may include: external decompression, internal neurolysis, excision of neuroma, neurorhaphy, nerve graft, nerve sharing, guided nerve regeneration, neurectomy, nerve capping, and nerve redirection.

Nerve lateralization can be performed by raising a mucoperiosteal flap, creating vertical osteotomies distal to the foramen and the second molar along the lateral cortical plate, and then joining the vertical cuts with a horizontal osteotomy. Using elevators, the cortical window and portion of medullary bone is removed, while using nerve hooks, the neurovascular bundle is displaced laterally. The nerve is then covered with a dressing or bone wax, and the dental implants may be inserted at that time or a later time (Khajehahmadi et al., 2013; Pasqual & Pasqual, 1967; Smiler, 1993).

Unlike nerve lateralization, nerve transposition is a higher risk treatment option which invloves the sacrifice of the incisive nerve (Khajehahmadi et al., 2013). Although some authors noted no long-term adverse sequelae (Smiler, 1993), others reported a high rate of transient permanent sensory dysfunction of up to 54.7% and damage of anterior teeth vitality (Ellies & Hawker, 1993; Kan et al., 1997; Khajehahmadi et al., 2013). This procedure must be considered carefully and should not be a first-line treatment option.

Apart from different descriptions for Accessory mental foramen (AMF), being aware of its probable existence is important to avoid pain, paralysis, and even parasthesia after surgical procedures (Balcioglu & Kocaelli, 2009; Imada et al., 2014; Mamatha et al., 2013; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Parnia et al., 2012; Singh & Srivastav, 2010).

CHAPTER 3: RESEARCH MEHODOLOGY

3.1 Introduction

The present research study was designed to identify and classify bifid and trifid mandibular canals as well as the presence of accessory mandibular or mental foramina in the mandible of Malaysian subjects using Cone-Beam Computed Tomography (CBCT) and SimPlant interactive software. This chapter will describe a general research methodology for the whole study while a detailed research methodology is described in each related chapter.

3.2 The materials of the study

Cone-Beam Computed Tomography (CBCT) images taken using i-CAT imaging system at the Division of Oral and Maxillofacial Radiology, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia were used. The relevant “Diacom” data was downloaded and saved in an external hard disc for the purpose of this study.

Latest CBCT records taken was the priority of selection; starting from records in the month of January 2015 and moving backwards in time until adequate number of patients were selected.

3.3 Sample selection

The sample comprised of 202 subjects who attended the Department of Oro-maxillofacial Surgical & Medical Sciences, Faculty of Dentistry, University of Malaya. Each CBCT dataset of the patients having the right or the left side of the mandibular posterior region were analysed. The required sample size was calculated according to the equation below and the required sample size was 195.92, for which we added 5% for possibility of unavailable data.

$$n = \frac{Z^2 pq}{\Delta^2}$$

Table 3.1 Sample size calculation

Z	1.96	**Z^2 =**	3.8416
p	0.15	Expected prevalence	
q	0.85	Compliment of prevalence	
pq	0.1275		
Δe	**0.05**	Margin of error	
n	195.9216	Required sample size	

Inclusion criteria for CBCT data set

- Males or females from 3 ethnic groups: Malays, Chinese and Indians aged 11-80 years old.
- Healthy, medically compromised or even previously radiated patients that did not involve the body of the mandible.
- Dentate and edentulous patients.
- Accessory canal can be seen and drawn in axial, coronal, sagittal, panoramic aspect.
- Accessory canal cortication (complete/partial) observed.
- Accessory canal must be connected to MC in the mandibular ramus
- Mental foramen and mandibular foramen is clearly visible with its cortication.

Exclusion criteria for CBCT data set

- CBCT scans showing injury to the mandible.
- Patients with existing pathological disorder at mandible such as cyst, tumor, osteomyelitis, fibrous dysplasia or other skeletal diseases.
- Syndromic patients and patients with congenital disorders that affect the size of the jaw bones.
- CBCT scan showing surgical intervention to the body of the mandible - like bilateral sagittal split orthognathic surgery, intraoral vertical ramus osteotomy or repair of a fracture.
- The reformatted CBCT images, which appear, distorted or blurred due to patients' movements.
- Severely atrophied mandible (flat mandible).
- CBCT images that did not include the mandible during scanning.

3.4 Methodology

3.4.1 Methods

The selected samples from the CBCT data were stored in an external hard disk. They were then exported to a workstation for further processing. The images were reformatted using SimPlant software version 13 from Materialise lnc (SimPlant 3-D Pro version 13.1; Materialise Inc., Leuven, Belgium). The SimPlant software allows viewing of axial, cross-sectional, Panoramic and 3D visualization of the jaw on the same screen.

The SimPlant workstation is most outstanding for the three-dimensional renderings. This workstation is capable of displaying an entire volume of data from a large number of angles. It therefore allows the operator to define the image elements that make up the osseous structures. In the 3D visualization, the jaw can be turned in space, rotated or spun 360 degrees and viewed from any angle.

The vital structures such as inferior alveolar nerve can be colored and displayed through the bone as if the bone were transparent. In this study, the anatomy of the whole mandible was assessed first in the axial, coronal and panoramic views. Then the bifid/trifid mandibular canal was examined and verified in all three planes. Mental foramen and mandibular foramen position and anatomical features were assessed as well. As such, this fully integrated planning tool allows identification of the canals with unparalleled precision and at the same time provides 3D digital visualization of the jaw and canals.

3.4.2 Image acquisition

i-CAT Imaging System (Imaging Sciences International Inc., Hatfield, USA) was employed for CBCT scanning. A standardized protocol for patient positioning and exposure parameter setting (120kVp, 3-7mA) and image acquisition was performed at 0.3mm voxel size. Patients were placed in a vertical position and stabilized with custom made head bands and chin support in the i-Cat machine and monitored to ensure that they remained motionless throughout the duration of the scan for a period of 20 seconds.

3.4.3 Processing the images (Measurements)

The visibility rating and dimensional measurements were performed by only one researcher who is trained in the interpretation of oral and maxillofacial images. Some suspected CBCT images were re-evaluated by a qualified maxillofacial radiologist to confirm their suitability in this research. The DICOM data obtained were imported into SimPlant and examined using cross-sectional images. Additional axial, and/or sagittal images in the volume were analyzed if necessary. Full measurement methodology is described in its related chapters for the structures studied.

3.4.4 Reliability of the measurement

The intraexaminer reliability and reproducibility of the measurements obtained were evaluated. A total number of forty patients' records which is 10% of the sample size were randomly selected and all the data was recorded twice with a break of three weeks using the same prescribed methods. The consistency of data was analyzed and the Cronbach alpha coefficient was calculated for all the measured data.

3.5 Ethical approval

This study received the Faculty Ethical Committee's approval prior to commencement (Approval no: DF DP1303/0014 [P]). The committee was aware that this was a retrospective study and that it was undertaken using patients' data and radiographs. As this is a teaching institution, all patients seeking treatment from the Faculty of Dentistry are informed of the possibility that all forms of their records may be used for teaching and research purposes, and verbal consent is taken with the assurance that their identity will remain anonymous.

CHAPTER 4: BIFID MANDIBULAR CANAL

4.1 Introduction

This chapter will cover the methodology used to detect and measure bifid mandibular canal and the result of analyzing these data which include the frequency of bifid mandibular canal, bifid mandibular canal diameter, length of bifid mandibular canal, bifid lumen shape, classification type and the vertical position of the bifid mandibular canal related to main mandibular canal amongst Malaysian population.

4.2 The variables of the study

The independent variables used for the purpose of this study shall be gender (male and female), race (Malays, Chinese, and Indians) and age, while the dependent variables were presence of bifid mandibular canal, vertical position, length, lumen shape, classification type and the mandibular canal diameter as shown in Table 4.1.

Table 4.1: Measurement records of dependent variables.

BMC	Existence of bifid case according to inclusion criteria.
BMC-VP	Vertical position of extra canal - either above main mandibular canal, same level or below it.
BMC-L	Length of extra canal - from the starting point of separation from the main canal to the terminal end that resides in the mandible, measured in mm.
BMC-Shape	Lumen shape- circular, oval or irregular.
BMC-Classification	Carter and Keen (Carter & Keen, 1971) classification, Nortje classification (Nortje et al., 1977), Langlais classification (Langlais et al., 1985), Naitoh classification (Munetaka Naitoh, Kino Nakahara, et al., 2009).
BMC-MCd	The diameter of the mandibular canal in the bifid mandibular canal case.
BMC-d	The diameter of the accessory bifid mandibular canal.

4.3 Measurements

The course and length of bifid mandibular canals were measured either in sagittal or panoramic reconstructed CBCT images using SimPlant software which allows the observer to measure and trace straight or curved structures (like bifid mandibular canal). Firstly, the mandibular foramen and mental foramen were identified and mandibular nerve was drawn and marked orange. Then, the bifid canal was drawn and marked white to distinguish it from main mandibular canal. The length of bifid mandibular canal was measured to be the starting point of separation from the main canal to the terminal end that resides in the mandible.

The diameter of the bifid mandibular canal was measured and classified into two categories: (1) greater than or equal to 50% or (2) lesser than 50% of the diameter of the main mandibular canal. The diameter of the main mandibular canal was measured immediately after bifurcation on the cross-sectional image and that of the bifid mandibular canal at the widest portion of the bifid canal.

Vertical position of the bifid mandibular canal according to main mandibular canal was recorded to be either above main mandibular canal, same level or below it. Lumen shape of the bifid canals were observed to be either circular, oval or irregular at the widest and the clearest portion of the bifid canal.

All data were gathered, entered and analyzed using SPSS 12.1 (SPSS Inc., Chicago, USA) software program. Descriptions of numerical parameters were given as number, mean ± standard deviation (SD), minimum and maximum value recorded.

Significant differences in the prevalence of the bifid mandibular canal, bifid canal classification, vertical position of the bifid canal and lumen shape type with respect to ethnicity, gender and age were studied using a chi-square test. Significant differences among the mean length and the diameter of the bifid canal in each type of bifid mandibular canal were investigated using one-way analysis of variance (ANOVA). When there were significant differences among the mean lengths and diameters, Bonferroni method for post-hoc analysis was conducted. Significant differences among the mean length and the diameter of the bifid canal among ethnicity and gender were investigated using Independent sample t-test. Differences were considered significant when the p-value was less than 0.05.

4.4 Result

The demographic characteristics of patients (n=202) summarized in Table 4.2. The sample for this study included imaging of 202 patients (94 males and 108 female) comprising of Malays, Chinese and Indians, with ages ranging from 11 to 80 years (mean age, 48.62±16.53 years). Each CBCT dataset of the patients included the right or the left side of the mandibular posterior region, so the total sample size was 404 hemi-mandibles. Figure 4.1 summarizes the age group distribution for the sample.

Table 4.2: Selection of cases based on gender and ethnicity (race).

Ethnicity (race)	Gender	No. of patients (Percent)	No. of hemimandible
Malay (n=93)	Male	42	186
	Female	51	
Chinese (n=72)	Male	32	144
	Female	40	
Indian (n=37)	Male	20	74
	Female	17	
	Total	202	404

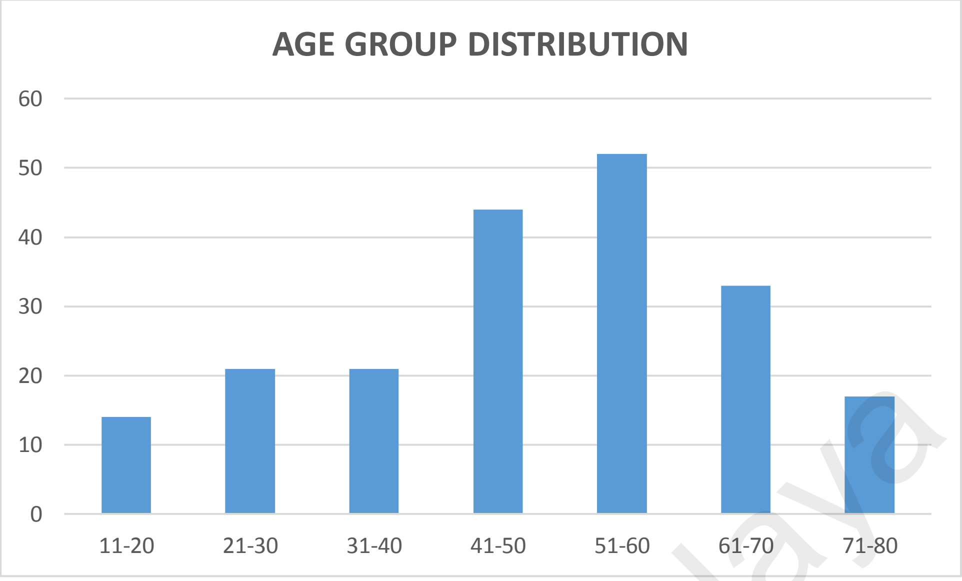

Figure 4.1: Age group distribution of sample size (n=202).

4.4.1 The prevalence of BMC

Bifid mandibular canals were observed in 46 (22.77%) of the 202 patients (Figure 5.2). Twenty patients had bilateral bifid mandibular canal while 26 were unilateral, all unilateral were in the right side only. In total, there were 66 BMC found in the 46 patients. These canals were observed in 24 males (11.88%) and 22 females (10.89%). There was no significant difference between gender with respect to the prevalence of the bifid mandibular canal (p=0.406) (Table 4.3).

Table 4.3: The prevalence of the bifid mandibular canal amongst gender.

Gender	Type of canals				prevalence of BMC
	Bifid canals			Non-bifid canals	
	Unilateral	Bilateral	Total		
Male (n=94)	13	11	24	71	25.53%
Female (n=108)	13	9	22	87	20.37%
Total (n=202)	26	20	46	158	22.77%

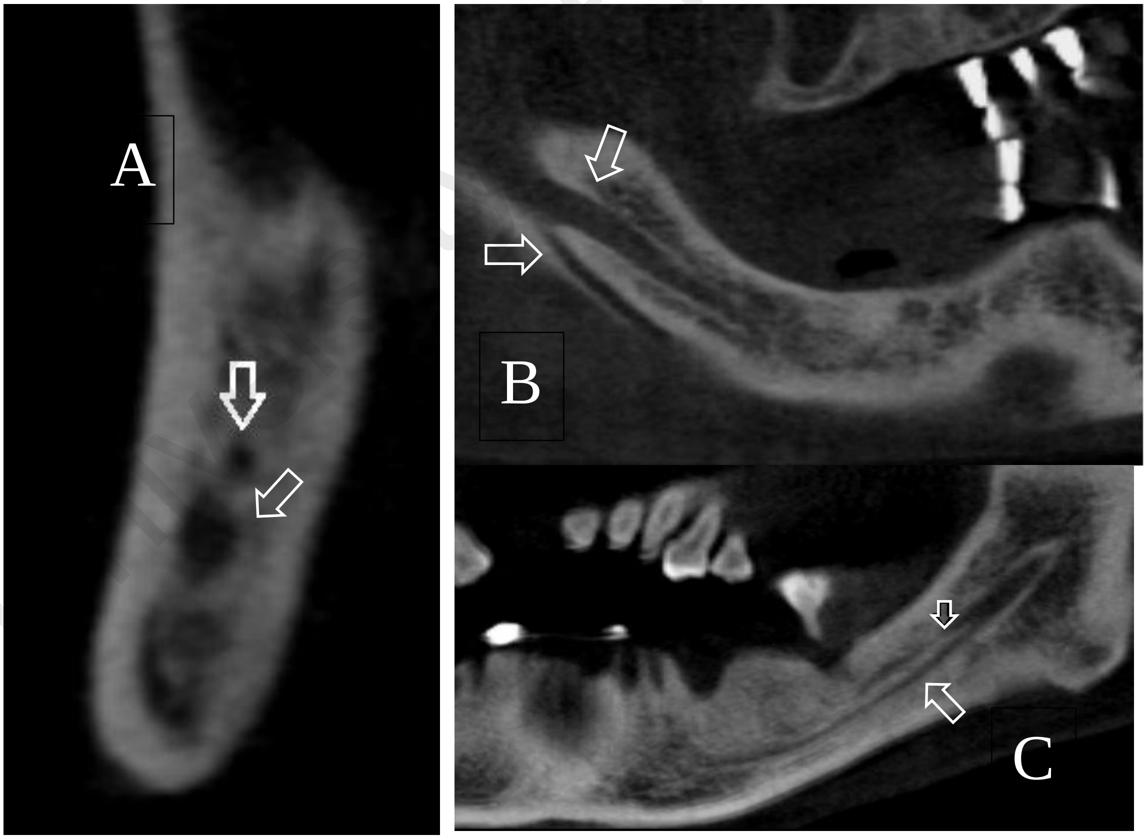

Figure 4.2: Bifid mandibular canal (White arrow) – Sagittal view (A) and panoramic view (B and C) of CBCT image improved with SimPlant software.

Similarly, there was no significant difference between ethnicity with respect to the prevalence of the bifid mandibular canal (p=0.585) (Table 4.4).

Table 4.4: The prevalence of the bifid mandibular canal between ethnicity.

Ethnic group	Type of canal		Prevalence	*P* value
	Bifid canal	Normal main canal		
Malay (n=93)	23	70	24.73%	0.585
Chinese (n=72)	17	55	23.61%	
Indian (n=37)	6	31	16.21%	

The prevalence of the bifid mandibular canal according to age was 0% for patients in their 20s, 4.76% for those in their 30s, 23.8% for those in their 40s, 39.53% for patients in their 50s, 24.52% for those in their 60s, 15.15% for those in their 70s, and 29.41% for those in their 80s. There was no significant difference in the prevalence with respect to age group (p=0.350) (Table 4.5).

Table 4.5: The prevalence of the bifid mandibular canal in different age group.

	Male			Female			Total number of patients with bifid canals (%)	P-value*
Age Group	**N**	**Bifid canals**	**%**	**N**	**Bifid canals**	**%**		
11-20 (n=14)	6	0	0	8	0	0	0 (0%)	0.350
21-30 (n=21)	7	0	0	14	1	7.1	1(4.76%)	
31-40 (n=21)	14	3	21.4	7	2	28.6	5(23.80%)	
41-50 (n=43)	19	10	52.63	25	7	28	17(39.53%)	
51-60 (n=53)	19	4	21.05	33	9	27.27	13(24.52%)	
61-70 (n=33)	20	4	20	13	1	7.6	5(15.15%)	
71-80 (n=17)	9	3	33.33	8	2	25	5(29.41%)	
Total (n=202)	94	24	25.53	108	22	20.37	46(22.77%)	

*Chi square
Total no. of patients – 202
Total no. of hemmandibles – 404
Total hemi-mandible BMC - 66

4.4.2 Classification of bifidity

Table 4.6: Data set classification according to BMC classification studies.

Carter and Keen (1971)		Type 1	Type 2	Type 3	
				19	
	Total canals	19			
	Missing*	47			
Nortje classification (1977)		Type 1	Type 2	Type 3	Type 4
			19	15	19
	Total canals	53			
	Missing*	13			
Langlais classification (1985)		Type 1	Type 2	Type 3	Type 4
		19	13		15
	Total canals	47			
	Missing*	19			
Naitoh classification (2009).		Type 1	Type 2	Type 3	Type 4
		19			47
	Total canals	66			
	Missing*	0			

*The bifid canals which couldn't be fit using this classification.

Based on the above finding (Table 4.6), it was discovered that not all bifid mandibular canals fit into the classification systems developed in the Western world, but instead can be classified according to anatomic location and configuration. Based on the findings of this study, a new classification was proposed. Five main patterns of bifid mandibular canals were suggested (Figure 4.3) and the distribution of the BMC according to the five main patterns are presented in Table 4.7.

Type 1 consisted of two canals originating from one mandibular foramen (Figure 4.3; A).

Type 2 was seen radiographically as two mandibular canals of equal dimensions arising from separate foramina in the mandibular ramus and joining together to form one canal in the molar region of the body of the mandible (Figure 4.3; B).

Type 3 consisted of one canal that arise from one mandibular foramen that divides in two divisions and ending in two separate mental foramina (Figure 4.3; C).

Type 4 consisted of accessory canal that arised from mandibular canal, travel for a distance and rejoined the main canal in the mandibular body. (Figure 4.3; D).

Type 5 consisted of an accessory canal branching from mandibular canal to retromolar region that may exit through a retromolar foramen (Figure 4.3; E).

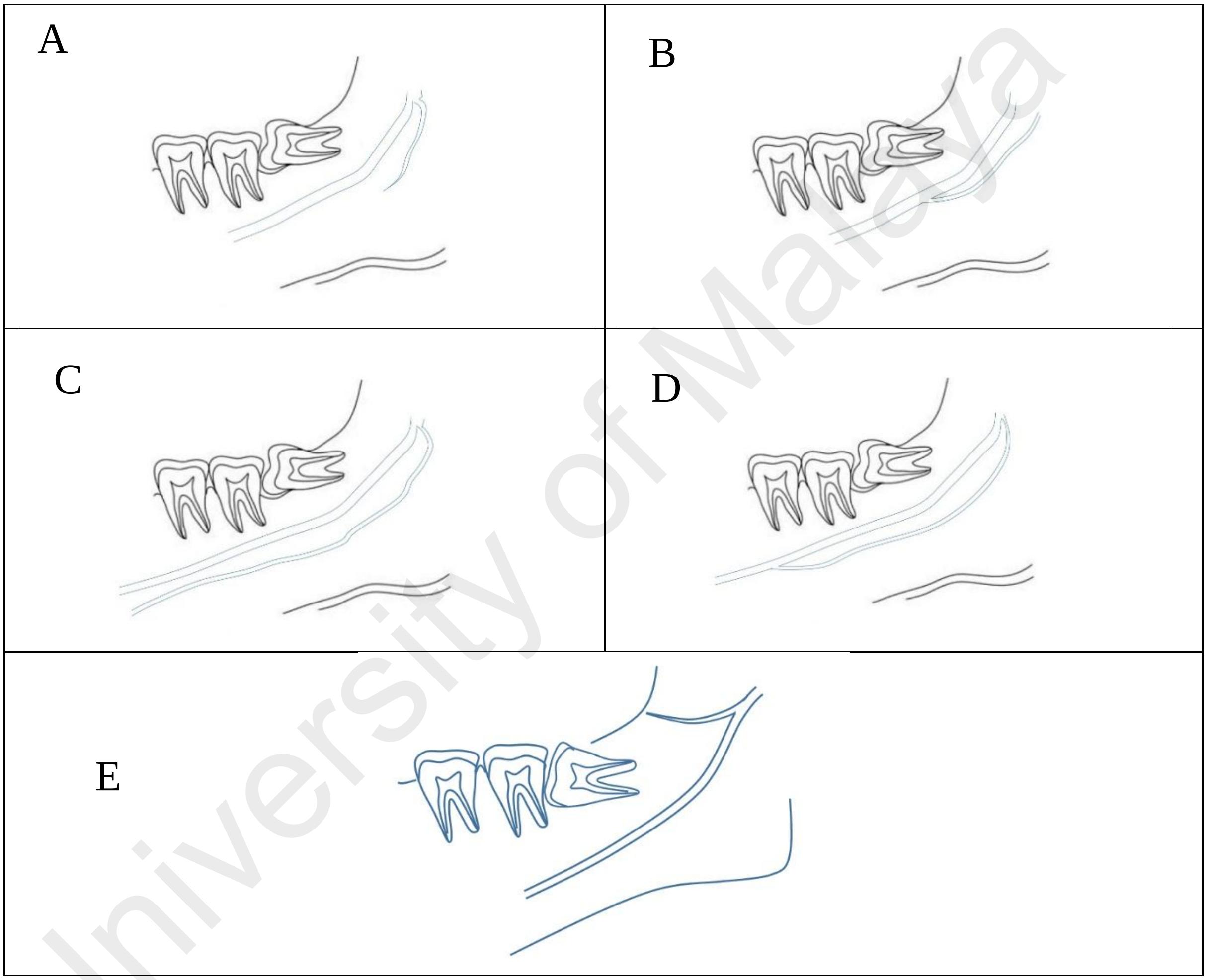

Figure 4.3: An illustration of configuration of the bifid mandibular canal as classified into five types: Type 1: Two canals originating from one mandibular foramen (A). Type 2: Two mandibular canals of equal dimensions arising from separate foramina in the mandibular ramus and joining together to form one canal in the molar region of the body of the mandible (B). Type 3: Bifid mandibular canals arise from one mandibular foramen then divides in two divisions and ending in two separate mental foramina (C). Type 4: An accessory canal arising from mandibular canal and rejoins together in the mandibular ramus (D). Type 5: consisted of an accessory canal branching from mandibular canal to retromolar region that may exit through a retromolar foramen (E).

The results obtained were reanalyzed using these classifications and are shown in Table 4.7. Type 1 of BMC occurred in 13 patients (16 hemi-mandibles) of whom 7 were males and 6 were females. Ten BMC canals were unilateral while bilaterally was noticed in 3 cases. The bifurcations were with 8 on the right side and 8 on the left. Seven BMC involves mandibles were noticed in Malays, 5 in Chinese and 1 in an Indian. Type 2 occurred in 9 patients (15 hemi-mandibles) of whom 8 of the right side and 7 of the left side. Nine BMC were unilateral and bilateral in 3 cases. The bifurcations were noticed in 5 males and 4 females. Five mandibles belonged to Malays, 3 to Chinese and 1 to an Indian. Type 3 configuration occurred in 2 patients (3 hemi-mandibles) of whom 1 on the right side and 2 on the left side. It was bilateral in one case and unilateral in one case as well. The bifurcations were noticed in 1 male and 1 female. One mandible belonged to a Malay and another to an Indian, respectively. Type 4 pattern occurred in 9 patients (13 hemi-mandibles) of whom 7 on the right side and 6 on the left side. Five canals were unilateral while bilaterally it was noticed in 4 cases. The bifurcations were noticed in 6 males and 3 females. Five mandibles belonged to Malays and 4 to Chinese. Lastly, Type 5 pattern occurred in 13 patients (19 hemi-mandibles) of whom 9 on the right side and 10 on the left side. Eleven BMC were unilateral while bilateral was in 4 cases. The bifurcations were noticed in 5 males and 8 females. 5 mandibles belonged to Malays, 5 to Chinese and 3 to Indians.

Table 4.7: Percentage of each type of the bifid mandibular canal.

Classification *	Number of patients (%)	Number of bifid MC in hemi-mandibles (%)	R (%)	L (%)	M (%)	F (%)	Malays (%)	Chinese (%)	Indian (%)
Type1	13 (28.3)	16 (24.2)	8 (24.2)	8 (24.2)	7 (29.2)	6 (27.3)	7 (30.4)	5 (29.4)	1 (16.7)
Type2	9 (19.6)	15 (22.7)	8 (24.2)	7 (21.2)	5 (20.8)	4 (18.2)	5 (21.7)	3 (17.6)	1 (16.7)
Type3	2 (4.3)	3 (4.5)	1 (3)	2 (6.1)	1 (4.2)	1 (4.5)	1 (4.3)	0	1 (16.7)
Type4	9 (19.6)	13 (19.7)	7 (21.2)	6 (18.2)	6 (25)	3 (13.6)	5 (21.7)	4 (23.5)	0(0)
Type5	13 (28.3)	19 (28.8)	9 (27.3)	10 (30.3)	5 (20.8)	8 (36.4)	5 (21.7)	5 (29.4)	3 (50)
Total	46	66	33	33	24	22	23	17	6

*No significant difference was found between classification type and side (p=0.971), ethnicity (p=0.317) and gender (0.570).

Table 4.8 shows the presence of bifid mandibular canal according to age-groups. Only one Type 5 canal was observed in patient in their 30s, while different number of bifid mandibular canals were observed in subjects between 31-80 years.

Table 4.8: Age group distribution for each classification type

Classification	***30s***	***40s***	***50s***	***60s***	***70s***	***80s***	***Total***	***P value***
Type1	*0*	*1*	*3*	*4*	*4*	*4*	*16*	*0.099*
Type2	*0*	*4*	*5*	*5*	*1*	*0*	*15*	
Type3	*0*	*0*	*3*	*0*	*0*	*0*	*3*	
Type4	*0*	*0*	*3*	*6*	*3*	*1*	*13*	
Type5	*1*	*1*	*10*	*4*	*1*	*2*	*19*	
Total	*1*	*6*	*24*	*19*	*9*	*7*	*66*	

4.4.3 The vertical position of the bifid mandibular canal

The vertical position of the canal was classified into three types according to the results; 29 bifid (43.9%) canals were above the main mandibular canal, and 37 (56.1%) were below the main MC. There was no significant difference found between bifid vertical position with gender (p=0.193), ethnicity (p=0.508), while significant difference was found between age groups (p=0.03) (Table 4.9, 4.10 and 4.11).

Table 4.9: Distribution of vertical position of bifid mandibular canal amongst gender.

Position	Number	Gender (number/percent)		*P* value
		Male	Female	
Above MC	29(100%)	18(62.1%)	11(37.9%)	0.193
Below MC	37(100%)	17(45.9%)	20(54.1%)	
Total	66(100%)	35(53%)	31(47%)	

Table 4.10: Distribution of vertical position of the bifid mandibular canals amongst race.

Position	Number	Race (number/percent)			*P* value
		Malays	Chinese	Indians	
Above MC	29(100%)	15(51.7%)	8(27.6%)	6(20.7%)	0.508
Below MC	37(100%)	20(54.1%)	13(35.1%)	4(10.8%)	
Total	66(100%)	35(53%)	21(31.8%)	10(15.2%)	

Table 4.11: Distribution of vertical positions of the bifid mandibular canals amongst age-groups.

Position	Age groups (years) [number/percent]						*P* value
	21-30	31-40	41-50	51-60	61-70	71-80	
Above MC (n=29)	1(3.4%)	3(10.3%)	16(55.2%)	4(13.8%)	2(6.9%)	3(10.3%)	0.033
Below MC (n=37)	0(0%)	3(8.1%)	8(21.6%)	15(40.5%)	7(18.9%)	4(10.8%)	
Total (n=66)	1(1.5%)	6(9.1%)	24(36.4%)	19(28.8%)	9(13.6%)	7(10.6%)	

4.4.4 Diameter of the bifid mandibular canal

All the accessory canals were smaller than the main mandibular canal. The diameter of the accessory canal was greater than or equal to 50% of the main canal in 54 (81.81%) and lesser than 50% in the remaining 12 (18.18%) hemi-mandibles. The mean diameter of the accessory canal was 1.42 mm (SD ±0.32) (range: 0.84-2.29 mm) and that of the main mandibular canal was 2.34 mm (SD ±0.46) (range: 1.47-3.88 mm).

There was no significant difference in the mean diameter with respect to age-groups (p=0.750) (Table 4.12), ethnicity (p=0.172) (Table 4.13) and to the bifid mandibular canal types (p=0.144) (Table 4.15); while a significant difference in the mean diameter was noticed with respect to gender (p=0.031) (Table 4.14).

Table 4.12: Comparison of bifid diameter by age group

Age group (years)	Number of BMC	Diameter of accessory canal (mean and SD in mm)	*P* value
21-30	1	1.62	0.750
31-40	6	1.42 (±0.20)	
41-50	24	1.47 (±0.34)	
51-60	19	1.34 (±0.34)	
61-70	9	1.47 (±0.30)	
71-80	7	1.36 (±0.30)	
Total	66	1.42(±0.32)	

Table 4.13: Comparison of bifid diameter measurement by ethnicity

Ethnicity	Number of BMC	Diameter of accessory canal Mean (SD) in mm	P-value
Malay	35	1.49 (±0.36)	0.172*
Chinese	21	1.36 (±0.28)	
Indians	10	1.29 (±0.18)	

*Levene's test p=0.044 (assumption not met), using non parametric test (Kruskal-Wallis non-parametric test).

Table 4.14: Comparison of bifid diameter measurement by gender.

Gender	Number of BMC	Diameter of accessory canal Mean (SD) in mm	*P* value
Male	35	1.50 (±0.35)	0.031
Female	31	1.33 (±0.25)	

Table 4.15: Comparison of bifid diameter by canal types.

New classification	Number of BMC	Diameter of accessory canal Mean (SD) in mm	*P* value
Type 1	16	1.32 (±0.32)	0.144*
Type 2	15	1.39 (±0.18)	
Type 3	3	1.17 (±0.12)	
Type 4	13	1.51 (±0.43)	
Type 5	19	1.50 (±0.31)	

Levene's test p=0.024 (assumption not met), using non parametric test (Kruskal-Wallis non-parametric test).

4.4.5 Length of the bifid mandibular canal

The mean length of the bifid mandibular canals was 32.33mm ± 19.96 (range: 7.20-86.33mm). Type 1 has the longest bifid mandibular canal length while Type 5 was the shortest. There was a significant difference between bifid canal length among bifid canal classification (p=0.000). Further test indicated a strong significant difference between bifid canal length among canal types 1,2,4 and Type 5. There is no significant difference between bifid canal length and gender (p=0.275). However, there was a significant difference among age groups (p=0.008) and ethnicity (p=0.041) (Table 4.16, 4.17, 4.18 and 4.19).

Table 4.16: Analysis for the difference in the mean length of the bifid canal between each types of bifid mandibular canals.

Classification	Number of BMC	Length of accessory canal Mean (SD) in mm	*P* value
Type 1	17	49.69 (±20.30)	0.000*
Type 2	15	36.61 (±14.30)	
Type 3	4	30.93 (±14.64)	
Type 4	13	35.41 (±14.09)	
Type 5	19	12.25 (±4.17)	

*Kruskal-Wallis non-parametric test (Type 1 versus Type 5, p=0.000) (Type 2 versus Type 5, p=0.000) (Type 4 versus Type 5, p=0.000).

Table 4.17: Analysis for difference of the mean length of the bifid canals amongst age groups

Age group	Number of BMC	Length of accessory canal Mean (SD) in mm	*P* value
21-30	1	11.75	0.008*
31-40	6	33.90 (±12.49)	
41-50	24	21.92 (±13.65)	
51-60	19	35.53 (±19.27)	
61-70	9	47.20 (±26.65)	
71-80	7	41.77 (±20.90)	

*Bonferroni Post-Hoc difference between age group (41-50 years) versus (61-70 years), P = 0.008

Table 4.18: Analysis for difference in the mean length of the bifid canals according gender

Gender	Number of BMC	Length of accessory canal Mean (SD) in mm	*P* value
Male	35	34.87 (±21.73)	0.275
Female	31	29.46 (±17.67)	

Table 4.19: Analysis in the difference of the mean length of the bifid canals according to ethnicity.

Race	Number of BMC	Length of accessory canal Mean (SD) in mm	*P* value
Malay	35	32.46 (±15.84)	0.041*
Chinese	21	38.54 (±25.56)	
Indians	10	18.80 (±13.60)	

*Kruskal-Wallis non-parametric test (Malay versus Indian, P = 0.01)

5.4.6 Lumen shape

Three types of lumen shape were identified in this study. Circular lumen was seen in 12 canal (hemi-mandible) (18.18%), oval lumen was seen in 2 cases (3%), and irregular lumen was seen in 52 cases (78.78%). There is no significant difference between bifid mandibular canal lumen shape among age group (p=0.405), gender (p=0.578), ethnicity (p=0.498), and canal types (p=0.866). (Table 4.20, 4.21, 4.22 and 4.23)

4.20: Analysis of the lumen differences of the different types of bifid canals

New classification	Number of BMC	Shape (number/percent)			*P* value
		Circular	Oval	Irregular	
Type 1	16(100%)	2(12.5%)	1(6.3%)	13(81.3%)	0.866
Type 2	15(100%)	3(20%)	0(0%)	12(80%)	
Type 3	3(100%)	0(0%)	0(0%)	3(100%)	
Type 4	13(100%)	2(15.4%)	0(0%)	11(84.6%)	
Type 5	19(100%)	5(26.3%)	1(5.3%)	13(68.4%)	
Total	66(100%)	12(18.2%)	2(3%)	52(78.8%)	

Table 4.21: Comparison of bifid lumen shape amongst gender.

Gender	Number of BMC	Shape (number/percent)			*P* value
		Circular	Oval	Irregular	
Male	35(100%)	8(22.9%)	1(2.9%)	26(74.3%)	0.578
Female	31(100%)	4(12.9%)	1(3.2%)	26(83.9%)	
Total	66(100%)	12(18.2%)	2(3%)	52(78.8%)	

Table 4.22: Comparison of bifid lumen shape among ethnicity.

Race	Number of BMC	Shape (number/percent)			*P* value
		Circular	Oval	Irregular	
Malay	35(100%)	9(25.7%)	1(2.9%)	25(71.4%)	0.498
Chinese	21(100%)	2(9.5%)	1(4.8%)	18(85.7%)	
Indians	10(100%)	1(10%)	0(0%)	9(90%)	
Total	66(100%)	12(18.2%)	2(3%)	52(78.8%)	

Table 4.23: Comparison of bifid lumen shape according to age-groups.

Age Group (years)	Number of BMC	Shape (number/percent)			P-value
		Circular	Oval	Irregular	
21-30	1(100%)	0(0%)	0(0%)	1(100%)	0.405
31-40	6(100%)	0(0%)	0(0%)	6(100%)	
41-50	24(100%)	7(29.2%)	1(4.2%)	16(66.7%)	
51-60	19(100%)	2(10.5%)	1(5.3%)	16(84.2%)	
61-70	9(100%)	0(0%)	0(0%)	9(100%)	
71-80	7(100%)	3(42.9%)	0(0%)	4(57.1%)	
Total	66(100%)	12(18.2%)	2(3%)	52(78.8%)	

4.4.7 Measurement of Agreement

Since this study consists of huge number of detail quantitative data, the intra-examiner reliability and reproducibility of the measurements obtained were evaluated. A total number of forty patients' records which is actually 10% of the sample size were randomly selected and all the data were measured again two months later by using the same methods described earlier. Regarding the assessment of intraexaminer agreement, all parameters showed an optimal agreement. For the assessments of length and diameter we have used intraclass correlation coefficient, *p* (Table 4.24), while for the categorical subclass agreement we have used Cohen's Kappa *k* (Table 4.25).

Table 4.24: Bifid parameters reliability test (Intraclass Correlation)

Subscale	**Intraclass Correlation**	**95% Confidence Interval (Lower Bound, Upper Bound)**	**p**
Length	0.845	0.051,0.948	0.020
Diameter	0.888	0.351, 0.981	0.009
Mandibular canal diameter	0.959	0.764, 0.993	0.001

Table 4.25: Bifid parameters reliability (Kappa test for categorical subcale)

Subscale	**Kappa *k***	**p**
Bifid	0.783	0.000
Vertical position	1.000	0.000
Lumen Shape	0.588	0.088
Pattern	1.000	0.008

4.5 Discussion

A number of previous studies have reported the prevalence of bifid mandibular canals using panoramic and CBCT images. The prevalence was in the range of 0.08-0.95% in studies using panoramic radiographs and was in the range of 15.6-64.8% in studies using CBCT images. Evidently, bifid canals were more easily noticed in CBCT scans than only employing panoramic images (de Oliveira-Santos et al., 2012; Kuribayashi et al.; M. Naitoh et al., 2009; Naitoh et al., 2010; Orhan et al., 2011). In the present study, the prevalence of the bifid mandibular canals was 22.77%, which was similar to the percentage reported by some earlier studies using same imaging technology (de Oliveira-Santos et al., 2012; Kuribayashi et al.).

Some studies classified bifid mandibular canals using different imaging technologies. Nortje et al. (1977) published 2 studies following a retrospective study of 3612 panoramic radiographs of clinical patients in South Africa. Three main patterns of duplication were found: Type 1 (the most common) – The 2 canals (main and extra) is originating from a single mandibular foramen, Type 2 - a short upper canal ranging to the second or the third molar area, and Type 3 (the least common) - 2 canals of equal size, originating from separate foramina that connect in the molar area. In their second article, they reported a new variation. Type 4 is a double-canal variation in which the supplemental canals arise from the retromolar area and join the main canals in the retromolar area (Nortjé et al., 1977). On the basis of panoramic radiography, Langlais et al. (1985) have classified the bifid mandibular canal into four types according to anatomical location and configuration. Type 1 consists of unilateral or bilateral bifid mandibular canals extending to the third molar or the immediate surrounding area. Type 2 consists of unilateral or bilateral bifid mandibular canals that extend along the course of the main canal and rejoin it within the ramus of the body of the mandible. Type 3 is a combination of the first two categories. Type 4 consists of two canals, each of which originates from a separate mandibular foramen and then joins to form a larger canal (Langlais et al., 1985). Both classification mentioned above were based on the findings using the panoramic radiography. A number of other research groups (Kang et al., 2014; M. Naitoh et al., 2009; Orhan et al., 2011) used CBCT imaging to classify the bifid mandibular canal according to the origin site and the direction of the bifurcated canal from the mandibular canal as 4 types: i) retromolar canal: the extra canal originating from the main canal, opening at the retromolar foramen; ii) dental canal: in this case, the end of the bifurcated canal approaches the root apex of the molars; iii) forward canal: the extra canal originating from the superior wall of the main canal; iv) buccolingual canal: the extra canal arising from the buccal or the lingual wall of the main mandibular canal. We attempted to correlate our findings with the classification provided by these 4 research groups but found that some of our finding cannot fit into these classifications (Table 4.6).

The current study classified the bifid mandibular canals according to our own criteria, since we have found new pattern of duplication that cannot suit in the other classification. CBCT imaging data were used for the detailed classification and observed that Type 5 was most frequently recorded types, whereas Type 2, 3 and 4 comes next with approximately equal frequency, while Type 3 was with the least frequently observed types.

The closest classification to ours was the one proposed by Naitoh et al. (2009), as the authors didn't focus on the origin of the extra canal and have classified all as originating from ramus only. However, our findings for the bifid mandibular canal origin is either from a separated mandibular foramen or same mandibular foramen in the ramus. Naitoh et al.'s (2009) classification focused on destination which is were either dental (Type2) reaching the 2nd molar or forward (Type 3) which advanced forward in the body of mandible. Furthermore, our Type 3 and Type 4 is considered as forward canal (Type 3) in their classification and that's the reason we couldn't consider their classification.

The length and the diameter of the bifid mandibular canal had been studied previously. Naitoh et al. (2009) reported that the mean length of the bifid canal was 9.6mm (range: 1.4-25mm) in the case of the forward canal; 1.6mm (range: 1.5-1.7 mm) in the case of the buccolingual canal; 8.9mm (range: 1.6-23.0 mm) in the case of the dental canal; and 14.8mm (range: 7.2-24.5 mm) in the case of the retromolar canal. In our study the mean length of the bifid mandibular canals was 32.33mm ±19.96 (range: 7.20-86.33mm). This shows the length in the Malaysian population was much higher than in Japanese. Gender had no influence on bifid canal length. However, age and ethnicity had an influence on length with statistical analysis of ($p=0.008$) and ($p=0.041$) respectively. We are, however, unable to explain for these phenomena.

Kuribayashi et al. (2014) reported that the diameter of the accessory canal was greater than or equal to 50% of the main canal in 23 (49%) cases and less than 50% in 24 (51%) cases. These results were not similar to the findings obtained by this study; the diameter of the accessory canal was greater than or equal to 50% of the main canal in 54 (81.81%) and lesser than 50% in the remaining 12 (18.18%) hemi-mandibles. The mean diameter of the accessory canal was 1.42 mm (SD ±0.32) (range: 0.84-2.29 mm) and that of the main mandibular canal was 2.34 mm (SD ±0.46) (range: 1.47-3.88 mm).

One interesting finding is that the vertical position of the bifid mandibular canal was found to be 29 bifid (43.9%) canals were above the main mandibular canal, and 37 (56.1%) were below the main MC. Such a relationship has not been reported previously.

The current study found that the irregular lumen shape of the bifid mandibular canal was the most common in 52 canals (78.78%). Circular lumen shape was seen in 12 canals (hemi-mandible) (18.18%), and oval lumen shape was seen in 2 cases (3%). These findings may be considered as having limited importance important clinically but it is important to familiarize practitioners with all anatomical variation of structures in this area. Such a description has not been studied previously.

Retromolar canal (RMC) is considered as Type 5 in our bifid classification and Type 1 in our trifid mandibular canal classification. Due to its clinical importance and high occurrence as compared to other types we have included this section. In this study the occurrence of the RMC (7.2%) was observed which is similar to Capote et al. (2015) findings.

Similar to our results, some studies didn’t observe differences in the right and left side of dry mandibles (Athavale et al., 2013; Filo et al., 2014; von Arx et al., 2011); others found more on the right than the left side (Galdámes et al., 2008; Narayana et al., 2003; Orhan et al., 2013). Whereas, in other studies, more RMCs were found on the left side (Bilecenoglu & Tuncer, 2006; Gupta et al., 2013; Rossi, Freire, Prado, Prado, Botacin, & Ferreira Caria, 2012; Schejtman et al., 1967).

In the present study, there was no association between the presence of the RMC and gender. Studies that assessed the occurrence of RMCs in computed tomography exams or in dry mandibles did not also observe that association (Filo et al., 2014; Galdámes et al., 2008; Patil, Matsuda, Nakajima, et al., 2013; von Arx et al., 2011). Interestingly, the present study found an influence of age on the presence of RMCs which contradicts von Arx et al. (2011) and Filo et al. (2014) findings.

According to some studies, the utilization of the CBCT is important before surgical procedures when there is a suspicion of RMC's presence in other radiographs (Fukami et al., 2014; J. S. Lee et al., 2009; Lizio et al., 2013). The clinical significant of these findings is crucial these days as the retromolar region is used as a donor site for bone graft and this mandates identification of any neurovascular tissue in this area (Khoury, 1999; Emeka Nkenke et al., 2002). Our current finding, also recommends the same suggestion.

CHAPTER 5: TRIFID MANDIBULAR CANAL

5.1 Introduction

This chapter will cover the methodology used to detect and measure trifid mandibular canal (TMC) and the result of analyzing these data which include the frequency of trifid mandibular canal, trifid mandibular canal diameter, length of trifid mandibular canal, trifid lumen shape, possible trifid classification and the vertical position of the trifid mandibular canals related to main mandibular canal amongst Malaysian population.

5.2 The variables of the study

The independent variables used for the purpose of this study shall be gender (male and female), race (Malays, Chinese, and Indians) and age, while the dependent variables were presence of trifid mandibular canal, vertical position of each accessory canal, length, lumen shape, classification type and mandibular canal diameter (Table 5.1).

Table 5.1: measurement records of dependent variables.

TMC	Existence of trifid case according to inclusion criteria
TMC-VP	Vertical position of accessory canal in the trifid mandibular canal case, either above main mandibular canal, same level or below it.
TMC-L	Length of accessory canal starting point of separation from the main canal to the terminal end that resides in the mandible
TMC-Shape	Lumen shape to be either circular, oval or irregular.
TMC-Classification Type Fig 5.1, Fig 5.2, Fig 5.3, and Fig 5.4	1A Retromolar canal ending in bone 1B Retromolar canal ending in foramina 2A Dental canal originating from one mandibular foramen 2B Dental canal originating from multiple mandibular foramina 2C Dental canal originating from the mandibular canal in the ramus 2D Dental canal originating from the mandibular canal in the body 3A Forward canal originating from one mandibular foramen 3B Forward canal originating from multiple mandibular foramina 3C Forward canal originating from the mandibular canal & ending in bone 3D Forward canal originating from the mandibular canal & ending in foramina 4A Buccolingual canal ending in bone 4B Buccolingual canal ending in multiple foramina
MCd	The diameter of the mandibular canal measurement
TMC	The diameter of the trifid mandibular canal measurement

A classification system has been deviced to study the trifid mandibular canal (TMC) in this part of the study as currently none exists (Table 5.1). This classification system is a modification of the system used by Naitoh et al. to study the bifid mandibular canal (BMC). The illustrations in Figures 5.1-5.4 help explain this classification system.

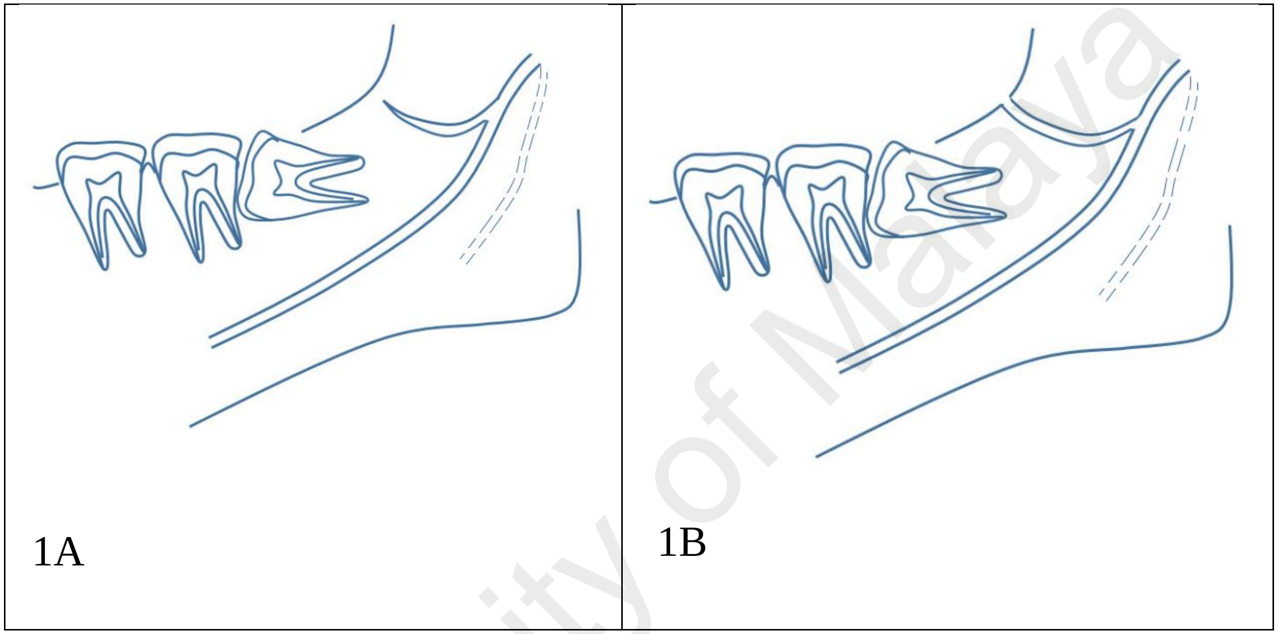

Figure 5.1: Illustrated diagram of trifid mandibular canal Type 1. 1A : Retromolar canal ending in bone ; 1B : Retromolar canal ending in foramina.

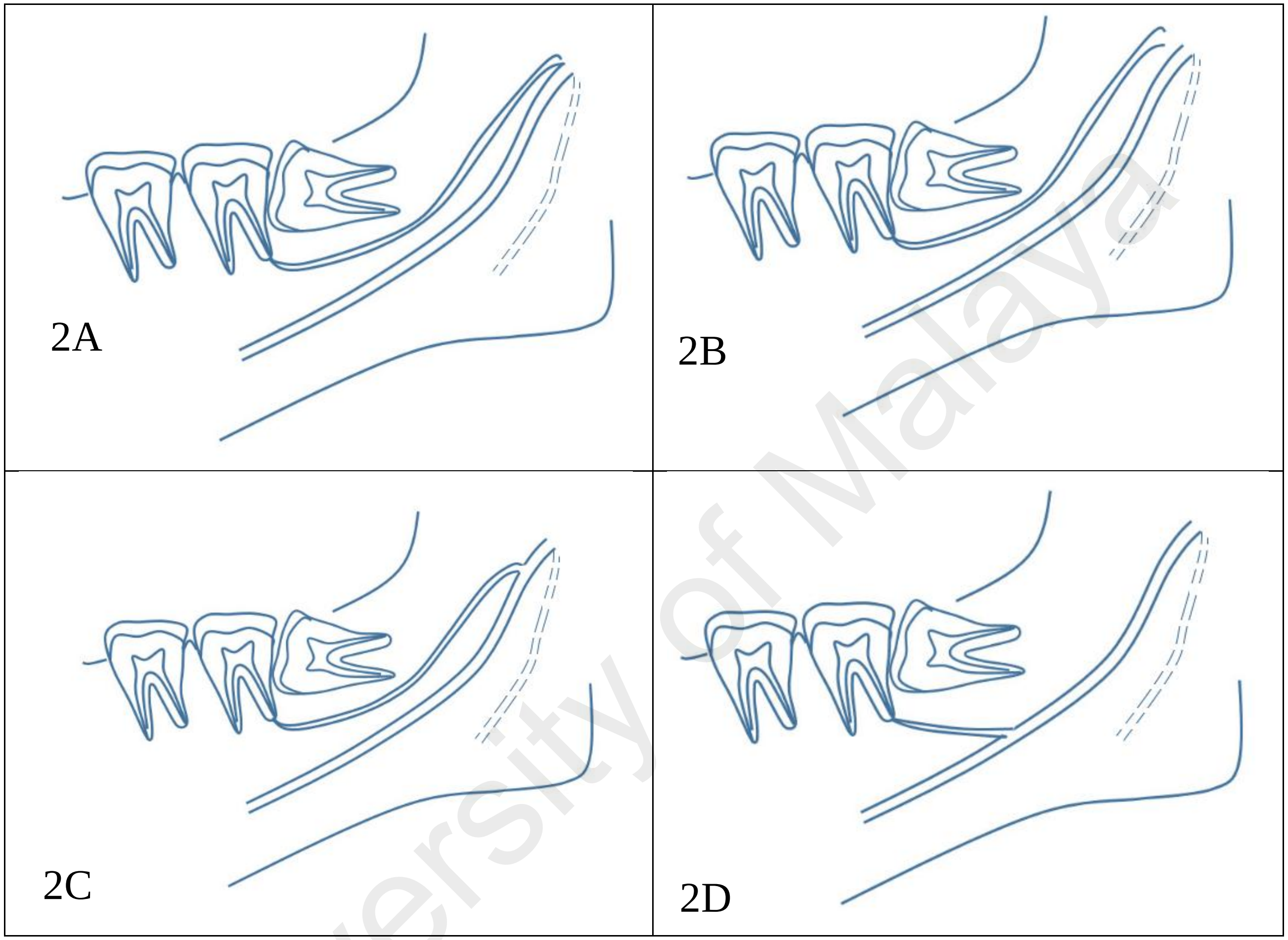

Figure 5.2: Illustrated diagram of trifid mandibular canal Type 2. 2A: Dental canal originating from one mandibular foramen; 2B: Dental canal originating from multiple mandibular foramina; 2C: Dental canal originating from the mandibular canal in the ramus; 2D: Dental canal originating from the mandibular canal in the body.

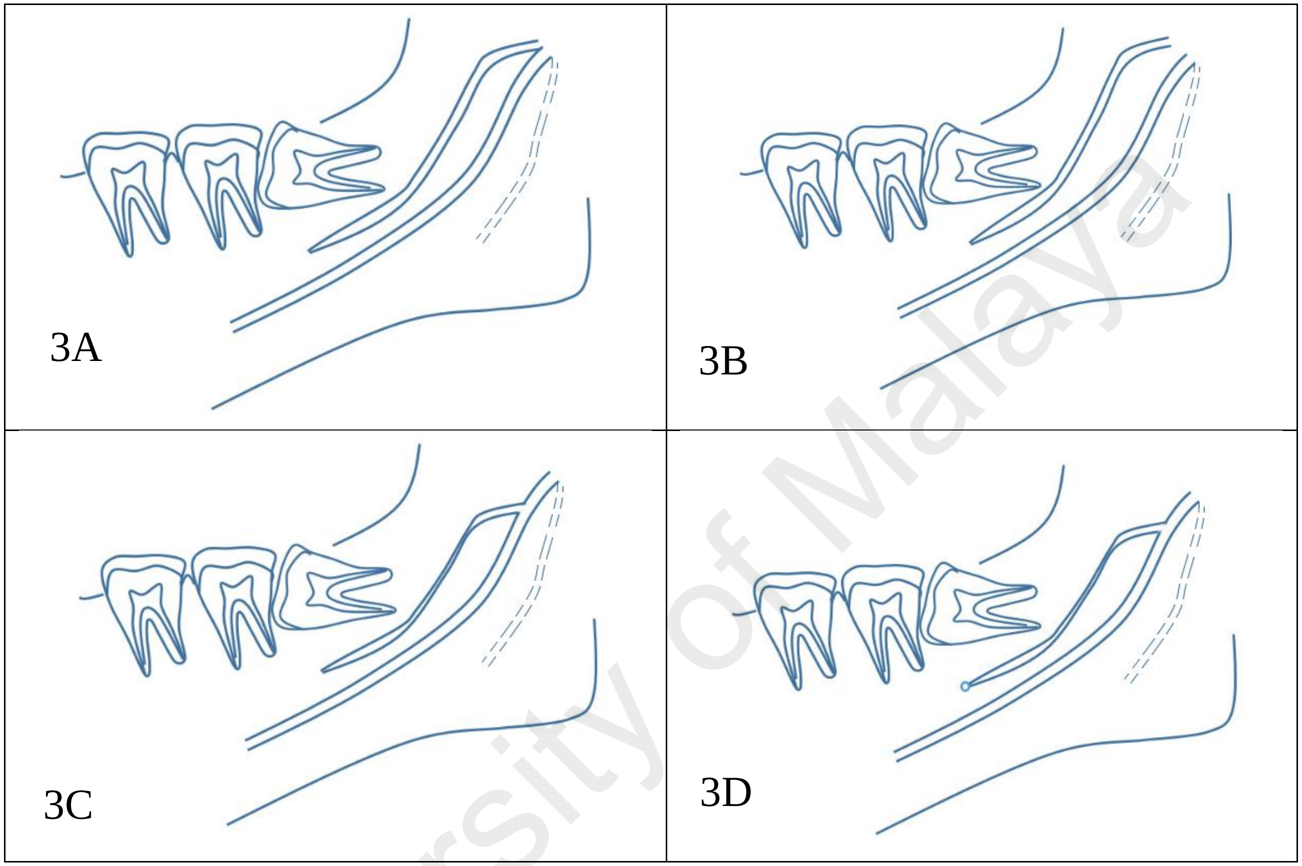

Figure 5.3: Illustrated diagram of trifid mandibular canal Type 3. 3A: Forward canal originating from one mandibular foramen; 3B: Forward canal originating from multiple mandibular foramina; 3C: Forward canal originating from the mandibular canal & ending in bone; 3D: Forward canal originating from the mandibular canal & ending in foramina.

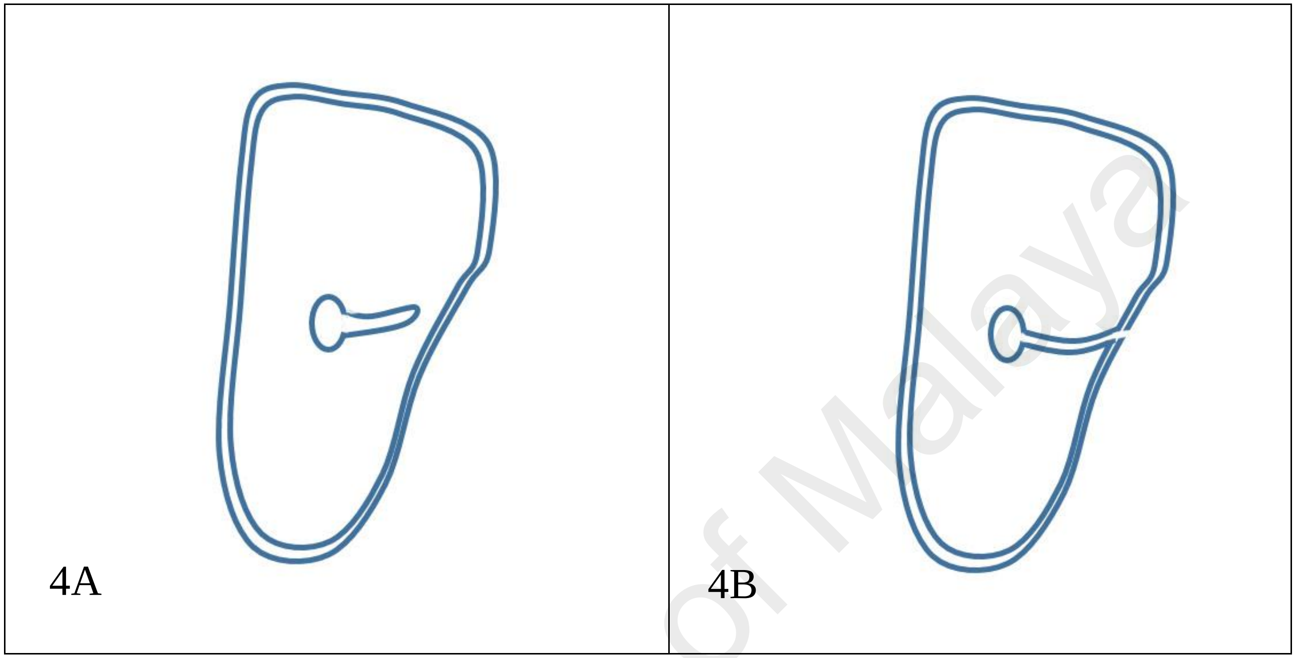

Figure 5.4: Illustrated diagram of trifid mandibular canal Type 4. 4A: Buccolingual canal ending in bone; 4B: buccolingual canal ending in a foramen.

5.3 Measurements

The course and length of accessory mandibular canals were measured either in sagittal or panoramic reconstructed CBCT images using SimPlant software which allows the observer to measure and trace straight or curved structures using the similar approach used to study the bifid mandibular canal (See Chapter 4). Firstly, the mandibular foramen and mental foramen were identified and mandibular nerve drawn and marked orange. Then, the accessory canals were drawn and marked white to distinguish it from main mandibular canal. The length of accessory mandibular canal was measured to be the starting point of separation from the main canal to the terminal end that resides in the mandible.

Similar to the approach to study the BMC, the diameter of the accessory mandibular canal was measured and classified into two categories: (1) greater than or equal to 50% or (2) lesser than 50% of the diameter of the main mandibular canal. The diameter of the main mandibular canal was measured immediately after bifurcation on the cross-sectional image and that of the trifid mandibular canal at the widest portion of the canal.

The vertical position of the accessory mandibular canal according to main mandibular canal was recorded to be either above main mandibular canal, same level or below it, similar to the approach used to study the BMC. Lumen shape of the accessory canals was categorized to be either circular, oval or irregular.

All data were gathered, entered and analyzed using SPSS 12.1 (SPSS Inc., Chicago, USA) software program. Descriptions of parameters were given as number, mean ± standard deviation (SD), minimum and maximum value recorded. Due to unmet assumption of parametric test, statistically P-value was not valid to be interpreted. Thus, the result will be represented descriptively.

5.4 Result

This study measures the frequency of trifid mandibular canal, its diameter and length amongst Malaysian population. The demographic characteristics of these patients (n=202) is summarized in Table 5.2. The sample for this study included imaging of 202 patients (94 males and 108 female) comprising of Malays, Chinese and Indians, with ages ranging from 11 to 80 years (mean age, 48.62±16.53 years). Each CBCT dataset of the patients included the right or the left side of the mandibular posterior region, so the total sample size was 404. Table 5.3 summarizes the age group distribution for the sample size.

Table 5.2: Distribution of the sample size based on the gender and ethnicity (race).

Ethnicity (race)	Gender	No. of patients (Percent)
Malay (n=93)	Male	42 (20.79%)
	Female	51 (25.24%)
Chinese (n=72)	Male	32 (15.84%)
	Female	40 (19.80%)
Indian (n=37)	Male	20 (9.90%)
	Female	17 (8.41%)
	Total	202 (100%)

Table 5.3: Age group distribution of sample size (n=202).

Age group	Frequency	Percent
11-20	14	6.9%
21-30	21	10.4%
31-40	21	10.4%
41-50	44	21.8%
51-60	52	25.7%
61-70	33	16.3%
71-80	17	8.4%
Total	202	100%

5.4.1 Trifid mandibular canal prevalence

Trifid mandibular canals were observed in 12 (5.9%) of the 202 patients. Four patients had bilateral trifid mandibular canal while 8 were unilateral. These canals were observed in 5 males (15.34%) and 7 females (14.35 %). Malays are more prone to have trifid mandibular canal (6 cases), followed by Chinese (5 cases), while one case was seen in Indians. There was no significant difference of the prevalence with respect to gender, ethnicity and among age groups (Tables 5.4, 5.5 & 5.6).

Table 5.4: The prevalence of the trifid mandibular canal between gender.

Gender	Type of canal		Prevalence (%)	*P* value*
	Trifid canal	Normal main canal		
Male (n=93)	5	88	5.37%	0.754
Female (n=109)	7	102	6.42%	
Total (n=202)	12	190	5.94%	

*Chi square P < 0.05

Table 5.5: The prevalence of the trifid mandibular canal in the 3 different ethnicities.

Ethnic group	Type of canal		Prevalence
	Trifid canals	Normal main canal	
Malay (n=73)	6	67	8.21%
Chinese (n=53)	5	48	9.43%
Indian (n=20)	1	19	5%

*Chi square P < 0.05

Table 5.6: The prevalence of trifid canals in each age-group.

Age	Gender						Total number of patients	*P* value
	Male			Female				
	Number	Trifid canals	Percent (%)	Number	Trifid canals	Percent (%)		
11-20 (n=14)	6	0	0	8	0	0	0	0.572*
21-30 (n=21)	7	0	0	14	1	7.14	1	
31-40 (n=21)	14	2	14.28	7	0	0	2	
41-50 (n=43)	19	0	0	25	5	2	5	
51-60 (n=53)	19	1	5.26	33	0	0	1	
61-70 (n=33)	20	1	5	13	1	7.69	2	
71-80 (n=17)	9	1	11.11	8	0	0	1	
Total (n=202)	94	5	5.31	108	7	6.48	12	

*Chi square $P < 0.05$

Figure 5.5: Trifid mandibular canal (White arrow); main mandibular canal (Black arrow). Sagittal view (A) and panoramic view (B) of CBCT image improved with SimPlant software

5.4.2 Classification of trifidity

The observed trifid mandibular canals were classified according to anatomic location and configuration. Four main patterns of trifid mandibular canals were pre-classified into subtypes (Table 5.7).

Table 5.7: The distribution of the trifid canals according to furcation type.

Classification	Number (%)		
	1st Accessory canal	2nd Accessory canal	Total
Type 1A	2 (12.5%)	2 (12.5%)	4 (12.5%)
Type 1B	8 (50%)	2 (12.5%)	10 (31.25%)
Type 2A	0 (0%)	4 (25%)	4 (12.5%)
Type 2B	1 (6.25%)	3 (18.75%)	4 (12.5%)
Type 2C	2 (12.5%)	3 (18.75%)	5 (15.6%)
Type 2D	0 (0%)	0 (0%)	0 (0%)
Type 3A	0 (0%)	1 (6.25%)	1 (3.12%)
Type 3B	1 (6.25%)	0 (0%)	1 (3.12%)
Type 3C	0 (0%)	1 (6.25%)	1 (3.12%)
Type 3D	1 (6.25%)	0 (0%)	1 (3.12%)
Type 4A	0 (0%)	0 (0%)	0 (0%)
Type 4B	1 (6.25%)	0 (0%)	1 (3.12%)
Total	16 (100%)	16 (100%)	32 (100%)

5.4.3 Vertical position of the trifid mandibular canal

Vertical position of the accessory canals was classified into three types; 18 canals (50%) were above the main mandibular canal, and 1 canal (3.12%) was located at the same level with main mandibular canal while 13 canals (40.62%) were below the main mandibular canal (Table 5.8, and 5.9).

Table 5.8: Distribution of accessory mandibular canal vertical position

Vertical positions	Number (%)	
	1st Accessory canal	2nd Accessory canal
Above Main MC	14 (87.5%)	4 (25%)
Same Level	1 (6.25%)	0 (0%)
Below main MC	1 (6.25%)	12 (75%)
Total canals	16 (100%)	16(100%)

Table 5.9: Accessory canals vertical position according to classification type

Classification	N	Number (%)		
		Above MC	Same Level	Below MC
Type1	14	14(100%)	0(0%)	0(0%)
Type2	6	3(50%)	0(0%)	3 (50%)
Type3	11	1(9.09%)	0(0%)	10(90.90%)
Type4	1	0(0%)	1(100%)	0(0%)

5.4.4 Diameter of the trifid mandibular canal

All the accessory canals were generally smaller than the main mandibular canal. The diameter of the accessory canal was greater than or equal to 50% of the main canal in 18 (50%) of the cases and lesser than 50% in the remaining 18 (50%). The mean diameter of the accessory canal was 1.29 mm (SD ± 0.23) (range: 0.93-1.89 mm) and that of the main mandibular canal was 2.40 mm (SD ± 0.38) (range: 1.46-2.89 mm) (Table 6.10).

5.4.5 Length of the trifid mandibular canal

The mean length of the trifid mandibular canals was 20.75 mm ± 14.43 (range: 5-52mm). Type 3 has the longest trifid mandibular canal length while Type 4 was the shortest. Measurement of length and diameter of the trifid mandibular canal according to vertical priority is summarized in Table 5.10 and according to trifid classification type is summarized in Table 5.11

Table 5.10: Length and diameter of accessory canal according to vertical priority.

Size	Accessory canal (Mean ± SD)	
	1st Accessory canal (mean)	2nd Accessory canal (mean)
Length	15.24 ±11.13 mm	26.26 ±15.55 mm
Diameter	1.28 ±0.24 mm	1.28 ±0.22 mm

Table 5.11: Length and diameter of accessory canal according to different types.

Classification	(n)	Length (mean)	Total	Diameter	Total
Type1	14	11.56(±4.09)	20.75 (±14.43)	1.35(±0.25)	1.29 (±0.23)
Type2	6	15.26(±9.66)		1.28(±0.16)	
Type3	11	36.80(±11.64)		1.24(±0.23)	
Type4	1	5.85		0.94	

5.4.6 Lumen shape

Three types of lumen shape were identified in this study. Circular lumen shape was seen in 14 canals (hemi-mandibles) (20.6%), oval lumen shape was seen in 2 cases (2.9%), and irregular lumen shape was seen in 20 cases (62.5%). The distribution of trifid lumen shape according to vertical priority of trifid canal is summarized in Table 5.12 and according to classification type is summarized in Table 5.13.

Table 5.12: Distribution of trifid lumen shape among vertical trifid canal.

Lumen shape	Number of cases (%)	
	1st Accessory canal	2nd Accessory canal
Irregular	9 (56.25%)	11 (68.75%)
Circular	5 (31.25%)	5 (31.25%)
Oval	2 (12.5%)	0 (0%)
Total	16 (100%)	16 (100%)

Table 5.13: Distribution of trifid lumen shape noticed in different types of trifid.

Classification	(n)	Shape		
		Irregular	Circular	Oval
Type1	14	8 (40%)	5 (50%)	1(50%)
Type2	6	6 (30%)	0(0%)	0(0%)
Type3	11	5 (25%)	5(50%)	1(50%)
Type4	1	1 (5%)	0(0%)	0(0%)
		20(100%)	10(100%)	2(100%)

5.4.7 Measurement of Agreement

A total number of 32 patients' records which is all sample size observed for the trifid cases were included in the agreement test and all the data were measured again two months later by using the same methods described earlier. Regarding the assessment of intraexaminer agreement, all parameters showed an optimal agreement. For the assessments of length and diameter we have used intraclass correlation coefficient, *p* (Table 5.14), while for the categorical subclass agreement we have used Cohen's Kappa *k* (Table 5.15). Average value for Bland-Altman analysis was 1.60.

Table 5.14: Trifid parameters reliability test (Intraclass Correlation)

Subscale	**Intraclass Correlation**	**95% Confidence Interval (Lower Bound, Upper Bound)**	**p**
Length	0.996	0.993,0.998	0.000
Diameter	0.763	0.569, 0.876	0.009
Mandibular canal diameter	0.923	0.849, 0.962	0.001

Table 5.15: Trifid parameters reliability (Kappa test for categorical subcale)

Subscale	**Kappa *k***	**p**
Trifid	0.843	0.000
Vertical position	1.000	0.000
Lumen Shape	0.733	0.000
Pattern	0.840	0.000

Table 5.16: Bland-Altman analysis

Parameter	**Percentage**
Length	0.21%
Acessory canal Diameter	2.19%
MC Diameter	0.22%
Average	0.87%

5.5 Discussion

The Trifid mandibular canals are considered as the second most reported mandibular canal variant in the literature. The presence and the configuration of the trifid mandibular canal as an anatomical variation are crucial in surgical procedures, similar to bifid mandibular canal, to refute difficulties when administering mandibular anesthesia or during surgery of the lower third molar, reconstructive mandibular surgery, placement of dental implants, prosthesis and orthognathic surgery. Vascular injury and traumatic neuroma are also added probable problems. Therefore, awareness of this variation is very important to practitioners (Karamifar et al., 2009).

The trifid canals were more easily noticed in CBCT scans than only employing panoramic images (de Oliveira-Santos et al., 2012; Kuribayashi et al.; M. Naitoh et al., 2009; Naitoh et al., 2010; Orhan et al., 2011). In the present study, the prevalence of the trifid mandibular canal was 5.94% and the retromolar canal type (Type1) was observed to be the most common type. These findings are similar to Rashsuren et al. (2014) study as the prevalence was 5.8% and retromolar canal type was among the most common type observed where among them 10 canals were ending in retromolar foramina while 4 were ending in the bone itself. This prevalence is considered high as compared to other 2 studies (Auluck et al., 2007; Mizbah et al., 2012) where only four cases of the trifid mandibular canals have been reported.

In the present study, we have developed our own classification for trifid canals. The closest available classification was by Naitoh et al. (2009) for bifid mandibular canal and this did not suit our study. It was observed that the retromolar canal type was the most common

(43.8%), followed by the forward canal type (34.4%), the dental canal (18.8%), and the buccolingual canal (3.1%).

The length and the diameter of the trifid mandibular canal were studied previously. Rashsuren et al. (2014) reported the length to be 20.1±5.8 mm which is similar to our study where the mean length of the trifid mandibular canals was also 20.75 (±14.43). Forward canal type has the longest trifid mandibular canal length while the buccolingual canal (type 4) was the shortest.

The diameter of the accessory canal was greater than or equal to 50% of the main canal in 18 (50%) cases and less than 50% in 18 (50%) of the 32 canals studied. The mean diameter of the accessory canal was 1.29 mm (SD ± 0.23) (range: 0.93-1.89 mm) while the main mandibular canal was 2.40 mm (SD ± 0.38) (range: 1.46-2.89 mm) indicating it indeed had a larger diameter. Such a finding has not been reported for trifid canal, and it is hoped that this information will be useful in assisting dentists/oral surgeons/oral radiologists in identifying TMC in scans.

Vertical position of the trifid mandibular canal was investigated and it was found that 40.6% was below main mandibular canal, 56% was superior to the main mandibular canal, while 3.1% was at the same level of the main mandibular canal. Shape of the lumen of the trifid mandibular canal was studied in this research. It was found that 62.5% was of irregular lumen shape (most common), 31.2% was circular and 6.2% was of oval shape. Similar to our observation for the BMC, this information has not been reported elsewhere, and may provide some clinical use in oral diagnosis.

5.6 Conclusion

Trifid mandibular canals among Malaysians have a high rate of occurrence during a CBCT evaluation and that the “retromolar canal” type is the most common type of the mandibular canal variation in this population. These complicated variations lend support to use CBCT more routinely for a detailed evaluation and it must become a standard of care before any mandibular surgery

CHAPTER 6: MANDIBULAR AND MENTAL FORAMINA AND ITS VARIATIONS

6.1 Introduction

This chapter will cover the methodology used to measure the shape and location of mental foramen, mental foramen opening distance, orientation of the opening, and the shape and location of the mandibular foramen. It will also include the prevalence of accessory mental foramen (AMF), accessory mandibular foramen (AmandF), and retromolar foramen (RMF). The second part of this chapter will include results of analyzing these parameters amongst the Malaysian population.

6.2 The variables of the study

The independent variables used for the purpose of this study shall be dentition status, gender (male and female), race (Malays, Chinese, and Indians) and age, while the dependent variables were the vertical and horizontal position of mental and mandibular foramen, mental foramen opening distance and opening direction, existence of accessory foramina (AMF, AmandF, and RMF) as indicated in Table 6.1.

Table 6.1: Measurement records of dependent variables

MF-I	Inferiorly from the lower edge of the mental foramen perpendicularly to the most inferior point of the lower border of the mandible.
MF-L	Lingually from the lingual edge of the mental foramen to the lingual cortical margin of the mandible.
MF-D	Distance between upper edge and lower edge of the mental foramen opening.
MF-Direction	Mandibular anterior loop opening direction.
MandF-I	Vertical distance from the lower edge of the mandibular foramen perpendicularly to the most inferior point of the lower border of the mandible.
MandF-B	Horizontal distance from the buccal edge of the mandibular foramen perpendicularly to the buccal cortical margin of the ramus.
IsBifid	Indicate if this hemi-mandible is a bifid case according to inclusion criteria in Chapter 4.
IsTrifid	Indicate if this hemi-mandible is a trifid case according to inclusion criteria in Chapter 5.
IsAMF	Indicate if this hemi-mandible has one or more accessory mental foramen according to inclusion criteria
IsAmandF	Indicate if this hemi-mandible has one or more accessory mandibular foramen according to inclusion criteria
IsRMF	Indicate if this hemi-mandible has one or more retromolar foramen according to inclusion criteria

6.3 Measurements

The position of the mental foramen was measured vertically from the lower edge of the foramen perpendicularly to the most inferior point of the lower border of the mandible, and horizontally from the lingual edge of the foramen to the lingual cortical margin of the mandible. The opening of the foramen was also measured at its opening aspect (distance between upper edge and lower edge of the opening) (Figure 6.1). The mental foramen opening direction was measured as well (Figure 6.2). While the vertical position of the mandibular foramen was measured from the lower edge of the mandibular foramen perpendicularly to the most inferior point of the lower border of the mandible and horizontally from the buccal edge of the mandibular foramen perpendicularly to the buccal cortical margin of the ramus (Figure 6.3).

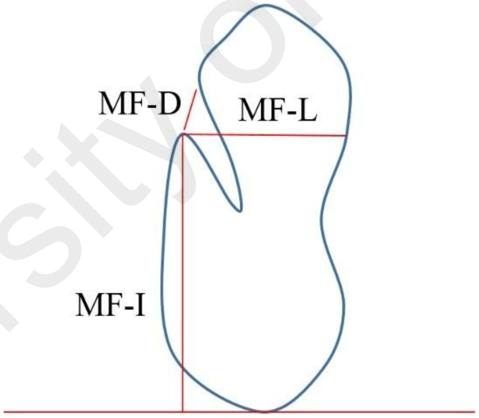

Figure 6.1: Illustrated diagram for the measurement of mental foramen location (MF-I, MF-L) and opening distance (MF-D) at the coronal view of the jaw.

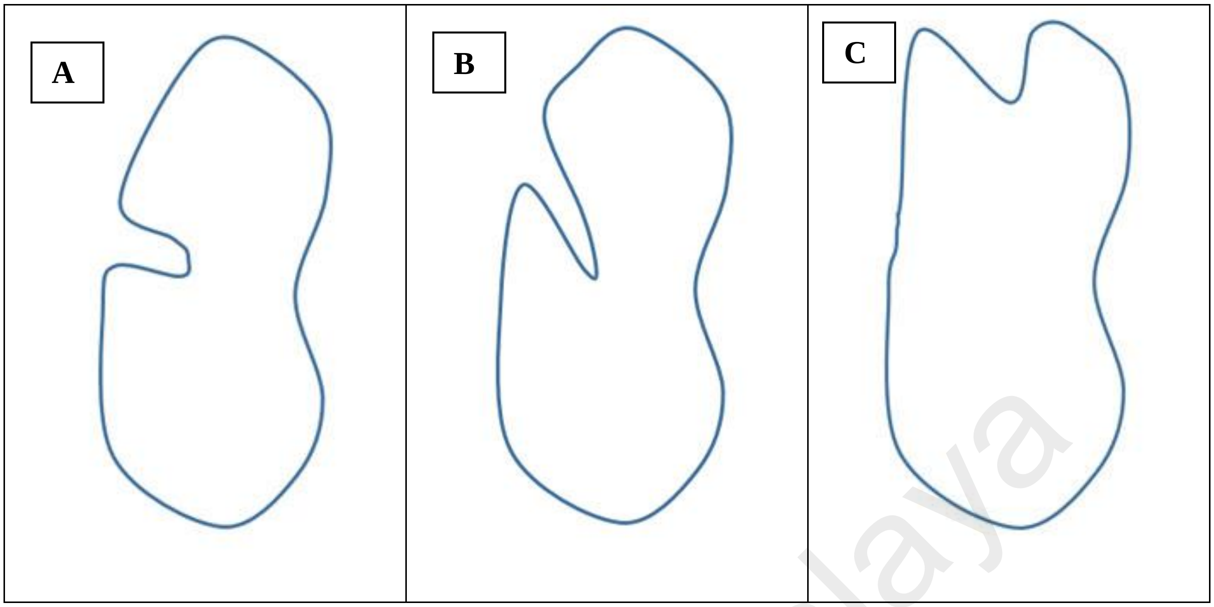

Figure 6.2: Illustrative diagram of the (mandibular anterior loop) opening direction. (A): Buccal opening, (B): Superio-lateral, (C): Superior opening.

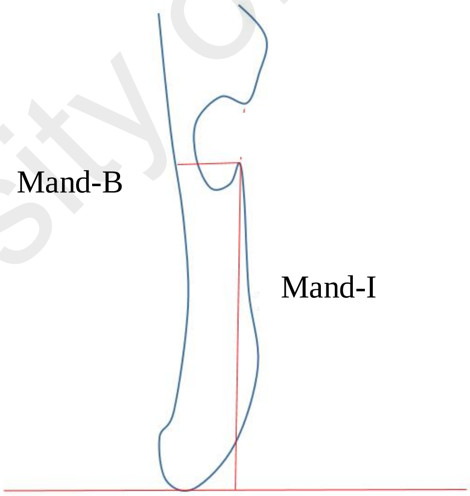

Figure 6.3 Illustrative diagram of the location of the mandibular foramen.

If the hemi-mandible was diagnosed to have a bifid mandibular canal according to the inclusion criteria (chapter 4) then its marked in SPSS sheet (IsBifid). Also If the hemi-mandible was diagnosed to have a trifid mandibular canal according to the inclusion criteria (chapter 5) then its marked in SPSS sheet (IsTrifid). Accessory mental foramen is recorded also as any foramen smaller than main mental foramen. Accessory mandibular foramen is recorded as any foramen near main mandibular foramen.

6.4 Results

The sample size studied earlier was 202 while the sample considered in this section was adult patients (18-80) to avoid mandibular changes during the earlier growth period. Thus, the total sample included was 194 patients (90 males and 104 females) comprising of Malays, Chinese and Indian, with ages ranging from 18 to 80 years (mean age, 50.10 ± 15.14 years). Each CBCT dataset of the patients included the right or the left side of the mandibular posterior region, so the total sample size was 388. The demographic characteristics of patients (n=194) summarized in Table 6.2. The age group distribution for the sample size which included only adult data set was summarized in Table 6.3.

Table 6.2: Distribution of the sample size based on the gender and ethnicity (race)

Ethnicity (race)	Gender	No. of patients	No. of sample specimens (combined sides)
Malay	Male Female	41 49	82 98
Chinese	Male Female	30 38	60 76
Indian	Male Female	19 17	38 34
	Total	194	388

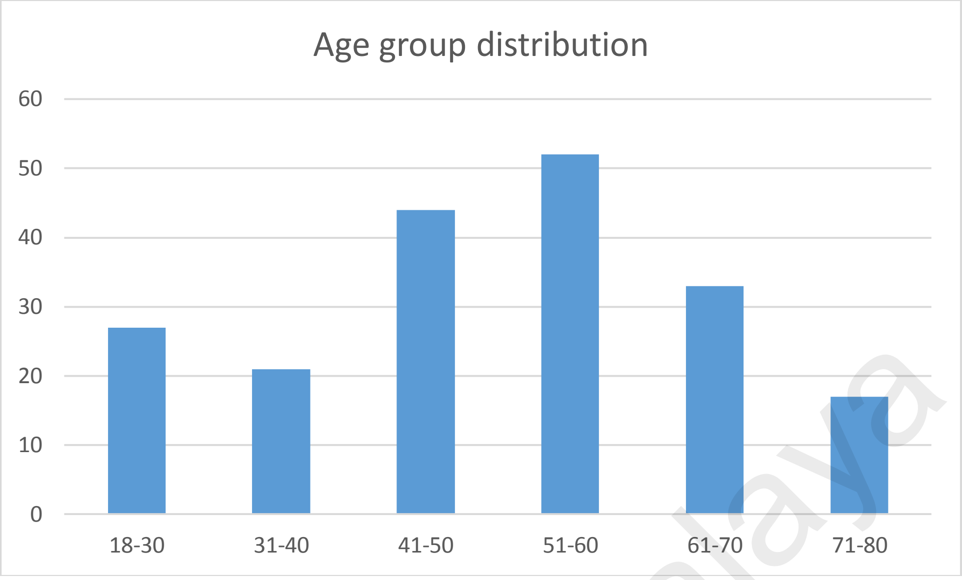

Figure 6.4: Age group distribution of sample size (n=194).

6.4.1 Comparison on the location of mental and mandibular foramen on the bilateral sides

In this study, there were 194 patients' records that were reviewed. The right and left parameter were measured and analyzed for each foramen. The measurement unit used was millimeters in all length values of this study. The interest was in determining a significant mean difference between the right and left side of the jaw for each foramen.

Table 6.4 summarizes the descriptive statistics for the right and left side of all foramen locations which involved mean, SD, mean of score different, *t*-statistics, df value and *P* value. Three parameters for the mental foramen and 2 parameters for mandibular foramen are considered in the statistical test and their P-values was more than 0.05, so there is no significant difference in the location of the mental foramen and mandibular foramen for the right and left side for the total sample (n=388).

Paired sample *t*-test was used to compare two population means in the case of the two samples that are correlated like in ‘before-after’ studies, or when the samples are the matched pairs or the case is a control study. All the data were assessed to check if it was normally distributed using the histogram.

Table 6.3: Comparison of length measurements for mental foramen and mandibular foramen on the right and left sides.

Parameters	Measurements [mean (SD)] in mm			*t*-statistics (df)	P value
	Right side	Left side	Mean of score different (95% CI)		
MF-D	1.88 (0.44)	1.85 (0.45)	0.034 (-0.02,0.09)	1.06 (193)	0.289
MF-I	14.05 (1.90)	13.95 (1.72)	0.10 (-0.11,0.32)	0.96 (193)	0.336
MF-L	10.87 (1.71)	11.03 (1.74)	-0.15 (-0.33,0.02)	-1.74 (193)	0.083
MandF-I	23.36 (3.49)	23.16 (3.73)	0.20 (-0.17,0.58)	1.06 (192)	0.287
MandF- B	5.90 (1.65)	5.87 (1.53)	0.034 (-0.18,0.25)	0.31 (192)	0.754

6.4.2 Mental foramen

6.4.2.1 Mental foramen Shape

There are two types of mental foramen shape identified in this study. Oval shape was seen in 139 foramina (hemi-mandibles) (35.9%), while round shape was seen in 249 foramina (64.1%). The distribution of mental foramen shape according to gender, age-groups and race are summarized generally in Table 7.4. Statistical analysis shows that there is no significant difference between mental foramen shapes amongst age-groups (p=0.270), and ethnicity (p=0.409) while there is a significant difference between gender (p=0.043). The data set was further scrutinized into dentate and edentulous samples (Table 6.5 & Table

6.6) respectively. Table 6.5 included dentate samples and shows there is no significant difference between mental foramen shapes amongst age-groups (p=0.091), ethnicity (p=0.826) and gender (p=0.267). Edentulous samples are included in Table 6.6, which shows a strong significant difference between mental foramen shapes amongst gender (p=0.003) and race (p=0.007) while there is no significant difference amongst age-groups (p=0.167).

Table 6.4: Comparison of mental foramen shape amongst gender, age-groups and race.

Parameters		**Oval** n=139 (%)	**Round** n=249 (%)	P-value*
Gender	Male (n=180)	74 (53.2%)	106 (42.6%)	0.043
	Female (n=208)	65 (46.8%)	143 (57.4%)	
Age (years)	18-30 (n=54)	18 (12.9%)	36(14.5%)	0.270
	31-40 (n=42)	12 (8.6%)	30 (12%)	
	41-50 (n=88)	28 (20.1%)	60 (24.1%)	
	51-60 (n=104)	40 (28.8%)	64 (25.7%)	
	61-70 (n=66)	23 (16.5%)	43 (17.3%)	
	71-80 (n=34)	18 (12.9%)	16 (9.4%)	
Race	Malay (n=180)	65 (46.8%)	115 (46.2%)	0.409
	Chinese (n=136)	44 (31.7%)	92 (36.9%)	
	Indian (n=72)	30 (21.6%)	42 (16.9%)	

*Chi-square test

Table 6.5: Comparison of mental foramen shape amongst gender, age-groups and race in dentate samples.

Variables		**Oval** n=124 (%)	**Round** n=230 (%)	P-value*
Gender	Male (n=160)	61 (49.2%)	99 (43%)	0.267
	Female (n=194)	63 (50.8%)	131 (57%)	
Age (years)	18-30 (n=54)	18 (14.5%)	36 (15.7%)	0.091
	31-40 (n=42)	12 (9.7%)	30 (13%)	
	41-50 (n=78)	22 (17.7%)	56 (24.3%)	
	51-60 (n=96)	35 (28.2%)	61 (26.5%)	
	61-70 (n=59)	22 (17.7%)	37 (16.1%)	
	71-80 (n=25)	15 (12.1%)	10 (4.3%)	
Race	Malay (n=160)	55 (46.8%)	105 (46.2%)	0.826
	Chinese (n=126)	43 (31.7%)	83 (36.9%)	
	Indian (n=68)	26 (21.6%)	42 (16.9%)	

*Chi-square test

Table 6.6: Comparison of mental foramen shape amongst gender, age-groups and ethnicity in edentulous samples.

Variables		Oval n=15 (%)	Round n=19 (%)	P-value*
Gender	Male (n=20)	13 (86.7%)	7 (36.8%)	0.003
	Female (n=14)	2 (13.3%)	12 (63.2%)	
Age (years)	41-50 (n=88)	6 (40%)	4 (21.1%)	0.167
	51-60 (n=104)	5 (33.3%)	3 (15.8%)	
	61-70 (n=66)	1 (6.7%)	6 (31.6%)	
	71-80 (n=34)	3 (20%)	6 (31.6%)	
Race	Malay (n=20)	10 (66.7%)	10 (52.6%)	0.007
	Chinese (n=10)	1 (6.7%)	9 (47.4%)	
	Indian (n=4)	4 (26.7%)	0 (0%)	

*Chi-square test

6.4.2.2 Mental foramen vertical and horizontal location

Table 6.7 summarizes the mental foramen location measurements means for dentate and edentulous samples. Two aspects were considered amongst the sample types which are the inferior and lingual measurements. Statistical analysis showed there is no significant difference between dentate and edentate sample groups for the two aspects considered.

Table 6.7 Comparison of mental foramen location by dentition status

Variable	**Dentition status**		**Mean difference (95% CI)**	**t-statistics (df)**	**P-value**
	Dentate (n=354) Mean(SD) mm	Edentulous (n=34) Mean(SD) mm			
MF-I	13.97 (1.78)	14.27(2.11)	-0.29(-0.94,0.34)	-0.91(386)	0.372*
MF-L	11(1.82)	10.83(1.92)	0.16(-0.47,0.81)	0.51(386)	0.610**

* Mann-Whitney U test **Independent t-test

In its simplest form, Mann-Whitney U test gives a statistical test of whether the means of two groups are all equal for non-parametric data. Therefore, Mann-Whitney U test was conducted to indicate that there was no difference in the location of mental foramen inferiorly between dentate and edentate samples (p=0.372). Independent t-test was conducted to indicated that there was no difference in the location of mental foramen lingually between the dentate and edentate samples (p=0.610).

Table 6.8 summarizes the mental foramen length value for two aspects considered in this study amongst three selected data set (dentate, edentate and both together), which are the inferior and lingual measurements respectively. There were 776 measurements to be made for mental foramen location, as there were two aspects and both sides of the jaw were measured (388 hemimandibles) in this study. Generally, the lingual edge was located, on average, 10.9 mm from the lingual cortex while the lower edge of the mental foramen was located, on average, 14 mm above the lower edge of the mandible.

Table 6.8 Descriptive statistics of mental foramen location measurements

		Mean (mm)	SD	N	Median	Minimum	Maximum
General	MFI	14	1.81	388	13.93	10.16	21.87
	MFL	10.99	1.83	388	10.97	5.43	19.90
Dentate	MFI	13.97	1.78	354	13.89	10.16	21.87
	MFL	11	1.82	354	11	5.43	19.90
Edentulous	MFI	14.27	2.11	34	14.43	10.62	17.63
	MFL	10.83	1.92	34	10.45	6.30	14.52

6.4.2.2.1 Comparison of mental foramen location between ethnicity

Table 6.9 summarizes the mental foramen location measurements means for the three races Malays, Chinese and Indians in 3 categories: general, dentate and edentulous. Two aspects were considered in each category which are the inferior and lingual measurements.

In its simplest form Kruskal-Wallis non-parametric test gives a statistical test of whether the means of the races are all equal. Therefore, Kruskal-Wallis test was conducted to indicate that there was a difference in the location of mental foramen inferiorly amongst races for the three sample groups – general, dentate and edentate (p=0.005, p=0.019, and p=0.005) respectively. Further analysis was performed and the findings indicated that there was a difference in the location of mental foramen inferiorly between Malays and Chinese (p=0.006), and between Chinese and Indians (p=0.004). One-way ANOVA was conducted to indicated that there was no difference in the location of mental foramen lingually between the races for the three sample groups (dentate, edentate and both) (p>0.05).

Table 6.9: Comparison of mental foramen location (mean measurements) by ethnicity.

		Mean Measurements (SD)			Total Mean (SD) N=388	F (df)	P-value
		Malays (n=180)	**Chinese (n=136)**	**Indians (n=72)**			
General	MFI	13.85 (1.99)	14.37 (1.51)	13.67 (1.76)	14.0 (1.81)	4.73(2)	0.005**
	MFL	11.17 (2.02)	10.97 (1.81)	10.56 (1.75)	10.99 (1.91)	2.84(2)	0.059*
		Mean Measurements (SD)			Total Mean (SD) N=354	F (df)	P-value
		Malays (n=160)	**Chinese (n=126)**	**Indians (n=68)**			
Dentate	MFI	13.75 (1.99)	14.33 (1.51)	13.83 (1.76)	13.97 (1.78)	4.01(2)	0.019**
	MFL	11.15 (1.91)	11.06 (1.72)	10.55 (1.75)	11 (1.82)	2.68(2)	0.070*
		Mean Measurements (SD)			Total Mean (SD) N=34	F (df)	P-value
		Malays (n=20)	**Chinese (n=10)**	**Indians (n=4)**			
Edentate	MFI	14.59 (2.05)	14.91 (1.49)	11.09 (0.36)	14.27 (2.11)	7.13(2)	0.005**
	MFL	11.30 (1.78)	9.93 (2.10)	10.73 (1.76)	10.83 (1.92)	1.77(2)	0.186*

* One-way ANOVA, ** Kruskal-Wallis non-parametric test

6.4.2.2.2 Mental foramen location by gender

Table 6.10 summarizes the mental foramen measurements for the two aspects in three sample groups amongst gender. Generally, the mean for the males is significantly greater than the mean for the females. Inferiorly, the mean for the male is 1.68 mm larger compared to the mean for the females. Lingually, the mean for the male is 0.14 mm larger compared to the mean for the females. A two tailed independent samples t-test (α = 0.05) was used to compare the means amongst gender and it was found that there was a strong difference in the inferior measurements between the two gender while no significant difference was found lingually.

Table 6.10: Comparison of mental foramen location between males and females.

		Gender mean measurements		**Mean difference (95% CI)**	**t-statistics(df)**	**P-value**
General		Male (n=180) Mean (SD) mm	Female (n=208) Mean (SD) mm			
	MFI	14.90(1.64)	13.22 (1.58)	1.68(1.36, 2.00)	10.28(386)	0.000
	MFL	11.07(1.91)	10.92(1.76)	0.14(-0.220, 0.51)	0.785(386)	0.433
Dentate		**Gender mean measurements**		**Mean difference (95% CI)**	**t-statistics(df)**	**P-value**
		Male (n=160) Mean (SD) mm	Female (n=194) Mean (SD) mm			
	MFI	14.88 (1.59)	13.22 (1.57)	1.65(1.32, 1.99)	9.80(352)	0.000
	MFL	11.11(1.87)	10.91(1.78)	0.19(-0.18, 0.57)	1.00(352)	0.315
Edentate		**Gender mean measurements**		**Mean difference (95% CI)**	**t-statistics(df)**	**P-value**
		Male (n=20) Mean (SD) mm	Female (n=14) Mean (SD) mm			
	MFI	15.07 (2.02)	13.13 (1.73)	1.93(0.57, 3.29)	2.90(32)	0.007
	MFL	10.72(2.20)	11.00(1.49)	-0.28 (-0.16, 1.10)	-0.41(32)	0.680

6.4.2.2.3 Mental foramen location amongst age groups

The comparison of mental foramen length mean between age groups is summarized in Table 6.11, where mean, SD, number, F-statistics and P value were included. To test the difference between these six age groups, one-way ANOVA was used as the inferential statistical method. These inferential statistical techniques require some assumption that needs to be met before conducting such techniques to test the difference between different age groups of participants. This assumption is the normality of mental foramen inferior measurement values. Exploring data can help to determine whether the statistical techniques that the researcher is considering for data analysis are appropriate or not. SPSS statistical software provides a variety of visual and numerical summaries of the data, either for all cases or separately for groups of cases. The exploration may indicate to use nonparametric tests. In this study, graphical and numerical methods were used to check the assumptions of normality of the data.

According to SPSS results, there is no statistical difference in the location of mental foramen inferiorly and lingually amongst age groups in the three samples considered in this study.

Table 6.11: Comparison of mental foramen location amongst age groups.

		Length measurements Mean (SD)						
General		18-30 (n=54)	31-40 (n=42)	41-50 (n=88)	51-60 (n=104)	61-70 (n=66)	71-80 (n=34)	P-value
	MFI	13.66(1.80)	14.32(1.62)	14.10(1.85)	13.86(1.84)	14.22(1.88)	13.85(1.68)	0.390*
	MFL	10.76(2.35)	10.92(1.66)	11.10(2.05)	10.99(1.64)	10.97(1.53)	11.15(1.65)	0.828**
Dentate		Length measurements Mean (SD)						
		18-30 (n=54)	31-40 (n=42)	41-50 (n=78)	51-60 (n=96)	61-70 (n=59)	71-80 (n=25)	P-value
	MFI	13.66(1.80)	14.32(1.62)	13.99(1.78)	13.80(1.77)	14.16(1.93)	14.22(1.64)	0.387*
	MFL	10.76(2.35)	10.92(1.66)	10.97(2.06)	11.01(1.63)	11.11(1.39)	11.44(1.64)	0.520**
Edentate		N/A		Length measurements Mean (SD)				
				41-50 (n=10)	51-60 (n=8)	61-70 (n=7)	71-80 (n=9)	P-value
	MFI	N/A	N/A	15(2.22)	14.64(2.59)	14.71(1.46)	12.80(1.40)	0.102*
	MFL	N/A	N/A	12.08(1.70)	10.74(1.79)	9.81(2.24)	10.32(1.49)	0.069*

*One-way ANOVA, ** Kruskal-Wallis non-parametric test

6.4.2.3 Mental foramen opening distance

There was no significant difference for mental foramen opening distance between the dentate and edentate sample groups (p= 0.831). Table 6.12 summarizes the mental foramen opening distance value considered in this study, which are the distance between upper edge and lower edge of the mental foramen opening. The values included in the table was number, minimum, maximum, mean, SD, Median, skewness, kurtosis and K-S test value. There were 388 measurements to be made for mental foramen opening distance, as both sides of the jaw were measured (388 hemimandibles) in this study. Generally, the distance was, on average, 1.86 mm ± 0.45 between upper edge and lower edge of the mental foramen opening. Based on the skewness and kurtosis values the data is symmetrical.

Table 6.12: Descriptive statistics of the mental foramen opening distance measurement.

	N	Mean (mm)	SD	Median	Min	Max
General	388	1.86	0.45	1.88	0.73	3.43
Dentate	354	1.86	0.45	1.88	0.73	3.43
Edentulous	34	1.88	0.45	1.91	0.92	2.84

Table 6.13 summarizes the mental foramen opening distance measurements means for the three races, namely the Malays, Chinese and Indians. One-way ANOVA test indicates that there is no significant difference among race in the three sample groups.

Table 6.13: Comparison of mental foramen opening distance by ethnicity.

	Mean Measurements (SD) mm			Total Mean (SD) N=388	F-statistics (df)	P value
General	Malays (n=180)	Chinese (n=136)	Indians (n=72)			
	1.82(0.43)	1.91(0.43)	1.88(0.52)	1.86 (0.45)	1.66(2)	0.190*
Dentate	Mean Measurements (SD) mm			Total Mean (SD) N=354	F-statistics (df)	P value
	Malays (n=160)	Chinese (n=126)	Indians (n=68)			
	1.81(0.42)	1.92(0.44)	1.87(0.50)	1.86 (0.45)	1.90(2)	0.150*
Edentate	Mean Measurements (SD) mm			Total Mean (SD) N=34	F-statistics (df)	P-value
	Malays (n=20)	Chinese (n=10)	Indians (n=4)			
	1.87(0.45)	1.82(0.21)	2.09(0.89)	1.88 (0.45)	0.483(2)	0.322**

* One-way ANOVA ** Kruskal-Wallis non-parametric test

Table 6.14 summarizes the mental foramen opening distance measurements means between males and females. Generally, independent *t*-test indicates that there is a significant difference amongst race in general sample group (p=0.020) and in dentate sample group (p=0.037), while no significant difference was found in edentulous sample group (p=0.288).

Table 6.14: Comparison of mental foramen opening distance between males and females.

	Opening distance Mean (SD) mm		Mean difference (95% CI)	t-statistics (df)	P value
	Male	Female			
General	1.92 (0.43)	1.81 (0.46)	0.10 (0.01, 0.19)	2.33 (386)	0.020
Dentate	1.92 (0.42)	1.82 (0.47)	0.10 (0.06, 0.19)	2.09 (352)	0.037
Edentulous	1.95 (0.52)	1.78 (0.34)	0.17 (-0.15,0.49)	1.07 (32)	0.288

The comparison of the mean mental foramen opening distance between age groups is summarized in Table 6.15, where mean, SD, number, and P value were included. According to SPSS results, there is no statistical difference in the mental foramen opening distance among age groups in the three sample groups considered.

Table 6.15: Comparison of mental foramen opening distance amongst age groups.

General	Length measurements Mean (SD)						
	18-30 (n=54)	31-40 (n=42)	41-50 (n=88)	51-60 (n=104)	61-70 (n=66)	71-80 (n=34)	P-value
	1.76(0.43)	1.91(0.40)	1.94(0.47)	1.86(0.49)	1.79(0.40)	1.88(0.41)	0.303
Dentate	Length measurements Mean (SD)						
	18-30 (n=54)	31-40 (n=42)	41-50 (n=78)	51-60 (n=96)	61-70 (n=59)	71-80 (n=25)	P value
	1.79(0.43)	1.91(0.40)	1.95(0.47)	1.86(0.47)	1.79(0.42)	1.85(0.42)	0.288
Edentulous	N/A		Length measurements Mean (SD)				
			41-50 (n=10)	51-60 (n=8)	61-70 (n=7)	71-80 (n=9)	P value
			1.89(0.44)	1.81(0.70)	1.84(0.18)	1.96(0.40)	0.924

6.4.2.4 The direction of opening for mental foramen

There are three types of mental foramen direction of opening were identified in this study. Buccal direction where the mental foramen opening is at approximately 90-degree angle as was seen in 71 foramina (hemi-mandibles) (18.2%), and superior-lateral opening were the mental foramen opening is neither buccal nor superior as was seen in 309 foramina (79.6%) and lastly the superior type as seen in 8 foramina (2%). Distribution of mental foramen direction of opening according to gender summarized in Table 6.16, according to race is summarized in Table 6.17 and according to age-groups is summarized in Table 6.18. Generally, there is no significant difference between mental foramen direction of opening amongst gender (p=0.216), while there is a significant difference among ethnicity (p=0.00) and age groups (p=0.00).

Table 6.16: Comparison of mental foramen direction of opening amongst gender.

	Variables	Gender		Total	P-value
General		**Male (n=180)**	**Female (n=208)**		
	Buccal (n=71)	38(53.5%)	33(46.5%)	71(100%)	0.216
	Superiolateral(n=309)	140(45.3%)	169(54.7%)	309(100%)	
	Superior (n=8)	2(25%)	6(75%)	8(100%)	
	Total (n=388)	180(46.4%)	208(53.6%)	388(100%)	
Dentate		Gender		Total	P-value
		Male(n=160)	**Female**(n=194)		
	Buccal(n=67)	36(53.7%)	31(46.3%)	67 (100%)	0.08
	Superiolateral(n=285)	122(42.8%)	163(57.2%)	285(100%)	
	Superior(n=2)	2(100%)	0(0%)	2(100%)	
	Total	160(46.4%)	194(54.8%)	354(100%)	
Edentulous		Gender		Total	P-value
		Male(n=20)	**Female**(n=14)		
	Buccal(n=4)	2(50%)	2(50%)	4 (100%)	0.004
	Superiolateral(n=24)	18(75%)	6(25%)	24(100%)	
	Superior(n=6)	0(0%)	6(100%)	6(100%)	
	Total	160(58.8%)	14(41.2%)	34(100%)	

Table 6.17: Comparison of mental foramen direction of opening amongst ethnicity.

	Variables	Race			Total (%)	P-value
General		**Malaya**	**Chinese**	**Indian**		
	Buccal	21(29.6%)	23(32.4%)	27(38%)	71(100%)	0.000
	Superiolateral	155(50.2%)	111(35.9%)	43(13.9%)	309(100%)	
	Superior	4(50%)	2(25%)	2(25%)	8(100%)	
	Total	180(46.6%)	136(35.1%)	72(18.6%)	388(100%)	
Dentate		Race			Total (%)	P-value
		Malaya	**Chinese**	**Indian**		
	Buccal	21(31.3%)	23(34.3%)	23(34.3%)	67(100%)	0.000
	Superiolateral	139(48.8%)	103(36.1%)	43(15.1%)	285(100%)	
	Superior	0(0%)	0(0%)	2(100.0%)	2(100%)	
	Total	16(45.2 %)	126(35.6%)	68(19.2%)	354(100%)	
Edentulous		Race			Total (%)	P-value
		Malaya	**Chinese**	**Indian**		
	Buccal	0(0%)	0(0%)	4(100.0%)	4(100.0%)	0.000
	Superiolateral	16(66.7%)	8(33.3%)	0(0%)	24(100.0%)	
	Superior	4(66.7%)	2(33.3%)	0(0%)	6(100.0%)	
	Total	20(58.8%)	10(29.4%)	4(11.8%)	34(100.0%)	

Table 6.18: Comparison of mental foramen direction of opening according to age-groups.

		Length measurements Mean (SD)						
		18-30 (n=54)	31-40 (n=42)	41-50 (n=88)	51-60 (n=104)	61-70 (n=66)	71-80 (n=34)	P-value
General	B	16(22.5%)	4(5.6%)	16(22.5%)	16(22.5%)	17(23.9%)	2(2.8%)	0.000
	SL	36(11.7%)	38(12.3%)	72(23.3%)	88(28.5%)	49(15.9%)	26(8.4%)	
	S	2(25.0%)	0(0%)	0(0%)	0(0%)	0(0%)	6(75.0%)	
		Length measurements Mean (SD)						
		18-30 (n=54)	31-40 (n=42)	41-50 (n=78)	51-60 (n=96)	61-70 (n=59)	71-80 (n=25)	P-value
Dentate	B	16(22.5%)	4(5.6%)	14(22.5%)	14(22.5%)	17(23.9%)	2(2.8%)	0.005
	SL	36(11.7%)	38(12.3%)	64(23.3%)	82(28.5%)	42(15.9%)	23(8.4%)	
	S	2(25.0%)	0(0%)	0(0%)	0(0%)	0(0%)	0(75.0%)	
		N/A		Length measurements Mean (SD)				
				41-50 (n=10)	51-60 (n=8)	61-70 (n=7)	71-80 (n=9)	P-value
Edentulous	B	N/A		2(50%)	2(50%)	0(0%)	0(0%)	0.001
	SL	N/A		8(33.3%)	6(25%)	7(29.2%)	3(12.5%)	
	S	N/A		0(0%)	0(0%)	0(0%)	6(100%)	

B: Buccal, SL: Superiolateral, S:Superior

6.4.2.5 Accessory mental foramen (AMF)

Accessory mental foramen (AMF) were observed in 5 (1.2%) of the 388 hemi-mandibles. These foramina were observed in 4 males (15.34%) and 1 female (14.35 %). Malays are more prone to have accessory mental foramen (4 cases), followed by Indians (1 case), while no case was seen in Chinese. There is no significant difference at the prevalence between gender, ethnicity and among age groups (Tables 6.19). Three accessory mental foramina (60%) are connected to bifid mandibular canals and two (40%) were connected to a trifid canals.

Table 6.19: The occurrence of accessory mental foramen (AMF) amongst gender, race and age-groups.

Parameters		Absent n=383 (%)	Present n=5 (%)	P-value
Sex	Male (n=180)	176 (46%)	4 (80%)	0.129*
	Female (n=208)	207 (54%)	1 (20%)	
Age	18-30 (n=54)	54 (14.1%)	0 (0%)	0.209*
	31-40 (n=42)	41 (10.7%)	1 (20%)	
	41-50 (n=88)	85 (22.2%)	3 (60%)	
	51-60 (n=104)	104 (27.2%)	0 (0%)	
	61-70 (n=66)	66 (17.2%)	0 (0%)	
	71-80 (n=34)	33 (8.6%)	1 (20%)	
Race	Malay (n=180)	176 (46%)	4 (80%)	0.222*
	Chinese (n=136)	136 (35.5%)	0 (0%)	
	Indian (n=72)	71(18.5%)	1 (20%)	

*Chi-square test

6.4.3 Mandibular foramen

6.4.3.1 Mandibular Foramen Shape

There are two types of mandibular foramen shape were identified in this study. Oval shape was seen in 370 foramina (hemi-mandibles) (95.3%), and round shape was seen in 18 foramina (4.7%). The distribution of mandibular foramen shape according to gender, race and age groups summarized in Table 6.20, according to dentate samples is summarized in Table 6.21 and according to edentulous samples is summarized in Table 6.22. Generally, there is no significant difference between mental foramen shapes among gender (p=0.082), and ethnicity (p=0.369) while there is a significant difference among age groups (p=0.002).

Table 6.20: Comparison of mandibular foramen shape amongst gender, age-groups and race.

Variables		**Oval** (n=370)	**Round** (n=18)	P-value
Gender	Male (n=180)	175(47.3%)	5(27.8%)	0.082
	Female(n=208)	195(52.7%)	13(72.2%)	
Age	18-30(n=54)	54(14.6%)	0(0%)	0.002
	31-40(n=42)	42(11.4%)	0(0%)	
	41-50(n=88)	78(21.1%)	10(55.6%)	
	51-60(n=104)	103(27.8%)	1(5.6%)	
	61-70(n=66)	62(16.8%)	4(22.2%)	
	71-80(n=34)	31(8.4%)	3(16.7%)	
Race	Malay(n=180)	173(46.8%)	8(38.9%)	0.369
	Chinese(n=136)	127(34.3%)	9(50%)	
	Indian(n=72)	70(18.9%)	2 (11.1%)	

Table 6.21: Comparison of mental foramen shape amongst gender, age-groups and race in dentate samples.

Variables		**Oval** (n=124)	**Round** (n=230)	P-value*
Gender	Male (n=160)	155(46%)	5(29.4%)	0.267
	Female(n=194)	182(54%)	12(70.6%)	
Age	18-30(n=54)	54(16%)	0(0%)	0.001
	31-40(n=42)	42(12.5%)	0(0%)	
	41-50(n=78)	68(20.2%)	10(58.8%)	
	51-60(n=96)	95(28.2%)	1(5.9%)	
	61-70(n=59)	55(16.3%)	4(23.5%)	
	71-80(n=25)	23(6.8%)	2(11.8%)	
Race	Malay(n=160)	153(45.4%)	7(41.2%)	0.538
	Chinese(n=126)	118(35%)	8(47.1%)	
	Indian(n=68)	66(19.6%)	2(11.8%)	

*Chi-Square test

Table 6.22: Comparison of mental foramen shape amongst gender, age-groups and ethnicity in edentate samples.

Variables		Oval(n=33)	Round(n=1)	P-value*
Sex	Male (n=20)	20(60.6%)	0(0%)	0.225
	Female(n=14)	13(39.4%)	1(100%)	
Age	41-50(n=88)	10(30.3%)	0(0%)	0.413
	51-60(n=104)	8(24.2%)	0(0%)	
	61-70(n=66)	7(21.2%)	0(0%)	
	71-80(n=34)	8(24.2%)	1(100%)	
Race	Malay(n=20)	20(60.6%)	0(0%)	0.290
	Chinese(n=10)	9(27.3%)	1(100%)	
	Indian(n=4)	4(12.1%)	0(0%)	

*Chi-Square test

6.4.3.2 Mandibular foramen vertical and horizontal location

Table 6.23 summarizes the mandibular foramen location measurements means for dentate and edentate samples. Two aspects were considered amongst the sample types which are the inferior and buccal measurements. Statistical analysis showed there is no significant difference between dentate and edentate sample groups for the two aspects considered.

Table 6.23: Comparison of mandibular foramen location by dentition status.

Parameters	**Status of dentition**		**Mean difference (95% CI)**	**t-statistics (df)**	**P-value**
	Dentate (n=353) Mean(SD)	Edentulous (n=34) Mean(SD)			
MandF-I	23.32 (3.62)	22.62 (3.51)	0.69 (-0.57,1.97)	1.07 (385)	0.283
MandF-B	5.91 (1.61)	5.58 (1.36)	0.33 (-0.22,0.89)	1.16 (385)	0.246

Table 6.24 summarizes the mandibular foramen length value for two aspects considered in this study, which are the inferior and buccal measurements respectively. There were 776 measurements to be made for mandibular foramen location, as there were two aspects and both sides of the jaw were measured (388 hemimandibles) in this study. Generally, the buccal edge was located, on average, 5.89 mm from the ramus while the lower edge of the mandibular foramen was located, on average, 23.26 mm above the lower edge of the mandible. Based on the skewness and kurtosis values the data is fairly symmetrical, so the two aspects value can be considered approximately normally distributed.

Table 6.24: Descriptive statistics of mandibular foramen location measurements.

		Mean (mm)	**SD**	**N**	**Median**	**Minimum**	**Maximum**
General	**MandF-I**	23.26	3.61	387	23.23	12.45	35.31
	MandF-B	5.89	1.59	387	5.91	2.61	18.15
Dentate	**MandF-I**	23.32	3.62	353	23.27	12.45	35.31
	MandF-B	5.91	1.61	353	5.92	2.61	18.15
Edentulous	**MandF-I**	22.62	3.51	34	23.37	13.98	29.5
	MandF-B	5.58	1.36	34	5.77	2.74	7.77

6.4.3.2.1 Comparison of mandibular foramen location between ethnicity

Table 6.25 summarizes the mandibular foramen location measurements means for the three races Malays, Chinese and Indians. Two aspects were considered which are the inferior and buccal measurements. Kruskal-Wallis test was conducted to indicate that there was no difference in the location of mandibular foramen inferiorly between the races (p=0.054). One-way ANOVA was conducted to indicated that there is a strong difference in the location of mandibular foramen buccally between the races (p=0.000). Further post-Hoc Bonferroni test shows significant difference amongst all races considered in this study.

Table 6.25: Comparison of mandibular foramen location by ethnicity.

		Mean Measurements (SD)			Total Mean (SD) N=387	F (df)	P-value
General		**Malays (n=180)**	**Chinese (n=135)**	**Indians (n=72)**			
	MFI	23.04(3.20)	23.83(4.33)	22.74(2.92)	23.26(3.61)	2.81(2)	0.054^{*}
	MFL	5.68 (1.49)	6.57 (1.65)	5.12 (1.17)	5.89 (1.59)	24.94(2)	0.00^{**}
		Mean Measurements (SD)			Total Mean (SD) N=354	F (df)	P-value
Dentate		**Malays (n=160)**	**Chinese (n=125)**	**Indians (n=68)**			
	MFI	23.02(3.27)	23.88(4.35)	23.01(2.72)	23.32(3.62)	2.32(2)	0.221^{*}
	MFL	5.67 (1.51)	6.61 (1.69)	5.20 (1.13)	5.91 (1.61)	22.57(2)	0.00^{**}
		Mean Measurements (SD)			Total Mean (SD) N=34	F (df)	P-value
Edentulous		**Malays (n=20)**	**Chinese (n=10)**	**Indians (n=4)**			
	MFI	23.19(2.66)	23.26(4.21)	18.19(2.92)	22.62(3.51)	4.32(2)	0.02^{a}
	MFL	5.73 (1.35)	6.03 (0.89)	3.75 (1.04)	5.58 (1.36)	5.41(2)	0.01^{b}

[*] Kruskal-Wallis non-parametric test, [**] One-way ANOVA (all races shows significant difference) - One-way ANOVA ([a] significant difference between Malaya-Indian, Chinese-Indian) ([b] significant difference between Malay-Indian, Chinese-Indian)

6.4.3.2.2 Mandibular foramen location by gender

Table 6.26 summarizes the mandibular foramen measurements for the two aspects among gender in three sample groups. Inferiorly, the mean for the male is 2.24 mm larger compared to the mean for the females and buccally, the mean for the male is 0.53 mm smaller compared to the mean for the females. A two tailed independent samples t-test ($\alpha = 0.05$) was used to compare the means among gender and generally, it was found that there was a strong difference in inferior and buccal measurements amongst gender.

Table 6.26: Comparison of mandibular foramen location between males and females.

		Gender mean measurements		Mean difference (95% CI)	t-statistics(df)	P-value
General		Male (n=180) Mean(SD)	Female (n=207) Mean(SD)			
	MandF-I	24.46(3.77)	22.21 (3.11)	2.24(1.55, 2.93)	6.40(385)	0.000**
	mandF-B	5.60(1.47)	6.14(1.64)	-0.53(-0.85, -0.22)	-3.36(385)	0.001*
Dentate		**Gender mean measurements**		**Mean difference (95% CI)**	**t-statistics(df)**	**P-value**
		Male (n=160) Mean(SD)	Female (n=194) Mean(SD)			
	MandF-I	24.50(3.79)	22.34(3.16)	2.15(1.42, 2.88)	5.81(351)	0.000**
	mandF-B	5.65(1.48)	6.13 (1.68)	-0.47 (-0.81, -0.14)	-2.79 (351)	0.005*
Edentate		**Gender mean measurements**		**Mean difference (95% CI)**	**t-statistics(df)**	**P-value**
		Male (n=20) Mean(SD)	Female (n=14) Mean(SD)			
	MandF-I	24.16(3.74)	20.42(1.44)	3.73(1.58, 5.88)	3.54(32)	0.000**
	mandF-B	5.14(1.36)	6.21 (1.11)	-0.47 (-0.81, -0.14)	-2.41 (32)	0.022*

*independent t-test **Mann-Whitney U

6.4.3.2.3 Mandibular foramen location amongst age groups

The comparison of mental foramen length mean between age groups is summarized in Table 6.27, where mean, SD, number, F-statistics and P value were included. According to SPSS results, generally, there is no statistical difference in the location of mandibular foramen inferiorly and lingually among age groups respectively.

Table 6.27: Comparison of mandibular foramen location amongst age groups.

General		Length measurements Mean (SD)						
		18-30 (n=54)	31-40 (n=42)	41-50 (n=87)	51-60 (n=104)	61-70 (n=66)	71-80 (n=34)	P-value
	MandFI	23.23(3.94)	22.60(2.96)	23.65(4.09)	23.20(3.59)	23.62(3.48)	22.58(2.68)	0.507*
	mandFB	5.66(1.37)	5.62(1.21)	6.08(1.44)	6.04(1.53)	5.59(2.31)	6.16(0.92)	0.465**
Dentate		Length measurements Mean (SD)						
		18-30 (n=54)	31-40 (n=42)	41-50 (n=78)	51-60 (n=96)	61-70 (n=59)	71-80 (n=25)	P-value
	MandFI	23.23(3.94)	22.60(2.96)	23.54(4.23)	23.41(3.52)	23.49(3.42)	23.29(2.72)	0.828
	mandFB	5.66(1.37)	5.62(1.21)	6.17(1.43)	6.16(1.49)	5.59(2.43)	6.01(0.80)	0.001**
Edentate				Length measurements Mean (SD)				
				41-50 (n=10)	51-60 (n=8)	61-70 (n=7)	71-80 (n=9)	P-value
	MandFI	N/A	N/A	24.55(2.76)	20.66(3.65)	24.69(4.09)	20.62(1.24)	0.022**
	mandFB	N/A	N/A	5.40(1.37)	4.69(1.49)	5.62(0.63)	6.56(1.15)	0.033**

* One-way ANOVA, ** Kruskal-Wallis non-parametric test

6.4.3.3 Accessory mandibular foramen

Accessory mandibular foramina were observed in 19 (4.9%) of the 388 hemi-mandible. These foramina were observed in 10 males (2.57%) and 9 females (2.31%). Malays are more prone to have accessory mandibular foramen (11 cases), followed by Chinese (5 cases), while 3 cases seen in Indians. There was no significant difference at the occurrence of accessory mandibular canal amongst gender, age groups and ethnicity (Tables 6.28). Fifteen accessory mandibular foramina were connected to bifid mandibular canals and 4 accessory mandibular foramina were connected to trifid mandibular canals. Eleven were observed on the right side while 8 were observed on the left side.

Table 6.28: Occurrence of accessory mandibular foramen (AMandF) amongst gender, race and age-groups.

Variables		Absent (n=369)	Present (n=19)	P-value
Sex	Male (n=180)	170 (46.1%)	10 (52.6%)	0.576*
	Female(n=208)	199 (53.9%)	9 (47.4%)	
Age	18-30(n=54)	54(14.6%)	0 (0%)	0.076*
	31-40(n=42)	37 (10%)	5 (26.3%)	
	41-50(n=88)	82 (22.22%)	6 (31.6%)	
	51-60(n=104)	98 (26.6%)	6 (31.6%)	
	61-70(n=66)	65 (17.6%)	1 (5.3%)	
	71-80(n=34)	33 (8.9%)	1 (5.3%)	
Race	Malay(n=180)	169 (45.8%)	11 (57.9%)	0.581*
	Chinese(n=136)	131 (35.5%)	5 (26.3%)	
	Indian(n=72)	69(18.7%)	3 (15.8%)	

*Chi-square test

6.4.4 Retromolar foramen (RMF)

Retromolar foramen were observed in 28 (7.2%) of the 388 hemi-mandible. These foramina were observed in 12 males (3.1%) and 16 females (4.1 %) hemi-mandibles. Malays are more prone to have retromolar foramen (14 cases), followed by Chinese (9 cases), while (5 cases) seen in Indians. There is no significant difference in the prevalence between gender and ethnicity while there is significant difference amongst age-groups (Tables 6.29). Nineteen RMF were connected to bifid mandibular canals and 8 were connected to trifid mandibular canals. One RMF was observed as a solitary foramen. Thirteen foramina were observed on the right hemi-mandibles while 14 were on the left side.

Table 6.29: The occurrence of retromolar foramen (RMF) amongst gender, race and age-groups.

Parameters		Absent (n=360)	Present (n=28)	P-value
Sex	Male (n=180)	168 (46.7%)	12 (42.9%)	0.697
	Female (n=208)	192 (53.3%)	16(57.1%)	
Age	18-30 (n=54)	53 (14.7%)	1(3.6%)	0.003
	31-40 (n=42)	40 (11.1%)	2 (7.1%)	
	41-50 (n=88)	73 (20.3%)	15 (53.6%)	
	51-60 (n=104)	97 (26.9%)	7 (25%)	
	61-70 (n=66)	64 (17. 8%)	2 (7. 1%)	
	71-80 (n=34)	33 (9.2%)	1 (3.6%)	
Race	Malay(n=180)	166 (46.1%)	14 (50%)	0.921
	Chinese (n=136)	127(35.3%)	9 (32.1%)	
	Indian (n=72)	67 (18.6%)	5 (17.9%)	

6.5 Measurement of Agreement

The measure the agreement of huge number of quantitative data, the intra-examiner reliability and reproducibility of the measurements obtained were evaluated. As stated earlier a total number of forty patients' records which is 10% of the sample size were randomly selected and all the data were measured again two months later by using the same methods described earlier. Regarding the assessment of intraexaminer agreement, all parameters showed an optimal agreement. For the assessments of length and width we have used intraclass correlation coefficient, p (Table 6.30), while for the categorical subclass agreement we have used Cohen's Kappa k (Table 6.31).

An alternative (and supporting) way of exploring the reliability of the measurements is to do a Bland and Altman plot. This approach is based on analysis of the differences between measurements, suggesting that estimates of 'agreement' between measurements may be better than reliability coefficients (Rankin & Stokes, 1998). The average value was 1.49 (Table 6.32).

Table 6.30: Intraclass correlation for numerical subscale.

Subscale	**Intraclass Correlation**	**95% Confidence Interval (Lower Bound, Upper Bound)**	**F**	**df**	**p**
MFD	0.961	0.841, 0.952	1.21	39	0.000
MFI	0.945	0.897, 0.971	0.462	39	0.000
MFL	0.956	0.917, 0.977	7.14	39	0.000
MandFI	0.970	0.943, 0.984	2.35	39	0.000
MandFL	0.926	0.859, 0.961	0.011	39	0.000

Table 6.31: Kappa for categorical subcale.

Subscale	**Kappa *k***	**p**
MF Shape	0.662	0.000
MandF Shape	1.000	0.000
Direction	0.861	0.000

Table 6.32: Bland-Altman analysis.

Parameter	**Value**
MFD	1.86%
MFI	0.62%
MFL	3.49%
MandFI	1.33%
MandF	0.17%
Average	1.49%

6.6 Discussion

Mental foramen is an important landmark of the mandible. The clinical implication of studying the mental foramen location is very crucial in proper delivery of local anesthesia for dental procedures, minimizing mental nerve damage during surgical procedures. It is also helpful in interpreting anatomical landmarks in oral pathology and forensics sciences as well (Neo, 1989).

Determination of anatomic variations of mental foramen has been the subject of many studies. These variations provide the ground to avoid surgical nerve damage and to gain successful anesthesia. Frequent failure of mental nerve block indicates its variable locations especially during jaw development. Therefore, the CBCT data set of adult patients who had completed their development was evaluated in this study.

Familiarizing practitioners about its shape is important to avoid iatrogenic injuries, since radiological misdiagnosis of mental foramen as a radiolucent lesion in the apical region of the mandibular premolars is expected. Additionally, to perform best practice treatment strategies for dental implant patients, one must be familiar about its location as well anatomy of the anterior loop of the mental foramen. This is as a critical surgical landmark and the significant reference point during treatment planning. It is widely agreed that improper assessment of mental foramen can cause iatrogenic trauma and that would result in paresthesia for periods of up to 3-16 months in 8.5% to 24% of the cases following implant surgeries (Gada & Nagda, 2014).

We have classified the samples in this study into 3 sample groups, namely: dentate sample group, edentate samples and general (dentate and edentate altogether). The inferior and lingual length measurements of the mental foramen were not altered between dentate and edentate samples. The mental foramen inferior length measurement was 13.97±1.78mm for the dentate samples and 14.27±2.11 for edentate samples while the lingual length measurement was 11±1.82 mm for the dentate samples and 10.83±1.92 mm for the edentate samples. These findings contradicts with Amorim et al. (2008) findings which stated that position of the mental foramen was altered in edentulous subjects when compared with dentate subjects.

Vertically, the mental foramen was averagely located 14±1.81 mm above the edge of the mandible which is larger than other studies using different assessment methods (Afkhami et al., 2013; A. Kalender et al., 2012; Saito et al., 2015). Saito et al. (2015) founded it to be

7.31 mm using CBCT while Afkhami et al. (2013) found the value to be 10.72 mm in panoramic radiographs. Kalender et al.(2012) found a mean distance ranging from 11.8 to 12.8 mm, in 386 tomographic slices. Dobrea et al. (2015) founded to be 11.41±2.63mm using CBCT. Our vertical findings among Malaysian population was similar to Chandra et al. (2013) in studies using cadavers in which mean values ranged from 12 to 15.6 mm were found.

In the present study, the distance of the mental foramen to the lingual cortex of the mandible averaged 10.99±1.81 mm. However, Pyun et al. (2013) located the horizontal location of the mental foramen by measuring it from the center of the mandibular canal to the lingual cortex of the mandible and reported a mean value of 5.60 mm using CBCT. Implementing similar imaging technique, Saito et al.(2015) measured the distance of the mental foramen to the lingual cortex of the mandible and reported it to be about 3.1 mm.

One of the most significant finding of this study is the difference in the vertical location of the mental foramen between Malays and Chinese race and between Chinese and Indians. Chen et al. (2013), using CBCT in Americans and Taiwanese, revealed no influence of the race on the distance from the mental foramen to the lower edge of the mandible between Americans (9.84 mm) and Taiwanese (10.13 mm). On the other hand, we have found no difference amongst gender in horizontal location of the mental foramen which is similar to Afkhami et al.’s (2013) findings.

One of the interesting findings of this study is that there is no effect of age on the location of mental foramen which contradicts with other studies reporting that age advancement caused the position of the mental foramen in a more posterior location. Our findings confirm that the posterior shift in positioning is due to the anterior tooth drift that occurs due to the expected age-related attrition of interproximal surfaces of teeth (Agthong et al., 2005; al-Khateeb et al., 1993; Al-Shayyab et al., 2015)

This study concludes that generally there is no statistically significant difference in the location of mental foramen amongst races horizontally, while there is a significant difference in the location of mental foramen vertically between Malays and Chinese, and between Chinese and Indians. We have found that there is no significant difference amongst race when considering dentate samples only or edentate samples only, similarly, there is still a statistical significant difference amongst races when considering dentate samples or edentate samples only. We can suggest that the vertical location of the mental foramen is a reliable landmark for distinguishing race but it is further necessary to do a study by considering a larger sample size.

When viewed relation to the dentition, the most common position of MF was below the second premolar and between the apices of the first and second premolar. MF is not always symmetrical in the same individual. From the present study. The possible presence of AMF should be borne in mind to avoid the occurrence of a neurosensory disturbance/hemorrhage following surgical procedures.

Many studies have reported two types of mental foramen shape, oval and round; one study considered the irregular shape as a third option (Al-Shayyab et al., 2015). We have recorded the shape as either round or oval. The majority of Indians were reported to have round mental foramen while Malawians had mostly oval shape. Round and oval shapes were reported to gain approximately equal percentage in Tanzanian and Zimbabwean populations (Al-Juboori et al., 2014; Fabian, 2006). In our study, round shaped MF was approximately twice greater in number than oval shaped MF, which contradicts Sheikhi et al.'s (2015) and Gershenson et al.'s (1986) findings where oval shape was twice greater than round shape. There is no statistically significant difference between foramen shapes amongst race and amongst age-groups while there is statistical difference amongst gender. We can conclude that mental foramen shape did not change with age increase. Taking the dentate samples into consideration for a more precise result revealed that there is no statistically significant difference between foramen shapes amongst gender, race and age-groups. However, after excluding the dentate samples and considering the edentate samples only, the findings showed that there is statistically significant difference between foramen shapes amongst gender and race.

Generally round-shaped mental foramen can be considered more than an oval-shaped foramen. Our findings are consistent with other similar studies in different populations (Al-Khateeb et al., 2007; Al-Shayyab et al., 2015; Singh & Srivastav, 2010) but contradicts findings in some other population (Agarwal & Gupta, 2011; A. Gershenson et al., 1986; Igbigbi & Lebona, 2006; Mbajiorgu et al., 1998; Prabodha & Nanayakkara, 2009; Souaga et al., 2004) which showed that the most frequent shape was indeed oval.
Interestingly, Al-Khateeb et al.(2007) showed that the most frequent shape of the mental foramen (round) was more common in females than males suggesting variation exist.

The opening direction of mental foramen has been evaluated in some races (Fabian, 2006; Kieser et al., 2002; Sheikhi et al., 2015; Wandee Apinhasmit et al., 2006). Our finding of the opening direction of mental foramen amongst Malaysian population was mostly superio-lateral (80%) which is similar to Sheikhi et al. (2015) and different from that of Kieser et al. (2002) as they found that posterior opening direction was the most common type. Our findings revealed that superior opening was the least common type which contradicts with the results of the study by Khojastepour et al. (2015) who reported posterior direction as the least common type although they used different classification for this direction. Our study can support the theory that mental foramen direction shows changes with age increase. During the development of mandible, the direction alters from the forward to upward and backward direction (Al-Juboori et al., 2014). Our study chose from the patients older than 18 years, whose skeletal growth had been sufficiently completed and the most common direction observed was superior-lateral.

This study showed an agreement in the opening direction of mental foramen in the right and left sides, and foramen opening direction was reported not to be gender-dependent in dentate samples while it is gender dependent in edentate samples. Our study, however revealed that there is a strong difference between opening direction amongst the races and age-groups in dentate and edentate samples.

The prevalence of AMF varies in different ethnic groups. According to Balcioglu and Kocaelli (Balcioglu & Kocaelli, 2009) the presence of AMF is a rather rare anatomical variation with prevalence ranging from 1.4 to 10%. Their report also revealed that non-Caucasians may have a higher prevalence of AMF than Caucasians. The highest prevalence is reported in Negros and Maori males (Kieser et al., 2002). None of these reports however, has related the presence of AMF with accessory mandibular canals. In the present study, the prevalence of accessory mental foramen (AMF) among Malaysian population was 1.2% which is less than those reported cases in previous studies in different populations (Balcioglu & Kocaelli, 2009; A Gershenson et al., 1986; Khojastepour et al., 2015; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009). This difference may have resulted from different methods of study employed. It may also be racially biased as ours is the only study that looked into the Mongoloids population apart from ethnic Indians.

The location of the mandibular foramen has been reported in many different studies. In this current study, the location of the mandibular foramen was studied using coronal images 387 selected hemi-mandibles. The mandibular foramen was localized by measuring 2 intraoral landmarks. The distance of the mandibular foramen to the buccal cortex of the mandible averaged 5.89±1.59 mm. Vertically, the mandibular foramen located 23.26±3.61 mm above the edge of the mandible. Strini et al. when analyzing dry mandibles found that the mandibular foramen presents itself in the intermediate third of the mandibular ramus in height and posterior in a anteroposterior direction. Da Silba Braga et al. (2015) measured mandibular foramen anteroposteriorly from anterior border of the ramus to the anterior wall of the mandibular foramen and reported this distance to be 11.81 mm. Some studies reported higher values for the distance from the anterior border of the ramus to the lingula. Lima et al. (2011) found a mean value of 19.48 mm. Smaller values were described by Prado et al. (2010), who found the average distance of approximately 18 mm between the center of the mandibular foramen and the anterior border of the ramus in dentate jaws. Chrcanovic et al. (2011) found in their measurements a distance of 17.5 mm between the anterior border of the ramus and the anterior wall of the mandibular foramen. This difference between the results of previous studies may be related to anatomical structures used by them as a reference for the measurements.

Variance in the anatomic location of the mandibular foramen as described by our finding and the literature makes clinical delivery of local anaesthesia challenging. Inability of mandibular IAN block and related safety concerns are common problems, with as many as 20% of mandibular IAN block reported to cause failed anesthesia (Kaufman et al., 1984; Khoury et al., 2011). Several of these failures are associated with vascular damage and variations in the anatomic pattern and position of the mandibular foramen and surrounding soft tissue located within the pterygomandibular space (Kaufman et al., 1984; Khoury et al., 2011; Narayana & Vasudha, 2003). Thus, the current finding provides an updated understanding about this landmark that will help the dentist to administer safe and effective IAN blocks to the Malaysian population.

In the present study, the prevalence of the accessory mandibular foramen was 4.9%, which is within the range of other studies (M. Chavez-Lomeli et al., 1996; Choi & Han, 2014; Murlimanju et al., 2011; Nortje et al., 1977; Patil, Matsuda, & Okano, 2013; Patra et al., 2015). This difference might be because of racial variations. Three ethnicities were included in this study namely the Malay, Chinese and Indians. Interestingly, it was discovered that the Malays were more prone to have accessory mandibular foramen (AmandF), followed by the Chinese and lastly, the Indians. There was no significant difference at the occurrence of accessory mandibular canal amongst gender and ethnicity while there is a significant difference among age groups. Most studies claim that there is no association between accessory mandibular foramen (AmandF) with sex and age (Gahleitner et al., 2001; A Kalender et al., 2012; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Naitoh et al., 2011b; Oliveira-Santos et al., 2011; Sisman et al., 2014; Zografos & Mutzuri, 1989). This findings contradicts the study by Hanihara and Ishida (2001) who found a higher prevalence in Asian males.

Since the clinical interest about the accessory mandibular foramen is crucial, very few studied the mandibular foramen location, shape and its variation with the same anatomical references we did in this study. Therefore, our investigation will support the oral maxillo-facial surgeons and oncologists in their clinical practice. Surgeons who perform any dental procedure of the lower jaw should be aware of these accessory foramina and thus plan anesthesia at an appropriate anatomical site. Early detection of these anatomical variations will help for an early adoption of necessary precautions during surgeries and thus avoid any neurovascular damage.

Anatomically, accessory mandibular foramen (AmandF) have been described as having smaller diameters as compared with the mandibular foramen (Serman, 1989; Toh et al., 1992). Other studies, however, have found no statistical significant difference in this respect (A Kalender et al., 2012; Katakami et al., 2008; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Oliveira-Santos et al., 2011; Sisman et al., 2014). We did not measure the diameters of the mandibular foramen and its variant as such data, however, should be interpreted with caution due to differences in inclusion and exclusion criteria related to different terminiologies used for each foramina as can be seen in Table 6.33 (Pancer, Garaicoa-Pazmino, et al., 2014).

Table 6.33: Terminology consideration for mandibular foramen variations

True accessory mandibular foramen	A foramen with direct continuity to the inferior alveolar canal as demonstrated by cone-beam computed tomography (CBCT) and to the inferior alveolar nerve itself
Accessorry mandibular foramen	All defects regardless of number (single, multiple), location (posterior, anterior, buccal, lingual), and size (>1 mm, <1mm). Foramen (for a single additional foramen) or foramina (for multiple additions)
Nutrient foramen	A foramen containing vessels only

CHAPTER 7: OVERALL DISCUSSION AND CONCLUSION

This chapter provides a comprehensive review of the current study and its findings. It integrates the findings from Chapters 4 to 6, and provide implications that can potentially affect our approach in performing procedures in the mandible.

7.1 Rationale for choice of the study topic

The current study was designed to study the presence of accessory canals and foramina in Malaysian population using appropriate application of CBCT and SimPlant software. The presence and contents of the neurovascular bundles in these accessory canals has been clearly identified in studies done by Deng et al. (2008) using High-Resolution Magnetic Resonance Imaging (HR-MRI). As such the function and importance of those structures has become evident and their correlation to most the pre-surgical and post-surgical complications that occurred in the mandibular region is better understood and needs no repetition here. Instead, we want to focus on the variations of the inferior alveolar nerve as represented by the different pattern of mandibular canals and foramina.

The choice of this topic was based on several reasons. Firstly, a perusal of data and records revealed that no such studies had previously been done in a Malaysian population and therefore the present study would act as a pilot to provide primary data on the mandibular variations among the Malay, Chinese and Indians. Dentists worldwide who are treating people of Malaysian ancestry who are made of up Mongoloids and Aryan descent can use this data as a reference. The data and finding presented will ensure that dentists treating this group of populations will become familiar and confident in dealing with their anatomical variations, especially when performing dentoalveolar and implant surgery on the mandible. Studies have shown that IAN is the most commonly injured nerve in the mandible (64.4%), followed by the lingual nerve (28.8%) (Tay & Zuniga, 2007). Hence, due attention shall have given to this nerve, especially with the finding that 22.77% of bifidity and 5.9% of trifidity is present in the Malaysian population.

7.2 Limitations of the study

As many number of measurements were required, the sample size of the CBCT records were limited to 202 (bilateral measurements – 404). Even though the results of this study were statistically relevant some may consider the sample size used was not sufficiently large.

7.3 Subject selection

A total of 202 suitable patient's records were selected based on gender, ethnicity and age groups. Males or females from racial groups, Malays, Chinese and Indians aged between eleven (11) and eighty (80) were included. For mandibular foramen and mental foramen measurements (Chapter 6), the sample considered was adult patients (18-80) to avoid growing mandibles of adelescents.

7.4 Method of study

7.4.1 Tool for measurement

Radiography is the only current method that can be used to plan treatment involving the mandible, and this advantage has been used to study the presence of accessory mandibular canal, mandibular foramen or mental foramen. CT has been previously used to improve depiction of the mandibular anatomical structures (Naitoh et al., 2008; Yang et al., 1999). However, compared to CBCT, CT equipment has been found to be very bulky, emitted high radiation and scatter, and are quite expensive.

CBCT are commonly used as a good standard for care to screen, diagnose, and select the best possible surgical approach and it was chosen as the imaging technique of choice for this study, Furthermore, this scanner-type images with 2D and 3D reconstructions can be produced without deformations and superimposition of structures at reduced radiation scan time and cost in clinical studies (Greenstein & Tarnow, 2006; Klinge et al., 1989; N. Mraiwa et al., 2003; Scarfe et al., 2006; Schramm et al., 2005; Yajima et al., 2006; Ziegler et al., 2002). Lastly, CBCT has been shown in some clinical studies to be more accurate and provided higher resolution compared to CT (Cotton et al., 2007). It is comparable to direct digital caliper measurements of various distances surrounding the mandibular canal (Kamburoglu et al., 2009) and was found to be reliable for linear evaluation measurements of other structures closely associated with dental and maxillofacial imaging (Lascala et al., 2004). It has been used previously in studies to detect anatomical variations like bifid/trifid mandibular canal (Rouas et al., 2006) and its foramina (Imada et al., 2014; Katakami et al., 2008; Naitoh et al., 2011b; Frederico Sampaio Neves et al., 2014).

Sanchis et al. (2003) described observing a triangular island of bone with its vertex at the root of separation of bifid canals as the pathognomonic feature on panoramic radiographs. They even established this feature in two patients for whom they had panoramic radiographs and CT scans. However, this ‘pathognomonic feature’ was not widely adopted as panoramic radiographs can be deceiving at times. In fact, a case with double mandibular canal, having two mandibular foramina and distinct mental foramina will not show this feature (Claeys & Wackens, 2005). In this current study, this pathognomonic feature was not observed in the panoramic view and the MPR view of CBCT scans.

Simplant software tools allow the marking to be done in any of the axial, cross sectional, panoramic and 3D view. It also permits scrolling through the entire volume with simultaneous viewing of axial, coronal and sagittal sections. The collective viewing of the images was useful to detect the canal. This software is friendlier when there is a need to view the mandibular canal together with its accessory canal or foramina.

7.4.2 Landmarks, Base line and Measurements

The mandibular canal was used as landmark for measurements in most of the cadaveric and radiographic studies. However, cadavers are processed specimen and fixed in formalin and because of this the nerve (being soft tissues) is prone to deformation and therefore becomes an inexact landmark. In contrast radiographic studies, the presence of cortical lining forming the wall of the mandibular canal act as a factor for their visualization (Rothman et al., 1988). However, the contrast media can leak out of the canal and causing unusual artifacts on the image. Cone-Beam computed tomography allows a precise demonstration of the mandibular canal and its variations (bifid/trifid) canals in relation to the alveolar crest, inferior border and bucco-lingual directions of the mandible. Moreover, the volumetric data can be transferred to third-party software for increased image quality manipulations.

7.4.3 Reliable landmarks for mandibular canal and foramina variant detection

The CBCT images selected in this study were all taken with Frankfort plane parallel to the floor. The interactive SimPlant software was used to produce dynamic high resolution cross-sectional and 3-D images, which allowed the visualization of the mandibular canal from any viewpoint on the computer screen.

The SimPlant software allows access to a measurement tools for linear measurements of the mandibular canal. The main concern in this study was selecting appropriate landmarks and base lines to allow optimum standardization and reproducibility.

Main mandibular canal was introduced and selected as base lines in the present study. The preliminary studies showed good standardization and reproducibility of the base lines and measurements. The data analyzed for reliability of the measurements using Bland and Altman test and showed an average value of 1.49, which strongly suggested the present method of obtaining data is considered as reliable and accurate.

7.5 Findings related to bifid and trifid mandibular canal

The mandibular canal is normally known as a single bony canal that originates from the mandibular foramen and terminates at the mental foramen where the nerves and vessels pass through the bony jaw bone. Surgeons must be aware about its location, pathway, and variations before any dental procedure for a successful treatment (Correr et al., 2013; Kuribayashi et al., 2014; Nortje et al., 1977; Xie et al., 1996).

The presence of a second or third mandibular canal, commonly referred to as the “bifid” and “trifid” canal is an anatomical variation containing a neurovascular bundle that appears to be of clinical significance (Langlais et al., 1985)Auluck et al. 2005, Auluck and Pai, 2005). Their early detection is crucial when performing dental procedures to minimize complications when administering mandibular anesthesia or during surgery of the lower third molar, orthognathic or reconstructive mandibular surgery, or placement of dental implants and prosthesis. Bleeding and traumatic neuroma are possible complications as well. Thus, consciousness of this distinction is very significant to practitioners (Karamifar et al., 2009).

Irrespective of the type of the BMC and TMC reported in this study or other previous studies, the occurrence of these variations has been reported to cause some clinical difficulties. Inadequate anesthesia in the mandible is the most frequent problem encountered in patients with a bifid or trifid mandibular canal, and it is often due to the conflict involving the location of division and the injection point (Auluck et al., 2007; DeSantis & Liebow, 1996). In the case of BMC, the position of bifurcation in the mandibular ramus is often superior to the most commonly administered injection point (H. Lee et al., 2009). So the traditional method of obtaining anesthesia in the mandible is to block the inferior alveolar nerve by depositing the anesthetic solution in the pterygomandibular space at a level slightly above the mandibular foramen may not work (Auluck et al., 2007; Lew & Townsen, 2006). Thus, a high inferior alveolar nerve block such as the Gow-Gates technique or the Akinosi technique should be the preferred mode of local anesthesia (Auluck et al., 2007). Nevertheless, these techniques should be used only when there is certainty of imaging evidence of multiple mandibular canals and failure of the standard inferior alveolar nerve block (Kang et al., 2014).

Conventionally, to confirm the effectiveness of conventional inferior alveolar nerve block there must be soft tissue anesthesia of the ipsilateral teeth, lip and chin. If the anesthesia is only in the soft tissue, with no anesthesia of the ipsilateral teeth, lip and chin then it is probably a local anesthesia technique failure and operator must repeat the anesthetic technique. However, if soft tissues, lip, and chin anesthesia is achieved successful with no effective tooth anesthesia then it is probably a mandibular canal variation and the operator has to consider other types of local anesthetic technique described above as repeating the same conventional technique is likely to be useless and may lead to postoperative pain and even trismus (Wadhwani et al., 2008).

Neurosensory disturbance that occurs following dental implant insertion is not a new problem (Palma-Carrio et al., 2011). Temporary paresthesia has been reported to range between 0% and 43.5%, while persistent problems are encountered in 0% to 13% of implant patients (Bartling et al., 1999; Ellies, 1992; Palat, 1991). Most of these cases involved the inferior alveolar nerve, and its terminal branch, the mental nerve and the accompanying anterior loop (Dao & Mellor, 1997; Hegedus & Diecidue, 2006). Throughout the last 3 decades, the prevalence of inferior alveolar nerve injury following implant surgery in the mandible has reduced dramatically because of improved awareness and the use of routine imaging (including volumetric scanned data) for presurgical assessment. Removing the offending implant has been the advocated practice in managing this complication (Khawaja & Renton, 2009). In addition, Serman (2012) highlighted that the inferior alveolar nerve may run for a short course extraosseously, therefore, this anomaly must be a concern when performing surgery in the region of the mental foramen. So far, there has been 1 case of BMC injury that has been reported to occur following third molar removal. In addition, a separate BMC and a TMC injury have been reported following implant surgery.

The first case involved a lower left third molar surgery in a subject with accessory canal (Wyatt, 1996). The presence of the bifid mandibular canal was acknowledged and conveyed to the patient prior to the surgery, with consent taken specifying potential nerve injury. The patient experienced a short period of partial paresthesia, after which sensation recovered spontaneously (Wyatt, 1996).

In the two cases relating to implant surgery, both patients experienced intractable burning pain that was resistant to all medical management. In the first case, this happened following the insertion of 3 implants at the left mandible. A cone-beam computed tomography (CBCT) scan showed that one of those implants (at site 37) impinged on an unusual accessory inferior alveolar nerve (Maqbool et al., 2013). Pain reduced significantly following the removal of this implant. The patient in the second case presented with an almost similar symptom following the insertion of 2 dental implants at the site of 35 and 36 (Aljunid et al., 2016). The authors removed the longer implant and patient was relieved of pain almost immediately, followed by the placement of a shorter implant. It is believed that by reinserting a shorter implant, the neurovascular bundle within the accessory canal was relieved of constant pressure caused by implant impingement. The patient never suffered from paraesthesia because the main inferior alveolar nerve was intact and was always functioning. The problem happened because of difficulty in identifying these trifid branches on the panoramic radiograph. These accessory canals appeared as radiopaque lines on panoramic images that can easily be mistaken as bony trabeculae. The canals were noticed on CBCT scans enhanced with Simplant software and the exact offending implant impinging the accessory canal was removed. Because of this, Chaushu et al. (2002) did not advocate placing implant as long as 12 mm at the molar region. They outlined several risk factors in women, namely a smaller mandible and age-related hormonal changes that result in increased bone resorption to support their statement.

It must be borne in mind that these findings highlight the importance to be familiar with the anatomical details of the mandibular canal, which include potential branching. Failure to identify anatomical variations can complicate surgery and result in adverse consequences. Because of this, Maqbool et al.(2013) strongly recommended that CBCT become a standard of care for implantology at the posterior mandible. The presence of accessory mandibular canal such as the BMC and TMC may be more common that what we think.

7.6 Retromolar canal-like structure in BMC and TMC

RMCs existence are functionally important in providing the neurovascular components of the mandible as reported since 1970s (Haveman & Tebo, 1976). Bilecenoglu and Tuncer (2006) confirmed that RMCs may contain blood vessels, striated muscle fibers, and myelinated nerve fibers. In the RMC the artery is a branch of the inferior alveolar artery, and the existing nerve is derived from the inferior alveolar nerve and supplied the third molar region, the retromolar triangle mucosa, the buccal mucosa, the vestibular gingiva of the premolar region, and probably the inferior molars (Kodera & Hashimoto, 1995). Due to the lack of awareness about the presence of RMCs, an anesthetic failure can happen, and moreover bleeding, paresthesia, or paralysis can occur during dental procedures.

Retromolar-like canals is best observed using computed tomography or volumetric imaging. This is because it was reported that when 30 RMCs were observed in CBCTs, only 7 were identified in panoramic radiographs (von Arx et al., 2011). Correr et al. (2013) had shown that when the third molars were present, half of the cases showed an intimate relationship, and another one-third of cases showed a close relationship between the roots of the third molars and the bifurcation of the mandibular canal. Having said so, some of the branch may not cause local anesthetic or postoperative problem, as described by Eliades et al. (2015). Hence a case of a supplementary canal that coursed towards the periapical lesion of a third molar was presented, but the tooth was successfully removed. They also reported a case of third molar surgery that was performed successfully despite the presence of a retromolar canal immediately distal to a mandibular third molar. This may be because of the fact that the retromolar foramina have been reported to be located between 4 and 4.5 mm from the third molar (Senthil Kumar & Kesavi, 2010). Mizbah et al.(2012) however, adopted a different surgical approach when a bifurcation was observed. They reported how the presence of a retromolar-like BMC adjacent to the mandibular right third molar in a 22-year-old female led them to section the tooth. The segments were subsequently individually mobilized in a strict buccal direction to avoid pressuring onto the inferior alveolar nerve and its accessory branch.

7.7 Findings related to accessory mental and mandibular foramina

7.7.1 Mental foramen

This current study considers the presence of normal mental and mandibular foramina, and their variations, which includes missing mental foramen, accessory mental foramen, assessory mandibular foramen, and retromolar foramen. We will begin this part of the discussion by reviewing findings related to the mental foramen and its variation in location, shape and number.

According to Pyun et al. (2013), the location of mental foramen could be classified into four groups based on its anteroposterior position: Type 1 below the apex of second premolar; Type 2 between the apices of second and first premolars; Type 3 between the apices of second premolar and first molar and Type 4 distal to apex of first molar. Kieser et al. (2002) instead classified the emergence type of mental nerve into four categories: posterior, anterior, right-angled or multiple-angled and found that a posterior direction was the most common emergence. Recently Iyengar et al. (2013), categorized the pattern of entry of mental nerve into the MF as straight, looping or perpendicular. This study however, did not follow any of the above classifications as determining the location of mental foramen from the adjacent teeth has limitations in many patients, as many of the implant applicants are partially or fully edentulous and have lost their molars and premolars a long time ago. Thus, further studies are recommended to analyze the invariable landmarks like the inferior border of mandible to locate mental foramen.

The horizontal and vertical distance of the mental foramen from the landmarks used was found to be different from that reported in the literatures. This variation in measurements may result from the fact that some studies used the center of the mental foramen as the point of reference, while others used the lower edge of the mental foramen as the reference point of the measurement. While in this study we have used the lower edge of the mental foramen opening as the reference point of measurement vertically and the buccal edge of the mental foramen perpendicularly to the buccal cortical margin of the ramus horizontally. Thus, our results were larger than those of the previous studies. The results of this measurement may help the professional to avoid injury to the lower alveolar nerve during implant procedures, or even in apical surgery on the premolars.

In this study, mental foramen was detected in both sides of mandible in all evaluated cases. However, in other studies, the absence of mental foramen has been reported, although rare. Freitas et al. (1976) investigated the absence of the mental foramen in 1435 dry human half mandibles (total of 2870 halves) and reported that the absence of the mental foramen in the right side (0.06%) to be twice as much the left side (0.03%). Recently, Hasan et al. (2010) also reported a case of bilateral absence of mental foramen during routine dissection tutorials on dry human mandibles. Perhaps we were unable to finding missing mental foramen since the number of our subjects was low.

The formation of mental foramen is incomplete until twelfth week of intrauterine life when the mental nerve divides into several branches (Imada et al., 2014). According to Toh et al. (1992) if the branching of the mental nerve occurs prior to formation of mental foramen, accessory mental foramen (AMF) can be formed. Being aware of its probable existence is important to avoid pain, paralysis, and even paraesthesia after surgical procedures (Balcioglu & Kocaelli, 2009; Imada et al., 2014; Mamatha et al., 2013; Munetaka Naitoh, Yuichiro Hiraiwa, et al., 2009; Parnia et al., 2012; Singh & Srivastav, 2010). The presence of AMFs has been evaluated with different methods including macroscopic investigations on dry skulls, plain radiography (including periapical and panoramic views), and computed tomography (CT or CBCT). Gershenson et al. (1986) in a study on 525 dry mandibles and dissections of 50 cadavers, reported that there were single and multiple MF in 94.67% and 5.33% of the cases respectively. Among them 4.3% of the mandibles had double MFs, 0.7% had triple and one mandible had 4 MFs on one side. None of our cases presented with this range of difference. Clinically if AMF is confirmed and there is insufficient room to place the dental implant, while respecting the suggested safety zones, the nerve should be repositioned or the ridge augmented to create adequate space (Hu et al., 2007).

7.7.2 Mandibular foramen

The current study found that there no difference in the location of the mandibular foramen measurements between right and left sides, similar to that reported by by Da Silba Braga et al. (2015) and Valente et al.(2012). This finding is of clinical relevance as it can be used to predict the contralateral site when performing local anaesthetic injection. Havinig said so, Gender difference was observed among our subjects, similar to that reported by Kane et al.(2000) and Lo et al.(2004). In adults it can be said that the differences observed in the skull were due to the female muscle frailty. This condition determines a smaller development of the mandibular ramus, which affects the position of the mandibular foramen (2010). Nevertheless, Da Silva Braga et al. (2015) observed that there was no significant difference when compared between the gender and this could be because of a different population studied.

The accessory mandibular foramen (AmandF) are known to transmit the branches of the inferior alveolar nerve and extra blood vessels which supply the bone (Jeyaseelan & Sharma, 1984). The position of the accessory mandibular foramen is variable, making it difficult to anaesthetize the IAN successfully (Nicholson, 1985). Among the Mongoloids, the highest percentage of accessory mandibular foramen (AmandF) prevalence was reported in Japan using CT by Patil et al.(2013) and in Korean by Choi & Han (2014).

Although not comparable, this current study found that the Mongoloids (Malays and Chinese) has a higher prevalence of accessory mandibular foramen when compared to the Indians. The presence of AmandF was higher in Malays (2.3%), than Chinese (1.5%) and to a lesser extent in Indians (0.77%). Others claim that the presence was higher in certain ethnic groups (Fishel et al., 1976; Sawyer et al., 1998). Sawyer et al. (1998) reported higher presence of AmandF as 1.4% in American Caucasians, 1.5% in Asian Indians, 5.7% in African Americans, and 9.0% in pre-Columbian Nazca Indians. The prevalence of accessory mandibular foramen in our Indian group is half of that reported by Sawyer et al. (1998)

Das and Suri (2004) confirmed that accessory mandibular foramen (AmandF) is connected to a canal that ends near 3rd molar root which may supply the latter with neural sensation and fail to achieve complete anesthesia during the surgery. Similarly, Lew et al. (2006) reported a case in which the presence of an accessory canal resulted in inadequate anesthesia at the time of the inferior alveolar nerve block. Hence, it is obvious that the awareness of the presence of this accessory mandibular foramen (AmandF), including the retromolar foramen is important for achieving a successful inferior alveolar nerve block.
Lastly, the knowledge of accessory mandibular foramen to radiotherapist while planning radiation therapy is of paramount importance as its presence makes it more susceptible to the perineural spread of the tumour cells from the cortical to the cancellous part of the bone following radiotherapy (Fanibunda & Matthews, 1999).

It was found during conducting this study that there is paucity of awareness about the accessory mandibular foramen as a variation in dental anatomy books, although it is been mentioned since 1930s (Simon & Komives, 1938). Practitioners must be familiar with the prevalence and the configuration of these foramina, since complications including unexpected bleeding, paresthesia and traumatic neuroma are known to occur because of trauma to the accessory foramina and canals (Kuribayashi et al., 2014). The surgeons as well must be aware during conservative rim resection procedures and should keep in mind about the tumor involvement in the region of the accessory mandibular foramen (Das & Suri, 2004). This knowledge is also important for orthognathic or reconstructive surgeries of the mandible and dental implant procedures (Quattrone et al., 1989; Slootweg & Müller, 1989). Palsson and Kjaer (2009) suggested that the morphology of the mandibular foramen and its variations should be included in the orthodontic and anthropological evaluation of normal and pathological mandibles.

7.7.3 Retromolar foramen

The distinction between accessory mandibular foramen and the retromolar foramen can be unclear at times. There have been occasion that the retromolar foramen has been reported as an accessory mandibular foramen and vice versa. The retromolar foramen can be found in the retromolar triangle and some branches from the inferior alveolar neurovascular bundle would pass through it, similar to that observed for the accessory mandibular foramen (Narayana et al., 2002; Narayana & Prashanthi, 2003).

Some authors may exclude the extra foramen and do not consider the presence of RMF near mandibular foramen according to their inclusion and exclusion criteria as in the study by Narayana and Prashanthi (2003). They found one accessory mandibular foramen located posterosuperior to the mandibular foramen and they did not consider this as a retromolar foramen due to its position outside the retromolar triangle and its larger diameter. So, in the current study, we termed all the foramina found on the ramus of the mandible as an accessory mandibular foramen although, where as the retromolar foramen is always associated with a retromolar canal, if present.

7.8 Diagnostic algorithm for mandibular canal and foramina variations

Based on the findings from the literature and from our study, we are proposing a diagnostic algorithm for mandibular canal and foramina variations, which we believe will be of importance clinically to practising dentists. This diagnostic algorithm is summarized in Tabel 7.1.

Table 7.1: Diagnostic algorithm for multiple mandibular canals with treatment planning implications.

Mandibular canal	**Identification features**	**Local anesthesia implication**	**Surgical Implication**
Single canal	- Radiolucent single canal - Superior and inferior well-corticated borders - Bilateral	None	None
Double canals that are fused posteriorly	2 distinct radiolucent canals one above another, separated usually by an island of medullary bone	Usually none if the inferior alveolar block is given at a higher level (before the nerve enters the canal)	Position of the canals may be somewhat superior; use caution while assessing the position of the canals before implant placement
Double canals that remain separate until the mental foramen region	2 distinct radiolucent canals separated by a uniform amount of medullary bone	Use caution while performing dental surgery in the region supplied by the mental nerve; if a mental nerve block is ineffective, an inferior alveolar block is recommended	Additional crosssectional CBCT images are necessary
Trifid canals that are fused posteriorly or remain separate until the mental foramen region	3 distinct radiolucent canals separated by islands of medullary bone; all canals have corticated boundaries	Use caution while performing dental surgery in the region supplied by the mental nerve; if a mental nerve block is ineffective, resorting to a full inferior alveolar nerve block is a better way to achieve optimal local anesthesia	Use caution while assessing the bone for implant placement; additional cross-sectional CBCT images are necessary; use caution while treatment planning implants both anterior and posterior to the mental foramen; additional cross sectional CT images are necessary
Accessory mental foramen	- Periapical image CBCT – different coronal planes at the mental region		
Accessory mandibular foramen	CBCT different coronal planes at the ramus		

7.9 Conclusion

The purpose of this study was to identify and classify BMC among Malaysian population and its prevalence was found to be about 22.77%. Although no Indian patients displayed any bifid mandibular canal, no significant differences in their prevalence between Malays and Chinese, age groups and gender was noticed. In the classification of the bifid mandibular canals, Type 1 and Type 4 were found in most of the cases. If the existence of a bifid mandibular canal is suspected in a panoramic radiograph, an advanced radiographic procedure using CBCT should be performed to confirm it. When a bifid mandibular canal is identified, the clinician must consider the need to modify the clinical technique to prevent complications during the treatment procedure. The flow chart for the full study with sample size selection and findings is illustrated in Figure 7.2

The following are the summary of findings, implications of the study as well as recommendations for further studies.

(i) The mandibular canal was identified as a major big canal in all the samples with 100% superb visibility.

(ii) Three criteria were considered reliable for the judgment of bifid/trifid mandibular canal: Accessory canal can be seen and drawn in all aspects, accessory canal must be corticated and accessory canal must be connected to main MC in the mandibular ramus.

(iii) The prevalence of the mandibular canal variations identified using CBCT technology was 22.77% for BMC and 5.9% for TMC among Malaysian population compromising of Malays, Chinese and Indians.

(iv) The mean length of the bifid mandibular canals was 32.33mm ± 19.96 (range: 7.20-86.33mm). No significant difference between bifid canal length among gender. However, there is a significant difference among the canal classification, age-groups and ethnicity. However, the mean length of the trifid mandibular canal was 20.75 mm ± 14.43 (range: 5-52mm). Type 3 (Forward canal) has the longest trifid mandibular canal length while Type 4 (RMC) was the shortest.

(v) The diameter of the accessory canal was greater than or equal to 50% of the main canal in BMC: 81.81%, TMC: 50%. And it was lesser than 50% in BMC: 18.18%, TMC: 50% of the 66 hemi-mandibles studied.

(vi) The mean diameter of the BMC was 1.42 mm (SD ±0.32) (range: 0.84-2.29 mm) but the main mandibular canal was 2.34 mm (SD ±0.46) (range: 1.47-3.88 mm) and indeed had a larger diameter, while the mean diameter of the TMC was 1.29 mm (SD ± 0.23) (range: 0.93-1.89 mm) and that of the main mandibular canal was 2.40 mm (SD ± 0.38) (range: 1.46-2.89 mm).

(vii) 56.1% of bifid mandibular canal was below main mandibular canal and 43.9% was superior to main mandibular canal while equal percentage was above and below main mandibular canal for trifid canals.

(viii) The lumen shape for BMC was 78.78% of irregular lumen shape (most common), 18.18% was circular and 3% was of oval shape, while for the TMC it was 62.5% with irregular lumen shape, 20.6% oval lumen shape and 2.9% circular lumen shape.

(ix) Retromolar canal type was the most frequent recorded canal variation in both BMC and TMC data set.

(x) The data from the left side of the jaw was approxiatly similar to the data from the right side of the jaw for all measured parameters concerning mental and mandibular foramen position.

(xi) Mental foramen round shape was 64.1% as compared to 35.9% oval shape.

(xii) Mental foramen position was, on average, 10.9 mm from the foramen lingual edge to the lingual cortex while the lower edge of the mental foramen was located, on average, 14 mm above the lower edge of the mandible.

(xiii) The distance between upper edge and lower edge of the mental foramen opening opening was 1.86 mm ±0.45. The direction of opening was 79.6% superiolateral direction.

(xiv) Accessory mental foramen (AMF) were observed in 5 (1.2%) of the 388 hemi-mandibles studied. 60% of the accessory mental foramina are connected to bifid mandibular canals and 40% were connected to a trifid canals.

(xv) Mandibular foramen was located 5.89 mm from the buccal edge of the foramen to the ramus while the lower edge of the mandibular foramen was located, on average, 23.26 mm above the lower edge of the mandible. Foramen oval shape was most commen (95.3%) as compared to round shape (4.7%).

(xvi) Accessory mandibular foramina were observed in 4.9% of the hemi-mandible studied. 78.94% of the accessory mandibular foramina were connected to bifid mandibular canals while 21% accessory mandibular foramina were connected to trifid mandibular canals.

(xvii) Retromolar foramen were observed in 7.2% of the hemi-mandible studied. 68% RMF were connected to bifid mandibular canals while 29% were connected to trifid mandibular canals. One RMF was observed as a solitary foramen.

(xviii) Diagnostic algorithm for treatment of bifid mandibular patient that can be used by any practioner to handle with minimal clinical complications.

(xix) CBCT proved a reliable means of distinguishing mandibular canal variations, determining canal length, measure foramen diameter.

(xx) The course and configuration of the mandibular canal should be carefully observed because it does possess variations. Bifid mandibular canals are rarely noticed with panoramic radiographs but definitely detected with enhanced CBCT images to avoid unwanted clinical complications.

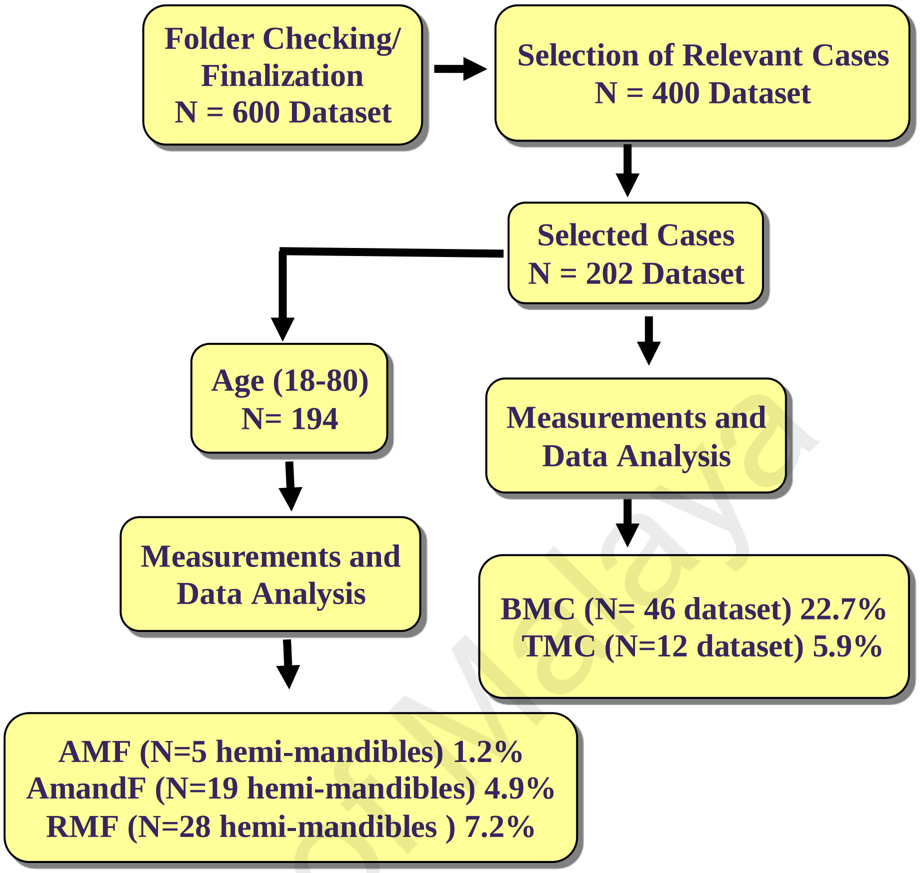

Figure 7.1 Flow Chart showing the methodology of the study

7.10 Implications of the study

This is a landmark study done on the images of life patients with CBCT and 3D simulation which must be very accurate and its result can be used as a safety guide during surgical procedures in oral implantology cases and oral and maxillofacial surgery to prevent postoperative complications. The research clearly showed variations in the mandibular canal and it should not be assumed that there is one canal at which it is safe for surgical intervention. Thus, it is highly recommended that the surgeons familiarize themselves with the anatomic variation at the mandibular canal region prior to any surgical intervention in order to avoid hemorrhage or neurosensory disturbances, as well as to safeguard themselves from unexpected medicolegal complications. Computed Tomography or Cone-Beam Computed Tomography (CBCT) is recommended for preoperative planning to overcome the shortfalls observed in other radiography.

7.11 Recommendations for further research

Many studies have attempted to measure or estimate the amount of radiation doses delivered to radiosensitive organs in the maxillofacial area, such as salivary gland thus, the risk of the ionizing radiation involved with radiographic techniques has been widely investigated. The CBCT has a very short exposure time (10-70) seconds and radiation dosage is 15 times less than the conventional medical CT scan. Deng et al. (2008) have recommended the use of High Resolution Magnetic Resonance Imaging (HR-MRI) to investigate the neurovascularization of the anterior jaw bone and surrounding soft tissue. It is similarly recommended using HR-MRI to visualize the canal in the Malaysian population. These imaging modalities do not use ionizing radiation and are considered non-invasive.

7.12 Conclusion

As a healthcare provider, it is our ethical duty to provide a harmless treatment to our patients. We have to anticipate and recognize the neurovascularization of the mandible to avoid any complications. Great care must be considered as these vasculatures are more complex and more variable than previously thought. Constant development of modern imaging modalities has improved tremendously our diagnostic capabilities.

It must be a legal requirement to have a CBCT scan prior to implant placement. CBCT imaging may sound extreme in cases where traditional imaging shows optimal anatomical host sites with favorable anatomical locations, However the use of CBCT as part of the workup would minimize the risk of IAN damage and potentially help identify any infrequent anatomical variations, as described in this thesis.

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