Chapter

External and Internal Anatomy of Maxillary Permanent First Molars

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Abstract

Adequate knowledge of the tooth morphology is of paramount importance for clinicians worked in the different branches of dentistry in order to maintain good oral health. Unfortunately, tooth morphology shows a high level of complexity and variability. These anatomical variations have been reported to be related to many factors including age, gender and ethnicity. The permanent first molars are the largest teeth in the maxilla which play an important role in mastication. Because of their early eruption, they are more vulnerable to caries and subsequent pulp and periapical pathoses. This chapter will summarize the internal and external morphologic features of these teeth with the reported variations in relation to age, gender and population in order to provide clinicians with the morphological knowledge necessary for performing successful dental treatments.

Keywords: morphology, maxillary, first molar, variations

1. External anatomy

1.1 Crown morphology

In the maxillary arch, the permanent first molar is the largest tooth. The anatomical crown of this tooth is broader buccolingually than mesiodistally (usually by 1 mm). This, however, may be changed from one individual to another. Even though, the crown is slightly shorter than premolars, it is wider both mesiodistally and buccolingually, giving the occlusal table its generous surface area that helps in food grinding [1].

This tooth has five cusps, four of which are well-developed to perform the intended function. These include the mesiobuccal, the mesiolingual, the distobuccal, and the distolingual cusps. The fifth one has yet been considered as a supplemental cusp of little physiological importance [1]. This little cusp have several names including accessory cusp, supplemental cusp, mesiolingual elevation, fifth lobe, Carabelli's tubercle, etc. [2] and can take various shapes ranging from a well-developed cusp to an interconnecting depressions, grooves, or pits on the mesial half of the palatal surface. The presence of this cusp or a developmental groove at its normal site is used to distinguish the maxillary first molar from other teeth [1]. In addition, it has been considered as a representative trait in anthropological and forensic studies for identifying different racial populations [1, 3]. High prevalence of Carabelli trait was reported in North West Europe origin Americans [4] whereas

Eskimo of unmixed descent had no Carabelli trait at all [5]. Russians [6], Brazilians [7], Malaysians [8] and Saudis [9] show moderate Carabelli trait prevalence.

1.2 Root morphology

Among the maxillary teeth, the permanent first molar has the strongest anchorage in the maxillary arch due to their well-developed widely separated roots [1]. Typically, this tooth has three roots, the mesiobuccal, distobuccal, and palatal [10]. These roots diverge in a manner parallel to the direction of the maximum force that could be applied diagonally against the crown in a buccolingual direction [1]. The palatal root is conical and smoothly rounded in shape. The mesiobuccal root is broader buccolingually with subsequent increased resistance to rotational forces. The distobuccal root is the smallest one with smooth rounded cross section. Normally, the palatal root is the longest one, and the other two roots have approximately similar lengths [1]. It has been reported that the average lengths of the mesiobuccal, distobuccal and palatal roots are 12.9 mm (8.5–18.8 mm); 12.2 mm (8.9–15.5 mm) and 13.7 mm (10.6–17.5 mm) respectively [11]. Generally, the average length of roots is approximately twice that of the crown [1].

Although anatomical variations have been reported in the literature however, the development of these teeth barely deviates from the typical morphology [1]. Several studies conducted in different populations (Korean, Thai, Chinese, polish, Russian, Burmese, and Kuwait populations) have reported that all or nearly all maxillary first molars presented with three separated roots [12–18]. It has also been reported that the prevalence of maxillary firs molars with two roots, four roots and single root are very low, (1.8%), (0.3%) and (0.2%) respectively [11]. However, Alrahabi and Sohail Zafar [19] used the CBCT technique to study the morphology of maxillary molars in a Saudi population and reported 94% of teeth with three separated roots, while the reminder 6% have four separated roots.

1.3 Root trunk and furcations

Normally, roots of the molars develop as one common root at the crown base before dividing into three roots (for the maxillary molars) or two roots (for the mandibular molars). This common root base is known as root trunk [1]. It extends from the cervical line to the entrance of the furcation [20]. In maxillary molars, the root trunk divides into three widely separated roots with three furcations, one buccally and two proximally. The access to these furcations is usually located in the coronal thirds of the roots. The buccal furcation entrance is approximately located at the center mesiodistally, while the entrances of the mesiopalatine and distopalatine furcations are slightly palatal to the center buccopalataly [21].

From a periodontal perspective, furcations of the maxillary first molars are more commonly involved than those of the mandibular first molars [22]. Additionally, the buccal furcations of the maxillary first molars are the most frequently affected, followed by the mesiopalatal and distopalatal furcations [23]. However, fortunately, the buccal furcation is the most accessible one for both patients and clinicians. The access to the periodontal lesion in proximal furcations represents a challenge for maintaining good oral hygiene and performing an optimal periodontal treatment [21].

It is generally accepted that root trunk length play an important role in the susceptibility of maxillary molars to periodontal disease [24]. Several studies evaluated the length of the root trunks in maxillary first molars [20, 25–30]. There was a general agreement in the majority of these studies that the mean trunk length in the buccal aspect is shorter than those in the mesial and distal ones [20, 25, 27, 29]. However, the mean length of the mesial and distal root trunks varies among different studies. Some authors found that the mean mesial root trunk is greater than the distal one [20, 27] whereas others reported that the distal root trunk was the longest one [28, 30]. Moreover, equal length of the mesial and distal root trunks has also been reported [26]. Although teeth with short root trunk are more susceptible for periodontal lesion on the furcation, however these teeth have a favorable prognosis after periodontal therapy since less attachment loss has occurred [31].

In maxillary first molars, a deep groove is frequently found on the buccal aspect of the root trunk which extends from the furcation to end as a shallow concavity at the cemento-enamel junction (CEJ) [1]. Jackson Lu [32] founded that about 94% of the evaluated furcations have a developmental depression of different depth on the root trunks of molars. These concavities may complicate the coronal adaptation of the membrane along the trunk surface during the guided tissue regeneration procedure. Furthermore, Kerns et al. [26] reported that the mean distances from the CEJ to these developmental grooves ranged between 1.35 mm and 1.65 in the maxillary first molars. Therefore, they stated that guided tissue regenerative therapy for short trunk molars could be compromised particularly if developmental root trunk grooves are present.

1.4 Root fusion

Root fusion is thought to be caused either by cementum deposition over time or due to inability of Hertwig epithelial sheath to form or fuse at the furcation area [33]. This is based on the fact that the three roots are initially developed as a single root projecting from the crown base then divided into three roots by the growth and fusion of the Hertwig root sheath. Frequently, root fusion in the mandibular molars takes the form of a C-shaped root, while maxillary molars may show different fusion patterns, such as partial or complete fusion of two or more roots [34]. According to Zhang et al. [34], there are six different patterns of root fusion in maxillary molars including Type 1 (MBR fused with DBR), Type 2 (MBR fused with PR), Type 3 (DBR fused with PR), Type 4 (MBR fused with DBR, PR fused MBR, or DBR), Type 5 (PR fused with MBR and DBR) and Type 6 (PR, MBR, and DBR fused to a cone-shaped root).

Generally, root fusion is less prevalent in maxillary first molars. The proportion of fused roots in maxillary second molars is about four folds greater than that in maxillary first molars [35]. Concluded from several cone beam computed tomographic studies, the averages of different types of root fusion in maxillary first molars are Types I (1.13%), type III (1.1%), type II (0.23%), type IV (0.2%), type V (0.2%) and type VI (0.1%) [11].

Although it is a rare variation, several studies have reported different proportions of root fusion in the maxillary first molars in different populations [10, 12, 36, 37]. Using cone-beam computed tomography (CBCT), Kim et al. [12] identified 0.73% of the first molars in a Korean population show fused roots. Neelakantan et al. [36] reported that root fusion present in 2.2% of the first maxillary molars in an Indian population. By using clearing techniques, Rwenyonyi et al. [37] found fused roots in 4.1% of the same teeth in Uganda. However, Al Shalabi et al. [38] reported that 11% of the maxillary first molars teeth of Irish population have fused roots. These variations could be in part due to that there has been no widely accepted definition of the fused root [12, 34]. Some authors have considered roots as fused if fusion extended along the entire root length. Others have categorized teeth in the fused group if one third or less of the roots were fused and subsequently ended up with higher prevalence. Therefore, the defining criteria of fused roots have to be clarified in to justify whether these differences in prevalence were true variations [12].

Root fusion has a strong clinical impact in periodontics and oral surgery and to a less extent in endodontics [35]. However, taking in consideration that a high proportion of fused roots also have their main root canals merging, it is obvious that root fusion represent challenges not only to root canal preparation but also to endodontic microsurgery [11, 35]. For example, merging canals can create angles which increase the stress on endodontic instruments. Moreover, roots with multiple canals show more isthmi and more complicated apical anatomy which may negatively influence the approach of the endodontic microsurgery [35].

1.5 Direction of apical root curvature

Knowledge of the apical root curvature is also an important factor that should be assessed properly before root canal treatment as well as prior to tooth extraction. Such knowledge enables the clinicians to perform a safe and efficient dental treatment through the selection of suitable instruments and approaches. According to Versiani et al. [11], the direction of the apical curvature for the three roots of the maxillary first molar has been reported. 78% of the mesiobuccal roots had distal apical curvature while 21% were straight and the remaining 1% showed s-shaped root. Although majority of the distobuccal roots were straight (54%), mesial curved, distal curved and s-shaped distobuccal roots have also been reported (19, 17 and 10% respectively). The palatal root showed buccal apical curvature in 55% of teeth while it was straight in 40.7%. In 3.2 and 1.1% of teeth, the palatal root showed mesial and distal curvature respectively. It is worth mentioning that root curvatures in the buccolingual direction are frequently underestimated and undiscovered clinically through the conventional projections of the two-dimensional intra-oral radiography. Therefore, different angled projections are necessary to identify the presence and direction of root curvature.

2. Internal anatomy

In 1907, Fischer [39] showed, for the first time, the anatomical complexity of the apical root canal by injecting the teeth with a collodion solution. Due to this unpredictability and complexity of the canal morphology, he came up with the widely used description “root canal System”. Therefore, the thought of a single uniform root canal with a single centered apical foramen is a misconception [40]. Generally, pulp cavity consists of the pulp chamber that is situated within the anatomical crown and the root canal system that is located inside the anatomical root [41]. Other anatomical features of the pulp space include pulp horns, canal orifices, furcation, lateral and accessory canals, inter-canal anastomosis, and apical foramina [41].

2.1 Pulp chamber morphology

Generally, the shape of the pulp chamber follows the shape of the tooth crown. Therefore, the pulp chamber of maxillary first molar is rather rectangular from the mesial aspect and squared from the buccal aspect of the tooth [1]. Theses shapes are usually constricted at the floor of the pulp chamber [21]. This tooth has a relatively large pulp chamber with four prominent projections (horns) under the well-developed four cusps [1]. However, the size of the pulp chamber is reduced with age either physiologically by the continued formation of secondary dentine or pathologically through the formation of reparative or tertiary dentine as a consequent of pulp irritation or dental trauma [42]. Moreover, the formation of the secondary dentin is not uniformly distributed. Greater amount of secondary dentine production takes place at the roof and floor of the pulp chamber when compared with the other walls [43]. Therefore, a flattened, disc-like pulp chamber is frequently seen in old aged patients which may complicate the access cavity preparation and canals identification during root canal treatment [41]. In such situation, the pulp chamber roof is very close to the floor which decreases the clinician's tactile perception and may result in perforation during access cavity preparation [44, 45].

It is clear that knowledge of the average dimensions and general location of the pulp chamber in molars may decrease the occurrence of chamber perforations during the access preparation. Unfortunately, few studies have been conducted to correlate external anatomical landmarks with the floor and roof of the chamber [46]. Sterrett et al. [47] measured the distance from the pulp chamber floor to the furcation of the maxillary and mandibular molars. They found that this distance range from 2.7 to 3 mm in maxillary and mandibular molars. In their study, Majzoub and Kon [48] reported that the average distance from the chamber floor to the furcation was not more than 3 mm in 86% of the measured maxillary molars. Several distances from multiple anatomical landmarks have been measured in the maxillary molars by Deutsch and Musikant [46]. The mean distance from the chamber floor to the furcation was 3.05 mm, from the chamber roof to furcation was 4.91 mm, from the tip of the buccal cusp to the furcation was 11.15 mm, from the buccal cusp tip to the chamber floor was 8.08 mm and from the buccal cusp tip to the chamber roof was 6.24 mm. They also found that the roof pulp chamber was located at the same level of the cementoenamel junction (CEJ) in 98% of the maxillary molars. Townsend et al. [49] conducted similar study on the maxillary first molars of an Indian population and found comparable results as follows: the distance from chamber floor to the furcation = 2.7 ± 0.63; distance from the chamber roof to the furcation = 5.34 ± 0.9; distance from the palatal cusp tip to the furcation = 11.58 ± 1.01; distance from the tip of the palatal cusp to the chamber floor = 8.86 ± 0.68; distance from the tip of the palatal cusp to the chamber roof = 6.2 ± 0.66. Similarly, the roof of the pulp chamber was found at the level of the CEJ in 96% of the measured teeth.

2.2 Canal orifices locations

The canal orifices of the maxillary first molars form a triangular shape in the floor of the pulp chamber; the base of the triangle connects the mesiobuccal and the palatal canals while the orifice of the distobuccal canal represents the apex of the triangle. The orifice of the palatal canal is located at the center lingually. The orifice of the mesiobuccal canal is located at the acute corner of the pulp chamber while the distobuccal canal is located somewhat distal and palatal to the mesiobuccal canal, close to the obtuse corner of the pulp chamber. If it is present, the second mesiobuccal canal (MB2) will be positioned palatal to the mesiobuccal canal and at or slightly mesial to the imaginary line connecting the mesiobuccal and the palatal canals [1].

This knowledge has a direct clinical influence on the form and extent of the endodontic access cavity. Conventionally, a triangular shaped access cavity was prepared during root canal treatment of these teeth. However, this seems to be inconsistent with the fact that maxillary first molars frequently have an extra-canal (MB2) in the mesiobuccal root which is difficult to locate and prepare [50, 51]. The presence of MB2 has to be expected by the clinician until the clinical and radiographic assessment show the opposite [50]. In order to locate the extra-canals, it has been proposed that the outline form of the access cavity should be guided by the morphology of the pulp chamber floor [52]. Therefore, several authors have advised to re-assess the shape and design of the endodontic access cavity for maxillary molar teeth [53–55]. To locate MB2 in maxillary molars, the shape of the access opening should be first modified from the conventional triangular outline to the rhomboidal shape [56]. Besides the access cavity modification, different angled radiographs, NaOCl bubble test, surgical loupe and operating microscope represent other clinical facilities for locating extra-canals [51, 52].

2.3 Root canal morphology

Root canal is the radicular portion of the pulp space. It starts as a funnel shaped orifice on the floor of the pulp chamber at or somewhat apical to cervical line, and ends as one or multiple apical foramina at or lateral (0–3 mm) to the center of the anatomical apex of the root [21, 57, 58].

The root canal morphology of the maxillary first molar is one of the most complex root canal anatomies in human dentition [11]. Generally, the most frequent pattern of the maxillary permanent first molar in the literature has three roots and four canals with a high incidence of a second canal in the mesiobuccal root (MB2) [10, 11]. This is consistent with the broad buccolingual dimension of the mesiobuccal root and with the root depressions on its proximal surfaces [1].

The horizontal shape of the root canals varies along its length. From the canal orifice to the midroot, the mesiobuccal canal is oval or flat oval in cross section and then tapers to terminate as a round canal with very small diameter. Frequently, the palatal canal and distobuccal canal are oval or round in shape and taper gradually to the apex [1, 11].

2.3.1 Accessory and lateral canals

Any branch of the pulp cavity, other than the main canals, that communicates with the periodontium is called an accessory canal. Additionally, any accessory canal extending horizontally from the cervical or middle third of the main canal is called a lateral canal [59]. These canals are thought to be formed during the calcification due to the entrapment of blood vessels from the periodontium into the Hertwig's root sheath [60]. Studying root canal anatomy of the human permanent teeth, Vertucci [57] reported that accessory canals were more commonly located in the apical third of the root (73.5%), followed by the middle third (11.4%) and the coronal third (6.3%). In the maxillary permanent first molars, he found that accessory canals are more prevalent in the mesiobuccal and palatal roots (51% and 48% respectively) than those in the distobuccal root (36%). In multi-rooted teeth, accessory canals can also be located in the trifurcation or bifurcation, and are called furcation canals [61]. They are forms as a consequence of blood vessels entrapment during the fusion of the root diaphragm [60]. The incidence of such canals in the maxillary first molars is 18% [11, 57]. Accessory canals represent an additional pathway for the transmission of irritants mainly from the pulp space to the periodontium, resulting in primary endodontic lesions [41].

2.3.2 Isthmi

An isthmus is a thin transverse anastomosis that connects two roots canals [62]. It can be found in any root with multiple canals [41]. This intercanal connection serves as a bacterial reservoir which is difficult to be cleaned mechanically even with the most sophisticated engine driven endodontic instruments. It has been reported that 52% of the mesiobuccal roots of the maxillary first molar show transverse anastomosis (10% coronally, 75% at midroot and 15% apically) [11, 41]. Weller et al. [63] reported that most of the anastomosis in the mesiobuccal root of the maxillary first molars was found at 3–5 mm short of the apex. The presence of such anastomosis may jeopardize the outcome of the surgical endodontic treatment [64, 65]. Therefore, Cambruzzi and Marshall [62] emphasized that these anastomosis should be cleaned, prepared and filled during endodontic surgery. They also suggested the use of methylene blue stain to facilitate the identification of an isthmus occurrence in the resected root surface.

2.3.3 Apical anatomy

In a large proportion of maxillary first molars, the apical foramina of the three root canals are located lateral to the corresponding root tip (82% of the palatal roots, 81% of the distobuccal roots and 76% of the mesiobuccal roots) [11]. On average, majority of the MB2 canals (61.6%) merge with the mesiobuccal canals at the midroot or apical region and share the same foramen while minority of them (38.4%) end in a separated foramen [10].

The presence of more than one apical foramen is not uncommon. Morfis et al. [66] used a scanning electron microscope to study the apical anatomy of 213 permanent teeth. They found that the presence of more than one apical foramen was observed in all roots except for the distal root of mandibular molars and the palatal root of the maxillary molars. They also reported that the mesiobuccal root of the maxillary molars showed a high prevalence of multiple apical foramina (41.7%).

Marroquín et al. [67] studied the apical anatomy of the maxillary and mandibular molars in an Egyptian population using stereomicroscope. They found that most of the roots (70%) have oval apical constrictions. The average of the narrow and wide diameters of the apical constriction in maxillary molars was 0.18–0.25 mm in the mesiobuccal and distobuccal root, and 0.22–0.29 mm in the palatal root. They also found a high frequency (71%) of two main foramina in the mesiobuccal root of the maxillary first molars. Additionally, the accessory foramina were found in about 33% of these roots.

Moreover, apical ramifications have been reported to be found in 32–86% of maxillary first molar teeth [11]. All these anatomical irregularities show the complex nature of the root canal system in maxillary first molars which invariably complicates the root canal treatment procedures.

2.3.4 Root canal curvature

Preoperative recognition of the root canal curvature is of paramount importance during the root canal treatment. This is considered as an important factor in determining the level of difficulty, and the probability of procedural errors during root canal treatment [68]. This will invariably guide the clinician to select the most appropriate technique and instruments to effectively prepare the root canal system. Root canal curvature could be a gradual smooth curve of the whole canal or a sharp bent in the apical part of the canal [41]. Versiani et al. [11] have reported the range of curvature degree for each root canal of the maxillary first molars in the clinical view (MB1 0–42°; MB2 23–49°; DB, 0–48°; P, 0–47°) as well as proximal views (MB1, 0–54°; MB2, 0–36°; DB, 0–41°; P, 0–38°). Several methods [69–71] have been proposed to assess the root canal curvature, by measuring the angle of the curvature and/or the radius of the curvature. Radiographically, Schäfer et al. [72] evaluated the degree of curvature of more than 1160 root canals in all human teeth from the clinical (0–75°) and proximal views (0–69°). They reported that the most severe curvature was found in the clinical projection of the mesiobuccal root canals of maxillary permanent molars and in the mesial root canals of the mandibular permanent molars. According to Vertucci [41], almost all root canals in human are curved apically, especially in the buccolingual direction. Therefore, in order to recognize the presence, severity, and direction of the root canal curvature, it is necessary to evaluate the tooth radiographically from different angled projections.

2.4 Variations in the root canal anatomy

2.4.1 Variations in the occurrence of MB2 in maxillary first molars

The internal anatomy of the mesiobuccal root is the main focus of many morphological studies as the incidence of more than one canal is highly variable [41, 73]. In addition to the variations due to the age [55, 74] and gender [74, 75], several studies in various populations revealed that, the anatomy of root canal system has ethnic features [13, 76–78]. Therefore, many researchers had studied the internal root anatomy of the maxillary first molar, mesiobuccal root in particular, in different racial populations and subpopulations using different techniques [12–15, 19, 38, 52, 57, 78–82].

A wide range of ethnic variations has been inferred from several studies conducted to evaluate the root and canal anatomy of mesiobuccal root of maxillary first molar in various populations. For example, a high prevalence of the MB2 has been reported in Japanese (88.2%) [52], Iranian (86.6%) [78], Ireland (78%) [38], Australian (73.6%) [83], Caucasian (71%) [84] and Saudi (70.6%) [19] populations. However, a lower prevalence has been reported in Korean (63.59%) [12], Thailand (63.3%) [13], Russian (59.8%) [17], Polish (59.5%) [15], Greek (53.2%) [85] and Pakistani (48%) [81] populations. According to two different studies, the lowest reported incidence of MB2 was in Brazil (42.63%) [80] and (25%) [86]. As a result of such ethnic variations, the evaluation of root canal anatomy for all populations and ethnic groups is indispensable [36, 87].

Regarding the variation with age, many studies concluded that the prevalence of MB2 decreases by aging, due to dentine apposition which subsequently results in narrowing and obliteration of the canal [55, 88, 89]. For example, Razumova et al. [17] evaluated the presence of MB2 canal in different age groups; young (20–44 years), middle-aged (45–60 years) and elderly (>60 years). They observed that the presence of MB2 was higher in young group with 48.8% than that in middle with 33.2% and elderly group with 18%. Similar results were obtained in a study by Zheng et al. [14] in which they observed a higher prevalence of MB2 among patients between 20 and 30 years of age. However, these findings are in contrast with those of Ratanajirasut et al. [13] and Katarzyna and Pawlicka [15] who did not find correlation between age and the prevalence of MB2 in the maxillary first molars. Unexpectedly, in a study conducted on a Chilean population, a higher occurrence of the MB2 canal in the maxillary first and second molars in older patients was observed [90]. These differences could be related to the sample size and the anatomical variations among populations. However, MB2 could exist in any age group, and the clinician should be aware of finding and treating it [17].

Few studies have reported gender differences in the morphology of the root canal system [91]. Sert and Bayirli [75] studied the root canal morphology of 2800 extracted teeth (1400 teeth from each gender) from Turkish individuals by using decalcification and clearing method. For each gender, they included 100 teeth of each type of the permanent dentition, except the third molars, in their sample. Even though only 100 teeth of each tooth type for each gender were evaluated, a significant morphological difference has been noted between males and females. Regarding the mesiobuccal root, type I Vertucci canal configuration was found in only 3% of males compared to 10% of females. Therefore, they suggested that morphological variations due to gender and ethnic background should be considered during the preoperative evaluation for the root canal therapy. Similarly, Kim et al.

[12] reported higher numbers of additional canals in males' mesiobuccal root of maxillary first molars. However, there are conflicting results with respect to gender and the number of canals [55, 75, 89, 92].

In addition to the previously mentioned variation factors, differences in reported results may also be influenced by the design of the study (clinical versus laboratory) [93]. Some authors conducted studies to compare the results of in vivo versus in vitro techniques. Seidberg et al. [94] found MB2 canal in 33.3% of 201 first maxillary molars in their clinical in vivo study compared to 62% in their in vitro sectioning evaluation of 100 of the same tooth type. These results were comparable to another study conducted by Pomeranz and Fishelberg [95]. They reported that MB2 canal was found in 31% of 100 teeth examined in vivo. This percentage increased to 69% when the same number of teeth was evaluated in their in vitro study. The more common use of SOM or loupes in recent clinical studies has resulted in an increased prevalence of the clinical detection of the MB2 canal [73, 96]. The effect of magnification on the incidence of MB2 was assessed in a clinical study by Buhrley et al. [96]. They reported that MB2 canal was located in 71.1% of the maxillary first molars treated with the aid of surgical operating microscope (SOM). When the dental loupe was used, this percentage was reduced to 62.5%. In the non-magnification group, the percentage was decreased dramatically to only 17.2% of the teeth. Sempira and Hartwell [73] concluded that the incidence of MB2 increased significantly when the SOM is used during the root canal therapy.

In conclusion, the wide variation in the reported prevalence of MB2 canal is significantly affected by the method of evaluation being used. As a result, any attempt to compare MB2 prevalence of different populations should take in consideration the similarity of the evaluation methods. For example, considering only CBCT in vivo studies, MB2 prevalence vary from 86% in Iran [78] to 30.9% in China [97], with in-between proportions in other countries such as Portugal (71%) [84], Korea (63.6%) [12], and Brazil (44.4%) [80]. Another issue is that all these studies were conducted by different research teams which can lead to variations in the CBCT assessment among different observers. This in turn affects the validity of any attempt of direct comparison.

To overcome these drawbacks, recent global in vivo study [98] has been conducted to evaluate the prevalence of the MB2 canal in the maxillary first molars in 21 different geographic regions around the world using CBCT method. The special issue in this study is that twenty-one observers from different countries have been uniformly pre-calibrated to reduce the inter-observers variability. They found that MB2 prevalence ranged widely from 48.0 to 97.6% among the studied countries, with a global MB2 proportion of 73.8%. However, the authors also clarified some drawbacks of their study. Bearing in mind the effect of age and gender on the MB2 prevalence, it seems to be difficult to compare the different regions in this study due to the high variations in their mean age and gender proportions. In addition, although serious attempts were performed to pre-calibrate the observers, assessment differences may still present due to the differences in personal experience and beliefs. They suggested that these limitations can be overcome by gathering CBCT databases of patients having the same age and enrolling both genders equally in the all different regions. Then, all these databases have to be assessed by a single qualified observer [98].

2.4.2 Bilateral existence of MB2 in maxillary first molars

Several studies have investigated the simultaneous presence of MB2 root canal in the contra-lateral maxillary first molars among different populations. High proportions of bilateral occurrence of MB2 canal in maxillary first molars have been reported in selected Korean [12], Malaysians [99], and Chinese [100] populations (82.9; 82.36;

and 74% respectively). Clinically, previous knowledge about the presence of MB2 in one maxillary first molar should make the clinician aware about the increased likelihood of MB2 occurrence in the contra-lateral molar of the same patient.

2.4.3 Variations in the number of distobuccal and palatal root canals

According to Cleghorn et al. review [10], single canal (98.3%) with a single apical foramen (98%) is the most frequent canal pattern in the distobuccal root. In a similar manner, the majority of the palatal roots have a single canal and a single foramen (99 and 98.8% respectively). Although anatomical variations for these root canals have been reported, they are significantly rare. Several studies addressed this issue in different populations. Alrahabi and Sohail Zafar [19] conducted a study on a Saudi population and found that the distobuccal and the palatal root had one root canal in 100% of cases. In Razumova et al. [17] study on a Russians population, the distobuccal root contained single canal in most of cases and two canals in 0.5%. Similar results were obtained by Ratanajirasut et al. [13] (Thai population), Zheng et al. [14] (Chinese), Neelakantan et al. [36] (Indians), and Kim et al. [12] (Koreans), in which second distobuccal was found in 1, 1.2, 2.2, and 1.25% of cases, respectively.

2.5 Anatomical anomalies

Generally, the most frequent pattern of the maxillary permanent first molar in the literature has three roots and four canals with a high incidence of a second canal in the mesiobuccal root (MB2), [10, 11]. Although anatomical anomalies have been reported in the literature however, they are barely mentioned in studies [10]. Maxillary first molar with four roots [101], five roots [101], two roots [102], single conical root [103, 104] and single O-shaped root [105] have been reported. Additionally, it has been inferred from several CBCT studies that the incidence of C-shaped root canals in maxillary first molars ranges from 0.3% to 1.1% with an average equal to 0.83% [11]. Other anatomical anomalies such as maxillary first molars with One canal [103], five canals [106], six canals [107], seven canals [108], eight canals [109], and hypertaurodontism [110] are extremely rare and have been documented as case reports.

Enamel pearls and trunk developmental grooves are most prevalent in the maxillary molars [1]. These anatomical anomalies are considered as local cofactors that increase the risk of periodontal disease development [111].

3. Clinical remarks

Maxillary first molars present the greatest clinical challenge for endodontic treatment. This is because the complexity of the root canal system surpasses that of all other teeth within the human dentition [11]. It is generally accepted that the mesiobuccal root of these teeth has a second canal in majority of cases. Although this canal is usually difficult to be negotiated, it must be expected to be there until clinical and radiographic examinations prove its absence [50]. Clinically, the location of this canal varies to a large extent, but it is frequently positioned mesial to or along the imaginary line connecting the mesiobuccal and palatal canals, within average area of 2 mm mesially and 3.5 mm palatally from the orifice of the MB1 canal [112]. Radiographically, it is mandatory to take and carefully evaluate two or more different angled radiographs which would provide much required information about the morphology of the root canal system [41, 113].

According to Görduysus et al. [112], 16% of MB2 canals cannot be negotiated down beyond the orifice. This could be due to several reasons such as the presence of a dentine ledge which covers the orifice, its mesiobuccal inclined entrance on the chamber floor, its route coronally which frequently shows single or multiple sharp curves and its tendency to be more calcified especially in old aged individuals [11, 41]. Therefore, Vertucci [41] suggested that countersinking or troughing of the developmental groove, which is located palatal to the MB1 canal, by using ultrasonic tips would eliminate most of these obstacles. During this procedure, the groove should be deepened apically (0.5–3 mm) and widened mesially. This may require a slight modification in the access outline to extend more mesially. Due to the presence of a concavity on the distal surface of this root, troughing should be prepared with cautions to avoid perforation into the furcation.

Despite their frequency of occurrence, high variations in the number of canals for maxillary first molars have been reported in the literature. Accordingly, the mesiobuccal and the palatal roots may have one, two, or three canals, whereas the distobuccal root may contain one or two canals [11]. In order to locate these additional canals properly, several diagnostic aids should be taken in consideration. These include examination of the chamber floor by using a sharp endodontic explorer, using methylene blue to stain the orifices, visual inspection of the bleeding points, performing the ‘champagne bubble’ test using sodium hypochlorite and magnification of the pulp floor using dental loupe or surgical operating microscope [41, 51, 52]. Surgical operating microscope (SOM) significantly enhances the visibility and lightening of minute details. Using SOM, clinician is able to remove obstacles and calcifications selectively in a precise manner that would minimize the procedural errors [41].

Although the palatal root usually has a large and easily accessible canal on the pulpal floor, it requires skillful cleaning and shaping procedure. This root canal often curves buccally in its apical part. Since it is difficult to be recognized with the two dimensional intra-oral radiograph, this may results in under-estimation of the working length with subsequent short preparation and obturation of this canal [21].

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