Root Anatomy and Canal Configuration of the Permanent Mandibular First Molar: A Systematic Review

Óliver Valencia de Pablo, DDS, Roberto Estevez, DDS,* Manuel Péix Sánchez, DDS,† Carlos Heilborn, DDS,‡ and Nestor Cohenca, DDS§*

Abstract

Introduction: The main goal of endodontic therapy is to prevent or heal apical periodontitis. However, root canal anatomy might present a clinical challenge directly related to the treatment outcome. The purpose of this study was to review published literature related to root anatomy and root canal configuration of the permanent mandibular first molar. **Methods:** An exhaustive search was undertaken to identify published literature related to the root anatomy and root canal morphology of the permanent mandibular first molar by using key words. The search of the MEDLINE database included all publications from 1966–May 2010. Selected articles were then obtained and reviewed. Data evaluated and summarized in the data sheet included methodology, population, number of teeth per study (power), number of root canals, type of root canal configuration, and identification of number of apical foramina. **Results:** Forty-one studies were identified including a total of 18,781 teeth. The incidence of a third root was 13% and was strongly correlated with the ethnicity of the studied population. Three canals were present in 61.3%, 4 canals in 35.7%, and 5 canals in approximately 1%. Root canal configuration of the mesial root revealed 2 canals in 94.4% and 3 canals in 2.3%. The most common canal system configuration was Vertucci type IV (52.3%), followed by type II (35%). Root canal configuration of the distal root revealed type I configuration in 62.7%, followed by types II (14.5%) and IV (12.4%). The presence of isthmus communications averaged 54.8% on the mesial and 20.2% on the distal root. **Conclusions:** The number of roots on the mandibular first molar is directly related to ethnicity. Root canal morphology and configuration might present the clinician with a complex anatomy requiring more diagnostic approaches, access modifications, and clinical skills to successfully localize, negotiate, disinfect, and seal the root canal system. *(J Endod 2010;36:1919–1931)*

Key Words

Mandibular first molar, root canal anatomy, root canal morphology, systematic review

The main goal of endodontic therapy is to prevent or heal apical periodontitis. From a biomechanical perspective this means cleaning, shaping, and disinfection that would allow for three-dimensional obturation of the root canal system (1, 2). However, the complexity of the root canal anatomy presents clinical challenges and difficulties that often jeopardize the primary goal of such therapy (3, 4). Knowledge of both normal and abnormal anatomy dictates the parameters of root canal therapy and can directly affect the probability of success (5). Thus, like for any surgical procedure, endodontic therapy should be preceded by a thorough knowledge of pulp chamber and root canal anatomy. Once this complex anatomy has been accessed, the outcome is directly related to the elimination and prevention of microbial contamination (6).

The mandibular first molar typically presents with 2 well-defined roots, a mesial root characterized by a flattened mesiodistal surface and widened buccolingual surface, and a distal root mostly straight with a wide oval canal or 2 round canals (7). The most relevant variable related to the number of roots is the presence of a third distolingual root, which incidence has been linked to specific ethnic groups (8). The morphology and buccolingual width of the mesial root allow for intercanal communications and isthmuses. Currently, the isthmus (anastomosis) is defined as a pulpal passageway connecting 2 or more canals in the same root (9). In 1997 Hsu and Kim (10) classified isthmus configurations, with type V being the most frequent among mesial roots of mandibular molars. Type V is recognized as a true connection or wide corridor of tissue between the 2 main canals.

Root canal morphology and configuration have been classified by Weine et al (11), Pineda and Kuttler (12), and Vertucci (13). Fig. 1 presents Vertucci's original classification and its modifications as reported in the literature (13–18).

Several methodologies have been used to study the root canal system configuration of the first mandibular molar. They include plastic resin injection (7), endodontic access and radiographs with files into root canals (12), retrospective evaluation of radiographs (19), clearing of samples with and without ink injection (15, 20), sectioning and macroscopic or scanning electron microscopy (SEM) evaluation (21, 22), computed tomography (CT) (21), spiral computed tomography (SCT) (23), micro–computed tomography (mCT) (24), and cone-beam computed tomography (CBCT) (25). Study design differences and the various origins of the investigated teeth could account for the highly variable results. Besides the possible third root, mesial and distal roots with 3 root canals or mandibular first molars with 5, 6, or even 7 canals have been reported (26, 27). The purpose of this study was to perform a systematic review of

From the *Department of Endodontics, Universidad Europea de Madrid, Madrid, España; †Department of Endodontics, Universidad de Salamanca, Salamanca, España; ‡Department of Endodontics, Universidad del Pacífico, Asunción, Paraguay; and §Department of Endodontics, School of Dentistry, University of Washington, Seattle, Washington.

Address requests for reprints to Dr Nestor Cohenca, Department of Endodontics, University of Washington, Box 357448, Seattle, WA 98195-7448. E-mail address: cohenca@u.washington.edu.

0099-2399/$ - see front matter

Published by Elsevier Inc. on behalf of the American Association of Endodontists.

doi:10.1016/j.joen.2010.08.055

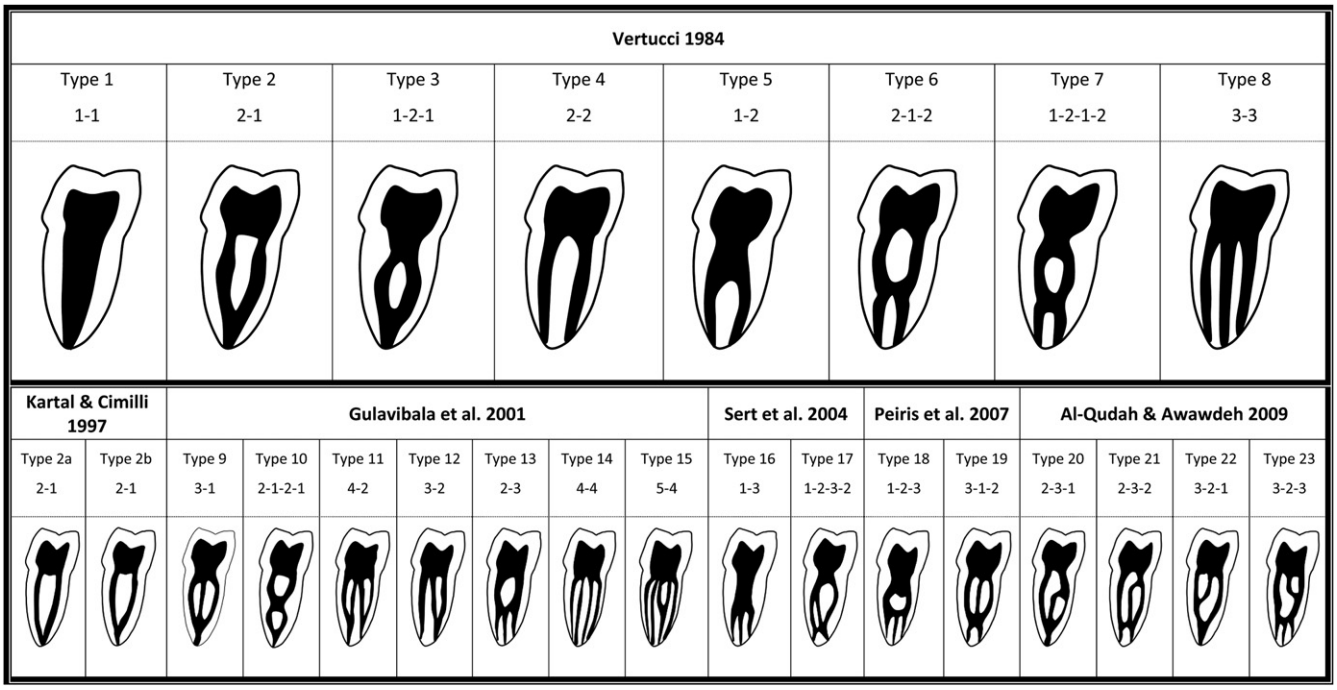

Figure 1. Mandibular first molar: root configuration reported in the literature.

the literature related to the root anatomy and root canal configuration of the permanent mandibular first molar.

Materials and Methods

Literature Search and Data Extraction

An exhaustive search was undertaken to identify published literature related to the root anatomy and root canal morphology of the permanent mandibular first molar. The MEDLINE database was searched via the PubMed search engine http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed (last accessed on May 25, 2010) by using the following search criteria: mandibular first molars, root anatomy, root canal morphology, number of canals and mesial root, root canal system configuration and mesial root, root canal system configuration and distal root, number of canals and distal root. The search included all years from 1966–May 2010. A similar search strategy was also applied by the Cochrane Database and manual searches, including journals, conference proceedings, reference lists, other reviews, and unpublished studies. No language restriction was applied to the search. Titles and abstracts were evaluated, and the relevance of each study to the anatomy and morphology of the mandibular first molar was determined. The full texts of the selected articles were then obtained and reviewed. Data extracted included methodology, population, number of teeth per study (power), number of root canals, type of root canal configuration, and number of apical foramina that were identified and included in the data sheet.

Results

The numbers of roots and root canals are presented in Table 1. Overall, 41 studies were identified including a total of 18,781 teeth (7, 8, 15, 17, 18, 20, 22, 28–60). The vast majority of teeth in these studies reported the presence of 2 roots. The incidence of a third root was 13% and was strongly correlated with the ethnicity of the studied population. The presence of a third root was higher among Asians, Mongolians, and Eskimos. The incidence of 4 roots was very rare and was only reported in 3 case reports (61–63).

The number of root canals in the mandibular first molar is summarized in Table 1. Eighteen studies were identified including 4745 teeth (7, 18, 22, 32, 33, 36–40, 51, 57, 60, 64–68). Three canals were present in 61.3%, 4 canals in 35.7%, and 5 canals in about 1% of the total number of cases.

Table 2 displays configuration and number of canals on the mesial root (6, 7, 12, 13, 15, 16, 18, 19, 31, 32, 36–38, 51, 54, 58, 69). Overall, 17 studies were included, accounting for 4535 mesial roots. Two canals were present in 94.4% of the cases, and 3 canals were present in 2.3% of the mesial roots studied. Root canal system configuration and number of apical foramina are also reported in Table 2 (7, 12–18, 20, 22, 31–33, 36–39, 54, 57, 58, 69–76). The most common canal system configuration was type IV with 52.3%, followed by type II with 35%. Fifty-nine percent had 2 separate foramina, 38.2% had 1 foramen, and 1.6% had 3 foramina. Further analysis of the mesial roots with 3 canals by using Vertucci's modified classification is reported in Table 3 (6, 13, 15, 16, 32, 36, 51, 54, 58, 69–71, 75, 77–81).

The analysis of the distal root included 22 studies and 3378 roots (Table 4) (7, 12, 13, 15–18, 20, 31–33, 36–39, 51, 57, 58, 69, 71, 74, 76). The most common root canal system configuration was type I with 62.7%, followed by types II with 14.5% and IV with 12.4%.

The presence of communications (isthmuses type V) within the mesial and distal roots was also analyzed (Table 5) (13, 15–18, 20, 36, 70, 73, 75, 76, 82–85). Fifteen studies and 1615 teeth were included. The presence of isthmus communications averaged 54.8% in the mesial root and 20.2% in the distal root.

In addition to research articles, 38 case reports were reviewed (Table 6) (6, 21, 26, 27, 51, 61–63, 77–79, 86–115). Clinical case reports included 84 mandibular first molars and described diverse anatomical configurations.

TABLE 1. Mandibular First Molar: Number of Roots and Canals

Author/year	Materials & methods	Population	Total no. of teeth	3 roots %	% of canals		
					3	4	5
Three-dimensional evaluation technique							
Gu et al/2010	*In vitro* (extracted teeth)	Chinese (Jiangsu)	122	32% (39)			
Huang et al/2010	*In vivo* (CBCT)	Taiwanese (Taiwan)	237	25.3% (60)	56.1% (133)	40.5% (96)	0
Song et al/2010	*In vivo* (CT)	Korean (Korea)	3,088	24.5% (756)			
Al-Qudah and Awawdeh/2009	*In vitro* (extracted teeth)	Jordanian (Jordan)	330	3.9% (13)	48.2% (160)	45.8% (151)	5.5% (18)
Chen et al/2009	*In vitro* (extracted teeth)	Taiwanese (Taiwan)	183	19.7% (36)	50.8% (93)	45.9% (84)	0
Rwenyonyi et al/2009	*In vitro* (extracted teeth)	African (Uganda)	224	0			
Chen et al/2009	*In vitro* (extracted teeth)	Taiwanese (Taiwan)	293	9.9% (29)			
Tu et al/2009	*In vivo* (CBCT)	Taiwanese (Taiwan)	246	25.6% (63)			
Reuben et al/2008	*In vitro* (SCT)	Hindu	125		85.5% (107)	6.4% (8)	0
Ahmed et al/2007	*In vitro* (extracted teeth)	Sudanese (Sudan)	100	3% (3)			
Peiris et al/2007	*In vitro* (extracted teeth)	Srilanker (Sri Lanka)	100	3% (3)			
Gulavibala et al/2002	*In vitro* (extracted teeth)	Thai (Thailand)	118	12.7% (15)	61% (72)	30.5% (41)	3.4% (4)
Gulavibala et al/2001	*In vitro* (extracted teeth)	Burmese (Burma)	139	10.1% (14)			
Zaatar et al/1998	*In vitro* (extracted teeth)	Kuwaiti (Kuwait)	49	0			
Sperber and Moreau/1998	*In vitro* (extracted teeth)	African (Senegal)	480	3.1% (15)	75% (360)	25% (120)	0
Zaatar et al/1998	*In vitro* (clearing technique)	Kuwait	49	0	67.3% (33)	26.5% (13)	0
Rocha et al/1996	*In vitro* (extracted teeth)	Unspecified (Brazil)	232	5.2% (12)	72.4% (144)	21.1% (42)	0
Loh/1990	*In vitro* (extracted teeth)	Malay (Singapore)	304	7.9% (24)			
Younes et al/1990	*In vitro* (extracted teeth)	African (Egypt)	457	0.7% (3)			
Younes et al/1990	*In vitro* (extracted teeth)	Asian (Saudi Arabia)	385	2.3% (9)			
Onda et al/1989	*In vitro* (extracted teeth)	Hindu (Caucasians living in Japan)	198	1% (2)			
Walker/1988	*In vitro* (extracted teeth)	Chinese (Hong Kong)	100	15% (15)			
Reichart and Metah/1981	*In vitro* (extracted teeth)	Thai (Thailand)	364	19.2% (70)			
Hochstetter/1975	*In vitro* (extracted teeth)	Unspecified (Guam)	400	13% (52)			
Curzon/1973	*In vitro* (extracted teeth)	English Caucasian (England)	390	3.3% (13)			
Curzon/1971	*In vitro* (extracted teeth)	Mongoloid Keewatin Eskimo (Canada)	98	27% (26)			
Skidmore and Bjorndahl/1971	*In vitro* (extracted teeth)	Caucasian (USA)	45	2.2% (1)	64.4% (29)	28.9% (13)	0
Tratman/1938	*In vitro* (extracted teeth)	Chinese (Singapore)	1,615	5.8% (94)			
	In vitro (extracted teeth)	Malay (Singapore)	475	8.6% (41)			
	In vitro (extracted teeth)	Japanese (Singapore)	110	10.9% (12)			
	In vitro (extracted teeth)	Hindu (Singapore)	453	0.2% (1)			
	In vitro (extracted teeth)	Japanese (Singapore)	168	1.2% (2)			
	In vitro (extracted teeth)	Eurasian (Singapore)	262	4.2% (11)			
Number of teeth			11,765				
Incidence of 3 roots				12.2% (1434)			
Number of teeth with 3 or more canals			1,766				
Incidence					64% (1131)	32.2% (568)	1.2% (22)

(*Continued*)

TABLE 1. (*Continued*)

Author/year	Materials & methods	Population	Total no. of teeth	3 roots %	% of canals		
					3	4	5
Two-dimensional evaluation technique							
Schäfer et al/2009	*In vivo* (periapical radiographs)	German (Germany)	1,024	0.7% (7)			
Song et al/2009	*In vivo* (periapical radiographs)	Korean (Korea)	1,304	33.1% (431)			
Pattanshetti et al/2008	*In vivo* (clinical evaluation + radiographs)	Kuwaiti and non-Kuwaiti (Filipino, Indonesian, Hindu, Srilanker, Egyptian, and Syrian)	110	3.6% (4)	53.6% (59)	46.4% (51)	0
Furri et al/2007	*In vivo* (periapical radiographs)	Unspecified	231		53.7% (124)	43% (99)	0.4% (1)
Huang et al/2007	*In vivo* (periapical radiographs)	Taiwanese (Taiwan)	332	21.7% (72)			
Tu et al/2007	*In vivo* (periapical radiographs)	Taiwanese (Taiwan)	332	17.8% (59)			
Al-Nazhan/1999	*In vivo* (periapical radiographs)	Saudi (Saudi Arabia)	251	6% (15)	42.2% (106)	57.8% (145)	0
Zaatar et al/1997	*In vivo* (periapical radiographs)	Kuwaití (Kuwait)	147	2.7% (4)	69.4% (102)	29.9% (44)	0
Suárez-Feito/1995	*In vivo* (periapical radiographs)	Spanish (Asturias)	198		72.2% (143)	26.3% (52)	1% (2)
Yew and Chan/1993	*In vivo* (periapical radiographs)	Chinese (Taiwan)	832	21.5% (179)	62.5% (520)	31.5% (262)	0
Ferraz and Pecora/1992	*In vivo* (periapical radiographs)	Caucasian (Brazil)	117	4.2% (5)			
	In vivo (periapical radiographs)	African (Brazil)	106	2.8% (3)			
	In vivo (periapical radiographs)	Japanese (Brazil)	105	11.4% (12)			
Steelman/1986	*In vivo* (periapical radiographs)	Hispanic (West Dallas)	156	6.4% (10)			
Fabra Campos/1985	*In vivo* (clinical evaluation + radiographs)	Unspecified (Spain)	145	0	50.3% (73)	47.6% (69)	2.1% (3)
Walker and Quakenbush/1985	*In vivo* (bite-wing radiographs)	Chinese (Hong Kong)	426	11.7% (50)			
Fabra Campos/1983	*In vivo* (clinical evaluation + radiographs)	Unspecified	219		46.6% (102)	49.3% (108)	4.1% (9)
Hartwell and Bellizzi/1982	*In vivo* (periapical radiographs)	Unspecified	846		64.8% (548)	35.1% (297)	0
Curzon/1974	*In vivo* (periapical radiographs)	Baffin Eskimo (Canada)	69	21.7% (15)			
de Souza Freitas et al/1971	*In vivo* (periapical radiographs)	Japanese (Brazil)	466	17.8% (83)			
	In vivo (periapical radiographs)	Caucasian (Brazil)	844	3.2% (27)			
Somogy-Csizmazia and Simmons/1971	*In vivo* (periapical radiographs)	Canadian, Alberta Indian (Mongoloid)	250	16% (40)			

(*Continued*)

TABLE 1. (*Continued*)

Author/year	Materials & methods	Population	Total no. of teeth	3 roots %	% of canals		
					3	4	5
Number of teeth			7,016				
Incidence of 3 roots				14.5% (1016)			
Number of teeth with 3 or more canals			2,979				
Incidence					59.7% (1777)	37.8% (1127)	0.5% (15)
Overall total number of teeth			18,781				
Overall incidence of 3 roots				13% (2,450)			
Overall total number of teeth with 3 or more canals			4,745				
Overall incidence					61.3% (2,908)	35.7% (1,695)	0.8% (37)

Discussion

The available literature related to root anatomy and root canal configuration of the permanent mandibular first molar varies significantly particularly in regard to the methodology used for evaluation. The number of roots has been the most common feature reported. Studies concur that ethnicity is a predisposing factor for anatomical variations such as number of roots, but they failed to demonstrate any direct relationship between ethnicity and configuration of the root canal system. The Mongoloid population exhibited significantly more mandibular first molars with 3 roots, with a 3:1 ratio when compared with Caucasians and African Americans. This variation could be considered a genetically determined characteristic (52). An overview at the global map (Fig. 2) clearly demonstrates a positive correlation between the incidence of a third root and ethnicity directly related to the geographical location of specific populations.

Brazil presents a unique variability because of the coexistence of multiple ethnicities. Ferraz and Pécora (41) reported the presence of a third root in 2.8% of African Americans, 4.2% of Caucasians, and 11.4% of Japanese descendants. Seven studies analyzed specifically the presence of a third root in Taiwan's population and determined the incidence of a third root to be greater than 20% (28, 32, 34, 35, 40, 56, 60). Only 1 study by Chen et al (32) reported an incidence of 9.9%. Most of the literature concurs that the presence of a third root is an expected anatomical characteristic of Mongoloid, Native American, Eskimo, and Chinese populations. The genetic component is reflected in its dominance in mixed populations of Eskimos and Caucasians, maintaining an elevated incidence ratio. All these observations suggest that the third root could be gene-related. Besides genetics, external factors during odontogenesis could also play a role in the extra root development (30). To date, only a few studies have reported the number of canals in the mandibular first molars as well as the canal system configuration. Studies reported in Table 3 present the total number of canals without analyzing the number of canals and configuration on each root.

When comparing methodologies, clearing was the predominant *in vitro* technique, although more contemporary studies used three-dimensional imaging systems. Retrospective observation of endodontically treated teeth by using two-dimensional periapical radiographs was found to be the most common *in vivo* technique. However, critical variables among studies were observed. When considering cases evaluated by trained endodontists (6, 33, 65), the incidence of 2 distal canals was close to 50%. This might indicate that experienced endodontists are able to identify more difficult anatomy during procedures and could explain the differences in success outcomes. Recently, Corcoran et al (116) reported that operator experience improved the ability to locate and fill additional canals in maxillary first and second molars. The use of a dental operating microscope has proved to be another important aid because it has helped tremendously in locating additional canals (117, 118).

Most classic literature articles describe the presence of 2 canals in the mesial root (3, 7, 12, 66), although the first evidence of an independent third mesial canal with its own access orifice and apical foramen was described by Vertucci and Williams (119) and by Barker et al (120). Later, Pomeranz et al (81) presented a comprehensive *in vivo* study describing its incidence and clinical management. In 1982 Weine (111) published a case of a third independent mesial root in a mandibular first molar that was located during endodontic retreatment. Thus, failing to locate and properly treat this canal could lead to endodontic treatment failure. Since then a number of articles reported the presence of a mesio-central or middle mesial canal with up to 14.8% incidence (21). Other anatomical anomalies described

TABLE 2. Mesial Root Canal System: Configuration and Number of Canals

Author/year	Materials and methods	Number of teeth	Type II	Type IV	Type VIII
Three-dimensional evaluation technique					
Gu et al/2010	*In vitro* (mCT)	45	11.1% (5)	64.4% (29)	2.2% (1)
Arora and Tewari/2009	*In vitro* (microscope 40×)	100	—	—	—
Al-Qudah and Awawdeh/2009	*In vitro* (clearing technique)	330	36% (119)	52.7% (174)	0.3% (1)
Chen et al/2009	*In vitro* (clearing technique)	183	29.5% (54)	55.2% (101)	5.5% (10)
Rwenyonyi et al/2009	*In vitro* (clearing technique)	224	13.8% (31)	44.6% (100)	0
Peiris et al/2008	*In vitro* (clearing technique)	177	24.9% (44)	60.5% (107)	1.1% (2)
Ahmed et al/2007	*In vitro* (clearing technique)	100	14% (14)	73% (73)	2% (2)
Peiris et al/2007	*In vitro* (clearing technique)	100	20% (29)	44% (44)	1% (1)
Sert et al/2004	*In vitro* (clearing technique)	200	44% (88)	43% (86)	1.5% (3)
Marroquin et al/2004	*In vitro* (microscope 40×)	286	—	—	—
Villegas et al/2004	*In vitro* (clearing technique)	63	52.4% (33)	34.9% (22)	4.8% (3)
Gulavibala et al/2002	*In vitro* (clearing technique)	118	21.2% (25)	50.8% (60)	1.7% (2)
Gulavibala et al/2001	*In vitro* (clearing technique)	139	28.8% (40)	38.1% (53)	0.7% (10)
Wasti et al/2001	*In vitro* (clearing technique)	30	23.3% (7)	66.7% (20)	3.3% (1)
Seperber and Moreau/1998	*In vitro* (sections)	480	16% (77)	84% (403)	0
Zaatar et al/1998	*In vitro* (Duralay)	49	57.1% (28)	34.7% (17)	0
Rocha et al/1996	*In vitro* (clearing technique)	199	47.3% (94)	45.2% (90)	0
Çalişcan et al/1995	*In vitro* (clearing technique)	100	37.3% (37)	44.1 (44)	3.4 (3)
Vertucci/1984	*In vitro* (clearing technique)	100	28% (28)	43% (43)	1% (1)
Skidmore and Bjorndal/1971	*In vitro* (plastic cast)	45	33.3% (15)	60% (27)	0
Number of teeth for canal system configuration		2,682			
Incidence			28.6% (768)	55.7% (1493)	1.5% (40)
Number of teeth for number of foramina		3,068			
Incidence					
Number of mesial roots for number of canals		1,414			
Incidence					
Two-dimensional evaluation technique					
Pattanshetti et al/2008	*In vivo* (clinical evaluation + radiographs)	110	74.5% (82)	25.5% (28)	0
Cimilli et al/2006	*In vitro* (radiographs with files)	102	52.9% (54)	47.1% (48)	0
Jung et al/2005	*In vitro* (radiographs with files)	42	47.6% (20)	47.6% (20)	0
Al-Nazhan/1999	*In vivo* (PA radiographs)	251	52.6% (132)	47.4% (119)	0
Kartal and Cimilli/1997	*In vitro* (radiographs with files)	697	40.7 (284)	53.7% (374)	0
Zaatar et al/1997	*In vivo* (PA radiographs)	147	56.5% (83)	42.9% (63)	0
Fabra-Campos/1989	*In vivo* (PA radiographs)	760			
Walker/1988	*In vitro* (radiographs)	100	—	—	1% (1)
Fabra Campos/1985	*In vivo* (PA radiographs)	145			
Martínez-Berna and Badanelli/1983	*In vivo* (PA radiographs)	1418			
Pineda and Kuttler/1972	*In vitro* (radiographs M-D & B-L)	300	30.3% (91)	40.3% (121)	0
Number of teeth for canal system configuration		1,649			
Incidence			42.7% (746)	44.2% (773)	0.1% (1)
Number of teeth for number of foramina		1,749			
Incidence					
Number of mesial roots for number of canals		3,121			
Incidence					
Overall number of teeth for canal configuration		4,331			
Incidence			35% (1,514)	52.3% (2,266)	0.9% (41)
Overall number of teeth for number of foramina		4,817			
Incidence					
Overall number of mesial roots for number of canals		4,535			
Incidence					

PA, periapical; M-D, mesiodistal; B-L, buccolingual.

in the mandibular first molar include cases with 7 canals (27), 4 roots (61–63), and C-shaped canals (105, 108).

Susin et al (121) demonstrated that one of the most difficult clinical challenges remains the cleaning and disinfection of root canal intercommunications and isthmuses. As described in Table 5, incidence of type V isthmuses in mandibular first molars ranges from 23%–77.4% in the mesial root and 8%–55% in the distal root. In a clinical study with endoscopic evaluation during periradicular surgery, von Arx (83) reported an overall presence of isthmuses in 83% of mesial roots (from which 29% were type V) and 36% of distal roots (from which 21% were type V). Therefore, the presence of these communications should be considered the norm rather than the exception. Because mechanical instrumentation of these areas is unfeasible, our efforts should concentrate on efficient delivery and activation of irrigants to achieve proper disinfection. Failure to access, debride, and disinfect this complex anatomy might have a direct effect on the treatment outcome.

Conclusions

1. The number of roots in the mandibular first molar is directly related to ethnicity of the populations studied. In the Mongoloid, Native

% of apical foramina			% of number of canals		
1	2	3	1	2	3
Three-dimensional evaluation technique					
20% (9)	77.8% (35)	2.2% (1)	8.9%(4)	88.9%(40)	2.2%(1)
33% (33)	46% (46)	16% (16)			
39.1% (129)	58.5% (193)	2.4% (8)	0.9% (3)	93% (307)	6% (20)
31.7% (58)	68.3% (125)	0	3.3% (6)	91.3% (167)	5.5% (10)
46.9% (105)	53.1% (119)	0	27.2% (61)	72.8% (163)	0
31.1% (55)	65% (115)	2.2% (4)			
17% (17)	71% (71)	11% (11)			
27% (27)	64% (64)	9% (9)			
51% (102)	47.5% (95)	1.5% (3)	2% (4)	96.5% (193)	1.5% (3)
12.9% (37)	87.1% (249)	0			
58.7% (37)	36.5% (23)	4.8% (3)			
35.6% (42)	60.2% (71)	3.4% (4)	3.4% (4)	89.8% (106)	6.8% (8)
42.4% (59)	50.4% (70)	7.2% (10)	4.3% (6)	84.9% (118)	10.8% (15)
23.3% (7)	73.3% (22)	3.3% (1)	0	96.7% (29)	3.3% (1)
16% (77)	84% (403)	0			
63.3% (31)	36.7% (18)	0			
54.8% (109)	45.2 (90)	0			
39% (39)	57.6% (57)	3.4% (3)			
40% (40)	59% (59)	1% (1)	12% (12)	87% (87)	1% (1)
40% (18)	60% (27)	0	6.7% (3)	93.3% (42)	0
33.6% (1031)	63.6% (1952)	2.4% (74)			
			0.7% (103)	88.5%(1252)	4.2% (59)
Two-dimensional evaluation technique					
74.5% (82)	25.5% (28)	0			
52.9% (54)	47.1% (48)	0			
52.4 (22)	47.6% (20)	0			
52.6% (132)	47.4% (119)	0	0	100% (251)	0
40.7% (284)	59.3 (374)	0			
57.1% (84)	42.9% (63)	0	2.7% (4)	97.3% (143)	0
			0	97.4% (740)	2.6% (20)
24% (24)	75% (75)	1% (1)	3% (3)	96% (96)	1% (1)
			0	97.2% (141)	2.8% (4)
			0	98.5% (1397)	1.5% (21)
43% (129)	57% (171)	0	12.8% (38)	87.2% (262)	0
46.3% (811)	51.3% (898)	0.1% (1)			
			1.4% (45)	97.1% (3030)	1.5% (46)
38.2% (1,842)	59.2% (2,850)	1.6% (75)			
			3.3% (148)	94.4% (4282)	2.3% (105)

American, Eskimo, and Chinese population, the presence of a third root should be considered a normal anatomical variation.

2. The mesial root usually presents with 2 canals. Types IV and II are the most common configurations. The presence of a third canal, known as middle mesial, was found to have an incidence of 2.6%. Several authors suggest modifications of the access preparation to enhance the diagnosis and exposure of this canal.
3. The most common root canal configuration in the distal root is type I with 62.7%, followed by type II with 14.5% and type IV with 12.4%.
4. The presence of root canal isthmuses averages 55% in the mesial root and 20% in the distal root. This anatomical canal configuration should be considered during nonsurgical and surgical endodontic procedures.

TABLE 3. Root Canal Configuration of Mesial Roots with 3 Canals

Author/year	N°	Root canal configuration									
		3-3	3-1	3-2	3-2-1	3-2-3	3-4	2-3	2-3-1	2-3-2	1-2-3-2
Gu et al/2010	1	1									
Arora and Tewari/2009	20	1	2	4	1	2		5	2	3	
Yu et al/2006	1										1
Sert et al/2004	6	3									3
Villegas et al/2004	3	3									
Mortman and Sunghee/2003	5	2	1	2							
Gulabivala et al/2002	7	2	2	1			1	1			
Gulabivala et al/2001	15	1	3	2				9			
Wasti et al/2001	1	1									
Çalişcan et al/1995	3	3									
Jacobsen et al/1994	3	1		2							
Fabra Campos/1989	20	1		19							
Walker/1988	1	1									
Fabra Campos/1985	4		1	3							
Vertucci/1984	1	1									
Martínez-Berná and Badanelli/1983	25*	1	4	20							
Pomeranz et al/1981	2	1		1							
Total number of mesial roots	128	33	13	54	1	2	1	15	2	3	4
Incidence		25.8%	10.2%	42.2%	0.8%	1.8%	0.8%	11.7%	1.6%	2.3%	3.1%

*First and second mandibular permanent molars.

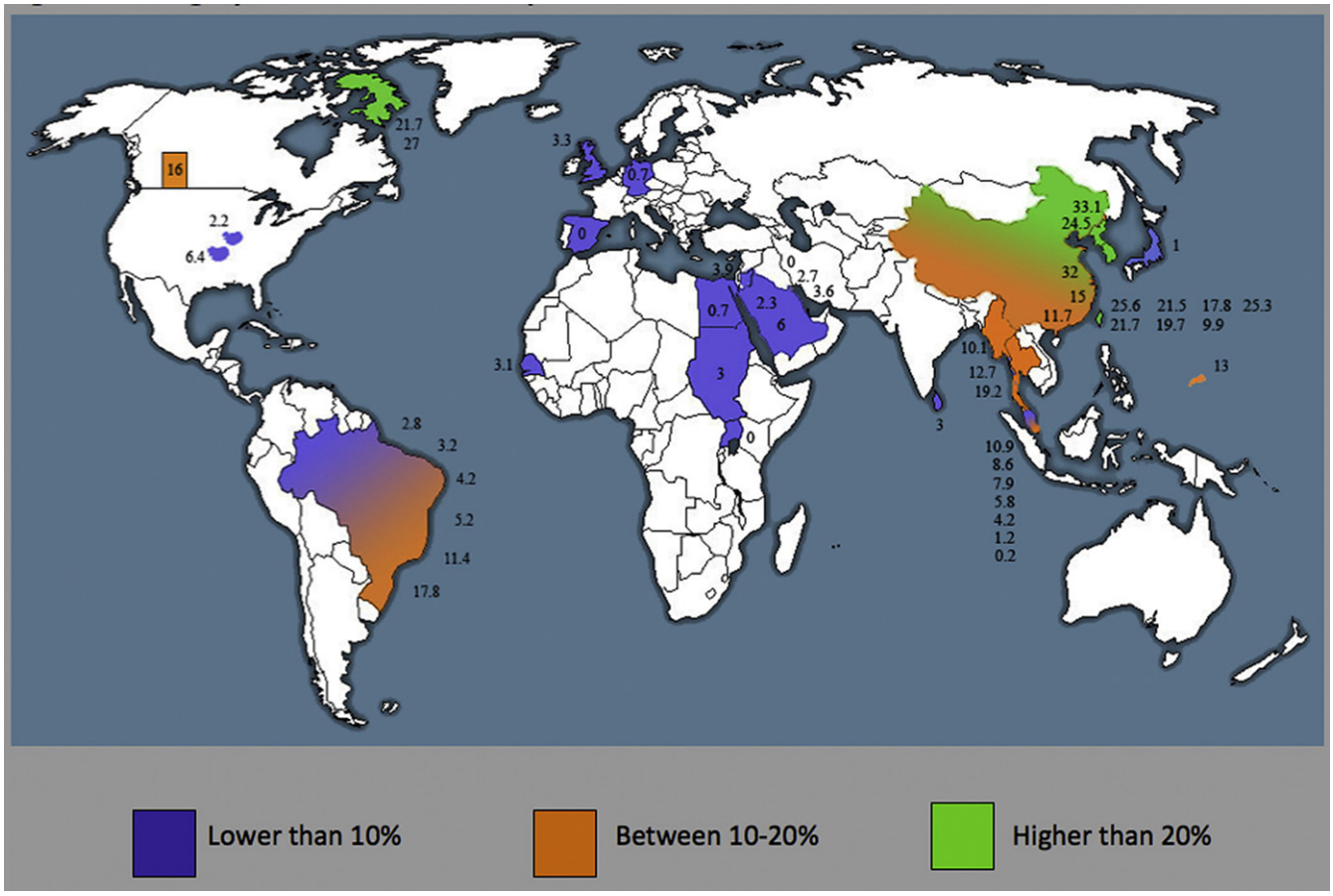

Figure 2. Geographic incidence of presence of a third root in the mandibular first molar. (This figure is available in color online at www.aae.org/joe/.)

TABLE 4. Distal Root Canal System Configuration

Author/year	Materials and methods	Number of teeth	Type I	Type II	Type IV	% of foramina 1	% of foramina 2
Three-dimensional evaluation technique							
Gu et al/2010	*In vitro* (mCT)	45	82.2% (37)	2.2% (1)	2.2% (1)	93.3% (42)	6.7% (3)
Arora and Tewari/2009	*In vitro* (microscope 40×)	100	—	—	—	75% (75)	22% (22)
Al-Qudah and Awawdeh/2009	*In vitro* (clearing technique)	330	54.2% (179)	17% (56)	9.4% (31)	77% (254)	22.1% (73)
Chen et al/2009	*In vitro* (clearing technique)	183	54.1% (99)	12.6% (23)	25.1% (46)	67.2% (123)	32.8% (60)
Rwenyonyi et al/2009	*In vitro* (clearing technique)	224	84.8% (190)	1.3% (3)	9.4% (21)	87.1% (195)	12.9% (29)
Peiris et al/2008	*In vitro* (clearing technique)	177	71.8% (127)	1.1% (2)	7.9% (14)	79.7% (141)	19.7% (35)
Ahmed et al/2007	*In vitro* (clearing technique)	100	38% (38)	28% (28)	22% (22)	65% (65)	31% (31)
Peiris et al/2007	*In vitro* (clearing technique)	100	70% (70)	1% (1)	0	85% (85)	14% (14)
Marroquin et al/2004	*In vitro* (stereomicroscope)	286	—	—	—	39.5% (113)	60.5% (173)
Sert et al/2004	*In vitro* (clearing technique)	200	53.5% (107)	12.5% (25)	9.5% (19)	87% (174)	12% (24)
Gulavibala et al/2002	*In vitro* (clearing technique)	118	61% (72)	4.2% (5)	15.3% (18)	77% (92)	17.8% (21)
Gulavibala et al/2001	*In vitro* (clearing technique)	139	66.2% (92)	15.8% (22)	10.1% (14)	84.2% (117)	15.1% (21)
Wasti et al/2001	*In vitro* (clearing technique)	30	30% (9)	26.7% (8)	20% (6)	56.7% (17)	43.3% (13)
Zaatar et al/1998	*In vitro* (Duralay)	49	75.5% (37)	8.2% (4)	16.3% (8)	83.7% (41)	16.3% (8)
Rocha/1996	*In vitro* (clearing technique)	199	78.9% (157)	11.6% (23)	9.5% (19)	90.5% (180)	9.5% (19)
Vertucci/1984	*In vitro* (clearing technique)	100	70% (70)	15% (15)	5% (5)	85% (85)	15% (15)
Skidmore and Bjorndal/1971	*In vitro* (plastic cast)	45	71.1% (32)	17.8% (8)	8.9% (5)	88.9% (40)	8.9% (5)
Total number of distal roots for canal system configuration		2,039					
Incidence			64.5% (1316)	11% (224)	11.2% (229)		
Total number of distal roots for foramina		2,425					
Incidence						75.8% (1839)	23.3% (566)
Two-dimensional evaluation technique							
Pattanshetti et al/2008	*In vivo* (clinical evaluation + radiographs)	110	52.7% (58)	24.5% (27)	19.1% (21)	76.4% (84)	23.6% (26)
Al-Nazhan/1999	*In vivo* (periapical radiographs)	251	42.2% (106)	35.1% (88)	22.7% (57)	77.3% (194)	22.7% (57)
Zaatar et al/1997	*In vivo* (periapical radiographs)	147	70.7% (104)	12.9% (19)	16.3% (24)	83.7% (123)	16.3% (24)
Fabra Campos/1985	*In vivo* (periapical radiographs)	145	50.3% (73)	26.2% (38)	20.7% (30)	76.6% (111)	23.4% (34)
Pineda and Kuttler/1972	*In vitro* (radiographs M-D and B-L)	300	73% (219)	12.7% (38)	3.7% (11)	85.7% (257)	14.3% (43)
Total number of distal roots for canal system configuration		953					
Incidence			58.8% (560)	22% (210)	29% (143)		
Total number of distal roots for foramina		953					
Incidence						80.7% (769)	19.3% (184)
Overall total number of distal roots for canal system configuration		2,992					
Incidence			62.7% (1,876)	14.5% (434)	12.4% (372)		
Overall total number of distal roots for foramina		3,378					
Incidence						77.2% (2,608)	22.2% (750)

M-D, mesiodistal; B-L, buccolingual.

TABLE 5. Intracanal Communications: Isthmus Type V

Author/year	Materials and methods	Number of teeth	Mesial root		Distal root	
			% Total	1/3 with higher incidence	% Total	1/3 with higher incidence
Al-Qudah and Awawdeh/2009	*In vitro* (clearing technique)	330	37.3	Middle/apical	13	Middle
Peiris et al/2008	*In vitro* (clearing technique)	177	77.4	All thirds	11.3	Middle
Ahmed et al/2007	*In vitro* (clearing technique)	100	62	—	8	—
Peiris et al/2007	*In vitro* (clearing technique)	100	67	All thirds	12	Middle
Jung et al/2005	*In vitro* (sections)	42	42.5	Middle (4 mm)	-	—
Mannocci et al/2005	*In vitro* (mCT)	20	50.25	Apical (3 mm)	-	—
Von Arx/2005	*In vivo* (endoscopy)	52	29	Middle (4 mm)	-	—
Von Arx/2005	*In vivo* (endoscopy)	28	—	—	21	Middle (4 mm)
Sert et al/2004	*In vitro* (clearing technique)	200	66	Middle/apical	22	Middle
Villegas et al/2004	*In vitro* (clearing technique)	59	75	Middle	-	—
Texeira et al/2003	*In vitro* (sections)	50	23	Middle	-	—
Gulavibala et al/2002	*In vitro* (clearing technique)	139	39.8	(average of middle and distal)		
Gulavibala et al/2001	*In vitro* (clearing technique)	118	51.8	—	10	—
Çalişcan et al/1995	*In vitro* (clearing technique)	100	51	Middle	22	Middle
Vertucci/1984	*In vitro* (clearing technique)	100	63	Middle	55	Middle
Total number of teeth		1,615				
% Total			54.8		20.2	

TABLE 6. Case Reports on Mandibular First Molar Anatomy

Author/year	Materials and methods	Number of teeth	Description
Kottoor et al/2010	*In vivo* (PA radiographs)	1	5 canals. 2 canals in M and 3 in D that merged in 1 foramen.
Faramazi et al/2010	*In vivo* (PA radiographs)	1	3 canals in M, with a broken instrument in ML.
La et al/2010	*In vivo* (PA radiographs + CBCT)	1	3 independent canals in M with 2-3 configuration.
Yesilsoy et al/2009	*In vivo* (PA radiographs)	1	5 canals, 5 foramina. 3 canals in M, 1 in D, 1 in DL.
Chandra et al/2009	*In vivo* SCT	1	5 canals, 4 foramina. 2 canals in M, 3 in D. DM merged with DB.
Barletta et al/2007	*In vivo* (PA radiographs)	1	DL root. 5 canals. 2 M, 2 D, and DL. 5 foramina.
Calberson et al/2007	*In vivo* (PA radiographs)	2	DL root. 4 canals, 4 foramina.
Forner Navarro et al/2007	*In vivo* (PA radiographs)	3	3 canals in M on each molar. Number of foramina not specified.
Ghoddusi et al/2007	*In vivo* (PA radiographs)	1	4 roots, 6 canals, 6 foramina. 1 canal on each M root and on DL, 3 canals on D.
Kontakiotis and Tzanetakis/2007	*In vivo* (PA radiographs)	1	5 canals. 4 on M that merge in 1 foramen, 1 canal on D.
Ashwin and Arathi/2006	*In vivo* (PA radiographs)	2	Taurodontism on both mandibular first molars of the patient.
Lee et al/2006	*In vivo* (PA radiographs) + CT	1	5 canals. 2 M and 1 on each of the 3 D roots.
Plotino et al/2006	*In vitro* mCT	4	4 mandibular first molars with only 1 ribbon-shaped canal on M.
Yu et al/2006	*In vitro* mCT	1	3 canals on M, 2-3-2 configuration.
De Moor et al/2004	*In vivo* (PA radiographs)	4	DL root on each case.
Baugh and Wallace/2004	*In vivo* (PA radiographs)	1	5 canals, 4 foramina. 3 canals on M, 2 foramina. 2 separated canals on D.
Min/2004	*In vivo* (PA radiographs)	1	5 canals, 2 foramina. 3 canals on M with 1 foramen.

(*Continued*)

TABLE 6. (*Continued*)

Author/year	Materials and methods	Number of teeth	Description
Mortman and Sunghee/2003	*In vivo* (PA radiographs)	1	5 canals, 5 foramina. 3 M and 2 D, all independents.
	In vivo (PA radiographs)	1	6 canals. 3 separated canals on M and 3 on D.
	In vivo (PA radiographs)	1	3 canals on M, 2 foramina (MM joins MB).
	In vivo (PA radiographs)	1	5 canals. MM + ML + MB. DB + DL. 2 foramina.
	In vivo (PA radiographs)	1	5 canals. MM + MB and ML, DB + DL. 3 foramina.
Tsesis et al/2003	*In vivo* (PA radiographs)	1	Fusion of mandibular molar with 2 premolars. 5 canals, 3 M through premolar access and 2 D, trough molar access.
Tiku et al/2003	*In vivo* (PA radiographs)	2	Taurodontism on both mandibular first molars of same patient.
Kimura and Matsumoto/2000	*In vivo* (PA radiographs)	1	5 canals, 2 M, 2 D, 1 DL.
Reeh/1998	*In vivo* (PA radiographs)	1	7 canals, 4 M + 3D.
DeGrood and Cunningham/1997	*In vivo* (PA radiographs)	1	5 canals, MM joins ML, 2 independent on D. 4 foramina.
Holtzman/1997	*In vivo* (PA radiographs)	1	5 canals, 3 separated M and 2 merging D. 4 foramina.
Ricucci/1997	*In vivo* (PA radiographs)	1	5 canals, 3 separated M and 2 merging D. 4 foramina.
Prabhu and Munshi/1995	*In vivo* (PA radiographs)	2	Bilateral DL. 4 canals on each mandibular molar.
Jacobsen et al/1994	*In vivo* (PA radiographs)	1	5 canals, MM + MB, ML, DB, and DL.
		1	4 canals, MM + ML, MB, DB, and DL. No data on foramina.
		1	5 separated canals. 3 M and 2 D. 5 foramina.
Fabra Campos/1989	*In vivo* (PA radiographs)	20	20 MM canals. 13 merge on MB, 6 on ML, and 1 separated.
Bond et al/1988	*In vivo* (PA radiographs)	1	5 separated canals. 3 M, 2 D. 5 foramina.
Bolger and Schidler/1988	*In vivo* (PA radiographs) + *in vitro* sections.	1	4 C-shaped canals. C-shape involves DL, DB, and MB. ML separated.
Beatty and Krell/1987	*In vivo* (PA radiographs)	1	5 canals. 3 M, 2D. No data on foramina.
Rice and Gilbert/1987	*In vivo* (PA radiographs)	1	C-shaped, involves MB, ML ends at D.
Barnet/1986	*In vivo* (PA radiographs)	1	C-shaped from MB to D. ML separated.
Friedman et al/1986	*In vivo* (PA radiographs)	1	4 roots, 1 M + 3 D. 5 separated canals: MB, ML, DB, MD, DL.
Quackenbush/1986	*In vivo* (PA radiographs)	2	3 roots, 5 separated canals. Both on same patient.
Beatty and Interian/1985	*In vivo* (PA radiographs)	1	5 separated canals. 2 M, 2 D, DL.
Martínez Berna and Badanelli/1985	*In vivo* (PA radiographs)	1	6 canals. 3 separated on M, DM merges with DL, DB separated. 5 foramina.
	In vivo (PA radiographs)	1	6 canals. 3 separated M, 3 merging D. 4 foramina.
Fabra Campos/1985	*In vivo* (PA radiographs)	1	5 canals. MM merges on ML. 2 separated D. 4 foramina.
	In vivo (PA radiographs)	2	5 canals. MM merges on MB. DB and DL merge. 3 foramina.
	In vivo (PA radiographs)	1	4 canals. MM merges on MB, 1 D. 3 foramina.
Stroner et al/1984	*In vivo* (PA radiographs)	1	3 roots. 5 canals: MB, ML, DB, DL. DL root with 1 canal. 5 foramina.
Weine/1982	*In vivo* (PA radiographs)	1	3 M canals with 1 foramen. 1 D canal.
Mena/1971	*In vivo* (PA radiographs)	2	Taurodontism on both mandibular first molars of the patient

M, mesial; D, distal; ML, mesiolingual; DL, distolingual; DM, distomedial; DB, distobuccal; MM, middle mesial; MB, mesiobuccal.

Acknowledgments

The authors deny any conflict of interest.

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