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Root canal configuration in mandibular anterior teeth: Insights from cone-beam computed tomography in a Turkish subpopulation

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Abstract

Aim: The aim of this study was to examine the structures, roots and canal numbers of mandibular anterior teeth using cone-beam computed tomography (CBCT).

Methods: The study evaluated 4830 fully developed mandibular anterior teeth from 953 CBCT scans. The final sample consisted of 515 scans of females and 438 scans from males, with ages ranging from 17 to 69 years. Among the assessed teeth, 2475 were located on the right side and 2355 on the left, including 2614 from females and 2216 from men. The teeth were free of any fillings, resorption, or cracks in the root or crown. The study analyzed the numbers of roots and root canals, location of the apical foramen, and canal type according to Vertucci's classification.

Results: 82.7% of teeth had single-root canals, whereas four lateral teeth (0.2%) and 42 lower canines (2.4%) had two-roots. The apical foramen was located centrally in 80.9% of the teeth (n = 3909), followed by buccal (8.8%), distal (4.2%), lingual (3.4%), and mesial (2.7%) positions. Using Vertucci's classification of root canal types, type-I was the most prevalent (65.3%), followed in order by types-III (28.6%), II (4.2%), V (1.5%), and VI (0.4%).

Conclusion: Turkish mandibular anterior teeth have intricate anatomy. To enhance comprehension of the complex anatomy of Turkish mandibular incisors and canines, including the numbers of canals and roots and canal configurations, further studies of more patients from diverse regions of Türkiye are needed. The tooth configuration was influenced by gender rather than by tooth position.

Keywords: Root canal morphology, Vertucci, apical foramen, cone-beam computed tomography, mandibular anterior teeth

Introduction

Endodontic treatment relies on proper shaping, cleaning, and hermetically obturating complex root canal anatomy (1, 2). Technological advances have improved the efficacy of root canal instruments, techniques, and materials, making the procedure faster and easier (3). However, the success rate depends on factors such as the operator's skill and presence of anatomical complexities. These factors can cause iatrogenic errors and an increased number of canals, leading to incomplete debridement and disinfection (4). Missed root canals contribute significantly to treatment failure. Therefore, it is crucial to understand the root canal morphology and identify any missing canals for successful endodontic therapy. The anatomy of the root canal cannot be altered (1). To comprehend the anatomy of a particular case that requires treatment, it is essential to use clinically relevant methods. Although methods such as clearing, cross-sectioning, and modified canal staining can provide a general understanding of root canal anatomy, they can be used only in vitro with extracted teeth (5).

In the past, angulated radiography was proposed to help dentists evaluate the location, number, and configuration of canals before treatment. Recently, cone-beam computed tomography (CBCT) has been proposed as a precise cost-effective tool to solve these problems (6). CBCT creates three-dimensional images of teeth, which is advantageous compared to the two-dimensional images of periapical and panoramic radiography. It is considered a decisive clinical approach to understand root canal morphology (6).

Typically, mandibular anterior teeth and canines have one canal and one root, making them relatively easy to treat. However, root canal morphology can vary, which may complicate treatment and negatively impact outcomes. The proportions of second canals, lateral canals, and apical deltas can vary with geography, gender, and age (7). The proportions of variants range from 9.2% to 21.5% in China (8) and from 18.63% to 28.43% in India (9).

Therefore, this study evaluates the canal configurations of mandibular anterior teeth in a Turkish population, considering the effects of gender, tooth type, side of the mandible, and the localization of the apical foramen using CBCT imaging. The null hypothesis held that there were no significant differences between men and women or between the right and left sides, in terms of Vertucci's classification, the numbers of canals and roots, and apical foramen location.

Materials and Methods

This retrospective study was approved by the Health Sciences University, Scientific Research Ethics Committee on December 29, 2023 (decision number 24126). Initially, 1678 CBCT images from the archives of the Department of Oral and Maxillofacial Radiology, Hamidiye Faculty of Dentistry, University of Health Sciences, were reviewed. After exclusions based on an insufficient field of view (FOV), criteria related to the mandibular anterior teeth, and poor diagnostic image quality, 953 mandibular scans were considered for analysis. This final sample comprised 515 scans from females and 438 scans from males, ranging in age from 17 to 69 years. Of the teeth evaluated, 2475 were on the right side and 2355 were on the left, with 2614 from females and 2216 from males.

The CBCT images were captured using a NewTom 5G (QR, Verona, Italy), with a power of 110 kV, voxel size of 75 µm, slice spacing of 0.2 mm, and 6 × 6 FOV. The images were from patients with various dental and maxillofacial issues. An experienced radiologist adhered to the 'as low as reasonably achievable' principle using the minimum exposure time necessary for adequate image quality according to the manufacturer's recommended protocol.

The study inclusion criteria comprised high-quality CBCT images of mandibular anterior teeth with fully formed apices, while exclusion criteria were teeth with extensive cervical and root caries, fused roots, dens invaginatus, embedded tooth roots, image artifacts from dental implants, insufficient diagnostic quality, coronal restorations, endodontically treated teeth with posts, and teeth with resorption or periapical lesions. After applying these criteria, 4830 mandibular anterior teeth from 953 eligible patients were analyzed using NNT software on a computer with a 22-inch monitor and an i-CAT Workstation® (Imaging Sciences International, Hatfield, PA, USA). Coronal, axial, and sagittal reconstructions were examined, and the sagittal, coronal, and axial sections were calibrated by two endodontists, with a third oral diagnostician and a radiologist providing a definitive assessment when consensus could not be reached.

To evaluate the inter-rater agreement for the morphological types assigned to the root canals, a second review and re-evaluation were conducted 6 weeks later, following Vertucci's classification (10). The data were entered into a Microsoft Excel® spreadsheet and then imported into the IBM Statistical Package for the Social Sciences® (SPSS) ver. 25 (IBM Corp., Armonk, NY, USA). The inter-rater reliability and consistency of the results were assessed using Cohen's kappa. In the study, kappa values of < 0.4, 0.41–0.6, 0.61–0.8, and 0.81–1.0 were considered 'low', 'moderate', 'high', and 'fully reliable', respectively, based on a study of the root and canal morphology of mandibular permanent anterior teeth in a Chongqing, China, population (11). The study was calibrated, and a reliable kappa index was obtained, indicating a fully reliable classification.

Documented parameters included patient age and sex, tooth type (central, lateral, or canine), numbers of root canals and roots, root canal configuration according to Vertucci's classification (10, 12), and location of the apical foramen of the roots (13). Vertucci's classification is based on the anatomy of the root canal system. Type I has a single root canal that extends from the pulp

chamber and ends as a single foramen. Type II has two root canals that extend from the pulp chamber and end as a single foramen. Type III has one root canal that extends from the pulp chamber, divides into two separate root canals, and ends as a single foramen. Type IV has two root canals that extend from the pulp chamber and end as two separate foramina. Type V has a single root canal that leaves the pulp chamber and ends with two foramina. Type VI has a pulp chamber with two root canals that reunite and terminate as two foramina. Type VII has a pulp chamber with one root canal that divides into two separate canals, which then merge back into a single canal and exit as two foramina. Type VIII has three root canals that end in three foramina (Fig. 1). A graphical illustration of the study is shown in Figure 2.

Statistical analysis

Analyses were performed by using IBM SPSS 25.0 software (IBM Inc., Armonk, New York, USA).

The relationships between categorical variables were tested using Pearson's chi-square test, provided that the sample size assumption (expected value > 5) was met. When this assumption was not met, Fisher's exact test was used. The significance level was taken as $p<0.050$.

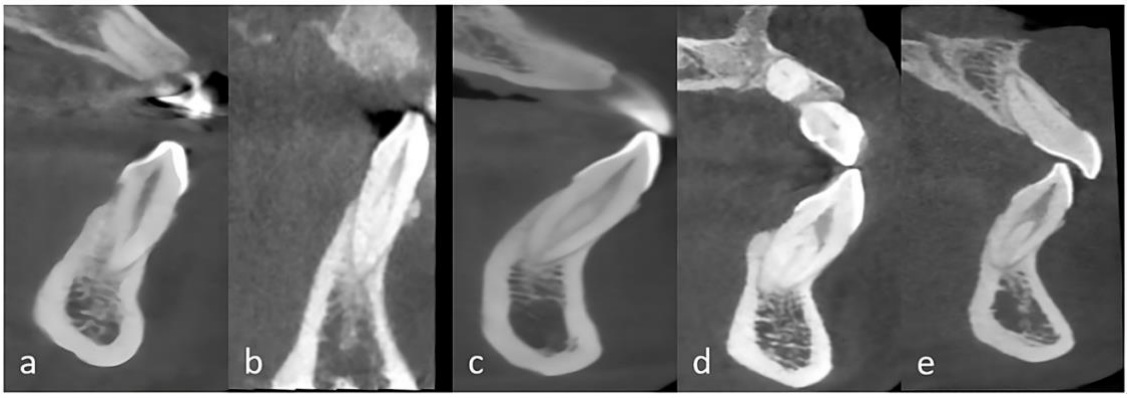

Figure 1. Types by Vertucci's classifications. (a: Type I, b: Type II, c: Type III, d: Type IV, and e: Type V)

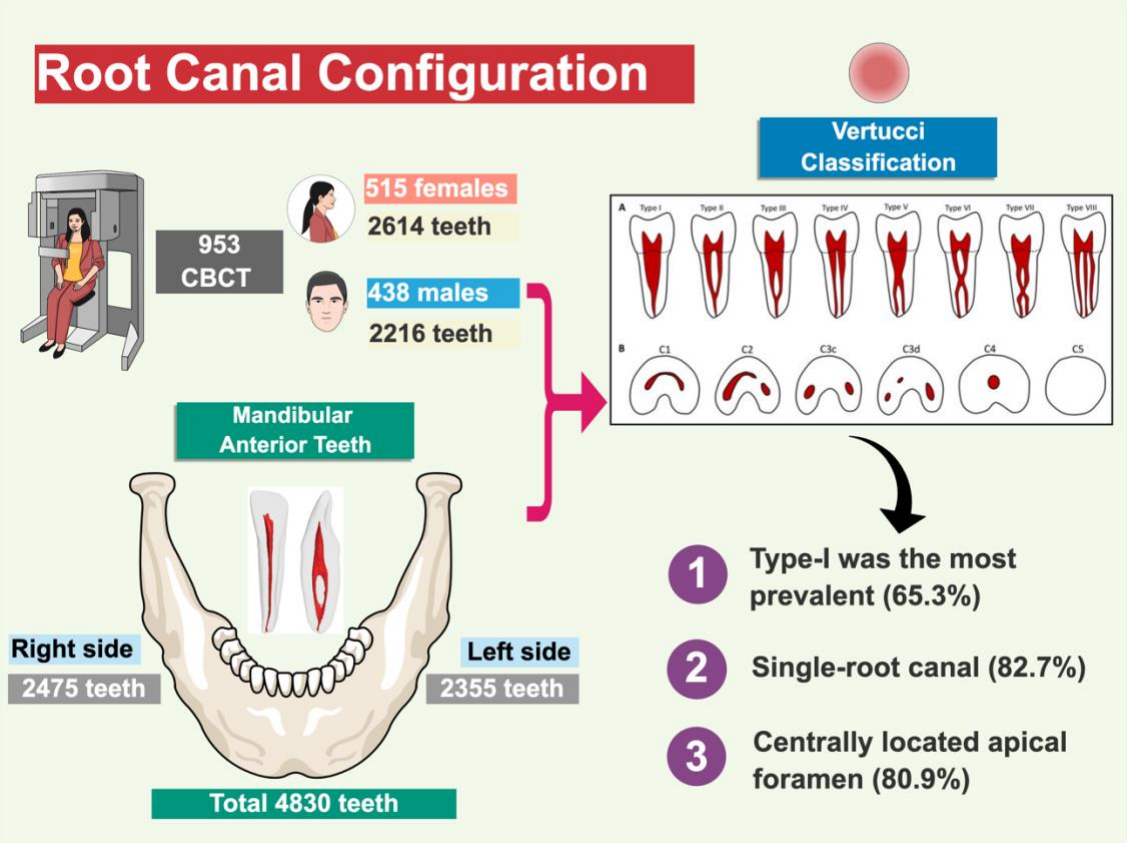

Figure 2. Graphical illustration of the study.

Results

Pearson's chi-square test was used to analyze the relationships between the Vertucci classification, tooth location (right or left side), and gender. There were no significant relationships between the Vertucci classification and location (side) or gender ($p>0.05$). Table 1 shows the even distribution of the Vertucci types among genders and the left and right sides.

The study used Pearson's chi-square and Fisher's exact tests to evaluate the relationships among the numbers of roots and root canals, region, and gender. A significant relationship was found between the number of root canals in lateral teeth and gender ($p<0.05$). Women's teeth usually had a single canal, while men's teeth usually had two canals. Table 2 shows the significant correlation ($p<0.05$) between the number of root canals and gender in all teeth. Pearson's chi-square test was used to examine the correlation between the location of the apical foramen, side, and gender. This showed a significant relationship between location and gender ($p<0.05$).

The apical foramen was located centrally (buccally or lingually) in women and medially (distally) in men (Table 3). There was a 20.4% incidence of two canals in lower central teeth, while none of the teeth had two roots in the same type of tooth (Table 2).

The incidence of two canals in lower lateral teeth was 20.4%, and only four (0.2%) teeth had two roots. For lower canines, 9.3% of the teeth had double canals, which was the lowest percentage compared to other types of teeth, and 2.4% had double roots, which was the highest percentage (Table 2, Fig. 3).

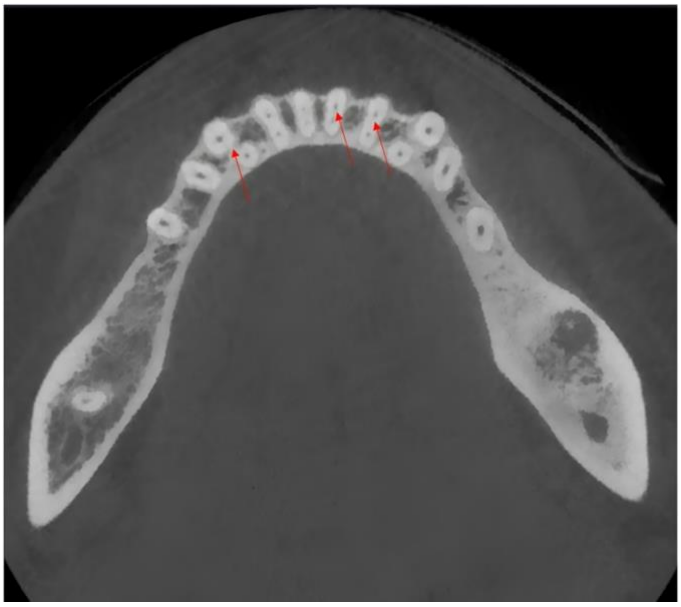

Figure 3. The arrows indicate a canine with two roots, a central incisor with two canals, and a lateral incisor with two canals, respectively.

Table 1. Relationship and cross-tabulation between Vertucci classification and region and gender

				Vertucci Classification																
				Type 1			Type 2			Type 3			Type 4			Type 5				
Tooth	Sex		Side	n	%	V%	n	%	V%	n	%	V%	n	%	V%	n	%	V%		Test statistics/ *p value*
CENTRAL	Man	678	Right	194	53.7	53.9	16	4.4	53.3	143	39.6	52.0	3	0.8	60.0	5	1.4	62.5	Side	0.705
			Left	166	52.4	46.1	14	4.4	46.7	132	41.6	48.0	2	0.6	40.0	3	0.9	37.5		0.951
	Woman	810	Right	217	53.7	50.5	17	4.2	51.5	165	40.8	49.0	3	0.7	50.0	2	0.5	50.0	Sex	2.360
			Left	213	52.5	49.5	16	3.9	48.5	172	42.4	51.0	3	0.7	50.0	2	0.5	50.0		0.670
Total Central		1488	Total	790	53.1	100	63	4.2	100	612	41.1	100	11	0.7	100	12	0.8	100		
LATERAL	Man	740	Right	196	51.3	51.7	8	2.1	50.0	171	44.8	51.5	2	0.5	50.0	5	1.3	55.6	Side	0.737
			Left	183	51.1	48.3	8	2.2	50.0	161	45.0	48.5	2	0.6	50.0	4	1.1	44.4		0.947
	Woman	864	Right	223	51.1	50.3	12	2.8	52.2	196	45.0	50.4	2	0.5	40.0	3	0.7	75.0	Sex	3.213
			Left	220	51.4	49.7	11	2.6	47.8	193	45.1	49.6	3	0.7	60.0	1	0.2	25.0		0.523
Total Lateral		1654	Total	822	49.7	100	49	2.9	100	721	43.5	100	9	0.5	100	13	0.8	100		
CANINE	Man	798	Right	362	89.2	51.0	21	5.2	45.7	13	3.2	56.5	0	0.0	0.0	10	2.5	52.6	Side	0.348
			Left	348	88.8	49.0	25	6.4	54.3	10	2.6	43.5	0	0.0	0.0	9	2.3	47.4		0.951
	Woman	940	Right	431	88.7	51.7	28	5.8	51.9	12	2.5	50.0	0	0.0	0.0	15	3.1	53.6	Sex	0.746
			Left	403	88.8	48.3	26	5.7	48.1	12	2.6	50.0	0	0.0	0.0	13	2.9	46.4		0.862
Total Canine		1738	Total	1544	88.8	100	100	5.8	100	47	2.7	100	0	0.0	0.0	47	2.7	100		
TOTAL TEETH	Man	2216	Right	752	65.4	51.9	45	3.9	48.9	327	28.5	51.9	5	0.4	55.6	20	1.7	55.6	Side	0.784
			Left	697	65.3	48.1	47	4.4	51.1	303	28.4	48.1	4	0.4	44.4	16	1.5	44.4		0.941
	Woman	2614	Right	871	65.7	51.0	57	4.3	51.8	373	28.1	49.7	5	0.4	45.5	20	1.5	55.6	Sex	0.538
			Left	836	64.9	49.0	53	4.1	48.2	377	29.3	50.3	6	0.5	54.5	16	1.2	44.4		0.970
TOTAL	Total	4830	Total	3156	65.3	100	202	4.2	100	1380	28.6	100	20	0.4	100	72	1.5	100		

%: Line percentage V%: Column percentage for Vertucci classification

Table 1. Relationship and cross-tabulation between the number of roots and root canals and region and gender

				Root Canal Number						Root Number						Side	Sex
				One Canal			Two Canals			One Root			Two Roots				
Tooth	Sex		Side	n	%	R.C. %	n	%	R.C. %	n	%	R.N. %	n	%	R.N. %		Test Statistics/ p value	Test Statistics/ p value
CENTRAL	Man	678	Right	283	78.4	53.4	78	21.6	52.7	361	100.0	53.2	0	0.0	0.0	Root	0.122	1.499
			Left	247	77.9	46.6	70	22.1	47.3	317	100.0	46.8	0	0.0	0.0	Canal	0.727	0.221
	Woman	810	Right	323	80.0	49.4	81	20.0	51.9	404	100.0	49.9	0	0.0	0.0	Root	-	-
			Left	331	81.5	50.6	75	18.5	48.1	406	100.0	50.1	0	0.0	0.0	Number	-	-
	Total	1488	Total	1184	79.6	100	304	20.4	100	1488	100	100	0	0.0	0.0			
LATERAL	Man	740	Right	272	71.2	51.2	110	28.8	52.6	382	100.0	51.6	0	0.0	0.0	Root	0.327	21.282
			Left	259	72.3	48.8	99	27.7	47.4	358	100.0	48.4	0	0.0	0.0	Canal	0.567	**0.000***
	Woman	864	Right	353	81.0	50.1	83	19.0	51.9	434	99.5	50.5	2	0.5	50.0	Root	-**	-**
			Left	351	82.0	49.9	77	18.0	48.1	426	99.5	49.5	2	0.5	50.0	Number	1.000	0.129
	Total	1654	Total	1235	80.0	100	369	23.0	100	1600	99.8	100	4	0.2	100			
CANINE	Man	798	Right	367	90.4	51.0	39	9.6	49.4	396	97.5	50.8	10	2.5	52.6	Roo	0.125	0.585
			Left	352	89.8	49.0	40	10.2	50.6	383	97.7	49.2	9	2.3	47.4	Canal	0.723	0.445
	Woman	940	Right	444	91.4	51.8	42	8.6	50.6	473	97.3	51.6	13	2.7	56.5	RootNu	0.204	0.008
			Left	413	91.0	48.2	41	9.0	49.4	444	97.8	48.4	10	2.2	43.5	mber	0.652	0.929
	Total	1738	Total	1576	90.0	100	162	9.3	100	1696	97.6	100	42	2.4	100			
TOTAL TEETH	Man	2216	Right	922	80.2	51.8	227	19.8	52.1	1139	99.1	51.8	10	0.9	52.6	Root	0.152	16.320
			Left	858	80.4	48.2	209	19.6	47.9	1058	99.2	48.2	9	0.8	47.4	Canal	0.696	**0.000***
	Woman	2614	Right	1120	84.5	50.6	206	15.5	51.6	1311	98.9	50.7	15	1.1	55.6	Root	0.179	0.392
			Left	1095	85.0	49.4	193	15.0	48.4	1276	99.1	49.3	12	0.9	44.4	Number	0.672	0.531
	Total	4830	Total	3395	82.7	100	835	17.3	100	4784	99.1	100	46	0.9	100			

*$p<0.05$. **: Fisher's Exact test. %: Row percentage. R.C.%: Column percentage for the number of root canals and R.N.%: Column percentage for the number of roots ($p<0.05$ is statistically significant).

Table 2. Apical foramen location

			Location															Side	Sex
			Central			Mesial			Distal			Buccal			Lingual				
Sex		Side	n	%	L%	n	%	L%	n	%	L%	n	%	L%	n	%	L%	Test Statistics /p value	Test Statistics /p value
Man	2216	Right	933	**81.2**	51.9	52	**4.5**	52.5	63	**5.5**	52.1	82	**7.1**	51.6	19	**1.7**	50.0	0.036	107.414
		Left	866	**81.2**	48.1	47	**4.4**	47.5	58	**5.4**	47.9	77	**7.2**	48.4	19	**1.8**	50.0	1.000	**0.000***
		Total	1799	**81.2**	100.0	99	**4.5**	100.0	121	**5.5**	100.0	159	**7.2**	100.0	38	**1.7**	100.0		
Woman	2614	Right	1070	**80.7**	50.7	16	**1.2**	48.5	41	**3.1**	51.3	135	**10.2**	50.8	64	**4.8**	51.2		
		Left	1040	**80.7**	49.3	17	**1.3**	51.5	39	**3.0**	48.8	131	**10.2**	49.2	61	**4.7**	48.8		
		Total	2110	**80.7**	100.0	33	**1.3**	100.0	80	**3.1**	100.0	266	**10.2**	100.0	125	**4.8**	100.0		
TOTAL	4830	Total	3909	**80.9**	100.0	132	**2.7**	100.0	201	**4.2**	100.0	425	**8.8**	100.0	163	**3.4**	100		

*$p<0.05$. %: Row percentage and L%: Column percentage for apical foramen location

Discussion

A precise understanding of root canal anatomy is crucial for successful endodontic treatment. CBCT has been used to evaluate the morphology of mandibular incisors and canines (14). CBCT is preferable to extracted teeth for understanding root canal morphology because it provides more clinically relevant information and potentially allows the evaluation of many more specimens (13, 15). CBCT imaging provides detailed information about the symmetry and differences in the jaws and teeth, as well as the morphology of the teeth and surrounding tissues (16, 17). Consequently, numerous anatomical studies have used CBCT. However, the numbers of roots and canals depend on geography, population, and gender (4). Therefore, results from different countries and populations may not be applicable to the Turkish population. There may also be variation within a country due to differences in population groups (18, 19). This study examined 953 CBCT images of 4830 teeth, specifically lower central incisors, lower lateral incisors, and lower canines, in the Turkish population.

In our study, 79.6% of lower central teeth, 80% of lower lateral teeth, and 90.7% of lower canines had one canal. In comparison, in a CBCT study by Pan et al, the respective percentages of teeth with one canal were 94.6%, 87.7%, and 94% (20). In an extracted tooth study, 73.8% of mandibular incisors had one canal (21), although Sert et al. found a lower percentage of single canals when compared with two canals (22). Although conducted within Türkiye, our study may have yielded different outcomes because of regional differences within the country and the fact that the other study examined extracted teeth. A second canal was found in 9.3% of lower canines, which is higher than the percentages reported by Rahimi et al. (8.4%) (23) and Han et al. (6.27%) (24), but lower than those reported by Sert et al. (24%) (22) and Vertucci (22%) (10). Inconsistencies regarding canal configurations, canal and root numbers, and apical foramen locations among the studies are related to the methodologies used. The current study found that most females have one canal, while most males have two canals. Similarly, other studies found that Turkish males have more canals (25), and gender is a significant determinant of root canal anatomy (26). Therefore, before treatment, it is important to evaluate the tooth morphology based on gender.

The location of the apical foramen differs by gender, appearing centrally (buccally or lingually) in women and medially (distally) in men. We found that gender and location (side) did not affect the Vertucci classification, only the types of teeth resulted in differences. Although various configurations have been examined, type I and III canal structures are the most frequent in mandibular incisors35; our results are consistent with this. The most frequently detected configuration in lower canines was type I, which is consistent with previous studies (23, 27, 28). Similar to Soleymani et al. (28), we also observed types II, III, and V, but not type IV in lower canines.

Various Vertucci configurations can pose treatment challenges due to the difficulty locating the canal orifices in teeth with differing canal configurations, and the complex root canal anatomy, which can hinder shaping, disinfection, and the hermetic root canal filling required for endodontics (29). Knowledge of the variation in root canal configurations is essential. The use of CBCT in clinical practice ensures an accurate endodontic diagnosis, which is crucial for root canal treatment, retreatment procedures, and managing endodontic complications.

Nevertheless, the methodology used in our study has limitations. CBCT obtained detailed information about the alveolar bone, anatomical structures and teeth (30, 31). Meanwhile, micro-computed tomography (micro-CT) yields more information about canal morphology (minor and major foramens and the distance between them, lateral canals, canal divisions, and the overall details of canal morphology and configuration) (29), but micro-CT studies usually examine fewer specimens, whereas CBCT offers a broad morphological overview (29). Our results are consistent with previous micro-CT studies (32), demonstrating the reliability of these two methodologies and giving relevance to our findings. Another method for understanding root canal anatomy is staining and clearing (5). However, micro-CT imaging systems and staining and clearing techniques can be used only to assess extracted teeth and cannot be used in vivo.

Conclusion

Mandibular incisors and canines in the Turkish population have complex anatomy. The tooth location did not affect the numbers of canals or roots, or canal configuration, but gender did. In females, the apical foramen was located centrally, buccally, or lingually, while in males it was located medially or distally. Furthermore, males had a higher incidence of second canals in mandibular lateral teeth. For a comprehensive understanding of canal morphology, further studies with more samples from all regions of Türkiye are necessary.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from the Health Sciences University, Faculty of Dentistry, Local Ethics Committee, in accordance the World Medical Association Declaration of Helsinki, with the approval number: 2023-24126.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – C.T.; Design – C.T., A.A.; Supervision – A.A.; Materials – C.T.; Data collection &/or processing – C.T.; Analysis and/or interpretation – A.A.; Literature search – C.T.; Writing – C.T.; Critical review – A.A.

Conflict of Interest: There is no any conflict of interest.

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