Atypical Radicular Anatomy in Permanent Human Teeth: A Systematic Review

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ABSTRACT: The aim of the present study is to classify and quantify the anatomical variations of teeth in terms of form and number of root canals reported in human teeth employing the classification systems proposed previously. An electronic (PubMed) and manual search were performed to identify case reports noting any of the anatomical variations. Each alteration was studied independently. The electronic search was performed using the following keywords: anatomical aberration, root canal, permanent Dentition, case report, c-shaped canal, dens invaginatus, palato-radicular groove, palato-radicular groove, palato-gingival groove, radix entomolaris, dental fusion, dental gemination, taurodontism, dilaceration. The initial search revealed 1497 papers, of which 938 were excluded after analyzing the titles and abstracts. Therefore, 559 potential papers were considered. Of those, 140 articles did not meet the inclusion criteria. For the final revision, 419 papers were considered. We found that the mandibular first premolar had the highest prevalence of C-shaped canals. Dens invaginatus was more frequently found in the mandibular lateral incisor. Taurodontism was more prevalent in the maxillary first molar and in the mandibular first molar. Dilaceration was not clearly associated with a particular tooth. The classifications systems used in this review allowed for the better understanding and analysis of the many anatomical variations present in teeth. The variations in shape most found were dens invaginatus and radix entomolaris. The most frequently reported anatomical variation was in the number of canals.

KEY WORDS: anatomical aberration, case report, C-shaped canal, permanent dentition, root canal

I. INTRODUCTION

The study of dental morphology includes a comprehensive inspection, description, and analysis of the tooth's crown, neck, and root.[1] Although the general anatomical characteristics of teeth were initially described by Leonardo Da Vinci and later by Eustachius in his seminal book *Libellus de Dentibus* in 1563, further anatomical studies revealed multiple variations, which nevertheless have a low prevalence. One of such variations, *dens invaginatus*, for example, has a prevalence ranging from 0.06 to 7.7%, being more commonly found in permanent teeth.[2] The prevalence of palato-radicular groove ranges from 2.8 to 8.5%.[3] *Radix entomolaris* is found in about 6% of all first mandibular molars and in 0.8% of second mandibular molars.[4] Other anatomical variations include fusion (53.5%), gemination (46.2%),[5] taurodontism (5.6%),[6] and dilaceration, which is more prevalent in permanent maxillary central incisors (70.6%).[7]

In endodontics, the appropriate knowledge of dental anatomy is mandatory in order to achieve a successful root canal treatment (RCT).[8–10] Additionally, the clinician must be cognizant of all anatomical variations not only to deal with them properly, but also because they have an impact on the prognosis.[11,12] Because these variations might be related to ethnicity, genre and genetics, a detailed clinical examination is mandatory.[13] Based on anatomical and radiographic studies, digital tools have been designed to help the clinician perform better root

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canal treatments. For example, Endoprep® (Dental Sciences Australia Pty. Ltd.), an application for Android and IOS that uses neural networks to predict the position of root canals challenging to locate, such as the second mesiobuccal (MB2) canal of maxillary molars. Another digital tool is the Root Canal Anatomy Project, which was proposed by Versiani.[14] This Project contains a database with videos and tridimensional reconstructions of the root canals using micro-CT; these images are loaded in software such as Mimics® or 3D Doctor® in which it is possible to reconstruct complex root canal anatomies. Nevertheless, these digital tools require adequate knowledge and analysis of the radicular anatomy. In this context, reviews like this one play a significant role for clinicians and new technology developers.

Over the years, many systems have been proposed to classify the aforementioned variations.[13,15,16] Recently, Ahmed et al.[17] and Ahmed and Dummer[18] proposed new systems to classify such variations. Ahmed and Dummer's[18] method was proposed to avoid the confusion factor noted in most endodontic clinical studies.[19] This system make possible to identify the number of roots, the number of canals in each root and the anatomical configuration of these canals, as shown in the example in Fig. 1, which describe a tooth number 16 with three roots, two canals in the mesial root with a 1-2-1 configuration, one canal in the distal root and one canal in the palatal root.

The purpose of the present study is to classify and quantify the anatomical variations of teeth in terms of form and number of root canals reported in human teeth employing the classification systems proposed by Ahmed et al.[17] and Ahmed and Dummer.[18]

II. MATERIALS AND METHODS

The review followed the PRISMA guidelines and was registered in PROSPERO database (CRD4201912572). An electronic (PubMed) and manual search were performed in order to identify case reports noting any of the anatomical variations described by Ahmed et al.[17] and by Ahmed and Dummer.[18] Each alteration was studied independently. The electronic search was performed using the following keywords: "anatomical aberration," "root canal," "permanent dentition," "case report," "C-shaped canal," "dens invaginatus," "palato-radicular groove," "palato-radicular groove," "palato-gingival groove," "radix entomolaris," "dental fusion," "dental gemination," "taurodontism," and "dilaceration."

A. Inclusion Criteria

Inclusion criteria were case reports: (1) describing anatomic variations according to the system proposed by Ahmed et al.[17] and Ahmed and Dummer;[18] (2) published between July 1963 to November 2018; (3) published in any language; (4) related to variations in the number of root canals; (5) related to permanent human teeth; (6) related to upper and lower molars having four atypical root canals; and (7) describing the internal configuration of the root canal system.

B. Exclusion Criteria

Exclusion criteria were case reports: (1) not employing the system proposed by Ahmed et al.[17] and Ahmed and Dummer;[18] (2) not describing anatomical variations in deciduous teeth; (3) in which the second mesio-vestibular canal of upper molars was presented as a fourth canal; (4) dealing with lower molars having four root canals; (5) related to upper and lower premolars having two or three root canals; (6) related to upper and lower molars with one or two root canals; and (7) related to deciduous teeth.

III. RESULTS

The initial search revealed 1,497 papers, of which 938 were excluded after analyzing the titles and abstracts. Therefore, 559 potential papers were considered. Of those, 140 articles did not meet the inclusion criteria. For the final revision, 419 papers were considered (Fig. 2).

Table 1 shows the main anatomical variations and the prevalence for each type of tooth, for C-Shaped canals, the most prevalent tooth with C-shaped canal was the maxillary first molar with seven reports. For *dens invaginatus*, the greatest

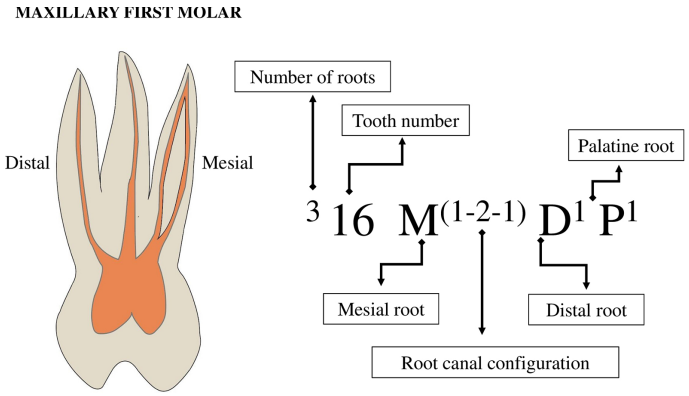

FIG. 1: Classification systems proposed by Ahmed and Dummer[18]

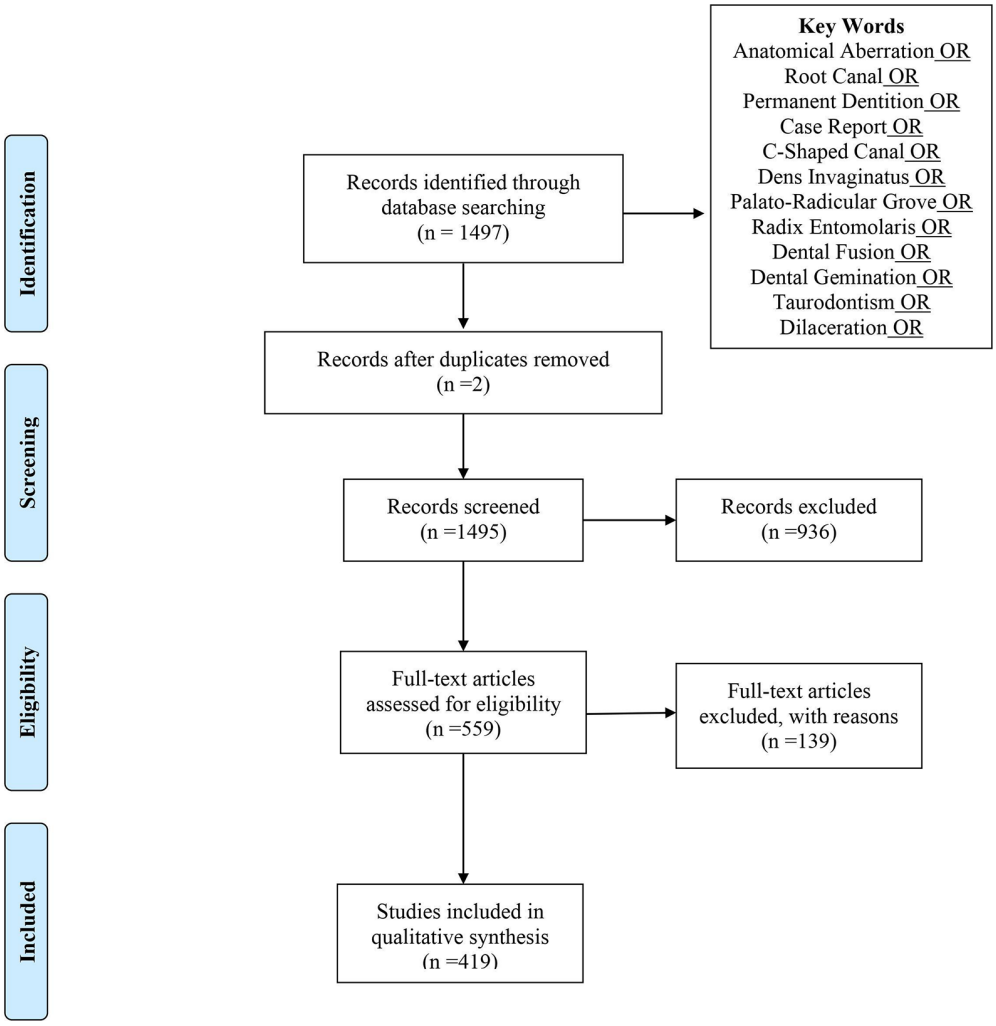

FIG. 2: Study selection process

TABLE 1: Anatomical variations in terms of form

Anomaly	Number of cases	Date	Journal	Type of tooth															Total
				MXCI	MXLI	MXC	MXFP	MXSP	MXFM	MXSM	MXTM	MDCI	MDLI	MDC	MDFP	MDSP	MDFM	MDSM	MDTM	
C-shaped	19	1984–2020	13	NR	1	NR	NR	NR	7	1	NR	NR	NR	NR	1	5	3	5	NR	23
Dens invaginatus	71	1977–2020	43	26	44	5	2	2	NR	NR	NR	3	2	1	2	4	NR	NR	NR	91
Palato-radicular groove	40	1972–2020	18	19	8	NR	NR	NR	NR	2	NR	9	7	NR	2	NR	NR	NR	NR	47
Radix entomolaris	21	2007–2020	17	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	50	2	NR	52
Fusion	35	1963–2020	23	19	5	NR	NR	NR	NR	1	2	5	7	2	NR	2	2	4	3	52
Gemination	18	1985–2020	17	7	7	1	1	1	NR	2	NR	NR	NR	NR	1	1	NR	NR	3	24
Taurodontism	34	1964–2020	21	NR	NR	NR	NR	1	15	7	NR	NR	NR	NR	5	7	8	9	NR	52
Dilaceration	43	1966–2020	33	35	2	2	NR	2	NR	NR	NR	7	2	NR	1	NR	NR	1	NR	52

MDC, mandibular canine; MDCI, mandibular central incisor; MDFM, mandibular first molar; MDFP, mandibular first premolar; MDLI, mandibular lateral incisor; MDSM, mandibular second molar; MDSP, mandibular second premolar; MDTM, mandibular third molar; MXC, maxillary canine; MXCI, maxillary central incisor; MXFM, maxillary first molar; MXFP, maxillary first premolar; MXLI, maxillary lateral incisor; MXSM, maxillary second molar; MXSP, maxillary second premolar; MXTM, maxillary third molar.

prevalence was the maxillary lateral incisor (44 cases reported).

Regarding palate-radicular groove 19 cases were reported for the maxillary central incisor. *Radix entomolaris* was found in 50 cases reported with the most prevalence in mandibular first molar. For fusion anomaly, the maxillary central incisor showed the greatest prevalence with 19 cases reported.

Gemination reported seven cases in the maxillary central and lateral incisor. Taurodontism was found with high prevalence in the maxillary second molar with 15 cases. For dilaceration the tooth with the greatest prevalence was the maxillary central incisor with 35 cases.

Variations in the number of root canals for anterior teeth and premolars are shown in Table 2. In anterior teeth, the mandibular canine with two canals was reported in 22 cases. Respecting to premolars, the mandibular second premolar with four canals were reported in eight cases.

Variations in the number of canals in molar teeth is depicted in Table 3. According to this table, 21 case reports described four canals for the maxillary second molar. Table 4 presents the variations in the number of atypical canals and their configuration in anterior and premolar teeth. In anterior teeth, the maxillary central incisor reported one case with four canals. Relating to premolars the second mandibular premolar showed a prevalence of four canals in five case reports.

Table 5 shows the variations in the number of atypical canals and their configuration in molar teeth. 38 reported cases showed that the tooth with the greatest variation in number was the maxillary first molar with five canals in 12 reported cases and six canals in three reported cases. For maxillary second molar 16 cases was reported, 13 cases had four canals. In mandibular first molar 16 cases were reported where six of them had five canals.

Tables 6 to 9 show the classification proposed by Ahmed et al.[17] in anterior teeth, premolars, and molars, respectively. Table 6 shows the configuration of atypical root canals for the maxillary central incisor 16 cases reported, eight cases described with two roots and two canals; the maxillary lateral incisor 15 cases reported, seven cases described with two roots and two canals; the maxillary canine eight cases reported, three cases showed two roots with two canals. Regarding mandibular anterior teeth, it was found that 21 mandibular canines had two roots and two canals. For the mandibular lateral incisor nine cases reported, 1 case reported two roots with two canals.

Table 7 depicts the configuration of atypical root canals in premolar teeth. The mandibular second premolar showed the highest number of configurations, 12 reported cases in which four cases presented one root with four canals. Table 8 shows the configuration of atypical root canals in maxillary molar teeth, the maxillary first molar with 28 cases reported, one case described a configuration of five roots with five canals, followed by three cases with four roots with four canals. nine cases reported three roots with different configurations, where the root with the greatest variations was the mesio-buccal. For the maxillary second molar with 21 cases reported, it was found that seven cases reported a configuration of four roots with four canals.

Table 9 shows the atypical root canal configuration in mandibular molar teeth. The mandibular first molar was reported in 20 cases of which 19 cases had two roots with different variations in the number of canals. Regarding the mandibular second molar, there were three reported cases with two roots with five canals.

IV. DISCUSSION

The aim of the present investigation was to classify and quantify the anatomical variations of teeth in terms of form and number of root canals reported in human teeth using the classification systems proposed by Ahmed et al.[17] and Ahmed and Dummer.[18] In order to fulfill the aims of this investigation, the authors designed an electronic (PubMed) and a manual search in order to identify case reports noting any of the anatomical variations described by the aforementioned authors. This methodology was initially described by Chegini et al.[20] who studied the prevalence of hepatic actinomycosis. Likewise, Wibisono et al.[21] performed a systematic review based on case reports to identify the characteristics of malignant syphilis in immunocompromised patients. The present investigation is a systematic

TABLE 2: Variations in number of root canals in anterior teeth and premolars

Number of cases	Date		Type of tooth																				
			MXCI			**MXLI**		**MXC**	**MDLI**		**MDC**		**MXFP**		**MXSP**		**MDFP**			**MDSP**			
84	1983–2020	Number of root canals	2	3	4	2	3	2	2	3	2	3	3	4	3	4	2	3	4	2	3	4	5
		Reported cases	10	2	1	10	2	9	1	1	22	4	1	1	1	2	1	2	2	2	1	8	1

TABLE 3: Variations in number of root canals in molars

Number of cases	**Date**		**Type of molar**														
			MXFM				**MXSM**			**MDFM**					**MDSM**		
54	1983–2020	Number of root canals	5	6	7	8	1	4	5	2	4	5	6	7	1	3	4
		Reported cases	17	8	2	1	1	21	2	1	7	9	3	1	2	1	3

TABLE 4: Number of atypical root canals in anterior teeth and premolars

Number of root canals in anterior teeth and premolars										
Number of root canals	**Maxillary central incisor**		**Maxillary lateral incisor**		**Maxillary second premolar**		**Mandibular first premolar**		**Mandibular second premolar**	
	Classification	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**
4	3V-1P	1	1V-1P-1M-1D	1	1M – 2D – 1P	1	1V – 1L – 1M – 1D	1	1V – 1L – 1M – 1D	5
									1M – 2D – 1P	1
									1MV – 1ML – 1DV – 1DL	1
5	NR	NR	NR	NR	NR	NR	NR	NR	1 MV – 2DV – 1DL – 1ML	1

D, distal; DL, disto lingual; DV, disto vestibular; L, lingual; M, mesial; ML, mesio lingual; MV, mesio vestibular; NR, not reported; P, palatine; V, vestibular.

TABLE 5: Number of atypical root canals in molars

Number of root canals in molars								
Number of root canals	**Maxillary first molar**		**Maxillary second molar**		**Mandibular first molar**		**Mandibular second molar**	
	Classification	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**
4	1MV – 1DV – 2P	5	1MV – 1DV – 2P	13	3M – 1D	2	3M – 1D	2
	1MV – 2DV – 1P	1	1MV – 2DV – 1P	1				
	2MV – 2DV	1	2MV – 2DV	2				
5	2 MV – 1DV – 2P	3	3 MV – 1DV – 1P	1	2MV – 1DV – 2 CC*	1	NR	NR
	3 MV – 1DV – 1P	3			3D – 2M	1		
	1MV – 1DV – 3P	3	2MV – 2DV – 1P	1	3M – 2D	6		
	2MV – 2DV – 1P	12						
6	2MV – 1DV – 3P	2	NR	NR	3M – 3D	4	NR	NR
	3MV – 2DV – 1P	3			4M – 2D	1		
	2MV – 2DV- 2P	2						
7	3MV – 2DV – 2P	2	3MV – 2DV – 2P	1	4M – 3D	1	4M – 3D	1
8	3MV – 3DV – 2P	1	NR	NR	NR	NR	NR	NR

CC*, central canal.

TABLE 6: Configuration of atypical root canals in anterior teeth according to Ahmed and Dummer[18]

Number of root canals in anterior teeth												
Root canals	**Maxillary central incisor**		**Maxillary lateral incisor**		**Maxillary canine**		**Mandibular central incisor**		**Mandibular lateral incisor**		**Mandibular canine**	
	Classification	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**
Uniradicular	^{1}**11** ^{3}	1	^{1}**12** ^{2}	1	^{1}**13** ^{2}	1	^{1}**31** ^{2}	1	^{1}**32** ^{221}	1	^{1}**33** ^{221}	1
	^{1}**11** ^{122}	1	^{1}**12** ^{3}	1			^{1}**31** ^{221}	2	^{1}**32** ^{331}	1	^{1}**33** ^{332}	1
	^{1}**11** ^{221}	2	^{1}**12** ^{433}	1	^{1}**13** ^{221}	2	^{1}**41** ^{2}	2	^{1}**42** ^{2}	3	^{1}**43** ^{221}	1
	^{1}**11** ^{331}	1	^{1}**22** ^{2}	2								
	^{1}**11** ^{443}	1	^{1}**22** ^{221}	3	^{1}**23** ^{21}	2	^{1}**41** ^{221}	3	^{1}**42** ^{221}	3	^{1}**43** ^{332}	1
	^{1}**21** ^{2}	2										
Biradicular	^{2}**11** V^{1} P^{1}	3	^{2}**12** V^{1} P^{1}	2	^{2}**13** V^{1} P^{1}	1	NR	NR	^{2}**42** V^{1} L^{1}	1	^{2}**33** V^{1} L^{1}	9
	^{2}**11** M^{1} D^{1}	2	^{2}**12** M^{1} D^{1}	1			NR	NR			^{2}**33** V^{1} L^{2}	1
	^{2}**21** V^{1} P^{1}	2	^{2}**22** M^{1} D^{1}	2	^{2}**23** V^{1} P^{1}	2	NR	NR			^{2}**43** V^{1} L^{1}	9
	^{2}**21** M^{1} D^{1}	1	^{2}**22** V^{1} P^{1}	2			NR	NR			^{2}**43** V^{1} L^{221}	2

^{X}**A**$^{Y:X}$ number of roots; A: tooth; $^{y:}$ number of root canals.

TABLE 7: Configuration of atypical root canals in premolars according to Ahmed and Dummer[18]

Number of root canals in premolars						
Root canals	**Maxillary second premolar**		**Mandibular first premolar**		**Mandibular second premolar**	
	Classification	**# Cases**	**Classification**	**# Cases**	**Classification**	**# Cases**
Uniradicular	$^{1}15^{4}$	1	$^{1}34^{4}$	1	$^{1}35^{4}$	3
					$^{1}35^{242}$	1
					$^{1}45^{144}$	1
					$^{1}45^{443}$	2
					$^{1}45^{553}$	1
Biradicular	NR	NR	$^{2}44\ V^{2}\ L^{2}$	1	$^{2}35\ M^{2}\ D^{2}$	1
	NR	NR				
	NR	NR				
	NR	NR				
Multiradicular	NR	NR	NR	NR	$^{4}35\ MV^{1}\ DV^{1}\ ML^{1}\ DL^{1}$	2
	NR	NR	NR	NR	$^{3}45\ MV^{2}\ DV^{1}\ L^{1}$	1

review that analyzing case reports of anatomical variations in form and number in different teeth in order to determine the frequency of such variations in both mandible and maxilla.

Several authors[8,12,13,19] have designed methods to study the anatomical variations in permanent teeth. New technologies such as cone-beam computed tomography (CBCT) have allowed a better characterization of these morphological changes with important clinical implications.[11,13]

Most of the images used by the articles referenced in this review were obtained through a cone-beam computed tomography system, which provides high-quality micrometric resolution images that allow excellent visualization by the dentist. It performs tomographic sections in short intervals, thus achieving 3D images through a computerized system connected to a scanner; it will enable projections to be obtained from all angles, providing a global or integral image of the patient.

In 2018, Kim et al.[22] reported a prevalence of 39.8% of C-shaped canals in mandibular second molars. Fan et al.[23] and Martins et al.[24] found that the mandibular first premolar had a high prevalence of C- shaped canals. Our findings are in agreement with the aforementioned reports. Regarding *dens invaginatus*, Mallineni et al.[2] found that this variation affects primarily the mandibular central incisor. Our review established that this condition is more frequently found in the mandibular lateral incisor.

Several papers,[3,25,26] including this review, have demonstrated that palato-radicular groove is more prevalent in the maxillary lateral incisor. Kuzekanani et al.[27] found *radix entomolaris* in 6% of the studied mandibular first molars and in 0.8% of the studied mandibular second molars. A similar finding was reported by Martins et al.[24] The prevalence of fusion and gemination was studied by Sekerci et al.[5] and Hamasha et al.,[28] who analyzed both conditions in permanent teeth. Both studies concluded that fusion and gemination is more prevalent in the maxillary central incisor, which is consistent with our findings.

The prevalence of taurodontism has showed variations among studies. Although Bronoosh et al.[6] established a prevalence of 76% for the mandibular second molar, Patil et al.[29] reported a prevalence of 53.2% for the same tooth. In contrast to those reports, we found that the maxillary first molar and the mandibular first molar are the teeth most frequently found with this type of anomaly. Such discrepancy might be related to the nature of the methodology that we employed.

Regarding dilaceration, there is not a single tooth clearly associated with this condition. Hamasha et al.,[30] for example, described a higher

TABLE 8: Configuration of atypical root canals in maxillary molars according to Ahmed and Dummer[18]

Root canals	Maxillary first molar		Maxillary second molar	
	Classification	# Cases	Classification	# Cases
Multiradicular	^{4}**16** MV^{1} MP^{221} DV^{221} P^{1}	1	^{3}**17** MV^{332} DV^{1} P^{1}	1
	^{3}**16** MV^{221} DV^{221} P^{1}	3		
	^{4}**16** MV^{1} DV^{1} MP^{1} DP^{1}	2		
	^{3}**16** MV^{221} DV^{1} P^{221}	1	^{4}**17** MV^{1} DV^{1} MP^{1} DP^{1}	6
	^{3}**16** MV^{332} DV^{2} P^{221}	1		
	^{5}**16** MV^{211} DV^{1} MP^{1} MiP^{1} DP^{1}	1		
	^{3}**16** MV^{332} DV^{221} P^{221}	1	^{4}**17** MV^{1} DV^{1} DV-II^{1} P^{1}	1
	^{3}**16** MV^{2} DV^{221} P^{211}	1		
	^{3}**16** MV^{1} DV^{1} P^{221}	2		
	^{3}**16** MV^{3} DV^{2} P^{1}	1	^{3}**17** MV^{1} DV^{1} P^{2}	4
	^{3}**16** MV^{331} DV^{1} P^{1}	1		
	^{3}**16** MV^{3} DV^{1} P^{1}	1		
	^{3}**16** MV^{2} DV^{1} P^{2}	1	^{3}**17** MV^{2} DV^{2} P^{1}	1
	^{3}**26** MV^{1} DV^{221} P^{1}	1		
	^{3}**26** MV^{2} DV^{1} P^{112}	1		
	^{4}**26** MV^{1} MP^{221} DV^{221} P^{1}	1	^{3}**17** MV^{1} DV^{1} P^{221}	1
	^{3}**26** MV^{211} DV^{211} P^{1}	1		
	^{3}**26** MV^{332} DV^{332} P^{221}	1		
	^{3}**26** MV^{221} DV^{1} P^{331}	1	^{3}**27** MV^{1} DV^{1} P^{2}	2
	^{3}**26** MV^{1} DV^{1} P^{3}	1		
	^{3}**26** MV^{332} DV^{2} P^{1}	1		
	^{3}**26** MV^{332} DV^{1} P^{1}	1	^{4}**27** MV^{1} DV^{1} MP^{1} DP^{1}	5
	^{3}**26** MV^{2} DV^{2} P^{2}	1		
	^{4}**26** MV^{1} DV^{1} MP^{1} DP^{1}	1		

prevalence in the mandibular first molar. Silva et al.[7] reported the highest prevalence for the maxillary lateral incisor. Miloglu et al.[31] identified the mandibular third molar as the one with the greatest number of dilacerations. In this review, the maxillary central incisor was the one most frequently found with dilaceration.

Martins et al.[24] reported a high prevalence of anatomical variations in number and configuration of root canals in Caucasians, noting cases of two canals in mandibular canines. In the present study, we found that maxillary central incisors and maxillary lateral incisors were the most frequently found with two root canals. The discrepancies, again, are best explained in the nature of the methodology we employed.

Martins et al.[13] performed a systematic review which analyzed the anatomy of the root canal using CBCT. They included 52 studies with data from 34,068 patients and 102,610 teeth, identifying variations in number such as the presence of a second canal in mandibular anterior teeth. In the present study, a high number of case reports of a second canal in both mandibular incisors and in maxillary incisors.

For this review the premolars with two or three canals as well as the maxillary and mandibular molars with four canals were not included as that this type of anatomical configurations are not considered

TABLE 9: Configuration of atypical root canals in mandibular molars according to Ahmed and Dummer[18]

Number of root canals in mandibular molars				
Root canals	**Mandibular first molar**		**Mandibular second molar**	
	Classification	**# Cases**	**Classification**	**# Cases**
Biradicular	^{2}**36** M^{332} D^{1}	2	^{2}**37** M^{3} D^{1}	1
	^{2}**36** M^{322} D^{322}	1		
	^{2}**36** M^{331} D^{321}	1		
	^{2}**36** M^{3} D^{332}	2		
	^{2}**36** M^{442} D^{2}	1		
	^{2}**36** M^{433} D^{3}	1		
	^{2}**36** M^{331} D^{1}	1	^{2}**47** M^{331} D^{1}	1
	^{2}**36** M^{322} D^{211}	1		
	^{2}**46** M^{331} D^{1}	2		
	^{2}**46** M^{2} D^{332}	1		
	^{2}**46** M^{2} D^{3}	1		
	^{2}**46** M^{332} D^{2}	1	^{2}**47** M^{442} D^{3}	1
	^{2}**46** M^{3} D^{2}	1		
	^{2}**46** M^{3} D^{331}	1		
	^{2}**46** M^{332} D^{332}	1		
	^{2}**46** M^{331} D^{2}	1		
Multiradicular	^{3}**36** M^{2} C^{2} D^{1}	1	NR	NR

anomalies and they can occur frequently as previous studies have shown.[8–10,13,16,19,32–39]

Martins et al.[13] found that maxillary premolars had one or two canals, while mandibular premolars had a higher prevalence of a single canal. In contrast to these findings, we found that maxillary premolars had as many as three or four root canals, while mandibular second premolars with four canals were identified.

Saber et al.[33] in a study carried out in an Egyptian population, reported that maxillary premolars are the ones with the greatest variations in number of roots, number of canals, and their configuration. Consistent with their findings, this review identified variations in maxillary premolars with four and five root canals in different configurations.

Zhang et al.[34] in a Chinese population, Rouhani et al.[35] in an Iranian population, and Gulavibala et al.[36] in a Burmese population reported that all disto-vestibular and palatal roots of the maxillary first molars presented a single root canal. The present systematic review, in turn, found maxillary molars with more than one root canal in disto-vestibular and palatal roots.

The mandibular first molar, in its usual anatomical configuration, presents two roots.[8] However, Martins et al.[13] reported 32% of cases of three roots in this molar in an Asian population. De Pablo et al.[37] analyzed 41 studies and found that 13% of the studied mandibular first molar presented a third root. Furthermore, they identified the presence of three root canals in 61.3% of cases, four canals in 35.7% of cases, and five canals in 1% of cases, which is consistent with the findings of the present review, where up to five canals were identified in the mandibular first molar.

According to our results, the root canal system of maxillary and mandibular teeth presents a complex and variable anatomy in the number and shape of root canals. Reviews such as this allow finding new methods and tools that allow the clinician to identify all the anatomic variations, thus improving

the diagnosis, expanding the range of treatment success, and avoiding mistakes by the dentist.

The challenge is to develop devices that may automatically detect the trajectories and anatomy of the root canal. For this purpose, techniques like those reported by Duan et al.[40] may be useful. Based on the neural network U-Net, they improved tooth and pulp segmentation on single-rooted and multi-rooted teeth to better planning of root canal treatment. In the same way, Gambarini et al.[41] suggest using 3D Endo software (Dentsply Sirona, Wels bei Salzburg, Austria) linked to CBCT images, which allows automatic identification and visualization of root canals' paths and junctions between them. Miki et al.[42] applied a deep convolutional neural network for tooth classification using CBCT for forensic purposes; however, this technology could also be a potential tool to automatically identify and classify the canal system's anatomy, for example, Ahmed and Dummer.[18] They used the 3D convolution technique with CBCT resolution and thus allowing the deep convolutional neural network to determine the root canal system more accurately.

As a teaching tool, Dolega-Dolegowski et al.[43] report technology based on holography and augmented reality (AR) to study the internal anatomy of the root canal system. These techniques are helpful nowadays in dentistry education due to the necessity of proposing alternatives to natural teeth that have ethical limitations in preclinic practice in many countries. These methods have been implemented today in different areas of medical training. Therefore, this topic is an area that requires more research to help the dentist, student, or professional, to see complete the 3D canal system in real-time, for example, by using dynamic navigation and consequently visualizing the morphology and classification of the root canal anatomy.

V. CONCLUSIONS

The classification system utilized in this review allow for the better understanding and analysis of the different anatomical variations present in permanent teeth. The variations in shape most often reported in the literatura include dens invaginatus and radix entomolaris, followed by fusion and gemination. Case reports of variations in the number of roots and canals are published frequently; the new technologies included in the practice of endodontics such as magnification and CBCT have contributed to the discovery of these new variations. This review found a significant number of case reports with new canal configurations in premolars and molars, changing the knowledge that was available until now about the anatomy of these teeth. The new findings have generated changes in the classification systems, forcing clinicians to maintain a permanent update to guarantee an adequate management of the endodontic treatments performed.

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