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Chapter

Morphology of Root Canal System of Maxillary and Mandibular Molars

Svetlana Razumova, Anzhela Brago, Haydar Barakat and Ammar Howijieh

Abstract

The root canal system is complicated and has many anatomical variations among different populations. It is so important to understand the morphology of root canal system before any endodontic procedure, since the lack of knowledge of root canal system could lead to missing the additional root canals which causes failure of endodontic treatment. The study of root canal anatomy was carried out by many researchers and among different populations using various techniques. The presence of additional root canals was most commonly observed in molars. The aim of this chapter is to provide an overview of the morphology of root canal system of maxillary and mandibular molars and its variation among populations.

Keywords: root canal, configuration, number of root canals, number of roots

1. Introduction

The success of endodontic treatment depends on the precise knowledge of root and root canal anatomy and morphology, which is an important challenge due to the complexity of the root canal system and the anatomical variations [1, 2]. This knowledge helps the clinicians in endodontic treatment planning and decreases the percent of endodontic failure. The root canal contains the dental pulp, which occupies the internal cavity of the tooth [3].

Root canal system varies among the teeth, especially in molar teeth. Recent studies have demonstrated that root canal system is very complex due to splitting and union of canals during their way to the apex [4, 5]. The root canal starts from the orifice in the pulp chamber and ends apically with an open orifice into the periodontium. The root canals present different configurations between the teeth and among different populations [6]. Many techniques have been used to study the root canal system from clearing and radiographs to microcomputed tomography and cone-beam computed tomography scanning, which has the advantage of the high-quality three-dimensional slices [2, 5, 7].

2. The classification of root canal system

The root canal system has been classified by different authors to set terms for communication, diagnosis, and treatment planning. The ideal classification of root

canal system is to define a number of roots, number of canals in each root, and the canal configurations [8]. Different configurations of root canals have been identified in numerous studies. Weine et al. [9] in 1969 were the first who studied the root canal configuration of maxillary second molars and defined four types as follows (**Figure 1**):

- Type I (1-1): single canal runs from the orifice to the apex.
- Type II (2-1): two canals start from the pulp chamber and join in one closer to the apex.
- Type III (2-2): two canals run separately from the orifice to the apex.
- Type IV (1-2): one canal starts from the pulp chamber floor and divides into two canals when coming closer to the apex.

In 1984, Vertucci [10] presented another classification for root canal configurations in maxillary first molars, and it has been commonly used in different studies. The classification was as follows (**Figure 2**):

- Type 1 (1-1): single canal runs from the orifice to the apex.
- Type II (2-1): two canals begin from the pulp chamber and join in one at the apex.
- Type III (1-2-1): one canal runs from the pulp chamber, splits into two canals during its way, and then unites into one canal at the apex.
- Type IV (2-2): two canals run separately from the orifice to the apex.
- Type V (1-2): one canal runs from the pulp chamber and splits into two canals when coming closer to the apex.
- Type VI (2-1-2): two canals run from the pulp chamber; during its way they unite into one canal and then again split into two canals at the apex.
- Type VII (1-2-1-2): one canal starts from the pulp chamber, then divides into two canals, again unites into one canal, and finally at the apex divides into two canals.
- Type VIII (3-3): three canals run from the orifice to the apex.

In the last decade, some authors studied the root canal configurations all over the world and added new types to Vertucci's classification, which demonstrates the complexity of root canal system. Kartal and Yanıkoğlu [12] identified two root canal configurations in mandibular anterior teeth: type (1-2-1-3) and type (2-3-1). In 2001 Gulabivala et al. [13] added seven new configurations to Vertucci's classification: type (3-1), type (3-2), type (2-3), type (2-1-2-1), type (4-2), type (4-4), and type (5-4) (**Figure 3**).

Also, in 2004, Sert and Bayirli [14] added 15 configurations (**Figure 4**), which have been observed in maxillary and mandibular teeth in Turkey. They were classified in the following order: type IX (1-3), type X (1-2-3-2), type XI (1-2-3-4), type XII (2-3-1), type XIII (1-2-1-3), type XIV (4-2), type XV (3-2), type XVI (2-3), type XVII (1-3-1), type XVIII (3-1), type XIX (2-1-2-1), type XX (4), type XXI (4-1), type XXII (5-4), and type XXIII (3-4).

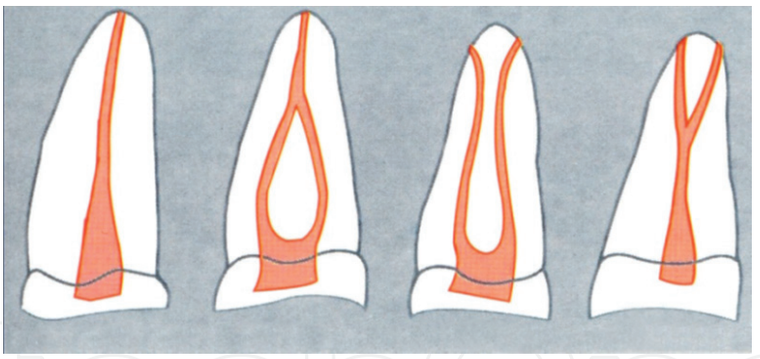

Figure 1.
Weine's classification of root canal configuration.

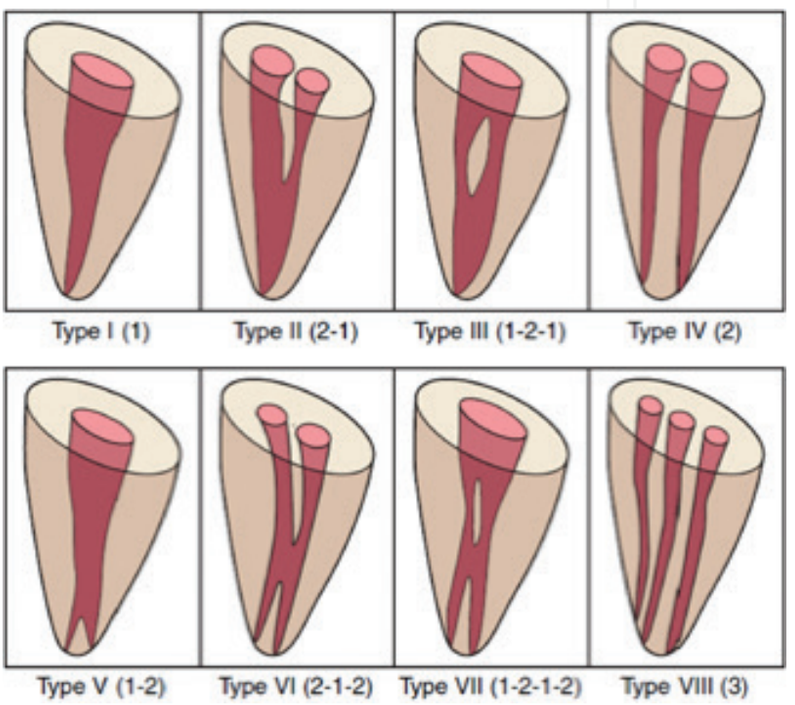

Figure 2.
Vertucci's classification of root canal configuration [11].

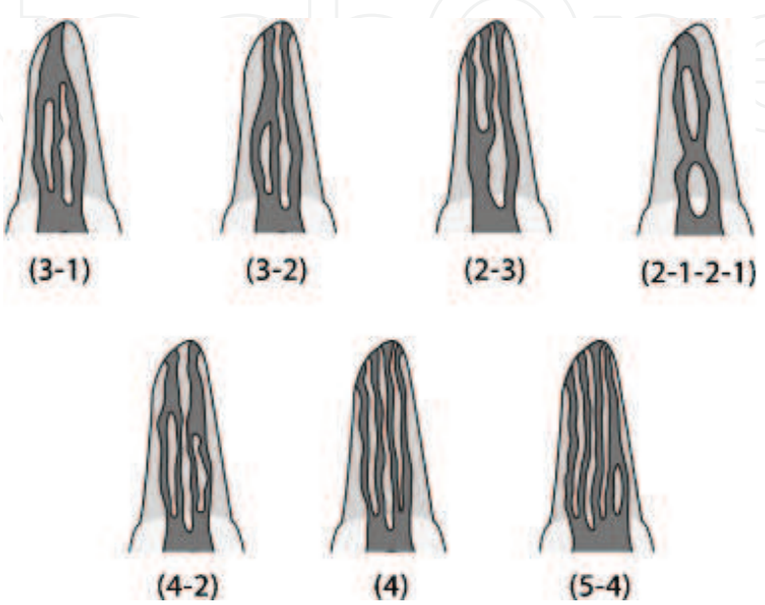

Figure 3.
Gulabivala's classification of root canal configurations.

Peiris et al. in 2008 observed two additional root canal configurations (1-2-3) and (3-1-2) in their study (**Figure 5A**) on mandibular first molar of a Sri Lankan population [15]. In 2008, Al-Qudah added four new types for root canal configurations of mandibular molars in Jordan population [16]: type XX (2-3-1), type XXI (2-3-2), type XXII (3-2-1), and type XXIII (3-2-3) (**Figure 5B**).

In addition to describing root canal system, many authors studied the root canal shape and the presence of isthmus (which is a narrow ribbon-shaped communication between two root canals that contain pulp tissue). The isthmus was found in 15% in maxillary anterior teeth, for maxillary premolars—it was identified in 16% at a 1-mm level of the apex and in 52% at a 6-mm level of the apex. The prevalence of the isthmus was high in mesiobuccal root of maxillary first molars (about 30–50%) in the apical third of the root. For mandibular first molars, 80% of mesial roots have connection in the middle and apical third of the root. Root canal shape varies between round, oval, and C-shaped. Kim et al. [17] classified root canal shape and the presence of connections between canals into five types (**Figure 6**):

- Type I: incomplete isthmus between two canals
- Type II: two canals with a definite connection between them
- Type III: very short complete isthmus between two canals
- Type IV: a complete or incomplete isthmus between three or more canals
- Type V: two or three canals without visible connection between them.

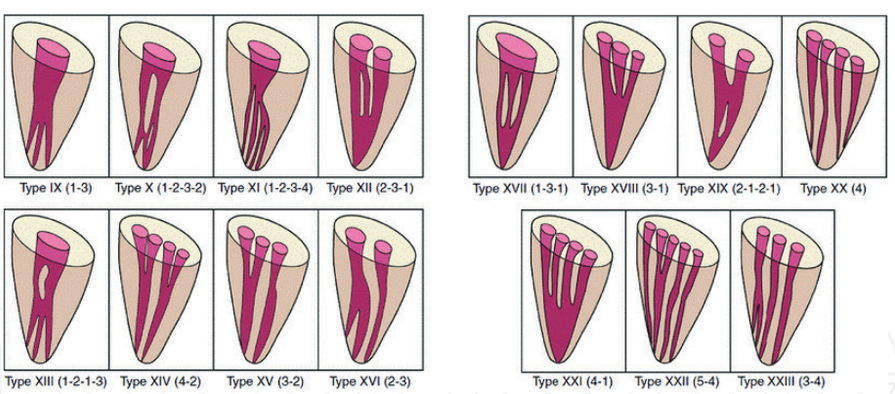

Figure 4.
Sert and Bayirli classification of root canal configurations [11].

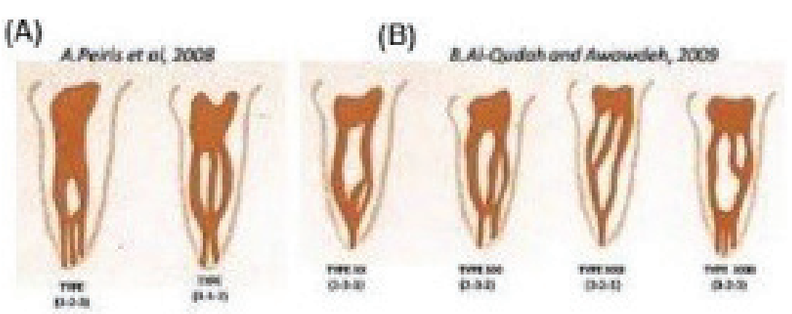

Figure 5.
Root canal configurations according to (A) Beiris and (B) Al-Qudah [8].

Figure 6.
Kim's classification of root canal shape [17].

In 2018, a review was conducted to study classification of root canal configuration to find a simple, reliable, accurate, and easy nomenclature system to identify the root canal depending on the tooth type, the number of roots, the course of the canal in each root, and the number of foramens [8].

3. Root canal morphology of maxillary molars

3.1 Maxillary first molar

The maxillary first molar is the earliest permanent tooth that appears in the oral cavity and that makes it vulnerable to caries and furthers to the need of endodontic treatment. It has three roots [mesiobuccal (MB), distobuccal (DB), and palatal (P)] with four canals. Despite this, in some populations these variations were observed: one, two, or four roots in the maxillary first molar [18–20]. Root fusion of this tooth was observed in about 0.9–3% [20–23]. The root canal system of the maxillary first molar is complex and has many variations among races; due to that it has the highest rate of endodontic failure. The palatal root is the longest and has the largest diameter; in most cases, it contains one round canal from the orifice of the pulp chamber to the apex. The presence of two or three canals in this root has been reported; in some population as in India, two canals were found in 5% [24]. The distobuccal root is conical and has one canal in most cases. The presence of the second distobuccal canal (DB2) has been documented in some studies, and its prevalence ranged from 0.5 to 9.5% (**Figure 7**) [25, 26]. The most common root canal morphology of the palatal and distobuccal roots is type I (1-1) (**Table 1**). The mesiobuccal root contains two canals (MB1, MB2) with a ribbon form type I by Kim et al. in most cases (**Figure 8**). The MB2 is one of the mysteries in endodontics; its orifice is located mesially or in the pulpal groove between the main mesiobuccal canal and palatal canal, 3.5 mm palatally and 2 mm mesially from the main mesiobuccal canal [27]. The prevalence of MB2 ranged from 48 to 88%, for example, in Russia MB2 was found in 59.8% [25], in Poland 59.5% [28], in Japan 88.2% [29], and in Portugal 71% [30]. The root canal system of the

mesiobuccal root has significant variations among populations. The most common canal configuration is type I (1-1) followed by type II (2-1) and then type IV (2-2) by Vertucci [20, 24, 25, 30–37]. Many recent studies have been conducted to analyze the morphology of root canal configuration of three rooted maxillary first molars among different populations as shown in **Table 1**. The most common root canal configuration of one and four rooted maxillary first molars is type 1 (one canal) [31].

3.2 Maxillary second molar

The maxillary second molar is smaller and shorter than the first molar. It has three separated roots in the most common form (MB, DP, and P). Available studies show this tooth can have from one to five roots [37, 38]. Moreover, fusion of roots of maxillary second molars is observed from 5.90 to 42.25% [39]. The fusion of palatal root with mesiobuccal root is the most prevalent form followed by fusion of buccal roots, and the least spread form is the fusion of the three roots (**Figure 9**) (Video 1)

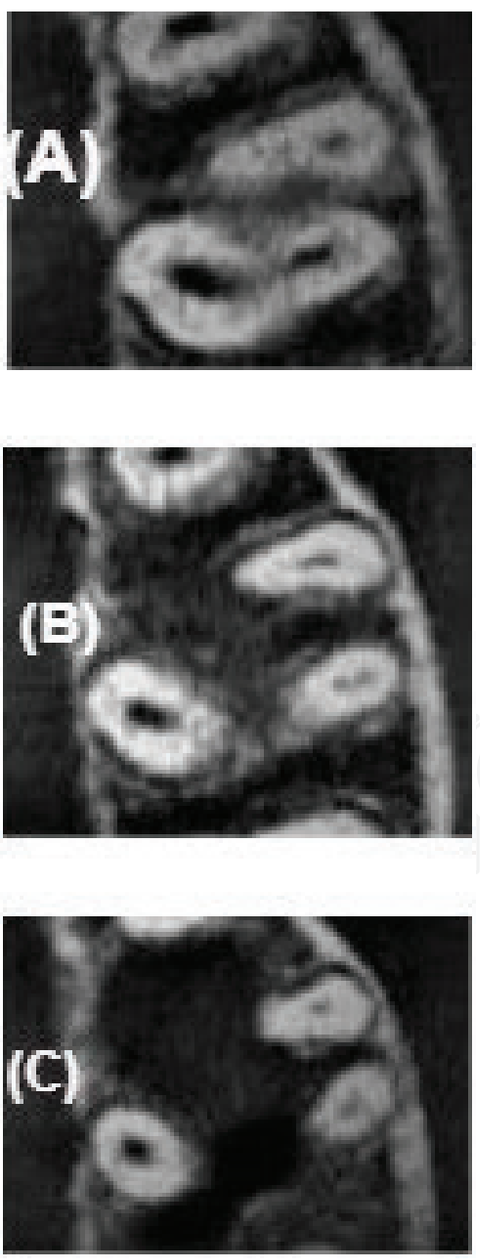

Figure 7.
A case of five canals in maxillary first molar. (A and B) Coronal and middle third: MB1, MB2, DB1, DB2, P. (C) Apical third: MB1 + MB2 + DP + P.

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-3)	Type (3-1-2)	type (1-3)	Type (3-2)	Type (2-3)	Type (2-1-2-1)
Neelakantan et al. [31]	India	MB	51.8	5.5	–	38.6	–	–	–	–	–	–	–	1	–
		DB	90.4	2.7	1.8	1.8	–	–	–	–	–	–	–	–	–
		P	88.1	1.8	–	4	1.4	–	–	–	–	–	–	–	–
Singh and Pawar [24]	South India (2015)	MB	69	24	–	4	2	–	–	1	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Alrahabi and Sohail Zafar [19]	Saudi Arabia (2015)	MB	29.4	47	11.8	11.8	–	–	–	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Martins et al. [30]	Portugal (2017)	MB	29	44.1	1	16.4	2	5.7	0.2	–	0.4	–	–	–	1.2
		DB	98	1.4	0.2	–	0.2	0.2	–	–	–	–	0.4	–	–
		P	98.2	0.4	1.4	–	–	–	–	–	–	–	–	–	–
Tian et al. [20]	China (2016)	MB	42.2	15.2	2.1	36.2	2	0.6	0.07	0.13			1.4		
		DB	98.2	0.3	0.6	0.3	0.5	–	–	–	–	–	–	–	–
		P	99.3	0.3	0.3	–	0.1	–	–	–	–	–	–	–	–
Ghobashy et al. [32]	Egypt (2017)	MB	25.4	45.6	0.99	27.2	0.5	–	–	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Pérez-Heredia et al. [33]	Spain (2017)	MB	13.8	56.5	–	23.2	–	4.3	–	–	–	–	0.7	–	1.4
		DB	97.1	1.4	–	–	1.4	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-3)	Type (3-1-2)	type (1-3)	Type (3-2)	Type (2-3)	Type (2-1-2-1)
Ratanajirasut et al. [34]	Thailand (2018)	MB	36.4	28.8	2.7	25.3	5.3	1.1	–	–	–	–	–	–	–
		DB	99	–	–	0.2	0.8	–	–	–	–	–	–	–	–
		P	99.8	0.2	–	–	–	–	–	–	–	–	–	–	–
Rezaeian et al. [35]	Iran (2018)	MB	38.7	16.2		13.7	8.7	7.5	1.2	–	–	5	3.7	2.5	2.5
		DB	98.7	–	–	–	1.2	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Razumova et al. [25]	Russia (2018)	MB	40.2	22.4		37.3	–	–	–	–	–	–	–	–	–
		DB	99.5	0.5	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–

Table 1.
Root canal configurations of maxillary first molar in different populations.

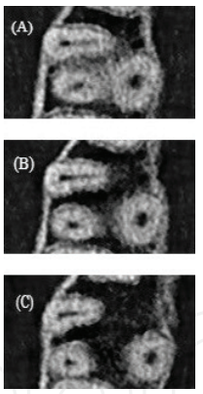

Figure 8.
A case of four canals in maxillary first molar. (A–C) Coronal, middle and apical third: MB1, MB2, DB, P.

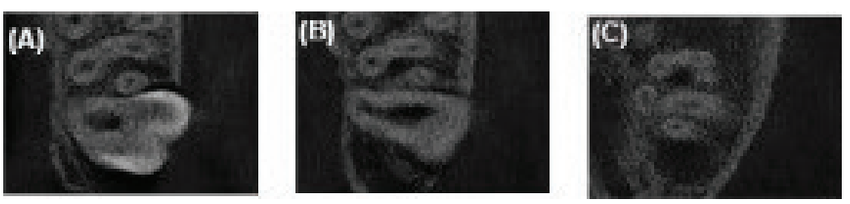

Figure 9.
A case of root fusion (MB + P) of maxillary second molar (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

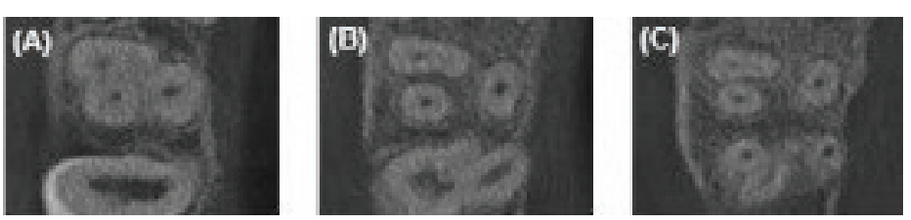

Figure 10.
A case of four canals in the coronal, middle and apical third of the maxillary second molar (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

[39]. Root canal morphology of this tooth varies among population and races. The most common root canal morphology of three-rooted second molar is four canals (MB1, MB2, DB, and P) (**Figure 10**). The incidence of MB2 ranged from 11.53 to 93.7% [40], in Russia—51.5%[41], and in Portugal—44% [30]. MB2 is located mostly 1 mm from the orifice of the mesiobuccal canal [39]. Root canal configuration of MB is so complex; type I (1-1) is common in MB root, followed by type II (2-1). Other types of root canal configurations were observed in some population like India, Portugal, and China [20, 30, 31]. Clinicians should pay attention to the presence of MB2 during endodontic treatment to avoid failure. The shape of the root canal in MB root could be ribbon-shaped when two canals exist or oval when just one canal (**Figure 11**).

For DB and P roots, they have one canal in most cases. Two canals in DB root were observed in some studies, and the prevalence of DB2 ranges from 0.6 to 4% [40]. Its orifice is located near the DB1. The most common root canal configuration in these roots is type 1 (1-1) (**Table 2**). The root canal shape of these roots is mostly round.

For one-, two-, and four-rooted maxillary second molars, type 1 (1-1) is mostly common [31]. **Table 2** presents the root canal configurations of three-rooted maxillary second molars in recent studies in different countries [20, 30–35, 42–44].

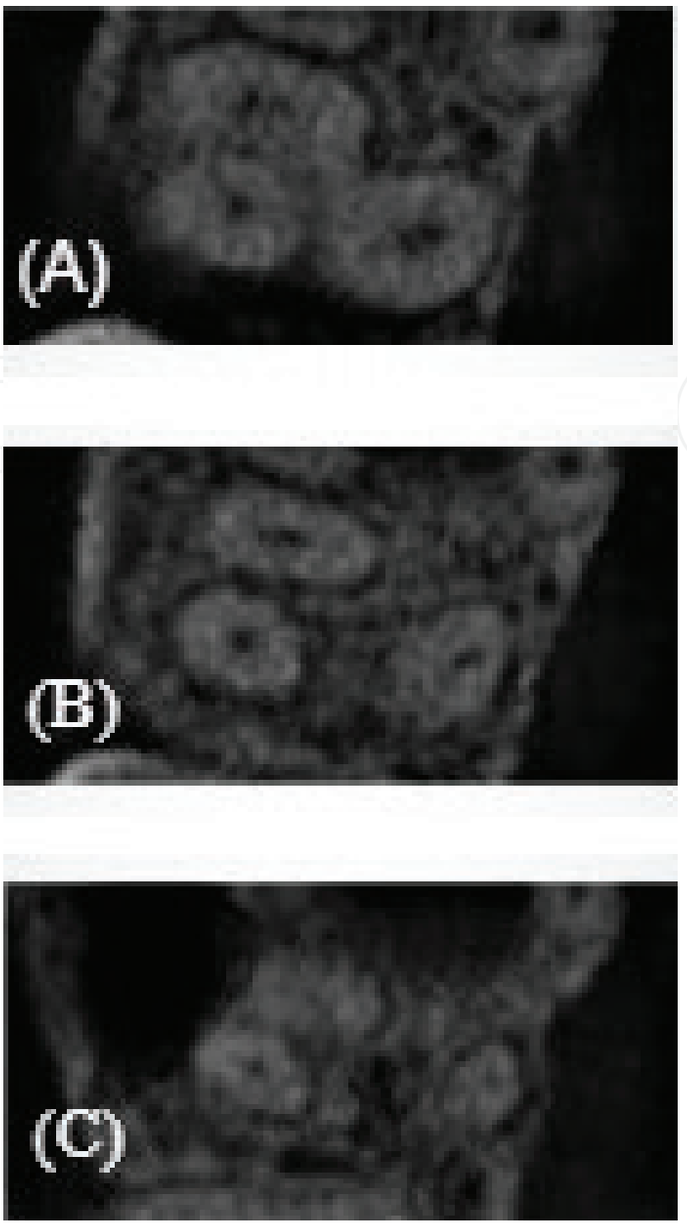

Figure 11.
Three canals of maxillary second molar. The shape of MB canal is oval while the shape of DB is round (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

3.3 Maxillary third molar

It is also known as wisdom tooth and generally erupts between the ages of 17 and 25 years old. The anatomy of the maxillary third molar is unpredictable and varies among populations, even in individuals in same populations [45–47]. A few studies were conducted to analyze the anatomy and root canal morphology of this tooth. It may have from one to five roots. Root fusion is common in this tooth, whereas Alavi et al. reported root fusion from 2 to 26.5% in Thai population [45]. Ahmad et al. found root fusion in 70% in Jordan population [46]. The fusion of three roots was the most common form. Regarding the number of root canals, it varies per root and generally ranges from one to six canals (**Figure 12**) [47]. **Table 3** shows the number of roots and root canals of maxillary third molar among different populations [41, 42, 45–51]. The most common root canal configuration for maxillary third molar is type I (1-1) followed by type II (2-1) (**Table 4**) [42, 47, 50, 51]. The incidence of C-shaped canals in this tooth was reported in two studies: in the USA (2.2%) [45] and in China (8.5%) [51]. The shape of the root canal in the coronal, middle, and

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-3)	Type (2-1-3)	type (3-1)	Type (3-2-1)	Type (2-1-2-1)
Weng et al. [41]	China (2009)	MB	82	8	–	6	4	–	–	–	–	–	–	–
		DB	92	2	–	–	6	–	–	–	–	–	–	–
		P	94	–	6	–	–	–	–	–	–	–	–	–
Neelakantan et al. [31]	India	MB	62	6.3		24.4	–	–	–	–	–	–	–	0.5
		DB	84.9	1.5	2.4	4.4	–	–	–	–	–	–	–	–
		P	87.8	–	–	3.4	0.9	–	–	0.5	–	0.5	–	–
Martins et al. [30]	Portugal (2017)	MB	56.2	27.1	0.7	7.6	3.4	4.2	0.2	–	–	–	0.2	0.4
		DB	100	–	–	–	–	–	–	–	–	–	–	–
		P	98.8	0.4	0.7	–	–	–	–	–	–	–	–	–
Tian et al. [20]	China (2016)	MB	70.3	12.9	5.3	6.8	3	0.4	0.3	0.1			0.9	
		DB	99.5	0.2	–	0.1	0.2	–	–	–	–	–	–	–
		P	99.7	0.2	0.1	–	–	–	–	–	–	–	–	–
Kalender et al. [42]	Turkey (2016)	MB	76.1	20.8	–	2.8	–	–	–	0.3	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–
Ghobashy et al. [32]	Egypt (2017)	MB	42.06	47.1	–	8.03	1.87	0.93	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–
Pérez-Heredia et al. [33]	Spain (2017)	MB	52.7	33	–	9.8	–	2.7	–	0.9	0.9	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-3)	Type (2-1-3)	type (3-1)	Type (3-2-1)	Type (2-1-2-1)
Ratanajirasut et al. [34]	Thailand (2018)	MB	70.6	14.6	2.3	7.5	3.5	1.5	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–
		P	99.7	0.3	–	–	–	–	–	–	–	–	–	–
Naseri et al. [43]	Iran (2018)	MB	23.5	18.5	3.2	11.5	7.6	26.8	–	–	–	–	–	–
		DB	94.3	–	0.6	–	3.8	1.3	–	–	–	–	–	–
		P	93.6	–	0.6	–	4.5	1.3	–	–	–	–	–	–

Table 2.
Root canal configurations of maxillary second molars in different populations.

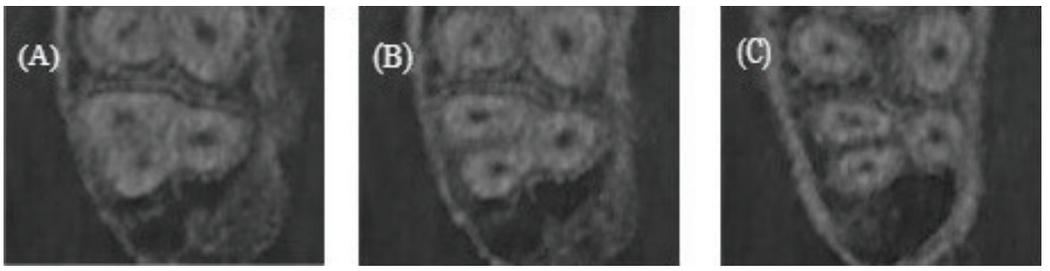

Figure 12.
Maxillary third molar with three roots and four canals (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

apical thirds varies per root such as, when the third molar has one root with one canal from the orifice to the apex, the shape of the canal may be oval or long oval in all parts (**Figure 13**). If the one-rooted tooth has two canals, the shape of the canal could be like a ribbon, type I, II, IV, or V by Kim et al. (**Figure 14**). A clinician should pay attention to the root canal shape when preparing and filling the root canal.

4. Root canal morphology of mandibular molars

4.1 Mandibular first molar

This tooth is the most common tooth exposed to caries and frequently requires root canal treatment. It has two roots in the most common form (mesial and distal); occasionally, it has three roots. The mesial root is characterized by a flattened mesiodistal surface and widened buccolingual surface. The distal root is mostly straight. The morphology of mandibular first molar has been investigated in different studies among different populations. The incidence of three-rooted teeth has been reported in some populations: Korea (25.8%) [51], Spain (4.1%) [33], and Turkey (3.6%) [52]; this third root is mostly located distolingually, and it is smaller than the distobuccal root. Root canal system varies from two canals to four canals. The incidence of four canals was reported in some races: in Russia (20.9%) [40], Turkey (15.3%) [52], Spain (52.9%) [33], and Korea (24.3%) (**Figure 15**) [51]. The fourth canal is usually located in the distal root. The mesial root has two separated canals in about 90% of cases (type IV), and in 10 % the two canals are joined into one canal at the apex (type II), while the distal root usually contains one straight oval canal (type I) (**Figure 16**). The incidence of C-shaped root canal is low in this tooth and about 2% [60] (**Table 5** shows the root canal configurations for mandibular first molar in recent studies [30, 33, 51–59]).

4.2 Mandibular second molar

This tooth is similar to the mandibular first molar. Usually, it has two roots (mesial and distal), although it may have one or three roots. The extra root is usually located lingually. The incidence of three-rooted teeth was found in some populations: in Chinese (1.27%) [59], Indian (7.5%) [61], Turkish (0.4%) [52], Spain (6.25%) [33], and Korean (1.1%) [62]. The prevalence of one-rooted mandibular second molar was observed in Russia (0.5%) [40], Spain (16.5%) [33], and Turkey (1.6%) [52]. The most frequent root canal system is three canals (two mesial and one distal) (**Figure 17**). The prevalence of three canals in various populations was in Russia (82.2%) [40], Turkey (86.4%) [52], India (53.5%) [61], and Spain (81.25%) [33]. The mesial root usually has two canals that tend to lie much closer together. The most common root canal configurations in the mesial root are type II

Author(s)	Country (year)	Type of study	Number of teeth	Number of roots				Number of canals					
				1	2	3	4	1	2	3	4	5	6
Sidow et al. [44]	USA (2000)	Clearing	150	15	32	45	7	7.4	3.3	57.3	27.3	2.7	0.7
Ng et al. [48]	Burmese (2001)	Clearing	72	19.4	19.4	55.6	5.6	5.6	25	47.2	22.2	–	–
Alavi et al. [45]	Thai (2002)	Clearing	151	1.3	6.6	88.1	4	9.9	11.3	48.3	29.1	1.3	–
Weng et al. [41]	China (2009)	Clearing	43	–	–	–	–	27.9	11.6	44.2	16.3	–	–
Sert et al. [49]	Turkey (2011)	Clearing	290	35.5	28.6	34.1	1.7	12.4	29.7	46.9	11	–	–
Cosić et al. [47]	Croatia (2013)	Sectioning	56	8.9	5.4	83.9	1.8	7.1	7.1	75	10.8	–	–
Ahmad et al. [46]	Jordan (2016)	Clearing	89	13.5	5.6	74.2	6.7	9	6.7	55.1	27	2.2	–
Zhang et al. [50]	China (2018)	Micro KT	130	51.5	19.2	25.4	3.8	–	–	–	–	–	–
Razumova et al. [40]	Russia (2018)	CBCT	238	47.9	–	52.1	–	13.8	11.8	72.3	2.1	–	–

Table 3.
Number of roots and root canals of maxillary third molars in different populations.

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (3-3)	Type (1-2-3)	Type (1-3)	Type (3-2-1)	Type (1-3-2)	Type (3-2)	Type (3-1)
Weng et al. [41]	China (2009) (HAN)	Single	63.2	21	–	–	–	5.3	10.5	–	–	–	–	–	–
		MB	62.5	20.8	4.2	8.3	4.2	–	–	–	–	–	–	–	–
		DB	87.5	–	4.2	–	8.3	–	–	–	–	–	–	–	–
		P	91.6	–	4.2	–	4.2	–	–	–	–	–	–	–	–
Sert et al. [49]	Turkey (2011)	Single	63.1	12.3	7	12.2	3.5	–	–	–	–	–	–	–	1.75
		MB	77.8	13.1	–	5.1	4	–	–	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Ahmad et al. [46]	Jordan (2016)	Single	66.8	–	8.3	–	8.3	8.3	–	–	8.3	–	–	–	–
		MB	55	5	–	20	15	–	–	5	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	100	–	–	–	–	–	–	–	–	–	–	–	–
Zhang et al. [50]	China (2018)	Single	51.4	12.8	5.7	1.4	12.8	–	–	–	1.4	5.7	1.4	1.4	1.4
		MB	72.7	–	–	12.1	12.1	–	3	–	–	–	–	–	–
		DB	100	–	–	–	–	–	–	–	–	–	–	–	–
		P	93.9	–	–	6.1	–	–	–	–	–	–	–	–	–

Table 4.
Root canal configuration of maxillary third molar in different populations.

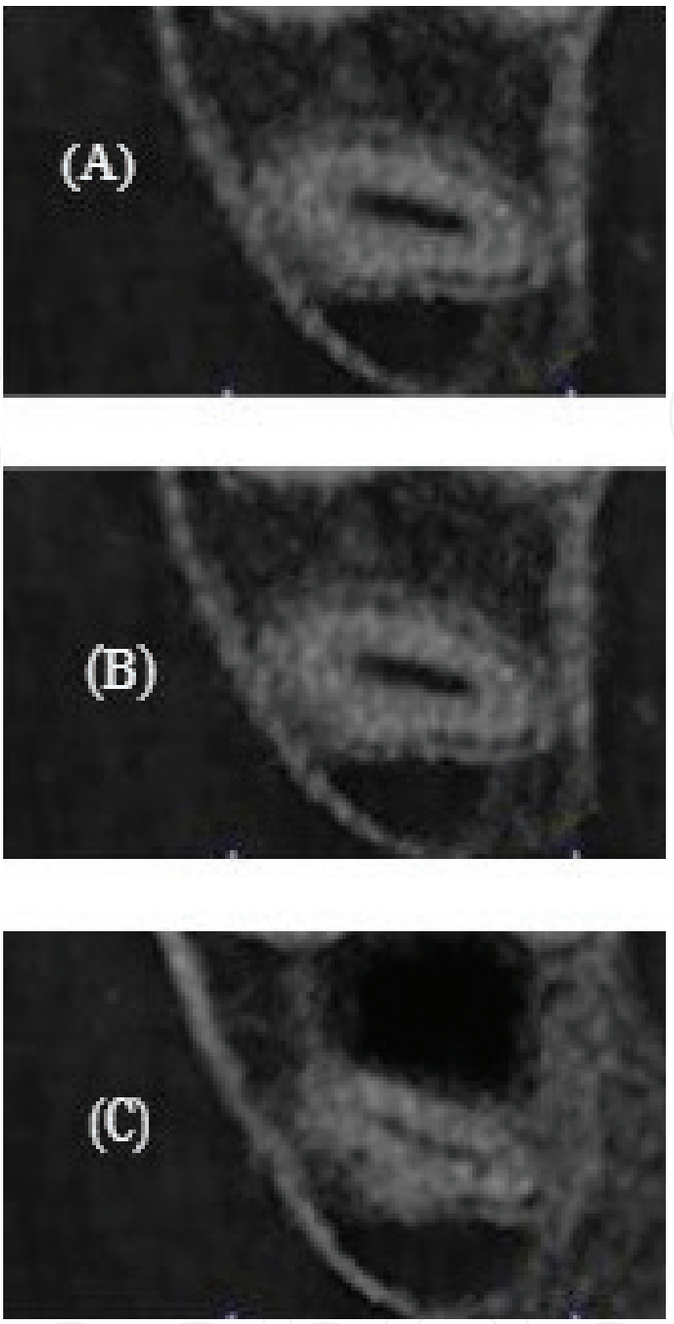

Figure 13.
Maxillary third molar with one root and one long oval canal (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

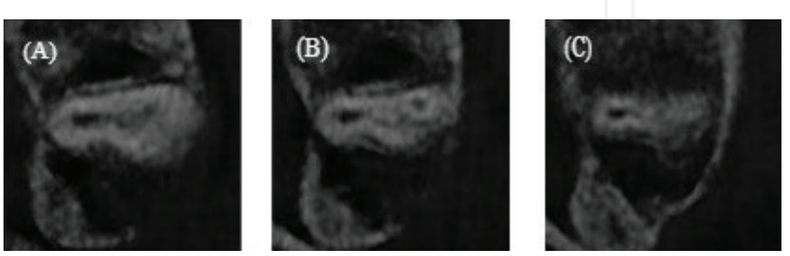

Figure 14.
Maxillary third molar with one root and two canals (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

(2-1) and type IV (2-2) (**Table 6**). The distal root has one straight canal with type I (1-1), and the incidence of two canals is less and ranged from 3.5 to 20% [61]. The incidence of C-shaped root canals is higher in this tooth than the other teeth

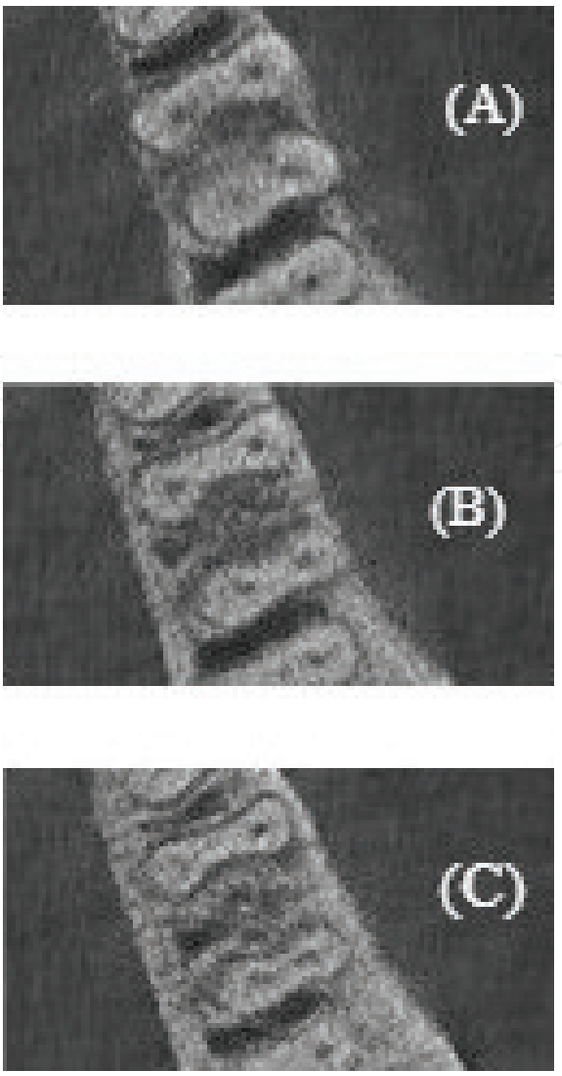

Figure 15.
Mandibular first molar with four canals (two mesial and two distal) (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

(**Figure 18**). Several studies have reported the C-shaped canals among various populations: India (13.12%) [61], Korea (40%) [62], Brazil (3.5–15.3%) [63, 64], China (29–39%) [59, 65, 66], Russia (8.5%) [67], Saudi Arabia (9.1%) [60], and Jordan (21.6%) [16]. This variation could be related to ethnic groups. Regarding the root canal shape, mesial roots tend to have ribbon-shape type I or V by Kim et al., and the distal root canal in most cases has an oval shape and round in some cases (**Figure 19**). **Table 6** represents the root canal configurations of two-rooted mandibular second molars.

4.3 Mandibular third molar

This tooth erupts between the ages of 17 and 25 years old. It has morphological radicular variations. Many dental treatment plans work on maintaining this tooth to use it as a strategic abutment when the first and second molars are missed, especially when there is sufficient room in the dental arch. Frequently, it has two roots (mesial and distal). A few studies in various populations found that mandibular third molar could have from one to four roots (**Figures 20** and **21**), which could be related to genetics and race differences; as in Croatia and China, one-rooted third molar was reported in 56% [47] and 48% [50] of cases, respectively (**Figure 22**) (**Table 7**). The root canal system of this tooth is unpredictable;

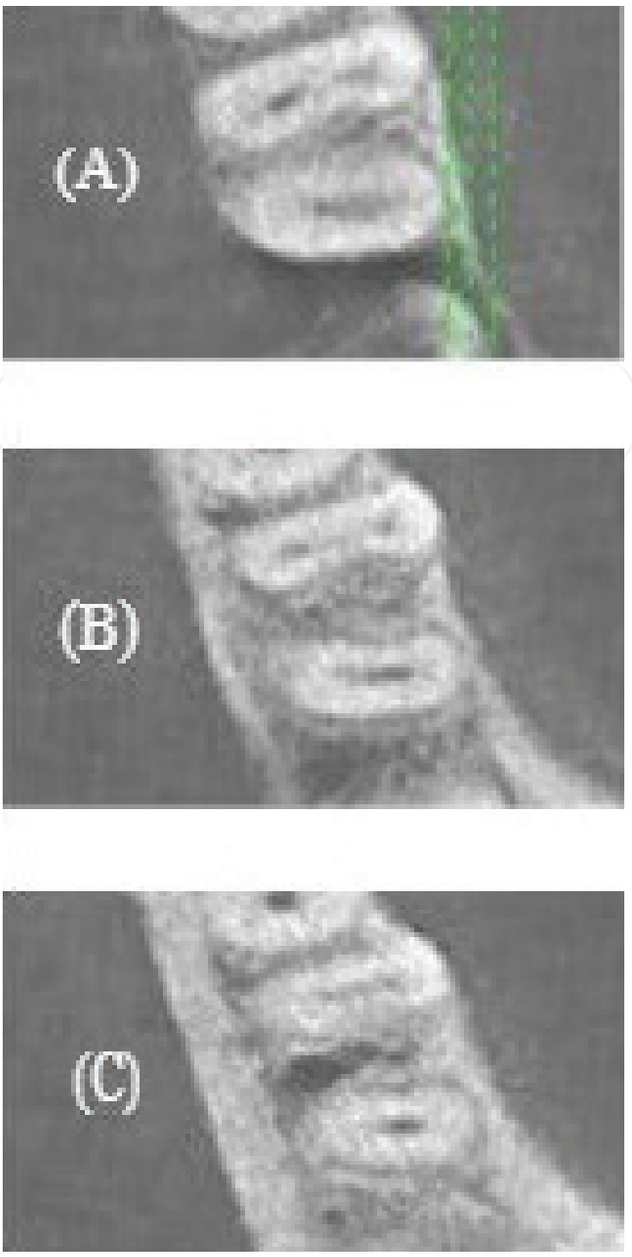

Figure 16.
Mandibular first molar with three canals (two mesial and one distal) the mesial canals shape have the ribbon type I by Kim, while the distal canal shape is long oval (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

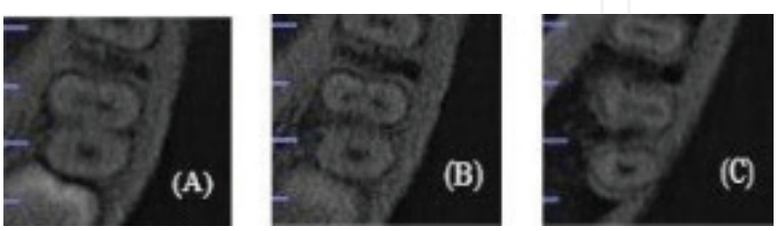

Figure 17.
Mandibular second molar with three canals (two mesial + one distal) (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

it could have from one to six canals [44]. The most common form is to have three canals (two mesial canals and one distal canal). **Table 7** presents the root and canal number in different populations. Regarding root canal configurations, type (1-1) prevailed mostly in mesial and distal roots of two-rooted teeth and in

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (2-3-1)	Type (2-1-2-1)	Type (3-2)	Type (2-3-2)	Type (3-2-1)	Type (1-2-1-2-1)
Chourasia et al. [52]	India (2012)	M	–	36.6	–	54	0.6	8	0.6	–	–	–	–	–	–
		D	65.3	20.6	1.3	9.3	3.3	–	–	–	–	–	–	–	–
Muriithi et al. [54]	Kenya (2012)	M	3.3	7.9	–	87.3	–	1.1	–	–	–	–	–	–	–
		D	50.3	18.5	1.6	22.2	5.3	–	–	–	–	–	–	–	–
Kim et al. [51]	Korea (2013)	M	1.8	20.2	0.3	76.9	0.5	–	–	–	–	0.1	0.2	–	–
		D	66.6	19	0.3	11.8	2.1	–	–	–	–	–	–	–	–
Zhang et al. [59]	China (2015)	M	0.9	5.6	4.8	87.7	0.9	–	–	–	–	–	–	–	–
		D	65.9	2.4	0.3	9.2	–	–	–	–	–	–	–	–	–
Torres et al. [56]	Chile 2015	M	2.9	19	28.5	21.9	21.9	21.9	3.6	–	–	–	–	–	–
		D	78.8	–	12.4	–	5.8	–	2.9	–	–	–	–	–	–
Torres et al. [56]	Belgium (2015)	M	1.4	5	33.6	16.4	42.9	–	0.7	–	–	–	–	–	–
		D	72.9	–	17.1	–	9.3	–	0.7	–	–	–	–	–	–
Celikten et al. [53]	Turkey (2016)	M	2.4	34.9	–	62.7	–	–	–	–	–	–	–	–	–
		D	84	11.8	0.3	3.4	0.3	0.3	–	–	–	–	–	–	–
Madani et al. [57]	Iran (2017)	M	7.3	31.5	2	57	2	–	–	–	–	–	–	–	–
		D	79.8	10.7	4.6	3.3	1.3	–	–	–	–	–	–	–	–
Martins et al. [30]	Portugal (2017)	M	1.1	46.5	–	41.9	–	4.1	–	–	0.9	2.1	0.2	3.2	–
		D	70.9	12.4	9.6	2.3	3.2	0.9	–	–	0.5	–	–	–	0.2
Pérez-Heredia et al. [33]	Spain (2017)	M	–	51.3	–	37.8	0.8	1.7	–	1.7	–	5.9	–	–	–
		D	72.3	18.5	5.9	2.5	–	–	–	–	–	–	0.8	–	–

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (2-3-1)	Type (2-1-2-1)	Type (3-2)	Type (2-3-2)	Type (3-2-1)	Type (1-2-1-2-1)
Gambarini et al. [58]	West Europe (2018)	M		41		59									
		D	100	–	–	–	–	–	–	–	–	–	–	–	–

Table 5.
Root canal configurations of mandibular first molars in different populations.

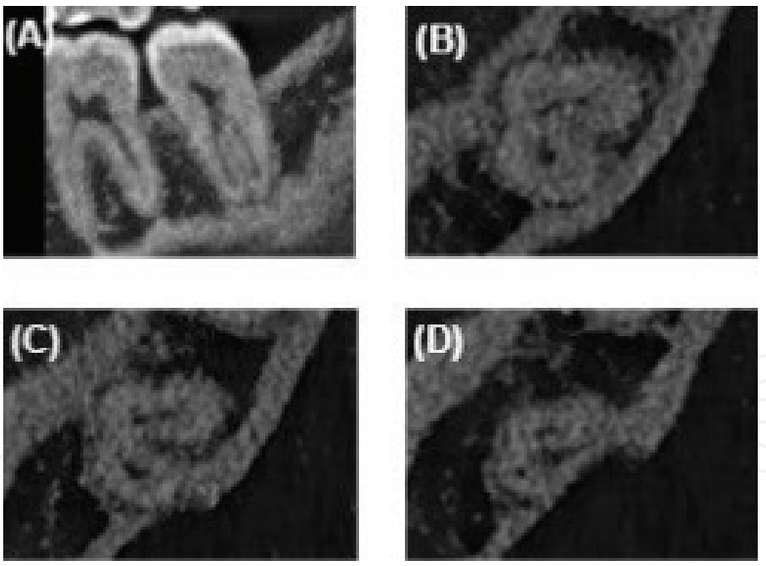

Figure 18.
Mandibular second molar with C-shaped canal (A) Sagittal view of mandibular second molar, (B) coronal third of root canals, (C) middle third of root canal, (D) apical third of root canals.

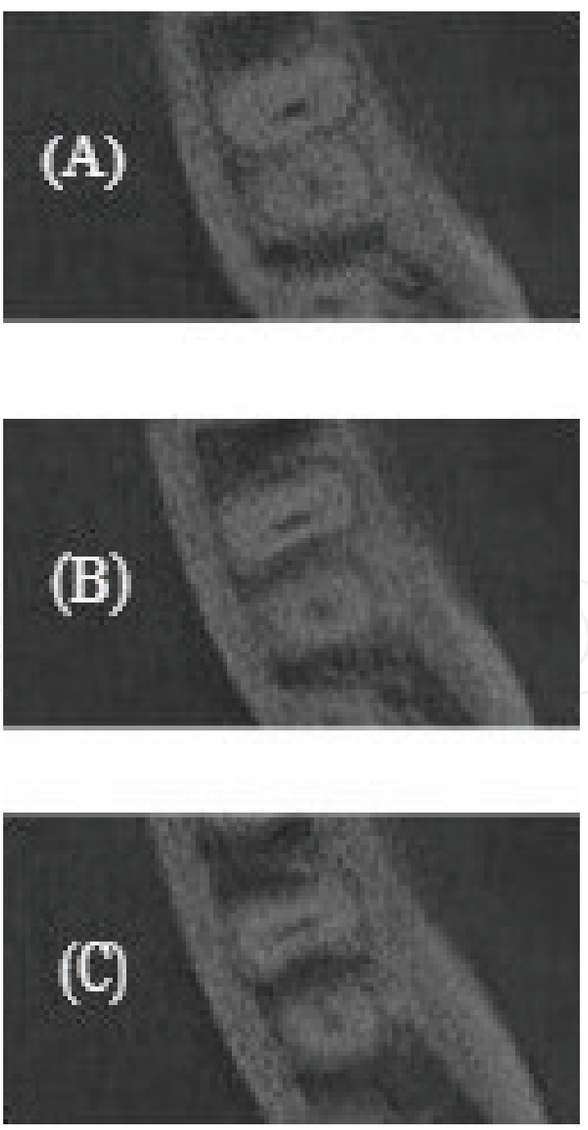

Figure 19.
Mandibular second molar two canals (one oval mesial + one round distal) (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-1)	Type (2-1-2-1)	Type (3-2)	Type (2-3-2-1)	Type (3-2-1)	Type (3-2-3-2-1)
Al-Qudah and Awawdeh [16]	Jordan (2009)	M	16.1	32.6	3.5	40.3	3.5	1	0.3	–	–	0.3	–	0.3	–
		D	79	7.7	2.6	4.5	5.5	–	–	–	–	–	–	–	–
Neelakantan et al. [68]	India (2010)	M	8.4	2	1.4	63.1	5.2	–	–	2	–	1.1	–	–	–
		D	64.9	4.6	0.6	11	1.7	–	–	–	–	–	–	–	–
Ceperuelo et al. [69]	Spain (2014)	M	12.5	56.2	18.7	–	6.2	–	–	–	–	–	–	–	–
		D	81.2	6.2	–	6.2	–	–	–	–	–	–	–	–	–
Torres et al. [56]	Chile (2015)	M	17.5	7.2	48.4	4.1	20.6	–	2.1	–	–	–	–	–	–
		D	99	–	–	–	1	–	–	–	–	–	–	–	–
Torres et al. [56]	Belgium (2015)	M	11.7	5.3	37.2	14.9	28.78	–	2.13	–	–	–	–	–	–
		D	98.4	–	–	–	1.06	–	–	–	–	–	–	–	–
Celikten et al. [52]	Turkey (2016)	M	7.1	32.3	0.2	60.3	–	–	–	–	–	–	–	–	–
		D	96.3	2.5	–	1	–	0.2	–	–	–	–	–	–	–
Kim et al. [62]	Korea (2016)	M	13.9	37.7	1.2	44.5	2.6	–	–	–	–	–	–	–	–
		D	96.6	2.1	–	0.9	0.4	–	–	–	–	–	–	–	–
Pérez-Heredia et al. [33]	Spain (2017)	M	3	78.2	–	14.9	1	–	–	1	–	2	–	–	–
		D	92.1	2	3	3	–	–	–	–	–	–	–	–	–
Martins et al. [30]	Portugal (2017)	M	8.1	63.9	5.2	18.1	0.5	1.6	–	–	0.4	0.2	0.4	1.4	0.2
		D	93.5	0.5	4.2	0.4	1.4	–	–	–	–	–	–	–	–
Madani et al. [57]	Iran (2017)	M	18.1	28	5.7	42.9	3.3	0.8	–	–	–	–	–	–	–
		D	91.7	3.3	0.8	1.6	1.6	–	–	–	–	–	–	–	–

Author(s)	Country (year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (1-2-1-2)	Type (3-1)	Type (2-1-2-1)	Type (3-2)	Type (2-3-2-1)	Type (3-2-1)	Type (3-2-3-2-1)
Pawar et al. [61]	India (2017)	M	7.2	32.5	0.9	45.2	1	–	–	–	–	–	–	–	–
		D	61.1	18.2	–	7.5	–	–	–	–	–	–	–	–	–

Table 6.
Root canal configurations of mandibular second molars in different populations.

Author(s)	Country (year)	Type of study	Number of teeth	Number of roots				Number of canals					
				1	2	3	4	1	2	3	4	5	6
Sidow et al. [44]	USA (2000)	Clearing	150	17	77	5	1	7.3	16.7	55.3	16.7	3.3	0.7
Gulabivala et al. [13]	Burmese (2001)	Clearing	58	–	100	–	–	1.7	51.7	44.8	1.7	–	–
Gulabivala et al. [70]	Thai (2002)	Clearing	173	11.6	86.7	21.2	0.6	6.4	64.1	28.3	5.2	–	–
Sert et al. [49]	Turkey (2011)	Clearing	370	24.9	69.5	5.4	0.3	10.8	52.7	17.3	18.6	0.5	–
Kuzekanani et al. [71]	Iran (2012)	Clearing	150	21.4	72.6	5.3	0.7	10	52	32.7	5.3	–	–
Cosić et al. [47]	Croatia (2013)	Sectioning	50	56	44	–	–	4	6	90	–	–	–
Ahmad et al. [46]	Jordan (2016)	Clearing	70	14.3	74.3	8.6	2.9	7.1	38.6	45.7	8.6	–	–
Zhang et al. [50]	China (2018)	Micro KT	130	47.7	46.1	5.4	0.8	–	–	–	–	–	–
Razumova et al. [40]	Russia (2018)	CBCT	210	20	80	–	–	0.5	40.9	58.6	–	–	–

Table 7.
The number of roots and root canals of mandibular third molars in different populations.

Author(s)	Country (Year)	Root	Type (1-1)	Type (2-1)	Type (1-2-1)	Type (2-2)	Type (1-2)	Type (2-1-2)	Type (3-3)
Sert et al. [49]	Turkey (2011)	Single	65.6	14.7	–	9.8	9.8	–	–
		Mesial	59	24.2	2.7	9.8	3.9	–	–
		Distal	99.2	0.8	–	–	–	–	–
Kuzekanani et al. [71]	Iran (2012)	Single	31.2	21.9	9.4	25	3.1	–	3.1
		Mesial	54.1	17.4	13.8	3.7	7.4	–	–
		Distal	92.7	1.8	2.7	–	–	–	–
Ahmad et al. [46]	Jordan (2016)	Single	55.6	22.2	11.1	–	–	11.1	–
		Mesial	40.6	18.8	3.1	28.1	9.4	–	–
		Distal	93.8	–	–	3.1	3.1	–	–
Zhang et al. [50]	China (2018)	Single	42.7	3.6	–	2.4	2.4	–	–
		Mesial	68.3	5	8.3	3.3	11.7	–	–
		Distal	100	–	–	–	–	–	–

Table 8.
Root canal configuration of maxillary third molar in different populations.

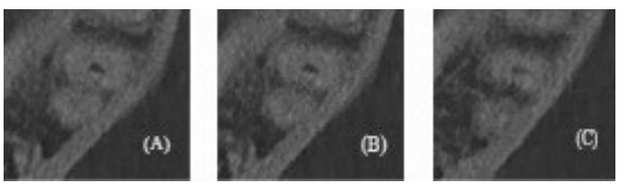

Figure 20.
Mandibular third molar with two roots and two canals(A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

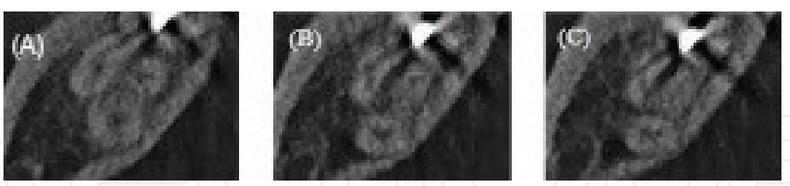

Figure 21.
Mandibular third molar with three roots and three canals(A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

Figure 22.
Mandibular third molar with one root and two canals(A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

single-rooted third molars (**Table 8**) [46, 49, 50, 71]. The incidence of C-shaped canals was reported in Thailand (11%) [70], Iran (3.3%) [71], and China (3.3%) (**Figure 23**) [50]. Root canal shape of mandibular third molar varies per root.

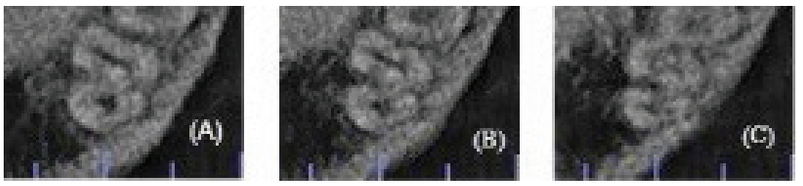

Figure 23.
Mandibular third molar with C-shaped canal (A) coronal third of root canals, (B) middle third of root canal, (C) apical third of root canals.

5. Conclusion

This chapter summarized the root canal system of the maxillary and mandibular molars in different populations. Root canal system of the molar teeth is so complex and unpredictable. It varies among populations and even in individuals in same population. The maxillary first and second molars have in the most common form three roots with four canals. The maxillary third molar may have from one to five roots with different numbers of canals ranging from one to six canals. Mandibular molars in the most common form have two roots with three canals. C-shaped canals are mostly common in mandibular second molars. Clinicians should pay attention to the additional canals and additional configurations when preparing for the root canal treatment, since knowledge of the basic root and root canal morphology as well as possible variation in anatomy of the root canal system is an important factor to achieve successful root canal treatment.

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