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Evaluation of mandibular and maxillary second molar root canal anatomy in a Turkish subpopulation using CBCT: comparison of Briseno-Marroquin and Vertucci classifications

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Abstract

Background This retrospective study aims to characterise the root canal morphology of maxillary and mandibular second molars using cone-beam computed tomography (CBCT). The number of roots and canal configurations were evaluated using both the Vertucci and Benjamı´n Brisen˜ o Marroquı´n classification systems.

Methods A total of 1084 second molar images (523 maxillary; 266 right and 257 left side and 561 mandibular; 285 right and 276 left side) were evaluated from 320 CBCT scans analyzed for the Turkish subpopulation. CBCT imaging provided superior visualisation of root canal anatomy compared to periapical radiography. The findings revealed diverse root canal configurations, with variations observed even within the same population. Statistical analyses, including the chi-squared test, were used to assess correlations between root number and demographic variables such as age and sex.

Results According to Benjamı´n Brisen˜ o Marroquı´n classification system, the most common configuration for upper right three-rooted teeth mesial root was $^{3}URM^{2-1}$ (n:66, 35.7%), for distal root was $^{3}URM^{1}$ (n:169, 91.4%), and for palatal root was $^{3}URM^{1}$ (n:165, 89.2%). Additionally, the most common configuration for upper left three-rooted teeth mesial root was $^{3}27^{1}$ (n:50, 28.4%), for distal root was $^{3}ULM^{1}$ (n:160, 90.9%), and for palatal root was $^{3}ULM^{1}$ (n:158, 89.8%). In lower left molars, the most common configuration in the two-rooted teeth mesial root was $^{2}LLM^{2}$ (n:114, 49.4%), and for the distal root was $^{2}LLM^{1}$ (n:170, 73.6%). For lower right the most common configuration for two-rooted teeth mesial root was $^{2}LRM^{2}$ (n:125, 52.5%), and for distal root was $^{2}LRM^{1}$ (n:173, 72.7%)($p < 0.05$).

Conclusion The primary outcome was observed that the root canal anatomy of upper and lower second molars may differ in both classifications of Turkish subpopulation. While Vertucci's classification was inadequate in some cases, Briseno-Marroquin classification was able to classify all upper and lower second molars with a single code. This new classification is a more useful system for classifying all second molars. There is a statistically significant difference exists among the new configuration according to the distribution of the teeth analyzed.

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Keywords CBCT, Root canal morphology, Vertucci classification, Benjamı´n Brisen˜ o Marroquı´n classification, Second molars

Introduction

The success of endodontic treatments relies heavily on several critical factors, including the intricate anatomy and morphology of the root canal system, thorough disinfection of the root canal, and effective sealing [1–6]. A deep understanding of root canal anatomy and morphology is crucial for the success of endodontic treatments [7–10]. Among many factors, the root canal system stands out as paramount due to the complexity of its anatomy and morphology. However, the root canal system may be complex and/or colonised by a variety of microorganisms. Thus, detailed knowledge of tooth anatomy is vital to pursuing endodontic treatment because the inability to detect and treat all identified canals may result in treatment failure [4, 11, 12]. Knowledge of root canal morphology is important for clinicians to master therapeutic techniques and clinical outcomes are improved. Understanding the root canal system involves identifying the number of roots and canals, the canal configurations, and their cross-sectional shapes [6, 13–15].

Weine et al. were the first to classify root canal morphology [7] within a single root, also they added an additional type in 1982 [7]. They focused on single-rooted teeth in their classification, creating four main categories. This classification is based on whether the canal is single, there are two canals from beginning to end, or the root is divided into two at the middle or apex. In 1974, Vertucci et al. recognized [7, 10, 16] further complex root canal systems and reported eight types of configurations according to the pattern of division in the main root canal from the pulp chamber to the apex of the root. However, Vertucci's classification may not allow for unambiguous description given their classification variability according to the Vertucci system. Sert and Bayirli [10] added fourteen supplemental types to Vertucci's classification system. A new classification was introduced n Brisen˜ o Marroquı´n et al. in the year 2015, which is simple, easy to understand, and more accurate at classifying root canal configurations compared to earlier systems [7, 17]. This system uses the three-dimensional diagnostic imaging advantages. The benefit of Benjamı´n Brisen˜ o Marroquı´n classification is its user-friendly coding system, which is accessible to both students and dentists [17]. The coding system assigns individual codes for the tooth number (TN), the number of roots, and the configuration of the canals.

Vertucci classified root canal morphology into eight types. This classification is more detailed than Weine's classification. The first 3 types have single apical foramen and contain separation inside them, except type I. From type IV to type VII, teeth have two apical foramina. Type VIII differs from the others by having three apical foramens (Fig. 1).

Sert and Bayirli added supplementary configurations to Vertucci's Classification due to the systems' limitations. The authors evaluated the root canal configuration in maxillary and mandibular permanent teeth amongst the Turkish population using a clearing technique. They added fourteen types to Vertucci's classification, numbering them from Type IX to Type XXIII [4, 10]. These added classes were developed to better describe intracanal branching accounting for situations with more than two canal openings and more than three apical foramina.

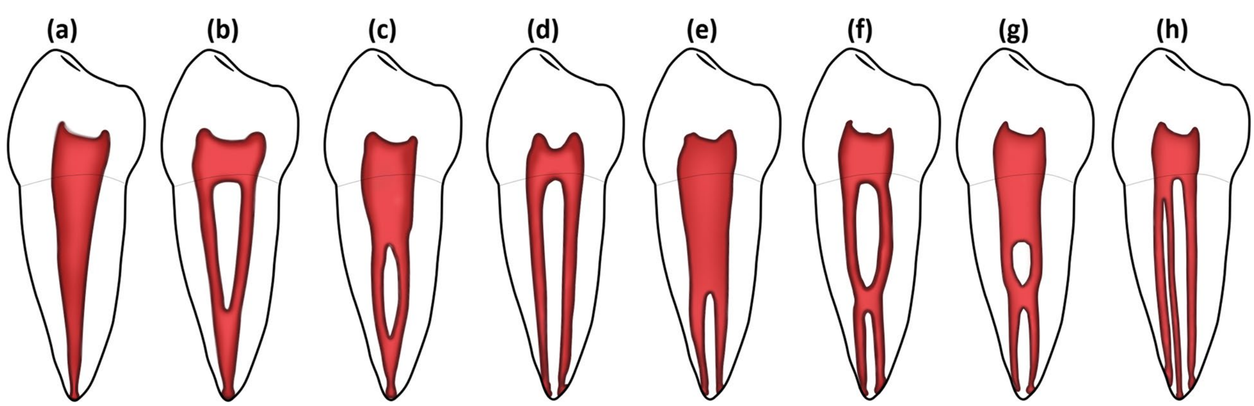

Fig. 1 Canal configurations as originally described by Vertucci in 1984. The configurations are described as follows: (**a**) type I, **b** type II, **c** type III, **d** type IV, **e** type V, **f** type VI, **g** type VII, and **h** type VIII

The Vertucci classification does not consider the number of roots in the anterior and posterior teeth which is a major shortcoming, this insufficiency in explaining the root canal anatomy creates a necessity for a new classification [4, 7, 10].

The new four-digit coding system describes the anatomical features of roots in a consistent manner regardless of the tooth type and whether a tooth is single or multi rooted [18]. This new system for classifying root and canal morphology has defined any 'division' of a root, whether in the coronal, middle or apical third, is coded as two or more roots. To enable researchers to interpret the configuration of the root canal consistently, the components of the pulp cavity, including the pulp chamber and root canal, should be defined accurately. For correct use of this classification correctly, it is essential to utilise three-dimensional imaging systems such as CBCT or Micro-CT [3, 19, 20]. Due to its high radiation exposure, micro-CT is not safe enough to use on patients. Conversely, CBCT has a lower radiation level, is more cost-effective, and provides sufficient information about the root canal system [11]. Several studies have found root canal configurations to be highly complex and found Non classifiable canal configurations during evaluation of internal and external anatomical canal variation using 3D imaging techniques [4, 11, 21, 22].

In this new classification used to define the root canal system, the canals are evaluated from the orifice to the apex. In single-rooted teeth, the orifice is located at the cementoenamel junction (CEJ), while in double and multi-rooted teeth, it is located at the furcation line [2, 7, 17, 18] (Table 1).

The two-dimensional nature of periapical radiographs may result in missed roots and canals [6, 23]. Changing the horizontal tube angulation may improve visualisation of the tooth anatomy, however this technique's applicability may be limited in patients who have a smaller mouth space [24]. With the improving technologies, three-dimensional diagnostic imaging modalities such as CBCT allow greater detection of root and canal morphology prior to endodontic treatment.

Micro-CT has become the "gold-standard" for evaluating bone morphology and microstructure in the ex vivo models [4, 14, 25]. On the other hand, clinical CBCT has been widely applied in dentistry for over two decades, offering high image quality with low radiation dose at a low cost. Compared to micro CBCT, CBCT is less invasive but still an accurate method that can be used in clinical works. Moreover, CBCT is superior to periapical radiography in successfully detecting root canal anatomy. The root can be easily examined in more detail with different sections [4, 10, 18]. Difficulty working in molar teeth and the complex anatomy of root canals may cause treatment failure. Two-Dimensional images taken from periapical radiographs may not always provide accurate results due to superpositions. At this point, treatment success increases when the relevant tooth is examined with 3D imaging methods such as CBCT and the canal anatomy is understood correctly [11, 26, 27].

This study aims to investigate the description and comparison of the differences among Vertucci and the Benjamı´n Brisen˜ o Marroquı´n classifications using CBCT evaluations of mandibular and maxillary second molars in a Turkish subpopulation primary and secondary outcomes. The null hypothesis of our study is that the classifications by which we assessed the root canal anatomy of the upper and lower second molars will be similar regardless of the left and right sides.

Materials and methods

Sample selection

Ethical approval for this study was obtained from the Non- Interventional Clinical Research Ethics Committee of Istanbul Medipol University (protocol no. 309/2024). Statistical analyses were performed using the G Power version 3.1 software program (Heinrich University, Dusseldorf, Germany) [28]. The Chi square test was used for analysing contingency tables, 764 samples of total groups,

Table 1 Explaining the number of roots for Benjamı´n Brisen˜ o Marroquı´n classification

Tooth type	Description
Single-rooted tooth	No bifurcation or bifurcation only at the apical portion.
Multiple-rooted teeth	Teeth with clear bifurcated roots, either two-rooted or three-rooted.
Root canal configuration	Starts with two canals at the pulp chamber; digits indicate canal numbers, with foramina separated by slashes.
Double-rooted teeth	A slash (/) or double slash (//) indicates separate or joined canals; root fusion can be noted if considered a variation.
Three-rooted teeth	Various presentations of root fusion; a double slash (//) indicates merged canals.

consisting of four sections. This was determined with an α (error margin) = 0.05, 0.15 effect (w), 0.95 power (1-β) level, yielding a minimum sample size of 191.

Patient selection and study duration

This cross-sectional retrospective study evaluated 1084 s molar images (523 maxillary; 266 right and 257 left sides and 561 mandibular; 285 right and 276 left sides second molars, respectively) obtained from 320 CBCT scans in the Turkish subpopulation (Fig. 2). The study included CBCT examinations showing mandibular and maxillary second molars with complete root development and integrity, and the ages of the patients examined ranged from 18 to 76 years [29].

The images were used to determine the root number and canal configurations of maxillary and mandibular second molars. Both left and right second molars were included. Scans from both male (n:503) and female (n:581) subjects were evaluated. Participant age at the time of the scan was recorded, but no information on race or ethnicity was collected. The existing CBCT database was used, and no new scans were acquired for this study. Scans were assessed chronologically back from the most recently acquired one until the necessary sample size was achieved. The study time period ranged from 2021 to 2024.

Inclusion criteria

Scans containing fully formed maxillary and mandibular molars were included in this research. The scans were needed to exhibit adequate quality for visualizing individual roots and canals. CBCT images that met the following criteria were included:

(i) Scans that included the entire pulp chamber and root canal system were considered (496 upper and 545 lower second molars).
(ii) Presence of a fully mature and erupted maxillary and mandibular second molar.
(iii) Participants over 18 years old
(iv) Participants selected from Turkish ethnicity.

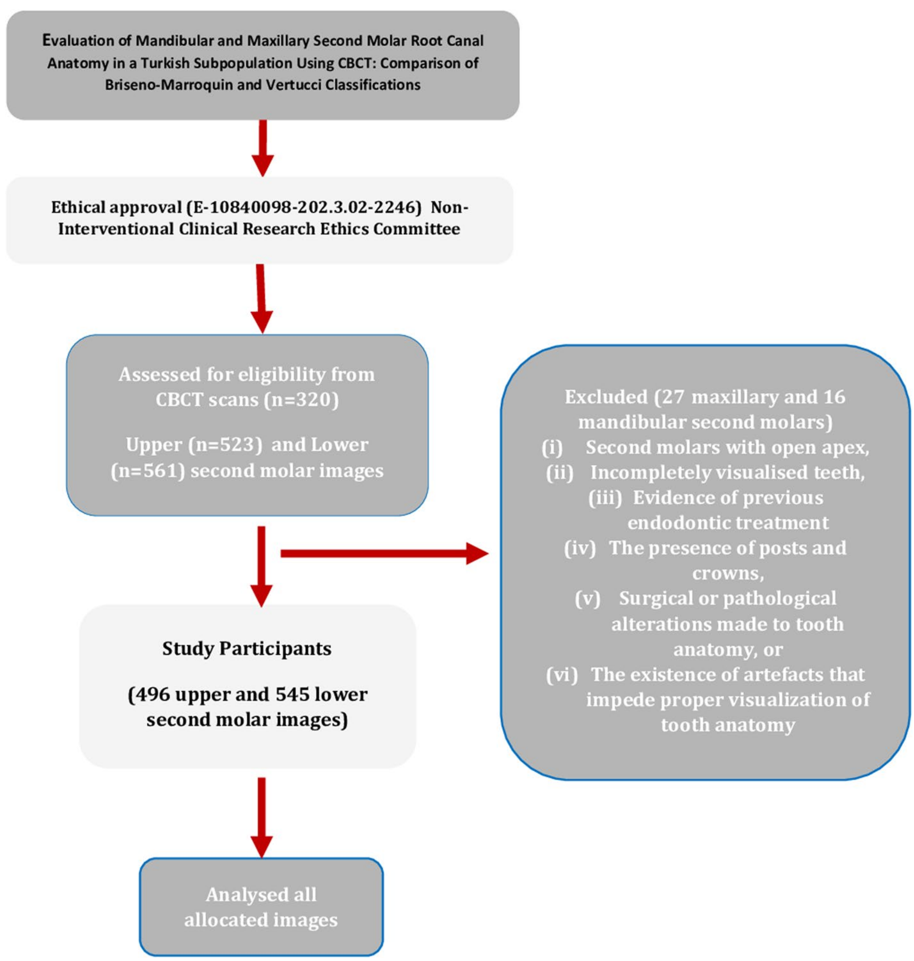

Fig. 2 Flowable chart of study design

Exclusion criteria

Teeth were excluded for the following reasons:

(i) Second molars with open apex,
(ii) Incompletely visualised teeth,
(iii) Evidence of previous endodontic treatment
(iv) The presence of posts and crowns,
(v) Surgical or pathological alterations made to tooth anatomy, or
(vi) The existence of artefacts that impede proper visualization of tooth anatomy.

Regarding these criteria, 27 maxillary and 16 mandibular second molars were excluded. The exclusion ratio was %5.

Evaluation of radiological images

All scans were previously acquired by using an I-CAT Next Generation CBCT (Hatfield, USA) unit in the Department of Dentomaxillofacial Radiology at Istanbul Medipol University. The principle of "as low as diagnostically acceptable," (ALADA) concerning the exposure of patients to ionising radiation, was strictly adhered to at the time of image acquisition. The images were viewed using the i-CAT Next Generation Vision software (Imaging Sciences International, Hatfield, USA). The scans were originally taken for several reasons including the diagnosis of maxillofacial trauma, impacted tooth, implant planning, and decision making for endodontic and orthodontic treatment cases. All scans were retrospectively analysed, and no new scans were acquired for the purpose of this study (Fig. 3).

The CBCT unit resolution ranged from 100 to 600 µm, with 300 to 750 basic frames. The anode current was 1 to 14 mA and the anode voltage was 54 to 90 kV. The focal spot was 0.6×0.6 mm (about 0.02 in) in diameter. The unit was capable of producing scans with a voxel size ranging from 100 to 600 µm, with fields of view ranging between 5.0×5.7 cm and 23.0×27.5 cm in size. During evaluation of the images, sagittal, axial, coronal slices with a thickness of 0.1 mm were evaluated. Also the 'line' property of the software was used to reform additional planes through the coronal, sagittal and axial planes.

Endodontic examination of images

Before all evaluations, a Dentomaxillofacial Radiologist (DMFR) trained the two Endodontist observers with regards to details of the planes, and forming new planes paralel to the longitudinal axis of the roots as well as the usage of the Vision software on 50 CBCT images that were not included into the study. Images were evaluated simultaneously by two calibrated examiners with 10 years of experience in endodontics through the planes that are mentioned above and a joint decision was made. In case of uncertainty, a dentomaxillofacial radiologist was consulted for a final opinion. For inter researcher rates, the DMFR rated %15 of all cases after 1 month. A maximum allowed voxel size of 200 µm was selected. Scans exceeding these thresholds are deemed insufficient quality for evaluation.

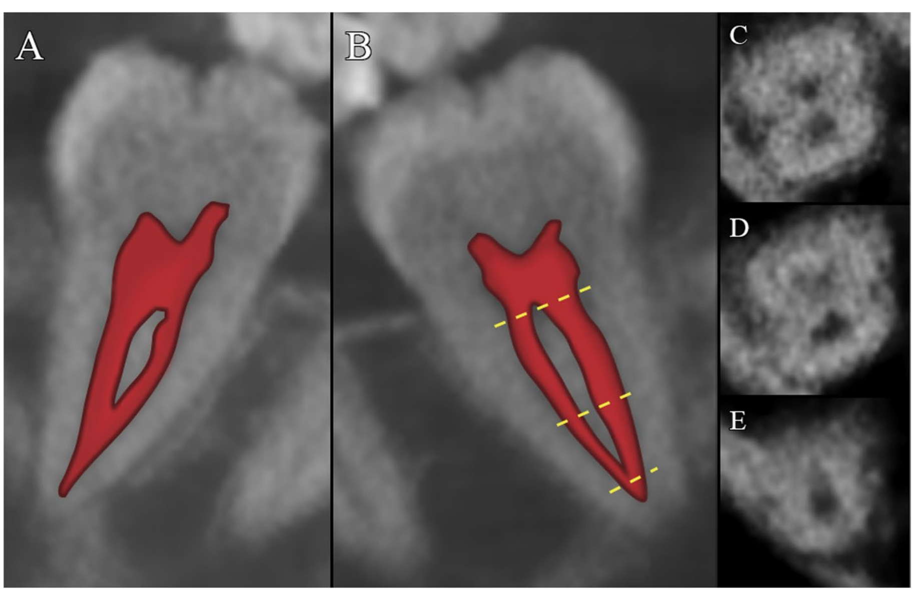

Fig. 3 Lower left molar (LLM) and Lower right molar (LRM) of the same patient. Vertucci's Classification Type II represents the LRM tooth (**A**) and Brisen˜ o Marroquı´n et al. classification $^{1}LLM^{2-1}$ represents the LLM tooth (**B**); the coronal slice (**C**), a section of the middle third (**D**), and a section of the apical third (**E**)

Single-rooted teeth do not have a bifurcation or have an indistinct separation at the extreme end of the apical third. This distinction is important for understanding root canal anatomy. Multi-rooted teeth have two, three or more roots that can be counted. In multi-rooted teeth, the furcation region can be clearly observed and a bifurcation can be seen from the very beginning or the middle of the root (Fig. 4). In the proposed classification, the root canal configuration begins with determining the number of canals in the pulp floor. Our first number is determined by the number of canals in the coronal third. Then, the number of canals in the middle third is determined. The numbers are separated by drawing a straight line. Then, the number of canals in the apical third and the apical foramina are determined. For example, the configuration of a tooth with 2 canals in the coronal and middle thirds, a single canal in the apex and a single foramina can be written as $TN^{2-2-1-1}$. To simplify the appearance, one of the consecutive numbers may not be written. In this case, an expression like TN^{2-1} will emerge.

For Double-rooted teeth, If the observer considers root fusion as a separate condition and will use a previously made classification to describe the type of root fusion, then can add the abbreviation describing the root fusion in the classification he will use to the left of the tooth number, just as he would for other dental anomalies.

In the new classification, root fusions in 3-rooted teeth can be shown in different ways as described by Zhang et al. [30] and can be used in the new coding system. It is not always possible to differentiate between single-rooted teeth with deep developmental grooves and teeth that have fused along the root. In such cases, the number of roots is normally considered to be the most common number of roots in that tooth. For example, deep developmental grooves can be seen in the buccolingual direction at the root of the lower central incisor. In this case, this tooth is still classified as single-rooted.

Fig. 4 Examples of cases found in second molar teeth: According to Brisen˜ o Marroquı´n et al. classification $^{1}LRM^{2-1}$ (**A**), $^{1}LRM^{2-3-2}$ (**B**), $^{1}LRM^{2-1}$ (**C**), $^{2}URM\ M^{2}$ (**D**),$^{1}URM^{3-1}$ (**E**), $^{1}LRM.^{1-2}$ (**F**)

Statistical analysis

Interobserver reliability was calculated using percentage agreements. Statistical analyses were performed using the SPSS version 26.0 software program (IBM Corp., Armonk, NY, USA). Within the scope of the study, measurement data for basic descriptive statistics were categorical and expressed as frequency and percentage. Chi-square analysis was used to compare the data from the study. Statistical significance level was accepted as $p < 0.05$.

Results

Interobserver correlation was performed with 130 samples to test the consistency of evaluation between two specialist dentists for vertucci and new classifications for canals. According to the results obtained from the correlation and Cohen's κ coefficients; there is high consistency between the two specialists in terms of the evaluation of measurements (Table 2).

Root morphology and number of roots

The data demonstrated a significant correlation between the number of roots in the upper molars of the patients ($x^2_=48.528$, $p < 0.05$). The ratio of teeth with three roots was found to be higher in upper molars. A substantial correlation was found between the number of roots in the lower molars of the patients ($x^2_=57.455$, $p < 0.05$). The ratio of teeth with two roots was found to be higher in lower molars (Table 3).

In the upper molar single-rooted teeth analyzed, the proportion was 2.7%. In two-rooted teeth, the proportion was 14.4%. In three-rooted teeth, the proportion was 81.1%, and in four-rooted teeth, the ratio was 1.8%. Moreover, there is a statistically significant difference in the patients based on the number of roots in the upper molars ($x^2_=48.528$, $p < 0.05$).

In the analyzed lower molar single-rooted teeth, the proportion was 5.8%. In two-rooted teeth, the proportion was 89.8%, and in three-rooted teeth, the proportion was 4.3%. There is a notable statistical difference in the patients according to the number of roots in the lower molar teeth ($x^2_=57.455$, $p < 0.05$).

Root canals configuration of second upper molars according to Vertucci's classification

As seen in Table 4, the most prevalent vertucci classification among the single-rooted upper teeth examined in the upper right region was XV (n:4, 28.6%). For the analysed two-rooted upper molars, the most common classification for the buccal root was IV (n:17, 37.8%). While type I (n:43, 95.5%) was the most frequently observed classification for the palatal root. Among the three-rooted upper molars analysed, the highest vertucci classification for specimens located in the mesiobuccal root was type II (n:67, 36.8%). In the distobuccal root, type I (n:169, 91.4%) was the most common classification, and similarly, type I (n:165, 89.2%) was the most frequently observed for the palatal root. Among the four rooted upper molars analysed, the highest vertucci classification was type I (n:2, 50.0%) for the specimens located in the mesiobuccal root. The Vertucci classification for all specimens in the

Table 2 Inter-observer and ıntra-observer correlation of two specialists' evaluations

	Cohen's κ Observer 1 (Intra-rater reliability)	Cohen's κ Observer 2 (Intra-rater reliability)	Cohen's κ (Inter-rater reliability) 1. Observing	Cohen's κ (Inter-rater reliability) 2. Observing
Vertucci classification	0.946*	0.984*	0.969*	0.977*
Benjamı´n Brisen˜ o Marroquı´n Classification	0.961*	0.961*	0.977*	0.946*

Chi-square analysis, *$p < 0.001$

Table 3 Number of upper and lower molars

		Number of roots				Total	x^2	p
		1	2	3	4			
Upper molar	**Total**	36 (2.7)	192 (14.4)	1083 (81.1)	24 (1.8)	1335	48.528	0.001*
	Root name	M	B,P	MB,DB,P	MB,DB,P, Add. Root			
			M,D	MB,ML,D				
Lower molar	**Total**	61 (5.8)	938 (89.8)	45 (4.3)	0 (0.0)	1044	57.455	0.001*

*Chi-square analysis, significant (p<0.05)

Table 4 Comparison of Vertucci classification according to the number of roots and canals in upper and lower molars

			Vertucci classification I	II	III	IV	V	VI	VII	VIII	IX	X	XII	XV	XVI	XVII	XVIII	XIX	S.D.	X^2	*p**
Upper right	One Root	M	1 (7.1)			1 (7.1)				3 (21.4)	1 (7.1)	1 (7.1)		4 (28.6)	1 (7.1)		2 (14.3)		12.8	256.074	0.001
	Two Roots	M	6 (13.4)	13 (28.9)	1 (2.2)	17 (37.8)		1 (2.2)						2 (4.4)			1 (2.2)				
		D	43 (95.5)	1 (2.2)	1 (2.2)																
	Three Roots	M	46 (25.3)	67 (36.8)	18 (9.9)	29 (15.9)	12 (6.6)	6 (3.3)	2 (1.1)					2 (1.1)							
		D	169 (91.4)	3 (1.6)	8 (4.3)		4 (2.2)	1 (0.5)													
		P	165 (89.2)	2 (1.1)	11 (5.9)		6 (3.2)	1 (0.5)													
	Four Roots	M	1 (50.0)	1 (50.0)																	
		D	2 (100)																		
		P	1 (50.0)				1 (50.0)														
		Add Root	1 (50.0)	1 (50.0)																	
Upper left	One Root	M	2 (13.3)	1 (6.7)						2 (13.3)			1 (6.7)	2 (13.3)	1 (6.7)	1 (6.7)	5 (33.3)		14.2		
	Two Roots	M	7 (13.7)	10 (19.6)		17 (33.4)	2 (3.9)			2 (3.9)				8 (15.7)	1 (1.9)						
		D	43 (84.3)		2 (3.9)	1 (1.9)	5 (9.8)														
	Three Roots	M	50 (28.7)	53 (30.5)	15 (8.6)	29 (16.7)	11 (6.3)	11 (6.3)	1 (0.6)						2 (1.1)			2 (1.1)			
		D	160 (90.9)	4 (2.3)	6 (3.4)		6 (3.4)														
		P	158 (89.8)	1 (0.6)	4 (2.3)		12 (6.8)				1 (0.6)										
	Four Roots	M	2 (50.0)	1 (25.0)										1 (25.0)							
		D	4 (100.0)																		
		P	4 (100.0)																		
		Add Root	4 (100.0)																		
Lower left	One Root	M	2 (10.0)	4 (20.0)	3 (15.0)	1 (5.0)	3 (15.0)			1 (5.0)				3 (15.0)			3 (15.0)		17.3		
	Two Roots	M	2 (0.9)	90 (39.8)	2 (0.9)	114 (50.4)	8 (3.5)	3 (1.3)	1 (0.4)					3 (1.3)			3 (1.3)				
		D	170 (74.2)	15 (6.6)	16 (7.0)	9 (3.9)	16 (7.0)		1 (0.4)								1 (0.4)	1 (0.4)			
	Three Roots	M	7 (70.0)			2 (20.0)	1 (10.0)														
		D	5 (50.0)	1 (10.0)		2 (20.0)	1 (10.0)	1 (10.0)													
		ML	5 (50.0)	1 (10.0)		2 (20.0)	1 (10.0)	1 (10.0)													
Lower right	One Root	M	2 (6.7)	8 (26.7)	4 (13.3)	4 (13.3)	2 (6.7)							7 (23.3)		1 (3.3)	2 (6.7)		15.6		
	Two Roots	M	3 (1.3)	90 (38.1)	1 (0.4)	125 (53.0)	5 (2.1)	3 (1.3)	1 (0.4)		1 (0.4)			2 (0.8)			3 (1.3)	2 (0.8)			
		D	173 (73.0)	22 (9.3)	19 (8.0)	10 (4.2)	11 (4.6)	2 (0.8)													
	Three Roots	M	3 (60.0)			2 (40.0)															
		D	4 (80.0)			1 (20.0)															
		ML	4 (80.0)			1 (20.0)															

*Chi-square analysis, significant ($p<0.05$)

distobuccal root was type I (n:1, 100%), and type I (n:1, 100%) was also the highest classification for teeth in the palatal root.

The most common vertucci classification in the single-rooted upper teeth examined in the upper left region was XVIII (n:5, 33.3%). For the analysed two-rooted upper molars, the most prevalent classification in the buccal root was type IV (n:17, 33.4%). While type I (n:43, 84.3%) was the most frequently observed classification for the palatal root. Among the three rooted upper molars examined, the highest vertucci classification was type II for specimens located in the mesiobuccal root (n:53, 30.5%). The highest vertucci classification for the specimens located in the distobuccal root was type I (n:160, 90.9%) and the highest vertucci classification for the teeth located in the palatal root was type I (n:158, 89.8%). Among the four rooted upper molars examined, type I (n:2, 50.0%) was the highest classification for specimens in the mesiobuccal root. All specimens in the distobuccal root were classified as type I (n:4, 100%) likewise the highest vertucci classification for teeth in the palatal root was type I (n:4, 100%). There was a statistically significant difference between the Vertucci classifications according to the distribution of the teeth analyzed ($x^2_=117.111$, $p < 0.05$) (Table 4).

Root canals configuration of second lower molars according to Vertucci's classification

The most common Vertucci classification for the examined lower left single-rooted teeth was type II (n:4, 20%). Among the two-rooted lower molars analysed, type IV (n:114, 50.4%) was the most frequently observed classification in the mesial root. In contrast, type I (n:170, 70.4%) was predominant in the distal root. For the three-rooted lower molars, type I was again the most common classification, found in the mesiobuccal root (n:7, 70.0%), the distal root (n:5, 50%), and the mesiolingual root (n:5, 50%). Turning to the lower right single-rooted teeth, type II was also the most common classification (n:8, 26.7%). In the analysed two-rooted lower molars, the mesial root again shows type IV as the most prevalent classification (n:125, 53.0%), while the distal root predominantly features type I (n:173, 73.0%).

Among the three-rooted lower molars on the right side, type I was the highest classification observed in the mesiobuccal root ($n=3$, 60.0%), distal root (n:4, 80.0%), and mesiolingual root (n:4, 80.0%). Overall, there is a statistically significant difference between the Vertucci classifications based on the distribution of the examined teeth ($x^2=256.074$, $p < 0.05$) (Table 4).

Root canals configuration of second upper and lower molars according to Benjamı´n Brisen˜ o Marroquı´n classification

For the proposed Benjamı´n Brisen˜ o Marroquı´n classification, the most common configuration for upper right single-rooted teeth was ^{1}URM$^{3-2}$ (n:4, 20%). The most common configuration for two-rooted teeth; buccal root was ^{2}URM^2 (n:17, 37.8%) and palatal root was ^{2}URM^1 (n:43, 95. 5%). The most common configuration for upper right three-rooted teeth; mesial root was ^{3}URM$^{2-1}$ (n:66, 35.7%), in distal root was ^{3}URM^1 (n:169, 91.4%), and in palatal root was ^{3}URM^1 (n:165, 89.2%) (Fig. 5). Only ^{4}URM^1 configuration was observed in all roots of upper right second molars with four roots.

For the Benjamín Briseño Marroquín classification, the most common configuration in the upper left single-rooted teeth was ^{1}ULM$^{3-1}$ (n:5, 31.3%). In the two-rooted teeth, the most prevalent configuration in buccal root was ^{2}ULM^2 (n:17, 33.4%), while in the palatal root was ^{2}ULM^1 (n:43, 84.3%). For the Benjamı´n Brisen˜ o Marroquı´n classification, the most common configuration for upper left three-rooted teeth; mesial root was ^{3}ULM$^{2-1}$ (n:52, 29.5%), in contrast the most prevalent configuration for distal root was ^{3}ULM^1 (n:160, 90.9%), and the most common configuration for palatal root was ^{3}ULM^1 (n:158, 89.8%). Notably, only ^{4}ULM^1 configuration was observed in all roots of upper right second molars with four roots (Table 5).

According to the Benjamı´n Brisen˜ o Marroquı´n classification, the most frequent configuration in the lower left single-rooted teeth was ^{1}LLM$^{2-1}$ (n:4, 14.8%), In the case of two-rooted teeth; the most common configuration in the mesial root was ^{2}ULM^2 (n:114, 49.4%), while the distal root exhibited the configuration ^{2}ULM^1 (n:170, 73.6%). For lower left three-rooted teeth, the configuration ^{3}ULM^1 was the most frequent for the mesiobuccal root (n:7, 70%), and this same configuration also appeared most often in both the distal root ^{3}ULM^1 (n:5, 50%), and the mesiolingual root ^{3}ULM^1 (n:5, 50.0%).

In the lower right single-rooted teeth, the predominant configuration was ^{1}URM$^{2-1}$ (n:8, 23.5%), For two-rooted teeth, ^{2}URM^2 was the most common configuration in the mesial root (n:125, 52.5%) and the distal root showed ^{2}URM^1 (n:173, 72.7%). When examining lower right three-rooted teeth, the most common configuration for the mesial root was ^{3}URM^1 (n:3, 60%), which was also the case for both the distal root ^{3}URM^1 (n:4, 80%), and the mesiolingual root ^{3}URM^1 (n:4, 80.0%). There is a statistically significant difference exists among the new configuration according to the distribution of the teeth analysed ($x^2=343.068$, $p < 0.05$) (Table 5).

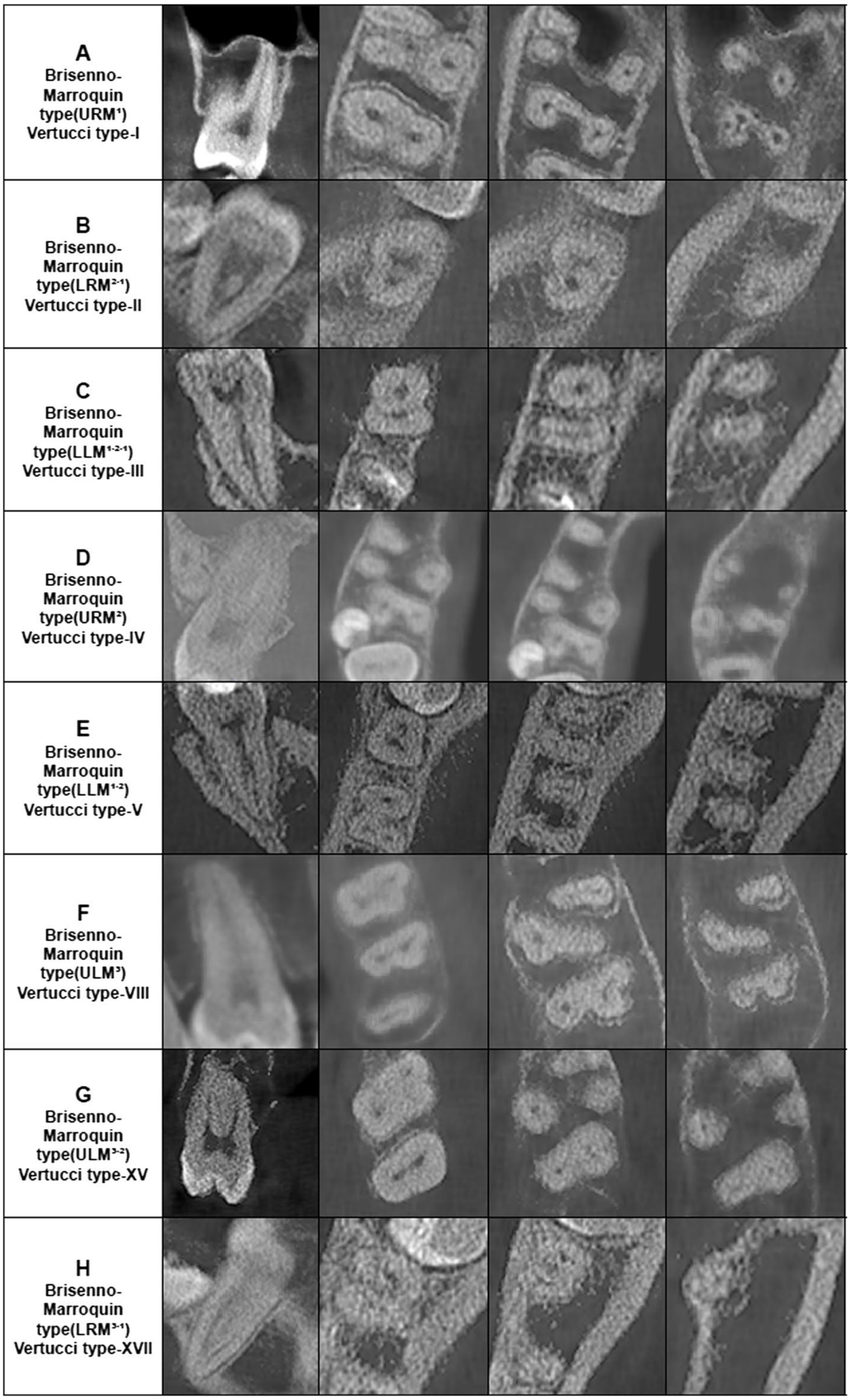

Fig. 5 Examples of most founded 8 type of root canal structers

Discussion

The outcome of root canal treatment can be influenced by several factors. The presence of bacteria is the main cause of most non-healed root canal treatments. Additionally, use of improper radiographic projections, including different mesiodistal angulations to identify

Table 5 Comparison of Benjamı´n Brisen˜ o Marroquı´n classification according to the number of roots and canals in upper and lower molars

			1	1–2	1–2–1	1–2–1–2	1–2–3–2	1–2–3–2–1	1–3	1–3–2	1–3–2–1	1–3–1	1–4	1–4–2-1	2	2–1	2–1–2	2–1–2–1-2–1	2–1–2-1
Upper right	One Root	M	1 (5.0)				1 (5.0)		1 (5.0)				1 (5.0)		1 (5.0)				
	Two Roots	B	6 (13.4)	1 (2.2)	1 (2.2)										17 (37.8)	13 (28.9)	1 (2.2)		
		P	43 (95.5)		1 (2.2)											1 (2.2)			
	Three Roots	M	46 (24.9)	13 (7.0)	18 (9.7)	2 (1.1)									29 (15.7)	66 (35.7)	6 (3.2)	1 (0.5)	
		D	169 (91.4)	4 (2.2)	8 (4.3)											3 (1.6)	1 (0.5)		
		P	165 (89.2)	6 (3.2)	11 (5.9)											2 (1.1)	1 (0.5)		
	Four Roots	M	1 (100.0)													1 (50.0)			
		D	2 (100.0)																
		P	1 (50.0)				1 (50.0)												
		add. Root	1 (50.0)	1 (50.0)															
Upper left	One Root	M	2 (12.5)									1 (6.3)				1 (6.3)			
	Two Roots	B	7 (13.7)	2 (3.9)	1 (1.9)										17 (33.4)	10 (19.6)			
		P	43 (84.3)	5 (9.8)	2 (3.9)										1 (1.9)				
	Three Roots	M	50 (28.4)	12 (6.8)	15 (8.5)	1 (0.6)									29 (16.5)	52 (29.5)	11 (6.3)		2 (1.1)
		D	160 (90.9)	6 (3.4)	6 (3.4)											4 (2.3)			
		P	158 (89.8)	13 (7.4)	4 (2.3)				1 (0.6)										
	Four Roots	M	2 (50.0)													1 (25.0)			
		D	4 (100.0)																
		P	4 (100.0)																
		add. Root	4 (100.0)																
Lower left	One Root	M	2 (7.4)	3 (11.1)	3 (11.1)									1 (3.7)	1 (3.7)	4 (14.8)			
	Two Roots	M	2 (0.9)	8 (3.5)	2 (0.9)	1 (0.4)									114 (49.4)	90 (39.0)	3 (1.3)		
		D	170 (73.6)	16 (6.9)	16 (6.9)	1 (0.4)		1 (0.4)			1 (0.4)				9 (3.9)	15 (6.5)			1 (0.4)
	Three Roots	M	7 (70.0)	1 (10.0)											2 (20.0)				
		D	5 (50.0)	1 (10.0)											2 (20.0)	1 (10.0)	1 (10.0)		
		ML	5 (50.0)	1 (10.0)		2 (20.0)	1 (10.0)	1 (10.0)											
Lower right	One Root	M	2 (5.9)	2 (5.9)	4 (11.8)					2 (5.9)		1 (2.9)			4 (11.8)	8 (23.5)			
	Two Roots	M	3 (1.3)	5 (2.1)	1 (0.4)	1 (0.4)			1 (0.4)						125 (52.5)	90 (37.8)	3 (1.3)		2 (0.8)
		D	173 (72.7)	11 (4.6)	19 (8.0)										10 (4.2)	22 (9.2)	2 (0.8)		
	Three Roots	M	3 (60.0)												2 (40.0)				

Table 5 (continued)

			1	1–2	1–2–1	1–2–1–2	1–2–3–2	1–2–3–2–1	1–3	1–3–2	1–3–2–1	1–3–1	1–4	1–4–2-1	2	2–1	2–1–2	2–1–2–1-2–1	2–1–2-1
		D	4 (80.0)												1 (20.0)				
		ML	4 (80.0)			1 (10.0)													
	2–3	**2–3–2**	**2–3–2–1**	**2–3–1**	**2–3–2-1–2**	**2–4**	**3**	**3–1**	**3–2**	**3–2–1**	**3–2–1–2**	**3–2–3**	**3–4–2**	**3–4–3–2**	**3–4–3**	**4–3**	**S.D**	**x**	***p****
Upper right	1 (5.0)		1 (5.0)				3 (15.0)	2 (10.0)	4 (20.0)			1 (5.0)			1 (5.0)	2 (10.0)	12.5	343.068	0.001
	1 (2.2)					1 (2.2)		1 (2.2)	1 (2.2)			1 (2.2)							
			1 (0.5)						2 (1.1)		1 (0.5)								
Upper left	1 (6.3)		1 (6.3)	1 (6.3)			2 (12.5)	5 (31.3)	2 (12.5)								14.3		
	1 (1.9)		1 (1.9)		1 (1.9)		2 (3.9)		8 (15.7)	1 (1.9)									
	2 (1.1)	1 (0.6)								1 (0.6)									
									1 (25.0)										
Lower left		1 (3.7)					1 (3.7)	3 (11.1)	3 (11.1)	2 (7.4)		1 (3.7)		1 (3.7)	1 (3.7)		17.1		
		2 (0.9)	1 (0.4)					3 (1.3)	3 (1.3)	2 (0.9)									
								1 (0.4)											
Lower right								2 (5.9)	7 (20.6)	1 (2.9)			1 (2.9)				16.8		
			2 (0.8)					3 (1.3)	2 (0.8)										
		1 (0.4)																	

* Chi-square analysis, significant ($p < 0.05$)

various root canal system aberrations, such as extra canals often result in failure, even with a correct diagnosis [31]. Other morphologic factors include lateral and accessory canals, canal curvatures, canal wall irregularities, fins, and isthmuses [32].

A comprehensive understanding and accurate description of root and canal anatomy is one of the critical preliminary steps for successful root canal treatment. Three-dimensional diagnostic imaging methods such as CBCT are non-invasive imaging methods that can be applied before starting endodontic treatment. With the help of CBCT, root canal anatomy can be easily examined [33]. A non-invasive technology that allows for 1:1 accurate three-dimensional assessment of tooth dimensions and root and canal morphology [27]. CBCT has been used to study a variety of tooth types, both experimentally and clinically [34]. To address deficiencies in existing systems, a new coding system for classifying root and canal morphology, accessory canals and anomalies has been introduced. In recent years, micro-computed tomography (micro-CT) [6, 14, 15, 17, 25] and cone beam computed tomography (CBCT) have been extensively used to study the details of root and canal anatomy in extracted teeth and within clinical settings [5, 6, 8, 9, 13, 21, 22, 24, 30, 31, 35–40].

Considering these findings, CBCT has been employed to evaluate the root morphologies in the present study. The number of root teeth were classified according to Vertucci's classification, whereas canal configurations and numbers were classified by using Benjamı´n Brisen˜o Marroquı´n [17] and Ahmad et al.'s [6] system. Voxel size was determined as 200 µm, similar to other studies [9, 36, 38]. Some of the previous studies focused on the comparison of C-shaped configurations in mandibular second molars between different populations in the world. In the present study, only the Turkish subpopulations root canal numbers and configurations were evaluated. Additionally, gender and age were considered as other criterias during classification in this study, similar to other previous studies [5, 9, 13–15, 21, 22, 24, 31, 37, 39, 40].

In this study, the most common Vertucci classification in buccal roots of two rooted upper molars was type IV, on the other hand Type I was most prevalent in palatinal roots. For three rooted upper molars, the highest Vertucci Classifications for Mesiobuccal, Distobuccal and Palatinal roots were; Type II, Type I and Type I respectively. Four rooted upper molars each root classified in Type I. No difference found between the right and left region of upper second molars. The results which are belong to two rooted upper molars are consistent with the findings of Buchanan et al.'s [9] who studied the maxillary second premolars, as well as Mheiri et al. [39], who examined the morphology of maxillary first molars, palatal and distal roots. Similarly, in the lower molars, type I was the most common Vertucci classification, followed by type IV. These results align with the findings reported by Kim et al. [26]. Mağat et al.classifed the mesiobuccal root canals in maxillary first molars according to both Vertucci's and Ahmed et al.'s systems. They found Type I was most common in mesiobuccal canals according to Vertucci's Classification. On the other hand, when they evaluated root canals according to Ahmed et al.'s system, they found $^{3}16MB^{1}$ and $^{3}26MB^{1}$ most common respectively in right and left regions. These results are not similar with our findings [41].

In this study, the most common type of Vertucci classification in lower molar single rooted teeth was Type II. In two rooted teeth, the most common Vertucci classification in the Mesial root was type IV, while Type I was the most common in Distal root. These findings are agreement with Saber et al.'s findings [2]. Among the examined lower molar three rooted teeth, the highest Vertucci classification was Type I for Mesibuccal, mesiolingual and distal canals. The findings found similar for both left and right regions. These findings indicate that both round-shape canals and single-canal anatomy are usually classified in Vertucci's classification Type I. Mesial roots which contain 2 canals, may be classified as Type IV or Type II. These results compatible with the other studies [9, 15, 21, 39]; however, those studies evaluated the teeth by using micro-CT and four-digit classifying system [17, 25]. The roots which have round shape, generally classified in Type I. Senan et al. [15], in agreement with our findings on a large scale. Type II was found in higher rate in mesial root of mandibular second molars whereas our findings mainly referred Type IV. Hatipoğlu et al.(2023) evaluated the middle mesial canal in the mandibular first molar teeth by using CBCT [42]. The prevalence ranged from %1-%23, overall %7. In another study, Hatipoğlu et al. [43] evaluated the distolingual canals in mandibular first molars using CBCT. They found the prevalence of distolingual canal ranged from %3-%50 and the overall prevalence %22. The overall findings assume similar with our findings (Type I) related to distal canal. They asserted the study varies by ethnicity, however in the present study different ethnicity wasn't compared each other. Only Turkish subpopulation was evaluated.

In the present study, when the teeth root configurations based on the region of the localisation according to Benjamin Brisen Marroquin's classification, it was found that the results were mostly similar for both right and left regions in the upper second molars, also it's similar for lower second molars. The most common configuration for upper right two-rooted teeth buccal root is $^{2}URM^{2}$ and but then for upper left two rooted teeth buccal root is $^{2}ULM^{2.}$ For the palatinal canals, the findings were similar both left ($^{2}ULM^{1}$) and right ($^{2}URM^{1}$) regions. For the Benjamin Brisen Marroquin's classification, the most common configuration for upper right three-rooted mesial root is $^{3}URM^{2-1}$, whereas for upper left three rooted mesial root is $^{3}ULM^{2-1}$, the most common configuration for distal root is $^{3}URM^{1}$ in upper right molars; $^{3}ULM^{1}$ is the most prevalent type in upper left second molars. For palatinal root configuration is commonly $^{3}URM^{1}$ in upper right second molars; $^{3}ULM^{1}$ in upper left second molars. These findings are correlated with the Wolf et al.'s study which evaluated the teeth by using microct [14]. They suggested that the root canal configuration of maxillary 2. Molar is heterogeneous [14]. However, comparison of the single rooted teeth results were quite different according to the region. The configuration canal results were for upper right second molar and upper left second molars; $^{1}URM^{3-2}$, $^{1}ULM^{3-1}$ respectively. In upper second molars with three roots, it was found that mesial roots have 2 canals which are fusing near the apex. Distal and palatinal roots have 1 canal for each. These findings are expected by the examiners in this study.

The evaluation of lower second molars root configuration according to Benjamin Brisen Marroquin's classification revealed to comment about the symmetrical structure of the teeth. The findings indicated that the root canal configurations were so similar in lower second molars. The most frequent type for lower left single rooted was $^{1}LLM^{2-1}$, while it was $^{1}LRM^{2-1}$ for lower right single rooted second molars for both left and right regions. In two rooted teeth's mesial canal configuration for lower left second molars and lower right second molars was $^{2}LLM^{2}$ and $^{2}LRM^{2}$ respectively. Distal roots findings were similar again both right ($^{2}LRM^{1}$) and left lower ($^{2}LLM^{1}$) second molars. The distribution of root canal configurations in lower left three rooted teeth was for all root canal types; MB:$^{3}LLM^{1}$, D:$^{3}LLM^{1}$ and P:$^{3}LLM^{1}$, on the other hand the results were so similar in lower right second three rooted molars. The most configuration in left second molars for mesiobuccal root, distal root and mesiolingual root was $^{3}LLM^{1}$. In the right region of mandibula, the findings were the similar. For MB:$^{3}LRM^{1}$, D:$^{3}LRM^{1}$ also ML: $^{3}LRM^{1}$, Abarca et al. evaluated the mandibular 1. and 2. molar root canals morphology using by CBCT, and classified the canals according to Ahmad et al.'s classification. They found the similar results with our findings [16].

These results obviously revealed that symmetrical structure of root canals commonly in Turkish subpopulation. In Contrary, Alfawaz et al. found the unilateral presence of C shaped root canal system more common [12]. The other studies suggested the symmetrically configuration of root canals [8, 15] In the present study; canal orifices generally begin with two canals and than canals are getting fused in the single rooted lower second molars. The root canal may have only a foramen near the apex. In two rooted lower second molar teeth, number of mesial canals were 2, while distal canals were 1. It was a predicted result for this study. When the three roots examined in lower second molars, it was seen that all the roots have 1 canal for each. If we adapt the Benjamin Brisen Marroquin's classification to Vertucci 's Classification system, all results of this study are coherent. The previous CBCT studies [1, 2, 7, 8, 10, 15, 18] mainly based on Vertucci's classification, whereas Buchanan et al.[1], Abarca et al. [16] classified the root canals in order to adapt the system that Ahmad et al.'s classification [13]. The results of studies that examined the micro-CT [3, 4, 6, 14] evaluated according to the 4 digit system. So, the comparison of the results between our study and the previous studies can achieve the explanation of the other classifications. The four digit system could be described; dividing the roots into thirds. Each of part includes coronal, middle and apical thirds, respectively. The fourth digit indicates the number of foramina [6]. If the litreature is searched, it can clearly seen that number of studies that had classified the roots according to the new classifications are so restricted. Because of these limitations, we compared our findings associated with the CBCT in addition to this microct studies.

Both Vertucci classification and the new coding system aimed to determine the anatomical variations in root structures. The classification systems which based on root canal structure on several root levels are more detailed and complicated when compared with the others.The new coding system describes the anatomical features of roots in a consistent manner regardless of the tooth type and whether a tooth is single or multi rooted [7].

Generally, morphological studies didn't explain the beginnig point of canal orifices and ending point Of the pulp chamber. Not only Vertucci's classification system but also Weine et al.'s classification system hadn't described these necessary points. The new system for root and canal morphology determines the the root canal configuration with a first point till foramen apicale through the canal [6]. Magat et al., classified the mandibular incisors according to Vertucci's and Ahmed's classification system. They emphasized that Vertucci's classification system is inadequate in some cases whereas Ahmed et al.'s system was able to classify all mandibular incisors with a single code [44]. Despite the similar findings between Vertucci's system and new coding system in our study; the new coding system allows more detailed classification.

In the present study, some images were not so clear in order to classify the root canals excessively correct. In such circumstances, two examiners evaluated the images in order to exclude or include with consensus and classifed according to the accurate image.

Conclusion

In Brief, the configuration of root canal morphologies classified according to Vertucci and Benjamin Brisen Marroquin's systems. Most of the findings exhibited that the anatomical structure is symmetrical for both sides in Turkish Subpopulation. Mesial canals configuratios can be variable when the compared with other roots. Palatinal roots and distal root canals indicated Type I (single structure) commonly. Mesial root canals both in maxillary and mandibulary teeth, exhibited Type IV and rarely Type II. The correlation between the gender and the root number was assesed. In terms of anatomic variation of root canals, the increased rate was found in female than male patients.

Limitations

Overall, this study emphasises the importance of employing comprehensive classification systems to accurately characterise root canal morphology and highlights the significance of adequate sample size determination for robust statistical analysis. The insights gained from this study contribute to enhancing the understanding of root canal anatomy, ultimately improving the success rates of endodontic treatments in clinical practice.

Abbreviations

CBCT	Cone-beam computed tomography
Micro-CT	Micro-computed tomography
TN	Tooth number
ULM	Upper left molar
URM	Upper right molar
LLM	Lower left molar
LRM	Lower right molar
M	Mesial
D	Distal
B	Buccal
P	Palatinal
MB	Mesiobuccal
DB	Distobuccal
ML	Mesiolingual

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Clinical trial number

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Authors' contributions

H.G.G: Writing – Original draft, Conceptualisation, Methodology, Validation, Investigation, Project administration; İ.Ö: Writing – review and editing, Supervision, Visualisation, Resources, Formal analysis; K.Ç: Data curation, Funding acquisition, Investigation; K.C.A: Data curation, Investigation, Software, Formal analysis. All authors reviewed the manuscript.

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Data availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University approved the study and informed consent to participate was waived (E-10840098–202.3.02–2246). This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants and images were anonymised.

Consent for publication

NA.

Competing interests

The authors declare no competing interests.

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